Performance assessment of the Wharf Street Constructed Wetland 2009-14

Summary report - February 2016

Department of Parks and Wildlife

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This project was the result of collaboration between The University of Western Australia and the Department of Parks and Wildlife Rivers and Estuaries Division as part of projects conducted by the Cooperative Research Centre for Water Sensitive Cities.

The detailed final report describing the analysis can be accessed at https://watersensitivecities.org.au/wp-content/uploads/2016/07/C4.1_1_2015_MH_Wharf_web.pdf or is available upon request.

KEY POINTS

- The Wharf Street Constructed Wetland was built to reduce nutrients and pollutants in water that flows from an urbanised catchment to the Canning River.
- The wetland is a multistage hybrid system consisting of open water and vegetated surface flow and subsurface flow components. Locally native plants provide the wetland and floodplain vegetation.
- Regular monitoring of hydrology, water and sediment quality as well as vegetation dynamics showed pollutant reduction was strongly seasonal and more effective during summer. The data suggested the observed seasonality was mainly due to changes in water retention time and dilution from ungauged inputs.
- Although the performance targets were not always met, the Wharf Street Constructed Wetland was able to significantly reduce the concentration of nutrients (particularly phosphorus) and pollutants in the water that reached the Canning River.
- Between 2010 and 2014, the mass of total nitrogen retained was 1658kg of 2526kg input (or approximately 65 per cent removal) and the mass of total phosphorus retained was 129kg of 286kg input (or approximately 45 per cent removal).
- The sediments retained significantly more nutrients than the wetland vegetation. The sediment continued to accumulate organic carbon and nitrogen with time, while the vegetation had highly variable nutrient uptake and storage throughout sites and seasons.

Project context

The Swan Canning estuary is showing signs of stress that are common to many urban waterways around the world. Intensive land use has resulted in the delivery of excessive nutrients and other pollutants from the catchment to the estuary. In the estuary, excessive nutrient input can cause sporadic algal blooms and low oxygen waters, leading to fish kills and a loss of biodiversity and recreational amenity. Under the Healthy Rivers Action Plan (HRAP), the Canning Plain Catchment was identified as one of eight priority sub-catchments of the Swan Canning river system which required a reduction in nutrients.

The Wharf Street Main Drain

The Wharf Street Main Drain (WSMD) receives nutrient-rich stormwater from a 129ha urban area within the Canning Plain Catchment and delivers it to the Canning River, just upstream of the Kent Street Weir. The Wharf Street Constructed Wetland (WSCW) was built to intercept the stormwater from WSMD in order to retain most nutrients and pollutants before they reach the Canning River, with high flows bypassing the wetland so that the WSMD storm conveyance capacity is maintained.

WSCW was designed by Syrinx Environmental PL and implemented through a partnership between the Parks and Wildlife Rivers and Estuaries Division, the City of Canning and the South East Regional Centre for Urban Landcare (SERCUL).

Creating a 'wetland'

The 4ha Wharf Street Constructed Wetland and Civic Parklands site is in the City of Canning Council Offices Parkland and the Canning River Regional Park in Cannington. Approximately 1ha of the site is dedicated to the constructed wetland (Figure 1). Key wetland components consist of:

- a diversion structure in the WSMD that accepts design flows into the wetland. This structure allows higher flows to bypass the wetland discharging them through a swale into the Canning River, avoiding scouring and ensuring adequate wetland retention times for pollutant removal
- a naturally clay lined wetland base limiting groundwater interaction
- a bubble up pit which discharges into a deep water pond reducing the velocity of stormwater flows and encouraging settlement of particulate pollutants and sediment. The deep water pond also facilitates periodic sediment removal
- a meandering flow path with vegetation fringed open water and densely vegetated surface flow wetland (SFW) areas increasing residence time and water contact with aquatic plants (macrophytes) and the biofilms that grow on them. These elements encourage sedimentation and pollutant removal
- vegetated subsurface flow wetland (SSFW) areas fed by low flow pipes to improve pollutant removal and provide an area for grassed public open space. The SSFWs were initially offline due to the elevated alkalinity coming from the recycled concrete material (RCM) used in their construction. This RCM was largely replaced in 2012 with a coarse laterite at which time the SSFWs were brought online
- densely vegetated stream banks that are flooded during moderate to high flows and encourage sedimentation and pollutant removal
- high flow bypass pipes which link the internal open water areas
- a recirculation system (supplemented by groundwater from the superficial aquifer during summer months) to ensure year round flow primarily for aesthetic purposes, but also allows for polishing of stormwater flows.

