GEOS 3018

Stormwater Pollution in the Georges River Catchment

Recommendations to the Sydney CMA

Andrew Edenborough, Chris Quill, Kyrie Tsang and Mischa Vickas

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1. Introduction

As Sydney's Georges River nears its mouth in Botany Bay, it passes the lower St George region, which is highly urbanised. Human activity leads to the release of polluted stormwater into the Georges River and its tributaries. Urban sprawl has also led to a decrease in the permeability of the land and consequently, an increase in run-off. Pollution ranges from litter to soluble nutrients and heavy metals. This pollution threatens biodiversity, poses a health risk to humans and destroys the amenity value of the river.

This report examines six sites that use different techniques in managing (or in some cases, mismanaging) stormwater pollution in the upper Georges River. Section 2 will first discuss the sources of stormwater pollution, as well as methods of source reduction by increasing public awareness. Section 3 provides an overview of the selected stormwater release sites. Section 4 outlines the treatment of water in natural wetlands and Section 5 assesses the constructed wetlands at Moore Reserve.

2. Study Area **(Andrew Edenborough)**

The issue of storm water treatment on the lower Georges River is the responsibility of local councils. In the local government areas of Kogarah and Hurstville City Council we have identified 6 different sites were stormwater is released into the Georges River. Each site has a different method of treating and releasing the storm water. The sites are arranged in order of human modification from the natural state of the site. The sites range from natural or untouched systems to heavily modified systems. Each site has a set of issues associated with it along with strengths that make it effective for the area. This section introduces the 6 sites and addresses their positives and negatives.

Our first site is a heavily modified system, Kyle Bay. Land surrounding the Kyle Bay site combines commercial, residential and recreational usage. Kyle Bay has 6 small stormwater pipes that flow directly into Kyle Bay (Figure 2.1). There is no observable measure to stop pollution and erosion from the pipes. Erosion from strong flow events is evident along with pollution stemming from unfiltered and untreated stormwater (Figure 2.2). Large pieces of paper and plastic can be seen flowing out of the pipes. This does not allow large treatment to occur. In our opinion this is the worst site, with a heavily modified system not making any attempt to filter the water and not creating an environment for the ecology of the region.

Carss Park is another heavily modified system that flows into The Georges River. It consists of a large open cement canal that is influenced by the tides (Figure 2.3). The only visible attempt to treat the stormwater is a floating net which captures large rubbish, but fails to stop dissolved sediment and pollution; this can be unsightly as is shown (Figure 2.4), with a large sludge collected at the net. The canal often gives off a noxious smell that is at odds for the surrounding expensive real estate. The canal is so heavily modified the biology of the region is almost extinct, only small fish where seen at the mouth of the canal while all plant life has been removed for surrounding land uses. An artificial wetland at the site is hypothetically possible in the park surrounding the canal but is unlikely to occur because of the sporting grounds that would be affected.

Moore Reserve Wetland is an unnatural engineered system constructed to act as a natural wetland. An in depth look at how this site works is provided in section 4. Water flowing in an underground pipe, which was initially Renown Creek, first goes through a gross pollutant trap (Figure 2.5) to catch large items before reaching the surface and entering a large sediment pool (Figure 2.6). The sediment pool allows the water to stagnate and drop suspended sediment that would otherwise enter the river. The water then travels through reeds (Figure 2.7) to removed dissolved elements in the water before going through another large pollution trap and back into a pipe to enter the river 300m away. It is evident that this system is desirable to the two previous mentioned schemes because the run off is treated before entering the river. The council's objectives of adding to the amenity value of the land as well as helping the biodiversity have been realised with many residents using the wetlands as a recreational walking destination and natural species are flourishing. The main draw back is the cost of the scheme to mimic natural settings, which cannot feasibly be paid to fix every site within a council budget.

The other three sites looked at had a large element of natural wetlands pre-existing. For an engineered scheme to be implemented the land must be available which it was in Moore Reserve but was not at the other two sites. Major issues with the site are vandalism of the educational signs around the wetland and feral animals such as foxes and cats and the high cost of maintenance (Kogarah Council 2012).

