Combating nutrient transport in drainage water using various conservation practices

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Tile: Michigan

- 2.3 million acres
- Agricultural subsurface drainage
- 29% total cropland is tiled

1992 data

Prepared by Ehsan Ghane.
Why subsurface (tile) drainage?

Near Willmar, MN: Photo taken on June 15, 2016

Photo taken on September 2, 2016
Great Lakes Algal Bloom Status?

- NASA Worldview
What can we do?

- Wetland
- Two-stage ditch
- Cover crop
- 4R approach (fertilizer: right place, right time, right rate, right form)
- Drainage Water Recycling
- Saturated buffer
- Drainage water management (Controlled drainage)
- Denitrification Bed (Woodchip bioreactor)
Drainage Water Management

• Main purpose is to reduce nutrient delivery to surface water
Research

- Initiated in 2007
- Four-year applied project
  - Seven sites
  - (2008-2011)
Water Management Zone

- Hardin-NW site (Ohio)
Percent Yield Increase
Water management Zone

Crop yield (bu/ac)

Corn
Soybean

6% Increase
4% Increase

Controlled Drainage
Free Drainage

Ghane et al. 2012; J of Soil and Water Conservation
Controlled Drainage

- Found **reduced flow (40% to 100%)**
- Reduce nutrient loss
Why would DWM be of interest?

• No land is taken out of production
• Low maintenance and requires management
• Reduces nutrient runoff (nitrate load reduction 15% to 75%)
• Improves crop yield with proper management and timely rainfall
Any Questions So Far?

• Drainage Water Management
Denitrifying Bioreactors

1. Denitrification Wall
2. Streambed Bioreactor
3. Denitrification Bed (woodchip bioreactor)

Fig. 1. Design sketch of Avon streambed bioreactor (adapted from Robertson and Merkley, 2009).

L. Schipper, U of Waikato, New Zealand
What’s a Denitrification Bed?

Subsurface Drainage

Excess nitrate

Bacteria

Denitrification Bed

N₂

N₂

N₂

Improved surface water quality

Reduced nitrate

NO₃⁻ → N₂

NO₃⁻ → N₂

NO₃⁻ → N₂

Improved surface water quality
Side View: Woodchip Bioreactor
Non-Darcy flow through woodchips

Specific discharge (cm/s) vs. Hydraulic gradient (cm/cm)

- Darcy
- Non-Darcy

Non-Darcy post linear zone

Old woodchips 2

- Darcy

Graph showing the relationship between specific discharge and hydraulic gradient for non-Darcy and Darcy flow through woodchips.
Ghane et al. (2014) data:

Darcy’s Law Flow Overestimation

![Graph showing flow rate (cm$^3$s$^{-1}$) over dates from 30-Oct-13 to 21-Jun-14. The graph compares Weir flow, Darcy prediction, and Forchheimer prediction. The data shows significant overestimation by Darcy’s Law compared to Forchheimer prediction.]
Galaxy of woodchip bioreactors
### Denitrification Bed (Woodchip Bioreactor) Model v2.0 Beta

**Ehsan Ghahe, Ph.D., The Ohio State U, and U of Minnesota**

#### Woodchip Media Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrinsic permeability, $k_m$ (cm/s)</td>
<td>0.000568</td>
</tr>
<tr>
<td>$\omega$ constant (s/cm²)</td>
<td>0.88</td>
</tr>
<tr>
<td>Effective porosity or drainable porosity, $n_r$</td>
<td>0.45</td>
</tr>
</tbody>
</table>

#### Nitrate Removal (Michaelis-Menten and Arrhenius Equations)

<table>
<thead>
<tr>
<th>Property</th>
<th>Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum nitrate removal rate, $V_{max}$ (mg-N/L-h)</td>
<td>7.1</td>
</tr>
<tr>
<td>Michaelis-Menten constant, $K_m$ (mg-N/L)</td>
<td>7.2</td>
</tr>
<tr>
<td>Temperature coefficient, $b$</td>
<td>1.109</td>
</tr>
</tbody>
</table>

#### Denitrification Bed Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denitrification bed depth, $d$ (ft)</td>
<td>60</td>
</tr>
<tr>
<td>Denitrification bed length, $L$ (ft)</td>
<td>15</td>
</tr>
<tr>
<td>Denitrification bed width, $w$ (ft)</td>
<td>0.001</td>
</tr>
<tr>
<td>Denitrification bed bottom slope, $S$ (ft/ft)</td>
<td>0.15</td>
</tr>
</tbody>
</table>

