Performance charac-terisation of a constructed wetland

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ABSTRACT

Performance of a constructed wetland is commonly reported as being variable due to the site specific nature of influential factors. This paper discusses the outcomes from an in-depth study which characterised the treatment performance of a wetland based on the variation in the runoff regime. The study included a comprehensive field monitoring of a well-established constructed wetland in Gold Coast, Australia. Samples collected at the inlet and outlet were tested for Total Suspended Solids (TSS), Total Nitrogen (TN) and Total Phosphorus (TP). Pollutant concentrations in the outflow were found to be consistent irrespective of the variation in inflow water quality. The analysis revealed two different treatment characteristics for events with different rainfall depths. TSS and TN load reduction was found to be strongly influenced by the hydraulic retention time where performance was relatively superior for rainfall events below the design event. For small events, treatment performance was higher at the beginning of the event and gradually decreased during the course of the event. For large events, the treatment performance was comparatively poor at the beginning and improved during the course of the event. The analysis also confirmed the variable treatment trends for different pollutant types.

Key words | constructed wetlands, multivariate analysis, stormwater quality, stormwater treatment

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INTRODUCTION

Constructed wetlands commonly form part of a Water Sensitive Urban Design treatment train (Wong *et al.* 1999; Lloyd 2001). Wetlands are particularly effective in the removal of nutrients and other pollutants associated with fine particulates by a range of processes such as settling, filtration, adsorption and biological uptake (Guardo 1999; Ronkanen & Kløve 2008). Performance of a constructed wetland is commonly reported as being variable and site specific. The variable performance of a constructed wetland is largely due to the sensitivity to rainfall characteristics and the corresponding hydraulic conditions which can influence treatment processes at both, spatial and temporal scales, and differently for different pollutant species (Holland *et al.* 2004).

However, knowledge relating to the linkage between constructed wetland performance and influential hydraulic parameters is limited. This is due to the common use of lumped hydraulic and water quality parameters for the analysis of treatment performance and the evaluation of long term treatment performance rather than event based performance. This paper presents the outcomes of a detailed study of a constructed wetland which was investigated to understand the role of influential hydraulic parameters on treatment performance and how treatment performance changes during the course of a rainfall event.

METHODS

Study site

The constructed wetland selected for the study is located at 'Coomera Waters' residential estate, Gold Coast, Australia. The wetland is surface flow type and consists of an inlet pond and two cells of macrophyte zones as the main treatment area. The sizes of the wetland components are inlet pond area of 149 m^2, Cell 1 (upstream macrophyte zone) area of 465 m^2 and Cell 2 (downstream macrophyte zone) area of 653 m^2. The total area is equivalent to 2.06% of the contributing catchment area of 6.15 ha. The wetland receives runoff from two sub-catchments (see Figure 1) of

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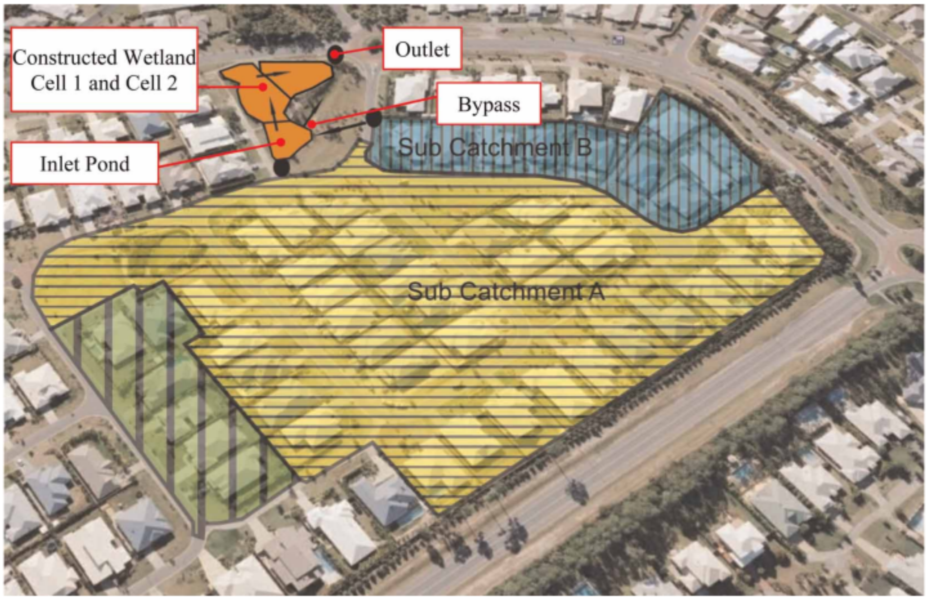