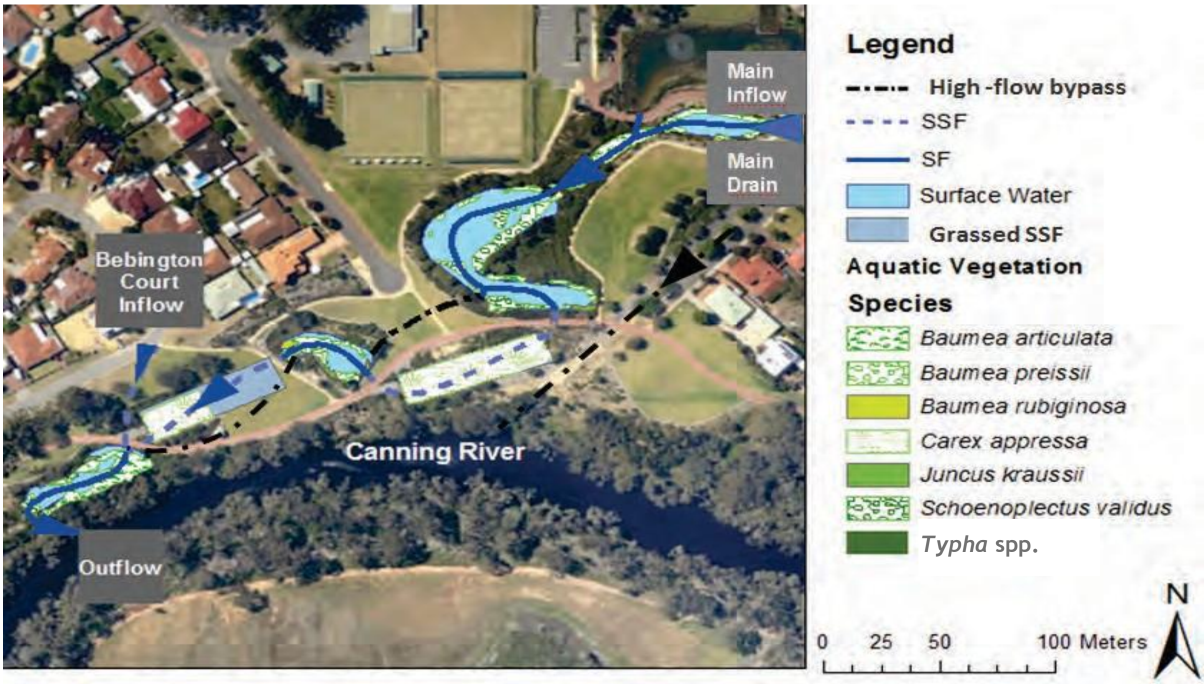


Figure 1 Schematic map of the Wharf Street Constructed Wetland. This depicts wetland types, flow paths and directions and dominant vegetation types

In summary, the WSCW project aimed to:

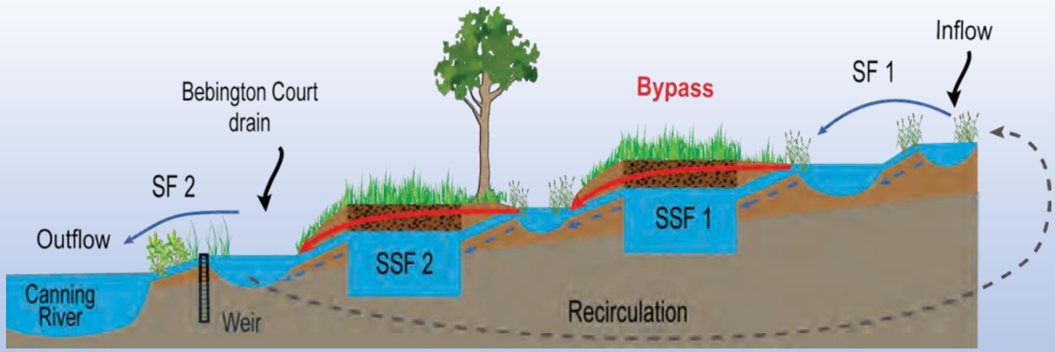
- retain and treat stormwater flows from the WSMD to reduce the delivery of pollutants to the Canning River
- reduce the delivery of nutrients to the Kent Street Weir pool, particularly during summer and autumn
- assess wetland maintenance requirements and costs
- fill knowledge gaps about the wetland's ability to improve water quality.

The secondary objectives of the WSCW project were to provide a passive recreational and educational asset to the community, create an ecological link between the Canning River Regional Park and Council Gardens, and enhance the ecological value of the area.

Wetland hydrology

As the water flows through the wetland, it carries nutrients and other pollutants. Therefore, a comprehensive understanding of the water dynamics is pivotal for understanding the nutrient pathways and efficiency of the wetland at decreasing these pollutants. The WSCW receives multiple water inflows that pass through a series of surface (SFW) and subsurface (SSFW) components. Minimum water levels are maintained by a system that recirculates water from near the wetland outlet back into the inflow point (Box 1) at an average rate of 3L/s (or 5 per cent of the total average wetland flow to maintain year round flow).

Box 1: Cross-section representing the water flow path in WSCW as it passes through a series of surface (SFW) and subsurface flow wetland (SSFW) components. Additional pipes allow the SSFWs to be bypassed under high flow conditions.



An ungauged volume of groundwater from the superficial aquifer is also added to the system. During storm events if flows are too high they will bypass the wetland, continuing down the main drain. Similarly if flows internally are too high to be received by the SSFWs they are bypassed, continuing to the next wetland compartment.

