Designing Constructed Wetlands For Removal Of Filterable Reactive P From Stormwater/groundwater In Areas Of High Water Tables In A Mediterranean Climate

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ABSTRACT

Perth (Western Australia) is situated on the Swan Coastal Plain, a series of parallel sand dune systems abutting the Darling Scarp to the east. The demand for housing is leading urban expansion into areas with high water tables (within 1-2 m of the surface). These areas are mainly situated on the Bassendean sands, which are highly leached and offer little binding capacity for nutrients. Stormwater drainage is therefore frequently contaminated with groundwater, resulting in a high ratio (up to 70%) of filterable reactive P to total P and high concentrations of dissolved organic C (DOC). The high water table complicates the siting of constructed wetlands to avoid becoming a discharge area or necessitating the treatment of large quantities of groundwater in addition to drainage. Perth's Mediterranean climate provides further design constraints for constructed wetlands, which typically dry in summer. This paper will examine a constructed wetland design for this type of environment and report on its effectiveness.

Three replicate experimental ponds (15 x 5 m), were constructed to represent at a 1:1 scale a single cell from a repeating 16 cell design proposed in 1997. Three 5 m zones of each pond were sampled, shallow (0.3 m) vegetated (*Schoenoplectus validus*) inflow and outflow zones and a deeper (1 m), V-shaped central zone. The V-shape was designed to increase hydraulic residence time, control the spread of plants and provide a pool of water to support the plant communities in summer. In 1998/99, inflows and outflow waters were intensively sampled and analysed for FRP. In addition, all major pools of P (plants, interstitial water, sediment) within the ponds, and important P removal processes (benthic flux, uptake by biofilm and *S. validus*) were quantified.

A removal efficiency of 5% (1998) and 10% (1999) was obtained for FRP. When scaled to operational sizes this indicates a removal rate of approximately 40-60% for FRP. Initial uptake was mainly in plant biomass, although the sediment became an increasing important sink. The highly coloured waters (DOC concentrations of 50 mg l^{-1}) were believed responsible for the very low biofilm biomass recorded (<1 g m^{-2}). This project has demonstrated that constructed wetlands can be effective in this type of environment, although the high water table does pose particular design challenges.

KEYWORDS

Amended sediment; biofilm; phosphorus; Western Australia

INTRODUCTION

In Australia constructed wetlands are being widely used for stormwater pollution control, (e.g. Lawrence and Breen, 1998; DLWC 1998; WRC, 1998). In Western Australia, the use of constructed wetlands is recommended as part of the Water Sensitive Urban Design manual (WRC, 1998). In practice there remains scepticism within Government Agencies regarding their cost-effectiveness. Early designs were essentially retrofitted groundwater recharge basins and more recent examples have been purpose built. Research by Braid (1995) and a review by WRC (1997) highlighted numerous problems with constructed wetlands in Perth (Western Australia), including construction not matching design, short-circuiting and poor performance. It has been speculated that constructed wetlands in Perth face greater difficulties in treating stormwater than elsewhere in the world due to the high DOC and filterable reactive P (FRP) levels (WRC, 1997). Perth has a Mediterranean climate and as a result stormwater and drainage flows are largely restricted to between May and November, therefore constructed wetlands (and associated plants) have to cope with prolonged dry periods.

Over 80% of Western Australia's population live on the Swan Coastal Plain (SCP) with the majority congregated in the city of Perth (Figure 1). The SCP consists of a series of parallel dunal systems of varying ages between the Indian Ocean to the west and the Darling Scarp to the east. As urban expansion pushes the limits of the city, many new developments are taking place on the older Bassendean sand dune system. This area was once considered only suitable for semi-rural development as it is largely situated over large groundwater mounds. These mounds are used to supplement (up to 50%) Perth's drinking water supplies and so have been traditionally protected from intensive urban development. In the 1990s the southern mound was opened up for high density urban development and drainage schemes were put in place to reduce the flooding risk. Bassendean sands are highly leached and have very poor nutrient retention capacities. The water table in winter is typically <2 m from the surface. This poses difficulties for housing but also for drainage. Stormwater drains often intersect the water table and become contaminated with groundwater. As a result stormwater and groundwater in these areas typically carry high concentrations (up to 70% of Total P) of FRP, nitrates/nitrites and ammonium. Initially, as the development commences, most of the baseflow within the drains is actually groundwater. Groundwater in Bassendean sands is often highly coloured by humic and fulvic acids (dissolved organic carbon (DOC)) leached from vegetation. This colour inhibits algal growth either through light limitation or more likely by forming complexes with P and trace elements (Lund and Ryder, 1997). Building constructed wetlands in these areas is complicated by the shallow water table and care must be taken to prevent the new wetland acting as a discharge point for groundwater. Where groundwater flows into or through a constructed wetland the impact this might have on the removal efficiencies of the design needs to be considered.

