Wetland Inventory and Management for the Myimbarr and Shell Cove Wetlands, Shellharbour

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Abstract
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Water, soil and vegetation analyses were undertaken to examine the wetlands. Water quality testing at Myimbarr/Tongarra Creek system revealed that water quality improves and becomes stabilised as it moves through the catchment, indicating the efficiency of the wetlands in treating stormwater runoff. Results obtained at Shell Cove sites indicated that water quality was good and conditions are quite consistent throughout the Shell Cove catchment, however as the ponds are disconnected from one another results are not indicative of patterns occurring on a system-wide scale. Soil types determined within the wetlands included silty clay, silty clay loam, silty loam and sand. Soil pollution was not identified at the Myimbarr/Tongarra Creek sites, however elevated readings of Cu, Zn and Pb obtained at one Shell Cove site indicate small-scale pollution may be present. Vegetation surveys showed that introduced species were problematic throughout both wetlands systems, as were dominant native species. It was determined that the wetlands were achieving their intended purpose in providing stormwater treatment and habitat, however areas for improvement were identified. Management should target water quality, sedimentation, vegetation and catchment practices to maintain the health and functionality of the constructed wetland systems and prevent future degradation.

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Wetland Inventory and Management for the Myimbarr and Shell Cove Wetlands, Shellharbour

by

Madeleine Harper

A research report submitted in partial fulfilment of the requirements for the award of the degree of HONOURS BACHELOR OF ENVIRONMENTAL SCIENCE

Faculty of Science
University of Wollongong

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The information in this thesis is entirely the result of investigations conducted by the author, unless otherwise acknowledged, and has not been submitted in part, or otherwise, for any other degree or qualification.

Madeleine Harper
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Chapter One

1.1 Introduction

The use of constructed wetlands is becoming increasingly popular to treat urban stormwater. In addition to treating and filtering urban runoff, constructed wetlands provide habitat for fauna and flora, public recreation space, and contribute to the overall aesthetics of the urban community. They provide ecological habitat to enhance a region’s biodiversity and are often considered to be an environmentally friendly technique used to manage stormwater and improve water quality. As such, they are frequently used in conjunction with urban development to ensure a project is sustainable and meets both environmental and social requirements (White, 1998).

Two constructed wetlands systems in the Shellharbour City Council (hereafter the SCC) Local Government Area (hereafter the LGA) are examined in this study to determine if the constructed wetlands are functioning as intended in providing stormwater treatment to urban runoff and providing habitat for a range of flora and fauna species. Both wetland systems were constructed by developers and when complete passed to the SCC for management and maintenance. SCC is now responsible for the ongoing management of the wetlands. Management of these systems faces a number of restrictions which are discussed in this report.

1.2 Study Context

1.2.1 Myimbarr Wetlands

The Shellharbour LGA has experienced rapid urban development in recent years to accommodate the massive expansion in population occurring throughout NSW’s coastline. As a result of residential development, a series of wetland systems have been constructed to treat stormwater and runoff, store floodwater and provide habitat and recreation areas. Completed in 2006, the Myimbarr Wetlands began construction in 2004 and were designed not only to treat stormwater and runoff, but also to provide a compensatory habitat for the loss of Shellharbour Swamp, due to the development of the Shell Cove Boat Harbour Marina (Cleary Bros, 2012; Sainty and Associates, 2005). The site was first made available to the developers Landcom for wetland construction in June 2000 in accordance with the Shell Cove Boat Harbour Consent (1996, Consent 95/133; Loemaker 2005; Sainty and Associates, 2005). They were constructed as a condition (Condition 2(a)) of the Shell Cove Marina
Development Application, and were required to contain both freshwater and estuarine components for habitat (Sainty and Associates, 2005). They were designed to provide water quality treatment to the upstream residential sub-catchment of Tongarra Creek, which drains to Elliott Lake. Myimbarr is located in the Tongarra Creek sub-catchment within the greater Elliott Lake catchment.

Originally named the Shadford Wetlands, the wetlands were only one component of the development of the site. They were later renamed by SCC to align with the broader area of the Myimbarr Community Park. Myimbarr is an Aboriginal word meaning “belonging to us”. The community park was designed to integrate the wetland habitat with recreational facilities to create a shared community area for residents, and now consists of sports fields and amenities buildings (Loemker, 2005). To construct the wetlands, 500,000 cubic metres of soil

Figure 1: Early sketch Myimbarr Community Park, detailing the location of the wetland ponds and Sports fields
were removed and 250,000 native plants were planted in the wetland and along the banks (T. Heather, pers. comm., 2012).

The wetlands were constructed by Cleary Bros under the supervision of Landcom (James, 2005). Construction occurred over two years, and formed one component of the 33 hectare Myimbarr Community Park project. The project was highly environmentally sensitive, and was recognised with an Environmental Excellence honour for Cleary Bros after construction. The wetlands project represented a major component of the joint venture of the Shell Cove Project between SCC and Australand (Cleary Bros, 2012).

Management

A management plan for Myimbarr was prepared by Sainty and Associates in December 2005. It addressed a number of management issues, made recommendations for future care and identified management goals for both the fresh and salt water components of the wetland. Management issues identified in the plan include creating the optimal hydrological regime; managing vegetation and habitat diversity; controlling pests and mosquitoes; assessing water quality and maintaining the structure of the wetland.

This preliminary plan outlined specific management goals and maintenance techniques for the Myimbarr system. It was noted however, that the climate, catchment and vegetation of Myimbarr would dictate the functions and processes occurring, and management actions will be secondary to this. It is also noted that the system is highly dynamic and as such will be subject to changes that are difficult to predict and plan for (Sainty and Associates, 2005). This management plan requires updating to take into account the changes that have occurred in the system since its establishment.

Myimbarr is currently managed by SCC who dedicates two staff members three days a week to maintain the wetlands. Staff work to manage nuisance weeds in the area and plant native species where required. Staff hand weed, spray annual weeds, target *Typha* and casuarinas through winter (if necessary), plant natives, remove aquatic weeds and remove rubbish. Funding is allocated only to the maintenance of vegetation, largely to improve wetland aesthetics and not functionality. Funding is not allocated to manage the ponds.
Issues

Since development, a number of management issues have arisen for Myimbarr. Sedimentation has become a significant problem, as continuing development in the catchment has caused excess sediment to enter waterways and be deposited in Myimbarr. This has led to a substantial build-up of sediment in the sediment forebay, which has altered the flow of water into the wetland system. Further complications arise regarding the removal of sediment due to poor access points to the ponds. Removal is costly as is relocation of sediment; sediment must be de-watered before relocation; and acid sulphate soils (ASS) may present an issue, which may require testing and treatment. Pest species also pose a threat: a number of weeds have infiltrated the Myimbarr wetland system and upstream tributaries, blocking water flow and outcompeting native species. This creates complications for management as pest species are difficult to remove or eradicate and spraying may pose a risk to native species and water quality. The wetlands have been designed to enable the alteration of water levels through a draw-down, scheduled to occur for 6-8 weeks once a year, during August-September to mimic natural flow conditions. Alteration of the hydrologic regime may not be sufficient to achieve management goals and a coordinated effort to maximise use of the draw-down to achieve specific management outcomes has not been initiated.

1.2.2 Shell Cove Wetlands

The Shell Cove wetland system is designed for water quality control and consists of a series of ponds in the newly developed and expanding residential area. This area is yet to undergo the most significant alteration with the proposed creation of a marina in Shell Cove. As with Myimbarr, the wetlands have been constructed by Cleary Bros under the supervision of Landcom, as part of the marina and boat harbour agreement. The wetlands provide stormwater treatment for the residential catchment in Shell Cove in conjunction with the residential and marina development. The Shell Cove wetlands are a component of the Shellharbour catchment, and consist of a series of constructed ponds and natural waterways that are still undergoing construction in the lower catchment where further development is progressing.

Management

Eco Logical Australia has recently completed an Ecological Assessment and Plan of Management for Shell Cove Reserve on behalf of the SCC. The plan, completed in February
2012, is in place to provide a framework for protecting and enhancing native vegetation, habitats and recreational areas within the Reserve area. The Reserve includes most of the Shell Cove wetlands of this study and the associated tributary.

The plan discusses in detail the fauna and vegetation present in the reserve, outlining threatened species and communities and actions for their management. It also identifies threats to the reserve, including introduced species, historic and current land use and rubbish dumping (Eco Logical, 2012). The plan, although useful for maintaining and enhancing ecological processes within the catchment, does not directly address wetlands, nor does it provide any management objectives for them. It should be used however as an accompanying document to ensure the health and functionality of the catchment is maintained, which will indirectly assist in improving wetland health and function.

The Shell Cove wetlands are currently managed by SCC who dedicates two staff members one day a week to manage vegetation. Hand weeding and spraying is used to target annual weeds along the perimeter of the wetlands, to improve the aesthetics of the area. Like Myimbarr, the wetlands are managed only in terms of vegetation, and this is to improve the aesthetics of the system in the urban environment, rather than improve the health and functionality of the wetlands.

Issues

Many of the issues found at Myimbarr are not reflected at Shell Cove. There is some sedimentation in study site SC 1 however this is not posing a significant problem, as there is less ground disturbance in the upper catchment. Like Myimbarr, pest species pose a threat. Problems in the management of Shell Cove are difficult to predict due to the large scale changes that are currently underway in the catchment. Further construction and the development of more stormwater treatment ponds will further alter the hydrologic regime and will likely result in a range of management issues for the wetlands. Using Myimbarr as a model, it can be predicted that sedimentation will become an issue in the wetlands in the near future. As such, management should be tailored to address forecasted problems so prevention rather than mitigation can be applied.

1.3 Legislation

The management of wetlands is governed by a range of policies and legislation in place on a national, international, state and local scale. This legislation provides a guideline for the
proper management of wetland ecosystems to ensure wetlands are preserved and protected. Policies pertain to a number of factors relevant to wetland management, including endangered and threatened species, migratory species, catchment management and water management, as well as legislation specifically related to wetlands and their management. A comprehensive listing of relevant legislation pertaining to the wetlands of this study can be found in Appendix 1.

1.4 Purpose of the Study

This project has been commissioned to evaluate the effectiveness of the wetlands with regards to function, and provide a series of recommendations for management. Since the creation of the Myimbarr and Shell Cove wetlands, resources to provide adequate management have been lacking and there has been little investigation into the effectiveness of each system. As such, a thorough investigation is required to determine if the systems are functioning as intended in providing both stormwater treatment and habitat in the Elliott Lake and Shellharbour catchments. The main issues effecting wetlands functionality will be identified and prioritised in a series of recommendations for management.

1.5 Objectives

The author aims to develop an inventory of the constructed wetlands in Shellharbour and Shell Cove with regards to:

- Water and soil quality
- Sedimentation
- Vegetation types
- Characteristics of each wetland system
- Species present, including native, migratory and introduced.

This inventory will be used to determine the current condition and functionality of the wetlands in regards to their intended purpose as stormwater treatment systems and habitat provision. The condition of water, soil and vegetation will be determined from field testing and laboratory analysis, which will reflect the overall health and effectiveness of the wetland systems. Current management strategies will be reviewed in conjunction with the testing, and based on these findings a series of recommendations to improve wetland function will be proposed. Recommendations will address areas of greatest concern as well as outlining
current actions that have proved successful. Recommendations must be compliant with relevant legislation and must ensure the wetlands systems meet their intended purpose. Management action plans will be proposed through a series of recommendations that outline the steps required to restore wetland function, with specific attention paid to water and soil quality, sedimentation, vegetation and pest species.
Chapter Two

2.1 Literature Review

2.1.1 Introduction to Wetlands

Wetlands are defined by the Ramsar Wetland Convention as “areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres” (Ramsar, 1971). They serve a number of functions, including habitat provision for a number of fauna species such as macroinvertebrates, amphibians, birds, fish and small reptiles and mammals; floral species including macrophytes, submerged and riparian vegetation; and often house endangered species and migratory birds. The conditions in wetlands are so distinct that a unique community of biota have developed, adapting to and depending on the diverse conditions a wetland environment provides. Wetland species have adapted to be dependent on the saturated or moist conditions present for at least one stage of their life cycle (NSW Wetlands Policy, 2010).

In addition to hosting an ecological community, wetlands filter stormwater and runoff, improving water quality within a catchment and reducing the impacts of floods and droughts. Many wetlands are ephemeral, and the periodic wetting and drying of wetlands is a common feature both in Australia and internationally, to the extent that much of the living community is dependent upon the ephemeral nature of the wetlands (NSW Wetlands Policy, 2010). As wetland conditions vary regionally and locally, each wetland has a unique cycle according to the climatic and catchment conditions present. During flood conditions, nutrients are released from the soil, stimulating the growth of drought resistant plants and germinating seeds of hydrophilic plants. As the wetland dries, light can penetrate to the bottom and stimulate the growth of different plant species. Dominant fauna species also vary seasonally, with the capability to regenerate and recolonise when conditions change, promoting biodiversity and habitat heterogenity in the ecosystem (Brock et al, 2000). Drying in a wetland provides additional benefits of managing and controlling pest species, through the removal of habitat or by allowing human access into the wetlands to manually remove pest species.

Wetlands are one of the most biologically diverse and productive habitats, supplying water and nutrients to a wide assemblage of faunal and floral species. They aid in primary production through the production of organic matter which is then consumed along the food
chain. They support aquatic systems within the catchment, acting as “kidneys” by filtering pollutants, sediments and nutrients to improve the health of adjacent water bodies such as rivers, estuaries and lakes. Thus the health of a wetland is vital not only to the ecosystem it supports, but also the entire catchment (EPA, 2004).

Characteristics of both terrestrial and aquatic ecosystems are present in wetlands, which function as an ecotone between the two habitats (Byomkesh et al, 2009). They are an incredibly important feature within a catchment, responsible for hydrologic processes and the transport and deposition of nutrients and sediments (Wang et al, 2010). Depending on the composition of the wetland, the services it provides will vary, and this is an important consideration when assessing the function of a wetland within the catchment (Richardson et al, 2011). Wetlands are also effective in carbon sequestration, a benefit that has only been uncovered in recent years, adding to the inventory of benefits a healthy and functioning wetland provides (Euliss Jr et al, 2008). The vegetation within a wetland is essential in the denitrification process, removing excess nutrients from catchment waters by fostering a suitable habitat for bacteria to mobilise nitrogen (Johnson and Smardon, 2011).

Wetlands are dynamic ecosystems that form an important part of the landscape, integral to environmental processes including nutrient cycling and water detention. They also allow for sediment trapping and detention, and enable the slow release of flood waters back into the catchment. In addition to providing ecological and environmental services, they are a thriving part of the community, both historically and at present. Historically they have been an important gathering point for Aboriginal communities around the country, and they are now a crucial component of fisheries, both commercial and recreational, timber production and tourism (NSW Wetlands Policy, 2010).

It is evident that the health of a wetland is vital to the health of a catchment and ecosystem, therefore it is important to know the indicators of a healthy functioning wetland system. Wetland health can be determined in reference to a baseline condition, the natural state of the wetland defined by the condition prior to European settlement, or the state in which the wetland is functioning optimally in regard to the ecosystem functions. These two states may differ greatly, and it is often difficult to determine pre-European conditions and equate them to the current landscape in Australia, due to Australia’s highly modified landscape. This is further complicated by climate change and continuing variation in environmental conditions, therefore it is often better to view wetland health in terms of optimal functionality (Saintilan
and Imgraben, 2012). In Australia, wetland health is indicated by a number of factors including biota, catchment disturbance, water and soil quality, fringing zone, hydrological disturbance and physical form and processes (Scholz and Fee, 2008). Catchment disturbance relates to the amount of disturbance within the catchment; water and soil quality refers to factors such as turbidity, salinity, pH and soil properties; fringing zone refers to the condition of the zone immediately surrounding the wetlands; hydrological disturbance relates to the level of modification of the natural water regime; and physical form and processes refers to changes in area, topography and soil in the wetland. The biotic factor refers to the biological components of the wetland, including birds, fish, amphibians, algae and vegetation. Biotic health is indicated by the presence/absence of native or endemic species, the presence/absence of introduced species or pests, and the relative abundance and richness of species (Scholz and Fee, 2008).

2.1.2 Wetland Degradation

Despite the irrefutable benefits a wetland holds for both ecosystems and communities, wetlands have suffered extensive and often irreparable damage from people for centuries (Fitzsimons and Robertson, 2005). It has been estimated that more than 50% of Australia’s wetlands have been lost, as habitats are destroyed to accommodate various land uses (ANCA, 1995). The major threat to aquatic ecosystems is habitat destruction, which damages the abundance and diversity of species that live in aquatic ecosystems such as wetlands, and thus the overall health of the wetland (DPI, 2007). Efforts to control and modify natural habitats has resulted in the elimination of natural flood pulses and water level variations through damming rivers or modifying the course of waterways, which results in habitat loss as species have become reliant on the variations in the hydrological cycle (Middleton, 2002). The health and function of a wetland is intricately connected to its position within the catchment, and health and biodiversity can only be restored when catchment hydrologic regimes are restored (Zedler, 2000).

A comprehensive summary of the causes of wetland degradation has been prepared by Hollis (1992) and McComb and Lake (1988). Hollis has identified the underlying causes of wetland degradation, whilst the direct and indirect causes of wetland destruction have been discussed by McComb and Lake. Underlying factors include population pressure, poor public awareness, poor planning and regulation, a lack of resources and trained personnel, and historical legacies of poor land use, amongst others. Direct causes of degradation include
Drainage, channel modification, groundwater extraction, habitat and land clearing, flood mitigation practices, pest invasion, inappropriate recreational activities and land use. Indirect effects, which may be less obvious, can be just as harmful and include nutrient and sediment influxes, salinisation, discharge of effluents, and erosion and flooding resulting from catchment clearing.

In Australia, wetlands have suffered extensive damage from the construction of dams, weirs, channels and diversions that have altered or prevented the natural flow of waterways. Changing the natural flow into wetlands is a core issue of wetland health, as it affects sedimentation and vegetation in the wetland (Finlayson and Rea, 1999). Changes in channel morphology can also result indirectly from catchment development, as changes in the stream channel initiate stream incision, altering the path of water flow and consequently flow volumes, concentrations and frequencies, which all have a flow-on effect to habitats and populations (Shields et al, 2010).

Land use is a major contributing factor to the degradation of wetlands internationally, indicated by the presence of contaminants such as sediments, nutrients and toxicants that have infiltrated the system as a result of land use in the catchment, such as clearing, agriculture and urbanisation (Euliss et al, 2008). The relationship between catchment land use and wetlands in terms of non-point source pollution (pollution from diffuse sources) can be described as follows; urban and agricultural land uses function as the sources of non-point source pollution in a catchment, whilst riparian zones and wetlands function as the sinks of non-point source pollution (Moreno-Mareos et al, 2008). This is a major threat to the health and ecological integrity of wetlands, and demonstrates the importance of catchment scale management when managing a wetland system.

The increase in urbanised environments is damaging wetland health. The proportion of impermeable surfaces in the catchment is growing due to the clearing of vegetation and soils and the introduction of infrastructure, which results in a loss of water retention that these systems provide. Changes in the hydrological cycle within the catchment alters peak flows, flood regimes and the quality and volume of water discharged into the wetland, and challenges the wetlands ability to process and filter the water entering the wetland (Scholes, 1998; Henrichs et al, 2007; Lee et al, 2009; Zhang et al, 2006). The increase in impermeable surfaces decreases the land available for storm water infiltration and the course of storm water is altered by purpose-built stormwater drains and structures designed to remove water.
from the land rapidly (Elting, 2003; Bernhardt and Palmer, 2007). This functions in opposition to natural stormwater processes, which slowly remove water through infiltration and some surface runoff before the water enters wetlands or other water bodies. This results in large volumes of water being delivered to wetlands or stormwater basins rapidly, which places much strain on the system to cope with such volumes of water that is often polluted as a result of urban and agricultural practices. Wetlands are unable to filter pollutants from such high volumes of water, which is generally accompanied by high volumes of sediment, resulting in the degradation of the ecological health of the ecosystem (Bernhardt and Palmer, 2007).

Agricultural land use practices cause topsoil to erode into waterways, resulting in excessive amounts of sediment feeding into waterways and into wetlands. Once in the water channel, sediments scour and erode banks, which causes undercutting and channel incision, altering the course of the water channel and resulting in sediment-filled channels (Richardson et al, 2011). Continued land use often undermines and compromises conservation, restoration and management efforts by continuing to alter the natural systems and flows present in the catchment, and preventing the restoration of natural systems (Gleason et al, 2003; Smith et al, 2008). It is, therefore, evident that management plans must address continuing land use practices and look for solutions to reduce the negative effects anthropogenic land use has on wetland systems in order for the management plan to prove effective and viable.

### 2.1.3 Constructed Wetlands

To compensate for the loss and degradation of natural wetlands, constructed wetlands are increasingly popular as they can improve habitat, stormwater detention, water quality, catchment conditions and the general health of the ecosystem. Constructed wetlands are engineered systems that use natural processes involving soils, microbial assemblages and vegetation to filter and treat water. Constructed wetlands moderate the flow of streams, retain rain and stormwater, purify and filter runoff and enrich the catchment’s water regime (Brydon et al, 2006; Henrichs et al, 2007; Chavan et al, 2008), and are low in energy and maintenance when compared with other methods used to treat stormwater (Vymazal, 2005; White, 1998). They are often considered to be an environmentally friendly technique used to manage stormwater and improve water quality, and are frequently used in conjunction with development to ensure a project is sustainable and environmentally friendly (White, 1998). Constructed wetlands have been used to treat various types of wastewater generated in a
variety of industries, including agricultural, industrial, food processing, mining and urban (Vymazal, 2005). In addition to treating water and runoff, they provide an ecological habitat that can improve biodiversity and house endangered and threatened species. Aside from the environmental services constructed wetlands provide, they offer recreational services for the community and improve the general aesthetics of a region. Wetlands may also be used for water extraction for a number of purposes, as was originally proposed for the Myimbarr wetland system of this study. Water extraction alters the hydrologic regime of the wetland and may not be suitable for all constructed wetland systems.

Constructed wetlands function to remove sediment, bacterial contaminants and dissolved contaminants, and are often designed with a series of ponds of varying size, shape and capacity to maximise water treatment. Their design must be carefully considered as a constructed wetland will not only function to improve water quality and runoff in an urbanised or agricultural area, it will also serve as a habitat provider, and thus ecological considerations must be taken into account in the design, construction and management phases (DIPNR, 2004). The construction and design may be relatively simple in terms of engineering, but due to the ecological complexity of a wetland system, a vast range of knowledge must be called upon in the design and construction phases, and the project’s success will reflect the designers understanding of wetland processes and interactions (White, 1998). Future development in the catchment must also be accounted for in the design of a constructed wetland system, as an increase in paved and non-permeable surfaces results in increased volume and velocity of runoff, which in turn results in a higher volume of water entering the wetland systems. The project’s success will too depend on the implementation of a viable and intelligent management plan that accounts for both ecological and stormwater processes and includes ongoing monitoring to ensure the system functions as intended and does not become degraded over time.

Considerations regarding the vegetation type and flow regimes are important during the design phase, and the design and type will depend on the environmental conditions present at the site and the purpose of the wetland (Vymazal, 2005). Constructed wetlands will be designed according to the priorities of the project, which may include water quality, habitat provision, biodiversity improvement, endangered/threatened species habitat provision or aesthetics, and each wetland will vary according to its design purpose. This complicates
management and design, as universal guidelines cannot be applied and plans will change for each wetland site according to its specifications (Hunter, 2012).

There are various zones that constitute a constructed wetlands system, which are:

- The inlet zone: consists of water control structures such as a GPT, detention basin or an energy dissipater
- Deep water zone: in place to manage high flows and allow sediment detention and habitat for submerged plants
- Littoral zone: contains edge plants for habitat creation and as bank stabilisers
- Macrophyte zone: contains reed beds to improve water quality
- Open water zones: can contain islands that provide habitat
- Outlet zone: like the inlet zone, contains water control structures, spillways and weirs, which protect wetlands during high flow and contain water during low flow.

These components are in place to provide maximum stormwater detention, improve water quality and habitat and prevent excess sedimentation (Webb and Russell, 2012).

Constructed wetlands can be used as compensation for the destruction of a natural wetland, however this is often flawed as wetlands cannot be replaced with a wetland of different habitat, type, and location in the catchment without losing ecological value (Burgin, 2010). Compensation wetlands are to be avoided if the wetland is being constructed to compensate for a viable and healthy wetland. Even with effective management, it is stated that constructed wetlands do not provide the same range of services as the natural ecosystems that are lost to development and land use practices and, therefore, the construction of compensation wetlands in place of natural wetlands is a practice that should be avoided where possible (Ellison and Daily, 2003; ten Kate et al, 2004). They should instead be used when a natural wetland is highly degraded and in need of mitigation methods, or to compensate for development in the catchment (Chovanec, 1994).

The use of constructed wetlands is becoming increasingly popular amongst housing developers, who view them as both a stormwater management solution and provision for public open space and recreation, requirements that must be met when undertaking new development. The use of constructed wetlands in this manner is often flawed due to a lack of foresight and planning for future management. Development in the catchment may exceed
the capacity of the wetland to treat stormwater, and the hydrologic regime within the catchment is greatly altered with an increase in non-permeable surfaces resulting in run-off of greater velocities and volumes. Constructed wetlands have proved successful in providing a number of environmental and stormwater treatment functions. A study conducted by Chovanec (1994) found that constructed wetlands can successfully provide refuge and habitat for endangered species of amphibians, even in highly urbanised areas.

Constructed wetlands also provide nutrient cycling, processing and removing nutrients such as nitrogen and phosphorous from a water body. Aquatic macrophytes sequester nutrients, relying on nitrogen and phosphorous for growth, whilst bacteria and microbial processes are responsible for transforming and processing nitrogen (Paul, 2012). Wetlands designed to treat organic wastes may typically remove 90% of disease-causing microorganisms, 80% of organic material and suspended solids, and about 60% of nitrogen (Shutes, 2001). The denitrification process relies heavily on vegetation that creates micro-environments suitable for bacteria to mobilise nitrogen, with as much as 90% of nitrogen removal attributable to vegetation surfaces (Bendoricchio et al, 2000; Luckeydoo et al, 2002). Well-designed constructed wetlands contain both aerobic and anaerobic zones that are essential in the nitrogen cycle: aerobic conditions are suitable for ammoniafying and nitrifying bacteria, whilst anaerobic conditions are required for denitrifying bacteria. Figure 2 details the processes in both the nitrogen and phosphorus cycles, integral to wetland function. If these conditions are not present, the nitrogen cycle will cease to operate and removal of nitrogen from the system will no longer occur (Szogi et al, 2003; Johnson and Smardon, 2011). Strecker et al (1992) stated that constructed wetlands generally perform better than natural wetlands in removing various constituents such as nutrients and organics.
Despite the benefits a constructed wetland may hold, it is important to note that constructed wetlands often do not operate as successfully as planned and do not meet design objectives. Turner et al (2001) suggested that approximately 80% of wetlands built for mitigation do not become fully functional, exemplifying the problems and challenges associated with implementing effective systems. Failure to perform as intended is often due to poor design and management plans that do not account for the complex web of interactions, chemical, physical and biological, that contribute to the overall function of the wetland (White, 1998). Constructed wetlands take time to become established, often requiring months or years to develop the organic soils and vegetation necessary for function. This can be a limiting factor on their use and implementation, and may result in projects being abandoned early or managed poorly as the system is prematurely deemed to be unviable (Johnson and Smardon, 2011). The restoration of a degraded wetland system may be preferable to implementing a new constructed wetland system, as studies have determined that drained and restored wetlands hold greater efficiency in nitrogen removal than constructed wetlands (Baker, 1992; Boesch et al, 2001; Driscoll et al, 2003; Ducks Unlimited, 2003). Again, this may be attributed to the greater start-up period constructed wetlands require (Johnson and Smardon, 2011).

