A Best Management Practice for reducing nutrient loss in drainage water

WOODCHIP BIOFILTERS

This publication is a guide to woodchip biofilters as a best management practice for nutrient reduction. The information contained in this document is intended to provide awareness on the function, design and suitability of woodchip biofilters. The case study examples should not be used as a design standard. This document may be updated as new information becomes available. Content contributors can be found at the end of this document to contact for more information.

UPPER THAMES RIVER
CONSERVATION AUTHORITY

Woodchip Biofilters

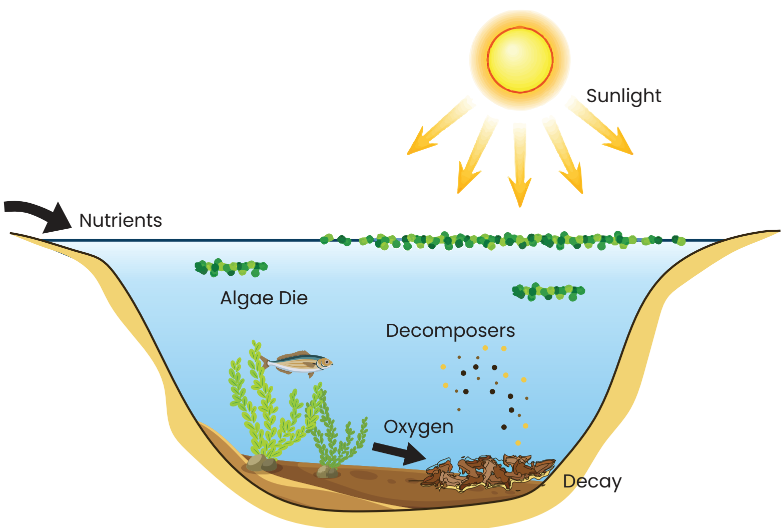
Water Quality Concerns

High concentrations of phosphorus and nitrogen lead to increased growth of algae. As algae die, bacteria decompose the dead organic material, and this process depletes available dissolved oxygen in the water. Low dissolved oxygen has implications for fish and other aquatic life. As well, some forms of algae (blue-green) may produce toxins, which limit the use of that water for human consumption and recreation.

Nitrate does not readily bind to soil particles and it is very prone to leaching. Nitrate losses are difficult to control, as excess soil moisture or increased infiltration will cause the downward movement of nitrate into tile drains or groundwater.

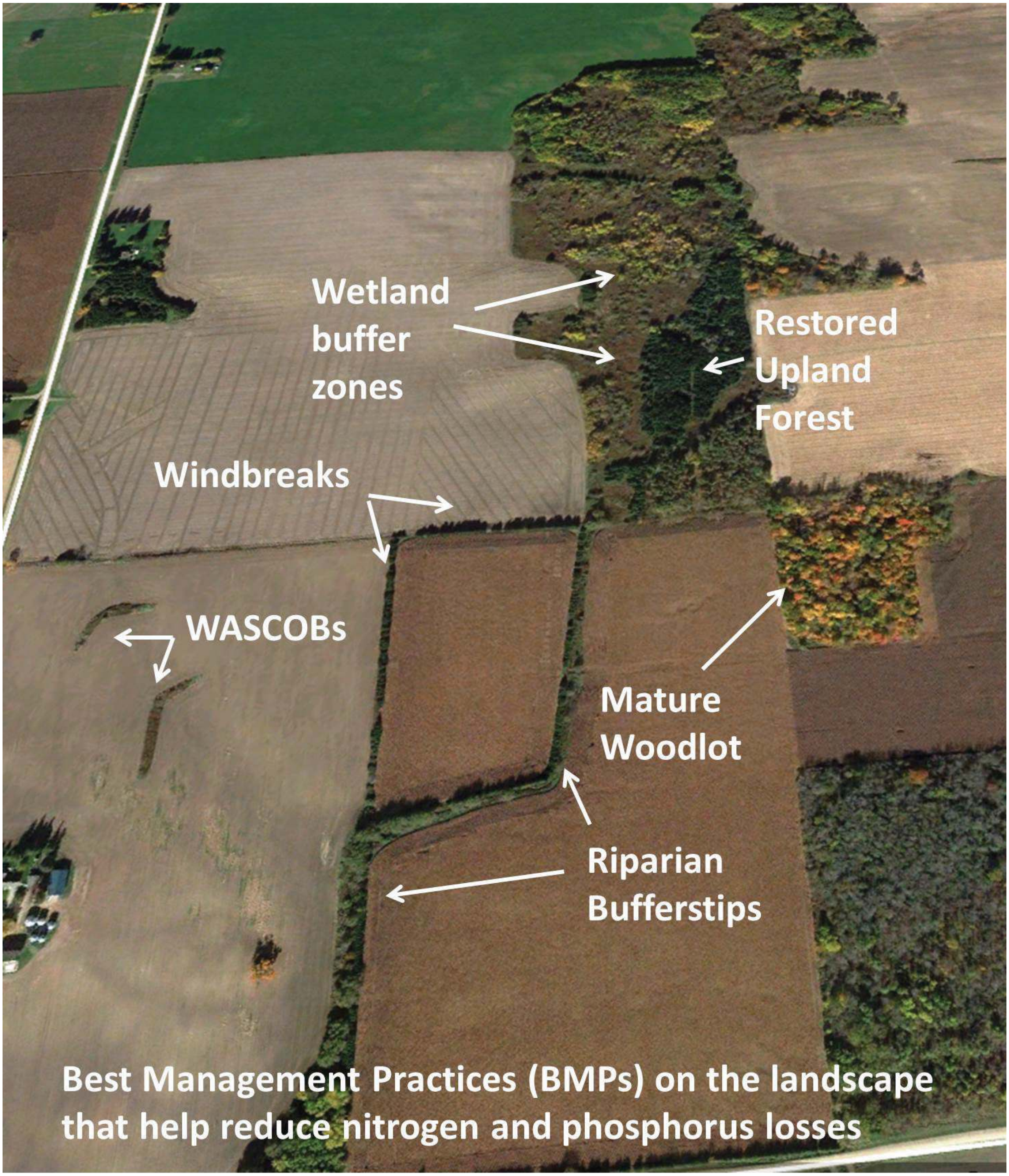
Phosphorus is highly reactive and binds tightly to soil particles. Erosion of that soil can result in the loss of particulate phosphorus. Dissolved phosphorus may also be leached when the soil's capacity to uptake phosphorus is exceeded. This can occur on agricultural lands where there have been long term applications of commercial fertilizer or manure.

