# Performance of Constructed Wetland on Nutrient Removal in Tropical Climate

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## ABSTRACT
Better urban stormwater quality can be achieved through a constructed wetland before discharge into rivers. Originally, urban stormwater carries varying pollutants that influence the aquatic ecosystem and environmental well-being. Rehabilitation of constructed wetlands in Universiti Sains Malaysia (USM) has been carried out in 2012 based on the design criteria and requirement as specified in MSMA 2nd Edition. The main focus of this research is to investigate the potential of constructed wetlands in enhancing urban stormwater quality through the removal of nutrients. In this study, the highest percentage removal of total nitrogen and total phosphorus was found in Cell 4 and Cell 1 which is 18.56 and 23.79%, respectively. The removal efficiency of total nitrogen and total phosphorus for constructed wetlands was 20.13 and 35.18%, respectively. Selection of the appropriate macrophyte, macrophyte zone bathymetry and hydraulic residence time are vital to enhance the stormwater quality in terms of total nitrogen and total phosphorus. Therefore, constructed wetlands can be used as an alternative to enhance the water quality of stormwater urban runoff before discharge into the receiving water bodies.

## KEYWORDS
Urban stormwater management, constructed wetland, nutrient removal, BIOECODS

## INTRODUCTION
Urban stormwater will carry varying pollutant, especially nitrogen and phosphorus due to nature and human activities such as landscaping and agriculture activities into the river (Wu and Chen, 2013). Water contaminated with nutrient will lead to deterioration of water quality through algal blooms or eutrophication and poses risk to public health and environmental well being (Munn *et al*., 2010). However, in order to treat the pollutant form urban stormwater, large catchment area is needed before the pollutant been discharged into the river water body. That is why constructed wetlands were being used and were usually built near the river. Constructed wetland had increasingly been used worldwide due to economical way as pollutant treatment, especially stormwater and wastewater such as in Malaysia, China and USA (Sim *et al*., 2008; Mangangka *et al*., 2013; Sundari *et al*., 2013). In Malaysia, Sim *et al*. (2008) indicate that constructed wetland can remove approximately 82.11% and 84.32% of total nitrogen and phosphate, respectively. Lim *et al*. (2001) had reported that the percentage removal of nitrogen in constructed wetland was 22%. Mohd. Noor (2009) found that total phosphorus removal was ranged in between 24% to 46% after throughout the constructed wetland.

Generally, there are three types of treatments that use in constructing wetlands namely, surface flow constructed wetlands, horizontal subsurface flow constructed wetlands and vertical flow constructed wetland. Usually, there are three types of macrophyte or plant that will be used as substrate in constructed wetlands namely, floating plant, submerged plant and emergent plant. The free water surface constructed wetland will have an open water area and seem like natural marshes (Kadlec and Wallace, 2008). According to the Urban Stormwater Management Manual for Malaysia or "Manual Saliran Mesra Alam" (MSMA 2nd Edition), constructed wetlands comprising of three main zones, namely, inlet zone, macrophtye zone and open water zone (DID, 2012). The macrophyte zone is proven play an essential component as pollutant removal in constructed wetland (Brix, 1997). This is due to a large surface area provided by macrophyte for microbial growth and supply oxygen in the rhizosphere. In addition, macrophyte reduces the current velocity and stabilized the bed surface. Therefore, the aim of this study is to investigate the potential of constructed wetlands in enhancing urban stormwater quality through removal of total nitrogen and total phosphorus.

The constructed wetlands at Universiti Sains Malaysia (USM) Engineering Campus, Nibong Tebal, Penang, had been studying for the performance of total nitrogen and total phosphorus removal in constructed wetlands under tropical climate. The area of USM Engineering Campus is about 320 acres and mainly made up of oil palm plantation land and is fairly flat. In Malaysia, Universiti Sains Malaysia (USM) Engineering Campus was carried out a national pioneer project based on the 1st Edition of MSMA, namely, Bio-Ecological Drainage System (BIOECODS) and the design was continuously improved in 2nd Edition of MSMA (Shaharuddin *et al*., 2013). BIOECODS consists of a series of component, namely ecological swales, on-line sub-surface detentions, dry pond, wet pond, detention pond, constructed wetlands, wading stream and a recreational pond. The combination of this component will increase runoff lag time, increase pollutant removal and reduce the rate and volume of runoff (Zakaria *et al*., 2003; Ab. Ghani *et al*., 2004).