Figure 1 | Study site showing the constructed wetland and contributing catchments (adapted from Parker *et al.* (2009))

area 5.10 ha (sub-catchment A) and 1.05 ha (sub-catchment B). The two inlets to the wetland and the single wetland outlet and the bypass outlet have been monitored since April 2008 using automatic monitoring stations to record rainfall and runoff data and to capture stormwater samples for water quality testing. Refer to Parker *et al.* (2009) for further details regarding the automatic monitoring stations and sample collection protocol.

Sampling and testing

Only runoff samples from rainfall events with more than five antecedent dry days were tested. This was to allow an appreciable amount of pollutants to be built-up on catchment surfaces. Egodawatta *et al.* (2006) have found that a minimum of five antecedent dry days can result in more than 75% of the maximum possible build-up on road surfaces. Samples were analysed for a suite of water quality parameters, as shown in Table 1 given below. Further details of the sampling protocol are explained in Mangangka *et al.* (2012) and Parker *et al.* (2009).

Table 1 | Test parameters and analytical methods used

Parameter	Test Method	Comments
TSS	APHA No. 2540D (APHA 2005)	Filtered using 0.45 μm glass fibre filter paper
TN as TKN + NO_2 + NO_3	TKN: US EPA No. 351.2 (US EPA 1993a). NO_2: US EPA No. 353.2 (US EPA 1993b). NO_3 : US EPA No. 354.1 (US EPA 1971)	Smartchem 140 instrument was used. For TKN, samples were digested using AIM600 block digester
TP	US EPA No. 365.1 (US EPA 1983)	Smartchem 140 instrument was used. Samples digested using AIM600 block digester

Constructed wetland conceptual model

A conceptual model was developed to replicate the hydraulic behaviour of the wetland. Greater details on the conceptual model development, calibration and simulation are explained in Mangangka *et al.* (2012). The conceptual model was primarily a combination of equations representing typical hydraulic devices, storages and channels and arranged in such a way as to collectively mimic the hydraulic response of the wetland system. The primary steps in the conceptual model developed are outlined below:

- The three basic elements of the constructed wetland, inlet pond, Cell 1 and Cell 2, were replicated using water balance equations typically used for storage device modelling.

- Inflow from the contributing catchments and direct precipitation were considered as inputs. Measured inflows were considered as the inflow from the contributing catchment. Measured rainfall was used to estimate direct precipitation.
- Outflow through the outlet structure, bypass flow, percolation and evaporation were considered as outflows. Each outflow was modelled based on equations commonly used in hydraulic engineering.

The model was used to generate hydraulic parameters based on simulations in order to undertake performance evaluation of the wetland. In this regard, four influential variables, average retention time (RT), outflow peak (OP), volume treated (VT) and average depth of the wetland (AD), were identified as being the primary influential parameters.

Analytical tools

The analytical tools were selected based on their ability for processing a multi-variable data set to investigate relationships between the objects and the variables. Among the range of multivariate techniques available, principal component analysis (PCA) was the most appropriate for this analysis (Kokot et al. 1998). PCA is essentially a pattern recognition technique which can be used to understand the correlations among different variables and clusters among objects. It has been used extensively as an analytical tool in water quality research (Liu et al. 2012; Miguntanna et al. 2010; Gunawardana et al. 2011).

