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Short communication

The effect of different baffles on hydraulic performance of a sediment retention pond

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ABSTRACT

Baffles have been utilised in the ponds and wetland to improve the rate of treatment for the polluted water. However, there is limited research in the optimum configuration and type of baffles for sediment retention ponds (SRP). In this study, the effect of porous and submerged solid baffles on the hydraulic performance of a model SRP is assessed. In order to optimise the type and configuration of baffles, several configurations were tested with four different metal meshes (with different aperture size and open area) as porous baffles, and acrylic sheets as solid baffles. The porous baffles were more effective in increasing the retention time and improving the overall hydraulic performance than the solid baffles. The finest mesh with 0.415 mm aperture size and 40% open area had the highest performance for most of the configurations with 3 or less baffles. However, for four and five baffles, the medium-fine mesh with 1 mm aperture size and 42% open area was the best. For three porous baffles, they were more effective when installed in the first half of the pond compared with when installed about the middle point of the pond, regardless of the mesh size. The two porous baffles with same aperture sizes but different open areas had different hydraulic performance which highlights the importance of mesh aperture in addition to the total open area.

1. Introduction

Sediment retention ponds (SRPs) have been widely used as a sustainable measure for settling the suspended sediments from the polluted runoff (ARC, 1999; Khan et al., 2013; Vymazal, 2014). The favourable flow regime in ponds, which is the plug flow (PF) condition, provides the ideal condition for high settling efficiencies (Nix, 1985). In the PF condition the inflow water particles travel within the pond "in single file" with limited mixing with the adjacent water, and exit the pond in the order in which they enter (Levenspiel and Bischoff, 1964). The pond's hydraulic performance can be attributed to the degree of departure of the flow regime from the ideal PF condition. In practice, however, the existence of hydraulic phenomena such as mixing, short circuiting (SC) and dead zones, makes it impossible to achieve a PF condition (Kadlec, 1994).

It has been clearly shown that the performance of a SRP is determined by its hydraulic characteristics. For example, Kilani and Ogunrombi (1984) studied the effect of baffles in model waste stabilisation ponds, and concluded that the longer retention times obtained as a result of using baffles corresponded with an improvement in the removal efficiency of organic and solid matter. Nighman and Harbor (1997) state that less residence time results in lower sediment removal due to less time for the suspended sediment to settle. Koskiaho (2003) also reported that high settlement of the suspended sediment in his study was associated with long residence times as well as high hydraulic efficiency.

1.1. Baffles

Several attempts have been made to improve the flow regime and performance of ponds by altering the pond layout (Persson 2000; Su et al., 2009), inlet and outlet design (Bodin et al., 2012), deflector islands (Khan et al., 2011), floating treatment wetlands (Khan et al., 2013), and baffles (De Oliveira et al., 2011; Nighman and Harbor, 1997).

Baffles are solid or porous impediments installed within ponds in any orientation, to improve the rate of treatment. They may be constructed from various solid or porous materials such as plywood or a silt fence for solid baffles (Nighman and Harbor, 1997), and jute mesh or braced geotextile curtains for porous baffles (Thaxton et al., 2004). They are installed in the ponds

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primarily to dissipate the inflow momentum and increase the residence time of the incoming water particles, which consequently improves the pond's hydraulic performance.

Porous baffles effectively distribute the flow over the entire width of a pond and result in increased deposition within the basin. Spreading the flow in this way utilises the full cross section, thereby increasing the effective volume, which results in higher settling opportunity for the suspended particles. It also reduces the chance of resuspension for the already settled sediments by reducing the local turbulence close to the pond's bed.

There is evidence that the implementation of baffles can improve the hydraulic performance and settling efficiency of ponds (Koskiaho, 2003; Wang et al., 2012). Nighman and Harbor (1997) state that the effectiveness of baffles mainly depends on their location and orientation in the pond. They placed a silt baffle near the inlet structure of a field stormwater pond and observed an increase in sediment settling. However, the sediment settling significantly decreased when the incoming storm overtopped the baffle as a result of sheet flow above the baffle.

Despite all the previous efforts, there remains little practical guidance specifically targeting selection and installation of baffles. In a recent study, Zech et al. (2014) reported that due to the lack of standards and guidelines for design and installation of baffles, the agencies in the US are reluctant to use them. This signifies the need for further investigation into baffle configurations in order to document their performance.

This study investigates the effect of porous and solid baffles on the hydraulic performance of a model SRP. The primary aims of this study are: (1) to investigate the effect of position and number of baffles, and (2) to investigate the effect of mesh aperture size and OA on the hydraulic performance of a model SRP. Also the performance of solid baffles is compared with that of porous baffles.