Lime Kiln Bay is similar to Moore Wetland but had a pre-existing Wetland with natural reeds and a large mangrove swamp (Figure 2.8). The City of Hurstville council has constructed 3 large sediment ponds to deal with sediment in the stormwater (Hurstville City Council 2008). Before entering the ponds stormwater travels through surface gross pollutant traps, which is unsightly and has a noxious odour (Figure 2.9). To handle a flood event there is an overflow, which bypasses the sediment ponds but is a strong orange colour (Figure 2.10). The beds of the creeks leading into the system have a strong orange colour (Figure 2.11), which may be clay or harmful metals which give them the appearance of contamination. This is an issue for water entering the system upstream but the wetlands mean this pollution does not enter the Georges River; This is covered in section 1. Due to the location of being next to the large nature reserve of Oatley Park there is strong biodiversity but vandalism of educational material was observed.

Poulton Creek catchment includes a heavily polluted creek, which flows into a mangrove swamp and an estuary before entering the river. Section 3 covers the workings of natural wetlands in depth. An underground gross pollutant trap has been installed before the creek surfaces from pipes. The creek is visibly heavily polluted with an orange sludge evident along with oil-based pollution sitting on the water (Figure 2.12), which is murky and has a pungent smell. The water quality is not treated until it reaches the rehabilitated mangrove swamp, which is 1 kilometre downstream. The creek flows through bushland that is overrun with introduced Flora and Fauna. The mangrove swamp has been rehabilitated from a state of being heavily polluted, which initially resembled a tip, to a thriving forest (Figure 2.13), which is used as an example of environmental management and education for schools. The estuary acts as a natural sediment pond (Figure 2.14), naturally achieving what costs millions of dollars at Moore Wetland and Lime Kiln Bay.

The Last site is almost untouched in terms storm water treatment. Myles Dunphy Reserve is heavily infested with invasive weed species while the wetlands, which flow through, give of a noxious odour. The orange sludge is observed as well as large amounts of the oily pollution on the surface of the stagnant water (Figure 2.16). A Mangrove forest provides the only water treatment but is a fraction of the size of Poulton Creek or Lime Kiln Bay. Illegal dumping is another major issue which affects the uncontrolled system.

First-hand observations of the six sites as referred to in Section 2

Figure 2.1: The stormwater release pipes at Kyle Bay

Figure 2.2: Pollution at Kyle Bay

Figure 2.3: The Carss Park Canal

Figure 2.4: Pollution at the Boom net at Carss Park

Figure 2.5: The underground gross pollutant trap at Moore Reserve, identical to the Poulton Creek gross pollutant trap.

Figure 2.6: the sediment pond with wildlife (ducks) swimming on the artificial pond.

Figure 2.7: the reeds at Moore Reserve.

Figure 2.8: The Natural wetlands at Lime Kiln Bay, looking towards the mangrove swamp.

Figure 2.9: the surface gross pollutant trap at Lime Kiln Bay.

Figure 2.10: The orange coloured by-pass at Lime Kiln Bay.

Figure 2.11: Visible pollution at Lime Kiln Bay, identical to Poulton Creek and Myles Dunphy Reserse.