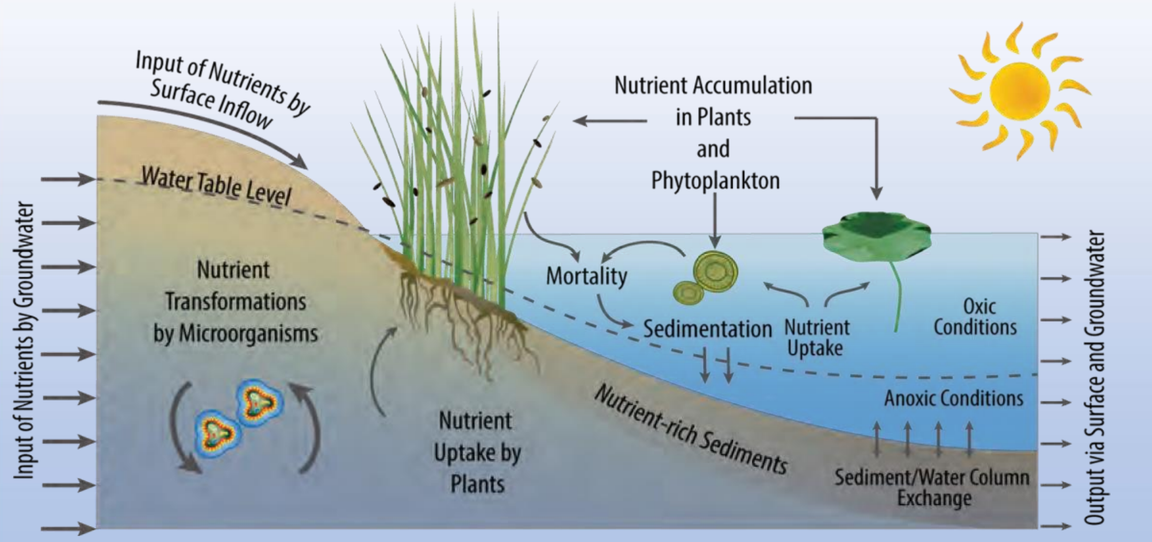
Analysis of the hydrological data indicated:

- a general tendency for the wetland to display large water losses during isolated rainfall events (both small and large) that occur during dry antecedent conditions prior to rainfall and during pumping cycles from spring to autumn
- large volumetric contributions from ungauged inflows during winter/spring events and large rainfall events that activate runoff from the Bebington Court drain catchment which enters the wetland near its outlet
- significant changes in water balance from October to December 2013, likely due to the longest dry spell on record being experienced during this period.

Nutrient removal processes

Constructed wetlands can improve water quality through a variety of interacting physical, chemical and biological processes (Box 2). As the water flows through the subsurface material, nutrients can be trapped by the soil or media. On the surface, plant stems increase the sedimentation of nutrients and pollutants by slowing flow. Microorganisms process the nutrients in the soil, sediments and water column. After microorganism processing, nutrients become available for plant and phytoplankton absorption. In return, plants and phytoplankton provide, through photosynthesis, much of the oxygen needed by organisms to live and process nutrients. However, some microorganisms can process nutrients even under anoxic conditions (where oxygen is not present).

Box 2: In constructed wetlands, nutrients are constantly being absorbed by plants and phytoplankton, buried in the sediments and processed by microorganisms present in the soil and in the water column. At the WSCW surface inflow via stormwater provides the major input of nutrients.



The rates of nutrient removal and level of improvement in the outlet water quality can vary between constructed wetlands. It is also often unclear which nutrient processing is more important in a particular system and the conditions needed for optimal nutrient removal. As nutrient removal by wetlands is often a slow-acting process, it works best when water moves slowly through the system. To better quantify the nutrient removal in the WSCW, detailed nutrient and pollutant monitoring has been conducted since its construction in 2009. This dataset has been interrogated to allow an insight into the system to be gained.

Estimating wetland performance

Water quality

Samples were collected and parameters measured in the SFW and SSFWs. Analyses of collected data aimed to develop a better understanding of the system and a measurement of its ability to remove nutrients and other pollutants from stormwater effectively. In the analysis conducted on the WSCW, the load and the event mean concentration (EMC) of nutrients and total suspended solids (TSS) were calculated for six storm events. In addition, the efficiency of WSCW was estimated according to the standardised delta concentration (SDC), which eliminates the need for measuring the flow, decreasing uncertainty in the assessment. A positive SDC indicates nutrient retention, whereas a negative SDC indicates nutrient release from the wetland. SDC is calculated according to:

$$\mathbf{SSSSSS} = \frac{\text{inlet nutrient concentration} - \text{outlet nutrient concentration}}{\text{inlet nutrient concentration}}$$

The performance assessment highlighted the importance of understanding the ungauged sources and the effect of seasonality in wetland removal capacity.

Dissolved oxygen (DO) is one of the most relevant water quality parameters, which directly influences ecosystem processes. In the context of constructed wetlands, low levels of DO promote anaerobic respiration, which may release phosphorus and heavy metals from particulates and sediments. A range of factors control DO concentrations, including temperature (impacting solubility), turbulence and wind (influencing aeration), photosynthesis, and biochemical and sediment oxygen demands.

In the WSCW, the outlets of the SFWs contained higher DO than the inlets, indicating that the low-oxygen water from the urban drains was oxygenated as it passed through the SFWs. A different scenario was observed in the SSFWs, where the DO level at the outlets was lower than the inlets, reflecting the reduced contact of water with the air and lower primary productivity (compared to the SFWs). DO concentrations were relatively low at the main inlet, the outlet of SSFWs and at the Bebington Court drain. Overall, the DO at the main outlet was higher than at the inlet (Figure 2).