Poor wetland performance can be primarily attributed to insufficient storage volume and poor hydrologic and hydrodynamic control. As such, the rate of capture, detention period and inflow distribution of water are vital considerations in the design process (Persson et al, 1999). Wetlands are only capable of removing a fraction of the total contaminant load, and

Figure 2: Nitrogen Cycling (A) and Phosphorous Cycling (B) in a freshwater wetland (Paul 2012).
rather than providing a permanent removal of contaminants, they function as a temporary storage facility for nutrients as part of the nutrient cycle (Helfield and Diamond, 1997; Faulkner and Richardson, 1989). It is argued that for a wetland constructed for water treatment to function effectively, it must remain isolated from wetland faunal species to maximise performance. This allows processes to be managed and manipulated, and allows maximum treatment of stormwater and removal of contaminants (Helfield and Diamond, 1997). This however may be difficult to establish and maintain, and limits the full range of ecological benefits constructed wetlands can provide. While acknowledging that habitat provision may compromise some of the water treatment functions of a wetland, it is preferable to design a wetland that can serve multiple purposes, providing habitat and refugia in urban areas, treating stormwater and runoff and providing a recreational and aesthetic factor.

2.1.4 Wetland Management and Monitoring

There are many challenges in the protection and preservation of both constructed and natural wetlands, and thus effective management that encompasses and accommodates both anthropogenic and environmental needs is a difficult task. Management and monitoring must be considered at the design phase of a constructed wetland, and initial plans should include ongoing management and monitoring recommendations. Ongoing management is vital to the ongoing health and functionality of a wetland system, and requires the implementation of a number of management practices to be used in conjunction with a comprehensive monitoring system (Finlayson and Rea, 1999). This should be budgeted at the design phase for constructed wetlands, and budgets should be flexible to allow for changes that will inevitably arise as the project develops (Shutes, 2001).

Effective management requires knowledge of legislation, social and political factors, catchment practices and dynamic wetland processes that all influence the wetland ecosystem (Euliss et al, 2008). Reference conditions can be used to determine management plans, and should be derived from wetlands that represent the desired functionality of the constructed wetland (King et al, 2003). Before determining a management plan, information regarding the geology, hydrology, biological processes, catchment development and landscape setting and processes must be gathered to ensure the full suite of factors affecting a wetland are encompassed (Euliss et al, 2008). Creating a comprehensive inventory is the first step in determining a management plan, as it gathers information specific to the wetlands and
enables actions to be prioritised and planned accordingly. It also identifies specific threats faced by a site, and enables the wetland to be considered within the broader catchment context (Finlayson and Rea, 1999). Management practices will vary according the intended purpose and design of the wetland, which can result in greatly differing management plans. For example, wetlands designed for habitat provision or protection of endangered species may require fencing around the wetland for a given time period, along with establishment and maintenance of refugia and habitat (Chovanec, 1994). Plans will also vary according to the location of the wetland, the size of the catchment and the land use occurring within the catchment. Sustainable management is often compromised as plans seek to address individual factors and outcomes rather than aim to improve the entire ecosystem (Euliss et al, 2008). Therefore, it is concluded that although management plans should be tailored according to the purpose of the wetland, they should as a whole aim to improve processes that will sustain the ecosystem.

Management has been hindered by poor monitoring systems that fail to collect sufficient data over sufficient time periods. Inventory and monitoring are vital practices in successful management, and must be based on scientific principles to be effective. The national data base for wetland monitoring and information is limited, with inadequate data regarding interactions both within the wetland and in the wider catchment, as well as limited reference data for hydrological processes (Finlayson and Mitchell, 1999). To prevent further degradation and ensure effective use of constructed wetlands, management performance and accountability are crucial components. This ensures that ongoing performance targets and objectives are met, and provides accountability when they are not met. Monitoring should be holistic and not simply aim to provide information on one aspect of a wetland. A broad range of data that covers the scope of wetland processes should be gathered to manage the overall function of the wetland, and assess areas of improvement and success (Finlayson and Mitchell, 1999). By gathering data pertaining to a range of wetland functions, the long term viability of a project is ensured. Areas requiring improvement can be more easily identified and actions can be implemented fast within appropriate time frames.

Poor management practices often result from a lack of understanding held by decision makers regarding the value of wetlands, which results in the protection and preservation of wetlands featuring low on the agenda (Byomkesh et al, 2009). Wetland management was initially focused on wildlife protection, and the management practice employed was simply to protect
the wetlands themselves. This however proved limited as development in the catchment increased and urban and agricultural land use practices dominated and overtook natural areas. It became evident that management techniques must encompass catchment processes and be implemented on catchment scales, as protecting the wetland area alone will not protect the ecosystem. The management technique of assigning protected areas has been employed in Australia, however it is important to note that activities occurring in the catchment will affect the wetland, therefore assigning protected land to a portion or even the majority of a wetland is likely to prove unsuccessful (Fitzsimons and Robertson, 2005). The results of Moreno-Mateos et al. (2008) drew similar conclusions, suggesting that water quality was greatly improved when actions were implemented on a catchment scale, and the creation of numerous wetlands in a catchment along with landscape heterogeneity could dramatically improve water quality. This is supported by Bedford (1999), who concluded that restoration efforts must be implemented on a catchment scale, and projects that address the wetland alone have little effectiveness in improving biodiversity and water quality. It can therefore be concluded that restoration projects must be integrated into greater catchment management plans to be successful.

Knowledge of the periodic wetting and drying of wetlands is crucial to wetland management. This will differ in season, frequency and severity depending on the location of the wetland, therefore location-specific information must be gathered for each site. Many problems in constructed wetlands arise due to the alteration of natural hydrological cycles, which then alters processes within the entire ecosystem (Euliss et al, 2008). As such, the cyclical nature of wetlands should be mimicked as part of ongoing management to ensure the system functions optimally (Keough et al, 1999; Smith et al, 2008). The management goals in place for many constructed wetlands aim to ensure conditions remain constant over time, however this is not the ideal management practice to sustain a productive and healthy ecosystem. The productivity of a wetland depends on periodic drying and fluctuations in water levels and volumes, therefore these conditions should be integrated into management aims. Ensuring natural variability is mimicked will maximise wetland productivity over time and will reduce the need for other management practices as the wetland becomes established and self-regulatory (Euliss et al, 2008). This process may however prove challenging for managers as variations in wetland hydrology may not meet the needs of the community in terms of stormwater filtering and pollutant removal. Therefore it is necessary to determine a
management program that meets both anthropogenic and environmental needs in order to ensure the long-term viability of the system.
Chapter Three

3.1 Site Description

3.1.1 Location

Shellharbour is located on the east coast of New South Wales in the Illawarra region, approximately 100 km south of Sydney. The City of Shellharbour is the Local Government Area (LGA) to the south of Wollongong and north of Kiama. The LGA covers 154 square kilometres, stretching from the Illawarra escarpment to the Pacific Ocean. It comprises 21 suburbs ranging from Lake Illawarra in the north to Dunmore in the south, and Macquarie Pass in the west to Shell Cove in the east (SCC, 2009). The population was estimated to be almost 68,000 at 30 June 2010, and is likely to have grown since due to residential expansion in suburbs such as Shell Cove (SCC, 2011).

3.1.2 Geology and Soils

Shellharbour is located on the coastal plain between the Illawarra Escarpment and the ocean. Located on an erosional landscape, the area is defined by low rolling hills and broad drainage
plains that are extensively cleared with intermittent stands of tall open forest and closed forest. Relief on slopes is 20-50 m, and the slope gradient is approximately < 20%. Concave footsteps grade into broad drainage plains that comprise the coastal Shellharbour region (Hazelton, 1992).

The coastal plain is characterised by gentle hills and valley floor topography of the Broughton Formation, including the Bumbo Latite Member. The coastal slopes and southern Lake Illawarra catchment slopes have formed in the Broughton Formation while the valley floors of the coastal plain have formed from alluvial sediment deposits. The catchments of Elliott Lake and Shellharbour lie on the Bumbo Latite and Broughton Formation of the Permian Gerringong Volcanics. The noticeable increase in sediment and water run-off that has occurred in the region over the last 100 years has resulted from extensive clearing and agriculture. Erosion and bank failure have occurred along creek lines, causing channels to become wider and shallower, and thus changing the hydrodynamics of the water courses (Mills and Associates, 1996).

The geology gives rise to deep Prairie Soils on the crests and upper slopes, brown Krasnozems on the midslopes and Red Podzolic Soils and Prairie Soils on the drainage plains and lower slopes. The area is subject to localised mass movement with a localised water erosion hazard, low wet bearing strength in subsoils along with high shrink swell tendencies in subsoils. The soil is shallow, with low permeability and a hardsetting nature. Soils are also subject to sodicity. The fertility of the soils is generally moderate due to their hardsetting nature and localised impeded drainage, erodibility is high as is the erosion hazard, however the soils are generally stable with low subsurface movement potential (Hazelton, 1992).

3.1.3 Water Catchments

The wetlands studied are located in the Elliott Lake and Shellharbour catchments within the LGA (see Figure 6). The Shellharbour Catchment covers an area of 484 ha and includes the suburbs of Shellharbour and Shell Cove. Extensive development has occurred in the catchment with the conversion of agricultural land to residential land, with areas dedicated to parks and reserves also found in the catchment (SCC, 2009). The Elliott Lake catchment includes Barrack Heights, Shellharbour, Flinders, Blackbutt and parts of Mt Warrigal and Warilla. The main waterways are Tongarra Creek, Bensons Creek and Oakleigh Creek. The catchment drains into Elliott Lake which discharges to the ocean (Cardno, 2011). The catchment covers a total area of 1,200 ha, much of which is residential area, with some land
used for commercial, agricultural and industrial purposes, and some land dedicated as parks and reserves (SCC, 2009). Myimbarr Wetlands are found in the Tongarra Creek sub-catchment within the Elliott Lake catchment, the total area of which is 525 ha (Patterson Britton & Partners Pty Ltd, 2006; Sainty and Associates, 2005).

3.1.4 Climate and Rainfall

Shellharbour experiences a relatively mild climate all year round. Maximum temperature in summer averages approximately 26.1°C, approximately 18.2°C in winter and 22.4°C annually. Minimum average temperature is approximately 16.2°C in summer, 7.2°C in winter and 11.4°C annually. Average rainfall is 883.4 mm per year, with rainfall occurring along the coast predominantly from February to June, according to data obtained at the Albion Park weather station (Bureau of Meteorology, 2012, Tourism Shellharbour, 2012). It is important to note that rainfall is variable throughout the LGA, and some areas, for example the escarpment, receive higher rates of rainfall than others.

3.1.5 Historical Land-use in the Catchment

Vegetation clearance on the hills and valley flats began with agricultural tenant farmers, however the industry soon developed and expanded with the introduction of dairying in the mid-nineteenth century. Further clearing occurred to make way for pastureland, and watercourses were altered and constructed, resulting in extensive drainage of wetlands throughout the Shellharbour area. The forestry industry was also prominent in Shellharbour in the early nineteenth century, with commercial felling occurring alongside land clearance for agriculture. Logging has affected all remnant patches of forest in the region – the density of old growth trees is low, and mainly composed of uncommercial species or individuals displaying faults. The region became industrialised as a result of these activities, with the extension of rail and other transport mechanisms to facilitate the movement of goods (Navin Officer Heritage Consultants, 2000).

Extraction and mining has also featured throughout Shellharbour’s history. Quarrying and use of latite rock began in the 1800’s and has continued intermittently since. There were two underground coal mines found in the LGA, both now abandoned, however their impact on the land surface continues. In addition, beach sand mining for shell grit and minerals occurred from the nineteenth century into the mid-twentieth century.
Urban development has expanded on a large scale since the initial townships of Shellharbour and Albion Park were established. Agricultural estates were subdivided into residential lots, allowing for extensive urban development and establishment of suburban estates. This resulted in broad-scale landscape modification.

### 3.1.6 Vegetation

The vegetation in the region has changed dramatically since European settlement, with extensive clearing and agriculture changing the vegetative landscape. Vegetation was once highly diverse, composed of a variety of plant groupings that varied according to the rainfall, topography, soil characteristics and distance from the ocean. Only 8% of the original forest cover remains on the coast at elevations below 100 metres, and where remnant vegetation does remain it is generally highly degraded (Mills, 1983). Prior to European settlement, this area was forested with intermittent areas of natural grassland. The rolling hills and coastal plain was scattered with sclerophyll forest and rainforest in more sheltered sites.

Presently, vegetation in the Shellharbour LGA comprises stands of remnant vegetation communities, agricultural pasture grasslands and woodlands (Fuller and Mills, 1985; SCC, 2010). Agricultural clearing has occurred on the lower slopes and along the coastal plain, resulting in the majority of remnant vegetation communities being located on moderate to steeper slopes along the western margin of the LGA, where clearing was not undertaken or maintained. Remnant vegetation can also be found along stream sides and estuaries on the valley floor. Most of the remaining forest is dry sclerophyll, with rainforest appearing only in small, protected and discontinuous pockets (Navin Officer Heritage Consultants, 2000). The remaining vegetation is highly important in preserving and maintaining biodiversity in the region, as it supports a number of threatened species and vegetation communities.

Native vegetation in the LGA is highly diverse, with thirty four vegetation communities found in the area (Mills and Associates, 1996). In order to protect the diversity of vegetation and conserve biodiversity, several vegetative reserves are in place within the LGA. These include Blackbutt Reserve and Shell Cove Reserve, both close to the wetlands of this study. Both reserves house endangered ecological communities listed under to NSW Threatened Species Conservation Act – Blackbutt Reserve has Illawarra Lowlands Grassy Woodland and Illawarra Subtropical Rainforest; whilst Shell Cove Reserve holds Illawarra Subtropical Rainforest and *Melaleuca armillaris* Tall Shrubland. They are also home to a number of endangered species, including *Pimelea spicata* (Spiked rice flower) and the Illawarra Zeria,
Zieria granulata (SCC, 2010). Other vegetative communities that exist include a variety of open and closed shrublands, Red Gum – Blue Gum Forest, Cumbungi Reedland, disturbed riparian vegetation and a number of plantings in the LGA, especially at the constructed wetlands where extensive planting occurred and is ongoing to maintain the vegetation of the system.

3.1.7 Fauna

A number of threatened and regionally significant fauna species can be found within the LGA. Threatened species include the Grey-headed Flying Fox, two bat species, a number of owl and bird species and the Green and Golden Bell Frog. Regionally significant species include the Platypus, a number of bird species, the Green Tree Frog and Maccoy’s Skink (Kevin Mills and Associates, 2007). Other mammals found in the LGA include the Common Wombat, the Short-beaked Echidna, a number of bat species and introduced species including the fox, the European rabbit, and the pig. A number of birds can also be found within the LGA, including migratory species listed under JAMBA and CAMBA legislation. Reptiles include lizards, skinks and turtles, and a number of frog species have also been identified (Ecological, 2012).

3.1.8 Land-use and Zoning

The Shellharbour Draft Local Environment Plan 2011 (LEP) is currently on public exhibition. In this plan, the wetlands in both catchments have been zoned as Zone RE1 Public Recreation. The purpose of this land is to provide area for open space and recreation and to protect and enhance the natural environment for recreational purposes. Any development in this zone must be granted consent, and development is limited to environmental, tourism and recreational facilities. The eastern portion of the Myimbarr system has been classed as Zone E3 Environmental Management. This zone has been designated to protect, manage and conserve areas that hold special values, including ecological, scientific, cultural or aesthetic. Only a limited amount of development that will not adversely impact the site is allowable in this zone (Shellharbour Local Environment Plan Draft, 2011).

3.1.9 Elliott Lake Catchment – Myimbarr Wetlands

Myimbarr Wetlands consist of nine deep freshwater ponds totalling 11.5 hectares, 1.4 hectares of saltmarsh and 1 hectare of open tidal lagoon, separated from the freshwater
components by a dam wall. It contains a habitat island, shallow submerged benches, endemic vegetation and buffer zones (Cleary Bros, 2012; Sainty and Associates, 2005).

Table 1, adapted from Kevin Mills and Associates Annual Report for Myimbarr Avifauna (Kevin Mills and Associates, 2007), contains specific details regarding the ponds in Myimbarr.

<table>
<thead>
<tr>
<th>Pond Number</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Entrance Pond</td>
<td>Entrance to Myimbarr where sediment detention basin lies. Old and well established deep pond, fringed with vegetation. Pond size is about 1.30 ha.</td>
</tr>
<tr>
<td>2</td>
<td>Western Pond</td>
<td>Pond size is about 0.83 ha, deep water fringed with vegetation.</td>
</tr>
<tr>
<td>3</td>
<td>Mid-Western Pond</td>
<td>0.90 ha, deep water fringed with vegetation.</td>
</tr>
<tr>
<td>4</td>
<td>Island Pond</td>
<td>About 1.95 ha in area, pond consists of a combination of deep water and shallower muddy flats with extensive vegetation.</td>
</tr>
<tr>
<td>5</td>
<td>Middle Pond</td>
<td>Approximately 1.90 ha in size, mainly deep water with some shallower muddy flats, extensive reeds fringing the pond.</td>
</tr>
<tr>
<td>6</td>
<td>Southern Pond</td>
<td>About 1.80 ha, similar to Pond 5 to which it joins at times of high water stands. Muddy flats exist during low water stands.</td>
</tr>
<tr>
<td>7</td>
<td>Eastern Pond</td>
<td>Combination of both deep and shallow water with muddy flats when water level is low. Extensive fringing vegetation.</td>
</tr>
<tr>
<td>8</td>
<td>Saltwater Pond</td>
<td>Saltwater component – tidal deep water and saltmarsh, approximately 3.02 ha in size.</td>
</tr>
<tr>
<td>9</td>
<td>Northern Pond</td>
<td>Narrow, deep water pond fringed with vegetation. 0.85 ha.</td>
</tr>
</tbody>
</table>
The Myimbarr system has been designed to provide both fresh water and saltwater habitat for fauna and flora. Water is filtered through the freshwater ponds before entering the saltmarsh component. The system has been designed so that approximately 70% of flow enters Pond 8 from the southern side (Pond 7), and 30% of flow enters from the northern side, Pond 9 (T. Heather, pers. comm., 2012). Water levels can be controlled at the weir between the fresh and saltwater components by benches and valves used to mimic the natural variation in wetland water levels (Sainty and Associates, 2005).

To mimic the natural hydrologic regime, an August-September draw-down occurs. This is to ensure that the natural wetting and drying cycles are replicated in accordance with local climatic conditions. This variation maximises species and habitat diversity and aids in the management of pest or prolific species. Rainfall is lower during August and September, therefore the draw-down of 300 mm occurs during this time, for a 6-8 week period. This encourages the inhabitancy of migratory birds and also provides SCC with management opportunities to remove weeds. The draw-down must be monitored, however, to ensure pools do not become too shallow and native fish remain protected (Cleary Bros, 2012; Sainty and Associates, 2005).
After construction, the wetlands were planted with 250,000 native species to mimic the vegetation naturally occurring in freshwater and saltwater coastal wetlands. Plantings varied throughout the wetland, and some areas, such as the deep pools, were expected to self seed. Intermediate pools and shallow benches were planted with a number of native species including *Phragmites australis*, *Juncus kraussii*, *Schonoplectus validus* and *Baumea articulata*. Phragmites was planted throughout the creek channel as well, and was expected to become a dominant species within the wetland. Eucalyptus, Acacia and Melaleuca species were planted in riparian areas, as well as wetland species such as *Gahnia sieberana* (Mills and Associates, 2007). The saltmarsh component of Myimbarr was sufficiently inundated by tidal action and expected to self seed with coastal saltmarsh species (Sainty and Associates, 2005).

Myimbarr Wetlands are located in the Elliott Lake catchment, within the sub-catchment of Tongarra Creek. A total of 31 gross pollutant traps (GPTs) are located in the Elliot Lake catchment, 27 of which are found in the Tongarra Creek sub-catchment. These function to trap gross pollutants in drains to prevent them entering waterways.

The Tongarra Creek water course has been altered significantly, demonstrated by the historical photo below (Figure 5): sections of the channel have been modified and straightened, especially leading into Myimbarr. There was no existing water bodies where Myimbarr is now found, but instead lay a meandering creek and swamp land the graded into a saltmarsh zone. The water course has been altered significantly with the construction of the wetland ponds, which mediate the water flow and velocities in the specially designed ponds. The saltmarsh zone is now separated from the freshwater zone by a constructed weir that prevents estuarine waters moving farther upstream, but allows the movement of freshwater downstream.
Figure 5: Historical image of Tongarra Creek from 1948, showing where the water course previously ran, and where Myimbarr Wetlands are now located. When compared with the Figure 8 below it is evident that the channel has been modified and straightened.

The catchment is extensively cleared, and residential areas are yet to be developed. There was no buffer zone of vegetation along the creek line, which is markedly different to the present creek line which has zones of riparian vegetation along the banks and grassed zones between residential housing and the creek line. The remnant patch of vegetation present at site TON 1 can be observed, however the vegetation was sparser in 1948 when the image was taken.

Within the Elliott Lake catchment, 30% of the land surface is impervious. It is estimated that the total amount of runoff that discharges into Elliott Lake from the Tongarra Creek catchment is 2,970 ML/yr. This is greater than the estimated 2,140 ML/yr that would have occurred prior to catchment development. The increase in stormwater runoff post-development is not drastic due to the stormwater treatments emplaced in the catchment, namely the Myimbarr wetland system itself, in conjunction with other constructed ponds and various gross pollutant traps (GPTs). If these measures were not in place, the annual runoff discharging through Tongarra Creek is estimated to be 3,190 ML/yr. As such, Tongarra Creek and Myimbarr are performing relatively well in removing toxicants, gross pollutants
and sediment entering the watercourse (Patterson Britton & Partners 2006).

Figure 6: Elliott Lake and Shellharbour Catchments. The Myimbarr System is located in the Elliott Lake catchment, and the Shell Cove system is found within the Shellharbour catchment.
3.1.10 Shellharbour Catchment – Shell Cove Wetlands

This study examines two ponds within the Shell Cove constructed wetland system to determine the effectiveness of the wetlands in regard to stormwater treatment and filtration. The Shell Cove wetland system has been constructed by Cleary Bros to fulfil the requirements of the boat harbour agreement and provide stormwater services to the newly developed Shellharbour catchment. Eight main ponds have been constructed to date, with a number more expected to be developed in coming months to accommodate further development in Shell Cove. Historical photographs indicate that the pond at the top of the catchment (study site SC 1) existed prior to development, but has been modified significantly in size and shape. The other ponds in the catchment have been constructed and did not exist prior to development. A number of additional temporary ponds are present within the catchment, however they will be removed or modified as the area is developed (T. Heather, pers. comm., 2012).

Information regarding the Shell Cove wetlands has been difficult to obtain, and has not been released from developers to SCC. As such, limited background information for the Shell Cove wetland system is included in this report; however, analysis of historical photos has uncovered information about the sequential development of the catchment. Historical photos from 1997 to 2012 were analysed to determine the succession of ponds in the catchment. Little urban development was evident in the catchment in 1997, and the Shell Cove suburb had not begun construction. The top pond (SC 1) was present, and had been established for some time before this, as it appears in historical photos from 1948. By the year 2000, urban development had begun in the catchment, and there is evidence of initial construction of a sediment control pond. This pond became established in 2001, when further development was occurring. In 2003 the modification of the SC 1 pond began, as the pond was altered to regulate flow. The channel downstream was also modified around this time. Aerial photographs from 2004 show the twin ponds downstream from SC 1 were established, and construction of the wetlands downstream in the catchment (study site SC 2) had begun. By 2005, many changes in the catchment had occurred. All ponds were established, and significant housing development had occurred.

The Shell Cove wetlands are located in the Shellharbour catchment. Within this catchment, 16 GPTs are in place to trap pollutants before they enter the waterways. Traps are designed
so that they can be emptied when full, and they require ongoing maintenance to function effectively.

A brief assessment was made regarding the percentage of permeable versus non-permeable land within the Shellharbour catchment. Approximately 50% of the catchment comprises of vegetated of grassed land with a permeable surface, and the remaining 50% consists of houses, roads and paved non-permeable surfaces. This will change in the near future, as further residential development and the creation of the marina will increase the amount of non-permeable surfaces, and thus increase the volume and velocity of water received into constructed wetland ponds in the eastern side of the catchment.

Figure 7: Historical image of Shell Cove from 1948, before the catchment was urbanised. The blue line indicates the previous water channel. The pond in the left of the image has been modified and is site SC 1. When compared with Figure 9 below, it is clear the channel has been modified and straightened, and ponds have been constructed along the channel.

The natural water course has been altered as the catchment has been developed. Figure 7 shows the Shell Cove study site in 1948. It is clear that site SC 1 was present as a natural water body, however it has been highly altered and modified into the pond that exists today. The channel has been straightened in some sections, and additional ponds have been
constructed where natural water bodies did not previously exist. It is interesting to note that the catchment has far more vegetation currently than was present in 1948, which could be attributed to the wide-scale land clearing that occurred for agriculture, and the conservation and regeneration efforts that have been made in the last few decades to preserve and enhance vegetation in the area. The creek lines are now vegetated with riparian vegetation, which was not present along the channels in the past. This would assist in stabilising the banks and in the prevention of erosion along the channel.

As shown in Figure 7, the catchment was grassed and houses/paved surfaces were not present. The velocity and volumes of runoff would still have been high however, as there was a lack of vegetated surfaces in the catchment, and the absence of buffer zones would have allowed runoff and sediment to enter the water channel directly. In recent times, a distinct buffer zone around the wetlands and along creek channels can be observed, providing a transition zone between residential land and the watercourse.
Chapter Four

4.1 Field Sampling Procedures

4.1.1 Sample Sites

Soil and Water

Sites were selected to obtain a representative sample of constructed wetlands and their catchments in both the Elliott Lake and Shellharbour catchments (see Figure 8). Samples were taken along each wetland tributary to obtain an overall picture of the water and soil quality in the catchment, which has an effect on the water quality of the wetlands. Samples were taken at the top and bottom of the catchments, and the inlet and outlet of Myimbarr to determine if the wetlands are working as intended in treating and filtering stormwater and runoff.

