Performance assessment of the Anvil Way Compensation Basin Living Stream 2004–13

Summary report - February 2016

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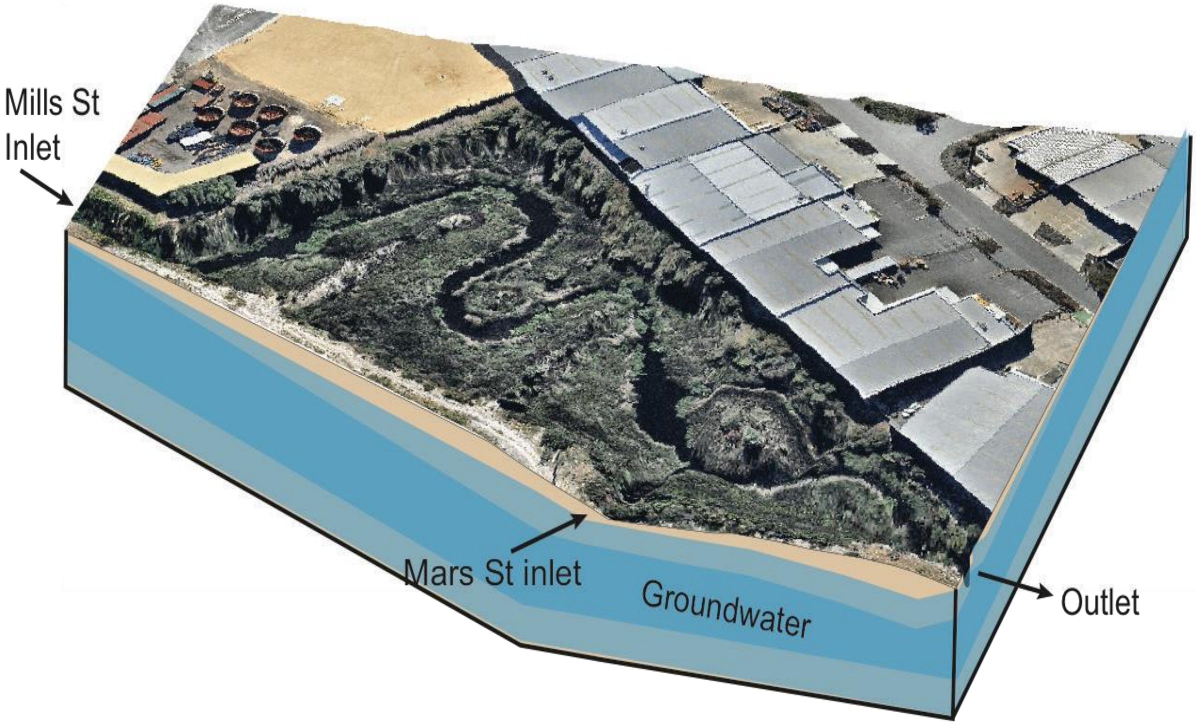


This project was the result of collaboration between The University of Western Australia and the Department of Parks and Wildlife Rivers and Estuaries Division as part of projects conducted by the Cooperative Research Centre for Water Sensitive Cities.

The detailed final report describing the analysis can be accessed at https://watersensitivecities.org.au/wp-content/uploads/2017/09/PC22-C4.1-FY1516-2_2015_MH_ANVIL_final.pdf or is available on request.

KEY POINTS

- The Anvil Way Compensation Basin (AWCB) was rehabilitated in 2010 to improve its ability to treat polluted stormwater from the Mills Street Catchment.
- The water quality at the site has been monitored regularly since 2004 providing a 10-year dataset covering the pre- and post-restoration conditions.
- An analysis of the wetland hydrology and nutrient status was undertaken to determine the performance of the living stream in reducing pollutant loads to the Canning River.
- While the living stream does not always remove all pollutants, a general decline in nutrient levels between the inlet and the outlet was observed under low to medium flow conditions, including for the most bioavailable fractions.
- Under high flow conditions, the retention time of the system is too low (less than one hour) to significantly reduce dissolved nutrients.
- Since the restoration, a large quantity of nutrients has accumulated in the basin sediments and vegetation, which would have otherwise entered the Canning River. The potential release of these stored nutrients back into the waterways must be carefully managed.
- In addition to improving water quality, the system is also a productive wetland environment that provides important habitat for local bird and animal species.
- This assessment focuses on the period 2004 to the end of 2013. Data collected following this assessment period has shown a decline in the living stream's ability to retain nutrients. The reason for this reduction in nutrient removal is not known, however is thought to be linked to low dissolved oxygen in influent waters, a hypothesis being further investigated by the Cooperative Research Centre for Water Sensitive Cities.

