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Assessment of In-Situ Water Sensitive Urban Design Elements

Niranjali Jayasuirya and Majell Backhausen

Abstract**—**Water Sensitive Urban Design (WSUD) features are increasingly used to treat and manage polluted stormwater runoff in urbanised areas. It is important to monitor and evaluate the effectiveness of the infrastructure in achieving their intended performance targets after constructing and operating these features overtime. The paper presents the various methods of analysis used to assess the effectiveness of the in-situ WSUD features, such as: on-site visual inspections during operational and non operational periods, maintenance audits and periodic water quality testing. The results will contribute to a better understanding of the operational and maintenance needs of in-situ WSUD features and assist in providing recommendations to better manage life cycle performance.

Keywords**—**Bio-retention swales, Maintenance plan, Operational plan, Water Sensitive Urban Design, Water quality improvement.

I. Introduction

THE need for sustainable practices has been adopted by many local government councils, all over the world. Most of the Municipalities in Victoria, Australia have implemented innovative and promoted sustainable urban water management practices over the past two decades. These Municipalities have a duty of care to its residence and an obligation to manage its diverse natural environments; this involves meeting the required sustainable practices set out by the Victorian and Commonwealth Federal Governments [1].

Minimising pollutant generation at the source is one way of protecting the environment from the effects of urbanisation. Water Sensitive Urban Design (WSUD) features are increasingly being used to treat and manage polluted stormwater runoff from urbanised areas. It is important to monitor and evaluate the effectiveness of delivering sustainability infrastructure overtime in achieving their intended goals and performance targets after constructing and operating these features.

The councils have incorporated a range of Water Sensitive Urban Design (WSUD) elements into newly implemented infrastructure as a 'philosophical approach to urban planning and design that aims to minimise the hydrological impacts of urban development on the surrounding environment' [2], WSUD elements throughout the Municipalities are designed following best practice guidelines set by various agencies including Melbourne Water and the Facility for Advancing Water Bio-filtration. Following published manuals such as Melbourne Water's [3], the Municipalities constructed WSUD features capable of achieving their intended outcomes. The overall expectation of these features is to improve the aesthetics of the urban landscape, convey and retard storm flows, reduce pollutant export of harvested stormwater and reduce irrigation requirements by recycling Stormwater [4, 5]. Pollutants commonly found stormwater runoff include phosphorus, nitrogen, nitrates, suspended solids, a multitude of heavy metals and gross pollutants such as litter. The selection and placement of WSUD elements within an urbanised landscape is determined during the concept design stage taking into account the required reduction in pollutant types, site conditions and associated costs. The most commonly used WSUD elements within councils include wetlands, retarding basins, sediment traps, sediment tanks, gross pollutant traps, swales, bio retention swales/rain gardens and porous pavement. The above WSUD features can provide effective removal of pollutants from stormwater [6, 7, 8].

The aim of this study is to assess the functioning performance of selected WSUD features and recommend operational and maintenance guidelines to better manage their performance and operational life. The study will investigate seven in-situ WSUD features constructed in various urban landscapes throughout the Mornington Peninsula Shire (MPS) in Victoria constructed in the last 5 years.

N. Jayasuriya is a Senior Lecturer in the School of Civil, Environmental and Chemical Engineering at the RMIT University in Melbourne Australia, (phone: +6139923795, fax: +61396390138; e-mail: nira.jayasuriya@rmit.edu.au).

M. Backhausen was a student in the School of Civil, Environmental and Chemical Engineering at the RMIT University. (Phone: +44(0)7934800615, e-mail: majellb@gmail.com).

II. Mornington Peninsula Shire

MSP is a large municipality (720 square kilometres) located 50 km south of metropolitan Melbourne which was established in 1996 (Figure 1). Urban and infrastructure development within the Shire is forever occurring, resulting in increased impervious surfaces and wastewater and stormwater runoff. The Shire's extensive size and varying landforms support diverse land uses including residential, agricultural, commercial and industrial. Typically, the upper reaches of the catchments are either in rural or undeveloped areas with a high amount of pervious surface and natural stormwater management/treatment processes. Urbanised and developed area with a high amount of impervious area occupies the lower regions of the catchments, situated along or near the coast. These urbanised areas require extensive forms of stormwater management draining over relatively short distances to Port Phillip Bay, Western Port Bay or the Victorian Bass Strait.