Sampling was conducted at seven locations in the Shellharbour LGA. Four sampling sites were selected at the Myimbarr wetlands and the upper tributary of Tongarra Creek in Flinders, and three sampling sites were selected in the Shell Cove wetlands and their associated tributary system. Sample sites were a combination of both natural tributaries and constructed wetlands. The Myimbarr and Tongarra Creek sites have been named with the prefix “TON”, while the Shell Cove sites were named with the prefix “SC”. Testing was conducted where the water depth was >30 cm, was clear and flowing, and free of debris and macrophytes where possible. Exact site locations were recorded using a GPS, shown in Table 2.
<table>
<thead>
<tr>
<th><strong>Site Name</strong></th>
<th><strong>Coordinate Reference</strong></th>
<th><strong>Site Description</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>TON 1</td>
<td>301828E, 6171414N</td>
<td>TON 1 is the first sampling site, at the top of the Tongarra Creek catchment where the natural creek line lies.</td>
</tr>
<tr>
<td>TON 2</td>
<td>302620E, 6170952N</td>
<td>TON 2 is a constructed wetland farther downstream from TON 1. Samples were taken off a bridge near the weir where water was flowing and depth was sufficient.</td>
</tr>
<tr>
<td>TON 3</td>
<td>303112E, 6171585N</td>
<td>TON 3 is at the inlet in the sediment forebay in the Myimbarr Wetlands.</td>
</tr>
<tr>
<td>TON 4</td>
<td>304036E, 6172000N</td>
<td>TON 4 is the outlet of Myimbarr that leads into Elliott Lake and the ocean. The sample was taken on the freshwater side of the concrete weir that separates the fresh and saltwater components of the wetland, on the south arm of the wetland that receives the greatest amount of flow (70%).</td>
</tr>
<tr>
<td>SC 1</td>
<td>302920E, 6169674N</td>
<td>SC 1 is the first sampling site, a constructed wetland located at the headwaters of the stream at the southern entrance to the Shell Cove suburb.</td>
</tr>
<tr>
<td>SC 2</td>
<td>304020E, 6170330N</td>
<td>SC 2 is located farther downstream from SC 1, one of the newest constructed wetlands near the proposed marina. The wetland lies adjacent to the natural creek line that runs through the catchment, and flows into the creek line downstream.</td>
</tr>
<tr>
<td>SC 3</td>
<td>0304034E 6170259N</td>
<td>SC 3 is located on the natural creek downstream of SC 1. Extensive construction is occurring immediately south east of SC 3. A soil sample only was obtained at this site.</td>
</tr>
</tbody>
</table>
Figure 8: Sample Site locations for Soil and Water testing within the Elliott Lake and Shellharbour Catchments. Note that a soil sample only was obtained at SC 3.
Vegetation

Vegetation surveys were conducted throughout the catchment across the tributaries and wetlands to determine the influence of upstream vegetation on the health of vegetation in the wetlands. A number of vegetation surveys and samples sites also gave a representative view of stream and wetland vegetation within the Elliott Lake and Shellharbour catchments. Eight vegetation surveys were conducted in total: five within the Elliott Lake Catchment (Figure 9) and three within the Shellharbour catchment (Figure 10). Sites were numbered V1 through to V8, beginning at TON 1 and ending at SC 3. In the Elliot Lake catchment, two surveys were conducted upstream along the natural creek line; one at TON 1 and the other upstream from TON 2; and three surveys were conducted through Myimbar; at the entrance (Entrance Pond), exit (Eastern Pond) and in the middle (Mid-Western Pond). In the Shell Cove catchment, one survey was conducted across the first constructed pond upstream in the catchment – SC1. Subsequent surveys were conducted downstream along the tributary, with the final survey located just upstream of SC 3.
Figure 9: Location of the vegetation transects in respect to the soil and water sampling locations in the Elliott Lake (Tongarra Creek) Catchment.
Figure 10: Location of the vegetation transects in respect to the soil and water sampling locations in the Shellharbour Catchment (Shell Cove).
4.1.2 Water Testing

Water testing was conducted on several occasions during the study period; preliminary samples were taken on 12 March 2012, and further sampling followed on 30 April 2012, 30 and 31 May 2012 and 12 September 2012. Sampling conducted on the first date (12 March 2012) only sampled one site (TON 2), and subsequent testing sampled all sites. Preliminary samples were taken at TON 2 to familiarise the author with the equipment and the sampling procedure. Water sampling was not conducted at SC 3 as the water depth was insufficient for sampling, therefore a soil sample only was taken from this site. Water sampling was conducted with the assistance of the project supervisors from both SCC and UOW. Water is tested in the field using a field probe (TPS 90FLMVT multi parameter) and samples are collected to be sent for analysis at Australian Laboratory Services (ALS). The field probe tests the following parameters:

- Temperature (°C)
- Dissolved Oxygen (%)
- pH
- Turbidity (ntu)
- Conductivity (µS/sec)
- Salinity (ppt)
- Oxygen Reduction Potential (mV)

Results are stored in an internal database that can be accessed via computer. Individual water samples are collected in bottles provided by ALS that have specific preservatives added.

Table 3: Preservatives contained in collection bottles for analysis at ALS. Different treatments are applied depending on the parameter tested.

<table>
<thead>
<tr>
<th>Parameter to be Tested</th>
<th>Preservative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutrients</td>
<td>Sulphuric Acid H₂SO₄</td>
</tr>
<tr>
<td>Metals</td>
<td>Nitric Acid HNO₃</td>
</tr>
<tr>
<td>Enterococci; Chlorophyll a; Total Suspended Solids</td>
<td>Sterile Bottle</td>
</tr>
</tbody>
</table>

Samples are then tested for the above parameters by ALS Wollongong. The samples must be kept at 4°C and delivered within 12 hours of collection.
The sampling probe is ordered from ThermoFisher Scientific and arrives calibrated and ready to use. The equipment is hired to ensure that the latest technology is used and the calibration is consistent. Sample bottles, ice and an esky are provided by ALS for collection and storage of samples that are being sent to the lab (T. Heather, pers. com., 2012). Field sheets used in this study for recording observations were prepared by the SCC for their rounds of quarterly water testing (see Appendix 2). Weather and rainfall data were recorded from the Bureau of Meteorology in the week/s prior to collecting the samples. A risk assessment was conducted prior to each sampling round to ensure safety and must be signed off by each participant.

Testing Using the Probe (TPS 90FLMVT multi parameter)

At each site, the probe was used to test certain water quality parameters. Before submerging the probes, the unit must be switched on and protective caps removed from each probe. To obtain an accurate sample, the probe must be held approximately 30 cm under the water level, ensuring all probe sensors are submerged and surface effects are unlikely to skew results. The probe was lowered into the water by hand or using an extendable grab pole sampler where required. Once the probes are in the correct position under water, the numbers on the screen will take around sixty seconds to stabilise. The numbers must stabilise sufficiently before a reading is recorded to ensure accuracy. Once stabilised, the data can be stored in the internal database by pressing STORE and then ENTER. Before and after testing, the probe should be rinsed using clean tap water to ensure no cross-contamination occurs. The probe must be wrapped up and stored in the case provided between sites to ensure no damage occurs.

Obtaining Samples for ALS

Bottled samples were collected in accordance with the Australian/New Zealand Water Quality – Sampling Guidelines for sampling of rivers and streams (AS/NZS 5667.6:1998). The water samples were collected using an extendable grab pole sampler. A 1 L bottle was used to collect the water sample, which was then transferred to other sampling bottles. Bottles were filled and the cap was removed for a short time only to limit the chance of contamination.

To collect the sample, the bottle was attached to the grab pole sampler and lowered into the water nozzle first to maintain a volume of air in the container and prevent the collection of surface films. The bottle was held approximately 15 cm underwater, facing upstream. The
bottle was moved forward slowly into the flow of water during collection. Water was sampled from locations that gave a representative sample of the water body from which it was taken; stagnant backwaters were avoided, as were areas filled with macrophytes or other organisms. Samples were obtained from clear flowing water where possible. Bottles were labelled with the date, site location and time using a marker pen that would not run when in contact with water. Collected samples were returned to the esky to ensure the sample remained cool before returning to the lab. Once testing was complete, bottled samples were delivered to ALS within the required time frame for analysis.

4.1.3 Soil Sampling

Soil samples were collected using an extendable pole sampler and transferred into clear, labelled ziplock sample bags. Preliminary samples from some sites were collected on 30 April 2012, however the majority of sampling across all sites was conducted on 25 June 2012 with the assistance of the UOW project supervisor.
At least one sample was collected for each of the study sites, and some sites had a number of samples collected, named a, b and c, respectively. Thirteen soil samples were collected in total. To collect the samples, the grab sampler was plunged into the soil, ensuring that the sample collected was sediment representative of the site. It was ensured that the volume of sediment collected was sufficient for analysis. Once the sample was bagged the tube was rinsed using water from the site and clean water.

4.1.4 Vegetation Surveying

Vegetation surveys were conducted in August 2012. Field sheets were prepared prior to undertaking fieldwork (see Appendix 2). They included an observation checklist for each site, listed the species type and percentage coverage, distance from the banks/water, depression from the bank height, water depth (where applicable) and observations of dying/poisoned plants. A long metre tape was set up perpendicular to the water channel, across the creek line from bank to bank. The GPS coordinates were recorded at both the start and finish of the transect. A 1 m quadrant square was placed at every second metre along the transect to obtain a representative survey. The interval of every second metre was chosen as it would display changes in the vegetation and give a representation of the vegetation at each site, as little change was observed at 1 m intervals. In the quadrant each species present was recorded, along with its percentage coverage in the quadrant. At each metre interval the height depression from the bank was recorded to obtain a height cross-sectional profile. The water depth was measured at each metre on the creek line, where accessible. In regions where the same vegetation stretched over several metres, this was noted in the observations rather than setting up a number of transects for the same vegetation type. Observations were also recorded to note any dying plants, whether it was due to seasonal changes or poisoning for weed management.

Field guide books were used to identify plants and weeds, along with field sheets prepared by the author and SCC. Any plants that were unable to be identified in the field were brought to the SCC for identification by qualified Bush Regeneration staff. The data obtained was used to create vegetation profiles for each of the sites surveyed, to determine species abundance and location within the wetlands.

Due to constraints within the field, estimations had to be made regarding the distance across water bodies, and the distance to banks due to accessibility issues. For site V8 a transect was not established and the quadrant was not used due to the poor accessibility to the banks from
the dense vegetation. Instead observations were used to record the species present on either side of the banks.

4.2 Laboratory Methods

Analysis in the UOW laboratories was required for the sediment samples collected. This included grain size analysis, X-ray florescence (XRF) and X-ray diffraction (XRD). The grainsize analysis gave the average grainsize of each sample at each site (sand, silt, clay), XRF analysis was used to determine elemental composition of the sediment and XRD was used to analyse the mineralogy of the sediment.

4.2.1 Grain size Analysis

Grain size was determined for each sample using a Malvern Mastersizer 2000. The Mastersizer runs a portion of the sample (larger sized particles removed) through the analyser to determine the average grainsize based on three readings. This is used to determine the percentage of sand, silt and clay present in the sample.

To analyse each sample, a small portion of soil was collected using a clean spatula and transferred into a small glass vial. A small amount of water was added and the sample was shaken to ensure mixing. This sample was transferred into the sample container through a sieve. The sieve was used to collect sediment particles larger than sand (2000 µm), which would clog the mastersizer. The sample was gently washed through the sieve using tap water, and oversized sediment was disposed. The sample container was placed in the mastersizer to detect the background and determine if the amount of sample in the container is appropriate for analysis, as indicated by a graph on the computer – when the sample reads within the green zone it is suitable for analysis. Once completed, the computer will indicate the sample is ready to be analysed. Once analysis is finished, three readings for percentage sand, silt and clay will be given, and an average grain size is obtained. This process was repeated for all samples.

4.2.2 XRF

To prepare for analysis, a portion of each soil sample was transferred into a small aluminium pie case. The cases were filled with the sample and labelled as appropriate. These samples were placed in the oven overnight at 60°C until they were dried completely. The samples were then crushed using the Tema machine. The samples were crushed to a consistent fine
powder to enable analysis. Each sample was placed in a stainless steel container, which was then placed inside the Tema and locked in. The machine was turned on for 10-15 seconds. Once crushed, the sample was then transferred into small labelled ziplock bags. In between crushing each sample the steel container was cleaned. This was done by placing a small amount of gap sand (blend of graded fine sands and additives) into the steel container, crushing it in the Tema, and dusting out the excess using a paintbrush and damp paper towel. Each part of the steel container was wiped with damp paper towel and dried using compressed air. This process was repeated for all samples.

Once the samples were crushed they had to be prepared as pressed pellets. Between 5.00 – 5.50 g of each sample was measured in a disposable plastic cup. 8-10 drops of PolyVinyl Acetate (PVA) binder was added to the sample and mixed to ensure consistency. The sample was compacted into a small aluminium cap using a presser, pressing to 2,500 psi. Each cap containing the sample was labelled for analysis and placed in a 65°C oven overnight to dry the PVC binder. Once dried, the samples were weighed and the weight recorded on the cap. The samples had to weigh between 5.00 – 5.50 g for analysis. Analysis was run using a SPECTRO XEPOS energy dispersive polarization X-ray fluorescence spectrometer (XRF) to determine the trace element composition in the soil.

4.2.3 XRD

The crushed samples were also used in XRD analysis. Once crushed, samples were given to UOW’s Jose Abrantes for XRD analysis by a Phillips 1150 Pw Bragg-Brentano diffractometer using CuKα radiation. Approximately 0.5 grams of sample was run through the XRD to determine the mineralogy of the sediment. Computer programs Traces and Siroquant were used to examine the XRD outputs and determine the dominant mineralogy of each sample. Quartz, feldspar, and aluminium peaks were analysed in Traces and the data was exported into Siroquant for further analysis. Using Siroquant the dominant mineralogy of each sample was determined, and presented as a percentage.
Chapter Five

5.1 Results

5.1.1 Introduction

This chapter contains the results obtained through water and soil sampling, and vegetation surveys throughout the Shellharbour and Elliott Lake catchments. Water testing conducted during the study period was used to determine the water quality in the catchments from March to September 2012. Historical water quality was obtained for the Myimbarr outlet from testing conducted by SCC since 2008 and was used to analyse water quality trends for the Myimbarr catchment. Historical water testing data was not available for Shell Cove. Soil was analysed to determine the average grainsize and classify the soil type for each sample and site location, XRF analysis was used to determine trace elements indicative of pollution at the sites, and XRD analysis was used to determine the dominant mineralogy of each sample and site location. It was found that water quality was variable, falling in an out of the ANZECC Guidelines for most parameters where guidelines are available. Soil sampling indicated that the sites were not contaminated, with the possible exception of site SC 3. Soil mineralogy was typical of the soil types present in the area. Vegetation surveys uncovered a variety of native and invasive wetland species, indicating that pest species are a problem for both catchments.

5.1.2 Water

ANZECC Guidelines

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality have been prepared to provide a guide for establishing water quality objectives that will sustain current and future environmental uses for Australian and New Zealand water resources (ANZECC, 2000). The guidelines do not provide mandatory values for water quality but are rather a flexible system that is to be adapted according to each scenario, to determine management goals and water quality objectives tailored to local conditions. There are a range of water quality indicators discussed in the guidelines, including biological indicators, physical and chemical stressors, toxicants and sediments.

A number of steps are taken in the application of the guidelines. First, the environmental values and human uses for the waterways are determined: in this project the environmental value and use is classed as Aquatic Ecosystems. Secondly, the water quality objectives are
determined, to protect environmental values or work towards achieving environmental values. A protection level is the assigned to the site: in NSW the default policy is to apply the level of protection designed for ‘slightly to moderately disturbed’ ecosystems. This level of protection has been used in this study. Expected issues and their water quality indicators were then determined for the site: as this study aimed to determine the overall water quality of the sites a range indicators were examined, including biological indicators, physical and chemical stressors and toxicants (metals) (DEC, 2006).

The trigger values determined for south-east Australia were used. Data was not available for wetlands in this region, therefore indicators for lowland rivers have been used as reference guidelines. Indicators are expressed either as trigger values which indicate a threshold value, or as a range of desirable values for that parameter. If the threshold is exceeded or readings fall outside the desired range it indicates that action should be taken to investigate risk to the environmental value (DEC, 2006).

**Historical Water Quality – Myimbarr**

Historical water quality data has been obtained from SCC for Myimbarr outlet (TON 4) for the following water quality parameters:

- Chlorophyll *a*
- Total Nitrogen (TN)
- Total Kjeldahl Nitrogen (TKN)
- Nitrogen Oxides (Nox)
- Total Phosphorous (TP)
- Total Suspended Solids (TSS)
- *Enterococci*
- Fecal Coliforms (FC)
- pH
- Dissolved Oxygen (DO)
- Turbidity
- Temperature
These data have been collected on twelve occasions from August 2008 to January 2012, however a full set of data is not available for all parameters tested. The data can be used to determine trends in water quality over the last four years for part of the Elliott Lake Catchment along Tongarra Creek and Myimbarr. As the data obtained was collected from the outlet of the wetland system, it can be used to indicate how effectively the system is working in filtering and treating urban stormwater runoff. It can also be used to infer the water quality of the catchment as it runs through Tongarra Creek to Elliott Lake. No obvious trends have been observed in the data, however it has been observed for all parameters that a spike occurred in January 2012. Results and the associated graphs depicting the Historical Water Quality Data are located in Appendix 3, and will be discussed in Chapter Six.

**Water Sampling Results for the 2012 Study Period**

Water quality sampling was conducted throughout the study period on 12 March, 30 April, 30 May and 12 September 2012. Results were obtained for a range of organic and inorganic parameters, including metals. Preliminary samples obtained in March only tested field parameters using the probe at site TON 2, and SCC sampled additional parameters at TON 4 as part of their regular testing on this date. Subsequent testing examined all parameters for sites TON 1 through to SC 2. SC 3 was not sampled as there was insufficient water in the channel, and any water that was present contained abundant plant matter and algae. September sampling at TON 1 was not possible as the channel was dry due to a lack of rainfall in the catchment in the preceding months. The following water quality parameters were tested as part of this project:

<table>
<thead>
<tr>
<th>Organic and Inorganic Parameters</th>
<th>Metals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia as N</td>
<td>Arsenic</td>
</tr>
<tr>
<td>Chlorophyll $\alpha$</td>
<td>Barium</td>
</tr>
<tr>
<td>Dissolved Oxygen (DO)</td>
<td>Beryllium</td>
</tr>
<tr>
<td><em>Enterococci</em></td>
<td>Cadmium</td>
</tr>
<tr>
<td>Faecal Coliforms (FC)</td>
<td>Cobalt</td>
</tr>
<tr>
<td>Nitrate as N</td>
<td>Chromium</td>
</tr>
<tr>
<td>Nitrite as N</td>
<td>Copper</td>
</tr>
<tr>
<td>Nitrogen Oxides (Nox)</td>
<td>Manganese</td>
</tr>
<tr>
<td>Oxidation Reduction Potential (ORP)</td>
<td>Nickel</td>
</tr>
<tr>
<td>pH</td>
<td>Lead</td>
</tr>
</tbody>
</table>
Temperature  Vanadium
Total Kjeldahl Nitrogen (TKN)  Zinc
Total Nitrogen (TN)  Mercury
Total Phosphorous (TP)
Total Suspended Solids (TSS)
Turbidity

**Dissolved Oxygen**

Figure 12 below shows changes in DO over the sampling period for each site. The shaded blue area indicates the acceptable ANZECC range of values that DO should fall into for lowland rivers. DO was variable in all sites, and there was little consistency in the results. DO did not remain in the acceptable range across all sampling dates for any sites, however every site with the exception of TON 1 had at least one result within the acceptable range. TON 1 had the lowest DO of all sample sites, far below the guidelines on both sampling occasions. Limited data was obtained for TON 1 due to weather conditions, so it is difficult to comment on trends. DO is trending upwards during the sampling period for all sites excluding TON 1 and SC 2. Nineteen samples were obtained in total, and of this only eight fell within the accepted range for DO.

![Dissolved Oxygen Graph](image)

*Figure 12: DO at each site during the sampling period. The blue shading indicates the acceptable range for lowland rivers, as defined by the ANZECC Guidelines.*
**Conductivity**

As displayed in Figure 13, only one sample obtained at TON 2 fell outside of the acceptable range for conductivity in lowland rivers. Samples obtained at SC 1 and SC 2 remained constant during the sampling period, however an upwards trend can be observed for TON sites. This trend is observed for all samples obtained along Tongarra Creek, which demonstrates that the increase in conductivity is consistent throughout this catchment. There is only a slight increase for TON 4, which indicates that although conductivity is heightened farther up in the catchment, it is only slightly increased as it leaves the wetland system.

![Conductivity Graph](image)

*Figure 13: Conductivity at each site during the sampling period. The blue shading indicates the acceptable range for lowland rivers, as defined by the ANZECC Guidelines.*

**pH**

pH was also variable throughout the sampling period, however most samples obtained yielded results within the acceptable range for pH in lowland rivers. pH readings at SC 1 and SC 2 both decreased during the sampling period. Throughout the TON sample sites consistent trends were observed: between April and May pH rose, and between May and September pH fell again, giving a reading that was lower than the April site for all samples. A pH reading was not obtained for TON 1 in September, however it is predicted that it would have
followed this same trend, as sites lower in the catchment all reflected a lower pH. pH fell in the acceptable range for all sites in September. Samples obtained along Tongarra Creek indicate that pH increases as it moves down the catchment: the lowest pH readings are obtained at TON 1, and the highest can be seen at TON 4.

![Figure 14: pH at each site during the sampling period. The blue shading indicates the acceptable range for lowland rivers, as defined by the ANZECC Guidelines.](image)

**Turbidity**

During the sampling period, turbidity was observed to decrease in most sampling sites. Turbidity was consistently lowest at the SC sites, and the highest readings were obtained at TON 2 and TON 4 in March and April respectively. A very high reading was obtained in March for TON 4, reflected in a sample taken at TON 2 as well. Despite heightened turbidity values higher in the catchment along Tongarra Creek, values are within the recommended range for both the inlet and outlet of Myimbarr, indicating that turbidity decreases as water moves down the catchment. The majority of results obtained fell within the acceptable ANZECC range for lowland rivers.
Temperature

The ANZECC Guidelines do not provide specific information regarding trigger values for water temperature, despite its importance in regulating wetland health and the associated problems that arise when temperature becomes too low or too high. Natural systems in the greater Sydney region do not normally experience water temperatures greater than 20°C, however constructed wetland systems commonly experience temperature up to and in excess of 24°C in the summer, and as low as 12°C in winter months (Hunter, 2012).

The temperatures obtained during the sampling period fall within this range, showing lower values in May when the climate is cooler, and warmer temperatures in March and September, when the climate is warmer. Due to the timing of the project, results were not obtained during summer months for most sites. The highest reading obtained was for TON 2 in March, when temperatures would have been warmer as summer was ending.

Figure 15: Turbidity at each site during the sampling period. The blue shading indicates the acceptable range for lowland rivers, as defined by the ANZECC Guidelines.
Figure 16: Temperature recorded at each site during the sampling period.

**Oxygen Reduction Potential (ORP)**

ORP was variable throughout the sampling period and similar trends were observed across all sites. ORP was observed to drop between April and May, and rise again by September. The least variability was experienced in the SC sites, whilst the greatest variability was noted at TON 4. ANZECC values do not exist for ORP. Most surface waters have an ORP of 100 – 200 mV, with any readings below 200 mV indicating reduced levels of oxygen, which is not desirable for aquatic ecosystems (Apps, 2012). Of the 18 samples obtained, ten fell within the above range. A significantly lower value was experienced in March at TON 2, however no other readings were taken at this time so it is not known if this trend was reflected at other sites.
Figure 17: ORP recorded at each site during the sampling period. The blue shading indicates the acceptable range for lowland rivers, as defined by the ANZECC Guidelines.

Chlorophyll $a$

Figure 18: Chlorophyll $a$ recorded at each site during the sampling period. The red line indicates the trigger value for lowland rivers, as indicated by the ANZECC Guidelines.
During the sampling period chlorophyll \( a \) was variable, and many readings obtained were above the recommended ANZECC guideline of 5 mg/m\(^3\). Of the eighteen samples obtained, only eight were within the recommended guideline. Chlorophyll \( a \) was lowered at each site in September, with the exception of TON 2. Chlorophyll \( a \) was extremely variable during the time period, and no trends are apparent in the data.

**Enterococci**

![Enterococci graph]

*Figure 19: Enterococci recorded at each site for during sampling period. The red line indicates the trigger value for lowland rivers, as indicated by the ANZECC Guidelines.*

Of the eighteen *Enterococci* samples obtained, eleven fell under the recommended trigger value of 35 cfu/100 mL. Readings at all sites fell under the trigger value in May’s testing, however TON 2 and TON 4 had risen above the guideline in September. SC 1 and SC 2 were the only sites that remained consistently low and under the guideline throughout the sampling period. Extremely high values were obtained at TON 4 and TON 3 in March and April respectively, and all TON sites were above the guideline in April’s testing, however they fell to within the range by May’s testing.
Total Suspended Solids

As mentioned previously, ANZECC values are not available for TSS, so the 2008 Statewide River Water Quality Assessment for Western Australia criteria has been used. According to this criteria, TSS is defined as Low (<5), Moderate (5-10), High (>10-25) and Very High (>25) (Department of Water, 2008). As such, four samples are defined as low; three are classed as moderate, eight as high and three as very high. There is little consistency across sites, as values obtained for all sites vary in levels of TSS. May sampling had the most consistent low readings, however readings still ranged between low to high for this month. This was expected due to the turbidity values obtained during this month.

![Total Suspended Solids (mg/l)](image)

Figure 20: TSS recorded at each site during the sampling period

Nitrogen Oxides (Nox)

The trigger value for Nox according to the ANZECC guidelines is 0.04 mg/L. As such, only five samples obtained fell under this value. Four results were close to this value at under 0.10 mg/L. The sample obtained at SC 2 in May greatly exceeded the guideline, at 22.8 mg/L. Readings were low at all sites in September, despite the fact that none fell under the trigger value. There was little consistency or trends observed in the results, exemplified by SC 2,
whose values jumped from 0.01 mg/L to 22.8 mg/L and then down to 0.12 mg/L during the sampling period. It is however noted that Nox seems to decrease for most sites during the sampling period.

![Nitrogen Oxides (mg/l)](image)

**Figure 21:** Nox recorded at each site during the sampling period. The red line indicates the trigger value for lowland rivers, as indicated by the ANZECC Guidelines.

**Total Nitrogen**

The trigger value for TN is 0.5 mg/L, and only one sample obtained fell under this value. Ten samples came close to the recommended value, falling under 1.0 mg/L. As with Nox, the SC 2 sample obtained in May was extremely high, however the values were dramatically lower in April and September (0.8 mg/L and 1.1 mg/L respectively). TON sites were consistently low during the sampling period, with slightly elevated values of 3.2 mg/L and 3.7 mg/L obtained at TON 1 and TON 2 in April. After this, almost all readings were under 1.0 mg/L.
No obvious trends are observed in the data, although it is observed that like Nox, readings were lower across all sites in September.

**Total Phosphorus**

Ten samples obtained were under the TP trigger value of 0.05 mg/L, and the remaining that exceeded this value were all under 0.10 mg/L. All values obtained in April were under the guideline, values at all sites were higher in May’s sampling, and then dropped again across most sites in September, but did not return to the low values obtained in April. The highest value was obtained for TON 4 in March, however as sampling was not conducted at other sites on this day, it is impossible to determine if this trend was apparent throughout the catchments.

Figure 22: Total Nitrogen recorded at each site for the sampling period. The red line indicates the trigger value for lowland rivers, as indicated by the ANZECC Guidelines.
Figure 23: Total Phosphorous recorded at each site for the sampling period. The red line indicates the trigger value for lowland rivers, as indicated by the ANZECC Guidelines.

**Metals, Ammonia, Nitrate, Nitrite and Total Kjeldahl Nitrogen**

Results for the above parameters have been tabulated and are located in Appendix 4. The trigger value for each parameter has been included (where one has been defined), and any values that exceed the trigger value are coloured red. The triggers values were not exceeded for arsenic, cadmium, manganese, nickel, mercury, and ammonia. No trigger values for aquatic ecosystems exist for TKN, nitrite and barium, and insufficient data exists to define trigger values for vanadium, cobalt and beryllium.

