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Evaluating performance and effectiveness of water sensitive urban design

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ABSTRACT

Water Sensitive Urban Design (WSUD) is something of a catch-all term for environmentally sustainable water resource management in urban areas. Water sensitive urban design offers an alternative to the traditional conveyance approach to stormwater management. It seeks to minimise the extent of impervious surfaces and mitigate changes to the natural water balance, through on-site reuse of water as well as through temporary storage. By integrating major and minor flow paths in the landscape and adopting a range of water sensitive design techniques, the size of the structural stormwater system required can be significantly reduced. WSUD techniques include detention and retention basins to lower peak flows, grassed swales and vegetation to facilitate water infiltration and pollutant filtration. WSUD has been adopted widely in Australia and is being implemented in varied local government areas. The major challenge to the success of WSUD is however its measure of effectiveness over the life cycle given that it demands high maintenance. The aim of this paper is to provide a snapshot of effectiveness of WSUD implemented in Kogarah Municipal Council using two case studies and presents results on improvement in water quality through both site specific and water quality monitoring of the bays.

Keywords: Water sensitive urban design; Urban stormwater quality; Catchment runoff

1. Introduction

As a result of growth in urban areas, urban stormwater represents a significant component of catchment runoff, constituting a significant underutilized resource at this time, while potentially impacting adversely on water quality and ecology of regional waterways. A number of pollutants are typically found in urban stormwater runoff. These pollutants originate from either point or non-point sources. Point sources are specific identifiable locations where stormwater pollution can occur, for example, illegal discharges of trade wastes and sewer overflows. Non-point sources or diffuse sources, are more general, and are comparatively difficult to identify and control—include litter, sediments, nutrients, oils and grease from road surfaces, toxic material, bacteria and organic material. Without appropriate stormwater treatment devices, the resulting impacts on receiving waters can be devastating, not only for aquatic ecosystems but also to community values such as aesthetics, recreation, economics and health of receiving water bodies.

Water sensitive urban design offers an alternative to the traditional conveyance approach to stormwater management. It seeks to minimise the extent of impervious surfaces and mitigate changes to the natural water balance, through on-site reuse of the water as well as through temporary storage. By integrating major and minor flow paths in the landscape and adopting a range

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of water sensitive design techniques, the size of the structural stormwater system required can be reduced. These techniques include detention and retention basins to lower peak flows, and grassed swales and vegetation to facilitate water infiltration and pollutant filtration.

An integrated approach to stormwater management is the key to water sensitive urban design. This integrated approach regards stormwater as a resource rather than a burden and considers all aspects of runoff within a development, including implementation of water quality/quantity controls, maximize water resuse/conservation and preservation of amenity and environmental values within the catchment.

2. Water quality issues in Kogarah

Kogarah Local Government Area is located approximately 14 km to the south of Sydney City centre. In recent years water quality in the Kogarah LGA, and the Georges River as a whole, has deteriorated at an alarming rate. Georges River is currently in crisis following the collapse of oyster and fishing industries along the river. Seagrass beds are extinct and fishing has been banned due to the toxic chemical residues in fish and river sediments.

Sediment build-up in the local waterways, such as Kogarah Bay, Connells Bay (see Fig. 1) and Kyle Bay, has become a major environmental issue threatening the local natural aquatic habitats economy and community's health.

As actions are required to improve the water quality Kogarah Council has introduced water quality management plans, strategy and community programs aiming to work with local residence to reduce waste and stormwater pollutants discharging into the waterways. Council has recently undertaken a number of water quality improvement projects as part of its Estuary Management Plan in 2005–2008 to improve water quality in the bays. Some significant water quality improvements have been completed in Kyle Bay, Connells Bay and Shipwrights Bay area of the LGA and two of them are presented as Case Studies in Section 3 of this paper.

The Georges River Watchers group is part of the Council's *Water Quality Management Strategy* which collects monthly water samples at varied sites within the LGA, see Fig. 2.

Results from the monitoring program are currently being used to monitor the success of varied Water Quality Improvement projects implemented recently in the LGA including the two case studies presented in this paper.

3. Case studies

Two case studies are presented for WSUD projects implemented within Kogarah Council local government area. The effectiveness of the WSUD are also presented based on results of water quality monitoring conducted both at sites and downstream of the treatment system at outlets to the bays.