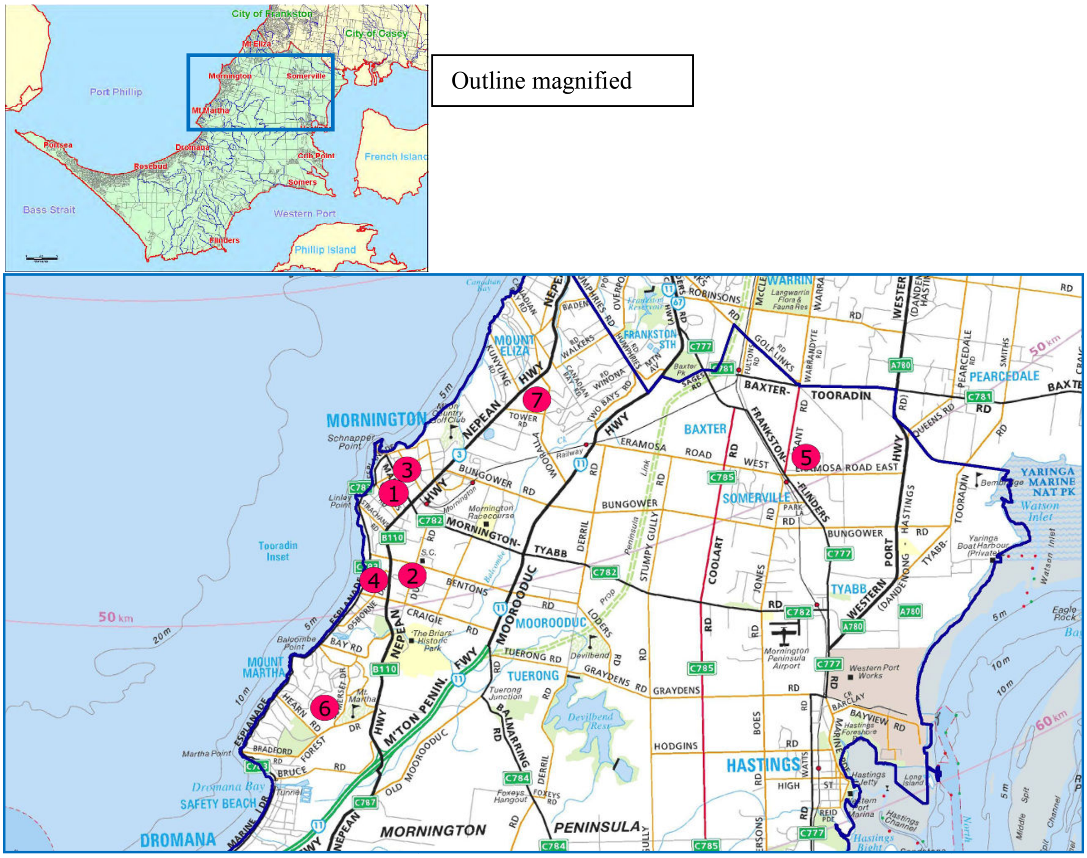

Fig. 1 Locations of the study sites

The features of he WSUD infrastructure are given below and their locations marked in Figure 1.

Site 1– Multiple Bio-retention Swales/Rain Gardens – Empire Street Car Park (104 D11)

Site 2 – Bio retention Swales/Rain Gardens, Mornington - Dunns Road Reserve (145 F8)

Site 3 – WSUD Street Tree Pits, Mornington – Mornington Main Street Streetscape works (104 D10)

Site 4 – Bio-retention swales/rain gardens, Mt Martha – Azura Place (145 C7)

Site 5 – Multiple Bio-retention Swales/Rain gardens, Somerville – Simcock Street (107 G11)

Site 6 - Bio-retention Tanks & Sedimentation Tanks, Mt Martha – Hull Road (144 H5)

Site 7 - Bioretention Trench/Swale – Waterview Close Mt Eliza (105 G6)

Bioretention Swale

Bio-retention swales provide two main functions: stormwater treatment and the ability to convey stormwater safely (Figure 2). The swale component of the system uses vegetation and gravity to pre-treat to the stormwater, removing course to medium sediments as well as litter and natural debris. After conveyance through the swale, the stormwater percolates through the prescribed filter media component of the Bio-retention system located at the base of the swale removing finer particles, nutrients and contaminants. The filter media achieves this through fine filtration, extended detention treatment and some biological uptake. If designed and constructed properly a bi-retention swale system should also have the ability to retard some stormwater flow during large storm events and provide protection to natural receiving waterways from the high flow velocities associated with piped flows. In the occurrence of a large storm event, overflow pits are also incorporated in the design, directly conveying excess water into the stormwater pipe network.