Limiting the amount of nitrate and phosphorus that reaches surface water is important for improving water quality.



Sources of nitrate and phosphorus :

- Commercial fertilizers
- Lawn and garden fertilizers
- Manure
- Animal feed lots
- Septic systems
- Industrial and municipal wastewater



There are many best management practices that can help reduce nitrate and phosphorus losses from the rural landscape. **Woodchip biofilters** are one edge of field practice that can be used in combination with the above best management practices to enhance the removal of nutrients.

Woodchip biofilters are an edge of field best management practice to improve water quality by removing nutrients in drainage water.

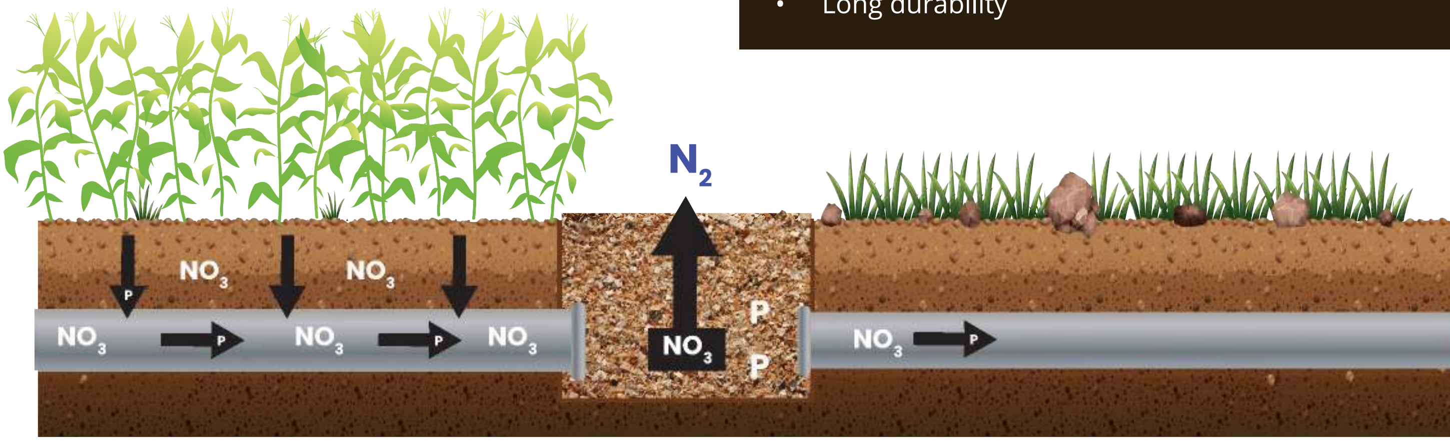
Woodchip biofilters are a trench filled with a carbon source, primarily woodchips, through which drainage water is diverted. Nitrogen is removed from the water by enhancing the natural biological process of denitrification. Microbes utilize the woodchips as a carbon food sources and convert nitrate (NO3) to nitrogen gas (N2) through respirations. The anaerobic (without oxygen) conditions ensure the microbes utilize the nitrate.

Benefits of biofilters

- High nitrate removal
- Little to no land taken out of production
- Low cost
- Low maintenance
- Long lifespan (up to 15-20 years)

Why Woodchips

- Low cost
- Relatively available
- High permeability
- High carbon to nitrogen ratio
- Long durability



Types of Woodchips

- Avoid woodchips from treated wood, as they limit the ability of the microbes to use the carbon in the wood.

