A pond-wetland-vegetated filter system to treat beef farm manure pile and exercise yard runoff

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Introduction

Livestock operations produce runoff from outdoor confinement areas and uncovered manure storage facilities. Management practices can include capturing the runoff in a holding pond and land applying the liquid following nutrient management guidelines [1] or treating the effluent in an on-farm treatment system and discharging the treated effluent either to a surface water body (drain, stream or lake) or to groundwater through a soil infiltration system. Nutrient levels in runoff are significant from an environmental perspective but low from an agronomic perspective, creating the need for innovative, low-cost treatment technologies.

Treatment pond-wetland systems, which are natural systems driven by solar energy, have been demonstrated to effectively treat agricultural runoff [2, 3, 4]. As well, vegetative filters, which utilise soil and vegetation to purify effluent, can also be effective at treating runoff [5, 6]. Vegetated filters have the added benefit of infiltrating the treated effluent into groundwater, avoiding surface water discharge, which often has more stringent government regulation.

An experimental demonstration treatment system was established in 2014 at a 30-head beef farm in Winchester, Ontario, 55 km southeast of Ottawa, ON, to treat the farm’s manure pile and exercise yard runoff. The system includes a pond-wetland system as well as two soil infiltration systems: a vegetated filter strip (VFS) and a natural flow path (FP). The system was monitored extensively for three years to evaluate performance of the pond-wetland system and to compare the performance of the two soil infiltration systems. Project findings will help support on-farm decision making regarding the management of livestock operations.

![Figure 1. Plan view of the exercise yard and pond-wetland system at the Pemdale farm, Winchester, ON. Google Earth V 7.3.1.4507 imagery (September 2\textsuperscript{nd} 2016, eye alt 137 m)](image-url)
System Configuration

The treatment systems consist of a primary settling pond (P1), a surface flow constructed wetland (W), a storage pond (P2) and two parallel soil infiltration systems - a vegetative filter strip (VFS) and a natural flow path (FP) (See Figures 1 & 2).

The manure is piled on a 1000 m² uncovered concrete pad. Accumulated manure is spread onto farm pasture fields every three years. Runoff from the concrete pad and exercise yard flows into a pump chamber (PC) which doses the first settling pond (P1). The settling pond has an area of 109 m² and a depth of 1.5 m. An overflow weir runs the entire width of the pond with the effluent flowing into the constructed wetland (W). The wetland spans 9 x 11.5 m (103.5 m²) and has an average depth of 0.3 m. The wetland effluent is stored in an existing farm pond (P2). The vegetated filter strip (VFS) and flow path (FP) are both dosed from P2.

The VFS consists of a 6.0 x 20.0m vegetated area in native clay-loam soil and graded with a 2-3% slope planted in Orchardgrass. The filter is dosed through a 6.0 m perforated 3.0 inch dia. header pipe to evenly distribute effluent across the filter. The FP consists of a single point discharge into a 39m long vegetated channel (FP5) following the natural field contours. Water quality samples were collected from 30 cm deep zero-tension lysimeters as well as from groundwater piezometers.

Figure 2. Plan view of Pond 2, vegetative filter strip and flow path at the Pemdale farm, Winchester, ON. Google Earth V 7.3.1.4507 imagery (September 2nd 2016, eye alt 94 m).
Runoff Quality

Runoff quality from the concrete pad is presented in Table 1. Significantly higher concentrations for all parameters were observed during spring runoff due to manure pile solids being washed into the pond. During the wetland operating season, BOD₅, TN and TP concentrations in the runoff were 2-3 times higher than domestic wastewater while COD was 10 times higher.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Spring Runoff (March-April)</th>
<th>Operating Season (May-November)</th>
<th>Domestic Wastewaterᵃ</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD (mg/L)</td>
<td>10,880 ± 3,870</td>
<td>3,413 ± 2,268</td>
<td>400</td>
</tr>
<tr>
<td>BOD₅ (mg/L)</td>
<td>3,505 ± 2221</td>
<td>354 ± 335</td>
<td>200</td>
</tr>
<tr>
<td>TSS (mg/L)</td>
<td>1,563 ± 1140</td>
<td>232 ± 152</td>
<td>200</td>
</tr>
<tr>
<td>TN (mg/L)</td>
<td>951 ± 535</td>
<td>144 ± 78</td>
<td>45</td>
</tr>
<tr>
<td>TP (mg/L)</td>
<td>60 ± 31</td>
<td>26 ± 12</td>
<td>10</td>
</tr>
</tbody>
</table>


System Performance

The removal of organic matter (COD and BOD₅) in the treatment systems is presented in Figure 1. Organic matter removal can be attributed to settling and filtration of solid particles as well as microbial degradation in both the pond-wetland system and the soil infiltration systems. COD and BOD₅ were reduced by 79 and 83 percent, respectively, in the pond-wetland system to concentrations of 714 mg/L COD and 61 mg/L BOD₅ in P2. The vegetated filter and flow path were both effective at polishing COD to final effluent concentrations of 155 and 116 mg/L, respectively, by the end of each filter. This represents a total COD reduction of 95-97 percent. COD concentrations in Piezometers 1 and 2 remained at background concentrations of 29 and 22 mg/l, respectively, while Piezometer 3 (directly below the VFS) was impacted by wastewater loading with an average concentration of 69 mg/L.