WSUD Street Tree Pits

WSUD tree pits are a practical way of introducing WSUD into urban streetscapes where there is limited space to work with and impervious areas dominate the landscape (Figure 3). WSUD tree pits work as small scale bio-retention systems. The entire foot print of a standard tree pit is usually 6.25 square meters and only has to accommodate the health of one plant. This is another credit to its success as it provides treatment options in areas where vegetation is limited and linear swales or larger scale rain gardens simply cannot fit. WSUD tree pits have the ability to remove medium to fine sediment, nutrients, contaminants and litter. With very limited documentation found on the exact design, construction and maintenance of this feature it is assumed that the process of implementation from the concept phase to operational phase follows the general guidelines of WSUD feature implementation.

Fig. 2 Bioretention swale Mornington Peninsula Shire Council, Victoria Australia

Sedimentation and Bio-retention Tanks

Sedimentation tank and Bio-retention tank systems have dual pollutant extraction ability. The sedimentation tank is the first course of treatment for harvested stormwater (Figure 4). Sedimentation removes gross pollutants, large and medium sized particles (sand, grit, rubbish). Bio-retention tanks will then receive the overflow pre-treated water and allow it to percolate through the filter media, removing finer particles, nutrients and contaminants (the same principles as the Bio-retention treatment in a swale). In the occurrence of a large storm event, allowances for water overflows are also incorporated in the design, directly conveying excess water into alternative pipe networks or creeks. With no documentation found on the exact design, construction and maintenance on this system, it is assumed that the process of implementation from the concept phase to operational phase follows the general guidelines of WSUD feature implementation.

A. Water Management within the Council

The responsibility of waterways and water infrastructure management within the MPS is shared amongst a number of authorities (local and regional) and other stakeholders. MPS is primarily responsible for land-use, land and local stormwater management. Through the use of planning provisions, development approval conditions and engineering specifications, the Shire directs the nature of development within the municipality. In addition, the Shire is responsible for the long-term maintenance and management of stormwater drainage infrastructure, natural waterways, public assets such as roads and car parks, provision of services (e.g. waste management) and management of public open space. Melbourne Water is responsible for managing local creeks and waterways.

Fig. 3 In-situ WSUD Street Tree Pit

Fig. 4 Hi-Capacity Sedimentation Tank

B. Environmental Management Guidelines

The Urban Stormwater Best Practice Environmental Management Guidelines (BPEMG, 2006) is a comprehensive document designed to meet the needs of people, companies and municipalities involved in the planning, design and/or management of urban land uses or stormwater systems [9]. The BPEM establishes stormwater quality objectives to assist in determining the level of stormwater management necessary to meet the State Environment Protection Policy (SEPP) - Waters of Victoria objectives. The SEPP is a statutory policy under Section 16 of the Environment Protection Act (1970) which identifies the beneficial uses of Victoria's waterways [9].

III. Data Collections And Results Obtained

A number of audits were carried in addition to collecting water samples from the field as detailed below.

A. Design and Construction Audits

Detailed design calculations and drawings were reviewed for its compliance with Best Practice Standards. Due to the WSUD features in-situ state, auditing their construction phase was not possible. However, for each WSUD feature the handover documents were reviewed confirming the construction of the features was done to the detailed design and approved. All Construction Issue detailed designs were approved for construction by Manager of Infrastructure Project Management or the Council's development engineer. All seven WSUD features were completed and functioning 5 years prior to this study. However, the Sites 2 and 3 were completed only within the last 2 years.

B. Operational Audit

The operational audit was executed by visiting each site during a rainfall event and assessing its performance. The assessment criteria included observing whether stormwater was entering and exiting the feature as intended, no water pooling or blockages were occurring, the feature was not posing any public hazards while providing positive aesthetics to the landscape and whether the feature was overall operating as intended according to design. An Operational performance checklist was prepared to assess the overall operation of the WSUD feature by looking at the key operational criteria. Table 1 summarizes the Operational performance checklist forms for Sites 1 to 7. The final comments for all 7 sites are summarized in Table 2.