Project context

The Swan Canning estuary is showing signs of stress that are common to many urban waterways around the world. Intensive catchment land use has caused an excessive amount of nutrient and organic matter to be delivered to the estuary. In addition, the climate of south-west Western Australia has been consistently drying during the last 30 years. The consequence is less streamflow, which increases nutrient concentration and reduces flushing to the ocean. This means nutrients and organic matter are more likely to be retained in the estuarine system. As a result, sporadic algal blooms and low oxygen waters have been observed, leading to fish kills and the loss of biodiversity and recreational amenity.

The Anvil Way Project is one of many activities implemented through the Healthy Rivers Action Plan (HRAP) to intercept and clean polluted water that flows through urban drains before it reaches the Swan Canning river system.

The Mills Street Main Drain

The Mills Street Main Drain (MSMD) runs through Welshpool and drains a 12km² residential-industrial catchment before discharging to the Canning River (Figure 1). MSMD has been identified as a priority catchment for upgrading drainage infrastructure due to its long-known high export rates of nutrients and contaminants. MSMD pollution inputs are significant due to a high degree of urbanisation, significant impervious surfaces, light industrial and commercial land uses, and periodic connectivity to shallow groundwater.

The Anvil Way Compensation Basin (AWCB) was built to convey stormwater away from landholdings with limited capacity to retain water. Approximately one third of the drainage area of the MSMD is located below the AWCB (Figure 1). In 2003, a Drainage Improvement Framework for the MSMD Catchment was prepared. This led to the restoration project being undertaken, with the aim to improve the retention and potential for treatment of small to medium flow pulses. In late 2010, approximately 1400m³ of sediments contaminated with metals and hydrocarbons were removed from the site and treated.