3.1. Connells point reserve WSUD

Connells Point catchment is approximately 57 hectares of residential land (66%) and Parks/Open space (34%) drains into Connells Bay. The ground slopes are mild to steep with an average of 4.4%. The shoreline of the bay is highly developed and little natural vegetation remains. The catchment (Fig. 3) is predominantly low density residential and no ongoing significant redevelopment in the zone.

Flooding was a recurring problem at Connells Point. Complaints regarding flooding of properties in Murdoch Crescent, Terry Street, Connells Point Road and Wisdom Street have been well documented at Council for over 15 years. Investigation into the catchment hydrology and hydraulics revealed inadequate capacity of two

Fig. 1. Sedimentation at connells bay, kogarah.

Fig. 2. Water quality monitoring sites.

outlets in carrying flows into the bay. A combination of high tide and heavy rains cause major flooding in the catchment. There were also problem of ongoing siltation at Connells Bay that impacted the water quality and recreational values in the bay.

The key objectives of this project were to:

- Decrease flooding that affected a number of residents in the area. This project was envisaged to mitigate recurring flooding problems in the area due to inadequate capacity of the stormwater drainage and tidal influence. Council through its intensive hydrologic/hydraulic modelling proposed number of options to community for mitigation of flooding. Following consultation, preferred solution accepted by community was diversion of the stormwater through the reserve from drainage pipe on Terry Street.
- Treat stormwater to reduce sediments and other pollutants entering the bay. The residents had brought this issue to Council's attention time and time again. Prior to the project's implementation, stormwater was discharged into Connells Bay without any treatment, causing siltation of the Bay. Stormwater outfalls situated at Connells Point Reserve had its opening beneath the tidal line. This caused sand to settle inside the pipe when the tide goes in, and the pipe often used to get blocked.
- Improve recreational and educational activities in the reserve without impacting on existing park facilities. Community concerns were that the stormwater design should be underground and blend with the natural look of the bay.

The final design incorporated underground stormwater treatment system that conveys and treats stormwater up to tertiary level and mimics the natural drainage of the area. This is a unique design that surpasses not only the water quality and drainage standards but also does not compromise the recreational use of the park. Retaining recreational use of the park was a major requisite demanded by the local community.

The treatment train comprises of gross pollutant trap (Primary treatment), low flow up to tertiary treatment (6 month ARI) through bio-retention trench and surcharge of high flows through the nature reserve from two surcharge pits (see Fig. 4). A number of litter trap inserts were also used within stormwater pits on the road for preliminary treatment before discharging into the gross pollutant trap.

The unique approach in design is the separation of low and medium flows through stormwater outlet and dissipation of high flows through the Connells Point Reserve. Low flows were treated in the bio-retention trench (0.69 m^3/s, 6 month ARI storm event), Medium flows upto 1 year ARI were conveyed through a unique bypass arrangement within the bioretention trench consisting of Atlantis matrix cells, High flows, upto 20 year ARI (2.5 m^3/sec) were dissipated through two surcharge pits within the reserve.

The Atlantis matrix cells act as a culvert, collecting and directing water to the concrete box culvert, which is

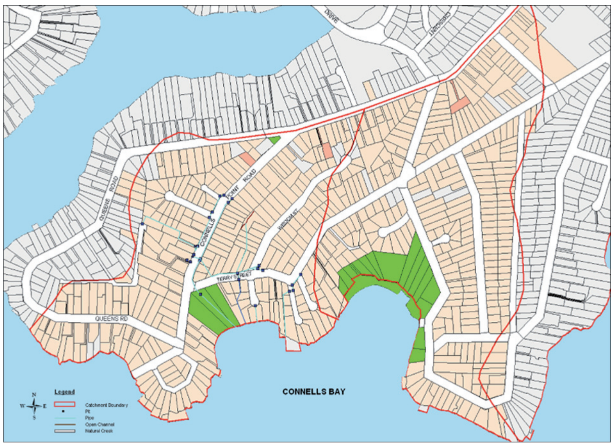

Fig. 3. Connells point catchment.