PCA transforms the original variables to a new orthogonal set of principal components (PCs) such that the first PC contains most of the data variance and the second PC contains the second largest variance and so on. Outcomes of PCA are typically presented as a biplot, which is a plot of two orthogonal PCs illustrating object scores and variable vectors (Goonetilleke et al. 2005). The objects that exhibit similar variances for the analysed variables have similar PCA scores forming a cluster when plotted on a biplot. Additionally, strongly correlated variables have the same magnitude and orientation when plotted, whereas uncorrelated variables are orthogonal to each other. Detailed descriptions of PCA can be found elsewhere (Adams 2004; Kokot et al. 1998).

RESULTS AND DISCUSSION

Analysis of event mean concentrations of inflow and outflow water quality

PCA was initially undertaken to investigate the treatment characteristics of the constructed wetland using the event mean concentration (EMC) values at the two inlets and the outlet. Pollutant parameters used were Total Suspended Solids (TSS), Total Nitrogen (TN) and Total Phosphorus (TP). Data from 11 storm events were investigated which formed a matrix with 33 objects due to the presence of three sampling locations. The resulting PCA biplot is shown in Figure 2.

As shown in Figure 2, EMC values for the two inlets are clustered into distinct regions and labelled as Cluster A and Cluster B. This suggests that inflow water quality characteristics from sub-catchment A and sub-catchment B are different, which is attributed to the differences in catchment characteristics such as area and impervious surface percentage (Liu et al. 2012, 2013). Objects representing outflow are clustered separately (Cluster C). Clustering of objects clearly illustrate the functioning of the wetland as a stormwater treatment device. Orientation of variables (vectors) is in the direction of inflow water quality objects indicating the relatively high pollutant concentrations in the inflow water. Outflow water quality objects are clustered opposite to the direction of most variables

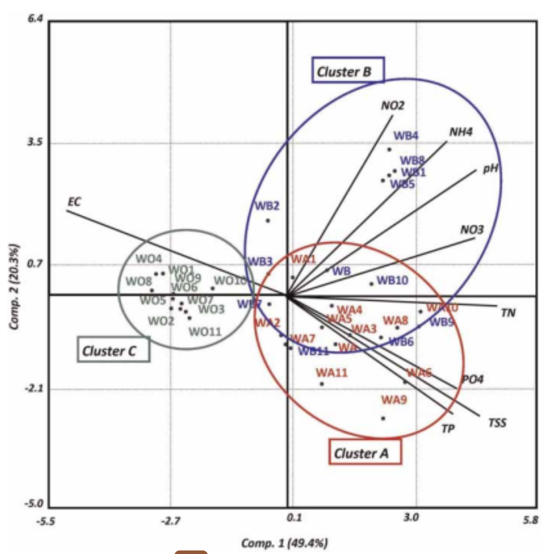

Figure 2 | PCA biplot for pollutant event mean concentrations at the inlets and outlet.

indicating lowered concentration due to the treatment action of the wetland.

As evident in Figure 2, outflow objects are clustered closely, indicating no significant variation in water quality. This suggests that outflow quality from the constructed wetland falls into a narrow range irrespective of the inflow quantity and quality. The functioning of a constructed wetland in this manner is beneficial to the downstream ecosystem as fluctuations in pollutant concentrations can have detrimental consequences.

Analysis of changes in pollutant concentrations

Analysis of the performance of the constructed wetland was undertaken based on the reduction in EMC values. Though, outflow water quality was consistent, the percentage reduction was not consistent due to the variability of inflow water quality. Table 2 shows the percentage concentration reductions (for example TSS-R is the percentage EMC reduction for TSS) for the 11 storm events. The percentage was calculated with respect to inflow water quality. As evident in Table 2, TSS concentration reduction varies from 7 to 92% with an average of 57% for the monitored storm events. Average concentration reductions for TN and TP are 29 and 30%, respectively.