If the WSUD feature passed the Operational audit, it was considered operational. It would then undergo Water Quality Testing. If the feature was deeming inoperable, further assessment would take place to identify the reasons for its failure. Due to the uncontrollable aspect of rain events, times of onsite assessment were unable to be pre-determined. This factor of uncertainty was accounted for with work flexibility and availability of appropriate transport at all times.

C. Maintenance Audit

The maintenance is an important aspect of a WSUD feature's post-construction performance as frequent servicing could be costly. The maintenance checklist involves on-site visual inspection of the assets and recording the inoperability of some features in some cases. The maintenance checklist was adopted from the WSUD Engineering Procedure, Stormwater [10]. It assesses the overall condition of the feature and the maintenance it may require to improve its effectiveness.

Table III summarizes the Maintenance checklist forms for Sites 1 to 7. The final comments for all 7 sites are summarized in Table 4.

D. Water Quality Testing

Water quality testing was carried out from 2 different storm events three months apart. Water samples were obtained from input and output points to the WSUD feature. The inflow point was at an upstream pit or channel kerb inlet point. The outflow point was always in a pit downstream of the WSUD feature. The water quality analysis was carried out by a National Association of Testing Authority (NATA) Australia accredited laboratory (ASL Water Resources Group).

IV. Discussion Of Results

The Best Practice Targets set by CSIRO is based on TSS, TN and TP loads (Victoria Stormwater Committee 1999). The percentage removal efficiencies calculated in the current study is based on nutrient concentration removal and not on nutrient loading. Although it was planned to measure the flow rates it was not possible to record from all inlets and outlets of all the sites. However, the objective of the study is to develop a maintenance plan for the WSUD features by regularly visiting the sites and observing the required maintenance to achieve maximum operational efficiency.

Water sampling was carried out only from Sites 1 to 4 as the other three were deemed not necessary as they were not in an operational form as given in Tables 1 and 3. The Sites 5 to 7 require urgent maintenance and re-instatement to perform as intended. By visiting the sites and filling in an Operational check list as given in Table 1 will assist in maintaining the WSUD feature's operational status.

The concentration levels observed in each site are given in Figures 5 to 7. The pollutant concentrations identified were consistent with Event Mean Concentration (EMC) and Land Use relationship reported by [11]. According to above author, urbanized areas which consist of residential, commercial and industrial land had concentration levels ranging from:

- Total Suspended Solids: 35 mg/L to 500 mg/L
- Total Nitrogen: 1.5mg/L to 5.5 mg/L
- Total Phosphorus: 0.13 mg/L to 0.9 mg/L

A close examination of the pollutant concentration values given in Figures 6 to 8 show that the TSS values for all sites except Site 4 is in the lower range of the EMC values reported by [11]. Similarly the nutrient concentrations are also in the lower range, except in Site 3. The pollutant concentration levels depend on the surrounding land use pattern and as such, it is important to select the appropriate WSUD feature to improve the stormwater quality.

TABLE I
OPERATIONAL CHECKLIST

Inspection Items	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6		Site 7	
	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
Is the feature providing a positive aesthetic benefit to the landscape?	X		X		X		X			X		X	X	
Is the feature demonstrating flow control during the rain event (retarding excess water)?	X		X		X		X			X				X
Is the feature collecting the intended harvested stormwater?	X		X		X		X			X				X
Is stormwater entering the system at appropriate inlet(s) and in the manner intended by design?	X		X		X			X		X		X	X	
Is stormwater exiting the system at appropriate outfall(s) and in the manner intended by design?	X		X		X		X			X		X		X
Is the feature posing any risk to public safety?	X			X		X		X		X		X	X	
Does water appear to be proceeding through the system as intended by design?	X		X		X		X			X		X		X
Is litter and visible coarse pollutants being removed early in the system?	X		X		X		X			X	X		X	
Does excess stormwater in intense rain events by pass to an outfall structure as required?	X		X		X		X			X		X	X	
Can the system be considered Operational?	X		X		X		X			X		X		X

