## Monitoring the Performance of Bioretention and Wetland Systems at Sydney University

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**Abstract.** This paper presents an overview and assessment of the performance of the WSUD measures implemented at Sydney University. These systems which were installed up to 5 years ago, since which time they have become a key demonstration site for WSUD practitioners in Sydney.

Students from the University have been monitoring two of these systems as part of research projects, with the results presented within this paper. The paper also outlines issues and problems that occurred with field monitoring which provide insight and lessons for councils wishing to undertake water quality monitoring of treatment elements.

Water quality and flow monitoring took place between May 2010 - September 2010 and flow monitoring continued until December 2010. A number of technical complications were encountered however reasonable estimates on the performance of the system and outflow water quality were obtained. Both systems have a dense vegetation cover, with small dead zones due to species die back and inappropriate species selection relating to water inundation within the wetland. These experiences will be presented.

## 1 Introduction

As part of its campus renewal project, Sydney University installed a combination of 11 bioretention systems (five gardens and six street trees) and a wetland to treat runoff from new development areas. The treatment systems include four stormwater storage systems for reuse for irrigation and toilets throughout the campus and new buildings. The water quality monitoring reported in this paper focuses on the two stormwater treatment systems:

- Darlington Road Catchment. A 5.4 hectare catchment that includes Darlington Road, with flows diverted from an existing drain into a 200m$^2$ wetland and 400m$^2$ bioretention system. The combined wetland / bioretention system form the central landscape feature of Gadigal Green. Flows are treated in the permanent water system and collected in a 150kL storage tank for reuse as irrigation of Gadigal Green. This system was completed in 2008.

- Shepherd Street Catchment. A 1.2 hectare catchment that includes flows from the University Sport and Aquatic Centre, tennis courts and local roads. The catchment flows to a 600m$^2$ bioretention system which forms the Shepherd Street entrance to the University. Once treated the stormwater collects into a 75kL storage tank, which is used for irrigation, and overflow from the treatment system discharges into an existing stormwater drainage system. This system was completed in 2006.

The locations of these systems are shown in Figure 1.


**Figure 1: Sydney University Darlington Campus showing City Road, the Gadigal Green wetland and bioretention system (1), and the Shepherd Street bioretention system (2).**

## 2 Current Performance / Operation of the WSUD Systems

The Shepherd Street bioretention system has been operating since 2007, when the system was planted with *Callistemons* with an understorey of *Dianella* and *Lomandra sp.* *Callistemons* were used to act as a visual barrier between the University and the adjacent child care facility. The bioretention system was designed to the available space and is larger than is required to meet best practice water quality standards. The system is long and narrow with one inlet, which means that stormwater rarely flows along the length of the system.

Despite this the vegetation within the treatment system is doing very well, with the *Callistemons* having nearly quadrupled their size in five years since planting (see Figure 2). The understorey of *Dianella* and *Lomandra sp.* has had issues with competition from the trees and growth is not as vibrant. There are no obvious signs of litter within the system.

The Gadigal Green wetland and bioretention systems were established in 2008. The dominant species used across the system was *Lomandra*, with bands of *Banksia* and other species. The vegetation growth in the past three years has been rigorous, especially when compared with similar species planted in standard garden beds adjacent to the bioretention system (i.e. that do not receive wetting) (see Figure 3).

It is noted that although at present the vegetation cover is dense across the majority of the treatment system, a small 'dead zone' exists close to the outlet of the wetland cell where the vegetation is sparse and relatively unhealthy. This is likely due to poor establishment, a sub-optimal permanent pool depth, coupled within inappropriate species planting for the depth of water. Vegetation is healthy but sparser towards the outlet end of the bioretention cell, which is likely due to the lower frequency of stormwater reaching the far end of the system.

