Effect of baffles on the hydraulic performance of sediment retention ponds
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ABSTRACT

An investigation of the effect of baffles on retention pond performance using a physical model of an existing sediment retention pond is presented. Analysis of residence time (RTD curves) was used to compare the hydraulic performance of different arrangements of baffles in the pond. Five different arrangements for the design of baffles were studied. The results show that placing a single baffle to deflect the influent to a sediment retention pond does not improve pond performance; rather, it stimulates short-circuiting. This is contradictory to the literature and is considered to be a consequence of the model pond incorporating sloping walls, which is a novel aspect of this study. Most of the previous studies have neglected the effects of battered walls. Conversely, the inclusion of more than two baffles was found to increase the hydraulic performance. The results reported here are limited to small and narrow ponds where a large portion of the pond is batter (i.e. made up of sloping walls). For large area ponds, batter effects may be negligible and are likely to be different from those reported here.

Key words | baffles, retention ponds, RTD curves

INTRODUCTION

It is important to design sediment retention ponds such that the flow regime in the pond results in a longer residence time and provides sufficient time for sediment particles to settle. Several studies have investigated the flow regime in retention ponds to enhance their performance (Walker 1998; Persson et al. 1999; Stamou 2008; Fang et al. 2015; Farjood et al. 2015; He et al. 2015).

The flow in the pond is governed by many factors, including length to width ratio (Thackston et al. 1987; Hvittved-Jacobsen et al. 1994; Walker 1998; Persson 2000; Shilton 2001; Persson & Wittgren 2003; Abbas et al. 2006; Gharabaghi et al. 2006), inlet and outlet arrangements (Wood et al. 1998; Persson 2000; German 2003; Shilton & Harrison 2005), bottom topography (Holland et al. 2004) and meteorological factors like temperature and wind (Torres et al. 1997; Shilton 2001; Adamsson & Bergdahl 2006). When short-circuiting exists, some of the water particles reach the outlet very quickly, in a time that can be much less than the nominal residence time of the pond. There are several ways suggested in the literature to prevent short-circuiting, including placement of baffles, optimised arrangement of the inlet relative to the outlet, optimisation of the length to width ratio and retrofitting a deflector island to diffuse the inlet jet. Baffles are an option to improve the performance of existing ponds, because they can be retro-fitted. Baffles are easy to build and may be significantly cheaper than reshaping a pond for its improved hydraulic performance. Most of the studies (numerical or experimental) to investigate the impact of baffles on the pond residence time were undertaken assuming the walls to be vertical, i.e. ignoring the batter slope.

Most of the research on baffle design reported in the literature suggests that the inclusion of a baffle improves the pond performance (Persson 2000; Shilton 2001; Shilton & Harrison 2003). The most comprehensive work is that reported by Shilton & Harrison (2003), for the hydraulic of waste stabilisation ponds. They tested the effect of installing a single baffle (baffle length = 2/3 of the pond width) located at $x/L_m = 0.5$, where $x$ = distance of the baffle from the inlet end of the pond and $L_m$ = length of the model pond. They found that a single baffle does give an improvement over an un-baffled case, but stepping up to an evenly...
spaced two-baffle system is far superior. They also suggested that the use of more than four baffles is not recommended as the additional improvement in pond performance was minimal and the arrangement may increase the cost significantly. Khan et al. (2012) first reported that including an island to deflect the influent to a stormwater retention pond does not improve pond performance in small and shallow ponds with sloping walls.

Although the literature strongly suggests that a single baffle does give an improvement over an un-baffled case, the inclusion of baffles may have different effects on different types of ponds due to the fact that pond hydraulics depend on the individual characteristic of ponds, i.e. pond shape, inflow and environmental conditions (Shilton & Harrison 2005).

In this paper, the effect of the number of baffles on the hydraulics of sediment retention ponds is studied using a rectangular pond with sloping sides, built in the hydraulics laboratory of the University of Auckland, New Zealand.

**Methodology**

The model pond was designed as an exact replica of an existing retention pond situated at the Alpurt B2 Motorway site, Auckland, New Zealand. The field pond has top dimensions of length \( L_p = 41 \) m, width \( W_p = 15 \) m and depth \( D_p = 2.3 \) m. The inlet and outlet pipe diameters are 450 mm and 1,050 mm, respectively.