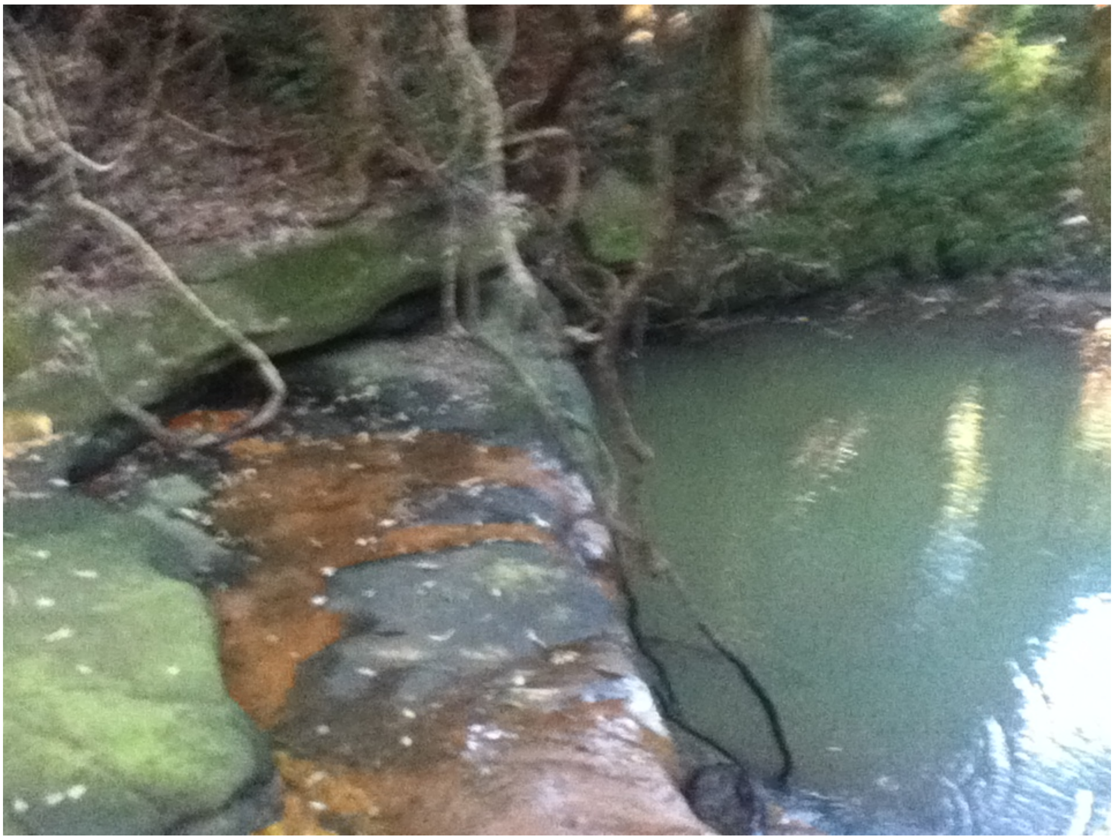

Figure 2.12: Pollution at Poulton Creek

Figure .13: The Rehabilitated mangrove forest

Figure 2.14: The Estuary

Figure 2.15: Stagnant and polluted water surrounded by weeds at Myles Dunphy Reserve.

3. Source reduction of urban stormwater pollution (Kyrie Tsang)

3.1. Sources of stormwater pollution

Based on field observations and the photographic evidence collected, it was clear that the majority of land-use surrounding the Georges River catchment was urbanised (see Figures 3.1.1, 3.1.2 and 3.1.3). In order to help manage stormwater the general public need an awareness of the issues of stormwater borne pollution; where it originates, how it is transported into the Georges River, the contaminants that are transported by it, and how these affect the Georges River and its biodiversity. If communities are made aware of all these factors they can make more informed and responsible decisions about the use and disposal of potential stormwater contaminants in urban environments.

Figures 3.1.1 (left) and 3.1.2 (right): Examples of urbanisation in Georges River catchment (Source: Kyrie Tsang)

Stormwater is a diffuse or non-point source pollutant. As such it is hard to identify where the pollution is coming from, in most cases it is coming from multiple sources simultaneously. Land-use type is a way to generalise the origin and types of stormwater pollutants. The majority of the land around the Georges River is heavily urbanised. With an estimated 77% of contaminant loading coming from urban stormwater, it has been described as the primary source of pollution in Australian waterways (Williams 1996).