PCA was undertaken to assess the stormwater treatment performance of the wetland based on the reductions in EMC values. For this analysis, four influential hydraulic parameters were also included in order to investigate the linkage between treatment performance with the underlying flow scenarios in the constructed wetland. The four variables selected were average RT, OP, VT and average water depth in the wetland (AD). The resulting PCA biplot is shown in Figure 3.

In Figure 3, objects representing the monitored storm events are in two clusters. With reference to event data presented in Table 2, Cluster D, which contains objects such as W2 and W6, represents comparatively large events and Cluster E, which contains events such as W5 and W8, represents comparatively small events. Storm events were considered as falling into three categories: large, medium and small. Events belonging to large and small events are located a distant apart along the PC1 axis. This suggests that the treatment performance of the constructed wetland is significantly different for storm events above and below the adopted design event.

As shown in Figure 3, TSS-R and TN-R correlate with AD and RT as these vectors form an acute angle with each other. Additionally, the vectors also point towards objects in Cluster E. This suggests that TSS and TN concentration reduction is high for events that result in a relatively longer RT. Such a hydraulic scenario is possible for relatively smaller rainfall events. Accordingly, it can be postulated that processes such as settling and nitrification are dominant treatment processes for such events.

On the other hand, TP-R correlates with VT and negatively correlates with RT (vectors forming an obtuse angle). This suggests that a high reduction in TP concentration occurs when a high volume of stormwater flows into the constructed wetland. This is postulated to be due to high TP wash-off during large events. It has been

Table 2 | Pollutant concentration reduction and relevant hydraulic parameters

Event ID	Rainfall category	EMC reduction (%) TSS-R	TN-R	TP-R	Average retention time (RT) (day)	Outflow peak (OP) (L/sec)	Volume treated (VT) (m^3)	Average depth (AD) (m)
W1	Small	81	62	61	3.17	1.2	98	0.35
W2	Large	92	11	71	2.93	2.3	493	0.46
W3	Large	86	42	89	2.70	2.7	524	0.54
W4	Medium	64	3	42	6.29	1.1	168	0.25
W5	Small	67	22	−4	6.73	0.8	44	0.27
W6	Large	19	16	10	2.65	2.5	594	0.45
W7	Medium	59	23	−3	3.33	1.8	383	0.40
W8	Small	79	32	−1	4.52	1.0	93	0.28
W9	Medium	62	51	4	3.87	1.5	228	0.33
W10	Medium	7	40	18	2.18	2.5	251	0.50
W11	Medium	13	14	50	2.42	2.2	255	0.44

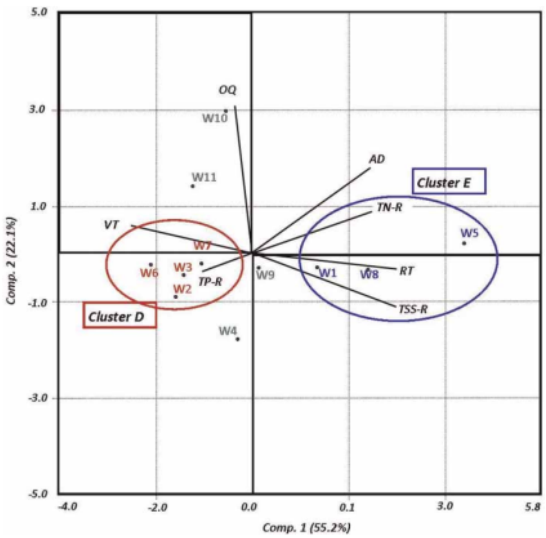

Figure 3 | PCA biplot for changes in pollutant concentrations and hydraulic parameters.

previously reported that phosphorus is mostly associated with comparatively larger particle size ranges with relatively greater wash-off taking place during higher intensity rainfall events (Miguntanna *et al.* 2013). The negative correlation of TP-R with RT also suggests that TP retention is not influenced by RT. This could be due to the high fraction of TP association with particles with high settling potential where relatively long RT is not required.