**Figure 2: Shepherd Street bioretention system in November 2007 shortly after planting (left), and in 2011 (right).**

**Figure 3: Gadigal Green bioretention system and wetland in September 2008 shortly after planting and being established off-line (left), and in 2011 (right).**

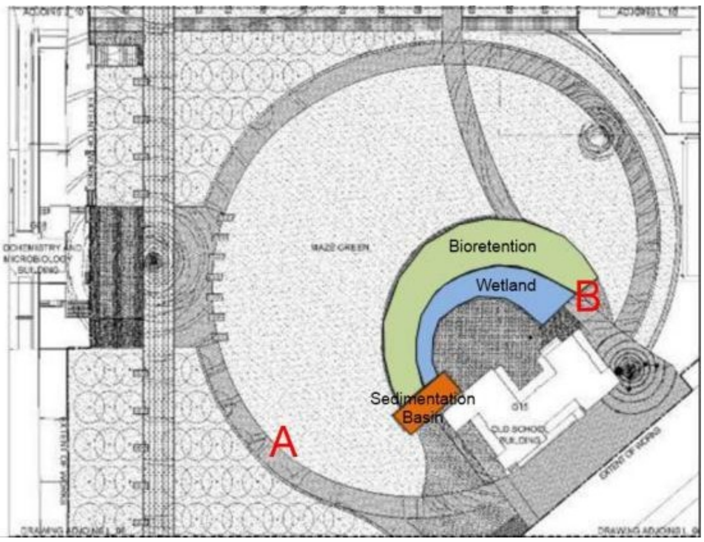

**Figure 4: Gadigal Green bioretention system and wetland configuration. Point A represents location of the inflow monitoring site, before flowing into the sedimentation basin, which overflows into the bioretention system and wetland. Point B represents the outflow monitoring site, immediately downstream of the point where outflow from the bioretention system and wetland converge.**

Plane tree seeds from an overhanging tree frequently germinate in the bioretention system. Maintenance crews from the University are reasonably effective at removing the saplings, and there has been no visible damage caused by the invasive saplings.

Surface ponding in the bioretention cell was not observed to last for more than three hours post any rain-event, showing that the hydraulic capacity of the system is operating as designed. However, there is a constant base-flow off the catchment into the bioretention system, which is observed at approximately 0.2L/s. While extended ponding can cause reduced effectiveness of bioretention cells due to clogging of the surface, the small surface area affected by base-flow is unlikely to have a notable effect on the overall performance of the system.

Organic and inorganic litter was observed primarily near the inlet of the treatment system and accumulated against the grate between the sedimentation basin and wetland and bioretention cells. Maintenance efforts are fairly effective at removing gross pollutants from the wetland and bioretention cells.

## 3 Monitoring Methodology and Issues

As part of an Honours thesis for the Department of Geography, water quality and flow monitoring of the Gadigal Green wetland and bioretention system took place between May 2010 and September 2010, with flow monitoring continuing until December 2010. As part of the project a complementary monitoring program was undertaken at Hawthorne Canal, a stormwater trunk drain flowing into Iron Cove. While this paper does not present results of the monitoring of Hawthorne Canal, it does refer to the experiences of this program as a discussion for organisations interested in monitoring, on key considerations in the monitoring set up and sampling methodology for water quality testing.

The methodology and issues experienced from two simultaneous monitoring projects, at the Darlington Road wetland and bioretention system and Hawthorne Canal, are outlined and briefly compared in this section.

The rationale for the monitoring methodology at the sites is based on the fact that the sampling period (the time between the collection of the first sample and last sample) should occur throughout the storm hydrograph to determine the event mean concentration (EMC) of a parameter measured in the stormwater samples (e.g. TN, TP, TSS). EMCs can be better estimated if the full hydraulic profile of stormwater flow from a rain event (i.e. the rising limb, peak flow and falling limb) can be captured. Design of the sampling regime requires a compromise between the fineness of time interval between samples and the duration of the sampling period (due to the finite number of sample bottles available). This compromise should be made based on an 'average' hydrograph for the sampling region. The most precise way to undertake this method of sampling is to deploy nested autosamplers, ideally over multiple rain events.

Undertaking grab samples does not provide sufficient data to produce a representative profile of pollutant concentrations, EMC, nor a useful estimate of pollutant loading due to the nature of pollutant build up in catchments, and highly variable nature of rain-events.