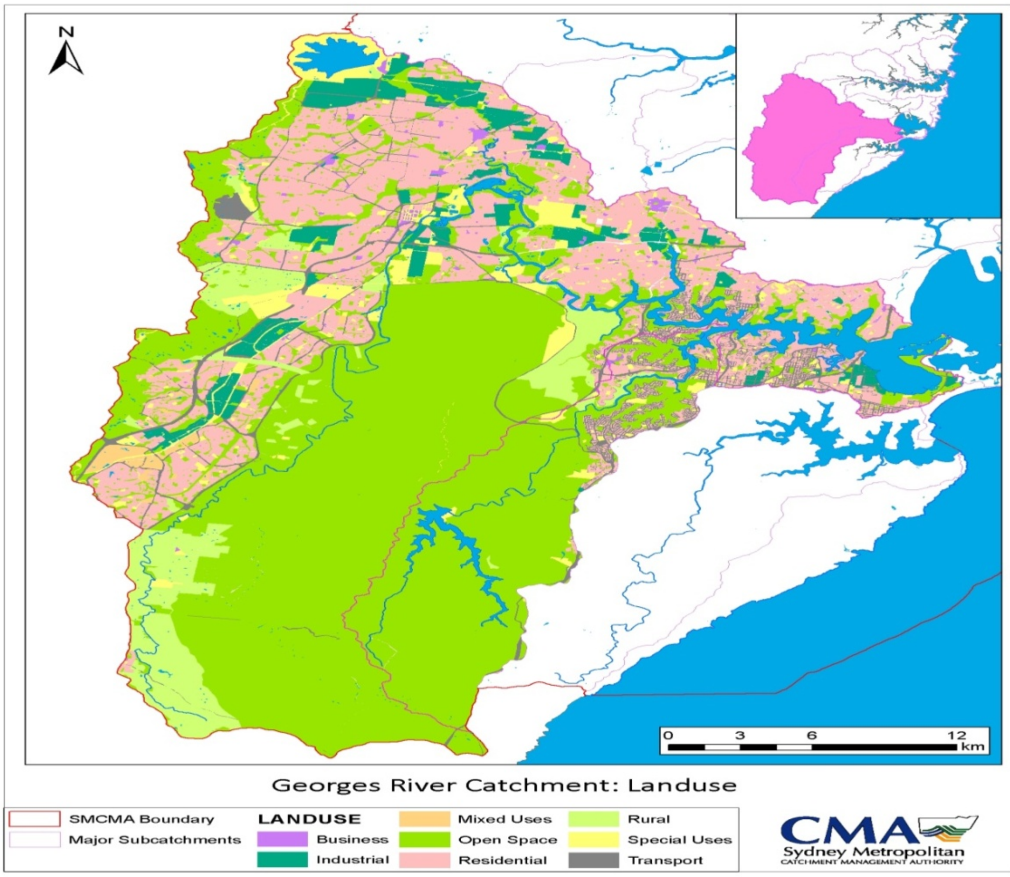

Figure 3.1.3: Land use in the Georges River catchment (SMCMA)

Urban stormwater is defined as runoff from urban areas. Rainfall picks up macro and micro contaminants from surfaces and transports them into waterways. Changes from natural landscapes to an urbanised landscape have led to a decrease in rainfall infiltration and consequently higher runoff from roads and other sealed surfaces. Many factors influence the amount of stormwater transported and the quantity of contamination it contains; such as duration and intensity of rainfall, proportion of impervious surfaces, geomorphology, land use, and design and management of stormwater systems (DEH, 2002).

The types of contaminants picked up by stormwater include suspended solids, nutrients, oxygen demanding materials, micro-organisms, toxic organic compounds, heavy metals, oils, and litter. Some common sources of these contaminants in the urban environment are from households. Heavy metals such as lead can be found in piping in old houses and lead based paint. Paints are also known to contain antimony, cadmium, and mercury. Disinfectants may contain mercury and copper. Insecticides and fungicides contain arsenic, antimony and cadmium (GURUM, S.2009). Anthropogenic sources of nutrients such as nitrogen include human and pet wastes, and also some fertilisers. Phosphorous is also found in most fertilisers (NOAA, 2012). Sediment is transported into the Georges River from construction, landscaping, or other human activities that leaves land cleared. Erosion rates from natural environments such as parkland is typically less than 1 ton/acre/year, while erosion from construction sites average around 7.2 to 500 tons/acre/year (EPA).

Some of the affects pollutants have on the Georges River and on its biodiversity are suspended sediments in runoff which have adverse effects on river water quality such as excessive biological growth caused by nutrients in the soil and increased turbidity. Furthermore transported sediment can build up in rivers and lower flow capacity, alter flow regimes and increase flood risk. An example of this is seen between Sandy Point and Alfords Point with sediment from the ridges washing into Mill Creek and then into the Georges River. Nutrients such as nitrogen and phosphorus act like a fertiliser and can cause algal blooms which feed off the excess nutrients. Microorganisms then feed off dead algae. The increased microbial activity causes increased turbidity and reduces the amount of dissolved oxygen in the water. This process is known as eutrophication. Eutrophication can cause harm to fisheries, recreation and public health (NOAA 2012). Heavy metals and pesticides that are washed into the Georges River can accumulate in the food chain. Smaller organisms will take up contaminants through respiration, the epidermis, and food intake. As the contamination moves through the food chain it bioaccumulates. This increased concentration of heavy metals such as cadmium and mercury, and pesticides, can be detrimental to the health of ecosystems and humans (Biology Online 2006).