## METHODS

Rehabilitation of constructed wetland in USM has been carried out in the year 2012 based on the design criteria and requirement as specified in MSMA 2nd Edition, 2012. A constructed wetland in BIOECODS as shown in Figure 1 consists of two zones, namely, macrophyte zone and open water zone and each zone took up 80% and 20% of the total constructed wetland area. In macrophyte zone consists various species, namely, *Elocharis variegata*, *Scirpus grossus*, *Phragmite karka*, *Typha angustifolia*, *Lepironia articulate* and *Hanguana malayana*. The sampling of water on constructed wetland started on June 2013 until December 2013 based on rainfall event. Samples were collected from Inlet, Cell 1, Cell 2, Cell 3, Cell 4 and Outlet. In every cell, there had three points of sampling.

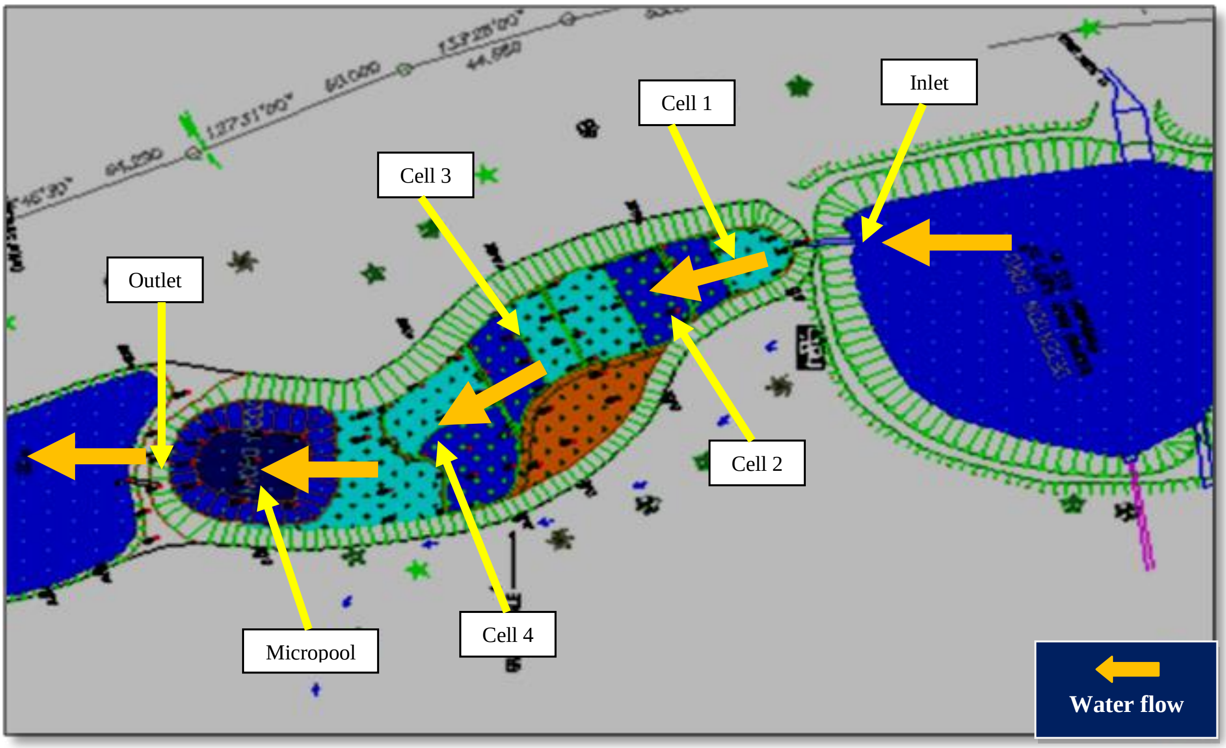


**Figure 1.** Constructed wetland at Universiti Sains Malaysia (USM) Engineering Campus.

The water samples were taken using grab sampling method and were preserved at freezer prior to analysis. In-situ measurement of temperature and pH were conducted using a YSI 60 and for velocity measurement by using Marsh Mcbirney Flo-mate TM Model 2000. The laboratory analysis of total nitrogen (TN) and total phosphorus (TP) were carried out to determine the concentration by referring Method 10071, Persulfate Digestion Method and Method 8190, PhosVer® 3 with Acid Persulfate Digestion Method (HACH, 2013), respectively. The testing was conducted in three replicate at laboratory by following the standard method which complies with the standard of the American Public Health Association (APHA), 1998. The percentage of removal on each sampling by rainfall event was determined using the equation as follow:

$$Percentage\ of\ removal, \% = \frac{C_{in} - C_{out}}{C_{in}}\ x\ 100$$

where $C_{in}$ and $C_{out}$ are the concentration of influent and effluent of the cell. Data analysis was conducted using Microsoft Excel.