- Avoid woodchips containing a high proportion of leaves or conifer needles, as their high nitrogen content will degrade the woodchips more quickly and reduce the longevity of the biofilter.

- Limit the amount of fine material (i.e., sawdust) in the woodchips. Too much fine material may alter the flow rate and the biofilter will not function as designed.

Design Considerations

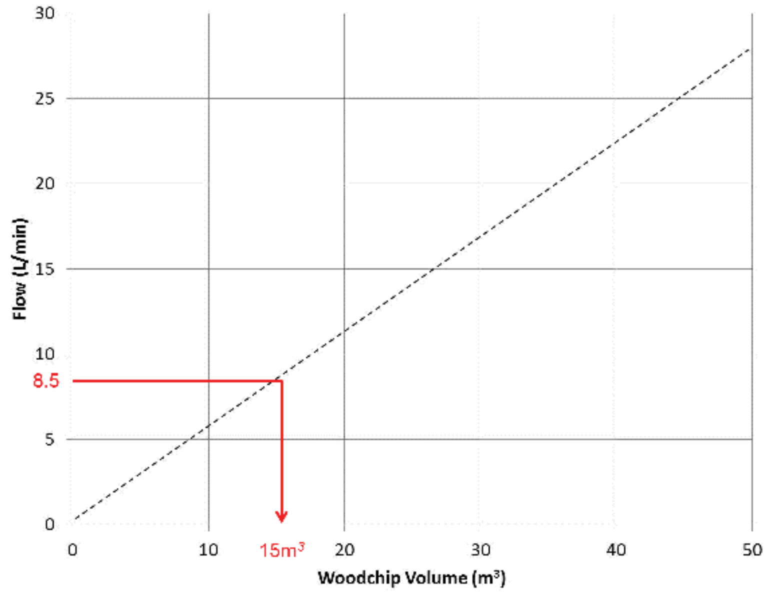
The amount of water the biofilter can treat will be influenced by the size of the contributing area.

- Watershed characteristics can be determined from drainage, topographic and soil maps.
- The amount of runoff will determine the volume of woodchips (ie. size of filter) required for treatment.

The amount of runoff is typically too high to effectively treat without a large scale biofilter. This may require a large amount of land to be taken out of production. An alternative approach is to take a portion of flow and route it through a smaller biofilter. Smaller biofilters can fit into the existing width of the riparian buffer, resulting in little land taken out of production and limited impacts on farming.

Design Example (See Chart)
For example: 15m3 of woodchips is required to treat tile flow at 8.5L/min. The size of biofilter can fit into an existing 3m (10ft) wide buffer strip by constructing a biofilter with the following dimensions:
- 5m x 3m x 1m (l x w x d)
- The 3m width (fixed) fits into the existing buffer. The length and depth can be adjusted to meet the size requirements.

This size of biofilter has the capacity to treat an average of 8L/min. Depending on the amount of total runoff generated; flow rate may need to be controlled to achieve desired flow rate through the biofilter.



$$\text{Retention time} = \frac{\text{total woodchip pore volume}}{\text{flow rate}}$$

**woodchip pore volume is 60% of woodchip volume*

Controlling Flow Rate

Controlling the amount of flow through the biofilter is critical. The typical retention time for water in a biofilter is 12-24 hours. Ensure the water drains within 48 hours during low-flow periods to avoid stagnant water, which may have an adverse impact on water quality.

Flow can be regulated by:

(a) Using a water control structure :
- Allows the water level to be raised or lowered to maintain desired flow through the biofilter.
- A control structure may be required at both the inlet and outlet to maintain desired flow.

(b) Rerouting a portion of flow through the biofilter using a wye or redistribution pipe off tile drain system.

(c) Adjusting the height of the outlet discharge pipe by:
- Manually changing the height of the discharge pipe,
- Setting the discharge pipe to a desirable elevation, or
- Designing a multiple outlet system to accommodate a variety of flows.


(a) Water control structure


(b) Wye to reroute portion of tile drainage


(c) Multiple Stage Outlet

Considerations

High Flow

An overflow (or bypass) is required on any biofilter to accommodate periods of high flow. Biofilters are not designed to treat stormflow events. The volume of water passing through the filter during these periods is too large to allow sufficient retention time to occur.

During this startup period, dark coloured effluent may result from the leaching of the soluble organic compounds (e.g., tannic acids) from the woodchips. **This water should not be discharged to surface water bodies.** Pump the effluent onto adjacent farm land until the dark, tea-like colouration of the effluent dissipates.

Undesirable Leachate

Avoid stagnant water or long retention times during low flow conditions, as this could result in the production of greenhouse gases and other toxins. If water is left stagnant in the biofilter during low flow periods, this water should also be pumped onto adjacent fields and not discharged to the watercourse.