Analysis of load reduction

Analysis of treatment performance based solely on concentration reductions could potentially lead to misleading conclusions. In the context of ecosystem protection, pollutant load reduction is also important. The analysis of pollutant load reduction was undertaken on the basis of variation in treatment performance within the course of a rainfall event. For this purpose, data from each event was separated into 10 equal segments by interpolating between data points. Prior to interpolation, it was verified that the selected events were sampled with adequate frequency to capture the variations in water quality. The influential hydraulic parameters relevant to the analysis were generated using the conceptual model developed and discussed previously.

Figure 4(a) shows the resulting PCA biplot. Due to the close clustering of objects and the resulting difficulty in interpretation, a reduced data matrix comprising comparatively large (Cluster D in Figure 3) and comparatively small events (Cluster E in Figure 3) was used for further analysis. Additionally, only three pollutant species, TSS, TN and TP, and the two most influential hydraulic parameters (RT, AD) were used. The resulting PCA biplot is shown in Figure 4(b).

As evident in Figure 4(b), data points corresponding to large events (such as W3 and W6) are located in the +ve PC1 direction and show comparatively which high correlation with vectors representing pollutant reductions. TSS,

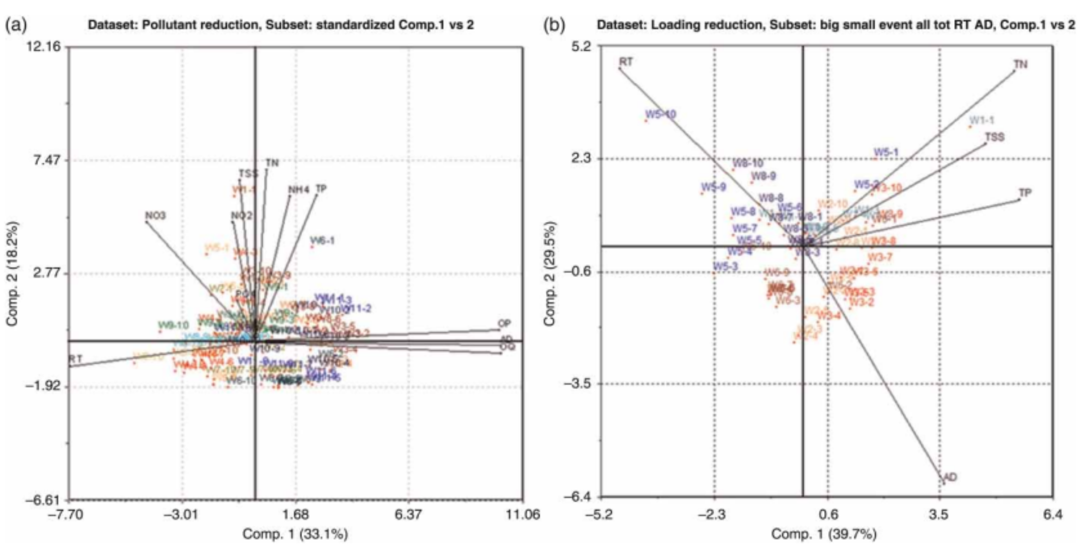

Figure 4 | Biplot of pollutant load reductions (a) for all events (b) for selected events.

TN and TP vectors also show a high loading in the +ve PC1 direction. This is primarily attributed to the presence of high pollutant loads in large events and fairly consistent effluent quality as pointed out in the section 'Analysis of Event Mean Concentrations of Inflow and Outflow Water Quality'. Importantly, there is a distinct pattern in the distribution of objects for large and small events. Large events, for example event 3, show a scattering of objects from the –ve PC2 to the +ve PC2 direction as the event progresses. The pattern is different for small events which are mostly located in the –ve PC1 direction. This suggests that the treatment performance during the course of a rainfall event is a function of the runoff volume received. To understand this phenomenon better, the percentage pollutant load reduction is plotted in Figure 5.