## RESULTS AND DISCUSSION

The water quality results in term of TN and TP for constructed wetland showed that water quality normally improved throughout the constructed wetland as shown in Table 1.

Table 1. Mean ± Standard deviation for TN and TP throughout constructed wetland.

| | Macrophyte | Marsh | Velocity (m/s) | TN (mg/L) | TP (mg/L) |
|---|---|---|---|---|---|
| Inlet zone | | | 0.18 ± 0.13 | 1.90 ± 0.99 | 0.50 ± 0.07 |
| Cell 1 | *Eleocharis variegata* | High | 0.04 ± 0.02 | 1.85 ± 0.94 | 0.38 ± 0.09 |
| Cell 2 | *Scirpus grossus* | High | 0.04 ± 0.02 | 1.78 ± 0.90 | 0.39 ± 0.08 |
| | *Phragmites karka* | Low | | | |
| Cell 3 | *Typha angustifolia* | Low | 0.03 ± 0.01 | 1.80 ± 0.85 | 0.40 ± 0.10 |
| | *Scirpus grossus* | High | | | |
| | *Lepironia articulata* | High | | | |
| Cell 4 | *Lepironia articulata* | Low | 0.04 ± 0.01 | 1.47 ± 1.04 | 0.36 ± 0.10 |
| | *Eleocharis variegata* | Low | | | |
| | *Eleocharis variegata* | High | | | |
| | *Hanguana malayana* | Low | | | |
| Outlet zone | *Typha angustifolia* | High | 0.28 ± 0.20 | 1.52 ± 0.86 | 0.32 ± 0.09 |

Based on the obtained result, the influent concentration of TN at the inlet was in the range of 0.20 mg/L until 5.43 mg/L while the effluent concentration of TN at the outlet was in the range of 0.10 mg/L until 5.20 mg/L. The influent concentrations of TN were characterized by a general trend of decreasing, increasing and decreasing again during the period evaluated. Overall performance of constructed wetland showed the decreasing trend of TN concentration with the percentage removal was 20.13% as shown in Figure 2.

The results obtained from this study also showed the influent concentration of TP at the inlet was in the range of 0.19 mg/L until 0.88 mg/L while the effluent concentration of TP at the outlet was in the range of 0.19 mg/L until 0.42 mg/L. The influent concentrations of TP were characterized by a general trend of decreasing, increasing and decreasing again during the period evaluated. Overall performance of constructed wetland showed the decreasing trend of TP concentration with the percentage removal was 35.18% as shown in Figure 2.

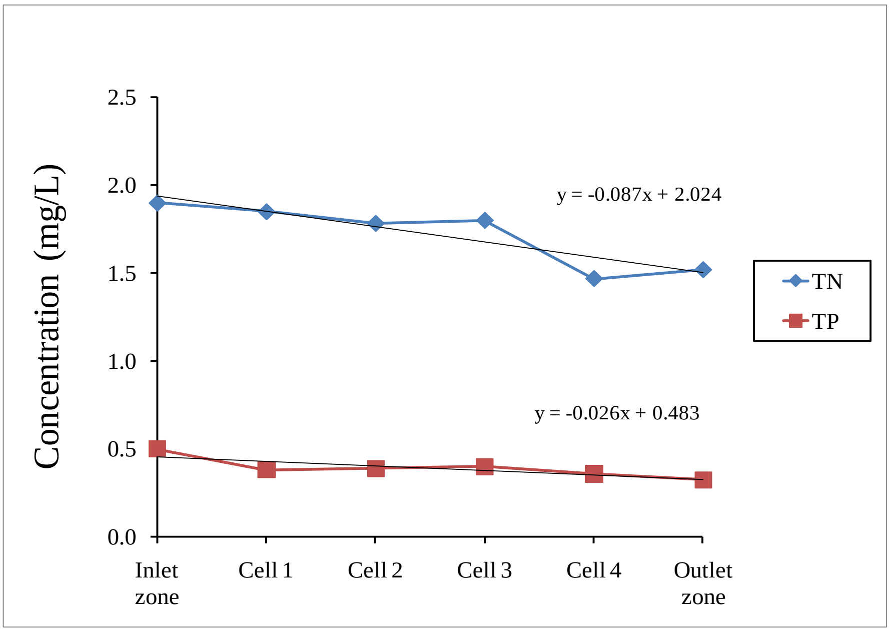


Figure 2. Trend of TN and TP concentration passing through the constructed wetland.