Dissolved oxygen may be reduced in water passing through the biofilter. Consider measures to re-oxygenate the water before it discharges into an adjacent watercourse, such as:

Aquatic Plants

Riffles

Rock Chute

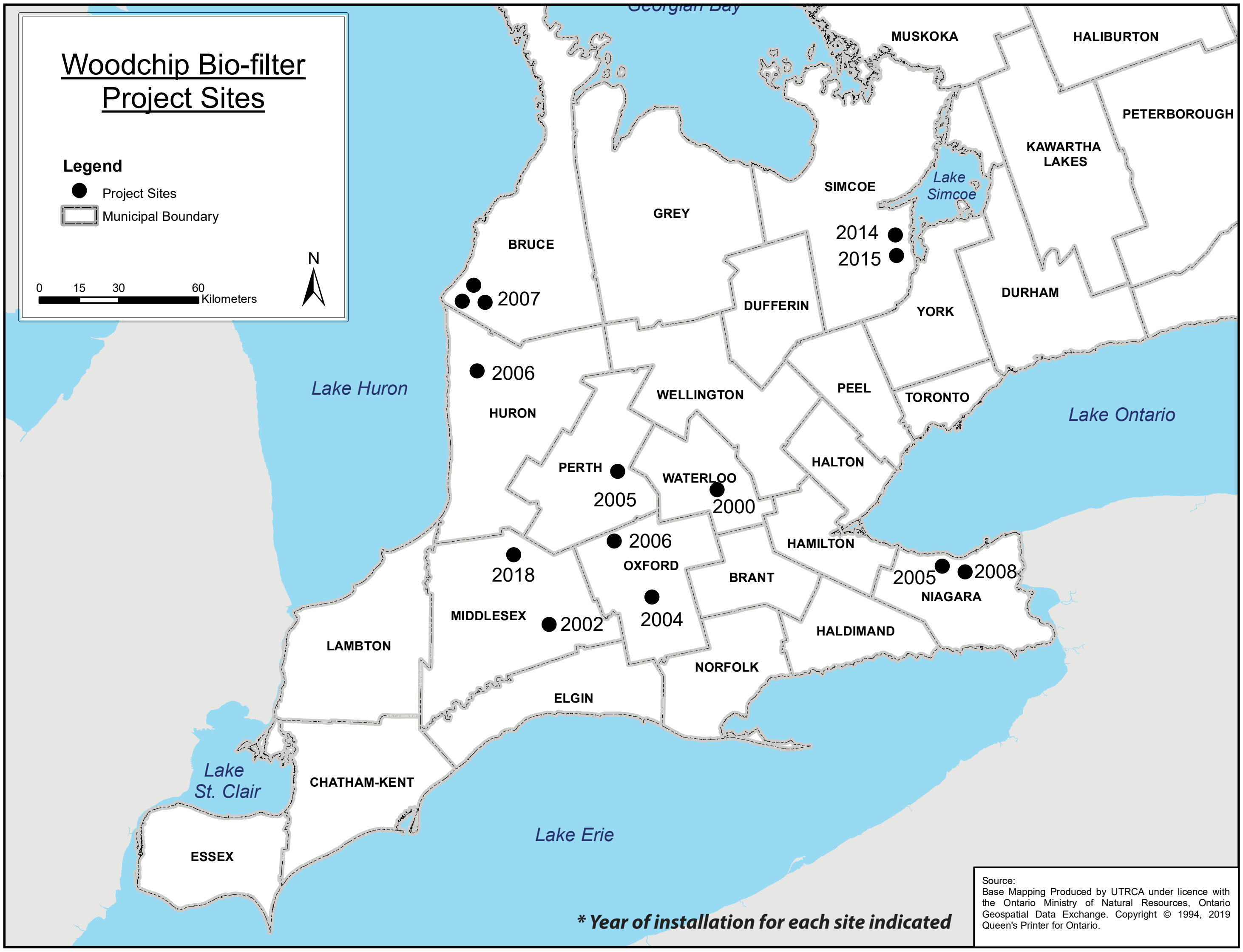
Aeration Trench

Sedimentation

Periodic sediment removal may be required to ensure the longevity of the filter, as the buildup of sediment can decrease flow rates and alter nitrate removal. It is good practice to regularly inspect the biofilter for sediment build up, especially after initial start-up and following significant runoff events.

Exclude surface water from the biofilter to reduce high sediment accumulation. Biofilters are not designed to treat water from tile drain lines with surface inlets.

One potential advantage of sediment retention is the simultaneous retention of particulate bound phosphorus in the woodchips. Over time, however, the retained phosphorus may be released from the trapped sediment.



Case Studies

Edge of Field Applications

- **Downflow Biofilter**
  - Medway Creek
  - Wildwood Conservation Area, St. Marys Ontario
- **Upflow Biofilter**
  - Fanshawe Conservation Area

Alternative Design: In-Stream Application

- Avon River, Stratford Ontario

Alternative Media Options

- Slag
- Red Sand

Edge of Field Applications

Downflow Biofilter (Lateral Flow)

Drainage water is directed overtop of the biofilter, forced down through the media by gravity, and collected in an underdrain system.