As evident in Figure 5, for small events, treatment performance is higher at the beginning and gradually decreases during the course of the event. This suggests that runoff from a small event initially flushes already treated water in the wetland until mixing occurs at a later stage. For large events, the treatment performance is poor at the beginning and improves during the course of the event. This is attributed to the rapid mixing of inflow with wetland water and re-suspension of pollutants due to rapid hydraulic changes within the wetland at the initial stage of the event. As the event progresses, rapid settling of large particles and associated pollutants points to an improvement in treatment. The analysis also confirmed the variable treatment trends for different pollutant types. For TSS and TN, it indicated similar treatment performance for events less than the adopted design event, whilst the treatment performance for TSS and TP are similar for events higher than the adopted design event.

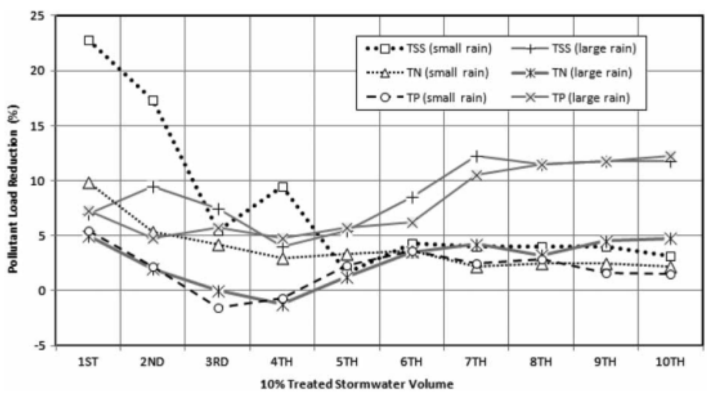

Figure 5 | Variation in percentage load reduction within the course of a rainfall event.

CONCLUSIONS

The primary conclusions from the study are as follows:

- Treatment characteristics of the constructed wetland show significant reduction in TSS, TN and TP event mean concentration values compared to inflow water quality. Pollutant concentrations in the outflow are relatively consistent irrespective of the significant variation in inflow water quality observed.
- Treatment performance of the constructed wetland was significantly different for large and small events. TSS and TN load reduction is strongly influenced by hydraulic RT where performance is higher for rainfall events below the design event.
- TP load retention is strongly influenced by the characteristics of TP wash-off from catchment surfaces. TP was found to be associated with particles with high settling ability where a long RT is not required for removal.
- For small events, treatment performance is higher at the beginning of the event and gradually decreases during the course of the event. This suggests that the runoff from small events flushes already treated water at the beginning and undergoes mixing to create poor outflow quality at the later stages.
- For large events, the treatment performance is comparatively poor at the beginning and improves during the course of the event. This is attributed to rapid mixing of inflow with wetland water and re-suspension of pollutants due to rapid hydraulic changes within the wetland at the initial stage. Removal of large particles and associated pollutants during the course of the event reflects an improvement in performance at the later stages of the event.

- TSS and TN indicated similar treatment trends for small events, whilst the treatment performances for TSS and TP are similar for large events.

REFERENCES

Adams, M. J. 2004 *Chemometrics in Analytical Spectroscopy*. Royal Society of Chemistry, Cambridge.

APHA 2005 *Standard Methods for the Examination of Water and Waste Water*. American Public Health Association, Washington, DC.

Egodawatta, P., Goonetilleke, A., Ayoko, G. A. & Thomas, E. 2006 Understanding the interrelationship between stormwater quality and rainfall and runoff factors in residential catchments. In: *7th International Conference on Urban Drainage Modelling and the 4th International Conference on Water Sensitive Urban Design*, Melbourne, Australia, pp. 43–50, http://eprints.qut.edu.au/4037/.