#### Denitrification Bed Summary

<table>
<thead>
<tr>
<th>Property</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflow height of water in the bed, $h_i$ (ft)</td>
<td>3.53</td>
</tr>
<tr>
<td>Outflow height of water in the bed, $h_o$ (ft)</td>
<td>0.61</td>
</tr>
<tr>
<td>Hydraulic gradient, $i$ (ft/ft)</td>
<td>0.049</td>
</tr>
<tr>
<td>Bed outflow temperature, $T$ (°F)</td>
<td>58</td>
</tr>
<tr>
<td>Outflow dynamic viscosity, $k$ (g/cm-s)</td>
<td>0.0116</td>
</tr>
<tr>
<td>Hydraulic conductivity at outflow temperature, $k_{f}$ (ft/s)</td>
<td>0.15</td>
</tr>
<tr>
<td>Analytical solution to Forchheimer’s Equation-0</td>
<td>0.0</td>
</tr>
<tr>
<td>Bed flow rate that makes Forchheimer’s Equation equal to zero</td>
<td>0.153</td>
</tr>
<tr>
<td>Denitrification bed flow rate, $Q$ (cfs)</td>
<td>0.121</td>
</tr>
<tr>
<td>Actual hydraulic retention time, AHRT (hr)</td>
<td>1.6</td>
</tr>
<tr>
<td>Overall Summary</td>
<td></td>
</tr>
<tr>
<td>Inflow nitrate concentration, $C_i$ (mg N/L)</td>
<td>12.1</td>
</tr>
</tbody>
</table>

#### Flow Conditions

<table>
<thead>
<tr>
<th>Property</th>
<th>Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drainage area (ac)</td>
<td>67.6</td>
</tr>
<tr>
<td>Drainage coefficient, $DC$ (in/d)</td>
<td>0.5</td>
</tr>
<tr>
<td>Control structure size (m)</td>
<td>10</td>
</tr>
<tr>
<td>Inlet height of stoplogs (ft)</td>
<td>7 (bottom stoplog only)</td>
</tr>
<tr>
<td>Outlet height of stoplogs (ft)</td>
<td>7</td>
</tr>
<tr>
<td>Inflow nitrate concentration, $C$ (mg N/L)</td>
<td>35</td>
</tr>
<tr>
<td>Bed inflow (tile water) (°F)</td>
<td>55</td>
</tr>
</tbody>
</table>

#### Weep Hole Properties (Optional)

<table>
<thead>
<tr>
<th>Property</th>
<th>Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weep hole on bottom stoplog?</td>
<td>Yes</td>
</tr>
<tr>
<td>Weep hole diameter (in)</td>
<td>0.5</td>
</tr>
<tr>
<td>Weep hole distance from bottom (in)</td>
<td>5.875</td>
</tr>
</tbody>
</table>

#### Control Structure Summary

<table>
<thead>
<tr>
<th>Property</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bypass flow from the inlet structure (cfs)</td>
<td>1.267</td>
</tr>
<tr>
<td>Flow depth above inlet stoplog crest (ft)</td>
<td>0.61</td>
</tr>
<tr>
<td>Flow depth above outlet stoplog crest (ft)</td>
<td>0.33</td>
</tr>
<tr>
<td>Drainage system capacity (cfs)</td>
<td>1.420</td>
</tr>
</tbody>
</table>

#### Weep Hole Summary

<table>
<thead>
<tr>
<th>Property</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weep hole flow rate (cfs)</td>
<td>0.003</td>
</tr>
<tr>
<td>Portion of bed flow through weep hole (%)</td>
<td>21</td>
</tr>
</tbody>
</table>

### Instructions:

This worksheet can be used to optimize the design parameters (i.e., length, width, and slope).

1. First, type all input values and then adjust the length and width. Try to obtain outflow nitrate concentration between 5 to 10 mg N/L total nitrate load reduction (bed+bypass flow) of at least 5%, and treatment of at least 15% drainage system capacity. These targets are expected to achieve the minimum target of 45% annual load reduction suggested in the Gulf Hypoxia Action Plan 2008.

2. It is suggested that the design parameters be determined for mid-spring when the outlet elevation of the tile is raised after planting, crop establishment, and spring field operations.

Note 1: If you get a “Compile error: Can’t find project or library”, load the Solver add-in. Then, re-open the Excel Worksheet.

Note 2: Clicking on the description in some boxes will give further information.
Results

Woodchip Bioreactor: Waterman site in Ohio

Date

Nitrate load (lb-N)

Inflow daily load
Outflow daily load
Why would a Woodchip Bioreactor be of interest?

- Little or no land is taken out of production
- Low maintenance
- Long life (15-20 years)
- Compatible with controlled drainage
- Remove nitrate
  - herbicide (atrazine), pesticides, and pathogens?
Subsurface Drainage
Nitrogen Transport
Woodchip Bioreactor
PhosphoReduc filter
Subsurface Drainage Nutrient Transport

\[ \text{NO}_3^- \quad \text{N}_2 \quad \text{P} \]

\[ \text{P} \]

\[ \text{PhosphoReduc} \quad \text{Environmental Solutions} \]
Results

Phosphorus Removal with the P-filter

Soluble reactive P concentration (mg/L)

- Bioreactor inflow
- Bioreactor outflow
- Phosphorus filter outflow

Storm Event:
- 12-Apr-13
- 24-Apr-13
- 10-May-13
- 13-Jun-13
- 1-Jul-13
- 27-Jul-13
- 23-Oct-13
- 7-Nov-13
- 23-Nov-13
- 25-Dec-13
- 12-Jan-14
Take Homes

• Long-term crop yield benefit and nutrient reduction from controlled drainage

• Denitrification bed (woodchip bioreactor) is effective in nitrate removal

• Each should be used in combination with other conservation practices
Thank you

More Questions?

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Friday, March 3, 2017