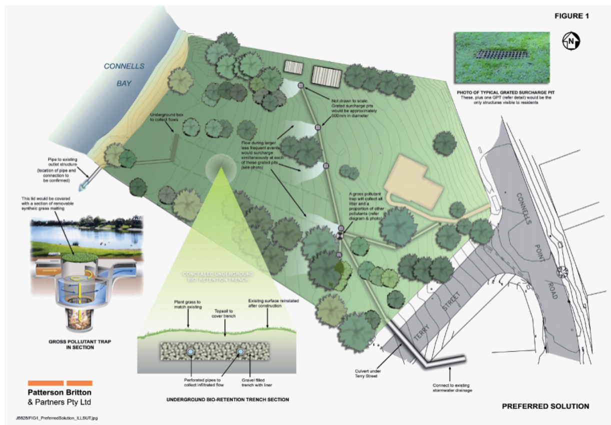

Fig. 4. Water sensitive urban design for stormwater treatment.

the outlet. The Atlantis matrix cells also allow for additional infiltration up until the concrete box culvert and provide some filtration as they are also wrapped in a geotextile fabric.

3.1.1. Gross pollutant trap

CDS vortex gross pollutant separation devices by CDS technologies, Australia were used at Connells Point. CDS Gross Pollutant Traps are an offline treatment unit with an offline storage sump. The offline treatment function ensures that the flows to be treated are only the flows entering the screening chamber of the unit. During periods of high flows in excess of the design flows, water overflows the fixed weir in the diversion chamber preventing disturbance and re-suspension of material already trapped in the sump. CDS gross pollutant traps are effective in removing gross pollutants and coarse particles greater than 2 microns [1].

3.1.2. Bio-retention trench

A bio-retention trench is a shallow, excavated trench filled with gravel or sand lined with geotextile fabric into which stormwater runoff drains. Stormwater enters the trench and undergoes a filtration process where particulates and some dissolved pollutants are retained in the trench and then the treated, runoff the exfiltrates from the trench [2].

Bio-retention systems generally provide the following functions as highlighted in [2]. Removing sediments and attached pollutants by filtering through surface vegetation, ground cover and underlying filter media, and delaying runoff peaks by providing retention capacity and reducing flow velocities.

The size and grading of the gravel was determined to achieve the desired removal efficiency of pollutants. The entire trench was filled with coarse sand with grading D_{10} 2 mm and D_{90} of 5 mm (10% larger than 5 mm and 10% smaller than 2 mm) and the entire trench was covered in geotextile. The flows were dissipated through series of slotted subsoil drains wrapped in geotextile within the trench.

Atlantis matrix cells wrapped in geotextile were used for collection of treated filtrate and act as flow bypass within the infiltration trench. Three per cent cross gradient was provided within the infiltration trench to drain flows towards the Atlantis matrix cells which discharged through a culvert into the bay.

3.1.3. Hydraulic modelling

The design was thoroughly tested using hydraulic models to achieve the desired flow levels in the diversion chamber for segregation of flows and for the design of the treatment units. Also, the surcharge through the pits in the reserve had to be designed in a way to achieve approximately equivalent flow depths in the reserve to avoid localised ponding. XP-Storm software [3] was used for testing the hydraulic design.

3.1.4. Water quality modelling

The design for water quality through the stormwater treatment was achieved using MUSIC model [4]. MUSIC is the Model for Urban Stormwater Improvement Conceptualisation and was developed by the Cooperative Research Centre for Catchment Hydrology, Australia.

MUSIC provides the ability to model stormwater quality and quantity for catchments of varying sizes, from single house blocks through to large catchments. The modelling program has a variety of inbuilt treatment measures and has the capacity to model anything from one structure through to treatment trains and distributed treatment measures.

The NSW EPA Publication, Managing Urban Stormwater: A Council Handbook, Environmentally Sustainable Development (ESD) objectives were used for design of stormwater train [5].

The results of MUSIC modelling predicted the following removal efficiencies for the stormwater train (see Table 1).

3.1.5. Monitoring results

The construction commenced in June 2005 with timeframe of 18 weeks and completed in late September 2005.

Table 1
MUSIC modelling results.

Pollutants	Existing loads (kg/year)	Loads after treatment (kg/year)	NSW EPA treatment objectives[a] % removal	MUSIC modelled[a] % removal
Total suspended solids	13,200	2,520	80%	81%
Total phosphorus	24	12.7	45%	47%
Total nitrogen	188	98	45%	48%

[a]Annual pollutant load in kg/year [5].

Fig. 5. Panoramic view of the park showing location of stormwater treatment.

A monitoring program is currently established to monitor the water quality of the Connells bay post development. A panoramic view of the park (see Fig. 5) shows the location of the underground stormwater treatment. The photo shows the area is aesthetically pleasing with recreational values of the park totally preserved after construction.

