Re-evaluation of the hydrology and pollutant removal/transformation performance of a linear, free-water surface-flow stormwater wetland, Blacktown, New South Wales, Australia

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Abstract
In this study the hydrology and the pollutant removal/transformation performance of a constructed wetland system receiving urban stormwater were assessed. In addition, possible nutrient concentration changes with time and the C/N ratio in the system were studied. Hydraulic loading to the wetland during specific base and storm flow periods, daily- rainfall and evapotranspiration records and seepage to groundwater were used to assess the wetland water budget. Water sampling was conducted on a weekly basis for 18 months. Targeted storm event sampling was undertaken in six occasions, intensive sampling in an interval of one hour in three occasions. Above ground biomass and plant litter were collected of four representative plots in the wetland. The wetland hydrology was found to be dominated by stormwater inflow. Evapotranspiration was significant during dry weather conditions. For the 18 months period, removal efficiencies were reported to be of approximately 85% for total suspended solids, 20% for phosphorus species, 55% for total Kjeldahl nitrogen, 20% for oxidized nitrogen and of no reduction for ammonium. No regular diurnal pattern of concentration changes were found. Reactive soluble phosphate and nitrate were reported to be increased during summer periods. No pronounced first flush effect was detected. The C/N ratio was found to be approximately 9.1:1. Considering the potential carbon contribution by wetland plants, the C/N ratio was reported to be approximately 15.4:1.

Keywords
Constructed wetland; nutrient transformations; pollutant removal; urban stormwater; wetland hydrology

INTRODUCTION

Degradation of rivers and streams is one of the major environmental issues in Australia. Non-point sources of pollution, such as stormwater from agriculture and urban areas are difficult to quantify and to manage (US EPA, 1983). In north-western Sydney, Australia, surface waters are degraded due to the discharge of nitrogen and phosphorus from the catchment. Most of the nitrogen and phosphorus inputs originate from urban development activities and the intensive periurban agricultural activities in the region. During the last fifteen years more than 3000 hectares of land has been designated for new urban development in the local region. The stormwater from this urban development carries significant quantities of gross pollutants (debris), sediments, nitrogen, phosphorus and heavy metals (Bavor *et al.*, 2001, Davies *et al.*, 2001).

The main objectives of the study were to assess the wetland water budget and the removal efficiency (RE) for suspended solids and various nutrient species (TP, PO_4^{3-}-P, TKN, NH_4^+-N and NO_x-N). The re-assessment of the RE's was based on the determination of pollutant loading rates rather than on concentration measurements only, as it was done in previous studies. Secondary aims of the project were the investigation of nutrient transformation processes, the characterisation of nutrient concentration patterns with time (diurnal-, seasonal patterns; first flush effect) and finally, the estimation of the C/N ratio in the system and the potential contribution of carbon to the system by wetland plants.

MATERIALS AND METHODS

Study site

Plumpton Park, situated in the local government area of Blacktown, New South Wales, Australia, is a recently established residential development, which produces large volumes of stormwater with high concentrations of suspended solids, nutrients and other pollutants during storm events (Hunter and Claus, 1995). Stormwater from this development flows via a creek system into the Hawkesbury River, further increasing the pollutant load to the river system that has already been degraded.

The 0.45 ha constructed wetland system at Plumpton Park was completed in 1995 and received the surface runoff of two catchments (60 ha and 15ha). It consisted of a gross pollutant trap to remove coarse sediment at the main inlet, a trashrack for the inlet of the smaller catchment, and a linear wetland dominated by *Phragmites australis*. The wetland was separated by loose rock weirs 400 mm high into five cells, each approximately 35 m long. Water depths were ranging from 200 – 600 mm.

Data collection

In order to characterize seasonal patterns of nutrient concentration changes and determine the long term removal efficiency of the system, discrete inflow and outflow water samples were collected manually on a weekly basis during the period January 2001 to July 2002. Additional fieldwork was conducted between March and August 2002 and consisted basically of base flow determination; of intensive sampling (at one hour intervals in order to determine diurnal patterns – conducted over three occasions); of the monitoring of storm events (taking samples and flow measurements – conducted over six occasions); of infiltration experiments, and of above-ground biomass collection (in order to determine potential carbon contribution to the system by wetland plants). For intensive sampling and the observation of storm events automatic water samplers were deployed. During storm events these samplers were triggered by flow meters when water levels at in- and outlet points reached certain height. Sampling was conducted on a time-based interval (0.5 or 1 h intervals). The data collected by the flow meters was used for calculating the flows, applying standard hydraulic procedures.

Rainfall data were obtained from a pluviometer, which was located within the bigger catchment and operated by Australian Water Technologies. Pan evaporation data were obtained from the weather station at the University of Western Sydney. For calculating the evapotranspiration (ET), the pan evaporation method with a pan coefficient of 0.75 was chosen. For the assessment of seepage to groundwater, a self constructed seepage meter was deployed.

Laboratory Methods

The determination of suspended solids, COD and nutrient species concentrations of the collected water samples, as well as the assessment of the dry mass biomass and it's volatile components, was conducted using standard methods adapted from APHA (1998).