2. Materials and methods

2.1. Hydraulic indices

A widely used method for assessing the hydraulic performance in ponds is analysis of the residence time distribution (RTD) (that is generated from a tracer study) and extracting hydraulic indices (Bodin et al., 2012; Khan et al., 2011). In this study, the hydraulic performance for different configurations was assessed using the hydraulic indices recommended by Farjood et al. (2014): for SC, t_5; for mixing, the Morril index (Mo); and for hydraulic efficiency, the moment index (MI). t_5 is the normalised time for 5% of the added tracer to exit the pond. The Morril index, Mo, is defined as t_{90}/t_{10}, where t_{10} and t_{90} are the times for 10% and 90% of the added tracer to exit the system, respectively. The moment index (MI) for hydraulic efficiency (introduced by Wahl et al. (2010)) is defined as:

$$\mathrm{MI} = 1 - \int_0^1 (1 - t')C'(t')\,dt' \qquad (1)$$

where $C' = C/C_0$, C is concentration of tracer at each interval, C_0 is mass of the added tracer divided by the pond volume, $t' = t/t_n$, t is measurement time and t_n is nominal residence time (pond volume/inflow rate). In this study the inverse of the Mo, (Mo^{-1}), is used instead of Mo, for consistency in the trend of the hydraulic indices. The higher the value of each index, the more hydraulically efficient is the system.

2.2. Experimental setup

Tracer experiments using Rhodamine WT tracer were carried out for several configurations of baffles in a model trapezoidal pond, which is made from acrylic sheets (Fig. 1). The pond dimensions are 4.1 m (height) × 1.6 m (width) × 0.3 m (depth); bank slopes are 2:1 (horizontal:vertical) and t_n = 453 s at 2 l/s flow rate. For addition of tracer, thirty plastic caps are fixed on a straight bar that is placed above the pond's inlet edge. The tracer is added to each cap and by rotating the bar, tracer is uniformly distributed over the inlet width.

For the outlet structure, three perforated pipes (the decants) with 48 mm internal diameter were attached to an outlet riser pipe. To allow water to exit the pond, the tubes were perforated with five rows of 6 mm diameter holes on each of the decants. The outlet riser pipe, which is made from PVC with 200 mm internal diameter, is 250 mm long and placed vertically. The decants were fixed to the outlet riser at 220 mm from the bottom and were

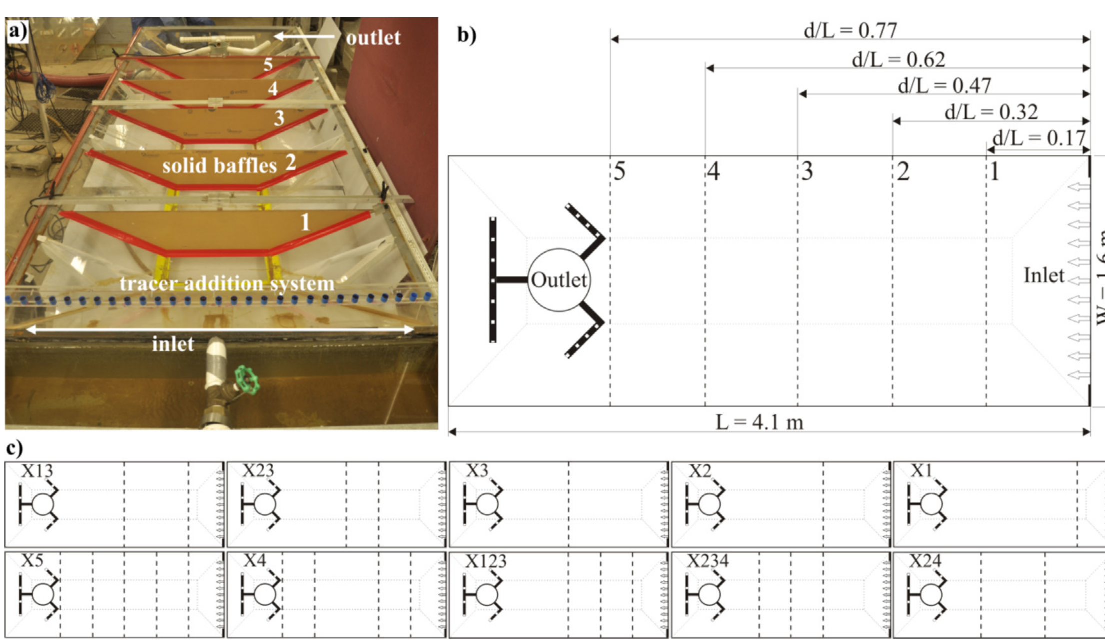

Fig. 1. The experimental setup, (a) the model SRP with solid baffles, (b) the sketch of the model pond with the position of baffles shown with dashed lines, d/L shows the distance of the baffle from the inlet, normalised to the length of the pond (L), (c) the tested baffle configurations, X is a general term for the mesh types (coarse, medium-coarse, medium-fine, or fine).