On site monitoring was conducted at the outlet of bio-retention trench near the bay for recent storm events in October 2006. A number of samples were collected for storm event lasting over 6 h duration. Sampling of the inflows to the stormwater treatment train was not possible due to limited resource and site constraints.

A number of heavy metals and organic matter in the treated water were also analysed, but only the design parameters are discussed. It appears that the concentration of suspended solids, total nitrogen and phosphorus are well below the design criteria set by Australian and New Zealand Environment and Conservation Council [6]. The results of sampling are given in Table 2.

Based on the Australian and New Zealand Environment and Conservation Council (ANZECC) guidelines, 2000, the following trigger values (see Table 3) have been identified as applicable to the Connells Point catchment.

The analysed samples indicate values for both pH and turbidity to be well below trigger values identified and the majority of heavy metals tested were in concentrations below testing capabilities.

The results show that bio-trench is effectively removing the nutrients discharging into the bay. There is significant reduction in sediments and nutrients that will improve the recreational value of Connells Bay.

3.2. Shipwrights bay WSUD

The Shipwrights catchment (Fig. 6) is approximately 59 hectares of special use (52%), residential land (37%), and Parks/Open space (11%) that drains into Shipwrights Bay. The catchment is the area bounded by Terry Street to the North, Princess Highway to the East, Castle Street to the West, and Coogarah Street to the South. The catchment consists of mostly rocky cliffs on the western side and the other end of the bay near Tom Ugly's bridge is used extensively for commercial uses such as hotels and marinas.

Currently the stormwater pipes that discharge in the northern and western parts of the reserve contribute to the seepage of nutrient rich stormwater into the normally dry sandy soils of Shipwrights Bay Reserve and promote weed invasion.

Between 2005–2006, Kogarah Council investigated strategies to reduce the sediment and nutrient loads to the bay. The most viable measure was the construction of stormwater treatment train that included rehabilitation of the creek, constructed wetland and stormwater treatment devices as pre-treatment, see Fig. 7.

Constructed wetland systems are shallow, extensively vegetated water bodies that use extended detention, fine filtration and biological pollutant uptake processes to remove pollutants from stormwater. Wetlands generally

Table 2
Sampling results.

Pollutant	Maximum	Minimum	Median	Modelled catchment EMC[a]	Potential removal rate %
pH	7.16	7.02	7.1	–	–
Total phosphorus (mg/L)	0.09	0.01	0.04	0.25	64–96%
Total nitrogen (mg/L)	0.21	0.13	0.15	2.0	90–94%
Turbidity (NTU)	2.85	2.67	2.72	120	98–99%

[a]EMC = Event Mean Concentration Ref: Australian Runoff Quality, 2005.

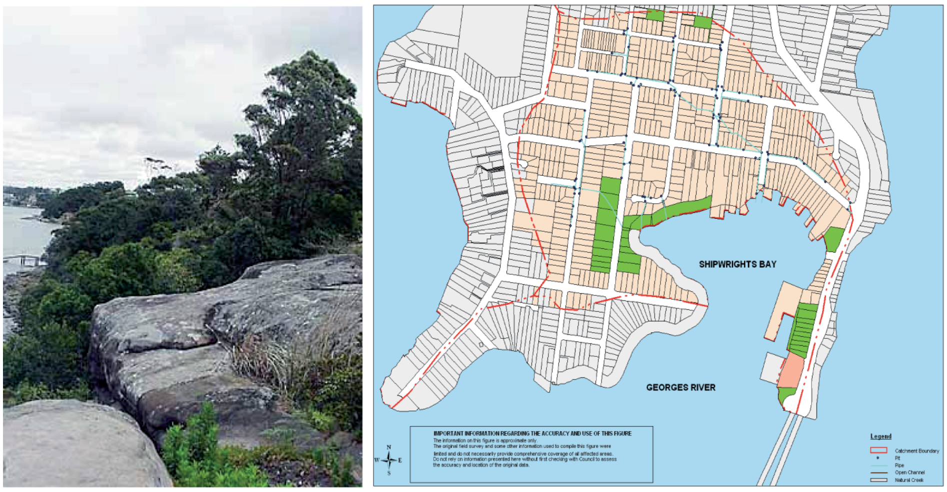

Fig. 6. Shipwright bay catchment.

Table 3
Trigger values for water quality monitoring.

Pollutant	ANZECC trigger value
pH	Lower trigger value –6.5 Upper trigger value –8.0
Turbidity	Trigger value between 6 and 50 NTU

consist of an inlet zone (sedimentation basin), a macrophyte zone and a high flow bypass channel.