3.2. Pollution reduction through public awareness

Mitigation or source reduction practices aim to reduce the amount of contamination in urban stormwater. Urban residential areas produce the largest percentage of stormwater pollution; therefore, public awareness is essential for managing contamination. Responsible use and disposal of household chemicals needs to be promoted. Household chemicals are not as regulated as industrial chemicals and safe storage and disposal is therefore dependant on individuals behaving responsibly. Improper storage, use, and disposal of household chemicals - paints, pesticides, cleaning agents, and automobile fluids - can lead to contaminated stormwater. The three main pathways of household chemicals getting into waterways are leaks and spills, improper use, and improper disposal.

Leaks and spills can be caused by improper storage of chemicals or leakage from poorly maintained automobiles, machinery, and faulty containers, and can accumulate on surfaces and be carried by runoff into rivers.

Improper use of chemicals, for example, not following the instructions provided with products, can lead to over application of chemicals such as fertilisers and pesticides in gardens. This can lead to accumulation in the soil and vegetation, which can enter waterways through groundwater leaching or in stormwater.

Improper disposal of household chemicals, for example, pouring unwanted products down drains, into gutters, and onto gardens can lead to river contamination. Drains and gutters often discharge straight into the river or ocean with no treatment. Chemicals that reach treatment plants can kill the microbes which are processing effluents and disrupt the treatment cycle. Chemicals disposed of in gardens can seep into the groundwater table or be transported by runoff (EPA).

The general public can make a difference by following some easy guidelines: Always read and follow product instructions to avoid over application of chemicals and fertilisers. Store and dispose of chemicals as instructed. Have automobiles and machinery serviced regularly to avoid leakage. Correct disposal of pet wastes (as stipulated by local councils) to reduce nutrients transported into waterways. Reduce activities that produce general waste and be conscious and responsible when buying household chemicals. There are many companies which produce eco-friendly everyday household products (EPA).

4. Natural Wetlands (Christopher Quill)

A wetland is an area that is covered with water for a period long enough each year such that its ecosystem characteristics are dependent on this water. A wetlands key feature is that of its hydric soils and hydrophytes (Verhoeven, J, T, A and Meuleman, A, F, M 1999). The region wetlands of The Lower Georges River being investigated in this report comprise of estuary wetlands, which occur when salt water and fresh water are converging on a river (Kogarah City Council 2010). Historically wetlands have been undervalued and converted into other uses over the past 200 years of European development. In Australia, approximately 50% of natural wetlands have been destroyed since 1788 (Department of Environment, Climate Change and Water NSW 2011). Fortunately society has acknowledged wetlands importance in the past 60 years and they have been widely protected and NSW government have identified them as a key area of protection and of rehabilitation.

4.1 Benefits of using natural wetlands to treat urban pollution

Natural wetlands are important in many areas, although this section of the paper will focus on the areas concerning the ability of wetlands to act as a treatment of the negative effects of storm water discharge within the Lower Georges River through the case studies of the natural storm water treatment wetlands of Poulton creek in Oatly Bay, Lime Kiln Bay and Myles Dunphy reserve in Gungah Bay (see section 3). Wetlands are an important defence against the damages of urban stormwater in number of ways, and provide further benefits, including:

- **Water purification**
- **Prevention of erosion**
- **Hubs of biodiversity**

Water Purification: Natural wetlands produce biofilters, hydrophytes and organisms that have the ability to remove toxic substances from waterways. This process is predominantly achieved through hydrophytes which are absorb and 'store' pollutants such as phosphorous, nitrogen, metals and further substances in the insoluble plant biomass. One of the most successful and common hydrophytes which performs that process are mangroves. Mangroves are present in the 3 natural wetlands examined and a number of other wetlands in the lower catchment. It is well established that that water flowing through mangrove forests and similar vegetation can result in 90% reductions in nitrate concentrations and reduced levels of phosphate, which can lead to algal blooms in high concentrations (Gilliam. J. W 1993) (Nichols, D, S 1983). The vegetation present in the wetlands in the Georges River further act as a trap for larger gross pollutants such as leaves and litter coming from storm water drains and prevent litter escaping into waterways.

Prevention of erosion: Wetlands in the lower Georges River provide further benefit in their reeds and grass stuff acting as a barrier to the movement of sediments such as sand and clay being carried out into the waterways of Botany Bay during heavy rainfall. Further the roots of the vegetation hold the soil together which otherwise would be eroded away by the velocity of the water emerging from the storm water drains as in Kyle Bay (see section 2).