Despite of this, there were many factors that influence the trend of decreasing or increasing the concentration of TN and TP as shown in Table 2.

Table 2. Factors that influence the concentration of TN and TP.

| Factor influencing the concentration | TN | TP |
|---|---|---|
| Uptake by macrophyte | Yes | Yes |
| Bathymetry of macrophyte zone | Yes | Yes |
| Hydraulic residence time | Yes | Yes |
| Animal waste | Yes | Yes |
| Inflow from side of constructed wetland | Yes | Yes |

The role of macrophyte in TN and TP uptake had been proven in many studies (Sim *et al*., 2008; Mohd. Noor, 2009; Mangangka *et al*., 2013; Sundari *et al*., 2013). In this study, six species of macrophyte had been planting in constructed wetlands. The highest removal of TN was shown from Cell 4 which is 18.56%. Cell 4 consists of three species of macrophyte namely, *Lepironia articulate*, *Eleocharis variegata* and *Hanguana malayana*. However, further study is needed in order to know which species of macrophyte have the capability in uptake of TN. Then, the highest removal of total TP was shown from Cell 1 which is 23.79%. *Eleocharis variegata* had shown their capability in order to uptake phosphorus in this study as only one species of macrophyte had been planted in Cell 1. Then again, further study is needed in order to know whether the removal were contributed by macrophyte itself or there have the other factor.

Next, the bathymetry of macrophyte zone also can affect the removal of TN and TP in term of high and low marsh zone which can be defined by water depth. According to MSMA 2nd Edition, high marsh zone is from 0.30m below the pool to the normal pool elevation while the low marsh zone is from 0.30m to 0.60 m below the normal permanent pool elevation or water surface elevation (DID, 2012). In this study, TN was shown the highest removal in Cell 4 where consist of one macrophyte is being planted in high marsh and three macrophytes were being planted in low marsh while TP was shown the highest removal in Cell 1 where consist of only high marsh zone. The type of bathymetry macrophyte zone might be influencing the TN and TP removal by settlement into soil. Therefore, further study is needed to find how the bathymetry of macrophyte zone affects the settlement of TN and TP into the soil.

Besides, hydraulic residence time also affect the trend of TN and TP concentration. Mangangka *et al*. (2013) found that, TN removal was strongly influenced by hydraulic residence time where for a small event the removal was higher at beginning then decrease compared to large event. Other studied also showed that TP and TN removal efficiency increases with the hydraulic residence time, but decrease during period of high precipitation (Sim *et al*., 2008). However, there is limited evidence on hydraulic residence time over the macrophyte species in order to retain the TN and TP for optimum uptake by macrophyte and settled into the soil.

Animal waste also the factor that influenced the oscillating of TN and TP concentration as constructed wetland can provide new habitat for each different species and contribute to the conservation of biodiversity. According to Shaharuddin *et al*. (2011), the diversity of bird species and animal was found in constructed wetland due to the source of their food which is fish.

According to Sim *et al*. (2008), the increasing of TN concentration was because of the discharge of higher nitrate-nitrogen concentration from the side inflow to the constructed wetland. This is also similar to the increasing of TP concentration.

Furthermore, the concentration of TN was also influence by nitrification and denitrification process in addition of increasing dissolved oxygen in constructed wetlands. Two parameters mainly affect the microbial nitrification were temperature and oxygen availability (Hammer and Knight, 1994; Spieles and Mitsch, (1999). In constructed wetland, macrophyte root will be the main oxygen source that released into the rhizosphere (WieBner *et al.*, 2002).

## CONCLUSIONS

In conclusion, the constructed wetlands had the potential to remove total nitrogen and total phosphorus in order to enhance the urban stormwater quality. The highest percentage removal of total nitrogen and total phosphorus was found in Cell 4 and Cell 1 which is 18.56% and 23.79%, respectively. The removal efficiency of total nitrogen and total phosphorus for constructed wetland was 20.13% and 35.18%, respectively. However, individually uptake of pollutant by macrophyte in constructed wetland is unknown and further study is needed. Furthermore, in order to achieve the maximum of removal, the appropriate selection species of macrophyte, arrangement of macrohyte, design of constructed wetland, especially in hydraulic residence time and bathymetry of macropyte zone are vital to enhance the stormwater quality in terms of total nitrogen and total phosphorus.

## ACKNOWLEDGEMENT

The author would like to acknowledge the financial assistance fully supported by from Ministry of Higher Education under Long Term Research Grant (LRGS) No. 203/PKT/672004 entitled Urban Water Cycle Processes, Management and Societal Interactions: Crossing from Crisis to Sustainability.

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