The trigger value for chromium (0.001 mg/L) was exceeded twice, at TON 4 in April and TON 2 in September. There were no exceedences at SC sites. Copper (0.0014 mg/L) was exceeded at least once across every site sampled. At sites TON 1, 2 and 4 the value was exceeded every sampling round. TON 3 was compliant in September, and SC 1 and SC 2 were compliant in May. The trigger value of 0.0034 mg/L for lead was exceeded on only one sampling occasion, at TON 2 in September. This was the same for zinc, whose value of 0.008 mg/L was exceeded only in September at TON 2. The nitrate trigger value of 0.7 mg/L was exceeded on six occasions, at TON 1 and 2, and SC 1 and 2. These exceedences occurred over all three sampling dates. The extremely high value obtained at SC 2 in May is reflected
in readings for both Nox and TN. Myimbarr (TON 3 and 4) did not present any values that exceeded the trigger.

Although trigger data does not exist for TKN, it is observed that all readings bar three fell under 1 mg/L. If the trigger value of 0.5 mg/L used by Cardno Forbes Rigby Pty Ltd (2008) was applied, only four samples would be compliant. Similarly with nitrite, all values were 0.01 mg/L with the exception of TON 3 in April. All results obtained for vanadium were <0.01 mg/L, with the exception of TON 4 in April (0.02 mg/L). This pattern was observed for cobalt also, whose values read as <0.001 mg/L or 0.001 mg/L, with the exception of one site at 0.002 mg/L. Insufficient data was available to determine a trigger value for beryllium, however all readings were <0.001 mg/L.

5.1.3 Soil

Grain size

Grain size results were obtained for all thirteen samples and represented the percentage of clay, silt and sand in each soil sample, as well as the average grain size of each sample. Clay was split into two different grain sizes; < 2 μm and < 4 μm, silt is classified as > 0.004 – 0.063 mm, and sand is > 0.063 – 2 mm. Using the percentage of clay, silt and sand, the soil classification could be determined for each sample, as shown in Table 4 below. Soil classification was determined by entering the percentages into an excel spreadsheet, that mapped the result as a conventional triangular diagram on a tri-plot (Graham and Midgley, 2000). The left-hand side of the tri-plot showed percentage clay, the right-hand side showed percentage silt and the bottom of the tri-plot showed percentage sand. Using the mastersizer data each sample was plotted on the tri-plot, and the classification was determined using a triangular texture diagram based on International Fractions (Marshall, 1947).
Table 4: Soil Classification for each soil sample derived from the percentage of clay, silt and sand.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Clay &lt;2um %</th>
<th>Clay &lt;4um %</th>
<th>Silt %</th>
<th>Sand %</th>
<th>Soil Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>TON 1</td>
<td>30.43</td>
<td>50.55</td>
<td>42.83</td>
<td>6.62</td>
<td>Silty Clay</td>
</tr>
<tr>
<td>TON 1a</td>
<td>23.71</td>
<td>42.14</td>
<td>52.88</td>
<td>4.99</td>
<td>Silty Clay</td>
</tr>
<tr>
<td>TON 2</td>
<td>11.21</td>
<td>26.11</td>
<td>70.45</td>
<td>3.44</td>
<td>Silty Clay Loam</td>
</tr>
<tr>
<td>TON 3</td>
<td>0.04</td>
<td>0.45</td>
<td>3.53</td>
<td>96.03</td>
<td>Sand</td>
</tr>
<tr>
<td>TON 3a</td>
<td>11.59</td>
<td>27.51</td>
<td>61.19</td>
<td>11.3</td>
<td>Silty Clay Loam</td>
</tr>
<tr>
<td>TON 3b</td>
<td>12.28</td>
<td>30.19</td>
<td>65.94</td>
<td>3.86</td>
<td>Silty Clay Loam</td>
</tr>
<tr>
<td>TON 4</td>
<td>6.84</td>
<td>13.88</td>
<td>52.78</td>
<td>33.33</td>
<td>Silty Loam</td>
</tr>
<tr>
<td>TON 4a</td>
<td>6.15</td>
<td>14.04</td>
<td>71.14</td>
<td>14.81</td>
<td>Silty Loam</td>
</tr>
<tr>
<td>SC 1</td>
<td>6.93</td>
<td>13.7</td>
<td>53.54</td>
<td>32.76</td>
<td>Silty Loam</td>
</tr>
<tr>
<td>SC 2</td>
<td>15.64</td>
<td>31.5</td>
<td>59.81</td>
<td>8.69</td>
<td>Silty Clay Loam</td>
</tr>
<tr>
<td>SC 3</td>
<td>4.63</td>
<td>10.42</td>
<td>67.03</td>
<td>22.55</td>
<td>Silty Loam</td>
</tr>
<tr>
<td>SC 3a</td>
<td>4.65</td>
<td>10.53</td>
<td>68.03</td>
<td>21.44</td>
<td>Silty Loam</td>
</tr>
<tr>
<td>SC 3b</td>
<td>2.9</td>
<td>6.66</td>
<td>61.37</td>
<td>31.97</td>
<td>Silty Loam</td>
</tr>
</tbody>
</table>

Figure 24: Triplot diagram with all samples depicted
As shown in Table 4, when multiple samples were obtained for the one sample site, the same soil classification was consistent for each sample, with the exception of site TON 3. Sample TON 3 is classed as Sand, whilst TON 3a and TON 3b are classed as Silty Clay Loam.

Table 5 displays information on the mean, mode and sorting of the grain size data for each sample. The mean in microns is far higher for sample TON 3, which is to be expected as the sample has been classified as sand. Mode 1 lies in the fine fractions for most samples. Modes 2 and 3 represent coarser fractions present in some samples, which may partly be accounted for by the presence of organic matter in these samples. The majority of samples are poorly sorted or very poorly sorted. Only sample TON 3 has been classed as moderately sorted, indicating the sample is moderately sorted sand. Of the remaining samples, five are poorly sorted and seven are very poorly sorted. For a complete listing of the results yielded in the Mastersizer analysis see Appendix 6.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Volume weighted mean (microns)</th>
<th>Mode 1 (microns)</th>
<th>Mode 2 (microns)</th>
<th>Mode 3 (microns)</th>
<th>Graphical Sorting</th>
</tr>
</thead>
<tbody>
<tr>
<td>TON 1</td>
<td>18.871</td>
<td>2.812</td>
<td>0</td>
<td>0</td>
<td>2.22</td>
</tr>
<tr>
<td>TON 1a</td>
<td>21.169</td>
<td>3.388</td>
<td>400.21</td>
<td>0</td>
<td>2.02</td>
</tr>
<tr>
<td>TON 2</td>
<td>17.476</td>
<td>14.656</td>
<td>0</td>
<td>0</td>
<td>1.71</td>
</tr>
<tr>
<td>TON 3</td>
<td>640.019</td>
<td>585.428</td>
<td>62.31</td>
<td>0</td>
<td>0.82</td>
</tr>
<tr>
<td>TON 3a</td>
<td>38.628</td>
<td>23.744</td>
<td>3.43</td>
<td>402.83</td>
<td>2.16</td>
</tr>
<tr>
<td>TON 3b</td>
<td>15.04</td>
<td>10.842</td>
<td>0</td>
<td>0</td>
<td>1.67</td>
</tr>
<tr>
<td>TON 4</td>
<td>103.745</td>
<td>33.146</td>
<td>419.07</td>
<td>0</td>
<td>2.64</td>
</tr>
<tr>
<td>TON 4a</td>
<td>42.867</td>
<td>14.051</td>
<td>395.4</td>
<td>0</td>
<td>1.96</td>
</tr>
<tr>
<td>SC 1</td>
<td>80.358</td>
<td>20.006</td>
<td>61.17</td>
<td>0</td>
<td>2.45</td>
</tr>
<tr>
<td>SC 2</td>
<td>28.025</td>
<td>11.301</td>
<td>370.23</td>
<td>0</td>
<td>2.06</td>
</tr>
<tr>
<td>SC 3</td>
<td>55.206</td>
<td>19.841</td>
<td>0</td>
<td>0</td>
<td>2.01</td>
</tr>
<tr>
<td>SC 3a</td>
<td>50.287</td>
<td>21.148</td>
<td>629.31</td>
<td>0</td>
<td>1.9</td>
</tr>
<tr>
<td>SC 3b</td>
<td>75.767</td>
<td>42.778</td>
<td>0</td>
<td>0</td>
<td>1.95</td>
</tr>
</tbody>
</table>
As shown in Figure 25, the mean particle size differs greatly between samples. Sample TON 1 shows the most frequent particle diameter as between 1 and 10 microns, which contrasts sample TON 3 where the most frequent particle diameter is almost 1000 microns. Most samples produced curves similar to TON 1, which is to be expected as these samples hold finer fractions of particles and are classed as Silty Clay, Silty Clay Loam or Silty Loam. TON 3 is the only sample that has been classed as Sand, therefore it is expected that the most frequent particle diameter in the sample is coarser. The graphs that relate to the remaining samples can be found in Appendix 5.

![Laser Size Analysis for TON 1](A)

![Laser Size Analysis for TON 3](B)

Figure 25: The most frequent particle diameter in microns present in samples TON 1 (A) and TON 3 (B).
XRF

X-ray fluorescence was used to determine the elemental composition of the thirteen sediment samples from seven sites in terms of their concentration, parts per million (ppm), equivalent to mg/kg. A total of 34 elements were analysed for each sample, and the results were compared with the National Environmental Protection Council Guidelines (NEPC, 1999) to determine if elemental concentrations were within target values. Concentrations that exceed the trigger values could indicate contamination at the site. The elements examined in this report are copper (Cu), lead (Pb) and zinc (Zn). These were selected as they are indicative of contamination and present a snapshot of the overall sediment quality of the site. For a complete listing of the elements tested and the results obtained through analysis see Appendix 6.

The NEPC interim Ecologically-based Investigation Levels (EILs) for urban landscapes were used to determine if the sites were contaminated. The guidelines are used to assess contamination only, and should be used as a prompt for further investigation when exceeded. When contamination values are exceeded a risk assessment is to be conducted to determine if the contamination is likely to have adverse effects on human or ecological health. Further information is provided to assist in determining if the exceedence requires a site specific risk assessment. Background variation ranges have been provided for a number of elements, which indicate natural variation in concentration that arises from the origins of the soil. If EILs are exceeded for an element, background levels may be more appropriate in determining if a site is contaminated.

Copper, lead and zinc were examined to determine if contamination was present at the sample sites, with the results graphed below (Figures 26, 28 and 29). The soil investigation EILs value for copper is 100 mg/kg. This value has been exceeded in five samples across three different sites; at TON 4, SC 2 and SC 3, as illustrated in Figure 26.
To investigate the reason for the exceedences, the results were analysed against the background copper value for the Bumbo Latite, on which the soils lie. The background value for the Bumbo Latite is up to 125 mg/kg, which could account for the heightened values found at TON 4, SC 2 and SC 3, as these soils have formed from weathered Bumbo Latite bedrock (Carr, 1984). In order to determine if the copper values exceed the background value for the Bumbo Latite, the value that exceeded the recommended 100 mg/kg was divided by the background value of 125 mg/kg to determine the enrichment factor for that sample. If the enrichment factor was less than 1, the high copper value can be explained by the background Bumbo Latite value. If the enrichment factor was greater than 1, the high copper value may be anomalous with the background value and could indicate further contamination. The below graph (Figure 27) displays the enrichment factor of each sample that exceeded the soil investigation EILs value for copper. The enrichment factor for sample SC 3 (1.24) demonstrates that the background value derived from the Bumbo Latite could not account for the raised copper value in this sample. However, two other samples collected at site SC 3 (SC 3a and SC 3b) did not exceed the enrichment factor of 1, despite having high copper readings in the sample.
Figure 27: The enrichment factor of the five samples that exceed the soil investigation EILs value for copper. An enrichment value of greater than 1 indicates that the copper value in the soil is not due to the background value for the Bumbo Latite.

The soil investigation value for zinc is 200 mg/kg. As shown in Figure 28, this value has not been exceeded in any samples obtained from the seven sites, with 167 mg/kg being the highest zinc reading obtained. For the majority of the samples the concentration of zinc is far below the recommended investigation value, indicating that contamination from zinc is not present at the sites.
The concentrations of lead, illustrated below in Figure 29, were well below the investigation value of 600 mg/kg, with concentrations ranging between 10 mg/kg at TON 3a and 29 mg/kg at SC 3. In addition to complying with the interim EILs value, the concentration of lead in the majority of samples did not exceed the Bumbo Latite background value of 20 mg/kg (Carr, 1984). Although readings of Zn and Pb were not exceeded in any samples, it is noted that samples obtained at site SC 3 yielded higher readings of Pb, Zn and Cu when compared with other sites, which may indicate moderate pollution at the site.
XRD

X-ray diffraction was used to determine the presence of minerals within each soil sample. Using Siroquant, mineralogy percentages were determined for the dominant minerals present in each sample, these being:

- Albite
- Calcite
- Chlorite
- Halloysite
- Illite
- Kaolin
- Labradorite
- Laumonite
- Mixed layer illite
- Quartz

Quartz and albite were analysed against one another, and an inverse relationship was observed (see Figure 30). As quartz became more abundant in a sample, albite became less abundant, and vice versa. This was particularly apparent in samples obtained at TON 3, which contained abundant quartz. While quartz values were highest at this site, the lowest albite values were recorded. Similar observations are noted in sites TON 1 and 2, where the lowest readings of quartz yielded the highest readings of albite. Quartz is most abundant in samples TON 3 and TON 3b, both of which were obtained at the Myimbarr inlet. These samples were taken from the sandy delta that has built up at the inlet, which contains quartz and coarse material that has been washed in during storm events from the adjacent roadway.
Figure 30: Percentage quartz vs. percentage albite in each soil sample obtained.

Figure 31 shows the relative abundance of each mineral in the samples collected, with quartz and albite excluded. High contents of halloysite, chlorite, laumonite, calcite and mixed layer clays are indicative of the source geology.
Figure 31: The relative abundance of minerals (excluding quartz and albite) in each soil sample obtained, as determined by XRD analysis.
5.1.4 Vegetation

Vegetation results are indicative of the presence or absence of weeds, noxious weeds or prolific plant species within the study sites. From the quadrants recorded along each transect representative data was gained regarding the dominant species and their proximity to the creek channel and distance along the banks. Vegetation was also noted outside each transect to determine dominant species of the overall site. Little rainfall occurred in the months prior to the vegetation sampling, which could account for some species observed to be dying off, and also resulted in water levels being lower and water channels being narrower than during rainfall periods. Locations of the vegetation surveys can be found in Figures 9 and 10.

Site V1

Figure 32: Images taken at site V1 (TON 1). A) The subtropical rainforest vegetation in which the transect was established. The creek is not visible as the water had dried and exposed the muddy substrate. B) Approximately 50 m downstream of A, where weeds are clogging the channel causing it to narrow significantly. B) Taken at the same location as B, the water channel is visibly overgrown with weeds including blackberry. The canopy is open and creek-line is open to sunlight.
Six different species were noted in the 4 quadrants recorded along the 10.5 m transect. Of the six, five were native and one was introduced, as shown in Table 6 below. The vegetation remained consistent as the banks of the water channel were approached, and was scarce overall, with the ground covered mainly in leaf litter and plant debris. The vegetation at this site is typical of NSW coastal subtropical rainforest. The canopy was closed and there was limited light penetration, however this changed dramatically approximately 50 m downstream of the sample site, where cleared vegetation and an open canopy gave rise to prolific weeds clogging the water channel. Only one introduced species was found on the transect, however downstream four of the five observed species were introduced. Along the transect the water channel was 2.3 m in width, although due to a lack of rainfall most of the channel was full of muddy substrate, with some shallow pools present.

Table 6: Species identified at V1, detailing the abundance of each species and whether they are native/introduced

<table>
<thead>
<tr>
<th>Site V1 Transect Species</th>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Native or Introduced?</th>
<th>Number of quadrants in which the species was found</th>
<th>Average percentage coverage in each quadrant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adiantum aethiopicum</td>
<td>Maidenhair Fern</td>
<td>Native</td>
<td>2</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>Aphanopetalum resinosum</td>
<td>Gumvine</td>
<td>Native</td>
<td>2</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Bidens pilosa</td>
<td>Farmer's friend</td>
<td>Introduced</td>
<td>1</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Geitonoplesium cymosum</td>
<td>Scrambling Lily</td>
<td>Native</td>
<td>1</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Streblus brunonianus</td>
<td>Whalebone Tree</td>
<td>Native</td>
<td>2</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>Baloghia inophylla</td>
<td>Brush Bloodwood</td>
<td>Native</td>
<td>1</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Observed Species (not found on the transect)</td>
<td>Acetosa sagittata</td>
<td>Turkey Rhubarb</td>
<td>Introduced</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Commelina cyanea</td>
<td>Scurvy Weed</td>
<td>Native</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Delairea odorata</td>
<td>Cape Ivy</td>
<td>Introduced</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Rubus fruticosus</td>
<td>Blackberry</td>
<td>Introduced</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Site V2

Ten different species were recorded in the 5 quadrants laid across the 15 m transect. Seven of these species are introduced, with only three species recorded as native. The ground was dry, compacted and disturbed, with poor vegetation coverage on one side of the bank. Along the creek channel and within the channel itself, *Typha orientalis* was the dominant species. Demonstrated in Table 7, introduced species dominated the transect in both the number and the abundance of species A noticeable difference in vegetation was observed along the banks where the riparian vegetation met the mowed lawns.

<table>
<thead>
<tr>
<th><strong>Stellaria media</strong></th>
<th>Chickweed</th>
<th>Introduced</th>
<th>N/A</th>
<th>N/A</th>
</tr>
</thead>
</table>
A grassed buffer zone is present on either side of the creek line, and this has been manicured and maintained by SCC. Along the creek itself native riparian vegetation has been planted. This riparian zone is overrun by weeds which have continued to the water course. Poor, disturbed soil has prevented the growth of native vegetation and has provided the ideal landscape for colonising weeds that can tolerate harsh conditions in full sunlight. The total channel width is 1.8 m, however this would be wider during times of greater rainfall.

Table 7: Species identified at V2, detailing the abundance of each species and whether they are native/introduced

<table>
<thead>
<tr>
<th>Site V2 Transect Species</th>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Native or Introduced?</th>
<th>Number of Quadrants in which the species was found</th>
<th>Average percentage coverage in each quadrant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetosa sagittata</td>
<td>Turkey Rhubarb</td>
<td>Introduced</td>
<td>3</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Araujia sericifera</td>
<td>Moth Vine</td>
<td>Introduced</td>
<td>1</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Cerastium glomeratum</td>
<td>Mouse-eared Chickweed</td>
<td>Introduced</td>
<td>1</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Dianella longifolia</td>
<td>Purple flax</td>
<td>Native</td>
<td>1</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>Geranium homeanum</td>
<td>Native</td>
<td>Native</td>
<td>3</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>Plantago lanceolata</td>
<td>Ribwort</td>
<td>Introduced</td>
<td>2</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>Rumex obtusifolius</td>
<td>Broad leaf Dock</td>
<td>Introduced</td>
<td>3</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Stellaria media</td>
<td>Chickweed</td>
<td>Introduced</td>
<td>4</td>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>Typha orientalis</td>
<td>Cumbungi</td>
<td>Native</td>
<td>2</td>
<td>70%</td>
<td></td>
</tr>
<tr>
<td>Urtica dioica</td>
<td>Stinging nettle</td>
<td>Introduced</td>
<td>1</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>Observed Species (not found on the transect)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acacia binervata/</td>
<td>Acacia</td>
<td>Native</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Acacia longifolia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Casuarina cunninghamiana</td>
<td>River Oak</td>
<td>Native</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>
Site V3

Figure 34: Vegetation present at site V3, the Myimbarr Inlet. (A) shows the sedges dominated by *Lomandra longifolia*, (B) shows *Schoenoplectus validus* located near the water’s edge and (C) shows that stands of tall casuarinas that line the western bank.

Twelve quadrants were recorded across a total transect distance of 74 m, of which approximately 40 m was open water. In these quadrants eleven species were recorded in total, five of which were introduced and six of which were native (see Table 8 below). Native species were dominant at the site in both abundance and number of species. The native
species have been planted at the site during its construction, and are generally well maintained on the banks of the river farther from the channel. Closer to the channel weeds become more abundant and compete with native species. Leaf litter, plant matter and sediment have been washed into the pond and accumulated on the sediment bank that has consequently formed, creating a build-up of sediment and plant matter on the east side of the pond. The west side of the bank contained far less weeds, which may reflect the hydrology of the pool – waters enters the pool on the eastern side, bringing with it seeds and plant matter that colonises on the east bank as a result.

Table 8: Species identified at V3, detailing the abundance of each species and whether they are native/introduced

<table>
<thead>
<tr>
<th>Site V3 Transect Species</th>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Native or Introduced?</th>
<th>Number of quadrants in which the species was found</th>
<th>Average percentage coverage in each quadrant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alisma plantago-aquatica</td>
<td>Water plantain</td>
<td>Introduced</td>
<td>1</td>
<td>70%</td>
</tr>
<tr>
<td></td>
<td>Baumea articulata</td>
<td>Jointed Twig-Rush</td>
<td>Native</td>
<td>2</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>Dianella longifolia</td>
<td>Purple flax</td>
<td>Native</td>
<td>3</td>
<td>67%</td>
</tr>
<tr>
<td></td>
<td>Hydrocotyle ranunculoides</td>
<td>Hydrocotyl</td>
<td>Introduced</td>
<td>5</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td>Lomandra longifolia</td>
<td>Spiny-headed mat-rush</td>
<td>Native</td>
<td>2</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Persicaria decepins</td>
<td>Slender Knotweed</td>
<td>Native</td>
<td>1</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>Plantago lanceolata</td>
<td>Ribwort</td>
<td>Introduced</td>
<td>2</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>Rumex crispus</td>
<td>Curled dock</td>
<td>Introduced</td>
<td>4</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td>Schoenoplectus validus</td>
<td>River clubrush</td>
<td>Native</td>
<td>8</td>
<td>33%</td>
</tr>
<tr>
<td></td>
<td>Typha orientalis</td>
<td>Cumbungi</td>
<td>Native</td>
<td>1</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>Urtica dioica</td>
<td>Stinging Nettle</td>
<td>Introduced</td>
<td>1</td>
<td>10%</td>
</tr>
</tbody>
</table>
Observed Species (not found on the transect)

<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Native or Introduced?</th>
<th>Number of quadrants in which the species was found</th>
<th>Average percentage coverage in each quadrant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casuarina cunninghamiana</td>
<td>River Oak</td>
<td>Native</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Site V4

A total of six quadrants were recorded along the 70 m transect. Seven species were recorded in total, only one of which was introduced (see Table 9). Native species were dominant at the site, possibly due to the extensive plantings of natives that occurred during the wetland’s construction, which would have prevented the colonisation of weed species along the banks. The vegetation was dense on both sides of the banks, so much so that access was restricted on the northern bank. *Lomandra longifolia* was found to be the dominant species at this site.

Table 9: Species identified at V4, detailing the abundance of each species and whether they are native/introduced.
Site V5

Access was restricted at this site, which prohibited the running of a transect across the banks. Instead, the dominant species were observed, photographed and noted, as listed below:

- *Isolepis nodosa*
- *Bolboschoenus fluviatus*
- *Juncus usitatus*
- *Persicaria decepins*
- *Phragmites australis*
- *Typha orientalis*
- *Acacia binervata/ Acacia longifolia*
- *Casuarina cunninghamiana*

Species found at this site are all native and are similar in composition to sites V3 and V4. This is expected as V5 is located in the Myimbarr wetland complex, downstream of the above sites. *Typha* was observed to be the dominant species along the water edge.

Figure 35: Vegetation at site V4 (A) and Site V5 (B). The vegetation profiles at both locations are very similar, and are dominated by *Phragmites australis*, as demonstrated in the images.
Site V6

Three quadrants were recorded across a total transect distance of 33 m, of this 28.8 m was water. A narrow strip of vegetation surrounded the pond on all sides, the edges of which were defined by a concrete ledge that separated the wetland vegetation from the mowed lawns. Outlined in Table 10, the majority of species within the quadrants were native, and introduced dock only represented a small percentage of the total vegetation. From either side of the banks macrophytes covered much of the open water surface, and were a combination of the native *Azolla filiculoides* and the introduced *Nasturtium officinale*. These two species covered approximately 25% of the total water surface of this pond. The vegetation provided ample habitat for native avifauna, and black swans were observed to be nesting. Other native and introduced species were observed at the site, found mainly at the entrance to the pond.
The entrance passageway was overrun by Phragmites through the channel, and much rubbish had accumulated there. Vegetation was prolific around the pond entrance, making water access difficult.

Table 10: Species identified at V6, detailing the abundance of each species and whether they are native/introduced

<table>
<thead>
<tr>
<th>Site V6 Transect Species</th>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Native or Introduced?</th>
<th>Number of quadrants in which the species was found</th>
<th>Average percentage coverage in each quadrant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lomandra longifolia</td>
<td>Knobby club-rush</td>
<td>Native</td>
<td>1</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Eleocharis sphacelata</td>
<td>Tall spikerush</td>
<td>Native</td>
<td>N/A</td>
<td>Found in middle of pond</td>
<td></td>
</tr>
<tr>
<td>Rumex obtusifolius</td>
<td>Broad leaf Dock</td>
<td>Introduced</td>
<td>1</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Typha orientalis</td>
<td>Cumbungi</td>
<td>Native</td>
<td>2</td>
<td>70%</td>
<td></td>
</tr>
<tr>
<td>Azolla filiculoides</td>
<td>Water Fern</td>
<td>Native</td>
<td>N/A</td>
<td>Approx 25% coverage of Azolla filiculoides and Nasturtium officinale over water</td>
<td></td>
</tr>
<tr>
<td>Isolepis prolifera</td>
<td>Knobby club-rush</td>
<td>Native</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Nasturtium officinale</td>
<td>Watercress</td>
<td>Introduced</td>
<td>N/A</td>
<td>Approx 25% coverage of Azolla filiculoides and Nasturtium officinale over water</td>
<td></td>
</tr>
<tr>
<td>Phragmites australis</td>
<td>Common Rush</td>
<td>Native</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Rubus fruticosus</td>
<td>Blackberry</td>
<td>Introduced</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>
Site V7

A transect of 11.2 m was lain at site V7, across which five quadrants were recorded. Six species were recorded, three natives and three introduced (see Table 11). One of the introduced species, *Sagittaria platyphylla*, is classed as a Weed of National Significance and a Class 5 Noxious Weed. *Sagittaria* was found in three out of the five quadrants recorded, in areas that were inundated with water. Native species were more abundant than introduced species, however they were equal in terms of total number of species. Other observed species were all found to be natives. Upstream of the transect, *Typha* was noted to be the dominant species, and was clogging the water channel, restricting flow. Downstream, *Eleocharis sphacelata* was observed, found throughout the water channel.