### 3.1 Gadigal Green - Inflow/Outflow Sampling Method

ISCO3700 autosamplers equipped with an ISCO 4230 bubble flow meter probe were installed at the inflow and outflow drainage pipes of the wetland bioretention system (figure 1). Twenty-four pre-cleaned 1L polyethylene bottles were fitted in each autosampler for each of the six rain events monitored. The autosamplers were programmed to collect 450ml of water for each sample. The flow meters were programmed to send one pulse to their respective autosamplers for every minute in which flow level was sustained above a trigger value (greater than the pre-measured base-flow level). The autosampler was programmed to take a sample after receiving 10 pulses from the flow meter, resulting in a theoretical minimum sampling interval of 10 minutes. After a sample was taken, the pulse count returned to zero. If flow level dropped below the trigger value after (for example) pulse six was received by the autosampler, the next pulse received by the autosampler (on return of >trigger value flow levels) would be registered as pulse seven, i.e. fluctuations in flow level did not disrupt pulse counts. This sampling program in retrospect was not ideal as the sampling interval, in particular on the rising limb of the hydrograph was too coarse to capture the rapid flow changes occurring. Higher resolution sampling was restricted by the programming options of the model of autosampler used and available monitoring gauges.

### 3.2 Stormwater Canal - Sampling Method

A SIGMA900 autosampler equipped with a tipping-bucket rain gauge and flow meter was installed adjacent to Hawthorne Canal in a lockable plastic housing. Base-flow and stormwater were sampled from the drain upstream of the fresh/salt water interface. Stormwater sampling was triggered by detection of >0.2mm of rainfall and a flow depth > the pre-measured base-flow in the canal. Twelve pre-cleaned 1L polyethylene bottles were fitted in the autosampler for each of the three rain events captured. Each sample collected approximately 450ml of water. Eleven samples were taken for each rain event at increasing time intervals to capture the steep rising limb of the hydrograph. The 12th bottle was used as a field blank for each rain event. The temporal sampling intervals were as follows: 3x6mins, 3x12mins, 3x24mins, 1x48mins totalling a sampling period of 168 minutes for each event.

Base-flow samples were collected using the same autosampler installation as that used for stormwater sampling. Base-flow conditions were defined as being after 48 hours of no rain. A random sampling design was adopted in an attempt to represent the high variability of pollutant concentrations observed in a previous study (Beck, 2001). Samples covered four temporal scales (hours, days, weeks and months) and were taken at three randomly chosen times (the only condition being that there be at least one hour between samples), on three randomly chosen days, within two randomly chosen weeks, within each month of sampling A total of 36 base-flow samples were taken during the sample period (June to August, 2010).

### 3.2 Monitoring Issues

The monitoring of the two systems has identified a series of issues, which act as a guide/checklist for councils to consider when undertaking field monitoring of water quality systems. The monitoring issues have been broken into logistics, sample design and mechanical misbehaviour.

**Logistics**

- Interpreting results from small rain events where inflow sampling is triggered but not outflow sampling. To consider pollutant removal to be 100% in these circumstances is not correct as the water will inevitably leave the system either as base-flow or in the next rain event. However, the results should not be discarded (unless it is suspected that there has been an equipment failure) as the detention of this water in the system is an important pathway for pollutant removal.
- Prompt collection and transportation of sample water to a laboratory environment to reduce changes in pollutant phase.
- Wetland monitoring requires consideration of the *detention time* of the wetland extended detention. Due to the considerable storage capacity of the wetland systems, the inflow into the system may occur over a few hours but the outflow will typically occur over a number of days. The quality of outflow water was affected by the intensity of the sampled rain event and time interval between the most recent antecedent rainfall event and the sample event. Hence monitoring the whole of the outflow of wetlands is important.
- 12 volt batteries were used to power the Hawthorne Canal sampling equipment. Despite regular checks and battery replacement, more than one rain event was missed due to a depleted battery. However, solar panels were established at the Darlington Road site and no power issues were experienced at this site.
- Heavy rainfall or littering/illegal dumping (predominantly in Hawthorne Canal) caused build up of organic and inorganic debris on many occasions. This disrupted the function of both the analogue and bubble flow meters. Accessing the underground stormwater pipes required booking and engaging the assistance of maintenance staff which often took some days.
- Both analogue and bubble flow meter have associated 'pros and cons'. All flow meters will cause disruption to the flow (as they themselves are an obstruction to the flow). This should be minimised by aligning the equipment parallel to the direction of the flow. The bubble flow meter probe is smaller and less obstructive to flow (3mm diameter rubber tube viced to the base of the pipe) than an analogue flow meter. However, the bubble flow

meter requires flow level to be greater than the diameter of the tube to operate, whereas the analogue flow meter (measuring velocity) can operate accurately in very low flow conditions.
- The autosampler model must accommodate for the sampling design. Some models come with slots for only 12 sample bottles, while other auto-samplers are not capable of sampling at less than 10 minute intervals which for this study was not a sufficiently fine sampling resolution. A more appropriate sampling design had to be compromised due to the software restrictions of the auto-sampler used.