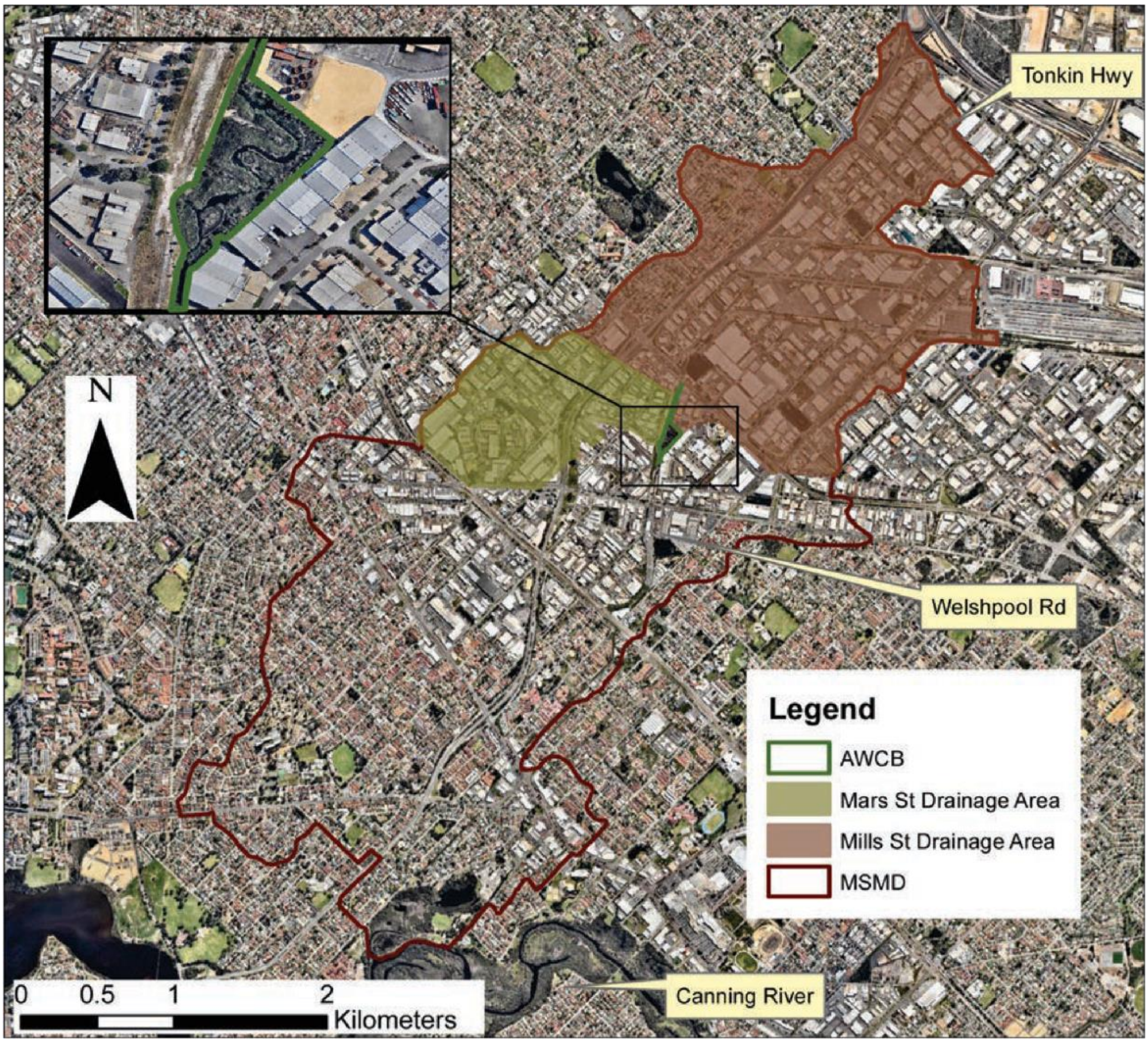


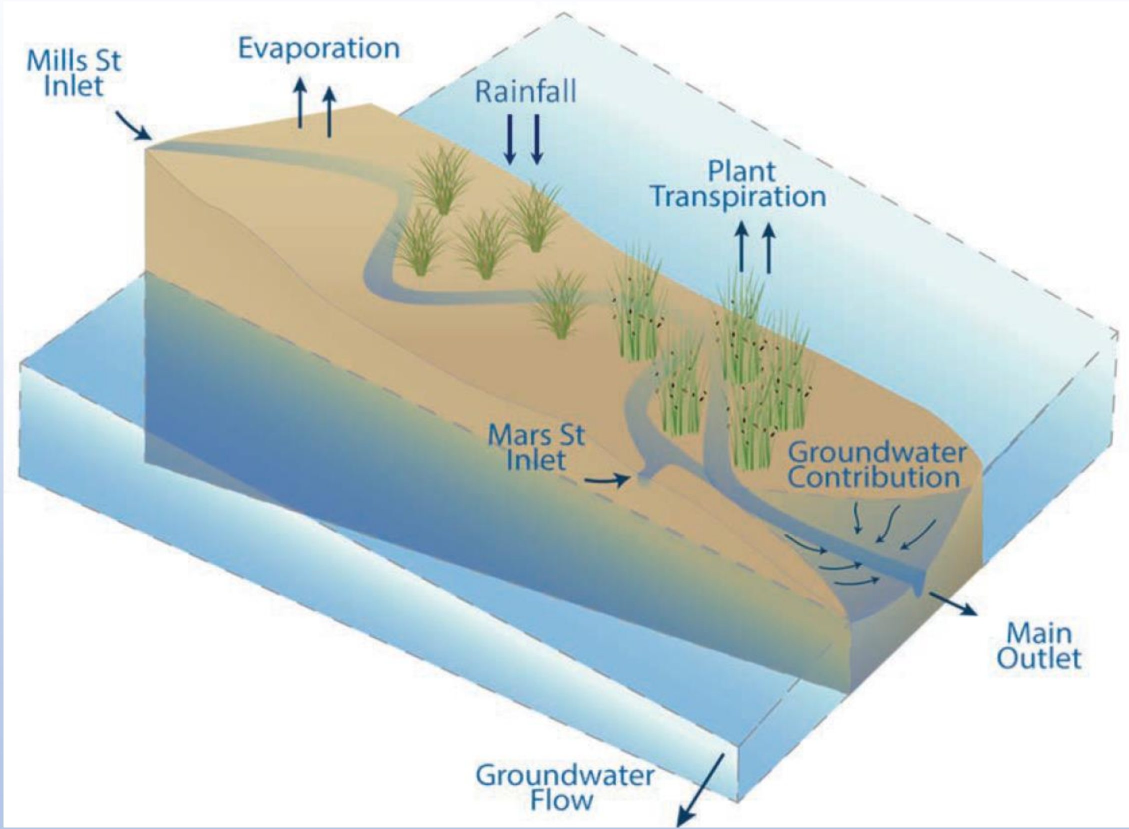
Figure 1 The Mills Street Main Drain Catchment area (delineated in red) and the Mills Street and Mars Street sub-catchments (in brown and light green, respectively), which drain into the Anvil Way Compensation Basin living stream (delineated in green). The Anvil Way Compensation Basin is shown in the inset.