TABLE II
FINAL COMMENT ON OPERATIONAL PERFORMANCE FOR EACH SITE

Site No	Comments
Site 1	The majority of the system is operating as intended. Maintenance works are required to improve performance of the feature and bring it back to operating at best practice standards WSUD FEATURE CONSIDERED OPERABLE
Site 2	The system operating as intended WSUD FEATURE CONSIDERED OPERABLE
Site 3	The system operating as intended WSUD FEATURE CONSIDERED OPERABLE
Site 4	The system requires clearing of sediment at inlet point to perform at optimum efficiency WSUD FEATURE CONSIDERED OPERABLE
Site 5	The system requires urgent maintenance and re-instatement to perform as intended. Clearing of the systems sediment built up, waste and litter collection, clearing of obstructions at inlet points and re-instatement of bollards and dead plant life should contribute to operational performance improvement of the system WSUD FEATURE CONSIDERED INOPERABLE
Site 6	The system requires urgent maintenance to perform as intended. Clearing of the systems sediment built up, and 'flush out' of the pipe network is required WSUD FEATURE CONSIDERED INOPERABLE
Site 7	System appears to be diverting all harvested storm water. The entire system appears to be blocked, as pits are full of water and direction of grass on swale demonstrate large amounts of water flow WSUD FEATURE CONSIDERED INOPERABLE

TABLE III
MAINTENANCE CHECKLIST

Inspection Items	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6		Site 7	
	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
Sediment accumulation at inflow points?	X			X	X		X		X					X
Litter within swale?	X		X			X		X	X		X			X
Erosion at inlet or other key structures (e.g. crossovers)?	X			X		X		X		X				X
Traffic damage present?		X		X		X		X	X					X
Evidence of dumping (e.g. building waste)?		X		X		X		X	X			X		X
Vegetation condition satisfactory (density, weeds)?		X		X	X		X			X				X
Replanting required?	X			X		X		X	X					X
Mowing required?		X		X				X		X			X	
Clogging of drainage points (sediment or debris)?	X			X				X	X			X	X	
Evidence of ponding?	X			X		X		X	X		X			X
Set down from kerb still present?	X		X				X		X				X	
Damage/vandalism to structures present?		X		X		X		X	X			X		X
Surface clogging visible?	X			X		X		X		X		X		X
Drainage system inspected?		X		X		X	X		X		X		X	
Re-mulching of trees and shrubs required?		X		X				X		X				X
Soil additives or amendments required?	X			X				X	X					X
Pruning and/or removal of dead or diseased vegetation required?	X			X				X	X					X
Resetting of system required?	X			X		X		X	X					X

TABLE IV
FINAL COMMENT ON MAINTENANCE STATUS ON EACH SITE

Site No	Comments
Site 1	A number of swales require extensive maintenance to improve water flow and performance of features
Site 2	Only weed and litter removal within the swale is necessary
Site 3	No maintenance required
Site 4	Cleaning of inflow point is required
Site 5	Large amounts of Maintenance required bringing the system back to operating standards. Multiple third party influences occurring including, waste dumping, vandalism of bollards and swales, diversions at inflow points. Action to be discussed and implemented Plant, litter, waste and mud removal required. Re-establishment of bollards and bioretention material required
Site 6	Large build up of Sediment at the inflow point is a significant problem and it is effecting the operation of the system. Overflow piping from the Sediment tank is not working. Water level is above pipes with no outflow occurring. Blockage in Outflow pipe assumed. Large amount of aquatic plants and grass is growing in Sediment and Bio-retention tanks. Removal required. Sedimentation tank has a water capacity of approximately 40% full with no outflow occurring.
Site 7	Major visible problem is the overgrown grass. Blockage in system may also be possible due to the water being retained in pit and not flowing through system