Table 11: Species identified at V7, detailing the abundance of each species and whether they are native/introduced

<table>
<thead>
<tr>
<th>Site V7 Transect Species</th>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Native or Introduced?</th>
<th>Number of quadrants in which the species was found</th>
<th>Average percentage coverage in each quadrant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternanthera denticulata</td>
<td>Lesser Jay Weed</td>
<td>Native</td>
<td>2</td>
<td>60%</td>
<td></td>
</tr>
<tr>
<td>Delairea odorata</td>
<td>Cape Ivy</td>
<td>Introduced</td>
<td>2</td>
<td>8%</td>
<td></td>
</tr>
<tr>
<td>Rumex obtusifolius</td>
<td>Broad leaf Dock</td>
<td>Introduced</td>
<td>1</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Sagittaria platyphylla</td>
<td>Arrowshead</td>
<td>Introduced – Noxious Weed</td>
<td>3</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>Triglochin procerum</td>
<td>Water ribbons</td>
<td>Native</td>
<td>1</td>
<td>15%</td>
<td></td>
</tr>
</tbody>
</table>

*Observed Species (not found on the transect)*

<table>
<thead>
<tr>
<th>Species</th>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Native or Introduced?</th>
<th>Number of quadrants in which the species was found</th>
<th>Average percentage coverage in each quadrant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia binervata/Acacia longifolia</td>
<td></td>
<td>Acacia</td>
<td>Native</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Eleocharis sphacelata</td>
<td>Tall spikerush</td>
<td>Native</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Cupaniopis anacardioides</td>
<td>Tuckeroo</td>
<td>Native</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Typha orientalis</td>
<td>Cumbungi</td>
<td>Native</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Figure 37: Vegetation transect at site V7. A) *Eleocharis sphacelata* growing throughout the water channel. B) A quadrant established along the transect. The quadrant is covering saturated ground where plants are emerging from the shallow water channel.

**Site V8**

Six quadrants were recorded across a transect 13.8 m in length. In the quadrants, 12 species were observed: five native and seven introduced. As recorded in the table below (Table 12) native species were more abundant across the transect, despite there being fewer varieties. This could be attributed to the abundance of *Typha*, and does not necessarily reflect positively on the site as *Typha* was seen to be blocking water flow. *Typha* was the dominant species in the water channel, and was observed both upstream and downstream of the survey site.
Figure 38: Vegetation present at V8. A) The image shows the wooden vegetation stakes that have been left at the site. B) *Lomandra longifolia* C) The creek channel, showing the sediment fence established on one side of the bank. The vegetation is clearly overgrown and unmanaged at the site.

The site was observed to be in poor condition – numerous wooden posts and star-posts had not been removed following vegetation plantings, some trees had been recently cut down, rubbish was present and vegetation was overgrown. A sediment fence was present along one side of the creek channel, adjacent to the construction, however it was proving ineffective as sediment was still entering the channel from the construction site.

<table>
<thead>
<tr>
<th>Site V8 Transect Species</th>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Native or Introduced?</th>
<th>Number of quadrants in which the species was found</th>
<th>Average percentage coverage in each quadrant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>Acetosa sagittata</em></td>
<td>Turkey Rhubarb</td>
<td>Introduced</td>
<td>1</td>
<td>20%</td>
</tr>
<tr>
<td><em>Coryza albida</em></td>
<td></td>
<td>Fleabane</td>
<td>Introduced</td>
<td>1</td>
<td>15%</td>
</tr>
<tr>
<td>Species</td>
<td>Common Name</td>
<td>Habitat</td>
<td>Abundance</td>
<td>Percentage</td>
<td></td>
</tr>
<tr>
<td>--------------------------</td>
<td>----------------------</td>
<td>---------------</td>
<td>-----------</td>
<td>------------</td>
<td></td>
</tr>
<tr>
<td>Delairea odorata</td>
<td>Cape Ivy</td>
<td>Introduced</td>
<td>1</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Geitonoplesium cymosum</td>
<td>Scrambling Lily</td>
<td>Native</td>
<td>1</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Hydrocotyle ranunculoides</td>
<td>Hydrocotyle</td>
<td>Introduced</td>
<td>1</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>Lomandra longifolia</td>
<td>Knobby club-rush</td>
<td>Native</td>
<td>2</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Persicaria decipiens</td>
<td>Slender knotweed</td>
<td>Native</td>
<td>1</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Rumex Crispus</td>
<td>Curled Dock</td>
<td>Introduced</td>
<td>1</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Rumex obtusifolius</td>
<td>Broad leaf Dock</td>
<td>Introduced</td>
<td>1</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>Schonoplectus validus</td>
<td>River clubrush</td>
<td>Native</td>
<td>2</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Taraxacum officinale</td>
<td>Dandelion</td>
<td>Introduced</td>
<td>2</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Typha orientalis</td>
<td>Cumbungi</td>
<td>Native</td>
<td>4</td>
<td>40%</td>
<td></td>
</tr>
<tr>
<td>Observed Species (not found on the transect)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Casuarina cunninghamiana</td>
<td>River Oak</td>
<td>Native</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

Table 12: Species identified at V8, detailing the abundance of each species and whether they are native/introduced.

Using data obtained in the eight vegetation surveys, along with reference data, the vegetation was classified as Fringing, High Edge, Shallow Edge and Deep Water, for both native and introduced species, shown in Table 13 below. This is to demonstrate where each species lies on the banks and through the channels of the wetlands.

Table 13: The distribution of vegetation species within a wetland. High Edge Species are those found in areas occasionally inundated, with generally damp ground. Shallow Edge Species are found in shallow water (approx 200-400 mm deep) and Deep Water Species are found in water 200 mm to > 1 m deep.

<table>
<thead>
<tr>
<th>Natives</th>
<th>Fringing</th>
<th>High Edge Species (Occasionally inundated, damp ground)</th>
<th>Shallow Edge Species (200-400 mm deep)</th>
<th>Deep Water Species (200mm-1m deep)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia binervata</td>
<td>Persicaria decipiens</td>
<td>Alisma plantago-aquatica</td>
<td>Schoenoplectus validus</td>
<td></td>
</tr>
<tr>
<td>Acacia longifolia</td>
<td>Adiantum aethiopicum</td>
<td>Juncus usitatus</td>
<td>Baumea articulate</td>
<td></td>
</tr>
</tbody>
</table>
Prominent wetland weeds found throughout the Shellharbour LGA and within the Myimbarr and Shell Cove Wetlands were photographed and are depicted in Figure 39 below.

<table>
<thead>
<tr>
<th>Aphanopetalum resinosum</th>
<th>Casuarina cunninghamiana</th>
<th>Persicaria decepins</th>
<th>Eleocharis sphacelata</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commelina cyanea</td>
<td>Gahnia sieberiana</td>
<td>Phragmites australis</td>
<td>Bolboschoenus fluviatus</td>
</tr>
<tr>
<td>Cupaniopsis anacardioides</td>
<td>Geranium homeanum</td>
<td>Typha orientalis</td>
<td>Triglochin procerum</td>
</tr>
<tr>
<td>Commelina cyanea</td>
<td>Gahnia sieberiana</td>
<td>Phragmites australis</td>
<td>Bolboschoenus fluviatus</td>
</tr>
<tr>
<td>Commelina cyanea</td>
<td>Gahnia sieberiana</td>
<td>Phragmites australis</td>
<td>Bolboschoenus fluviatus</td>
</tr>
<tr>
<td>Commelina cyanea</td>
<td>Gahnia sieberiana</td>
<td>Phragmites australis</td>
<td>Bolboschoenus fluviatus</td>
</tr>
<tr>
<td>Commelina cyanea</td>
<td>Gahnia sieberiana</td>
<td>Phragmites australis</td>
<td>Bolboschoenus fluviatus</td>
</tr>
<tr>
<td>Commelina cyanea</td>
<td>Gahnia sieberiana</td>
<td>Phragmites australis</td>
<td>Bolboschoenus fluviatus</td>
</tr>
<tr>
<td>Commelina cyanea</td>
<td>Gahnia sieberiana</td>
<td>Phragmites australis</td>
<td>Bolboschoenus fluviatus</td>
</tr>
<tr>
<td>Commelina cyanea</td>
<td>Gahnia sieberiana</td>
<td>Phragmites australis</td>
<td>Bolboschoenus fluviatus</td>
</tr>
<tr>
<td>Commelina cyanea</td>
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**Introduced**

**Fringing**
- *Araujia sericifera*
- *Bidens pilosa*
- *Hydrocotyle ranunculoides*
- *Cerastium glomeratum*
- *Nasturtium officinale*
- *Delairea odorata*
- *Rumex crispus*
- *Rumex obtusifolius*
- *Sagittaria platyphylla*
- *Rumex crispus*
- *Rumex obtusifolius*
- *Stellaria media*
- *Taraxacum officinale*
- *Urtica dioica*
Figure 39: Wetland Weeds found in Myimbarr and Shell Cove. A) *Sagittaria platyphylla*, a Class 5 Noxious Weed and Weed of National Significance; B) *Acetosa sagittata* or turkey rhubarb, found in both wetland systems; C) *Rumex crispus* or curled dock, a problem species in both wetland systems; D) *Hydrocotyle ranunculoides*, a pest species found in permanent freshwater bodies; E) *Aralia serecifera* or moth vine, a prolific seeder found at Shell Cove; F) *Delairea odorata*, also known as cape ivy, a climber found throughout both wetland systems; G) *Nasturtium officinale* or watercress, a water weed prevalent in Myimbarr and also found in Shell Cove and H) The seed head of *Rumex crispus*
Chapter Six

6.1 Discussion

6.1.1 Introduction

Constructed wetlands are dynamic and ever-changing ecosystems, the management of which is dependent on a number of factors that vary on a regional and local scale. Each constructed wetland system is different, designed to achieve specific goals within the catchment, and tailored to accommodate local catchment, hydrologic and climatic conditions. As such, the management of a constructed wetland system must too be tailored to address the specific design goals of the wetland, whilst accounting for local conditions that affect the wetland system.

To determine management priorities for the Myimbarr and Shell Cove wetland systems, water quality, soil quality and vegetation were examined. These components of a wetland are intricately linked with one another and will indicate the overall health of the wetland system, how well it is functioning, and where management priorities lie. The results obtained are used to determine the functionality and health of the Myimbarr and Shell Cove systems in regards to their intended purpose and design as stormwater treatment facilities and habitat providers.

6.1.2 Water Quality

Water quality testing at Myimbarr/Tongarra Creek revealed that water quality improves and becomes stabilised as it moves through the catchment, indicating the efficiency of the wetlands in treating stormwater runoff. The Shell Cove ponds are disconnected from one another therefore results are not indicative of patterns occurring on a system-wide scale. However, results obtained at both SC sites yielded similar results indicating conditions are quite consistent throughout the Shell Cove catchment.

Water quality was variable over the sampling period, demonstrating the changeable nature of water quality and its sensitivity to changes that occur within the catchment. Changes in water quality can be attributed to a number of factors: temperature; rainfall; changes in catchment practices; and sources of pollution entering the system. Processes that occur within the wetlands themselves can also result in changes occurring in the water quality of the system (White, 1998).
Wetland systems take many years to establish, therefore it is expected that water quality would fluctuate during the years following construction as the ecosystem transitions and the wetlands become established in the catchment. It is also expected that during this time water quality results may exceed guidelines as the wetlands and their processes become stabilised, as was found by Johnson and Smardon (2011).

A detailed explanation of the causes of variation in water quality parameters and the implications this has on the health of a wetland can be found in Appendix 7.

**General Trends Observed in Water Quality at Myimbarr and Shell Cove**

A number of trends in water quality were observed across both systems during the sampling period. Dissolved oxygen was lowest at the beginning of the catchment, however as the water moves along Tongarra Creek into the wetlands, DO is improved and increases. DO was observed to vary with rainfall, with higher rainfall correlated with lower DO. This was reflected in readings obtained in September, where increased drying in the catchment resulted in higher DO at all sites. It is evident that DO is highly variable and sensitive to changes in local conditions, difficult to interpret without knowledge of typical seasonal and diurnal changes.

Conductivity was observed to increase during the sampling period at almost every site. This may be due to the increasingly dry weather experienced in the catchment from April onwards. Conductivity is known to increase with dry weather, as the wetlands dry and evaporate due to a lack of rainfall.

Water temperature varied seasonally as atmospheric temperatures changed, with the lowest temperatures recorded in May before the winter months began, and higher temperatures recorded in April and September, when the climate was warmer. All temperatures recorded were within the ranges supplied for constructed wetlands by Hunter (2012).

Ammonia, the most toxic form of N, did not exceed guideline levels in any samples. TKN was high on a number of occasions when assessing it against trigger values determined by Cardno Forbes Rigby Pty Ltd (2008). As TKN is the sum of organic nitrogen, ammonia and ammonium, it is concluded that the high values are derived from the amount of ammonium and organic nitrogen in the system, as results for ammonia were consistently low for all sites.
As predicted, an inverse relationship was observed between pH and ORP across all sites. ORP was highly variable and many readings obtained were lower than desired for an aquatic ecosystem. This may be attributed to high levels of organic matter within the water column: levels of organic matter in the system exceed the systems capability to remove organic matter, resulting in lower ORP readings. This indicates that a higher level of biomass was present when ORP readings were low. The unusually low value obtained in March 2012 at TON 3 is likely due to the presence of a decomposing organism or plants at the site during the time of the reading, as values have risen significantly at this site after this date.

Of the thirteen metals tested, exceedences were recorded in four: chromium, copper, lead and zinc. It is noted in the ANZECC guidelines that metals that exceed the guideline value may not present a threat to the aquatic biota when metal speciation is considered. Free metal ions are the most toxic metal species, however these represent a small portion of the total dissolved metal concentration. Metal bioavailability is also highly dependent on pH, dissolved organic matter and redox potential. Chromium, copper, lead and zinc can all experience metal speciation, therefore readings obtained that exceed the guidelines may not actually present a threat to the wetland ecosystems, as the metals may not be bioavailable (ANZECC, 2000). Further testing would be required to determine the speciation of the metals that exceeded the guidelines.

Copper had the most measurements over the trigger value. The reason for the heightened values may be attributed to the soils present in the catchments. The soils have been derived from Bumbo Latite bedrock, which has a naturally high background reading for copper (Carr, 1984). The copper value for soils was exceeded at TON 4, and across all SC sites. Where the value was not exceeded, copper readings were close to the trigger value at all sites. This indicates that the soil present at the sites contains naturally high levels of copper. As such, it is logical to conclude that water at these sites would also contain heightened copper values, as sedimentation accumulates in waterways from catchment soils. Even though the trigger value was exceeded on some occasions, the exceedences were minor and unlikely to have detrimental effects on the ecosystem.

Lead was only above the trigger value at one site on one occasion, but it was only slightly above the value. The same was noted for zinc and chromium, although chromium experienced exceedences on two occasions. It is observed that exceedences in chromium, lead and zinc were all recorded at TON 2 in September. This may be attributed to the lack of
rainfall experienced in the catchment prior to this sampling date. Water was stagnant at this site, and a lack of flushing may have allowed the accumulation of metals that would have exited the system during times of higher flow. Even though the trigger value was exceeded on some occasions, the exceedences were minor and unlikely to have detrimental effects on the ecosystem.

**Myimbarr**

**TON 1**

A limited range of results were obtained for TON 1, as testing was only conducted in April and May. September testing could not be conducted as the channel had dried as a result of low rainfall. It was observed that water quality varied between these two sampling dates, due predominantly to changes in rainfall in the catchment.

DO readings were consistently low for this site. The low DO recorded may be attributed to an anaerobic exchange at the sediment-water interface. The sediment-water interface would be particularly important for this site as the water depth is shallow, therefore DO measurements would be taken closer to the sediment surface (ANZECC, 2000).

Rainfall could account for the changes in nutrients and chlorophyll *a* at the site. High levels of rainfall preceding the April sampling have resulted in higher inputs of nutrients to the water, reflected in readings of TN, Nox, nitrate and TKN. Excessive loadings of nitrogen entering the system have resulted in an increase of biomass production in the system which has caused chlorophyll *a* values to increase.

Low levels of pH recorded could result from the adjacent construction site, where soils are highly disturbed and exposed, and sediment fencing is not adequate in preventing sediment entering the creek. Leaching of H⁺ ions is common in disturbed topsoils and these ions are transported to waterways with stormwater runoff. Runoff from the construction resulting from rainfall in the catchment prior to sampling is likely to be accountable for the low pH readings obtained.

Although turbidity and TSS readings were not particularly high at the site, it is concluded that sedimentation is a problem, indicated by the dried channel during low rainfall, where accumulated sediment was exposed.
TON 2

A more complete data set was obtained for TON 2, with preliminary samples taken for a number of parameters. As such, it is easier to analyse trends and determine patterns in water quality at this site. Water quality was quite consistent at this site across all parameters.

Turbidity and TSS readings were consistently low for this site. The turbidity guideline was exceeded in the March sampling only. Wet weather events were experienced prior to this sampling date, which would considerably raise the sediment loads entering the water, as well as disturb suspended particulate matter (SPM) that had previously fallen out of suspension (Note – a wet weather event is defined as >25 mL received in 24 hrs; A. Williams, pers. comm., 2012).

pH readings fell within guideline ranges on all sampling dates, temperature fluctuations varied seasonally as expected and Enterococci readings were mostly compliant, and where values were exceeded it was marginal. This, in conjunction with consistent DO, TSS and turbidity readings indicate that water quality at the site is good.

The rise is chlorophyll a values recorded in September may be due to poor flushing in the catchment resulting from low rainfall. Algae and organic matter have accumulated at the site and have not been flushed downstream due to a lack of flow and turbulence.

Nutrients including Nox, TN, nitrate and TKN were observed to be highest in March, with readings progressively lower until September. This pattern directly correlates with catchment rainfall, as the catchment became progressively drier during the sampling period. The opposite was observed for TP, indicating that influxes of this nutrient cannot be correlated with rainfall. TP levels may instead be explained by runoff from urban households that contains fertilisers.

TON 3

Results obtained at TON 3 give an insight to water quality as it enters the wetlands from the Tongarra Creek tributary.

Like TON 2, turbidity and TSS were consistently low and did not correlate with rainfall patterns, even during wet weather events in March and April. It was observed however that Enterococci varied significantly with rainfall: a significantly high reading was recorded in April following rainfall, whilst it fell dramatically by May, with both May and September
readings within the guidelines. This indicates the wetlands ability to rapidly remove pollutants from the system.

Values obtained for conductivity, pH, temperature and nutrients varied slightly across sampling dates, however the majority of results obtained fell within the recommended ANZECC values. This indicates that water quality is sufficient as it enters the system, placing less pressure on the wetlands to filter and remove pollutants and improve water quality.

**TON 4**

Results obtained at TON 4 give an insight to water quality as it exits the Myimbarr wetlands, and thus indicates the effectiveness of the system in treating water quality. Water quality was analysed using both historical data and data obtained as part of this thesis.

Historical trends for DO at TON 4 were variable, however the majority of samples obtained between August 2008 and January 2012 were just below the recommended 80% minimum. A reading of 169.9% was obtained in January 2012, however this is thought to be anomalous as this reading is unusually high and could not be easily explained by processes occur either in the catchment or the wetlands. Results obtained during the sampling period indicate that DO stabilised at site TON 4, and now lies within the guideline recommendation.

Historical data obtained for pH at TON 4 between 2008 and 2012 had many readings missing due to equipment failure and limitations within the field, therefore it is difficult to report on trends present in this time period. It can be observed however that pH was far more variable at this time, and more alkaline readings were obtained on a number of occasions. pH readings were highest at this site out of any of the TON sample sites, however they did not exceed a pH of 9 therefore they do not present a threat to the health of the aquatic ecosystem (ANZECC, 2000). The higher pH could be a result of the timing the samples were taken, as more alkaline readings are likely to be obtained if sampling is conducted late in the day, due to consumption of CO₂ by plants during photosynthesis. It may also reflect the presence of an algal bloom at the time of sampling, which too causes pH to rise due to the effects of photosynthesis (Addy et al, 2004).

Turbidity results were very high in March, due to high amounts of rainfall that month. With the exception of the sampling conducted in March, readings obtained at TON 4 were generally low, indicating that as water moves throughout the wetlands, it spends enough time
in the ponds to allow sediment to fall out of suspension. This indicates that the wetlands are functioning effectively in filtering and removing suspended particles from the waterway, and water detention periods are sufficient.

TON 4 experienced the least variability in salinity with consistently low readings, which demonstrates that the wetlands regulate salinity well, and changes farther up in the catchment have not negatively impacted the wetland system.

A spike in chlorophyll \(a\) was recorded in April 2012 at TON 4, however this was not reflected in measurements of phosphorous or nitrogen at this site, which were all low or below the guideline values. High measurements of Nox and TN were recorded higher up in the catchment at TON 2, so it may be that nutrient pollution higher up in the catchment is resulting in an increase in biomass in the wetlands downstream, due to the rainfall experienced at the time.

Shell Cove

Due to the limited sampling sites in Shell Cove, the data for both sites is discussed together. Dissolved oxygen was observed to fluctuate at SC sites during the sampling period. Two of the three samples obtained at SC 1 were below the guidelines, possibly indicating that poor circulation occurred in the pond at those times. DO is dependent on the turbulence present in the ponds as this allows DO to circulate, and it is possible poor circulation at the site DO was sampled resulted in the low readings. DO has an inverse relationship with temperature, so the high reading obtained at SC 2 in May could be somewhat dependent on the cooler water temperatures at this time.

Conductivity was low and within the recommended ANZECC values, therefore salinity did not present an issue in the Shell Cove wetlands nor did pH, as all readings obtained were within guideline values, indicating that these values were stable and did not vary with seasonal changes during the sampling period.

Turbidity readings fell below the recommended guideline on a number of occasions at Shell Cove sites. Such low turbidity values allow greater light penetration into the water, which may result in a change in habitat as macrophytes can grow in deeper waters. This could be a contributing factor to the high chlorophyll \(a\) readings at SC sites, as increased light penetration would increase plant production and biomass. Readings for TSS were also lower
in the Shell Cove wetlands, and were correlated with turbidity readings in April and September. High turbidity and TSS were not recorded when high rainfall occurred in the catchment. This indicates that there is a low sediment load transported to the system from the catchment during rainfall, which shows that the catchment is stable and does not suffer from high levels of erosion and land degradation. It may also indicate that vegetation and buffer zones serve to slow and stop the flow of sediments before they can enter wetlands. If turbidity readings remain low during summer months, water temperatures may rise significantly as light penetrates the ponds. This should be monitored during summer, as increased light and heat may result in an increase in plant matter or algal blooms that thrive in warmer temperatures.

It was found that a spike occurred in Chlorophyll $a$ values in May 2012 at SC 2. This spike was also observed in nitrogen oxides, total nitrogen and nitrate. As such it is inferred that nutrient pollution occurred at that site prior to sampling, resulting in the higher readings of N and enabling the prolific growth of biomass at the site. This spike was unusual: rainfall is generally the cause of increased nitrogen in a system, as nutrients are transported to the site with stormwater runoff. This was not the case for the May sampling, as very little rainfall was recorded in the catchment prior to the sampling date. As this pond is offline, the pollution would not have been derived from pollution upstream in the catchment. Water enters the pond via a stormwater drain, therefore it is concluded that the nutrient pollution was sourced from this drain. TP was observed to increase during the sampling at SC 1, which was unusual as less rainfall was experienced in the catchment in May and September. This may be a result of urban practices whereby nutrients derived from fertilisers are washed into the drain system (T. Heather, pers. comm., 2012).

Enterococci results were consistently low at Shell Cove sites during the sampling period, presenting better results than the Myimbarr catchment for all sampling dates. Results were consistently well under the trigger value, even when rainfall in the catchment was higher, indicating that the system is stable and pollution from faecal matter is not entering water bodies at this time.

Results obtained for Shell Cove generally indicate good water quality in the constructed wetlands of the catchment. However, it is important to note that results were not taken farther downstream as this area is currently being developed and is inaccessible, so any changes in water quality as it moves through the catchment could not be recorded. Although SC 2 is
located downstream of SC 1, it is not located online and therefore only receives stormwater runoff. Water samples were unable to be taken at SC 3, the downstream site in the catchment. This was due to insufficient water depth at this site, and excessive amounts of algae and plant matter in the channel.

This indicates poor water quality and flow through the lower reaches of the catchment, most likely caused by low rainfall, excessive sedimentation and prolific growth of plants that have clogged the channel. This holds further implications for water quality: the channel will become stagnant, macrophytes will encroach the water channel and water temperatures will raise, resulting in lower DO at the site. Development is occurring adjacent to this site, which could account for the increased sedimentation due to controls being inadequate. The creek in this location is currently not being actively managed by SCC.

Figure 40: Photograph of the creek at SC 3. Water is turbid, shallow and covered in plant matter, with an oily sheen present on the surface. On the right the sediment fence built to protect the creek from the adjacent construction is pictured, while in the top left wooded stakes left from previous plantings can be seen.

### 6.1.3 Soil

Wetland soils have specific characteristics that impact on the condition of a wetland, and can be a determinate factor in water quality, fauna and vegetation. Characteristics of wetland soils include abundant organic matter, soil mottling, segregations of iron or manganese, oxidising root channels and green-blue-grey soil colours (DEEDI, 2011). As grab samples of soil were
obtained for this study, in depth analysis of soil properties was not conducted, however soil was characterised according to grainsize, tested for contamination and analysed to determine mineralogy.

Soil types determined within the wetlands included silty clay, silty clay loam, silty loam and sand. The type of soil present determines the infiltration capacity of the soil at each site. Sandy soils have the highest infiltration capacity, whilst silty and loamy soil types have moderate to high infiltration capacity. Silty and loamy soils are ideal for wetlands, as they are soft and friable allowing for rhizome and root penetration of plants, in addition to having a high capacity for retaining nutrients. Clay soils comparatively inhibit root penetration and lack nutrients, so are less suitable for wetlands. Sandy soils, unlikely clay soils, do not limit root penetration, but they are not ideal wetland soils as they do not readily retain nutrients or pollutants (Kuginis et al, 1998).

In addition to providing a suitable substrate for plant growth, silty and loamy soils provide the ideal soil-water contact, retaining water for sufficient time periods to remove and retain contaminants (Kuginis et al, 1998). Silty soils exhibit a suitable particle size for benthic organisms to burrow, and are a more appropriate habitat than clay soils (ANZECC, 2000).

**Myimbarr**

Soil types determined at Tongarra Creek and Myimbarr include silty clay, silty clay loam, sand, and silty loam. These soil types are classified as mineral soils, derived from bedrock (DEEDI, 2011). Where multiple samples were taken at one site, they all consisted of the same soil type, with the exception of samples obtained at TON 3. At this site, two samples were classified as silty clay loam, and one as sand. The reason for the differences in soil types at this site are reflective of the sampling process, as sample TON 3 was derived from a delta of coarse sandy material that had built up at the fore of the Myimbarr inlet, most likely sourced from washed in debris from the adjacent road. It is evidenced that the soils types found in the Myimbarr system are suitable wetland soils that will enhance the biota of the wetlands as well as aiding in the removal of nutrients and pollutants.

Samples were also analysed to determine if contamination was present at the site, by testing levels of trace elements in the soil and analysing concentrations of lead, zinc and copper. Zinc and lead were found to be well below the trigger value at all TON sites, indicating that contamination from these elements is not present. High values were obtained for copper,
which was investigated by analysing the samples in regards to the background value for the soils. The source material from which the soil is derived is the Bumbo Latite, a volcanic rock that lies in Shellharbour. The background copper value for the Bumbo Latite is up to 125 mg/L (Carr, 1984) which means that soils derived from this bedrock are likely to have high readings of copper naturally, and that pollution may not be the reason for the high values. Only one sample obtained along Tongarra Creek and within Myimbarr exceeded the recommended NEPC trigger value for copper. This sample, obtained at the Myimbarr outlet, was analysed against the background reading for the Bumbo Latite, to determine if the value was still high when the background was taken into consideration. The enrichment factor determined for this sample was less than 1, which indicates that the value was not anomalous when compared with the background value for that site, and that pollution was unlikely to be the cause of the raised copper value.