Hubs of biodiversity:

Wetlands are considered to be the most biologically diverse of all ecosystems, acting as a habitat for innumerable flora and fauna. The estuary wetlands in the Lower Georges River are no different (Goodall, H. et al 2010). The dominate mangrove forests provide habitat for huge numbers of crabs, oysters, barnacles and fish, while frit bats feed on the flowers (Kogarah City Council 2010). Seagrasses act as a nursery for many native fish including mollusks, mullet, tailor and bream. Over 70% of all fish caught globally breed in estuary wetlands, although fishing and oyster farming in the lower catchments of the Georges River have been banned due to pollution levels (SSEC 2008). This provides further benefit of wetlands in the Georges River

4.2 Comparison of different natural wetlands treatment success

The three identified natural wetlands in the Lower Georges River exhibit similar vegetation make up but they differ quite significantly from each other in size and human management, affecting their successfully treat the urban pollution.

Poulton creek:
A large, natural, rehabilitated and managed managed system. The wetlands show success in treating nutrient levels in the water and increasing levels of dissolved oxygen. This is evident in improvements in visual water quality and smell between the creek and the mangrove forest (see section 2 and figure 2. 13). The smell is a symptom of low levels of dissolved oxygen in water which results in excessive anaerobic decomposition which releases the foul smelling hydrogen sulfide gas (Nichols, D, S 1983).

Myles Dunphy Reserve:
A small, natural, unmanaged system. The wetlands show a failure in treating the polluted storm water before it reaches the river (see section 2 and figure 2.15). This is exhibited through the consistent smell throughout the river.

Lime Kiln Bay:
A large, natural/constructed and managed system (see section 2 and figure 2.8). The wetlands exhibit success in treating the polluted storm water before it reaches the river. Exhibited in the lack of litter and reduction in colour and smell of the water

The reason for these differences is that here is a threshold to the amount of pollutants a system can absorb. High levels of urban pollutant above this level cause eutrophication and deterioration of fauna (Carleton, J, N. et al 2000) (Ramsar convention on wetlands 2011). Myles Dunphy Reserve is experiencing this overloading as a result of the areas limited size and number of mangroves to treat the water. Further the system is not managed and protected from invasive species; as a result weeds including lantana have chocked the system (Oatley flora & fauna conservation society, inc 2012). Poulton creek is able to clean the water with overloading due to its extensive size. Lime Kiln Bay is also able to do so due its similar size and the additions of constructed ponds and leachate traps (see figure 2.9) (Hurstville City Council 2008) (see section 5). These findings highlight that natural wetlands cannot be expected to treat urban storm water without additional support.

5. Stormwater treatment using constructed wetlands: Moore Reserve (Mischa Vickas)

The physical, chemical and biological processes that occur within natural wetlands (as described in Section 4) can be mimicked within an artificial setting to allow for the controlled treatment of urban stormwater. Trials of this technique began as early as the 1950s in Germany (Vymazal 2010) and constructed wetlands have been used in North America for over 30 year (Kadlec 2003). This section describes and assesses the application of this technique at Moore Reserve in Kogarah, Sydney, within the Georges River catchment.

5.1. Features and function of constructed wetlands

Pond:

Within the pond, ionic pollutants are adsorbed onto the surface of colloidal (microscopic) organic matter before undergoing sedimentation with other particulates. In this regard, the pond is regarded as a pollutant sink (NSW EPA 1997).

The pond is also the site of biological and chemical processes. Microorganisms oxidise organic matter to decompose it into simpler molecules such as water and carbon dioxide. Metal ions can also be reduced to an insoluble form, allowing for sedimentation. The pond surface also provides an area for disinfection through UV exposure of pathogens.

Wetland:

The wetland is a permanently inundated, yet shallow body water containing dense vegetation, mostly reeds. The vegetation is responsible for the biological uptake of pollutants, such as phosphorous, nitrogen and metals, from the saturated soil or directly from the water. This secures pollutants in the form of insoluble plant biomass. The plant surface also provides a surface for pollutants to adsorb onto, producing a bio-film.