The macrophyte zone generally has an extended detention depth from 0.25 m to 0.5 m, specialist plant species (depending on the desired operation and target pollutant) and a notional detention time of between 48 and 72 h. The pollutant removal process is through solubilisation of nutrients and uptake by plants within the wetlands. Pre-treatment is required for removal of gross pollutants and coarser sediments prior to wetland.

3.2.1. Hydraulic modelling

The design was thoroughly tested using hydraulic models to achieve the desired detention and hydraulic capacity. XP-Storm software [3] was used for testing the hydraulic design.

3.2.2. Water quality modelling

The design for water quality through the stormwater treatment was achieved using MUSIC model [4]. MUSIC is the Model for Urban Stormwater Improvement Conceptualisation and was developed by the Cooperative Research Centre for Catchment Hydrology,

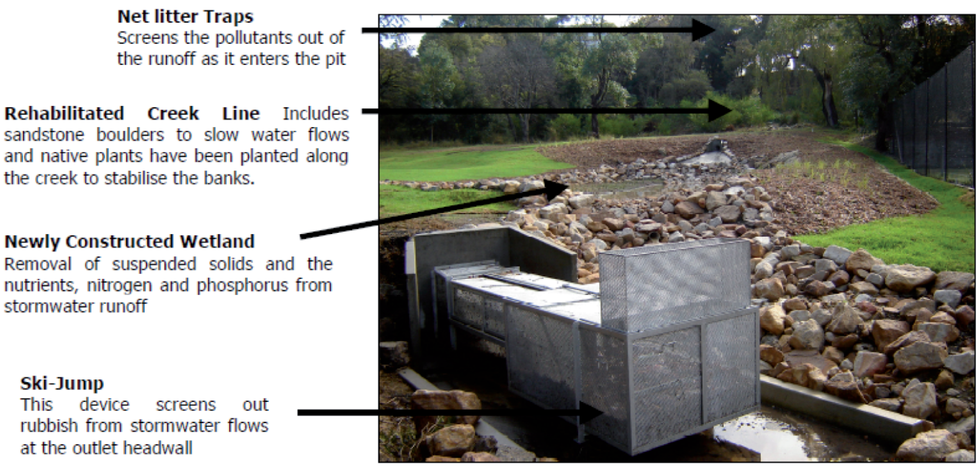

Fig. 7. Stormwater treatment train.

Table 4
Sampling results.

Pollutant	Maximum	Minimum	Median	Modelled catchment EMC[a]	Potential removal rate %
pH	7.2	7.0	7.1	–	–
Turbidity (NTU)	15.00	3.50	7.2	120	87–97%
Total nitrogen dry weather (mg/L)	0.2	0.05	0.1	2	90–98%
Total nitrogen wet weather (mg/L)	0.25	0.1	0.15	2	88–95%
Total phosphorus dry weather (mg/L)	0.07	0.02	0.05	0.20	72–92%
Total phosphorus wet weather (mg/L)	0.09	0.04	0.06	0.20	64–84%

[a]EMC = Event Mean Concentration Ref: Australian Runoff Quality, 2005.

Australia. The model was used to design the stormwater treatment train to meet the water quality objectives of the bay.

3.2.3 Monitoring results

Following community consultation, a small urban wetland was constructed in a natural reserve area in conjunction with GPTs to form a stormwater treatment train to reduce sediment and nutrient loads to the bay.

Post construction water quality monitoring downstream of the treatment train (August 2006–December 2008), indicates significant improvement in water quality of the bay downstream (Table 4). The water quality within the bay in proximity to the discharge point to Shipwrights Bay is with ANZECC [7] guidelines. The Wetlands have also provided a habitat for flora and fauna and enhance the amenity of the reserve that is being used for recreational purposes.

4. Conclusion

The WSUD projects reached its objectives through good design development, community and stakeholder consultation, project management and innovative construction of stormwater treatment system.

Monitoring of the stormwater quality by Council's Water Quality monitoring program has shown significant reduction in sediment loads and nutrients to the bays. The water quality at the outfalls has surpassed all relevant statutory standards for discharge to the bay. It is anticipated that reduction of nutrient and sediment loads will provide habitat for flora and fauna in Connells and Shipwrights Bay that will improve the recreational value of the area. It is also planned in future to recycle the treated water for irrigation and toilet flushing use in the park area thereby providing an integrated stormwater treatment system to the community of Kogarah.

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