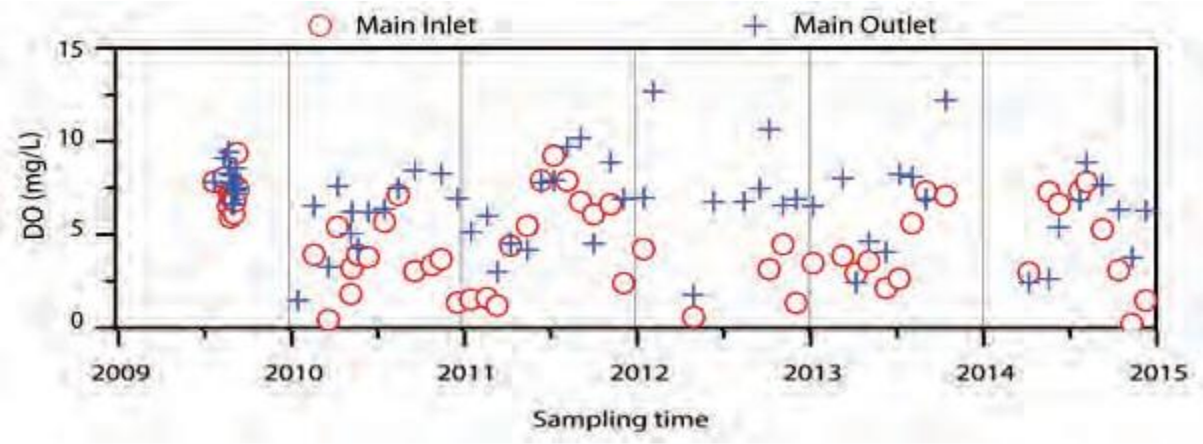


Figure 2 Dissolved oxygen dynamics at the main inlet and outlet of the Wharf Street Constructed Wetland

Hydrological conditions also affect the nutrient concentration and reduction. Overall, storm event flow (≥ 5L/s) considerably increased the mass of nutrients in the wetland (Table 1) when compared to base flow conditions where the flow rate was <5L/s. The inflows from Bebington Court drain appeared to be the main reason for the sporadic increases in nutrient mass during measured rainfall events.

Table 1 Estimates of total nutrient load at the inlet, at the outlet and retention by the Wharf Street Constructed Wetland during periods of storm and during base flow conditions

		Total Nitrogen				Total Phosphorus			
Year	Flow type	Inlet load (kg)	Outlet load (kg)	Load Δ (kg)	Load removal (%)	Inlet load (kg)	Outlet load (kg)	Load Δ (kg)	Load removal (%)
2010	Base	162.09	83.27	78.82	49%	14.492	5.11	9.37	65%
	Event	991.90	242.95	748.94	76%	99.71	65.79	33.91	34%
2011	Base	18.89	14.02	4.86	26%	1.8102	0.49	1.32	73%
	Event	290.17	129.31	160.85	55%	29.17	20.60	8.56	29%
2012	Base	4.696	1.80	2.89	62%	0.939	0.59	0.34	36%
	Event	166.07	67.66	98.41	59%	16.69	10.76	5.92	36%
2013	Base	25.71	24.95	0.75	3%	3.84	0.04	3.79	99%
	Event	324.30	150.57	173.73	54%	32.60	23.79	8.81	27%
2014	Base	52.25	52.86	-0.60	-1%	3.96	3.583	0.37	10%
	Event	490.21	100.66	389.55	79%	83.10	26.73	56.36	68%

At the outlet, the average concentrations of TP during base flow and storm events were 0.04 and 0.06mg/L respectively and 0.81 and 0.86mg/L respectively for TN. In general, total nitrogen (TN) was more efficiently reduced during storm events, whereas total phosphorus (TP) was more efficiently reduced during base flow, with TP more consistently reduced between the wetland inlet and outlet.

Nutrient concentrations measured in the SFW and SSFWs were compared with the HRAP targets (blue line) and ANZECC and ARMCANZ (2000) guidelines (black line). Overall, the TP reduction in the WSCW was sufficient to meet the HRAP targets and ANZECC guidelines approximately 95 per cent and 88 per cent of the time (respectively) with TN meeting these guideline values approximately 85 per cent and 90 per cent of the time respectively (Figure 3). Compliance to the guidelines was found to be different for each nutrient species assessed.