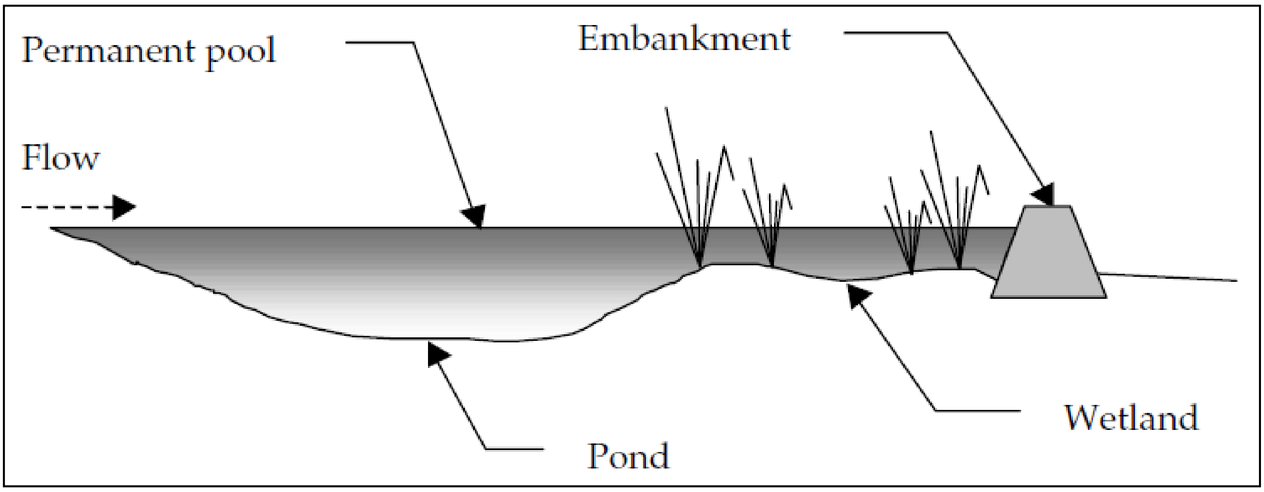

Figure 5.1: Simplified layout of a constructed wetland (NSW EPA 1997)

5.2. Moore Reserve, Kogarah

Moore Reserve contains a 2 km^2 constructed wetland that treats stormwater from 2% of the Georges River catchment (Dalby-Ball and Olson 2011). Treated stormwater is discharged into Oatley Bay.

Moore Reserve can be considered a multi-purpose system. A well as providing stormwater treatment, it also serves as a public amenity and habitat for flora and fauna. This effectively improves benefits relative to the cost of construction and operation of the system. This, however, also gives rise to competing interests. For example, the Reserve's car park, an important feature encouraging public use of the Reserve, was formerly the site of Mangroves, which could have otherwise been used as part of the stormwater treatment system.

5.3. Results of 2011 assessment and recommendations for wetland improvement

A major assessment of the wetlands was conducted in 2011 (Dalby-Ball and Olson 2011) by Dragonfly Environmental at the request of Kogarah Council. This assessment showed that vegetation cover has decreased substantially since 2004 from 70% to as little as 5%. This is evident from a comparison of aerial photographs (see Figure 5.3.1). Vegetation reduction represents a significant loss in productivity of the system. In response, the assessment recommended revegetation to restore macrophyte cover to at least 30% and the creation of more shallow marsh areas (< 30cm) to encouragement vegetation growth. Kogarah Council undertook revegetation of the Reserve in 2011 involving 400 large (8-inch) aquatic plants and 9600 seedlings. 30% of wetland area was revegetated according to Tom Heath, Catchment Management Officer at Kogarah Council (in an e-mail correspondence during May 2012). This is supported by first-hand observations made in April, 2012 (see Figure 5.3.2 and 5.3.3).

Important findings from water testing are summarised in Figure 5.3.4 below.