Creating a 'living stream'

Following the removal of the sediments, the shape of AWCB was changed to create a meandering flow path, increasing the time the water remained in the basin. Revegetation efforts were also undertaken, transforming a traditional drain into a living stream (Box 1).

BOX 1: WATER BALANCE

In AWCB, the main water inflows are the Mills Street and Mars Street inlets. Groundwater can constitute an inflow during wet seasons. The groundwater, evaporation and plant transpiration are not directly measured but can be theoretically estimated.



The Anvil Way Project was implemented through a partnership between the Department of Parks and Wildlife Rivers and Estuaries Division, South East Regional Centre for Urban Landcare (SERCUL), City of Canning, Water Corporation and Public Transport Authority, with a funding contribution by the State Natural Resource Management (NRM) Office.

The project aims to:

- maintain the required storage capacity of the drainage system
- improve the quality of urban stormwater runoff by reducing nutrients and other contaminants
- create habitat for birds and other biota and therefore add ecological value to the site
- provide a demonstration wetland to promote improved stormwater and pollution management.

Living stream hydrology

In the AWCB, the main surface water inlet from Mills Street and the main outlet

(Box 1) have been systematically monitored. The inlet from Mars Street has not previously been monitored as it was not considered to provide a significant contribution of flow to the basin. However, this study has identified that the drain provides a significant contribution to the basin water balance (Figure 2).

Between the inlets and the outlet, the water may follow a number of paths which are not directly measured but include groundwater exchange, evaporation and transpiration (see Box 1). Through monitoring or predicting all the surface water flows and by studying the processes that control the water paths, a more detailed water balance can be estimated. This helps us to understand how the living stream responds to storm events and seasonal or longer term changes in hydrology.

Analysis of hydrological data collected from the site allowed the estimation of the amount of "ungauged" water entering the system. The 9000m^2 reconstructed system drains between 1.8 and 3.6km^2 of the Mills Street Catchment, depending on seasonal connection with the upstream compensation basin network. The amount of ungauged water was found to vary considerably (from 10-70 per cent) depending on the size of a storm event and the prior wetness of the catchment. Most of this ungauged water was attributed to the Mars Street inlet (Figure 2). However, some water input via seepage from shallow groundwater is also thought to occur in the wetter months.