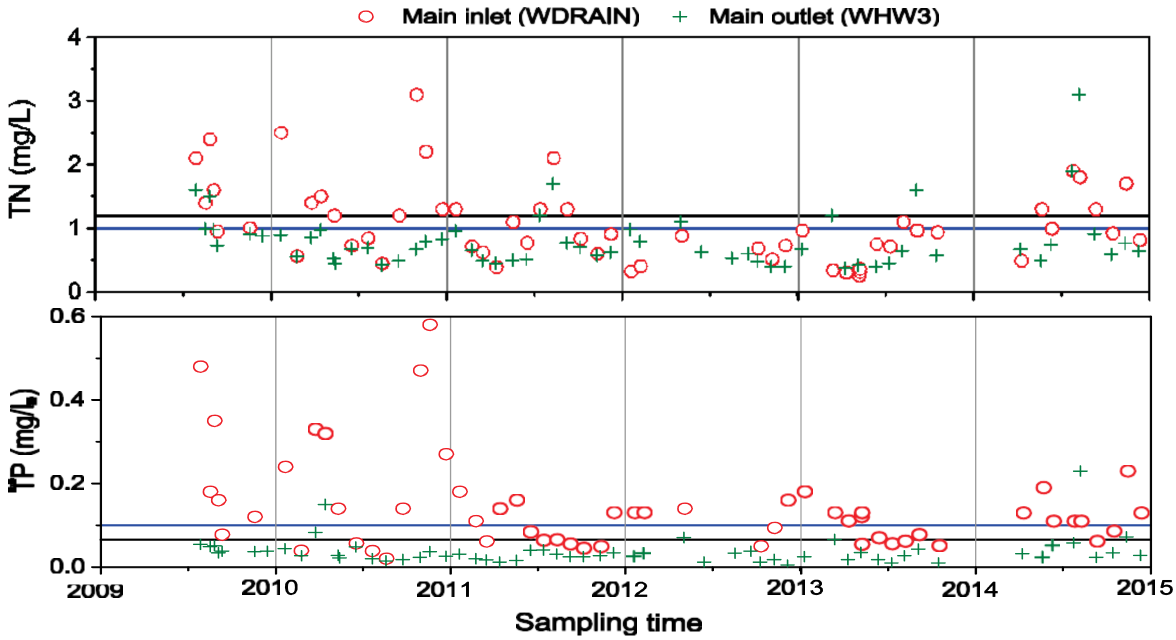


Figure 1 Total phosphorus and nitrogen concentrations from monthly grab samples at the Wharf Street Constructed Wetland inlet and outlet

Analysis of data using the standardised delta concentration (SDC) method reflected consistent total and soluble phosphorus (FRP) removal, as shown in (Figure 4). The SSFWs showed higher attenuation of TP than the SFW’s. The SDC also showed that the SSFWs enhanced phosphorus reduction after being bought on line in 2012.

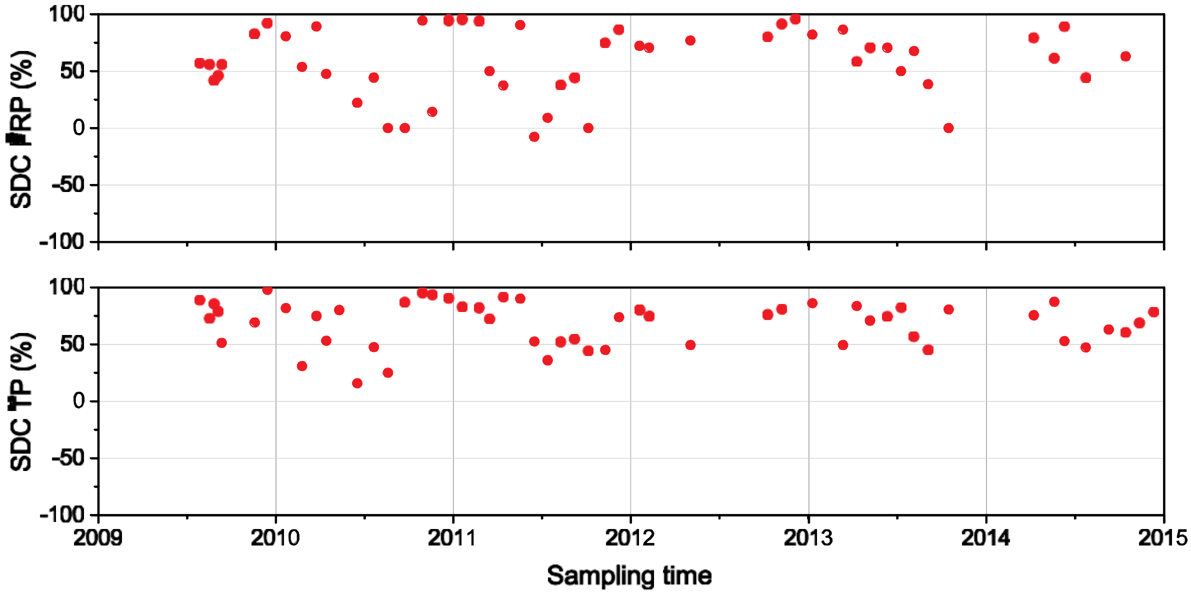


Figure 4 Overall reduction (per cent) of phosphorus species by the Wharf Street Constructed Wetland. Positive SDC indicates a reduction while negative indicates an increase

TN showed a general reduction across the wetland between the inlet and outlet, although removal was variable. The inorganic fraction of nitrogen species was significantly reduced at the wetland outlet most of the time. The majority of samples contained ammonia (NH_3) concentrations below the ANZECC guideline by the outlet. This was also the case for nitrate-nitrite (NOx) concentrations but to a lesser extent, as this parameter was influenced by occasionally high levels of NOx discharging from the Bebington Court drain, contributing to the variability in outlet TN (Figure 5).

Dissolved organic nitrogen (DON) concentrations showed a general increase from inlet to outlet. The release of DON from sediment or senescent macrophytes in the wetland is most likely to be responsible for this observed pattern (Figure 5). Although the wetland showed this general increase the SSFWs removed DON.