If designing a downflow biofilter, consider using a layer of gravel on top of the woodchips to remove sediment as water moves downward.

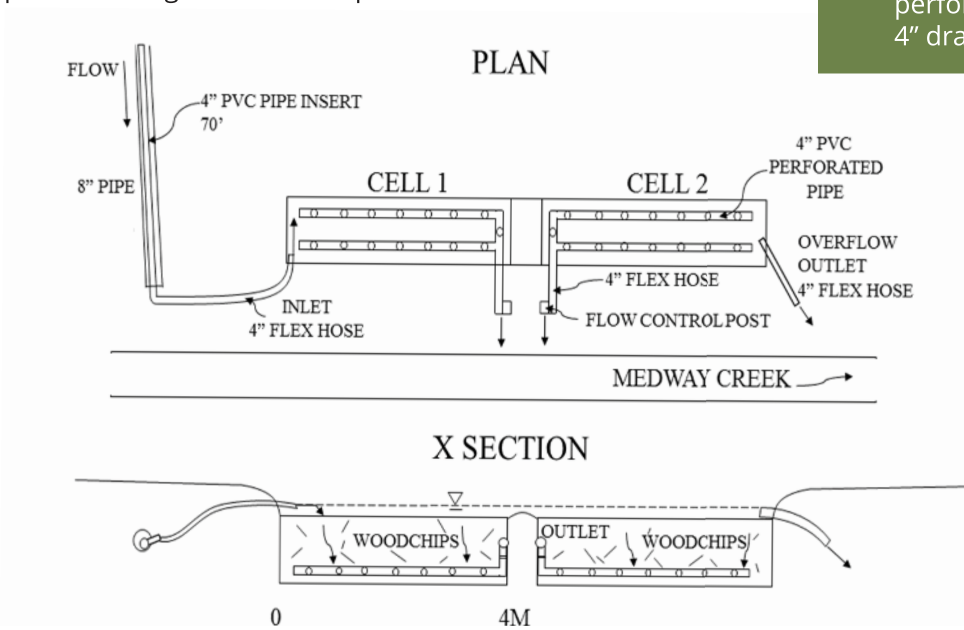
Design

- Field drainage tile outlet
- Dimensions: 4m x 1m x 1m (each cell)
- Woodchip volume: 4m3 layered woodchips
- Flow enters top of filter to drains downwards
- Average flow 60m3/day

Underdrains can be constructed using perforated pipe and are placed at the bottom of the trench before it is filled with woodchips. These pipes collect the treated water after it passes through the woodchip media.

Flow is controlled at the outlet of the biofilter through the filter with perforated drainage pipe

- Outlet flow rate controlled by 4” inch perforated PVC pipe with flexible 4” drainage line



This two cell system was used to investigate the removal of phosphorus (Cell 1) and nitrate (Cell 2) from a woodchip biofilter.

Step 1: Trench is dug within riparian buffer strip.

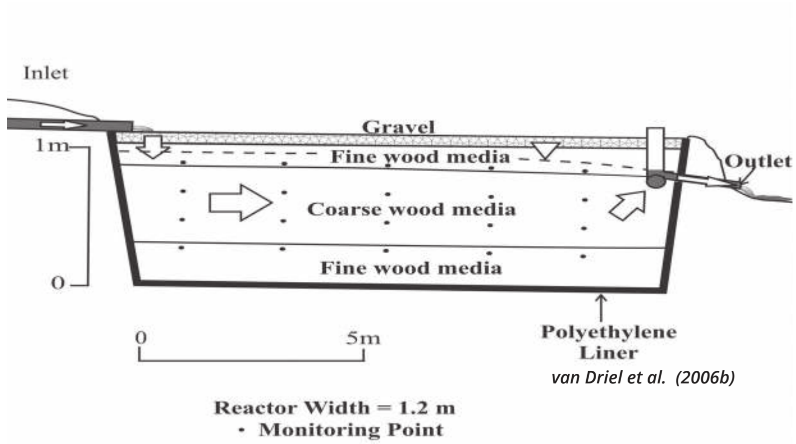
Step 2: Underdrains installed at the bottom of trench to drain the biofilter

Step 3: Trench is backfilled with woodchips

Alternative Design: Downflow Biofilter

Drainage water is directed underneath the biofilters, forced upwards through the media by pressure, and outlets at the top of the filter.