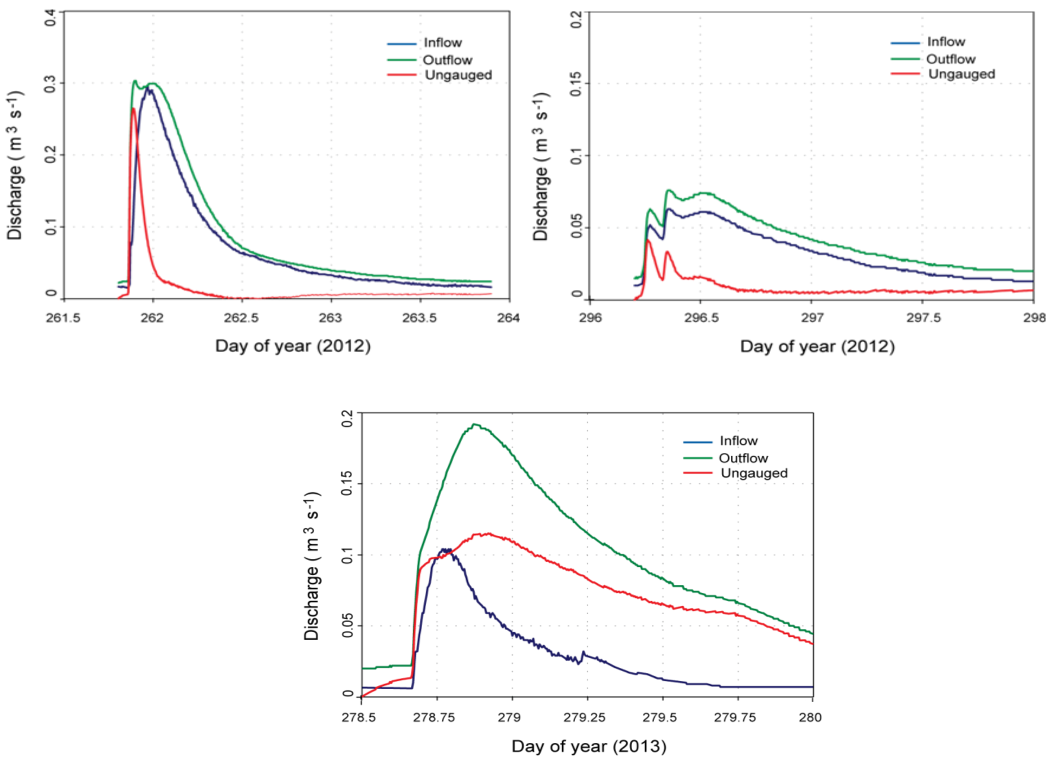


Figure 2 Event hydrograph analysis for small to medium storm events, showing that ungauged inputs (Mars Street and groundwater) make up to 70 per cent of the total storm flows

Nutrient removal processes

Constructed wetlands can improve water quality through a variety of interacting physical, chemical and biological processes (see Box 2). As the water flows through the subsurface, nutrients can be trapped by the soil. 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).

The current design of AWCB includes:

- a sedimentation pond close to the inlet for the settling of particulate nutrients, which facilitates periodic removal of deposited material entering the basin
- a meandering low-flow path to increase water residence time and contact with aquatic plants (macrophytes)
- densely vegetated stream banks that are flooded during moderate to high flows and encourage sedimentation and pollutant removal

- a low flow diversion from the Mars Street inlet to the inlet sedimentation pond for the most polluted inputs entering the system
- an adjustable outlet weir to increase retention time and water levels in the wetland and facilitate maintenance activities.

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. Under high stormflow conditions, the water passes through AWCB in just few hours. Therefore, it is expected the wetland would be more effective at reducing nutrients under low to moderate flows.

To better quantify the nutrient removal in AWCB, detailed nutrient monitoring has been conducted since its restoration in 2010. The new and the historical dataset (collected prior to the restoration) have been interrogated to allow insights into the system to be gained.

Estimating wetland performance

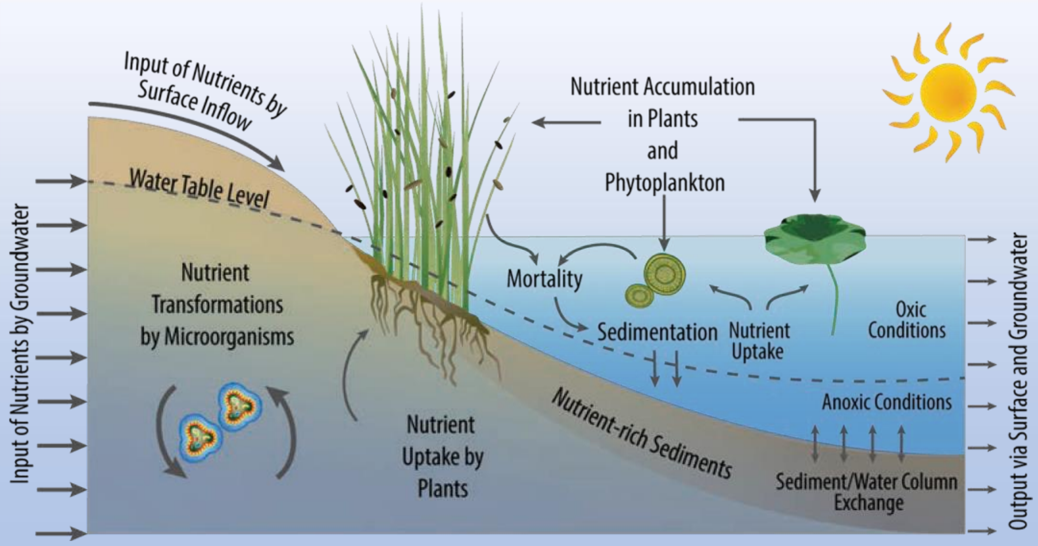
A decrease in nutrient loads between the inlet and outlet of a wetland indicates that the nutrient removal processes are working effectively. The first step is to estimate the nutrient load entering and exiting the system, which can be expressed according to:

$$\text{Nutrient load (mg/day)} = \text{nutrient concentration (mg/L)} * \text{flow rate (L/day)}$$