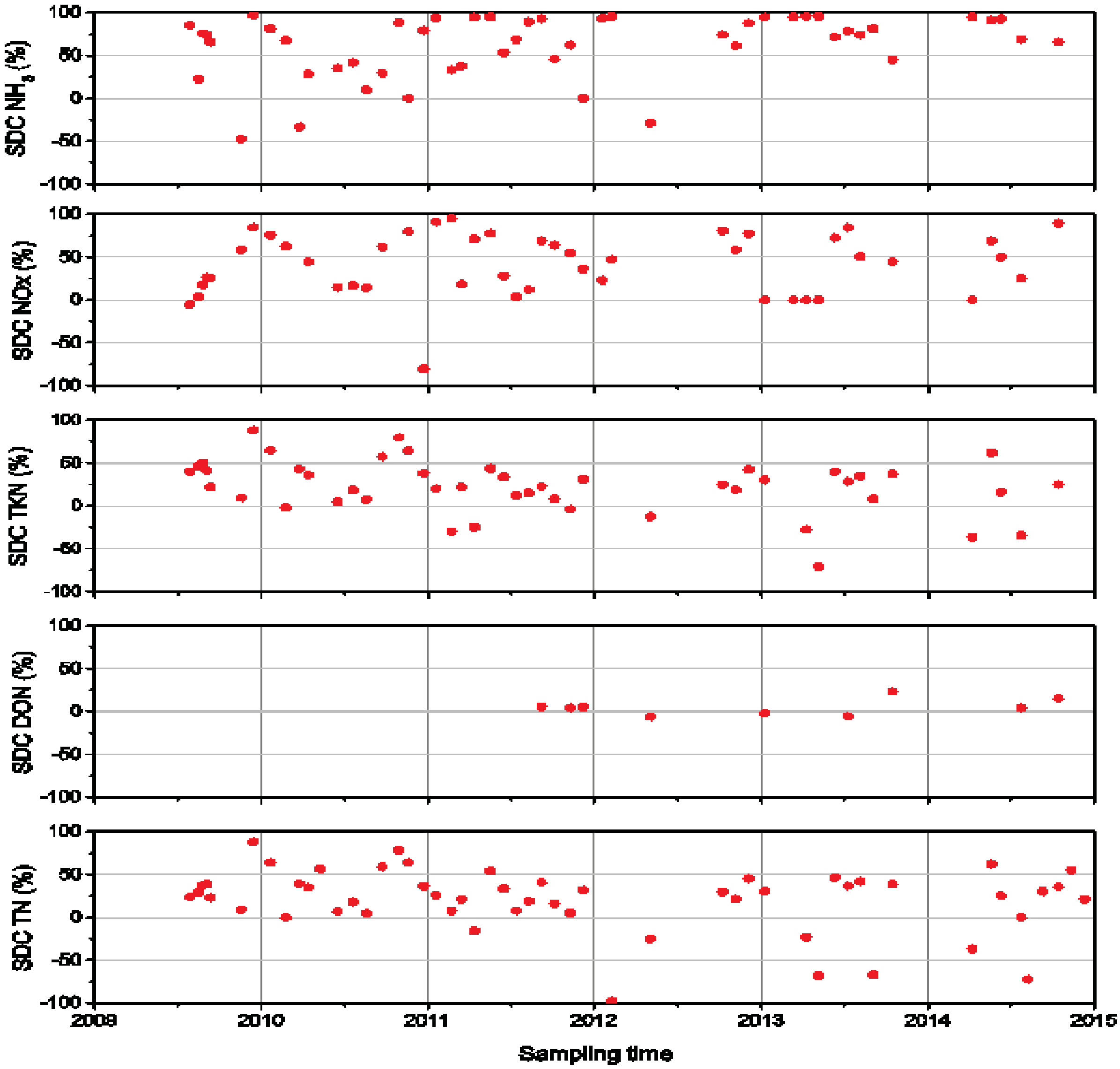


Figure 5 Overall reduction (per cent) of nitrogen species by the Wharf Street Constructed Wetland.

Of the six storm events monitored 2009-14, on average TN and TP load was reduced by 41 per cent and 66 per cent respectively with three events releasing TSS. Nutrient reduction depended on the amount, duration and intensity of rainfall, antecedent dry conditions, hydraulic residence times, volume of inflows and outflows.

From storm event and base flow monitoring over a five-year period (2010-14) the total mass of TN retained by WSCW was estimated as 1658kg of 2526kg input (or approximately 65 per cent removal) and the total mass of TP retained was estimated as 129kg of 286kg input (or approximately 45 per cent removal). This retention accounts for the nutrients stored in the sediments and macrophytes.

Metal content at the main inlet and outlet were measured and compared to the ANZECC and AMCANZ 80 per cent and 95 per cent protection limits for freshwater ecosystems. The main inlet (WSMD) and the Bebington Court drain were the major contributor of metals and other pollutants in the WSCW, however it is also possible that metals could be released from the wetland sediments.

Levels of Arsenic, Nickel, Chromium and Lead (Pb) were within the guidelines, whereas concentrations of Aluminium (Al), Copper and Zinc (Zn) exceeded these limits on occasions. Arsenic was the only pollutant reduced in all samples. All metals showed better reduction during dry periods.