Design
- Field drainage tile outlet
- Dimensions: 13m x 1.2m x 1.1m
- Layered biofilter (fine-coarse-fine material)
- Woodchip volume: 20m3 layered pine woodchip and sawdust media lined trench
- Water flows across top pf filter and percolates downward
- Top layer provides filtering of sediment

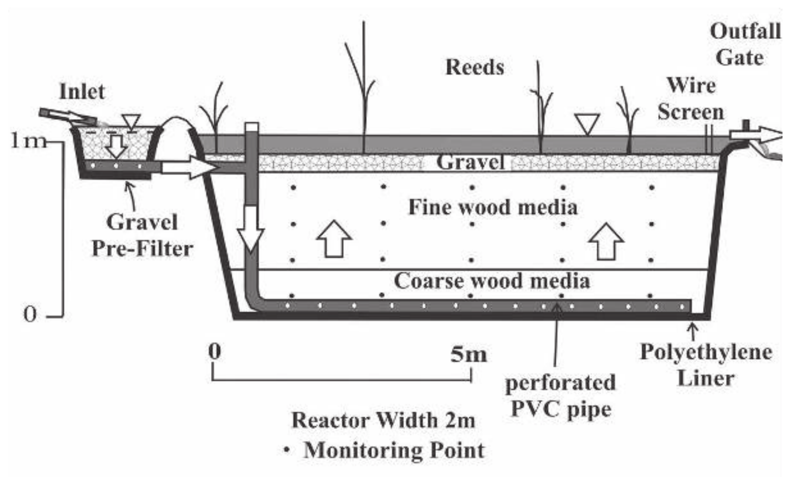


van Driel et al. (2006b)

Alternative Design: Upflow Biofilter

Drainage water is directed underneath the biofilters, forced upwards through the media by pressure, and outlets at the top of the filter.

Design
- Field drainage tile outlet
- Dimensions: 10m x 2.0m x 0.8m
- Layered biofilter (fine material overlying course material)
- Woodchip volume: 16m3 layered media
- Water flows into a pipe along the bottom of the trench, which flows upward through media
- 4" PVC pipe (perforated along the bottom)
- Outflow gate controls flow rate through biofilter
- Gravel pre-filter was used to filter sediment from inflow

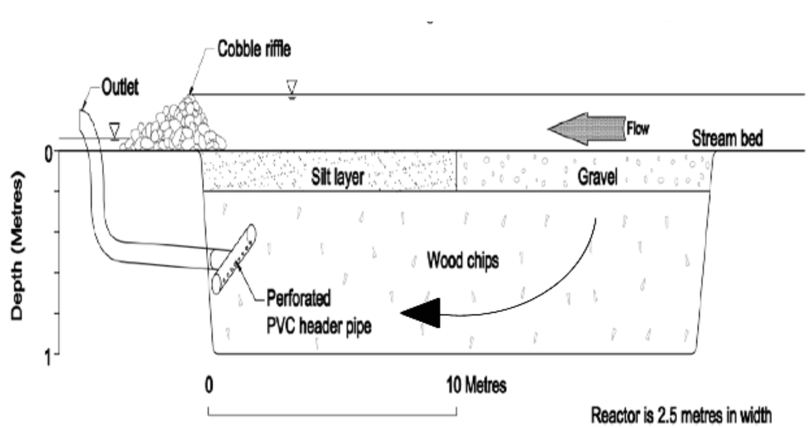


Alternative Design: In-Stream Application

When private land is unavailable, an in-stream biofilter may be an alternative approach. Consult with your local Conservation Authority as to whether this is an applicable option. Consult your local drainage superintendent before beginning any work within a municipal drain.

Design
- Trench excavated into the bottom of the streambed
- Dimensions: 20m long x 2.5m wide x 1m below streambed
- Woodchip volume: 40 m3 in excavated trench
- Single day construction

Flow controlled through the filter with outlet drainage pipe
- 4" inch perforated PVC pipe with flexible 4" drainage line
- Water level increased over the biofilter by constructing a 30cm high cobble berm at downstream end