Guardo, M. 1999 Hydrologic balance for a subtropical treatment wetland constructed for nutrient removal. *Ecological Engineering* **12**, 315–337.

Goonetilleke, A., Thomas, E., Ginn, S. P. & Gilbert, D. 2005 Understanding the role of land use in urban stormwater quality management. *Journal of Environmental Management* **74** (1), 31–42.

Gunawardana, C., Goonetilleke, A., Egodawatta, P., Dawes, L. & Kokot, S. 2011 Role of solids in heavy metal pollution of receiving waters. *Journal of Environmental Engineering* **138**, 490–498.

Holland, J. F., Martin, J. F., Granata, T., Bouchard, V., Quigley, M. & Brown, L. 2004 Effects of wetland depth and flow rate on residence time distribution characteristics. *Ecological Engineering* **23**, 189–203.

Kokot, S., Grigg, M., Panayiotou, H. & Phuong, T. D. 1998 Data interpretation by some common chemometrics methods. *Electroanalysis* **10** (16), 1–8.

Liu, A., Egodawatta, P., Guan, Y. & Goonetilleke, A. 2013 Influence of rainfall and catchment characteristics on urban stormwater quality. *Science of the Total Environment* **444**, 255–262.

Liu, A., Goonetilleke, A. & Egodawatta, P. 2012 Inadequacy of land use and impervious area fraction for determining urban stormwater quality. *Water Resources Management* **26** (8), 2259–2265.

Lloyd, S. D. 2001 *Water Sensitive Urban Design in the Australian Context*. Cooperative Research Centre for Catchment Hydrology, Monash University, Melbourne, Australia.

Mangangka, I. R., Egodawatta, P., Rajapakse, J. & Goonetilleke, A. 2012 Understanding treatment characteristics of constructed stormwater wetlands. In: The 2012 Hydrology & Water Resources Symposium, Sydney, Australia, http://eprints.qut.edu.au/55219/.

Miguntanna, N. S., Egodawatta, P., Kokot, S. & Goonetilleke, A. 2010 Determination of a set of surrogate parameters to assess urban stormwater quality. *Science of the Total Environment* **408** (24), 6251–6259.

Miguntanna, N. P., Liu, A., Egodawatta, P. & Goonetilleke, A. 2013 Characterising nutrients wash-off for effective urban stormwater treatment design. *Journal of Environmental Management* **120**, 61–67.

Parker, N., Gardner, T., Goonetilleke, A., Egodawatta, P. & Giglio, D. 2009 Effectiveness of WSUD in the 'real world'. In: *Proceedings of the 6th International Water Sensitive Urban Design Conference*, Perth, Western Australia, http://eprints.qut.edu.au/26520/.

Ronkanen, A. K. & Kløve, B. 2008 Hydraulics and flow modelling of water treatment wetlands constructed on peatlands in Northern Finland. *Water Research* **42**, 3826–3836.

US EPA 1971 *Method 354.1: Determination of Nitrite Nitrogen by Automated Colorimerty (EPA/600/4–79/020)*. US Environmental Protection Agency, Washington, DC.

US EPA 1983 *Method 365.4: Phosphorus, total (Colorimetric, Automated, Block Digester AA II) (EPA/600/4-79/020)*. US Environmental Protection Agency, Washington, DC.

US EPA 1993a *Method 351.2: Determination of Total Kjeldahl Nitrogen by Semi Automated Colorimetry (EPA/600/4-79/020)*. US Environmental Protection Agency, Washington, DC.

US EPA 1993b *Method 354.1: Determination of Nitrate Nitrogen by Automated Colorimerty (EPA/600/4-79/020)*. US Environmental Protection Agency, Washington, DC.

Wong, T. H. F., Breen, P. F., Somes, N. L. G. & Lloyd, S. D. 1999 *Managing Urban Stormwater Using Constructed Wetlands*. Cooperative Research Centre (CRC) for Catchment Hydrology and Department of Civil Engineering, Monash University, Melbourne, Australia.

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