If flow rates and concentrations of all inflows are not measured, the estimation of the loads requires certain assumptions. In the case of AWCB, it was assumed that the ungauged inlet (Mars Street) water contained zero nutrients, a conservative approach.

BOX 2: NUTRIENT REMOVAL PROCESSES

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.



The second step to determine whether nutrients are being taken up by a wetland is to estimate the difference between the inlet and outlet nutrient concentrations. The standardised delta concentration (SDC) is an indicator of nutrient reduction. SDC can be calculated as:

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

The SDC can be estimated during environmental conditions that are likely to impact nutrient cycling such as rainfall events, inflow rates and the concentration of dissolved oxygen in the wetland. A positive SDC indicates the wetland removes nutrients, while a negative SDC indicates the wetland releases nutrients to downstream waters.

Many periods prior to the restoration in 2010 indicated AWCB was a source of nitrogen and phosphorus to downstream waters (Figure 3). After the restoration, fewer periods of nutrient release were identified. In addition, it was found that the wetland has increasingly been exposed to very low levels of dissolved oxygen. Low dissolved oxygen may promote the release of phosphorus but the removal of nitrogen via denitrification.

After the restoration, on some occasions it was possible to calculate the efficiency of the wetland as the reduction in loads. The reduction in dissolved and total nutrients based on event analysis indicated a substantial reduction of ammonia (NH_3) (about 70 per cent; equivalent to a mass removal between 0.1 and 11kg/day) and modest reductions in nitrate (NO_3) and filterable reactive phosphorus (FRP) (about 20-40 per cent), and total nitrogen (TN) and total phosphorus (TP). The soluble fraction of phosphorus seems to be removed with more efficiency than TP.

Nutrient concentrations at the outlet of the wetland were compared with HRAP targets. TN concentrations were typically below the HRAP target (TN < 1mg/L), while TP concentrations generally exceeded the HRAP target (TP < 0.1mg/L), although TN, TP and nutrient species all had episodes where nutrient targets were not being met. The causes of intermittent reduction in nutrient removal efficiency of the living stream are not yet completely understood.

Estimation of the nutrient pools within the living stream suggests that nutrients are being stored predominantly in the wetland soils and sediments. In AWCB, the net assimilation of nitrogen through time (t) (since Nov 2011) in soils and sediments can be estimated (p=0.84) as:

$$\mathrm{TN\ (kg/day)} = 18.64 * \mathrm{t} + 62.67$$

As such, the total mass of N stored in the soil/sediment pool from November 2011 to October 2013 was 15,800kg.