RESULTS AND DISCUSSION

Wetland water budget

The assessment of the wetland water budget showed that the wetland's hydrology was dominated by inflows caused by rainfall. Rainfalls with an intensity > 15 mm per day were found to contribute 67%, rainfalls with an intensity < 15 mm per day were found to contribute 29% of the total inflow volume of 418.920 m^3 during the period January 2001 to July 2002. The remaining 4% originated from base flow during dry-weather conditions. Surprisingly, it was found that groundwater was exfiltrating to the wetland, however, the low volume of 169 m^3 was considered to not impact the system significantly. ET losses were particularly important over the dry-weather periods. Approximately 46% of the base flow volume was lost by ET, which led to a noteworthy reduction of the discharge volume during these conditions.

Pollutant removal performance / nutrient transformations

Singular storm events. The calculation of the pollutant RE values for single storm events indicated the highest removal rate for total suspended solids, which ranged from 81 to 91%. The removal of P - forms varied to a higher extent for the several storm events, but was normally within 15 to 40% for PO_4^{3-}-P, as well as for TP. TKN was removed by 23 to 40%. The highest variation in the RE values was observed for NH_4^+-N, ranging from –30 to 54%. NO_x removal was low and always under 20%.

It was considered that the processes of ammonification of organic N, nitrification of NH_4^+ - N and denitrification of NO_x were likely to occur simultaneously in the system, however, each of them to a variable degree during the various storm events. It might be hypothesized that the release of NH_4^+ - N during some events was a consequence of a high ammonification rate, which would be indicated by the average reduction of organic N by 53.8%. The lower removal of NH_4^+ - N might then be due to high oxygen demand of heterotrophic bacteria decomposing the organic matter.

Dry weather conditions. For the determination of the RE during dry weather periods days with rainfall and 2 days after rainfall were excluded from consideration. This category showed an increase of the mean concentration of P, especially during the period January to May 2001. A possible explanation for this trend may have been related to a scenario in which heavy rainfalls in January and February transported high organic loads into the wetland leading to reducing conditions, which led to the release of stored sediment phosphorus. The resulting higher PO_4^{3-} - P concentrations may have led to increased algae growth, which might then result in high TP concentrations in effluent water. Also water birds may have increased sediment/suspended solids associated P concentrations by bioturbation.

A lower reduction of organic N during dry weather periods than during storm events, in combination with increased removal of NH_4^+ - N, and above all of NO_x , was consistent with a hypothesis of low oxygen concentration in the system during these conditions.

Overall results. Based on weekly sampling results and on intensively monitored storm events, the REs for the period January 2001 to July 2002 was assessed. The results are shown in Table 1.

Table 1. Loads and REs of Each Nutrient Form for the Period January 2001 to July 2002

Pollutant	Load Inlet I	Load Inlet II	Tot. Load Inlet	Load Outlet	RE [%]
TP [kg]	111.72	30.61	142.34	109.93	22.8
PO_4^{3-} - P [kg]	46.30	12.64	58.93	47.77	18.9
TKN [kg]	452.44	160.03	612.47	272.17	55.6
NH_4^+ - N [kg]	72.05	27.94	99.98	105.87	-5.9
NO_x - N [kg]	220.76	72.73	293.49	247.79	15.6

Generally speaking, the RE values presented in Table 1 are within reported performance ranges figures in the scientific literature.

Nutrient concentration changes with time

Intensive sampling showed hardly any concentration changes over 24 hour sampling periods. Occasionally detected peak concentrations were considered to reflect isolated upstream events, such as vehicle washing, irrigation events or fertilizer application. Generally it was noted that phosphorus species had a higher degree of homogeneity than nitrogen species, which was likely to be a consequence of the basically different transformation cycles of both nutrients.

No pronounced first flush effect could be detected, however, this phenomenon could not be excluded with certainty due to the relatively low intensity of the monitored storm events.

The only clear pattern for concentration changes with time during storm events were: at the Inlet II, total suspended solids concentrations were positively related to discharge, which might be a consequence of higher soil erosion during heavier rainfall. At the same sampling point, a decrease of total Kjeldahl nitrogen concentrations with time was monitored. It was likely that organic nitrogen was quickly washed off at the beginning of a rain event.

At the outlet, total suspended solids concentrations had a tendency to increase during a runoff event, which might be the result of higher shear stresses at the wetland soil surface and of higher turbulences in the wetland water body during storm events.

Apart from the increased concentration of the soluble inorganic nutrient forms PO_4^{3-}-P and NO_x in influent as well as in effluent waters during summer periods, no significant seasonal pattern could be detected.

C/N Ratio – carbon contribution by wetland plants

The C/N ratio in influent water was found to be approximately 9.1:1. This would indicate that there was enough carbon available for denitrification of total nitrogen, even without the carbon contribution by wetland plants. Considering the potential carbon source including wetland plants, the over all C/N ratio was assessed to be approximately 15.4:1. Thus, nitrogen removal was likely to be limited either by ammonification- or nitrification rates. However, the potential capacity of the stormwater wetland system for treating higher oxidized nitrogen loads was confirmed.

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