This project aims to determine the suitability and effectiveness of constructed wetlands in areas of high water table. This aim will be addressed through measuring the efficacy of a 'state of the art' design for FRP removal in highly coloured stormwater through intensive in and outlet monitoring, and quantification of P sinks and the processes responsible for any accumulation.

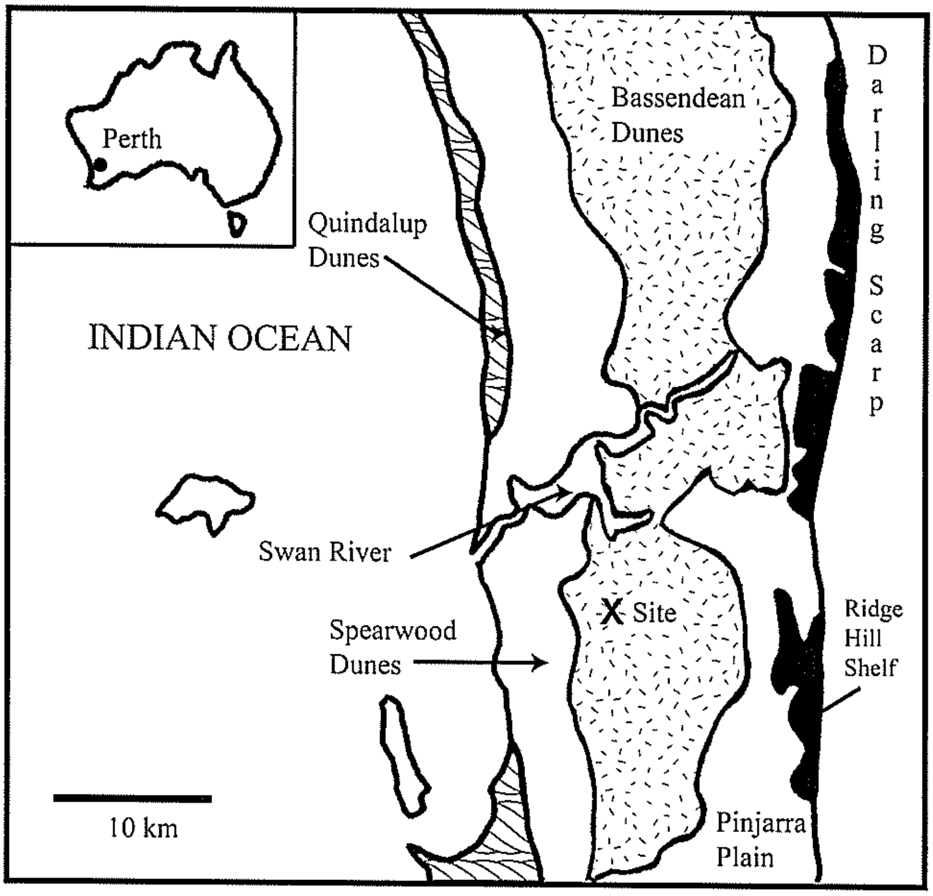

Figure 1 Location map of the study site and the dunal system of the Swan Coastal Plain. The City of Perth covers the majority of the plain shown east of the Darling Scarp

METHODS

Study site

A conceptual design for Henley Brook was proposed in 1997, this design consisted of a series of 16 repeating cells (Figure 2), designed specifically to facilitate P removal (see Lund et al. 2001).