Modelled versus actual nutrient removal

The measured effectiveness of the WSCW was compared with pre-construction predictions. The average outlet concentrations of TN and TP under base flow was 0.81mg/L and 0.04mg/L respectively, agreeing with the preconstruction predictions (1.01mg/L and 0.055 mg/L for TN and TP respectively).

TP reduction was 65 per cent during base flow agreeing with predictions of 57 per cent. However, TN reduction was lower than predicted. There were some occasions when outlet TN concentration was higher than the inlet concentration with Bebington Court drain a possible source.

Sediment quality

To assess the amount of nutrients and pollutants stored in the sediments of WSCW, samples were collected at the three open water sites throughout the wetland. Nutrient content in the sediments is the result of plant nutrient assimilation, sediment adsorption, nutrient precipitation and senescent plant material.

In the WSCW, TN and total organic carbon (TOC) concentrations stored in the sediments generally increased between 2009 and 2014 (Figure 6). The analysis also confirmed the important role sediments play in trapping nutrients, with sediments a significantly greater pool of nutrients than the macrophytes. Sediments were also found to be rich in TOC.

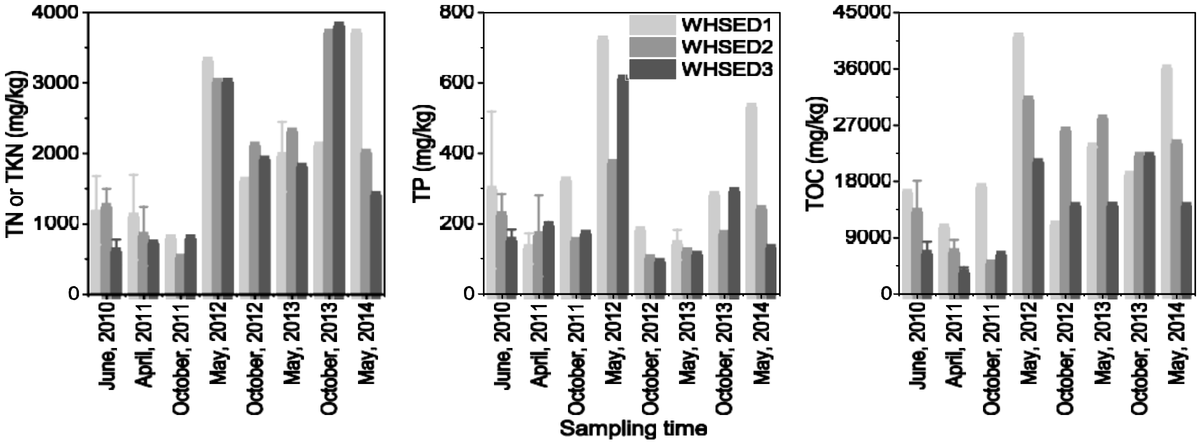


Figure 6 Total nitrogen, total phosphorus and total organic carbon concentrations found in the Wharf Street Constructed Wetland sediments

TN, TP and TOC concentrations present in the sediments was lower in samples closer to the outlet (WHSED3), particularly between 2010 and 2011, suggesting nutrient retention as the water flows through the wetland. In subsequent sampling periods, nutrient retention between the inlet (WHSED1) and WHSED3 was more variable, until 2014 when this trend in retention towards the outlet was re-stablished.

Wetland sediments were rich in Al, Iron (Fe) and Zn. At the wetland inlet, Zn concentrations consistently exceeded ISQG-low trigger value and once exceeded the ISQG-high trigger value. At the same inlet site there was only one occasion when Pb exceeded the ISQG-low trigger value.

Vegetation dynamics

To understand the vegetation dynamics in WSCW as well as to estimate the amount of nutrient assimilated by the vegetation, the four dominant macrophyte species (*Baumea articulata, B. rubiginosa, B. preissii* and *Schoenoplectus validus*) were harvested at three sites in the wetland. The biomass and nutrient content (TN and TP) of their tissue (below and above ground) was analysed.

Macrophytes are seen to be a highly variable nutrient store, between sites and across seasons. However, macrophytes are important in constructed wetlands because they can serve as a biofilm substrate in the water column. They also reduce water velocity, which enhances sedimentation of suspended solids. Plants excrete oxygen, which supports aerobic biodegradation of nutrients and promotes the growth of nitrifying bacteria. Some plants can also store trace metals and other potential toxins in their tissues.

Plants provide a critical component in nutrient removal, with analysis indicating that they absorb and store nutrients in their biomass during the growth phase, though some of these nutrients are released back into the water and sediment as they senesce.

The most abundant macrophyte species present in WSCW *are Baumea articulata, B. rubiginosa, B. preissii, Carex appressa, Juncus kraussii, Schoenoplectus validus* and *Typha domingensis*. On average, the macrophytes stored up to 12g/kg of TN and 1g/kg of TP (Figure 7) in above ground plant tissue. TN was stored primarily above ground, whereas TP was more efficiently stored in the below ground biomass. Nutrient content per unit area was significantly greater in *Schoenoplectus validus* and *Baumea articulata* than in other species.