![Figure 1. Organic Matter in Pond-Wetland and Infiltration Systems over 3 Operating Seasons (Average ± 95% C.I.)](image-url)
No significant changes in total suspended solids (TSS) concentrations were observed between the inlet and the wetland, with TSS concentrations of 232 ±154, 209±223 and 241 ±290 mg/L at Inlet, P1 and W, respectively. However, a 48 percent reduction in TSS was observed in P2, with effluent concentrations of 125 ±122 mg/L. The TSS measured in the system is likely more a representation of internal processes than that of migrating solids from the influent, including the observed development of duckweed in the ponds and resuspension of detritus in the wetland cell.

The removal of phosphorus across the systems are presented in Figure 2. The predominant form of phosphorus measured was soluble reactive phosphorus (SRP). Most of the organic phosphorus was removed by settling in the pond-wetland system with the remaining organic P removed through filtration in the soil infiltration systems. SRP removal mechanisms likely included plant uptake in the pond-wetland system as well as soil adsorption in the soil infiltration systems. TP was reduced by 64 percent in the pond-wetland system to 9.4 mg/L in P2. The vegetated filter and flow path were both effective at further reducing TP to final effluent concentrations of 1.4 and 1.5 mg/L, respectively, by the end of each filter. This represents a total TP reduction of 94-95 percent. There does not appear to be any effect of loading on groundwater quality with piezometer SRP concentrations varying from 0.11 to 0.23 mg/L.

The removal of nitrogen across the systems are presented in Figure 3, with nitrogen present in the forms of organic N, ammonia and nitrate. Approximately half of the organic nitrogen was removed in the pond-wetland system, either through physical settling or through ammonification, while the remaining organic N was removed through filtration in the soil infiltration systems. Ammonia and nitrate removal in the pond-wetland system, as well as in the soil infiltration systems, can be attributed to a combination of plant uptake and microbial nitrification and denitrification. TN was reduced by 75 percent in the pond-wetland system to 38 mg/L in P2, and further reduced to 6.5 and 7.9 mg/L in the vegetated filter and flow path, respectively. This represents a total TN reduction of 95-96 percent, with the remaining nitrogen predominantly in the form of nitrate. Piezometers 1 and 2 remained at background concentrations of 1.0 and 0.9 mg/L of total inorganic nitrogen (TIN), respectively, while Piezometer 3 (directly beneath VFS) was impacted by effluent loading, with an average TIN concentration of 2.6 mg/L.
Costs

Capital costs to build the system are described below. The major expenses related to the installation of cattle fencing around the systems and the construction of the pond and wetland cells. The installation of an impermeable liner may be required in some cases, which would add an additional cost to the construction. Operating costs will include electricity and machinery time to cut the grass in the vegetated filter and around the ponds and wetland. Operating costs should not exceed $1000/year.

<table>
<thead>
<tr>
<th>Construction Costs</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Cattle fencing (electric)</td>
<td>$4400</td>
</tr>
<tr>
<td>Excavation (Backhoe)</td>
<td>$940</td>
</tr>
<tr>
<td>Gates</td>
<td>$140</td>
</tr>
<tr>
<td>Gravel/culvert (access to field)</td>
<td>$620</td>
</tr>
<tr>
<td>Pumps (x2)</td>
<td>$1000</td>
</tr>
<tr>
<td><strong>TOTAL (CAD)</strong></td>
<td><strong>$7100</strong></td>
</tr>
</tbody>
</table>

Conclusions and Recommendations

The pond-wetland system was effective at reducing organic matter and nutrient concentrations from beef farm manure pile and exercise yard runoff by 64-83%; however, effluent quality would not meet typical surface water discharge requirements. The performance of two soil infiltration systems, a vegetated filter strip and a natural flow path, were compared in a side-by-side trial. Both systems were very effective at increasing total removal rates to 94-97%, with groundwater quality only marginally impacted directly below the vegetated filter strip. In conclusion, a combination of a pond-wetland-pond technology followed by either a vegetated filter strip or a natural flow path is a promising solution for beef producers which can provide excellent treatment at low cost.
Acknowledgements

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References


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