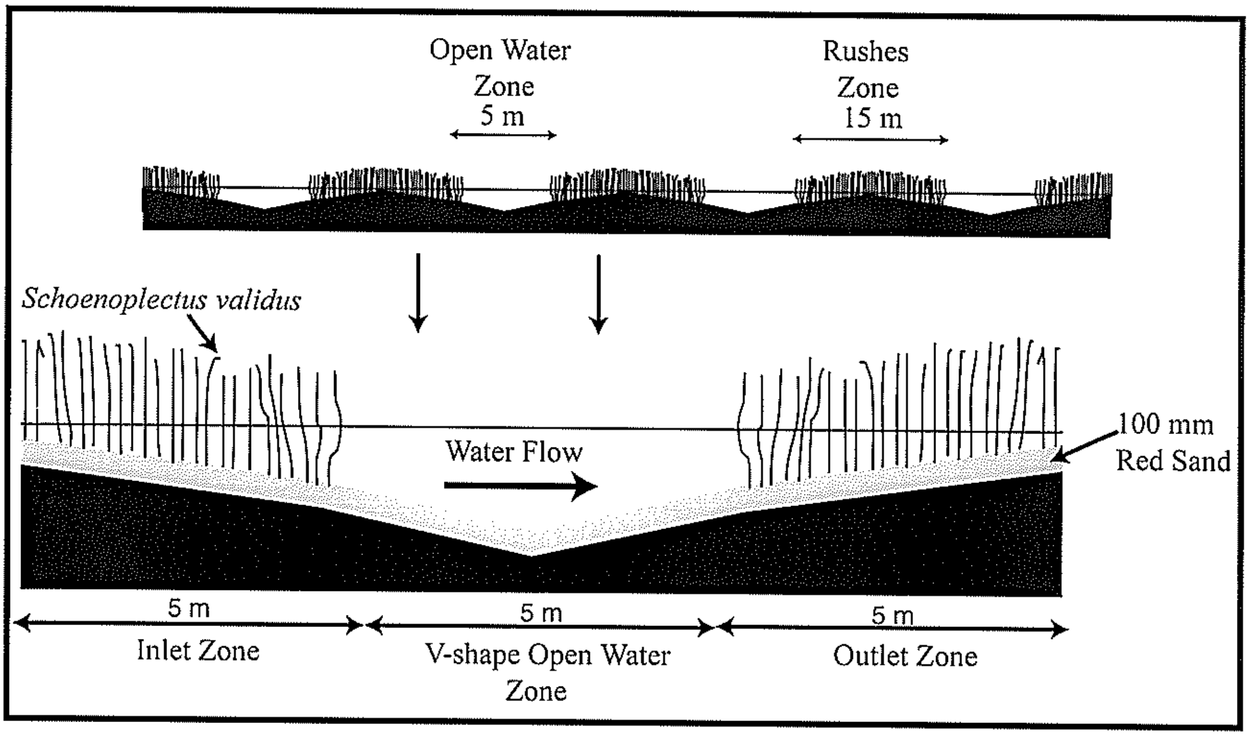

Figure 2 Illustration of the Henley Brook design showing the repeating cells, the lower diagram shows the section used in the experimental ponds

Three experimental ponds (15 m long by 5 m wide) were constructed next to the Thomsons Lake Main Drain in Jandakot (Figure 1). They represent a single cell from the Henley Brook design at 1:1 scale. However unlike the Henley Brook design the ponds were isolated from the groundwater by a concrete shell covered with a PVC liner. The liner was covered by 0.4 m of Bassendean sands (from the site), covered with a 0.1 m layer of red sand. Bauxite residues neutralised by Gypsum have been tested as soil amendment to improve P retention on SCP farmlands with reasonable success (see Summers *et al.*, 1996 a and b). The residue is available in two forms, commonly called red mud (<150 μm particle size fraction) and red sand (≥150 μm particle size fraction), red mud has been used in several constructed wetlands as a sediment amendment. Red sand was used as it is less prone to redistribution and clumping than red mud, although it does have a lower P retention Index (WRC, 1998). Each pond was divided along its length into three 5 m wide zones. The inlet and outlet zone was vegetated with the native rush *Schoenoplectus validus*, these zones slope (1:7.5; 0.2 to 0.5 m water depth) towards the central zone. A 1:5 sloped V-shape occupies the central zone (maximum water depth ~1 m). The slope was determined to minimise sediment slippage and limit plant encroachment of the open water section. The V-shape was used to increase the volume of water in the wetland to increase the hydraulic residence time (HRT). In the Henley Brook design, the V-shape was designed to intersect the water table. In addition, during periods of no flow (i.e. summer), the V-shape should retain water to support the plants. A V was used as this has been found to facilitate the establishment of natural convection circulation patterns that should ensure the bottom of the V remains oxygenated. This was seen as essential to preventing a redox driven release of P following reestablishment of flow conditions. Inlet and outlet structures were designed to facilitate plug flow through the ponds. The HRT was 8 h and 24h in 1998 and 1999 respectively. Eight hours more accurately reflects the HRT of individual cells of the HBD. Flow rates were constant throughout the experiment. When the Thomsons Lake Main Drain was flowing (June to November), a sump pump was used to lift the water into a small header tank where flow was regulated into each pond, outflow was directed back into the drain downstream of the sump pump. Further details of the experimental design are given in Lund et al. (in press).