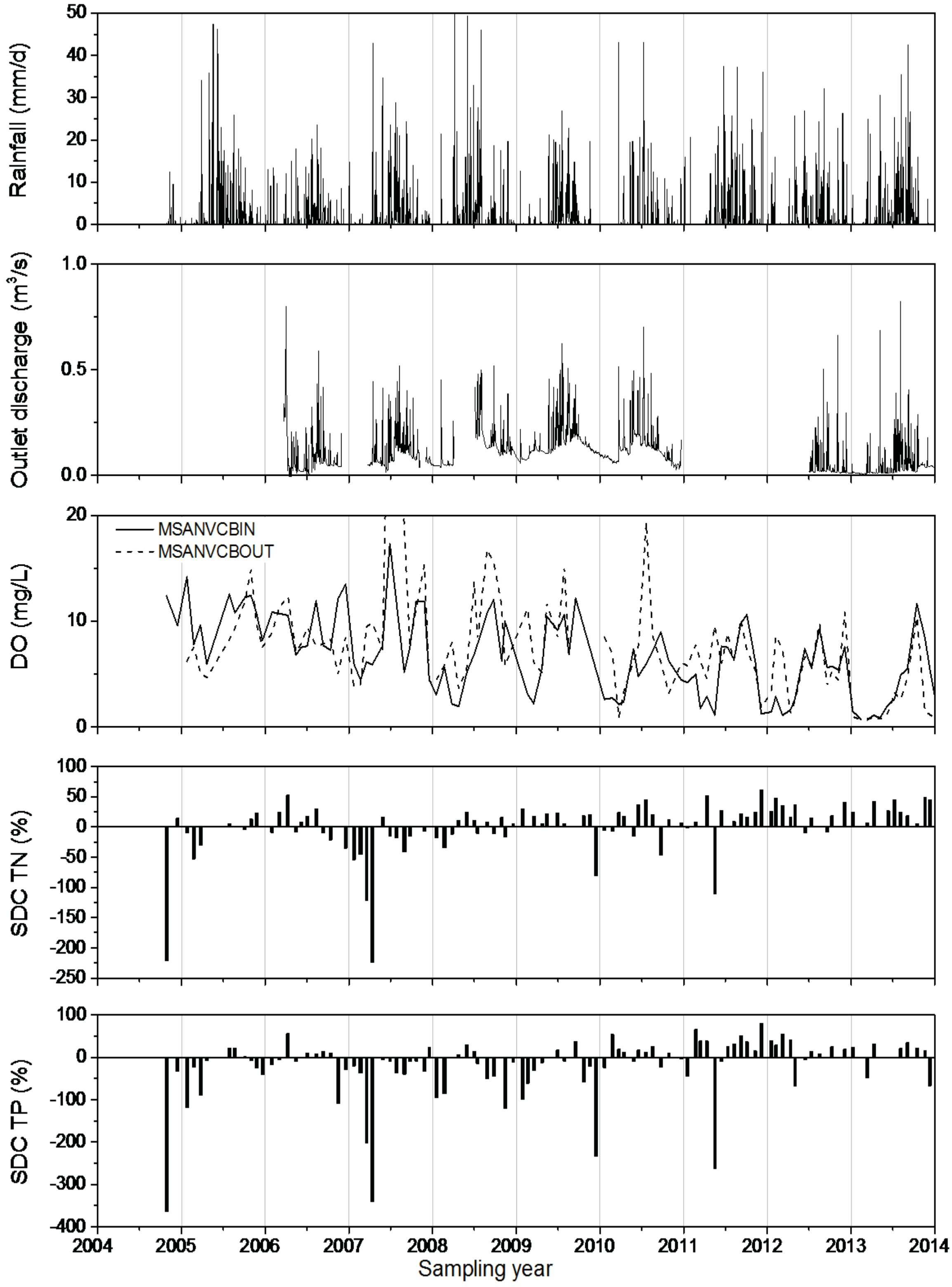


Figure 3 Monitoring data from 2004–14 showing rainfall (top panel), flow rate through wetland (second panel), dissolved oxygen (DO) at the Mills Street inlet and outlet (middle panel), standardised delta concentration (SDC) of total nitrogen (TN) (fourth panel) and SDC of total phosphorus (TP) (bottom panel). Positive SDC indicates nutrient attenuation along the living stream; negative SDC indicates nutrient release to the receiving waters

Similarly, the net assimilation of total organic carbon (TOC) by AWCB can be estimated (p=0.92) as:

$$\text{TOC (kg/day)} = 240.7 * \text{t} + 9163$$

By October 2013, this pool was estimated to be 164,000kg. The temporal trend for P assimilation was less obvious (p=0.55) and described as:

$$\text{TP (kg/day)} = 1.866 * \text{t} + 122.6$$

The total P store in the soils/sediments was 2010kg by October 2013.

Metal concentrations in the sediments decreased after the restoration of the wetland due to the initial removal of sediments during construction, but have since been increasing.

With the wetland dominated by the native plant species *Schoenoplectus validus*, it is estimated that the total vegetation nutrient pool is approximately 140kg P and 660kg N. Below-ground macrophyte biomass is storing significantly more nutrients than above-ground biomass, but the nutrient pool in macrophytes was far less than that stored in the soils and sediments. The sediments and below-ground macrophyte biomass should be carefully managed to ensure the stored nutrients are not released back into the living stream.

Conclusion

The restoration of the Anvil Way Compensation Basin to create a living stream has led to significant reductions in nutrient concentrations entering the Canning River. However, several challenges remain as the living stream continues to release nutrients sporadically (with a slight reduction in frequency after the restoration).