The mineralogy of each sample was also analysed. The minerals present are indicative of the source geology from which the soils are derived, namely the Bumbo Latite. The Bumbo Latite is a basaltic volcanic rock found in the coastal plain of Shellharbour. Basalts weather to form soils dominated by clay minerals. Clays include chlorite, halloysite, illite and kaolinite, which form from the weathering of primary minerals. Feldspars (albite and labradorite) are typically derived from basaltic origins and are common in soils that have formed from basalt source geology, and labradorite is commonly found as large phenocrysts in the Bumbo Latite (Geoscience Australia, 2012). Quartz and kaolinite suggest derivation from volcanic grains present in the Broughton Formation, of which the Bumbo Latite is a member (B. Jones, pers. comm., 2012).

A negative relationship is observed between albite and quartz. This is due to the weathering profile of these minerals: albite is more readily leached and therefore more susceptible to weathering; quartz is resistant, so as albite is leached quartz becomes the dominant mineral present. Feldspars such as albite are rapidly leached in the soil profile due to the acidity of the soil, however pH is more neutral in fluvial systems and therefore albite is still present in all samples (Nesbitt et al, 1997).

**Shell Cove**

Soils in the Shell Cove wetland system were classified as silty loam and silty clay loam according to their grainsize, demonstrating consistency throughout the catchment with
regards to soil texture. The soil textures at Shell Cove are ideal for wetland habitats, allowing root penetration of plants, burrowing of benthic organisms, and high retention of nutrients and metals, as discussed previously.

Analysis of trace elements was used to determine if contamination was present at the sites. The trigger value for copper was met or exceeded in all samples obtained from Shell Cove sites. As with Myimbarr samples, Shell Cove sediment samples were analysed against the background value to determine if contamination was present. When analysed against the background value, only one sample, SC 3, yielded an enrichment factor greater than 1, indicating that the background value could not account for the high copper reading in the sample. However, two other samples obtained at site SC 3 yielded enrichment factors of 1 or under, indicating that high values were likely to be derived from the background value. The heightened value obtained for one sample at SC 3 indicates that the copper reading derived may have been anomalous or may represent small-scale localised pollution in some soil at the site. Readings of Zn and Pb were also higher at this site, despite not exceeding guideline values. This indicates that low levels of pollution may be present at the site, most likely derived from accumulated runoff from roads upstream in the catchment, received into the waterway via stormwater runoff. The higher rates of urban runoff received into the lower reaches of the catchment would account for the pollution present.

Mineralogical analysis used for Shell Cove sites uncovered similar results to Myimbarr. The mineralogy present was once again indicative of the source rock from which the soil was derived, and was the same as the mineralogy of samples obtained at Myimbarr.

6.1.4 Vegetation

A unique suite of vegetation is present in wetlands, adapted to the moist or saturated soils, and variations in flow and flooding that occur in wetland environments. Wetland vegetation is determined by climate, soil and water flow (Arthington and Zalucki, 1998).

Vegetation is vital to wetland health; it provides habitat and food to a number of species; it regulates and improves water quality, filters and removes nutrients, captures soil and pollutants, monitors flow both within and along the banks of the wetland, prevents erosion and provides a buffer zone around the wetland that serves to protect the ecosystem and its processes. As such, the preservation of wetland vegetation is highly important. Vegetation is sensitive to changes that occur both in the wetland and the catchment. Extensive clearing of
Riparian vegetation has led to widespread degradation of wetland habitats, as increased erosion and sedimentation affects the hydraulics of the wetland. Clearing of riparian vegetation allows pollutants such as nutrients and sediments to easily enter the water column and be transported, as the riparian vegetation no longer functions as a buffer zone.

Wetland vegetation has been degraded by the invasion of introduced species, which colonise wetlands and outcompete native species. Introduced species are most suited to wetlands that are disturbed, where they can adapt to and survive in conditions that native vegetation cannot. Vegetation surveys were used to determine the number and abundance of both native and introduced species to help determine the overall health of the wetlands.

**Myimbarr**

Vegetation surveys conducted along Tongarra Creek and within Myimbarr wetlands uncovered much about the vegetation present within the catchment (see Figure 9). Vegetation profiles obtained in the wetland complex varied from those obtained upstream, due to the different conditions present at these sites. Vegetation at the top of Tongarra Creek was recorded to be coastal subtropical rainforest, a remnant patch of the type of vegetation present in the area prior to European settlement. Native species dominated this site, however this changed markedly shortly downstream where the rainforest was cleared and the canopy was open. The cleared native riparian vegetation and increased sunlight allowed weeds to colonise and become dominant along the creek line. The change in vegetation has in turn altered the flow of the water; the channel became far narrower as weeds clogged the channel and prohibited flow. Increased sedimentation at this site resulting from the clearing of riparian vegetation would also have contributed to the narrowing of the channel downstream.

The vegetation present upstream in the catchment will obviously affect vegetation communities downstream, as seeds and plant matter are transported in the water channel, by wind, animals or birds downstream, which then has implications for the vegetation at Myimbarr. A second survey conducted along Tongarra Creek showed noticeable differences in vegetation types on either side on the creek banks. One side of the bank was more vegetated, planted with riparian vegetation that stabilised the banks and limited light penetration to the lower canopy. Melaleucas, acacias and casuarinas were noted, however some weed species were still present. On the other side of the bank, riparian vegetation was absent and highly disturbed and compacted soils gave rise to colonising weed species. Within
the water channel itself, vegetation presented an issue as prolific growth of the native Typha restricted flow. Typha is commonly found in saturated grounds in wetlands and creeks, and can be both detrimental and beneficial in wetlands. Typha regulates flow so that large volumes and velocities of water are slowed before they enter wetlands or flow through the system, and it captures and retains sediments and other pollutants. Typha becomes a problem however, when prolific growth clogs creek channels and water ways, preventing the flow of water which results in poor water quality and limits habitat (Sainty and Associates, 2005). This was evidenced at site V2, where flow was low and decomposing organic matter, red staining and an oily sheen were visible in the water. The presence of vegetation in the water column was not the only factor contributing to the low flow of water, as a lack of rainfall in the months prior to sampling would have also contributed to low flows.

The three vegetation surveys at conducted along Myimbarr and Tongarra Creek showed that vegetation was improved in the wetlands, and far more native species were found here than along Tongarra Creek. The banks at Myimbarr were all planted following the wetlands construction, and are maintained on a weekly basis by staff at SCC. Although a number of non-native species were recorded, native species were far more abundant both in number and percentage coverage at the site. It was noted that more weed species were recorded closer to the water channel. This may be attributed to their ability to withstand variable flow conditions in the saturated ground, and the difficulty faced when trying to maintain and manage pest species in the water channel. Vegetation in Myimbarr’s first pond was observed to improve farther into the pond. The inlet contained more abundant pest species, able to colonise and withstand conditions of variable flow, where sediments and nutrients enter the wetland. More weed species were noted on the east bank of the pool, as this is where flow enters the water, and with it seeds that have been transported downstream. The accumulation of a sediment bank on this side has provided the ideal location for weeds to colonise as they enter the wetland, washing up and becoming established on the disturbed saturated soil. The noxious weed *Sagittaria platyplylla* has been recorded upstream of Myimbarr, and although it is not currently found in the wetland system it is likely to establish there in the future as it moves downstream (A. Lee, pers. comm., 2012).

A second survey was conducted across Myimbarr’s third pond. Like the previous Myimbarr site, this pond was extensively planted when Myimbarr was constructed, and ongoing maintenance is in place to manage vegetation. The vegetation was dense and well established,
so much so that access to the banks was restricted. An absence of introduced species may be
due to the density of established natives at the site, which outcompete weeds and prevent
them colonising along the banks. A similar vegetation profile was ascertained downstream
again across Myimbarr’s seventh pond. The lack of introduced species at these sites may too
be a reflection of their location in the wetland: further in the wetland complex there is less
opportunity for seeds to be transported downstream with water flow, as they would more
likely have been already deposited farther upstream. If seeds were to be transported farther
into the wetlands, they would have less chance to become established as the well vegetated
banks would prevent the colonisation of weed species.

Shell Cove

Three vegetation surveys were conducted along the Shell Cove wetland system to uncover
the dominant wetland vegetation present (see Figure 10). Pond 1 experienced abundant
macrophyte growth across the pond surface, with Azolla and watercress recorded as
dominant species. Azolla, despite being a native species, is a pest at many wetlands as it
blankets open water, limiting light penetration and altering the wetland habitat. This in turn
results in lower DO in the water, as light cannot penetrate the surface and the oxygen
exchange is compromised. Nutrient enrichment at the site may be a contributing factor to the
growth of azolla, as TP, nitrate, and TN were all recorded to be high around the time the
vegetation survey was recorded. Azolla is not recorded in ponds downstream, therefore care
must be taken to prevent its transport to other locations. Most of the fringing vegetation was
planted natives that provide habitat to water birds such as swans, observed to be nesting at the
site. Weeds were noted off the transect line, especially around the entrance to the pond and
through the entrance channel. The channel was dominated by phragmites and a number of
non-native species were also observed. The hydraulics of flow as water enters a wetland is
highly important as it determines the water quality of the pond, which in turn has an effect on
many other wetland components. If flow is altered or restricted by vegetation, it can result in
areas of the wetland stagnating, degrading the habitat within the wetland.

The transects recorded downstream differed significantly, as the vegetation surveyed was
along the natural creek line in comparison to the planted wetland. At these sites, introduced
species were greater in number than native species, however native species were still more
abundant. The noxious weed Sagittaria platyphylla was noted to be growing within the creek
channel at site V7. This species is a prolific seeder that will outcompete native species, and is
classified as a Class 5 noxious weed, meaning its presence must be reported to the Illawarra Noxious Weeds Authority. The presence of this species is problematic and creates complications for management. The native tuckeroo was also recorded at this site. This species has been planted throughout the Shell Cove suburb, however it is becoming a problem in fringing areas. The seeds are readily transported by birds and when planted outcompete other native species, becoming dominant along water channels (A. Lee, pers. comm., 2012). Typha was once again the dominant species within the channel, outcompeting other species and slowing the flow of water in the channel. The vegetation survey recorded at SC 3 demonstrated that more introduced species were present at the site than native species. Analysis of the quadrants determined that native species were most abundant at the site, however this is due to the presence of Typha throughout the channel, and may not reflect positively on the vegetation of the site. The site was highly degraded and the vegetation profiles were poorest out of all the Shell Cove sites. Management is not currently undertaken at the site, and this is evidenced by the presence of wooden stakes and starposts left by the developers of the subdivision (T. Heather, pers. comm., 2012).

6.1.5 Fauna

Although fauna was not recorded as part of this study, observations regarding fauna were made at each site where possible, to determine the presence of native or introduced species, and the implications this may have for the wetlands. Waterbirds were recorded at almost every site: ducks and swamphens (*Porphyrio porphyrio*) were observed throughout both wetland systems; swans were observed to be nesting at Shell Cove; and pelicans and seagulls were found at the saltwater component of Myimbarr. Of the species observed, swamphens are considered to be the most problematic: they uproot and trample vegetation, especially newly planted individuals, when building their nests, and they are aggressive to other species, which can result in the exclusion of other species from the sites. The presence of avifauna at the sites is important, particularly at Myimbarr where the wetlands have been designed, in part, to provide habitat to migratory birds.
A report by Kevin Mills and Associates completed in 2007 discussed in detail the presence of avifauna at the site through a monitoring program. This program surveyed avifauna on a number of occasions over a two-year period to determine the species present at the site. The surveys revealed that a total of 41 native species use the site, with the total number of species recorded as 46. A number of the species are migratory, and only present in Australia during summer, and others are nomadic Australian wetland species. Although the Shell Cove wetlands have not specifically been designed for avifauna habitat and do not contain the same diversity of habitat as Myimbarr, it is inferred that a number of avifauna use these sites for habitat as well, however specific studies to support this have not been conducted.

In addition to avifauna, a number of other species were observed at the sites. Frogs were heard at several sites throughout Myimbarr/Tongarra Creek, and at both Shell Cove ponds. The species are unknown, and a call play-back system would be needed to determine the species present at each site provided they could not be determined in the field. Other methods to detect frog species include visual spotting and sweep netting to identify tadpoles (T. Heather, pers. comm., 2012). Frog species are important as the endangered Green and Golden Bell Frog was previously recorded within the LGA, although its current presence is not
known. This species is listed under both state and commonwealth legislation, and if it was recorded in the wetlands it may have implications for their management. The common European rabbit was recorded at one site along Tongarra Creek, demonstrating the presence of introduced pest species in the catchment, which compete with natives and alter vegetation through grazing (NSW State of the Environment, 2009). A number of other native species are expected throughout the wetlands, including skinks, turtles, lizards, bats and flying foxes (DECCW, 2011; Eco Logical, 2012).

6.1.6 Assessment of the Health and Functionality of Myimbarr Wetlands and the Associated Catchment

Results obtained through the analysis of water, soil and vegetation in the Myimbarr Wetland system and Tongarra Creek indicate the health and functionality of the wetlands. In addition to the analysis of these parameters, many observations were recorded in the wetlands and throughout their catchment, to give an overall picture of the health of the system.

Water quality results indicate that the overall water quality in the catchment and the wetlands is generally in good health. Although water quality was seen to fluctuate in and out of recommended guideline values, no parameters remained persistently outside guideline values, indicating that ongoing problems with certain water quality parameters are not present. This is anticipated, as persistent issues with one water quality parameter would degrade the overall water quality of the site, as each parameter is intricately linked. Despite there being no obvious ongoing problems resulting in degraded water quality, the variation present across all parameters indicates that the system is very sensitive to changes in the catchment and within wetland process, and a more stabilised system and catchment would likely result in more stabilised water quality results. Management implications for water quality determined in this study are discussed in Chapter Seven.

The vegetation surveys conducted revealed that weed species were a persistent problem throughout the catchment and within the Myimbarr wetland systems. This has many implications for management. Vegetation species affect the communities present at the sites, the availability of food and habitat for native fauna, insects and fish, sedimentation build-up, and the velocity of flows entering the water body. From the surveys conducted, it is concluded that planting and maintaining riparian and native vegetation is the best defence against weed species on wetland banks. Weed species were noted to colonise where maximum light penetration occurred, as many of these species require full sunlight for
growth and survival. They also occurred in areas where the banks were disturbed and native species were absent. Where banks were established and native vegetation prevented full sunlight reaching soils, introduced species were far fewer in number and abundance.

Sedimentation is a problem in the wetlands and along Tongarra Creek. Sedimentation can be directly linked to catchment land use practices, with construction occurring at the top of the catchment that has caused exposed soils to easily erode and become transported into the water during rainfall. This is especially evident at TON 1, where the water channel had dried completely during September’s water testing, preventing a sample from being taken at this site. The lack of rainfall in the catchment would have been the main cause for the dried creek bed, however increased sedimentation at the site would have created a shallow channel more prone to drying. It is difficult to assess the amount and rate of sedimentation occurring at the site, however measurements recorded during the vegetation surveys noted that approximately 30 cm of unconsolidated mud was found in the channel.

![Figure 42: The dried water channel in September at TON 1. The muddy sediment is exposed and is cracking as it dries due to a lack of rainfall and a build-up of sediment at the site.](image)

Such an accumulation of sediment has many health implications for the site, and also for the wetlands downstream: when the channel dries habitat is lost, and encroaching sediment alters the morphology of the creek and thus the water flow. Plants will colonise on the encroaching sediment, contributing to the cycle of degradation, as discussed by Paul (2012). Water quality
is reduced, temperatures will become higher in the small, shallow pools, dissolved oxygen will lower and turbidity and suspended solids will increase dramatically with rainfall.

Figure 43: The eastern bank of Myimbarr’s first pond after a flood event. The bank has been inundated with flood waters that have brought with them sediment, gross pollutants (litter) and organic matter, flooding the banks and destroying the vegetation.

Sedimentation was also evidenced to be a problem at Myimbarr’s inlet, where a distinct bank of sediment and organic matter had accumulated. On the eastern bank of Pond 1, 13 m from the bank’s edge where vegetation began, a distinct sediment bank had formed. This bank was measured to be at least 50 cm high and was colonised by a number of native and introduced species. It is located where the greatest amount of flow is received into the wetland, which brings sediment and organic matter suspended in the water. The poor distribution of flow entering the wetlands coupled with high loads of suspended sediment has caused this
sediment bank to form, which reflects the main problems occurring in the wetland. The poor distribution of flow may have further effects in the wetland, such as low hydraulic mixing which can cause some areas of the wetland to become stagnant, however evidence of this is not seen at Myimbarr.

Observations recorded after a number of flood events in March, shown in Figure 43, demonstrate the problems caused by the sediment bank at the inlet. The eastern bank has been covered in flood waters, which have inundated the bank and deposited sediment, organic matter and litter, which has in turn smothered vegetation. This problem becomes a vicious cycle, as weeds and plants colonise the sediment bank, trapping sediment and encouraging further deposition in subsequent flows. Litter is a problem as not only does it detract from the overall aesthetics of the site, it is harmful to waterbirds if ingested, releases pollutants during decomposition and smothers plants and organisms (DIPNR, 2004). The deposition of gross pollutants such as litter during high flows may reflect on the inefficiency of GPT’s farther up in the catchment. A number of GPT’s are located upstream of Myimbarr and at the stormwater inflows along the wetlands, however one is not located at the entrance. A GPT trash rack or solid pollutant filter should be located closer to the entrance to reduce and prevent litter entering the wetlands during flooding. This would also help prevent organic matter from being transported downstream into the wetlands. GPT’s are only effective when maintained and emptied on a regular basis, which requires management planning and resourcing.

Figure 44: The GPT discharging to Myimbarr’s third pond. Attempts have been made to remove the sediment accumulated in front of the outlet.
Problems associated with the poor management of GPT’s are evidenced farther into Myimbarr, at the GPT outlet to the third pond. Sedimentation has built up in front of the GPT, preventing stormwater flow into the wetlands and resulting in the prolific growth of vegetation, which exacerbates the problem of reduced flow. Attempts to manage this are evidenced by the dredging of sediment in front of the GPT, however the extent of the dredging is insufficient and any flow received through the pipe will simply settle in the depression at the pipe’s outlet. The mesh netting used to retain gross pollutants has been removed from the pipe, essentially rendering the GPT useless in retaining litter.

The hydraulic regime of a wetland has implications for a number of wetland processes, including sedimentation, vegetation, habitat heterogeneity and water quality. Water flows and volumes at Myimbarr are altered during the August-September draw-down, which occurs for 6-8 weeks in order to mimic local conditions, maximise habitat diversity and encourage a response from migratory birds (Sainty and Associates, 2005). This draw-down should be exploited by SCC as an opportunity to remove weed and pest species, which will be further discussed in the recommendations for management.

The wetlands are generally performing well in regards to their intended purpose in providing habitat and stormwater treatment, however this study has revealed a number of areas of improvement.

6.1.7 Assessment of the Health and Functionality of Shell Cove Wetlands and the Associated Catchment

The analysis of results obtained at Shell Cove, in conjunction with analysis of observations recorded during sampling are used to determine the health and functionality of the wetlands. Like the Myimbarr catchment, water quality results were variable across most parameters, however results were consistent for turbidity and TSS. This indicates that sedimentation flowing into the wetlands with stormwater is far lower at Shell Cove than Myimbarr. The lower rates of sedimentation are due to catchment practices at Shell Cove, where urban development and clearing is not currently underway farther up in the catchment.

Vegetation surveys demonstrated that like Myimbarr, weed species are a problem throughout the Shell Cove catchment. It was also observed that vegetation issues too arose from native species reaching prolific numbers and becoming dominant at the site. This was observed for
Typha and Azolla. The dominance of certain vegetation species has negative impacts on the overall health of a wetland: Typha is problematic in water channels as it restricts flow, captures and detains sedimentation, which in turn changes the hydraulic regime of the wetlands, and changes channel morphology as sediment fills the channel and causes it to become shallower (Sainty and Associates, 2005). Typha may also be beneficial as it regulates water flow and prevents large volumes of sediment entering the ponds, which may account in part for the low TSS and turbidity recorded in Shell Cove. The presence of Azolla and other floating species at SC 1 may account for the low DO recorded there, demonstrating the effects vegetation can have on water quality, and the importance of maintaining healthy vegetation in wetlands. Encroaching vegetation has significantly reduced open water at this site and vegetation was observed to be choking the channel at the entrance to the wetland pond. Reduced open water will in turn affect the avifauna species present at the site (T. Heather, pers. comm., 2012).

The dominance of some plant species in the wetlands and throughout the creek channel may be an outcome of the altered flow regime that has resulted from changes in channel morphology and the regulation of stormwater flow. This supports studies conducted by Nielsen and Chick (1997), who found that altering the channel structure through the management of stormwater limits the variability of environmental flows within a system. This in turn reduces the frequency and volumes of flood events, as well as mediating drying and the associated low flows. Changes in the flow regime often cause changes in the vegetative composition of the wetland, as flora depends on the duration, frequency and volumes of high and low flows. Disturbance results in heterogeneity of vegetation species present, maintaining plant diversity and preventing the dominance of one species, whether native or introduced, at the site. The findings are supported by Middleton (2002) and Arthington and Zalucki (1998), who concluded that vegetative habitat loss results from the moderation of environmental flows.

Gross pollutants were observed within the entrance channel to the pond at SC 1. A GPT is located approximately 150 m upstream of the entrance, however the amount of litter present in the wetland entrance indicates that the GPT is not effective, either due to insufficient maintenance or the proximity to the entrance. If the GPT was closer to the entrance it may prove more effective, as would frequent emptying to ensure the trap did not become full, and thus not function efficiently.
Sedimentation is observed in SC 1 however it was not observed to be a major issue in the Shell Cove ponds of this study. On the natural creek line sedimentation was viewed to be a problem. The SC 3 site was highly degraded, infilled with sediment and encroaching macrophytes that resulted in shallow waters and low flow. The sediment fencing at the site was completely inadequate, as is evidenced in Figure 45. The sediment fence has fallen and a build-up of sediment around the fence has resulted in it almost disappearing, thus it is not serving its purpose in retaining sediment and preventing sediment entry into the creek. The site is not maintained, and this is evidenced by the numerous wooden stakes that have remained since initial vegetation plantings. The construction occurring adjacent to the site is clearly having detrimental effects in the health of the creek: sedimentation has increased, allowing vegetation to encroach the banks and further impede water flow; water quality, although not tested, is likely to be poor with low dissolved oxygen as the creek has become stagnant, and organic matter decomposes. This supports findings by Arthington and Zalucki (1998), who found that sedimentation and channel morphology in turn effects vegetation and water quality. A lack of flushing through the creek has allowed hydrocarbons from stormwater to accumulate in the water, resulting in an oily sheen covering the water. Furthermore, this oily sheen may have resulted from decaying organic matter at the site.

Additional construction will be occurring shortly downstream in the catchment, which will have further implications on the health of the upstream catchment. Construction will alter the flow in terms of both volumes and the direction of flow: sedimentation has the potential to accumulate downstream due to soil disturbance and erosion, which effectively may act like a dam on water flow, and the channel will be altered as discharge points change to accommodate the creation of the boat harbour. Altering the downstream hydrological regime will affect sediment deposition and transport, resulting in greater amounts of sediment being deposited upstream in the channel as water flow is hindered. This will place increasing pressure on an already degraded stream system, further reducing water quality and habitat. As SC 2 discharges to the degraded stream, it too may be affected by downstream changes. If sediment accumulates at the discharge zone it may result in a cessation of flow, which would have detrimental effects on the water quality of the pond. If flow is not able to discharge through normal channels, flooding may ensue during high flow events. It is evident that careful management of the downstream catchment must be followed during further construction, as it will affect the upstream catchment and degrade the constructed wetland upstream.
6.1.8 Summary

Sedimentation build-up, flooding and the water regime all have implications for vegetation in the study area. Maintenance of the natural flow regime, with periodic flooding and drying, encourages habitat heterogeneity, favours native species which have adapted to local conditions and prevents the dominance of one species at a site. Alterations to the flow regime conversely will favour introduced species, as does clearing or draining wetlands (DECCW, 2009). Water availability is a key determinant for vegetation communities, which are dependent on the frequency, duration volume and season of flooding. As suggested by Arthington and Zalucki (1998) an intermediate level of disturbance (flooding) is desired to maximise species richness and diversity. Just as flow regimes affect vegetation, vegetation affects flow regimes, altering the velocity of flows and changing the volumes and rates of sediment deposition.

High flows are also important as they flush sediment and organic matter that has accumulated in riffles, to maintain interstitial habitats and improve habitat heterogeneity. Drying of wetlands is equally important, increasing productivity through the release of nutrients as organic matter decays, which enables the wetland to flourish upon re-flooding. Channel
morphology is dependent on flow, which in turn affects habitat availability, bank stability and the transport of sediments (Arthington and Zalucki, 1998).

All processes within a wetland are interlinked, and if one is allowed to degrade it will have flow on effects to other processes, which will be detrimental to the overall health of the wetland. This supports the findings of Scholz and Fee (2008), who determined that wetland health was dependant of a range of factors, including biota, buffer zones, hydrology, disturbance and water and soil quality. Closely linked to the flow regime is the presence of vegetative buffers around creeks and wetland systems. Buffers and riparian vegetation are important to wetland health and the management of the flow regime as they serve to slow flows and retain runoff, pollutants and sediments, as well as providing habitat for native fauna. A well-established buffer zone will regulate and reduce the impact of flood water, minimise the invasion of weed species and contribute to wildlife corridors within a catchment, as was established by DEEDI (2011). The importance of all these wetland processes are evident in both Myimbarr and Shell Cove wetlands, where the interdependency of wetland processes and the effects degradation of one wetland component has on the whole system is evident.

Both wetland systems are generally performing well in regards to their intended purpose in providing habitat and stormwater treatment, however this study has revealed a number of areas that require improvement. Management recommendations outlined in the following chapter have been devised to improve the health of the wetlands and their associated catchment to further aid in treating stormwater and creating habitat so the wetlands are functioning optimally.
Chapter Seven

7.1 Recommendations for Management

7.1.1 Introduction

The ongoing monitoring and management of a constructed wetland system is critical to its success. As the wetlands at Myimbarr and Shell Cove have been designed to provide both stormwater detention and treatment and habitat, management goals must be in place to achieve both these outcomes. Through the creation of an inventory for the wetlands, the following issues are identified as management priorities for the wetland systems:

- Sedimentation
- Vegetation and Weeds
- Gross pollutants
- Water quality
- Catchment Management
- Hydrology
- Buffer zones

Management goals must be tailored to address the entire system and the catchment within which it lies, as plans that only aim to achieve individual outcomes or goals will not be successful due to the connectivity of wetland processes (Euliss et al, 2008). Management of the sites is hindered by the lack of baseline data available for the catchments prior to the construction of the wetlands, and the major changes in the morphology and hydrology of the catchment that have resulted in highly altered flow regimes, which are influential on the water quality, sedimentation and vegetation of the wetlands.

7.1.2 Myimbarr Wetland Complex

The Myimbarr Wetlands have been specifically designed to provide stormwater detention and treatment to the sub-catchment of Tongarra Creek within the larger Elliott Lake catchment, as well as providing compensatory habitat for the loss of Shellharbour Swamp. As such,
management goals must address both water quality and habitat, which in turn are linked to hydrology, sedimentation and catchment land use and practices.