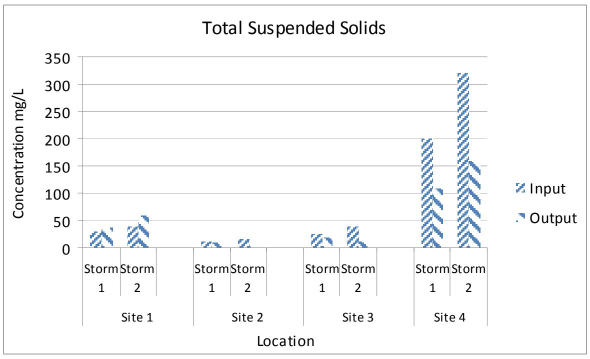

Fig. 5 Total Suspended Solids concentrations at each site

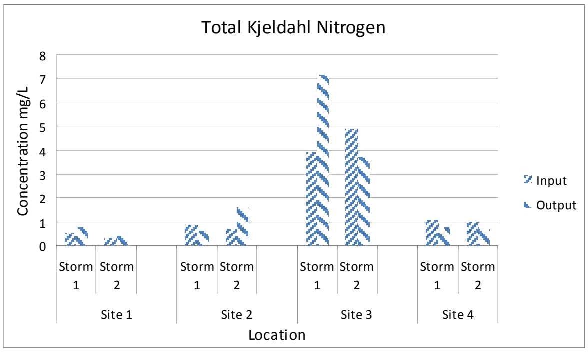

Fig. 6 Total Kjeldahl Nitrogen concentrations at each site

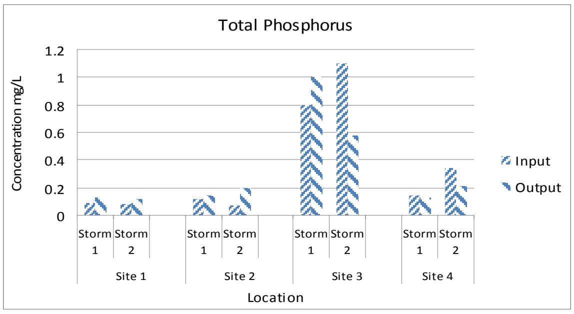

Fig. 7 Total Phosphorus concentrations at each site

The water quality values were measured upstream and downstream. The removal efficiencies were used to determine the percentage removal of TSS, TN, TP and heavy metals using Equation 1. The summary of water quality testing results given in Table 5 demonstrates the effectiveness of the WSUD feature in treating and reducing the pollutant concentrations of the harvested untreated stormwater.

$$\text{Removal}(\%) = \frac{\text{Concentration}_{\text{input}} - \text{Concentration}_{\text{output}}}{\text{Concentration}_{\text{input}}}$$

Equation 1

The Sites 1, 2 and 4 are installed with Bio-retention swales and rain gardens and Site 3 has a tree pit. According to Figures 6 to 8 and detailed in Table 5 depict TSS, TN, TP and some heavy metal concentrations have increased in both storms for Site 1 where as for Site 4, TSS, nutrients and for most of the heavy metals the concentrations have reduced.

A closed examination of Site 1 showed that:

- There is sediment accumulation at inflow point and removal of leaves and litter is required
- There is erosion of the swales due to surface clogging and plant overgrowth diverting the water
- Weeds are present and there is an overgrowth of vegetation
- Replanting of dead plants is recommended
- Clogging of drainage points and evidence of pooling due to leaf and litter accumulation at inflow point
- Soil additives or amendments required to re-establish soil washed away by erosion
- Pruning of overgrown swale vegetation is required

In contrast, Site 4 only needs removal of some concrete material and sediment that is present at inflow point. The Sites 2 and 3 gave mixed results for TSS TN & TP concentrations. For above 2 sites almost all heavy metal concentrations in water have increased from input to output for the second storm. There were no major maintenance requirements in Sites 2 and 3, except that weed and litter removal within the swale in Site 2 and there was slight sludge build up in inflow pit at Site 3.

Reasons for the concentration levels of the output stormwater to be higher than the input are considered due to the following reasons:

- Complete filter media saturation: the filter media could be completely clogged with sediment and fine pollutant particle, so it does not have the ability or capacity to retain any further pollutant particles
- Inability for water to penetrate through the surface, conveying the stormwater directly to the overflow pit by passing the filter medium.
- Excessive litter and debris in the swale my reduce the level of treatment and increase pollutant concentrations of the storm water as it passes over the swale.
- Pollutant uptake from plants may be at a minimum. This could be due to the winter season or the plants may be too old incapable of pollutant/ nutrient uptake.
- The in-situ system may have a saturated hydraulic conductivity (K) which meets or exceeds the currently recommended range of 50 to 200 mm/h.
- Increases in pollutant concentration can be a result of the filtration system not experiencing a steady water flow due to the lack of rain, therefore pollutants are stored and ‘flushed out’ in the early rain events in the winter season. Reason unlikely due to consistent results explained in the separate water quality tests results
- Inadequate maintenance plan, and post construction establishment of the WSUD feature.