Column1	**Inlet**	**Outlet**	**Change at outlet relative to inlet (%)**
Total Nitrogen (mg/L)	0.8	1.1	+38
Total Phosphorous (mg/L)	0.05	0.07	+40
Faecal Coliforms (FCU/L)	4000	12000	+300
Pesticides (mg/L)	<1	<0.1	-90
Arsenic (mg/L)	10	10	0
Chromium (mg/L)	19	17	-11
Copper (mg/L)	100	48	-52
Lead (mg/L)	110	74	-24
Mercury	0.2	<0.1	> -50
Nickel (mg/L)	14	14	0
Zinc (mg/L)	450	250	-44
Cadmium (mg/L)	<0.5	<0.5	-

Figure: Results of water quality testing conducted at Moore Reserve on March 7, 2011 (Dalby-Ball and Olson (2011)

Figure 5.3.1: Aerial photographs showing vegetation cover in 2004 (top-left), 2007 (top-right), 2009 (bottom-left) and 2011 (bottom-right). A progressive loss of vegetation can be seen (Dalby-Ball and Olson 2011)

Figures 5.3.2 (left) and 5.3.3 (right): Examples of first-hand observations made in April 2012 showing evidence of revegetation (Source: Andrew Edenborough)

Reductions in most toxic heavy metals in both water and sediment are a promising sign. Nonetheless, levels of most heavy metals were above recommendations, as will be discussed later. Testing also revealed reductions in pesticide content of the water at the outlet.

Dissolved oxygen was below recommended levels at all tested sites. Low dissolved oxygen is unfavourable for aquatic fauna and may lead to excessive anaerobic decomposition and consequent release of foul-smelling hydrogen sulphide gas. Furthermore, total nitrogen and phosphorous in the water (pollutants that can cause algal blooms) increased upon water entered the wetlands. Turbidity was within recommended levels at inlet and outlet sites, indicating effective sedimentation of particulates in the system. Sustained removal of pollutants is best achieved through regular revegetation and maintenance of existing vegetation.

Faecal coliform levels were three times higher at the outlet than at the inlet. This is likely as a consequence of droppings from birds entering the water. Heath regards this as a "Catch 22"; the encouragement of biodiversity, often a positive step towards general wetland health, may also have adverse water quality impacts. This is again an example of competing interests due to the multi-purpose character of the system. It is important to find an appropriate balance between these interests, for example, by avoiding over-encouragement of bird life.

Sub-surface sediment showed similar trends as water quality. Sediment should not currently be disturbed to avoid release of heavy metals and other pollutants back into the water. Sediment is, of course, continually added to the system from stormwater, and removal may be necessary if the system shows signs of poor health (Dalby-Ball and Olson 2011, p. 25).

5.4. Critique of 2011 assessment

Pollutant recommendations referred to in the assessment were sourced from the Australian and New Zealand Environment Conservation Council (2000). However, guidelines refer to natural wetlands and not constructed systems. As such, authors of the assessment may have had too-high expectations for water and soil quality at Moore reserve as its primary purpose is to treat urban stormwater, that is, it is *inherently polluted*. This suggests that a new set of guidelines may need to be adopted in future assessment that is a more realistic indicator of the performance of a constructed system used for this purpose. Furthermore, more emphasis may need to be placed on reducing pollution sources (See Section 1) if water quality at Moore Reserve is to meet recommendations for natural wetlands.

According to Heath, assessment conducted during the 2011 had low replication because in-field measurements of water and sediment quality were conducted on only one day. As the authors highlight, results from the assessment should not be considered as a definitive indicator of the system's health and performance; the assessment was considered a "snap-shot" of the system. Further assessment should be undertaken to isolate the *causes* of poor performance areas. This should involve testing at different times of day and year, as well as greater replication.

6. Conclusion

Heavy urbanisation of the Georges River catchment and consequent discharge of polluted stormwater into waterways has created issues in both human and non-human environments. An examination of six different sites around the catchment has revealed cases of stormwater mismanagement, specifically, the discharge of untreated stormwater through pipes and channels, as well as neglect of natural wetlands. A phasing out of these practices is required to ensure long-term sustainability of stormwater management. Nonetheless, examples of proper management have been found at sites of constructed wetlands and restored natural wetlands. Although these methods may be costly and maintenance-intensive, they represent a more sustainable alternative to past practices.

It is recommended that the Sydney Catchment Management Authority develop a long-term plan to a) retro-fit existing stormwater pipes and channels with simple pollutant traps b) rehabilitate degraded wetland sites identified at Lime Kiln Bay, Poulton Creek and Miles Dunphy Reserve and c) continue vegetation maintenance and conduct thorough water quality monitoring at Moore Reserve.

Ultimately, the treatment of stormwater will be an inefficient exercise if source-reduction of pollution is not addressed, requiring public education about responsible water use. This may include school-based education programs, such as those conducted at Poulton Creek.

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