**Water Quality**

Water quality management would be improved if water quality readings were obtained on a daily basis for dissolved oxygen, pH, temperature, turbidity and conductivity to determine background data for the site. Autosamplers have been installed at Myimbarr, however there are issues surrounding the transfer of data to SCC (T. Heather, pers. comm., 2012). This should be remedied as readings for these parameters are highly variable and significant changes can occur on a diurnal basis. Data obtained each day in the morning and evening would be highly beneficial in determining the normal fluctuations in water quality, to gather baseline data. These inorganic parameters are highly influential on the overall water quality in a site, and can be measured in the field to obtain instantaneous results.

By gathering baseline data to determine the ongoing patterns in water quality at the site, persistent issues or degradation of water quality can be easily identified, as these are hard to determine from spot measurements. This data can also be used to predict the effects of flooding or seasonal changes on the wetland, to determine the changes in water quality that are likely to follow high or low flows. As these parameters can vary significantly on a daily basis, information regarding the best time to sample in order to obtain representative data can be determined, as readings of DO and temperature may vary in the evening compared to the morning. Additional testing of nutrients should be conducted after rain events to determine nutrient inputs from the catchment. As water quality results did not indicate ongoing water quality degradation, specific water quality management goals are not devised. The implementation of total catchment management should instead be used to maintain and improve water quality, by managing sedimentation, vegetation, water flows, buffer zones and pollutants, which in turn will ensure water quality does not become degraded.

**Sedimentation**

Sedimentation management goals are devised as sedimentation was a problem both within the wetland and upstream in Tongarra Creek. Sedimentation evident along Tongarra Creek, especially in the upper reaches of the catchment, would be reduced if more effective barriers were used at the boundary of the construction site. Sediment fencing at the site is insufficient, resulting in the accumulation of sediment throughout the upper creek channel. Improved
barriers to prevent sediment movement would reduce the deposition of sediment downstream, and improve the water quality of these sites. It is important to note that large-scale construction that has exposed vast amounts of topsoil, as is occurring at the head of Tongarra Creek, will still result in some sedimentation discharging to the channel. The goal should be to reduce sedimentation as much as possible, and continue monitoring the site so any changes in sedimentation can be addressed as soon as possible.

Sedimentation was also a significant issue in Myimbarr’s first pond, where the accumulation of sediment and organic matter has resulted in the formation of a distinct sediment bank. Much of this sediment would have accumulated in previous years when the catchment was still undergoing extensive development and sediment inflow volumes were higher. Although sediment volumes entering the wetland now are likely to be reduced, the location of the bank still presents a problem, as it alters inflows into the wetland and encourages further accumulation of sediment and organic matter. Sediment volumes could be reduced through the installation of a sediment trap just before Myimbarr’s inlet. This sediment trap must be regularly maintained and be designed so sediment can be easily removed when it reaches capacity. The removal of sediment once it is deposited in the wetland ponds is costly and complicated.

Removal of sediment currently accumulated at the site would be the ideal solution to reduce sedimentation, vegetation encroachment and weeds at the site, as well as improving the circulation of flow received. This is complicated however by the difficulties faced and costs associated with the removal, drying and transportation of sediment for disposal. Removal is difficult as site access to remove sediment was not included in the original design and is therefore restricted, as heavy machinery would need access to the pond in order to manually remove sediment. Once removed the sediment would need to be tested to see if acid sulphate soils (ASS) are present, which would create further management implications to mitigate the effects of exposed ASS in the wetland, and also for the treatment and disposal of contaminated soils. In addition to the physical difficulties faced with the removal of sediment, the job would be very costly to SCC. If removal was to be undertaken, the site would have to undergo assessment to determine the expected environmental impacts, and removal would have to occur in stages to minimise environmental degradation. Investment in removing sediment, although costly, is likely to be a one-off solution to the problem, and if coupled with other mitigation techniques would prevent subsequent sediment accumulation at
the site. Sediment traps, as suggested above, would have to be emplaced before the inlet to prevent the same problem recurring.

**Riparian Vegetation and Buffer Zones**

Improved riparian vegetation upstream on the south side of Wattle Road would also assist in preventing sedimentation recurring in the inlet, serving as a buffer zone to retain sediments and reduce flow volumes and velocities. Problems associated with high volumes and velocities of flow were apparent in March, after high flow resulted in the deposition of abundant organic matter and litter on the sediment bank, smothering native vegetation and most likely causing a reduction in water quality as the organic matter decayed. Planting of riparian vegetation would be required to improve the buffer zone, ideally meeting the suggested 80% ground cover required for an effective vegetative buffer zone (DEEDI, 2011). Improving the buffer would have beneficial outcomes for water quality, as nutrients would be retained by riparian vegetation. In addition to this a well vegetated buffer system may reduce weeds downstream by preventing the establishment and spread of weed species.

**Wetland Vegetation**

The management of vegetation should be prioritised to reduce the impact of weed species, improve species diversity and provide habitat for native fauna. SCC should continue to manage weed species targeted at Myimbarr, including *Acetosa sagittata, Hydrocotyle ranunculoides, Nasturtium officinale* and *Rumex crispus*, which are removed through a combination of methods including hand-pulling, spraying with herbicides, removing seedheads and cutting the stems of juvenile plants (A. Lee, pers. comm., 2012). Management should also address native species *Phragmites* and *Typha* in instances where vegetation has become prolific and is impeding or diverting flow, such as is occurring along Tongarra Creek. *Typha* is also a problem throughout the Myimbarr wetland channels separating the ponds. *Typha* should be targeted in the spring and autumn to manage population numbers, and control is achieved by early intervention to physically remove plants, or when this is not possible cutting plant stems below the water level or herbicides can be used. Whilst *Phragmites* is preferable to *Typha* throughout creek channels, management actions such as herbicides may be required if population density becomes too high.

The noxious weed *Sagittaria platyphylla* should be targeted using herbicides upstream of Myimbarr to prevent its establishment in the wetlands, and its presence should be reported to
Ongoing vegetation management should continue to ensure that native species continue to be dominant at the wetlands. Planting of riparian vegetation upstream along the creek channel would assist in the management of weeds by providing competition and increasing canopy cover, which creates a less suitable habitat for weed species dependent on full sunlight. Vegetation management should occur on a catchment scale, targeting Tongarra Creek as well as Myimbarr, as maintaining healthy vegetation upstream and preventing weeds entering Myimbarr by managing the upstream tributary will prove easier than managing and removing weed species once they have entered Myimbarr.

The annual draw-down of Myimbarr wetland that occurs for 6-8 weeks during August and September to mimic natural conditions should be used in conjunction with vegetation management to target species when water levels are lower and accessibility is improved. Nuisance weeds in fringing areas would be particularly affected by the draw-down, and this in conjunction with targeted removal or spraying could result in the eradication or reduction of pest species. The draw-down should also be used to target Typha and phragmites when necessary.

**Gross Pollutant Traps**

To prevent the litter entering the wetlands, a GPT should be installed closer to the wetland inlet, to trap litter and other gross pollutants before they enter the wetland. This would improve the visual amenity of the wetland, which enhances the community’s value and perception of the wetlands. Existing GPT’s should be monitored and emptied on a regular basis to prevent them reaching capacity and becoming arbitrary. Sediment accumulating in front of GPT’s should be removed so water flow is not restricted, however vegetation should remain to slow flows entering the wetland, provided the vegetation is not so thick it prevents flow.

**7.1.3 Shell Cove Wetland Complex**

The Shell Cove wetlands have been designed to provide water quality control to the entire residential catchment of Shellharbour. Designed more as a water control system than a habitat provider, and as such water quality is the management priority for the ponds. However the ponds should also be managed to provide habitat, as habitat has been lost through development and through the destruction of Shellharbour Swamp. Managing the habitat of
the ponds will improve the water quality of the ponds as all wetland processes are interlinked and interdependent.

**Water Quality**

As suggested for Myimbarr, the collection of baseline data for dissolved oxygen, pH, temperature, turbidity and conductivity would be highly beneficial for the wetlands, to determine the normal daily and seasonal variations that occur in water quality and highlight the need for further management. The collection of baseline data should occur at SC 1 to give an indication of the baseline data for the catchment, as water quality trends observed at this pond would have flow-on effects to ponds downstream in the catchment. Further testing of nutrients should be performed in SC 2 to determine if nutrient pollution is sourced from stormwater drains downstream in the catchment. Water quality should also be tested downstream along the creek line and in the twin ponds located between SC 1 and SC 2 to determine water quality trends for the catchment, which in turn can be used to infer the functionality of the pond system in treating stormwater. If low DO continues at SC 1, management of surface macrophytes such as Azolla should occur to raise DO at the site. Azolla should not be eradicated, but excessive quantities should be removed by manual harvesting.

**Wetland Vegetation**

Vegetation management should target vegetation along the creek within the catchment, as vegetation at the ponds was generally quite good. Vegetation management performed by SCC in the wetlands should continue, to target weed species and problem natives. Management at site SC 1 should target Azolla and Typha, as these species proved problematic. Although native, these species can become pests if population densities become too high. Azolla should be targeted through manual removal should it become detrimental to water quality. Typha should be targeted in the channel entrance to SC 1, where it is currently inhibiting water flow into the wetland. Typha should also be targeted downstream in the channel at SC 3, where it is once again limiting flow. The noxious weed *Sagittaria platyphylla* is found within the catchment, and should be targeted through the use of herbicides and reported to the Illawarra Noxious Weeds Authority.
Flow management

There are no structures in place to enable flow management through a draw-down at Shell Cove. The catchment would benefit from the management of water flow that reflects natural variations in flow, as occurs at Myimbarr. The regulation of flow would create disturbance through the water channel and within the ponds, to create maximum habitat diversity and assist in the management of weeds and pests species that have colonised and become dominant whilst conditions have remained constant. Flow management would allow SCC to target weeds during low flow, coordinating both the use of reduced water availability and herbicides to target weed species reliant on saturated conditions. The hydrophilic Sagittaria platyphylla would be affected by reduced flows, and targeted management during these periods would assist in the eradication of this noxious weed throughout the water channel downstream of SC 1. The management of flow would also be beneficial at site SC 3, where ongoing low flows have resulted in shallow stagnating water and encroaching macrophytes along the creek banks. Pulses of flow would create diversity in the creek by improving water quality and flushing macrophytes and sediment that have encroached during times of low flow. As discussed in a study conducted by Shields et al (2010), inundation of the banks would prove beneficial at the site, as weed species that are intolerant of saturated conditions would deteriorate and their numbers would be reduced.

Downstream Catchment Management

Management is not currently occurring downstream in the catchment adjacent to the construction works. This should be prioritised as further construction in the downstream catchment will likely result in further degradation of the creek and the upstream catchment. Management actions should target vegetation and sedimentation to improve channel morphology and flow, and thus improve water quality and habitat. Management of water flow throughout the catchment would also be beneficial to this site, as poor regulation of flow has allowed the site to degrade. Management plans that target the lower catchment should be devised in conjunction with the new development to minimise harm from further construction and prevent construction damaging the upstream ponds. Improved management and regulation of the sediment and erosion controls on construction sites within the catchment is required to prevent further sedimentation occurring. This should include improved sediment fencing and ongoing monitoring to prevent site degradation. SC 3 is currently a public hazard.
as starposts and wooden posts fixed in the ground present a hazard to those who enter the vegetation, and as such these should be removed immediately to prevent harm to people.

7.1.4 General Recommendations and Limitations

The wetland systems in both catchments would benefit from more time and funding allocated to their maintenance. Current management only targets vegetation and this is mainly to improve the aesthetics of the sites, however targeted management that addresses all components of the wetland and their associated catchments is required.

Fauna, avifauna, invertebrates and fish were not studied in this report, and studies to collect information regarding these species would be beneficial to create a more complete inventory for the wetlands. Studies of avifauna and frogs are particularly important, as Myimbarr was designed to provide habitat and may serve as a breeding ground for avifauna including migratory birds, and frog surveys would indicate the presence of the endangered Green and Golden Bell Frog, which would have further implications for the management of the sites.

Further soil testing should be conducted to determine the organic matter content and pH of the soil, as these are important indicators of wetland soil quality, which in turns impacts on other wetland characteristics. Time constraints prevented bank profiling along the creek line and throughout the wetlands, and data obtained during vegetation surveying regarding the depth profiles of the banks was not used. Profiles of the creeks and ponds would be useful to determine the amount and rate of sedimentation occurring, and the deviation in pond shape from original designs.

Investigations into mosquito populations would also be beneficial, as the proximity of the wetlands to urban populations may hold health implications for the community. Mosquitoes are not only a nuisance species, they are also disease vectors and may pose a risk to the community if populations of disease-carrying mosquitoes come in to contact with the community. If mosquito populations are found to be an issue, management actions can be taken to minimise populations, including: routine wetland maintenance; management of water flow and water levels; draining of the wetland and managing plants to enable water flow and predator access (Webb and Russell, 2012).

The possible effects of climate change have not been investigated as part of this study. Climate change is predicted to influence wetlands in a number of ways, including:
- Flooding and sea level rise.
- Extreme weather conditions, including drought, rainfall, bushfires and temperature extremes
- More frequent storm surges
- Increased salinity
- A loss of vegetation communities (DECCW, 2010)

As such, investigations into the predicted effects of climate change on the wetlands of this study would be beneficial to determine forward-thinking management plans that accommodate expected or predicted changes. Although climate change is not an exact science, a lack of full scientific knowledge should not prevent affirmative action to mitigate the effects of climate change (EPBC, 1999).

A lack of baseline water quality data limited the analysis of water quality results, as ‘normal’ fluctuations in water quality are not known. Water quality should be tested at approximately the same time of day for each testing round, due to the changes that can occur in some parameters diurnally. Water quality testing should also be conducted farther downstream in the catchment at Shell Cove to determine the effectiveness of the pond system in treating water quality: although water quality was tested lower in the catchment at SC 2, these ponds are not online and therefore do not indicate water quality as it moves through the system. Water quality testing could not be performed at SC 3 due to insufficient depth, so testing should be conducted in an appropriate location upstream to give an indication of the water quality of the overall catchment.

A condition that dictates the requirement of regular monitoring of water bodies and the native flora and fauna associated with the water bodies for the life time of the subdivision should be incorporated into subdivision development approvals (DA’s). Monitoring results obtained should regularly be submitted to Council. In conjunction with this condition a management plan that addresses the wetland and associated riparian system should be devised according to SCC’s specifications, prior to allocating the asset to SCC for management. The management of wetland systems should be integrated into future plans at the approval of the subdivision to ensure an adequate resource base exists once the wetlands become the Council’s asset.
Chapter Eight

8.1 Conclusions

The analysis of water quality, soil and vegetation, in conjunction with field observations, was used to create an inventory of the Myimbarr and Shell Cove Wetlands located in the Elliott Lake and Shellharbour water catchments within the Shellharbour LGA.

The aims and objectives outlined in Chapter One of this thesis were to assess the health and functionality of the Myimbarr and Shell Cove wetland systems in order to determine management recommendations for each system. The analysis of water quality, soil and vegetation, in conjunction with field observations, was used to create an inventory of the wetland systems located in the Elliott Lake and Shellharbour water catchments within the Shellharbour LGA. From this inventory a series of recommendations were determined for each wetland system. It was found that different management objectives were required for each system to address the problems experienced in the different catchments.

It was established that water quality for both systems would benefit from improvement, as although the overall quality was sufficient, ANZECC exceedences were experienced across a number of parameters at each site. Improvements in water quality would result from erosion prevention, improved wetland vegetation, improved riparian and buffer zones and improved catchment management to reduce nutrient inputs. Water quality is highly variable and as such it is difficult to draw conclusions without knowledge of baseline data. Analysis of historical water data at the Myimbarr outlet indicates that water quality has generally improved with time, demonstrating the effectiveness of the wetlands in treating stormwater runoff.

Soil analysis determined that the soil types present in both wetland systems (silty clay, silty clay loam, silty loam and sand) provided the ideal soils for wetlands, allowing maximum root penetration of plants, retaining nutrients and pollutants and providing the ideal soil-water contact to enable the removal of contaminants. The mineralogy of the soils was indicative of their source geology, typical of soils derived from the weathering of basalts. This was expected as the Bumbo Latite is the basaltic volcanic rock that comprises much of the bedrock of the region, and weathers to form a series of clay minerals and feldspars. Contamination was not found to be a problem at the sites: zinc and lead values were well within guideline recommendations, and high readings of copper obtained at some sites were
accounted for by the background value for copper in the Bumbo Latite, with the possible exception of site SC 3, where low levels of contamination may be present.

Vegetation surveys revealed that the presence of weeds is problematic in both the wetlands and along tributaries within the greater catchment. A number of weed species were found both within the wetlands and along the creek tributaries, including noxious weed *Sagittaria platyphylla*. Native species were also observed to be problematic in both catchments in areas where they have become dominant and outcompeted other species. Problems with vegetation at the sites could be attributed to land clearing, which reduced canopy cover and enabled weed species to colonise; erosion and bank degradation which prevented species establishing on the unstable banks; competition from weed species that favoured the altered conditions in the catchment; and a lack of wetting and drying at the sites, which would prevent the dominance of one species and favour native species adapted to variability in the system.

Several observations were recorded at the sites which were also used to determine the efficiency of the wetlands. Observations regarding sedimentation and gross pollutants indicated that sedimentation and litter were both presenting problems in the wetlands. Sedimentation was caused by catchment practices that resulted in high rates of erosion and transport of sediment to the systems, exacerbated by inadequate sediment fencing and insufficient buffer zones to capture sediment before it enters the system. Litter was found deposited at the inlets of the wetlands and amongst stands of macrophytes, especially during times of high flow. This demonstrates the inefficiency of the GPT’s currently in the catchment and the need for better maintenance and placement of the GPT’s in regards to the wetland inlets.

Fauna, avifauna, fish and invertebrates were not studied as part of this inventory, so information regarding these species is limited to what has been provided in other studies and a limited range of observations recorded in this study. The wetlands would benefit from a detailed study to assess these components of a wetland to create a more complete inventory of the systems.

Both wetland systems are generally performing well in regards to their intended purpose in providing habitat and stormwater treatment, however this study has revealed a number of areas of improvement, addressed in the management objectives outlined in Chapter Seven. Recommendations differed for each system depending on the results uncovered through
testing and the intended purpose of the wetlands. The following issues were identified as management priorities for the wetland systems:

- Sedimentation
- Vegetation and weeds
- Gross pollutants
- Water quality
- Catchment management
- Hydrology
- Buffer zones

The wetlands require greater allocation of resources to manage, improve and maintain their condition, especially as changes in the catchment result from the creation of the marina in Shell Cove, which will place greater pressure on the Shell Cove system. Inadequate resourcing to manage the systems is a consequence of a lack of understanding of the complexity of constructed wetland systems, and the time and management required to maintain their processes. Rather they are seen as simple one-off solutions put in place to manage stormwater, which does not allow for ongoing management and monitoring. Current management of the systems that mainly targets vegetation is inadequate and management that targets the greater wetland system and the greater catchment is required to improve the functionality of the wetlands and prevent their degradation.

Constructed wetlands are extremely important environmental systems, integral in hosting ecological communities, improving water quality and mitigating the impacts of floods and droughts. In addition to the range of environmental services wetlands provide, they enhance the aesthetics of a community region and provide opportunities for recreation. All processes within a wetland are interlinked, and if one is allowed to degrade it will have flow on effects to other processes, which will be detrimental to the overall health of the wetland. The importance of all these wetland processes are evident in both Myimbarr and Shell Cove wetlands, where the interdependency of wetland processes and the effects degradation of one component has on the whole system can be seen.
References


*Coastal Wetlands (State Environmental Planning Policy No. 14) - SEPP 14 (NSW)*


Eco Logical Australia, 2012, *Ecological Assessment and Plan of Management Shell Cove Reserve*, prepared for Shellharbour City Council, Project No. 11NARECO-0004


*Environment Protection and Biodiversity Conservation Act 1999* (Cwlth)


Mills and Associates (1996). *Wetlands in the City of Shellharbour NSW*. A report for Shellharbour City Council, Jamberoo, NSW


Navin Officer Heritage Consultants, 2000, *Shellharbour City Council Area Aboriginal Heritage Study*, Prepared by Navin Heritage Consultants for Shellharbour City Council, Deakin ACT


*Noxious Weeds Act 1993 (Cwlth)*

*NSW Coastal Policy 1997 (NSW)*

*NSW Wetlands Policy 2010 (NSW)*


*Shellharbour Draft Local Environment Plan 2011*


*The China–Australia Migratory Bird Agreement 1988 (Cwlth)*

*The Japan-Australia Migratory Bird Agreement 1981 (Cwlth )*

*The NSW Wetlands Management Policy 1996 (NSW)*


*Threatened Species Conservation Act 1995* (NSW)


*Water Management Act 2000* (Cwlth)


Appendix 1

Legislation, Policies and Planning Instruments
Legislation, Policies and Planning Instruments

The management of wetlands is governed by a range of policies and legislation in place on a national, international, state and local scale. This legislation provides a guideline for the proper management of wetland ecosystems to ensure wetlands are preserved and protected rather than exploited and degraded. Policies pertain to a number of factors relevant to wetland management, including endangered and threatened species, migratory species, catchment management, water management as well as legislation specifically related to wetlands and their management.

Definitions:

Legislation

Laws made at a state or national level.

Planning Instruments

Legally binding documents that regulate land use and development at the state or local level including, State Environmental Planning Policies (SEPPs), Regional Environmental Plans (REPs) and Local Environmental Plans (LEPs).

Policies

Plans of action that are not legally binding to guide decisions made about land use and the environment.

Agreements

Agreements that are not legally binding between governments

Legislation:


The Environment Protection Biodiversity Conservation Act (EPBC) is a national piece of legislation that governs matters of national environmental significance. The Act utilises and promotes principles of ecologically sustainable development, promotes conservation of biodiversity and protection of the environment, and aims to achieve a collective approach to
environmental protection and management across all levels of government and within the community.

Matters of national environmental significance include migratory species, which are covered by the Act. This is relevant to my area of study as migratory species have been recorded in the selected wetlands. As such, protection of the species and their habitat must be in accordance with the specifications outlined in the Act. It is also applicable to threatened or endangered species and communities, which is once again applicable to the wetlands in this study as threatened species and communities are recorded in the Shellharbour LGA, including the Green and Golden Bell Frog. Any actions likely to have a significant impact on threatened migratory species or threatened species must be referred to the minister and undergo environmental assessment and approval.


The Water Management Act is in place to ensure the sustainable and integrated management of water resources for both current and future generations. Water management principles outlined in the Act are relevant in the management of wetlands and their associated ecosystems. Water should be used in a way that minimises or avoids soil erosion, contamination, decline of native vegetation, salinity (where appropriate) and acidity, and land degradation should too be minimised.

The principles of the Water Management Act must be applied in the management of the wetlands in this study. Water should be used in a way that protects and enhances that wetland ecosystem and functionality, to preserves the ecosystem and provide habitat. Water use in the catchment should not degrade or compromise the health of the wetland water body, and should avoid the release of contaminants, sediments and salinity into the wetland. The Act also regulates extraction for irrigation and a permit from the NSW Office of Water is required before extraction can take place. Extraction has been proposed for Myimbarr Wetlands but has not yet taken place.

**Noxious Weeds Act (1993)**

The Noxious Weeds Act establishes control mechanisms on weeds to reduce their impact on the economy, community and the environment. The mechanisms aim to prevent the establishment of significant new weeds, prevent, eliminate or restrict the spread of significant
weeds and effectively manage widespread significant weeds in the state. It also provides for monitoring and reporting on the effectiveness of weed management.

Weed control orders declare a plant as a noxious weed, apply a control class to the plant, specify the area to which the order applies, specifies the control measures that are to be used along with the control objectives, and finally specifies the term of the order (no longer than 5 years). There are 5 Classes under the Noxious Weeds Act. Classes 1, 2 and 5 are classified as ‘notifiable weeds” and must be notified to authorities when found.

In accordance with the Noxious Weeds Act, Shellharbour Council is responsible for the control of noxious weeds on council owned land, which includes wetlands in the LGA. Noxious weeds must be controlled according to their control order and any notifiable weeds must be reported to the Local Control Authority – the Illawarra District Noxious Weeds Authority. Control of noxious weeds in the LGA is of particular importance to prevent their spread into water bodies and into the wetlands, which will compromise the ecological value of the wetland and threaten the wetland ecosystem.

**Threatened Species Conservation Act (1995)**

The Threatened Species Conservation Act aims to conserve biological diversity and promote Ecologically Sustainable Development; prevent extinction and promote recovery of threatened species, populations and communities; protect critical habitats of threatened species, populations and communities; eliminate or manage processes that threatened survival or ecological development of threatened species, populations and communities; ensure the proper assessment of any action with the potential to impact threatened species, populations and communities and encourages the conservation of threatened species, populations and communities by adopting means of co-operative management.

The Threatened Species Conservation Act is applicable to the wetlands in this study as they provide habitat for a number of native species, both flora and fauna. The Green and Golden Bell Frog (*Litoria aurea*) is an endangered species under both state and national legislation and has been reported in the area. This demonstrates the need for ongoing monitoring and management of the wetlands to investigate their use as habitat by threatened species. The catchments in the Shellharbour LGA house a number of threatened ecological communities and their preservation is a priority in ensuring biodiversity is maintained and enhanced in the LGA.
Planning Instruments:

*State Environment Planning Policy No 14 – Coastal Wetlands (SEPP 14)*

The SEPP 14 Coastal Wetlands Policy aims to ensure the preservation and protection of coastal wetlands for both environmental and economic interests. Development and clearing and levee construction is restricted on land to which the policy applies, and approval must be sought from local council with concurrence of the Director-General of Planning before development is undertaken. Development proposals must be accompanied by an Environmental Impact Statement.

The environmental effects of the proposed development must be considered, including the effect on native plant communities, native wildlife populations, provision and quality of habitats for native and migratory species and changes that may occur in surface and groundwater characteristics both on and surrounding the proposed site. The implementation of restoration works is also restricted, and can only be carried out with approval from local council and concurrence of the director. This policy is applicable to wetlands within the catchment and within the Shellharbour LGA.

*Illawarra Biodiversity Strategy*

The Illawarra Biodiversity Strategy is a regional plan for the Illawarra that aims to conserve and manage biodiversity in accordance with the *Local Government Act 1993*. Biodiversity is an essential component of the environment and is under threat from a number of anthropogenic pressures, therefore its protection and conservation is paramount. The strategy incorporates a number of councils in the Illawarra, including Shellharbour Council, to guide and unify the protection and enhancement of biodiversity in the region.

Freshwater wetlands are listed as a vulnerable community under the strategy, under threat from salinisation, decreasing water flows and changes to water temperature and chemistry. Estuarine and wetland habitats are addressed in the strategy due to the diverse range of species they house and the important habitats they provide. As they house migratory bird species they are listed as areas of national environmental significance, which priorities wetlands and their management on a national scale. Freshwater wetlands including wetlands in Shell Cove are listed as endangered ecological communities, and as such the management and preservation is of priority.
**Shellharbour Local Environment Plan**

The Shellharbour Local Environment Plan 2000 (LEP) is currently undergoing review with a draft currently on public exhibition. This plan aims to act in accordance with the EPBC Act to ensure environmental planning provisions comply with the standard environmental planning instrument under section 33A. More specifically, the LEP aims to encourage development that exhibits ecological sustainability whilst meeting the social and economic needs of the community. Land with ecological and conservational value will be protected and enhanced to benefit both current and future generations. Wetlands are specifically mentioned in the aims of the LEP, which outlines that wetland areas and their associated water regime, water quality, catchments and buffer zones must be protected and conserved. Another aim of the plan particularly relevant to wetlands in this study relates to minimising risk to the community from scenarios such as flooding, coastal inundation and acid sulphate soils.