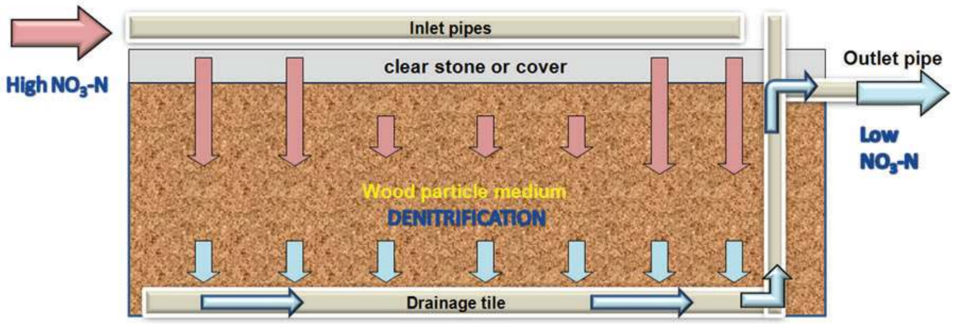


Alternative Design: Horticultural Application

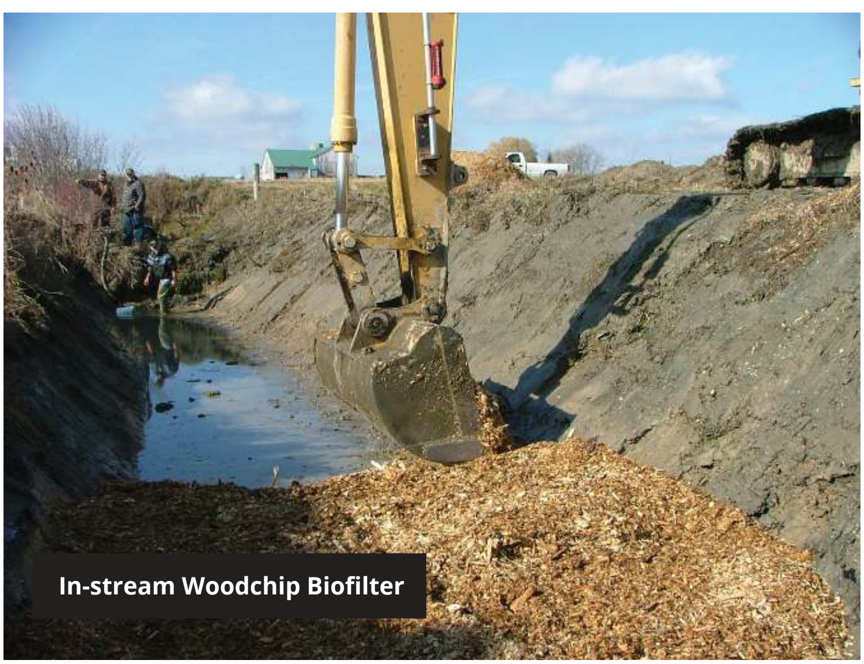
Horticulture operations have installed woodchip biofilters to remove nitrate from greenhouse production water.

Design:

- Downflow Biofilter
- Dimensions: 7mx 14m x2.5m
- Woodchip Volume: 245m3
- Production water is directed into perforated pipe overtop of woodchip biofilter
- Water percolated down through woodchips, where underdrains collect the water to discharge through the outlet pipe
- Top gravel layer was used to filter sediment and solids from the inflow
- Flow is controlled at the inlet



Greenhouse Woodchip Biofilter



In-stream Woodchip Biofilter

Edge of Field Woodchip Biofilter

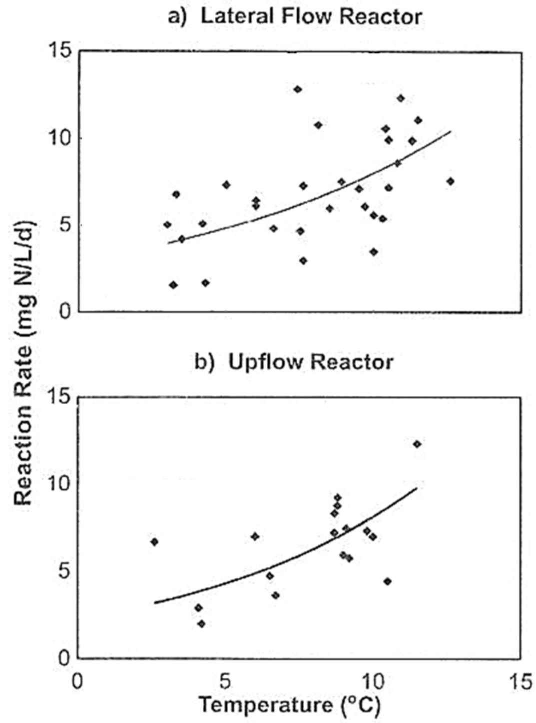
Before you begin

- Planning, design and construction should be carried out by qualified professionals.
- Contact your local Conservation Authority to obtain written approval prior to undertaking construction or site alteration within or adjacent to Natural Hazard features. Natural Hazard features include: watercourses, wetlands, flood plains, erosion hazards, and shorelines.
- Contact your local Conservation Authority or Drainage Engineer for technical assistance.
- Approval is required from your local Drainage Superintendent to conduct any work within or next to a municipal drain.

Performance

Woodchip biofilters have been shown to effectively remove nitrate for up to 15 years.

- Replacing the woodchips should be considered after this time, as nitrate removal is dependent on the availability of carbon from the woodchips.
- The woodchips will decompose over time and additional woodchips should be added to maintain the supply of carbon for the microbes.



Nitrate removal can occur at low temperatures; however, most occurs as air temperatures increase (Van Driel et al., 2006b).

Other media types, such as corn stalks and straw, have been used to replace woodchips. However, these sources of carbon are easily depleted and may need to be replaced more often.

Alternative Media

Phosphorus removal

The woodchip material can also reduce phosphorus through physical filtration. As water passes through the biofilter, sediment is trapped between the woodchips, which retains phosphorus bound to that sediment. However, the dissolved (plant available) phosphorus in runoff is not effectively removed by biological processes or filtration. Other types of media may be more effective in removing dissolved phosphorus from drainage water. These phosphorus absorbing media, such as slag or iron enriched sand, work similar to the soil, where naturally or enhanced iron and aluminum compounds in the media chemically bind dissolved phosphorus to the material. These alternative media filters are currently being tested.