**Sampling Design**

Determining a sampling program to capture the best representation of the hydrograph needs to be carefully considered. Although the hydrograph of rain events in a region follows a normal distribution curve, the variation over a relatively short sampling period is significant. The sampling method applied at Hawthorne Canal was designed to capture the first flush where as the method applied at the wetland-bioretention system was designed to sample at consistent intervals for the duration of the rain event or four hours (being the maximum period possible using 10 minute intervals).

Mechanical Misbehaviour:

- Unpredictable sampling intervals, which were different to the programmed intervals.
- Autosampler overwriting older data. A key issue is to regularly download data from the flow monitors to ensure that the data is not over-written.
- Incomprehensible flow data whereby outflow flow volumes exceeded inflow volumes with large and non-linear discrepancies.

## 4 Results

### 4.1 Hydraulic Profiles

Figure 5 illustrates the flow rates of stormwater passing through the inflow and outflow sampling stations of the Darlington Road wetland bioretention system during one of the sampled rain events. The volume of outflow water greatly exceeds the volume of inflow water in each case despite the closed design of the system. This data was rendered unusable and despite a number of tests and hypotheses were pursued to determine the cause of the failure, no reliable conclusion was met during the study period. The primary hypothesis for the discrepancy between inflow and outflow volumes was that a 10 minute interval for water level data was too coarse to capture a representative hydraulic profile, in particular for inflow levels given the small size of the catchment (wherein stormwater flow is highly responsive to rainfall) and the often acute nature of heavy rainfall. A model was created based on this hypothesis which interpolated flow at one minute intervals reduced the volume discrepancy from outflow 765% > inflow to outflow 30% > inflow.