The geometric scale ratio between model pond and field pond is \( L_r = 1:10 \) (model: prototype). At this scale, the top dimensions of the model pond are \( 4.1 \) m (pond length, \( L_m \)), \( 1.5 \) m (pond width, \( W_m \)) and \( 0.23 \) m (pond depth, \( D_m \)).

The model pond is shown in Figure 1. It comprises a rectangular tank with sloping sides (2:1, horizontal: vertical), similar to the field retention pond.

The model pond was constructed from transparent acrylic sheets fitted on a steel frame. The 45 mm diameter inlet is aligned horizontally and positioned in the centre of the front wall of the pond, such that its crown is just below the water surface. The inlet consisted of a flexible tube, which was tightly fixed with a clamp to a 1 m long PVC pipe. The 105 mm diameter outlet was positioned on the opposite end of the pond at its centre. The flow rate \( Q \) at the inlet was controlled using a small valve installed just before the inlet pipe. The flow control valve had an accuracy of ±1%. The outlet is fixed on a moveable plate to control the water depth in the pond.

During testing, the pond was filled until a steady state was achieved, with the volume of water in the pond remaining constant. Flow depth was recorded to estimate volume and residence time (pond volume/discharge).

Five cases of different arrangements of baffles in the pond (Table 1) were tested as shown in Figure 2. The baffles were evenly spaced with the length of each baffle equal to 70% of the width of the pond, i.e. \( 1.05 \) m. The baffles were

**Table 1** Experimental listing of baffle design

<table>
<thead>
<tr>
<th>( l/L_m )</th>
<th>No. of baffles</th>
<th>No. of experiment recordings</th>
</tr>
</thead>
<tbody>
<tr>
<td>–</td>
<td>No baffle</td>
<td>3</td>
</tr>
<tr>
<td>0.5</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>0.33</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>0.25</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>0.2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>0.16</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

\( l \) – the distance between baffles.

Figure 1 | Model pond specification (view from the outlet end of the pond).

Figure 2 | Experimental arrangements for baffles.
carefully sealed to the pond boundaries to avoid any leakage that might cause short-circuiting.

**Hydraulic parameters**

The pond performance is normally measured in terms of quantities derived from the RTD curves, termed ‘hydraulic parameters’ herein. Similarly to previous studies, the hydraulic parameters used in this study are short-circuiting, effective volume ratio, hydraulic efficiency, and moment index.

The short-circuiting factor \( S \) is the ratio of \( t_{16} \) to \( t_n \), where \( t_{16} \) is the time when the 16th percentile of the tracer added at the inlet has passed the outlet and \( t_n \) is the nominal residence time, calculated as pond volume divided by inlet flow rate. A value of \( S \) greater than 0.4 is considered good, indicating an efficient pond, while a value less than 0.3 indicates short-circuiting, \( S_c \). The latter is calculated as \( 1 - S \). The maximum value for this parameter is unity, which would indicate no short-circuiting in the pond. The effective volume ratio \( e \) is the ratio of mean residence time \( t_{\text{mean}} \) to the nominal residence time \( t_n \). The maximum value of \( e = 1 \) indicates completely mixed flow or plug flow. \( t_{\text{mean}} \) (the average time that a tracer particle spends in the pond) can be calculated using the following equation:

\[
t_{\text{mean}} = \int_0^\infty tCdt / \int_0^\infty Cdt
\]

where \( C \) = tracer concentration measured at the outlet, at time \( t \). Hydraulic efficiency \( \lambda \) is defined as the ratio of \( t_{p1} \) to \( t_n \), where \( t_{p1} \) is the time when the first higher peak of the RTD curve occurs. A value of hydraulic efficiency above 0.5 is considered satisfactory (Persson & Somes 1999).

Moment index \( M_f \) is derived from the first moment of the normalised RTD curve \( M_p \), i.e. \( M_f = 1 - M_p \), and \( M_f \) is calculated at \( t' = t/t_n = 1 \) using the following equation:

\[
M_f = \int_0^1 (1 - t'_c)C'dt'
\]

where \( t'_c \) = normalised distance on time-axis from origin to the centroid of the area under the normalized RTD curve between \( t' = 0 \) and \( t' = 1 \), and \( C' = C/C_0 \) = normalised concentration, where \( C_0 \) is the amount of dye added to the pond divided by the pond volume. An advantage of using \( M_f \) is that it is independent of the effects of the long tail of the RTD curve. The maximum value of \( M_f = 1 \) indicates plug flow (Wahl et al. 2010).