TABLE V
PERCENTAGE REDUCTIONS (OR INCREASES) IN WATER QUALITY PARAMETERS BETWEEN INLET AND OUTLET PITS (-VE - REDUCTION AND +VE - INCREASE)

	Site 1		Site 2		Site 3		Site 4	
	Storm 1	Storm 2	Storm 1	Storm 2	Storm 1	Storm 2	Storm 1	Storm 2
SS mg/L	23	55	-33	-81	-31	-71	-45	-50
TN mg/L	60	33	-33	129	85	-25	-27	-30
TP mg/L	44	50	17	186	25	-47	-7	-38
Al mg/L	-40	-66	157	500	-58	278	-19	-19
Boron	50		200	200				
Barium	-64	-56			-39	183	-26	-30
Copper	-54	-60	25	100	-59	233	-22	-20
Iron	-52	-76	-17	440	-63	333	-28	-28
Manganese	-40	-79	-75		-6.7	192	-36	-33
Nickel	-50	-50	100	100	100	100	-33	-25
Lead	-50	-75			-80	733	-20	-20
Strontium	25	56	130	195	100	-33	64	25
Titanium	-31	-55	110	300	-67	183	-28	-27
Zinc	30	294	-73	-40	-38	150	-35	-31

Reasons for the concentration levels of the output stormwater to be higher than the input are considered due to the following reasons:

- Complete filter media saturation: the filter media could be completely clogged with sediment and fine pollutant particle, so it does not have the ability or capacity to retain any further pollutant particles
- Inability for water to penetrate through the surface, conveying the stormwater directly to the overflow pit by passing the filter medium.
- Excessive litter and debris in the swale my reduce the level of treatment and increase pollutant concentrations of the storm water as it passes over the swale.
- Pollutant uptake from plants may be at a minimum. This could be due to the winter season or the plants may be too old incapable of pollutant/ nutrient uptake.
- The in-situ system may have a saturated hydraulic conductivity (K) which meets or exceeds the currently recommended range of 50 to 200 mm/h.
- Increases in pollutant concentration can be a result of the filtration system not experiencing a steady water flow due to the lack of rain, therefore pollutants are stored and 'flushed out' in the early rain events in the winter season. Reason unlikely due to consistent results explained in the separate water quality tests results
- Inadequate maintenance plan, and post construction establishment of the WSUD feature.

Developing, implementing and adhering to an adequate maintenance plan is important to eradicate most, if not all of the issues affecting the performance of the in-situ WSUD features. As a result, the following recommendations are made for future implementation for effective functioning of WSUD features.

- Immediate remedial works to restore existing systems back to its 'as constructed' condition, ensuring they comply with best practice standards
- Establishing and adhering to an adequate maintenance plan for all the WSUD features (see below)
- Completing final installation of the WSUD feature after all surrounding subdivision or project construction is complete or when the contractor activity in the surrounding area is reduced to a minimum.
- Undertake consistent assessments and checks of the performance and condition of the WSUD features
- Address problems identified by field observers promptly
- Continue to consider using new innovative WSUD features and incorporating design alterations
- Establish proper interface management between design and construction personnel. This is to ensure there is no 'Loss of Design Intent' during the construction phase
- Provide education and awareness to the public of the sensitive garden infrastructure in place, including: signage in appropriate areas and availability of website and leaflet information
- Provide training to personnel responsible for the maintenance of the WSUD features. To ensure they employ appropriate care and cleaning techniques and their actions around the feature do not affect its performance.

Appropriate maintenance is essential for the long term viability, performance and aesthetics of any WSUD landscape feature. It should address the following three components:

- Establishment phase maintenance - include the replacement of dead or failing plants, weed and mulch management where appropriate,
- Routine ongoing maintenance – include litter removal, sediment removal, pipe network inspection, weed and plant management; and
- Long term testing and renewal – include the water quality testing and filter media to ensure efficient hydraulic conductivity and pollutant removal.

V. Conclusion

The Municipalities have a core responsibility to incorporate sustainable development and environmental management into its capital works program to improved urban stormwater quality. The adoption of WSUD into new and existing landscapes to demonstrate Municipalities determination to become sustainable infrastructure providers. Neglecting the proper post-construction maintenance of the stormwater treatment systems can result in ineffective performance, including poor pollutant removal and negatively impacting the aesthetics of the urban landscape. It is important for Municipalities to develop and then adhere to a proper Operational and Maintenance plan for optimal use of the constructed WSUD feature through its life cycle.

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