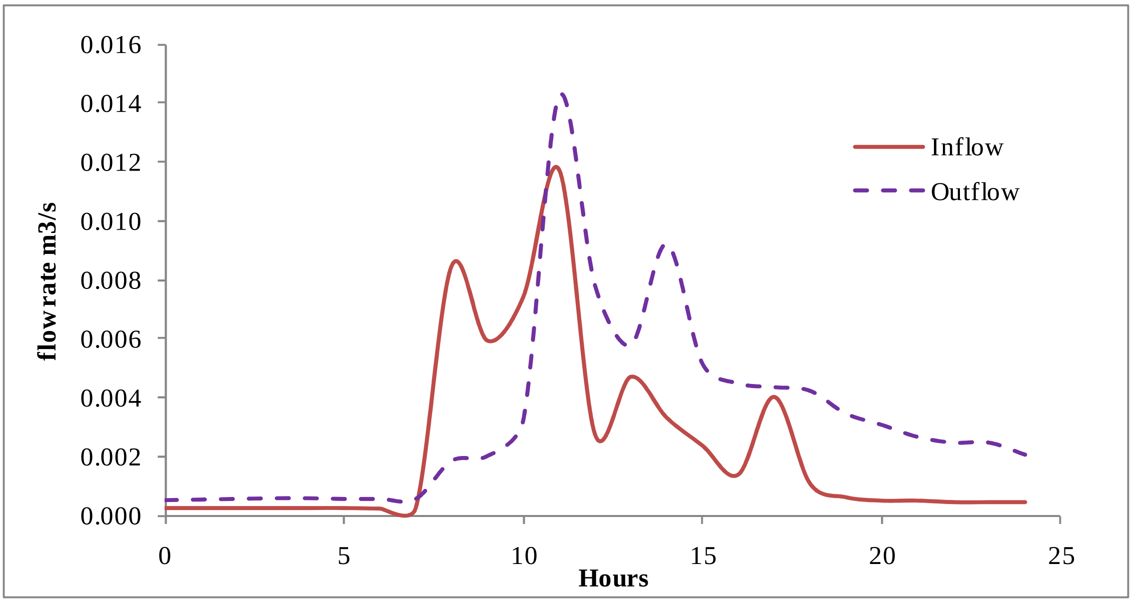


**Figure 5: Hydraulic profile of a rain event from Darlington Road system.**

### 4.2 Pollutant Removal

Pollutant removal efficiency is calculated using the EMC. Because EMCs estimate annual inflow or outflow pollutant loads and volumes were not able to be calculated, the pollutant removal was estimated through analysis of the percentage difference between mean inflow and outflow concentrations, these results are presented in Table 1. T-tests for significant difference were performed for total (all samples across all rain-events) inflow and outflow concentration data. Outflow concentrations were significantly lower than inflow concentrations for the suite of contaminants tested (Table 1). The exception to this was Mn for which significant leaching was observed in each event. However, the prevalence of Mn in the environment is well recognised and mean outflow concentrations were below ANZECC recreational toxicity guidelines (2000) in all events and may be considered harmless. One possible reason for the higher concentrations of Mn in the outflow is that the filter media used in this systems was high in Mn and that this Mn is being leached out of the soil.

It is interesting to note that the pollutant inflow concentrations are significantly lower than standard typical stormwater concentrations. For example:

- TSS inflow concentration of 16 mg/L is significantly lower than the average inflow of 140 mg/L reported in ARQ (Engineers Australia, 2005)
- TP inflow concentration of 88 µg/L compared to 250 µg/L reported in ARQ (Engineers Australia, 2005)
- TN inflow concentration of 0.9 mg/L compared to 2.4 mg/L reported in ARQ (Engineers Australia, 2005)

It is also interesting to note that the pollutant outflow concentrations were similar to the background concentrations used in MUSIC for wetlands but were significantly lower than the bioretention background concentrations. For example:

- TSS outflow concentration of 7 mg/L is similar to the 20 mg/L background concentration typically adopted for bioretention systems and 6 mg/L adopted for wetlands
- TP outflow concentration of 51 µg/L is similar to the 130 µg/L background concentration typically adopted for bioretention systems and 60 µg/L adopted for wetlands
- TN outflow concentration of 0.5 mg/L is lower than the 1.4 mg/L background concentration typically adopted for bioretention systems and 1 mg/L adopted for wetlands

**Table 1: Statistical summary of total non flow-weighted concentration data. NB. Sample numbers for TN were Inflow(n=43) and Outflow (n=53)**

| Element | TSS | Cu | Fe | Mn | TP | TN | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|
| | mg/L | µg/L | µg/L | µg/L | µg/L | mg/L | µg/L | µg/L | µg/L |
| **Inflow Mean (n=93)** | 16 | 51 | 680 | 12 | 88 | 0.9 | 9 | 36 | 1 |
| **Outflow Mean (n=128)** | 7 | 18 | 463 | 25 | 51 | 0.5 | 2 | 18 | 0.7 |
| **Sig. difference** | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| **% Difference Mean Concentration** | 56 | 65 | 32 | -108 | 42 | 44 | 77 | 50 | 30 |
| **Inflow Range** | 0.6–146 | 7–212 | 136– | 3–89 | 6–283 | 0.2-2.7 | 2–41 | 4–211 | 0.2–5 |
| **Outflow Range** | 1–27 | 4–49 | 230–1449 | 6–356 | 13–163 | 0.05-2.4 | 2–12 | 2–67 | 0.2–6 |
| **Inflow SD** | 20 | 35 | 688 | 13 | 63 | 0.6 | 7 | 33 | 0.8 |
| **Outflow SD** | 4 | 8 | 180 | 37 | 42 | 0.3 | 2 | 10 | 0.5 |

The mean concentrations of metals and nutrients in the outflow were below ANZECC (2000) recreational toxicity levels for all tested contaminants except for Fe (Table 2). The concentration of metals Cu, Pb, Zn, Cd, Ni in outflow across the six monitored rain-events were reasonably consistent (low standard deviation) whereas metals Mn, Fe and nutrients TP and TN demonstrated greater variability. The greater variability in TP and TN may have been influenced by the low sample number for TN and also due to the lack of soluble phase analysis (these elements have a lower affinity to soils and fluctuate readily between soluble and particulate phases). It should be noted that the mean pollutant concentrations of inflow were also below the ANZECC (2000) toxicity guidelines; however the quality of this water was more variable and thus the probability of inflow pollutant concentrations exceeding ANZECC (2000) guidelines is higher. Furthermore, the interval between rain-events was, in some cases < 7 days, resulting in relatively low pollutant build up in the catchment and thus low inflow concentrations.