For the present study, Rhodamine W T was used as dye tracer. Rhodamine W T is a non-toxic dye, which receives minimal background interference and has low adsorption and degradation rates. A 10 mL amount of 1 g/L solution of Rhodamine W T was injected as a pulse at the inlet. The dye was injected 72 cm away from the inlet to allow complete mixing of the dye with water. After some preliminary experiments it was noted that the amount of 10 mL was sufficient to be tracked successfully and was also within the detection limits of the measuring instrument. Most importantly, this amount was small enough not to affect the flow rate into the pond.

The dye concentrations were measured with a Seapoint Rhodamine Fluorometer (SRF). The SRF was placed in the outlet pipe to measure the amount of dye in terms of voltage output as it passed through the outlet. The effects of any background lights in the laboratory were minimised by wrapping a black polyethylene plastic sheet around the outlet pipe.

**RESULTS AND DISCUSSION**

The RTD curves resulting from the tracer studies are shown in Figure 3 and the hydraulic parameters derived from these RTD curves are given in Table 2 and Figure 4. The RTD curves are a representation of the tracer distribution and its movement through the pond and indicate the time that every water particle resides in the pond. For comparison purposes, the RTD curves are normalised, i.e. plotted in terms of \( C' \). The shift in the plots due to normalising the...
The time-axis is insignificant, because the baffle width is small enough not to affect the overall pond volume, and hence the difference in the \( t_n \) values for all the cases presented in Figure 3 is marginal (see Table 2).

Analysis of these curves gives the concentrations of the dye leaving the pond, the occurrence of the tracer peak concentration at the outlet and the time at which it occurs, directly indicating the residence times for each case. The hydraulic parameters calculated on the basis of these RTD curves are related back to the performance of the pond.

The RTD curve for the basic case where no baffles are present (Case 1) features two peaks. The time corresponding to the first concentration peak of the RTD curve represents the time that the tracer in the core of the inlet jet needs to pass from inlet to outlet. The second peak represents the time that the tracer takes to reach the outlet after completing a second circuit of the pond. The first peak occurred a very short time after the tracer injection, indicating strong short-circuiting. The peak occurred after 2 min of the injection of the tracer as compared with 12.1 min nominal residence time, demonstrating poor performance for this layout (Figure 3 and Table 2). The second peak indicates recirculation in the pond. Similar results have been reported by Wood et al. (1998) and Adamsson et al. (2005). The hydraulic efficiency was 18% and short-circuiting was 67% (Table 2). However, the effective volume was 97%.

It was envisioned that the time of first appearance of the tracer at the outlet and the time of the first tracer peak could be delayed by placing a baffle in front of the inlet, as is reported in the literature (Persson 2000; Shilton 2001; Shilton & Harrison 2003). However, when a baffle was placed halfway along the pond \((x/L_m = 0.5)\), the time for the first appearance of the tracer to reach the outlet was reduced (Cases 2) to 50% of that for the case without a baffle. The inlet jet was diverted towards the sloping walls of the pond, from where it travelled towards the outlet very quickly. A possible reason is the very shallow depth of water at the sloping walls causing less mixing, allowing the jet to travel to the outlet without any disturbance. This is apparent in Figure 3, where the higher and narrow peak of the RTD curve for Case 2 indicates less mixing in the pond.

It is apparent that the installation of a baffle does not always improve the pond performance for horizontal inlets. Conversely, the previously reported studies (Persson 2000; Shilton 2001; Shilton & Harrison 2003) show that a single baffle at \(x/L_m = 0.5\) can significantly improve the pond hydraulics. The results of this study are attributed to the sloping walls of the pond. Sloping walls give limited