Recommendations

Based on the synthesis of the available data, the following recommendations are made.

- Quantification of nutrient removal during seasonal saturation of the riparian zone is necessary for a better understanding of the processes involved. Sediment saturation can trigger intense biogeochemical processing and impact the effectiveness of riparian nutrient reduction. Examination of these zones can provide insights into wetland function and contribute to explaining aspects of the variability described above. Comparison of nutrient species and concentrations within the surface water, groundwater and soil pore water can also be used to inform water quality model parameterisation as well as facilitate wetland design optimisation.
- Preliminary dissolved oxygen data has highlighted diurnal shifts from 0-10mg/L over the course of several hours when flow is low. This has particular implications for nutrient transformations, wetland water quality and nutrients delivered downstream on the first flush after a period of no flow. The linkage between wetland metabolism and seasonal flow, sediment saturation, oxic and anoxic conditions, and nutrient attenuation still requires further

understanding. An indicator or proxy such as aquatic productivity or respiration may serve as a simple indicator of wetland function.

- Nutrient release from the sediments to the overlying water column needs to be investigated as a potential and occasional source of nutrients. The overall contribution of macrophytes to nutrient reduction remains uncertain but potentially significant and should be further investigated.
- Groundwater/surface water interactions and their contribution to the overall nutrient budget of the basin need to be investigated. Monitoring of groundwater bores, tracer/isotopic test or/and modelling could be used to support investigations.

Where feasible, recommendations from this assessment will be implemented by the Department of Parks and Wildlife and project partners to appropriately manage the Anvil Way Project. This will help maintain or improve the living stream nutrient and pollutant removal. 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 a part of their research.

If you require more information on the Anvil Way Project or this report please contact rivers.info@dpaw.wa.gov.au.

Table 1 Summary of findings across all variables monitored in the Anvil Way Compensation Basin living stream

Compartment	Parameter	Performance summary
Surface water	Hydrology	Ungauged water was sourced from the Mars Street drain and shallow groundwater
		Volumetric contribution from ungauged areas was up to 70 per cent for small storm events (< 1 ARI)
		Residence times varied from 1.2 to 4.8 hours
	Dissolved oxygen	Dissolved oxygen (DO) concentrations showed seasonal trends decreasing over time, with highest concentrations during winter and lowest during summer
		The inlet and outlet waters have been sub-oxic during summer since 2010
	Nutrients	Total nutrient (TN) concentrations at the basin outlet were typically below the Healthy Rivers Action Plan (HRAP) target, while total phosphorus (TP) concentrations generally exceeded the HRAP target
		Reduction of inorganic dissolved fractions (NOx and NH_3) was higher than total (TN) and dissolved organic nitrogen (DON) fractions
		Reduction of TP and filterable reactive phosphorus (FRP) showed high variability
		Low levels of DO can trigger nitrogen reduction via denitrification
		Low levels of DO can trigger release of phosphorus from sediments
		TN and TP were reduced more under low to medium flow than high flow conditions
	(Heavy) metals	At the outlet, both the soluble and total fractions of Al, Cr, Cu and Zn still exceeded ANZECC guidelines
		Up to 50 per cent reduction of Al, Cu, Fe, Pb and Zn occurred in the system

Groundwater	Dissolved oxygen	Dissolved oxygen concentrations were consistently low, ranging from 0 to 2mg/L No seasonal trends found Groundwater may deliver anoxic water to surface water, particularly during wet periods
	Inorganic nutrients	Concentrations of TN, NOx, NH_3, FRP and TP were above the ANZECC guidelines
	(Heavy) metals	Average soluble Al, Cr, Cu and Zn concentrations and average total Al, Cr, Cu, Fe and Zn concentrations were above the ANZECC guidelines
Sediment	Nutrients	TP content in sediments has increased since the restoration of the living stream In-stream sediment sites stored more TP, while the seasonally wet sites stored more TN and total organic carbon (TOC)
	(Heavy) metals	Metals content decreased after the basin restoration due to the removal of sludgy sediments, but it has increased since
Vegetation	Nutrients	Below-ground biomass accumulated significantly more nutrients than above-ground biomass with *Baumea articulata* providing a greater nutrient store than *Schoenoplectus validus*, as well as less seasonal loss of biomass TP content was an order of magnitude higher in sediments than in macrophyte biomass TN content in the sediments was twice that contained in macrophyte biomass

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