**Table 2: Mean outflow concentrations compared with ANZECC (2000) recreational toxicity and irrigation guidelines**

| | TSS (mg/L) | Cd | Ni | Cu | Mn | Fe | TP | TN | Pb | Zn | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Recreational Toxicity Guideline (ug/L)** | NA | 5 | 100 | 1000 | 100 | 300 | NA | 1,000-100 | 50 | 5000 | 50 |
| **Irrigation Recommendations (up to 100years) (ug/L)** | 50 | NA | NA | NA | NA | NA | 50 | 5,000 | NA | NA | NA |
| **Mean Outflow Concentration** | 7 | BD | BD | 18 | 25 | 463 | 51 | 500 | 2 | 18 | 0.7 |

## 5 Conclusions

The monitoring undertaken through this project has sought to determine the effectiveness of the WSUD elements constructed at Sydney University. The process of undertaking the project has identified a series of implications for organisations wishing to monitor the effectiveness of stormwater treatment systems. These implications include:

- Stormwater monitoring is costly and time consuming. It therefore requires extensive pre-planning and preparation including clearly outlining the purpose and objectives of monitoring including costs and benefits analysis of the monitoring, well thought through methodology, careful choice of equipment (to accommodate for the chosen sampling design), choice of probes and gauges. As an interim step it maybe more cost-effective to undertake initial steps in determining the effectiveness of vegetated stormwater treatment systems such as testing the hydraulic conductivity of the filter media.
- Field testing and calibration of equipment needs to be carried out throughout the monitoring period, including in situ calibration of flow meters, behaviour of autosamplers and flow meters
- Probes should be checked at every visit (in particular after each rain event) to check for obstructions.
- Flow and rainfall data should be uploaded from the equipment after every rain event and processed to verify that the results are reasonable and equipment is functioning as expected.
- High variability of sediment and pollutant build up in catchments, rainfall profiles and frequencies, and system performance based on its condition prior to a given rain event make sampling over multiple rain events necessary in order to perform any statistical analysis of water flow and quality data.
- Multiple samples within a rain event are also necessary to calculate reasonable estimates of EMC and thus loads and removal efficiency of systems.

There are also a number of wider implications from the monitoring undertaken at Sydney University. These implications include:

- The concentrations of contaminants monitored in this study met guidelines for reuse without further additional treatment such as further filtration suggesting that stormwater treated by bioretention and wetlands may be suitable for use without additional treatment.
- Concentration data from the catchment, particularly for TSS, was lower than the values typically used in standard water quality models such as MUSIC. This has also been found in the studies in other Sydney based monitoring (for example see Birch, 2004, Birch 2005, Kandasamy et al 2008, and Birch 2009) where TSS loads have consistently been found to be lower than 100 mg/L and in small catchments (less than 10 hectares) lower than 50 mg/L.
- Filter media selection continues to be an important consideration. These studies show that the filter media in this treatment system is potentially leaching Mn from the soil. These sites pioneered the use of this media and now this media has become common media used throughout Sydney.

The Sydney University WSUD elements have been in place for five years, and have been the focus of numerous site visits and demonstration sites in that time. The treatment systems are an excellent demonstration site to express the integration of stormwater treatment and reuse systems into the landscape. The treatment systems are also an excellent model of learning in action and for the provision of students to learn by doing.

The monitoring undertaken in this research shows that the treatment systems are functioning effectively. The systems reduce average concentrations of the inflow by approximately 50% for TSS, TP and TN and generally reduce outflow to typical background concentration levels for the treatment systems. It is possible that the overall pollutant load reductions could be higher than reported in this study, as in smaller rain events no outflow was observed from the treatment systems and thus the concentration reduction analysis, using total inflow sample data and total outflow sample data, did not account for stormwater detained in the systems.

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