### Table 2 | Calculated hydraulic parameters for arrangements of baffles

<table>
<thead>
<tr>
<th>Case</th>
<th>( t_{mean} ) (min)</th>
<th>( t_{sd} ) (min)</th>
<th>( t_{so} ) (min)</th>
<th>( t_{pe} ) (min)</th>
<th>( t_n ) (min)</th>
<th>e</th>
<th>Sc</th>
<th>( \lambda )</th>
<th>Dye recovery (%)</th>
<th>( M_I )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>11.8</td>
<td>3.9</td>
<td>9.4</td>
<td>2.2</td>
<td>12.1</td>
<td>0.97</td>
<td>0.67</td>
<td>0.18</td>
<td>98</td>
<td>0.71</td>
</tr>
<tr>
<td>Case 2</td>
<td>9.8</td>
<td>2.0</td>
<td>8.3</td>
<td>1.2</td>
<td>12.1</td>
<td>0.81</td>
<td>0.85</td>
<td>0.10</td>
<td>89.4</td>
<td>0.63</td>
</tr>
<tr>
<td>Case 3</td>
<td>11.7</td>
<td>4.1</td>
<td>10.4</td>
<td>2.1</td>
<td>12.1</td>
<td>0.97</td>
<td>0.66</td>
<td>0.18</td>
<td>92.7</td>
<td>0.73</td>
</tr>
<tr>
<td>Case 4</td>
<td>11.8</td>
<td>4.8</td>
<td>10.7</td>
<td>5.2</td>
<td>12.0</td>
<td>0.98</td>
<td>0.60</td>
<td>0.43</td>
<td>92.7</td>
<td>0.76</td>
</tr>
<tr>
<td>Case 5</td>
<td>11.6</td>
<td>5.4</td>
<td>11.1</td>
<td>6.4</td>
<td>12.0</td>
<td>0.97</td>
<td>0.55</td>
<td>0.53</td>
<td>89.7</td>
<td>0.78</td>
</tr>
<tr>
<td>Case 6</td>
<td>11.4</td>
<td>5.8</td>
<td>10.9</td>
<td>6.9</td>
<td>12.0</td>
<td>0.95</td>
<td>0.52</td>
<td>0.58</td>
<td>89.0</td>
<td>0.79</td>
</tr>
</tbody>
</table>

| Figure 4 | Hydraulic performance of baffle arrangements, where \( M_I \) is moment index, \( \lambda \) is hydraulic efficiency and \( Sc \) is short-circuiting.
volumes of water to the end of the baffle, allowing the inflow to quickly bypass the area around the end of the baffle. Comparing the results with those from previous studies, it is recommended that baffle design should be considered in relation to the pond shape and inlet position. The results of this study are limited to small and narrow ponds with similar length to width ratio and where a large portion of the pond is batter.

For two baffles (Case 3) the performance is similar to that for the basic arrangement of Case 1 (Figure 3 and Table 2). This is attributed to the fact that although the length of the flow path has increased, the inflow quickly passes the ends of the baffles, rendering the two-baffle combination ineffective. This is also a significant finding of this study, contradictory to the literature suggesting that two baffles provide far superior performance. However, three baffles (Case 4) were found to have superior performance, improving the hydraulic efficiency of the pond by 140% compared with the un-baffled case (Case 1). Pond performance was further improved using four and five baffles (Cases 5 and 6). However, increasing the number of baffles beyond four baffles was found to have minimal further improvement (Figures 3 and 4). The results indicate that the baffle design needs careful attention, and may not always improve the pond’s performance. Improper inclusion of baffles in a pond may lead to increased short-circuiting. For example, the case of a single baffle (Case 2) exacerbated the short-circuiting by 24%, causing a reduction of 44% in hydraulic efficiency and 11% in moment index. Given cost implications, the use of more than four baffles in sediment retention ponds is not recommended, while a minimum of three baffles is appropriate as a compromise between cost and pond performance.

CONCLUSIONS

The findings of this study make it clear that baffle design needs careful attention, and addition of baffles may not always improve pond performance. The following conclusions are drawn from the study:

1. Inclusion of a single baffle was found to exacerbate short-circuiting in the pond, causing a reduction of 44% in hydraulic efficiency, this being contradictory to previous reported studies. Further, the inclusion of two baffles in retention ponds with sloping walls is ineffective. These novel and contradictory findings of the study are attributed to the sloping walls of the pond.

2. The addition of three or more baffles was found to further improve pond performance compared with the un-baffled case. However, the improvements stemming from more than three baffles are minimal, i.e. three baffles represent a good compromise between improved pond performance and the associated increased cost of adding baffles to ponds. Given cost implications, the use of more than four baffles is not recommended.

3. Comparing the results of this study with those of the existing literature, it is recommended that baffle design be considered in relation to the pond shape.

REFERENCES


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