There are guidelines regarding earthworks (excavations and filling) in place to prevent detrimental effects that earthworks may have on the environmental functions and processes. Development consent must be granted for significant earthworks, which takes into consideration the likelihood of disruption or detriment to drainage patterns and soil stability, the quality of the fill or soil to be excavated and the proximity to and potential to damage a watercourse or an environmentally sensitive area.

**Policies:**

**NSW Wetlands Policy**

The NSW Wetlands Management Policy has been commissioned to ensure the NSW Government’s ongoing commitment to the protection of natural wetlands. The policy aims to provide protection for NSW’s wetlands, in accordance with ecologically sustainable use and management. The focus of the policy lies on sites of international importance (Ramsar sites), national importance (sites listed in the Directory of important wetlands of Australia) and regional significance.

There are twelve guiding principles that should be used when making decisions regarding the management of wetlands. They have been devised to complement other legislation applicable to wetlands by providing an explicit definition of wetlands, aiding decision making in regards to wetland ecosystems and providing direction where existing legislation is unclear. The
policy is applicable to natural wetlands, however the guiding principles can be modified and adapted to address management of constructed wetlands, and provide a basis for constructed wetland management plans.

**NSW Coastal Policy (1997)**

The NSW Coastal Policy aims to protect and conserve the coast for future generations, by employing sustainable management techniques and integrating principles of ecologically sustainable development (ESD). The coastal zone has been defined to include a one kilometre strip alongside the coastline, three nautical miles seaward and all coastal rivers, lakes, lagoons, estuaries and islands. The policy contains key actions that relate to wetlands, including the rigorous promotion of the SEPP 14 Coastal Wetland legislation to ensure recognition and protection for these valuable ecosystems.

The Shellharbour coastal zone was integrated into the Coastal Policy in 2005 when the Coastal Zone was extended to include the greater metropolitan area of Sydney, which included Shellharbour. The Coastal Policy dictates the level and type of new development that can occur in coastal areas, monitors the use of resources and ensures conservation values are integrated into management and development plans. Local councils are primarily responsible for planning and development in the coastal zone, and the Coastal Policy should be integrated into management plans developed by the council. The Policy should also be incorporated into Local Environment Plans, and when reviewing applications for development in the coastal zone. For the purpose of this policy, the Coastal Zone is defined by the SCC as one kilometre alongside the coastline. The wetlands of this study are included in the Coastal Zone for Shellharbour therefore the NSW Coastal Policy is applicable.

**The NSW Wetlands Management Policy (1996)**

This policy is in place to encourage the management of wetlands and encourage the restoration of wetlands to improve the quality of NSW’s wetlands. The common goal of the policy is to ensure “The ecologically sustainable use, management and conservation of wetlands in NSW for the benefit of present and future generations.” Guiding principles are in place to achieve the above goal, including: the maintenance and restoration of water regimes; rehabilitation of wetlands through land use and management practices, ensuring water entering wetlands is of sufficient quality and volume, and the active conservation and rehabilitation of wetlands, where practical. These principles should be applied by local
governments when making decisions regarding activities that could affect wetlands. The policy integrates principles of Total Catchment Management and Ecologically Sustainable Development to provide guidance for best management practices and rehabilitation works.

The policy is applicable to the wetlands in this study as it covers all natural wetlands and wetlands that have been constructed as compensation for the degradation or destruction of a natural wetland, as is the case with the Myimbarr system. As such, the goals and principles outlined in this policy should be applied to the management of the wetlands in this study, and management plan should be devised in accordance with the policy.

Agreements:

**JAMBA and CAMBA - The Japan-Australia Migratory Bird Agreement and the China–Australia Migratory Bird Agreement**

JAMBA and CAMBA are agreements between the Australian Government and both the Japanese and Chinese Governments that protect migratory birds that move between Australia and China and Australia and Japan. Migratory birds hold significant environmental worth and play a role in enriching the natural environment. The JAMBA agreement is also in placed to protect species or subspecies in danger of extinction. ‘Migratory birds’ refers to species for which there is evidence of their migration between the countries in agreement, excluded species that have been introduced to the countries in question.

Both CAMBA and JAMBA are applicable to the wetlands in the Shellharbour LGA, as migratory birds have been recorded and sighted at these locations. As such, the protection and enhancement of these wetlands is vital under the migratory bird agreements to protect species and their habitats. This is especially relevant for the Myimbarr Wetland system, which was constructed, in part, as habitat for migratory bird species.

Other relevant pieces of Legislation, Policies and Planning Instruments relating to wetlands include:

- *Protection of the Environment Operations Act 1997*
- *Wetlands Policy of the Commonwealth Government of Australia 1997*
• *The NSW State Groundwater Dependent Ecosystems Policy 2002*

• *NSW Wetland Recovery Program*

• *Guidelines for Riparian Corridors on Waterfront Land*

• *Illawarra NRM Action Plan – Southern Rivers Catchment Management Authority*

• *Illawarra Regional Plan*

• *Ramsar Convention*

Constructed wetlands have limited legislation that guide or govern their planning and management, as seen in this review. As such, it is advised that legislation applicable to natural wetlands, coastal zones, migratory and threatened species and environmental management outlined above are applied to the constructed wetlands and their catchments in this study.
Appendix 2
Field Sheets – Vegetation Surveys and Water Sampling
## Water Sampling Field Sheet

### FIELD RECORD SHEET

**Officer/s:**

**Date:**

**Project:** Environmental/Stormwater_Surface Water Sampling  
**Time:** Start:  
**Finish:**  

### Field Observations

<table>
<thead>
<tr>
<th>Site</th>
<th>Time/Date</th>
<th>Weather: wind strength/direction, cloud cover</th>
<th>Water surface condition</th>
<th>Water flow, level, tide</th>
<th>Colour and appearance of water - Any odour?</th>
<th>Presence of oily sheen on either the surface or on bank/shoreline?</th>
<th>Presence of floating debris?</th>
<th>Presence of nuisance organisms/ prolific plant growth (i.e. aquatic weeds, macrophytes, algae)?</th>
<th>Other observations</th>
</tr>
</thead>
</table>
Vegetation Field Sheet

Site Number:  
Transect Location: Start A)  
Finish B)  
Date:  
Time:  
Total Transect Length:  
Conditions: Weather:  
Flow:  
Odours:  
Water Surface Condition:  
Oily Sheen?:  
Floating Debris:  

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Appendix 3

Historical Water Data for Myimbarr Outlet (TON 4) from 2008 to 2012
**Dissolved Oxygen**

Dissolved oxygen was tested on six occasions between August 2008 and January 2012. Only once in this time period did the result fall within the ANZECC guideline for lowland rivers, between 80 – 110%. Most of the samples yielded results just short of the 80% guideline, however data obtained in January 2012 was far above recommended guidelines, at 169.9%. This number is very high and is likely to be an anomaly for that site, as other sites tested on that date were within the normal range of values.

![Dissolved Oxygen Graph](image)

**pH**

An incomplete data set was obtained for pH between 2008 and 2012. Only six readings were collected in total, and the lack of data can be attributed to equipment failure and insufficient water depth for sampling on one occasion. pH was variable during this time period, although it is observed that pH readings were always more alkaline than acidic, exceeding the ANZECC guideline range on a number of occasions.
Turbidity

Data was obtained for turbidity at the Myimbarr outlet on nine occasions between August 2008 and January 2012. The highest reading obtained was 23.3 ntu in August 2008. Since then all readings remained steadily below 10 ntu until September 2011 when they began to rise again. The ANZECC Guidelines recommend that turbidity readings should lie between 6.0 – 50 ntu for lowland rivers. The majority of results comply with the guidelines; nine readings obtained fall within the guidelines range and only one reading from December 2008 fell below the recommended range.
**Temperature**

Temperature was recorded on six dates between August 2008 and January 2012. Temperature during this time was variable and changed seasonally at the Myimbarr outlet, TON 4. The lowest reading obtained was 11.26°C in August 2008, and the highest was 28.4°C in January 2012. Such variation is expected in shallow waters, as water temperature is sensitive to changes in atmospheric temperature, that varies seasonally and diurnally.

![Temperature Graph](chart.png)

**Chlorophyll a.**

Results for chlorophyll a have remained fairly constant over time, with almost all readings under 10 μg/l (mg/ m³). According to the ANZECC Guidelines for water quality, chlorophyll a should be under 5 mg/m³ for a lowland river. Of the twelve samples collected between August 2008 and January 2012, six were within the acceptable range and 6 exceeded the ANZECC trigger values. The highest value obtained was 59 mg/m³ in January 2012. This value was significantly higher than all other readings and the recommended guideline.
Enterococci and Faecal Coliforms

Testing was conducted for faecal coliforms from August 2008 to May 2010, at which point the parameter tested was changed to Enterococci, as determined by the Office of Environment and Heritage NSW. This was changed as Enterococci remains longer in the water body and is therefore a better indication of faecal contamination (T. Heather, pers. comm., 24 September 2012). Faecal coliform values have not been established for Aquatic Ecosystems, and values are only available for Primary Industries. These values dictate the level allowable for food or water to be consumed by people or animals for human consumption, and therefore are not applicable to this study. The trigger value for Enterococci is 35 cfu/100 mL, and this has been exceeded in five samples, with only one sample (September 2011) falling under the guideline level between December 2010 and January 2012.
**Total Suspended Solids (TSS)**

Total Suspended Solids were variable throughout the time period, with the lowest readings obtained in May 2010 and September 2011, and the highest readings obtained in April 2010 and December 2010, with the exclusion of the January 2012 spike. An overall trend that saw TSS decrease over the time period is observed. ANZECC trigger values are not available for TSS, so Guidelines prepared by the Government of Western Australian Department of Water have been used. The 2008 Statewide River Water Quality Assessment for Western Australia developed a classification system that defined TSS as Low (< 5), Moderate (5 – 10), High (10 – 25) and Very High (> 25) (Department of Water WA 2008).

According to this classification, two samples are classed as low, six are classed as moderate and four are classed as high. It is important to note however, that these guidelines are used as a broad reference system for TSS, as TSS should be assessed on a site-specific basis (ANZECC 2000).

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**Nitrogen Oxides**

Results were obtained on five dates from December 2010 to January 2012. Three of these samples fell under the trigger value of 0.04 mg/L. Two samples exceeded the guideline, the highest being 1.4 mg/L in March 2011. This demonstrates the variable nature of Nox in
aquatic ecosystems, and it can be seen that even when values rise outside the trigger values, they return to acceptable levels, therefore Nox does not remain high in the system over long time periods.

**Total Nitrogen (TN)**

Total Nitrogen was lowest in 2008 and early 2009, and increased steadily until it peaked in December 2009, settling after this and remaining fairly constant between 0.6 and 0.8 mg/L until the January 2012 spike. Only three samples from August 2008, December 2008 and June 2009 fell under the ANZECC trigger value of 0.5 mg/L for TN in lowland rivers.
**Total Phosphorous (TP)**

Total Phosphorous was variable throughout the time period. Results ranged from 0.006 mg/L in June 2009 to 0.11 mg/L when it spiked in January 2012. The majority of readings fell between 0.01 mg/L and 0.08 mg/L. The ANZECC Guidelines define 0.05 mg/L as the trigger value for lowland rivers. Of the twelve samples obtained, eight are compliant with the lowland rivers value.

![Total Phosphorous (mg/L)](image)

**Total Kjeldahl Nitrogen**

Measurements of TKN were obtained on 5 occasions between December 2010 and January 2012. The majority of these results measured 0.6 mg/L and 0.7 mg/L, however one result was higher at 1.5 mg/L. ANZECC guidelines do not exist for TKN, however a report by Cardno Forbes Rigby Pty Ltd (2008) used 0.5 mg/L as a trigger value for TKN when testing water quality in streams in Vincentia, NSW. If this value is to be used, all samples taken between 2010 and 2012 exceed this value, but only slightly.

![Total Kjeldahl Nitrogen (mg/L)](image)
Appendix 4

Water Quality Results for Metals, Ammonia, Nitrite, Nitrate and Total Kjeldalh Nitrogen
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NOTE: ID means Insufficient Data. Metal values may vary according to the level of species protection at each site. The colour red indicates that values have exceeded the guideline value for that parameter.
Appendix 5

Mastersizer Output Graphs for Particle Diameter
Laser Size Analysis for TON 1

Laser Size Analysis for TON 1a

Laser Size Analysis for TON 2

Laser Size Analysis for TON 3
Appendix 6

Soil Results Tables – Mastersizer and XRF

Trace Elements
**Mastersizer Results**

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Appendix 7

Water Quality, Variations and their Implications
Dissolved Oxygen

Dissolved oxygen can fluctuate considerably on a daily (diurnal) basis, dependent on factors such as temperature, biological activity, salinity, and the rate of oxygen transfer that occurs within the atmosphere. Temperature has the greatest effect on DO; DO is higher when the temperature is lower, and becomes depleted when temperature is raised (Addy and Green 1997). Salinity also affects the DO content of water, as higher salinity reduces the amount of oxygen that can dissolve in water. Other factors that affect DO include turbulence, which circulates oxygen through a water body and plants, which photosynthesize during the day and consume oxygen at night through respiration and eutrophication, resulting in an increase of the availability and consumption of organic matter, causing a depletion of DO as a result of the respiration of microorganisms. DO is sourced predominantly from exchange with the atmosphere, which is increased under turbulent conditions (Addy and Green 1997, ANZECC 2000).

It is important to note however that DO readings can be misleading and easily misunderstood, due to the fluctuations that readily occur on a daily basis. Spot measurements are not particularly useful in determining the DO of a system, as changes can be highly localised. It is suggested in the ANZECC Guidelines (2000) that proper interpretation of DO data can only be attained when the full range of diurnal changes are known, over a number of days with different weather conditions.

DO concentrations can greatly affect aquatic ecosystems. Low DO negatively affects fish, invertebrates and microorganisms that depend of oxygen to function. In addition to the negative effects lowered DO has on the metabolism of organisms, low DO can increase the toxicity of many toxic compounds, including zinc, lead copper and ammonia.

Conductivity

Also known as salinity, electrical conductivity measures the concentration of inorganic ions (salts) in water. Conductivity can be raised if a wetland is permitted to dry out, often through draining, damming or irrigation. Salinity may also be increased if groundwater is pumped to the surface, or interacts with the water body, as groundwater is generally more saline than freshwater. An increase in salinity may also be attributed to extensive land clearing and agricultural land use (Wetland Research – Restoring the Balance).
There are many problems associated with increased salinity in a wetland. Most organisms can only adapt to a narrow range of salinity, therefore notable increases or decreases in salinity adversely affect many species. Salinity affects an organism’s ability to osmoregulate, which can be lethal to a number of species. Salinity will affect the composition of the ecosystem, which has knock-on effects to a number of organisms. Mosquitoes and flies are known to increase with an increase in salinity, while other insect populations decrease (Wetland Research – Restoring the Balance).

**pH**

pH in natural freshwater systems generally lies between 6.5-8, and is controlled by the carbonate-bicarbonate buffer system. Most water bodies can buffer or regulate pH, due to the presence of bicarbonate ions derived from the dissolution of soils and rocks in the catchment. If a system has poor buffers however, pH can change diurnally. Acidity in waterways can be attributed to a number of factors, including: geology; agriculture; acid deposition and acid sulphate soils. Agriculture practices clear and disturb the soil, which can result in leaching that leaves an excess of H+ ions in the topsoil. If runoff from this topsoil enters waterways it can lower their pH. Similar processes can occur when land is cleared and soil disturbed for urban development (ANZECC 2000). If acid sulphate soils are exposed to the atmosphere through anthropogenic processes such as clearing, dredging or draining waters, the exposed acid leachate may be transported into water systems with subsequent rainfall.

No lethal effects to biota have been recorded when pH is maintained between 6.5 and 9 (Alabaster & Lloyd 1982, CCREM 1991), however pH lower than this is evidenced to negatively affect macroinvertebrates, by altering the supply of food. A low pH may also increase the toxicity of toxins such as cyanide and aluminium, while conversely a high pH increases ammonia toxicity (ANZECC 1992).

**Turbidity and Total Suspended Solids**

Turbidity measures the amount of clay, silt, phytoplankton and detritus in the water, otherwise known as suspended particulate matter (SPM). Suspended solids and turbidity are used conjunctively to indicate the amount of suspended matter in water. Turbidity in wetlands can be correlated within rainfall, as higher rainfall events causes silt and sediment to be transported into waterways. The majority of SPM is transported to a wetland during flood events (Cosser 1989). Increased water flow from the catchment also causes settled sediments
to become re-suspended, again contributing to high turbidity in the water. Some pest species such as the European carp also contribute to heightened turbidity readings, as they disturb bottom sediments and cause particles to become re-suspended (Roberts et al, 1995). If turbidity readings are consistently high, it may be due to poor land practices and management within the catchment. Land clearing, agriculture and urban development can disturb soils and make the topsoil layer vulnerable to erosion. Eroded and exposed sediments can be more readily transported into waterways during rain events. Similarly the removal of vegetation, especially riparian vegetation, can cause an increase in turbidity, as plants are not there to slow and capture sediments before they enter waterways.

High amounts of SPM adversely affect wetlands both in suspension and when settled out. High turbidity in suspension reduces light penetration into the water, which then causes a decrease in primary production by organisms reliant on sunlight (Lloyd 1987). Primary production in shallow, clear water systems experiences the greatest response to change in even small amounts of turbidity. SPM may have nutrients of toxicants adsorbed to their surface, which can alter the growth and biomass of aquatic plants (Newcombe & MacDonald 1991). The downstream movement of toxicants and nutrients is aided when they are adsorbed to SPM (Wagner and Jackson 1993). High turbidity can affect fish species by coating their gills, impairing feeding behaviour in species that rely on visual cues when foraging, and the growth and development of young and eggs are hindered by damaged respiration. Benthic macroinvertebrates may be smothered by suspended particulate matter, or their feeding apparatus may become clogged when levels increase. Their habitat becomes altered as small riffles are filled, and the decomposition and availability of detrital material is altered, affecting the availability of food for macroinvertebrates (ANZECC 2000).

**Temperature**

Temperature is one of the most important factors in determining water quality as it has many flow-on effects within an ecosystem, and changes in water temperature have the potential to greatly influence ecosystem health. Despite this, an ANZECC guideline for acceptable temperature ranges does not exist due to insufficient data for Australian waters (ANZECC 2000). Natural variations in temperature occur seasonally and diurnally, and changes in temperature may be induced by human activities. Temperature can be a determinant factor in the levels of DO present in water, and can alter the toxicity of chemicals (Tasmanian Planning Commission 2009). Changes in temperature can also have an effect on organisms,
whose metabolism, respiration, growth rates and ability to photosynthesize can all be dependent on temperature. Organisms have a tolerance range for temperature, and if temperature rises too far above or falls below this range the organism may not survive. Rates of biochemical reactions depend on temperature, with reactions doubling with every 10°C increase in temperature. Warm water can become anoxic or hypoxic due to a decreased ability to hold DO and increased bacterial respiration (Armand et al 2012). Changes in water temperature adversely affect aquatic ecosystems by influencing primary production and resulting in a loss of biota and habitat.

Changes in water temperature can arise from natural or anthropogenic causes: natural variations occur seasonally and diurnally, especially for surface waters that are heated by the sun during the day. Natural variation can also arise from the hydrology and currents present at the site, caused by flow or wind-driven currents, which result in hydraulic mixing. Thermal pollution occurs through discharge of municipal stormwater into a water body. This is because water is heated as it travels over roads and paved sources before being discharged into waterways. The impact of this is generally small for larger water bodies, however measurements taken at the site of stormwater discharge may be skewed (Water on the Web 2008). Loss of riparian vegetation may also result in raised temperatures in streams (ANZECC 2000).

**Oxygen Reduction Potential**

ORP is a measure of a systems capability to oxidize material, measured as a number that defines the systems potential to gain or lose electrons. The activity and strength of oxidisers and reducers in relation to their concentration determine ORP readings. Oxidising and reducing reactions result from bacterial activity, that gains energy from the reactions. Oxidisers include chlorine, hydrogen peroxide, bromine, ozone, and chlorine dioxide, whilst reducers include sodium sulphite, sodium bisulphate, hydrogen sulphide, nitrate, nitrite and free oxygen. An oxidising environment gives a positive value, whilst a reducing environment gives a negative value. ORP is closely correlated with DO levels and pH. ANZECC values do not exist for ORP. Oxidising environments are desirable in natural systems, however levels of between 100 – 200 mV are common in surface waters. Cleaner natural water bodies have values of around 400 mV (Apps YEAR). The standard for drinking water according to the World Health Organisation is 700 mV (Myron L Company 2012). At an ORP of 650 mV, water is disinfected and bacteria and viruses such as E. Coli become inactivated.
High ORP levels mean that bacteria work more efficiently in breaking down organic material and contaminants. ORP is dependent on the amount of DO in the water, and depletions in either of these elements can result in increased levels of contaminants and increased toxicity of metals (Home and Goldman 1994). An inverse relationship between pH and ORP is generally observed. ORP indicates changes in nitrate and ammonium occurring in a system (Li and Bishop 2004). Sudden drops in ORP levels may result from an influx of organic molecules released from a decomposing organism. ORP values increase significantly when organic matter is removed from a system.

**Chlorophyll a**

Chlorophyll $a$ is used as an indicator of biomass as plants, cyanobacteria and algae contain approximately 12% chlorophyll $a$. This is then used as an indicator of the growth rates and volumes of these organisms in the aquatic ecosystem. If chlorophyll $a$ is very high, it may indicate nutrient pollution at the site, as excess nutrients can result in prolific growth in algae and cyanobacteria. Chlorophyll $a$ levels may also be increased during warmer months or if there is high exposure of the water to sunlight, as photosynthetic rates in algae increase, thus their biomass does too. There may not always be a distinct relationship between chlorophyll $a$ levels and biomass, due to physiological differences amongst species, and this should be considered when interpreting results (ANZECC 2000).

**Enterococci**

*Enterococci* are bacteria naturally found in the intestines of people and other mammals that can indicate the presence of faecal contamination in a water body. *Enterococci* remain in water longer, so it is often a better indication of contamination than faecal coliform measurements (Higham et al, 2001). Although the *Enterococci* bacteria itself is not harmful, it can indicate the presence of other harmful bacteria, viruses and protozoa derived from faecal contamination (WA Public Health 2012). High levels of *Enterococci* found in water can indicate influx of sewerage material or stormwater runoff entering the waterway. It may also be a result of agriculture, as the faecal matter of cattle and other mammals can enter waterways either directly or via stormwater runoff.
Nitrogen

Nitrogen is a nutrient that is essential to organisms in aquatic ecosystems such as algae and macrophytes, which rely on it as a food source. Nitrogen is contained in many forms, including Ammonia (NH$_3$), Nitrate (NO$_3^-$), Nitrite (NO$_2^-$) nitrogen oxides (Nitrate and Nitrite as N) and TKN, which are discussed here. These compounds are all related to each other, and the form in which nitrogen is presented is dependent on the chemical reactions occurring in the system. The transformations that occur as part of the nitrogen cycle are reliant on bacteria and microorganisms, as well as pH and temperature (Paul 2012). Nitrification converts ammonia to nitrate, with nitrite as the intermediate product. Nitrate is considered to be the least toxic nitrogen product, whilst ammonia is the most toxic (Molleda 2007). TKN is the sum of organic nitrogen, ammonia and ammonium present in water.

The most common problem associated with excess nutrients in a system is the stimulation of growth of cyanobacteria, algae and nuisance macrophytes that thrive on the increased nutrients. This can result in a bloom of one or more of these species, which is detrimental to wetland health. Blooms affect a wetland by limiting light penetration, obstructing waterways, reducing habitat for fish and invertebrates, causing odour, resulting in diurnal fluctuation in pH and DO and in severe cases resulting in fish kills.

The most problematic issue is the growth of toxic cyanobacteria, which is damaging to human and animal health. Excessive growth of cyanobacteria is a symptom of environmental degradation, such as the loss of riparian vegetation, regulation of water flow and high nutrient discharges. Toxicity of nitrate, nitrite and ammonia is also a major problem. Nitrite is toxic to some fish as it alters the capability of haemoglobin in the blood to carry oxygen. Ammonia is toxic to biota at high concentrations, which is exacerbated by the fact that with a decreasing DO ammonia increases, placing high amounts of stress on aquatic ecosystems. High concentrations of nitrate have also been shown to be damaging to the juvenile life stages of some organisms (ANZECC 2000).

High concentrations of nutrients are expected at the start of the wet season or after flood events, when higher loads of sediments and nutrients are transported to waterways in floodwaters. Persistent high levels of nutrients may indicate point-source pollution for sewerage effluents or poor land management practices that has resulted in increased erosion (ANZECC 2000).
**Total Phosphorous**

Like nitrogen, phosphorous is a nutrient essential to wetland processes, however once concentrations become too high it creates many problems in the aquatic ecosystem. Both dissolved and particulate forms of nitrogen can be found in wetlands, dependent on pH, temperature and DO. If the ratio between P:N is altered an algal bloom can be triggered, as discussed above. The bloom will result from an influx of one of the nutrients entering the water body.

Phosphorous can enter waterways naturally through weathering and dissolution of soils in the catchment, however problems arise when artificial sources of phosphorous export excessive concentrations to water bodies, through poor land management practices, use of fertilisers and via wastewater discharges. Phosphorous pollution results in similar problems as nitrogen pollution, as listed above. Floods and rain events greatly increase the amount of phosphorous entering water from the catchment, and concentrations measured at this time are expected to be high.

**Metals**

High levels of metal in water are undesirable as they can damage aquatic ecosystems. Many metals can be bioaccumulated in organisms, and do not break down in their systems, which has implications for many trophic levels within an ecosystem. Lead reduces plant’s ability to photosynthesize, which in turn affects its ability to grow and respire. Lead is also damaging to microorganisms, and microorganisms may make lead more available to plants, which increase its uptake. High levels of lead have detrimental effects on animals, inhibiting their ability to produce red blood cells and will eventually lead to death in concentrations are sufficient. Invertebrates may accumulate lead in their systems, which in turn is damaging to organisms that consume them as a food source (Greene, 1993). Extremely high concentrations of zinc are toxic to organisms, however sublethal levels are not of a great concern and most organisms have the ability to regulate levels of zinc in their system. Zinc is highly soluble in water systems.

Zinc in interlinked with pH levels, and may be of a concern in a system where pH levels are more acidic (Besser et al, 2007).
Copper is required in small doses for many organisms, however becomes toxic at high concentrations. Copper binds easily to sediments and organic substrates, and is moderately soluble, but does not bioaccumulate in trophic levels. Fish and algae are far more sensitive to copper concentrations than other organisms, therefore its presence in water bodies is of particular concern. Copper affects the gills of fish so that they can no longer regulate salt transport, and it affects their ability to smell, which they rely on to find food, avoid predators of return to breeding grounds. Copper toxicity to fish becomes intensified in acidic waters. Copper is an algaecide, causing decreased algal growth in aquatic ecosystems. This has subsequent effects as algae constitute the base of a food chain. Insects are intolerant to copper-polluted waters, which affects fish populations reliant on them as a food source (Solomon 2009).

The toxicology of chromium is dependent of pH, temperature and salinity of the water, as well as the oxidation state of chromium. Chromium has the potential to bioaccumulate, which can have detrimental effects on an ecosystem (Velma et al, 2009).