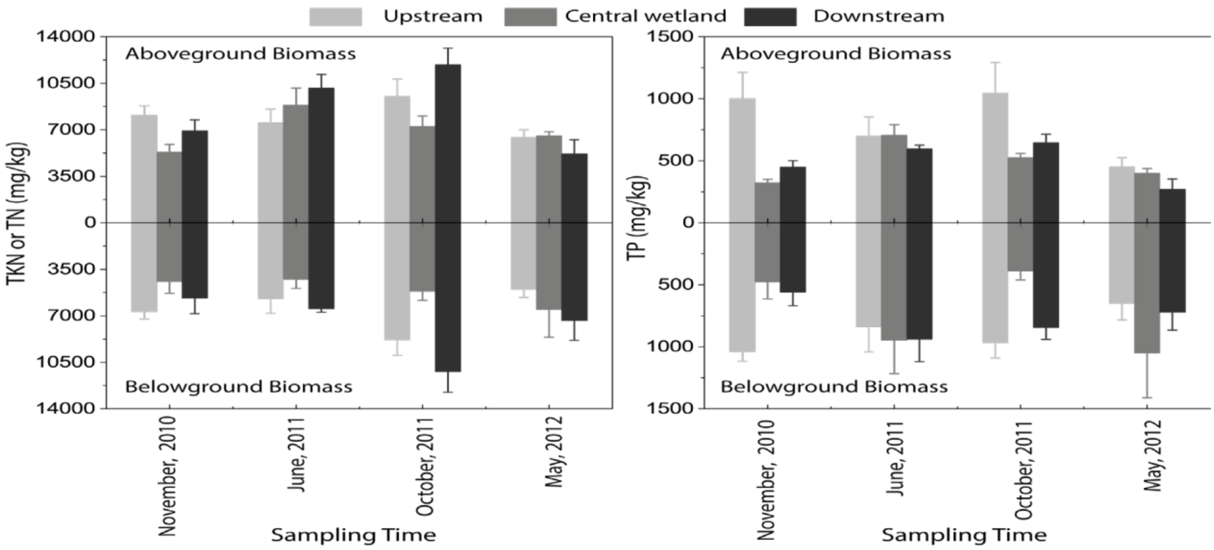


Figure 7 Average and standard error of nutrient concentrations in macrophytes

Conclusion

Analysis of data collected at the WSCW between 2009 and 2014 has shown the wetland is subject to complex hydrological system dynamics and identified temporal and spatial variability of pollutant levels across the wetland. Results have shown that concentrations of pollutants were generally reduced, but not always sufficiently to meet water quality targets. Water quality results also highlighted the effect of seasonality on pollutant reduction, in response to changes in retention time and potentially due to dilution from ungauged inputs. Maximum nutrient reduction occurred during dry summer periods with the system overall reducing phosphorus species more effectively than nitrogen species.

The nutrient content per unit area was significantly greater in *S. validus and B. articulata* than in other species. As such, it is suggested to increase the area planted with these species. The overall contribution of macrophytes to nutrient uptake is significant and should be further investigated. Nutrient release from the sediments to the water column also requires further investigation, as occasionally the SFWs act as a source of nutrients.

Sediment saturation can trigger intense biogeochemical processing and impact the effectiveness of riparian nutrient attenuation. Moreover, the SSFWs provide effective adsorption sites for nutrients and can also be a good chamber for biofilm growth, which can influence nutrient reduction. Therefore, further investigations of the SSFWs can provide insights on wetland function and contribute to explaining aspects of the variability found in WSCW. In addition, the understanding and quantification of the nutrient removal processes during different hydro-meteorological conditions is necessary.

It is also suggested to continue comparison of nutrient species and concentrations within the surface water and soil pore water to inform future nutrient reduction model setup for wetland design optimisation. An indicator such as wetland metabolism may serve as a simple proxy for wetland functioning. However, a clearer linkage between nutrient attenuation and DO changes, and between hydraulic residence time and reduction, needs to be established.

Recommendations

Based on the analyses of the available data, final recommendations are:

- improve the inlet flow gauging accuracy and estimation of the currently ungauged flows into the system, including from the Bebington Court drain and the pumped groundwater used to maintain water in the system
- analyse the nutrient and metal content of the groundwater input
- include monitoring of sediment nutrients and metals at site close to main wetland outlet
- undertake vegetation species mapping at the time of vegetation tissue sampling
- monitor sediment nutrients to determine if macrophyte nutrients are being transferred to the underlying sediment and monitor metal accumulation in macrophytes to assist in determining their metal uptake efficiency
- understand the potential for hypoxia/anoxia to accelerate the release of nutrients (both organic and inorganic) and metals from the sediment and macrophytes
- investigate the removal of senescent macrophytes periodically (at least before winter) from the wetland as these may be a source of organic carbon and nutrients to the system
- undertake a life-cycle cost benefit analysis for the wetland
- continue sediment incubation experiments to verify the potential release of pollutants from the sediment.

Where feasible recommendations from this assessment will be implemented by the Department of Parks and Wildlife and project partners to appropriately manage the WSCW and ensure wetland nutrient and pollutant removal is maintained or improved.

Cooperative Research Centre for Water Sensitive Cities projects C4.1 "*Multi-functional urban water systems*" and B2.4 "*Hydrology and nutrient transport processes in groundwater / surface water systems*" will also address a number of the recommendations made in this report as part of their research.

If you require more information on the Wharf Street Constructed Wetland project or this report please contact rivers.info@dpaw.wa.gov.au.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