Sampling methods

In 1998, the ponds were sampled between 1/10/98 and 28/11/98 and in 1999, between 20/7/99 to 23/11/99. Details of the sampling program are given in Lund et al. (in press). In summary, autosamplers collected samples from the inlet and each pond outlet. These were analysed for Total P, FRP, DOC (1998 only) and total suspended solids (TSS, 1999 only). Flow meters on the inlets were used to determine flow. Seasonal samples were taken to estimate P pools in sediments, biofilm and plants.

RESULTS AND DISCUSSION

The ponds proved very successful at removing FRP in 1998 with removal efficiencies ranging between 1.5-4.5%, increasing to 11.4-12.1 % in 1999. These figures suggest that the ponds are performing extremely well, certainly in the predicted range for the Henley Brook design when scaled to an operational size. The removal efficieny for Total P in the ponds was substantially poorer at –1.8 to 2.4% in 1998 and 4.2 to 7.5 % in 1999. This appears to be due to the poor sedimentation (it was not designed to promote sedimentation) and resuspension of sediment.

The ratio of FRP:TP was very high (~70%), which supports the suggestion that flow in the Thomsons Lake Drain had a large groundwater component. Very small biomasses of biofilms were recorded, presumably due to the highly coloured water (mean DOC concentration of 50.8±1.6 mg C l^{-1}. The reasons are twofold with rapid attenuation of PAR, such that below 0.4 m there is effectively no light available for photosynthesis and chelation of essential elements (Lund and Ryder, 1998).

Lund et al (2001) describes the major removal pathways identified and provides a conceptual model of the removal processes occurring in the ponds. Incorporation of P into *S. validus* was the main uptake pathway, with sediment being an important contributor. Biofilms were expected to make a valuable long-term contribution to removal of P by incorporating it into sediment.

Areas of high water table provide a challenge to constructed wetland designers in Western Australia by necessitating that the wetland treats not only stormwater but also groundwater. Groundwater in the Perth area is typically high in dissolved nutrients and is heavily stained (high DOC). This project has shown that wetlands can be constructed that effectively removes this dissolved fraction. Unfortunately current practice is to build constructed wetlands in the least desirable areas for development, usually at the bottom of the catchment. In these areas water tables are very high and any excavation is likely to go into the water table. The use of impervious barriers may help reduce groundwater intrusion, but will add substantially to the construction costs. Another alternative currently being considered is to build the wetland up above the water table and pump the water in. This has the advantage that the wetland is offline and can be easily maintained. The disadvantages are the annual running costs and construction costs. A high water table can be a useful asset to a constructed wetland as careful selection of wetland depth could ensure the survival of emergent plants during the summer dry. The water sensitive urban design manual (WRC, 1998) suggests that smaller constructed wetlands be built higher in the catchment, this would tend to reduce the problems associated with high water tables in some areas. In much of Perth, particularly in Bassendean sand areas the catchment gradient is very low and little height above the water table could be gained by moving up the catchment. Aligning the constructed wetland with the direction of groundwater flow would ensure that the groundwater is treated prior to leaving the site, this may necessitate increasing the size of the wetland to treat the increased flow.

CONCLUSIONS

The experimental ponds proved extremely effective at removing FRP from incoming water in their second year of operation. The sediment accounted for little of the P removal, with P incorporation into plant biomass responsible for the majority of removal. As the plant stand has now become established it is anticipated that plant uptake will become less significant in subsequent years. Biofilm appears to be an important long term removal pathway for P. This suggests that the long term removal capacity of constructed wetlands is reasonable with an estimated removal efficiency of 40-50% for P believed to be achievable. The results show that constructed wetlands are capable of treating groundwater effectively, however high water tables present problems for wetland design to ensure that the wetland does not become a discharge point for groundwater. Wetlands may need to be larger than suggested by the drainage flow as they will have to treat groundwater as well. High water tables may be useful in maintaining rushes in the wetland during the summer dry. Constructed wetlands do appear to a viable way of treating stormwater drainage in areas of high water table although groundwater poses both challenges and opportunities for designers.

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