Slag ranges in particle size from fine dust to larger gravel

Slag is a byproduct of steel production, consisting largely of iron oxide, magnesium oxide, and calcium oxide. Slag can remove phosphorus from water through chemical reaction as the water passes through the media.

Red sand is an iron rich sand that can strongly bind phosphorus. As water slowly passes through the sand, the media removes some of the phosphorus. Research is underway to better understand the potential for phosphorus removal using this media alternative.

This document is intended to provide an overview of woodchip biofilters and the scenarios in which they can be utilized as a best management practice. Cost-share opportunities may be available for woodchip biofilters.

Contact your local Conservation Authority staff for funding, Ontario Soil and Crop Improvement Association or visit https://ontarioprogramguides.net.

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UPPER THAMES RIVER CONSERVATION AUTHORITY

Ontario

Literature cited and additional resources

Addy, K., Gold, A. J., Christianson, L. E., David, M. B., Schipper, L. A., & Ratigan, N. A. (2016). Denitrifying bioreactors for nitrate removal: A meta-analysis. *Journal of Environmental Quality*, *45*(3), 873–881. https://doi.org/10.2134/jeq2015.07.0399

Choudhury, T., Robertson, W. D., & Finnigan, D. S. (2016). Suspended sediment and phosphorus removal in a woodchip filter system treating agricultural wash water. *Journal of Environmental Quality*, *45*(3). https://doi.org/10.2134/jeq2015.07.0380

Christianson, L., Castelló, A., Christianson, R., Helmers, M., & Bhandari, A. (2010). Hydraulic property determination of denitrifying bioreactor fill media. *Applied Engineering in Agriculture*, *26*(5), 849–854. https://doi.org/10.13031/2013.34946

Christianson, L. E., Lepine, C., Sibrell, P. L., Penn, C., & Summerfelt, S. T. (2017). Denitrifying woodchip bioreactor and phosphorus filter pairing to minimize pollution swapping. *Water Research*, *121*, 129–139. https://doi.org/10.1016/j.watres.2017.05.026

Christianson, L. E., & Schipper, L. A. (2016). Moving Denitrifying Bioreactors beyond Proof of Concept: Introduction to the Special Section. *Journal of Environmental Quality*, *45*(3), 757–761. https://doi.org/10.2134/jeq2016.01.0013

Dar, M. U. D., Shah, A. I., Ali, S. R., & Bhat, S. A. (2021). Woodchip Bioreactors for Nitrate Removal in Agricultural Land Drainage. In *Agricultural Waste* (Issue October, pp. 99–118). https://doi.org/10.1201/9781003105046-5

David, M. B., Gentry, L. E., Cooke, R. A., & Herbstritt, S. M. (2016). Temperature and Substrate Control Woodchip Bioreactor Performance in Reducing Tile Nitrate Loads in East-Central Illinois. *Journal of Environmental Quality*, *45*(3), 822–829. https://doi.org/10.2134/jeq2015.06.0296

Flowers Canada Growers. (2019). *Denitrifying Woodchip Bioreactors: wood particle treatment for removing nitrogen from production water*. https://www.flowerscanadagrowers.com/uploads/2017/01/factsheet%202%20final%20bioreactors%20en%202017-01-19.pdf

Goodwin, G. E., Bhattarai, R., & Cooke, R. (2015). Synergism in nitrate and orthophosphate removal in subsurface bioreactors. *Ecological Engineering*, *84*, 559–568. https://doi.org/10.1016/j.ecoleng.2015.09.051

Jaynes, D. B., Kaspar, T. C., Moorman, T. B., & Parkin, T. B. (2008). In Situ Bioreactors and Deep Drain-Pipe Installation to Reduce Nitrate Losses in Artificially Drained Fields. *Journal of Environmental Quality*, *37*(2), 429–436. https://doi.org/10.2134/jeq2007.0279

Penn, C. J. (2021). The past, present, and future of phosphorus removal structures. In *Water (Switzerland)* (Vol. 13, Issue 6). https://doi.org/10.3390/w13060797

Penn, C. J., Frankenberger, J., & Livingston, S. (2021). Introduction to P-TRAP software for designing phosphorus removal structures. *Agricultural & Environmental Letters*, *6*(1). https://doi.org/10.1002/ael2.20043

Penn, C., Chagas, I., Klimeski, A., & Lyngsie, G. (2017). A review of phosphorus removal structures: How to assess and compare their performance. In *Water (Switzerland)* (Vol. 9, Issue 8). MDPI AG. https://doi.org/10.3390/w9080583

Penn, C., McGrath, J., Bowen, J., & Wilson, S. (2014). Phosphorus removal structures: A management option for legacy phosphorus. *Journal of Soil and Water Conservation*, *69*(2). https://doi.org/10.2489/jswc.69.2.51A

Robertson, W. D., Blowes, D. W., Ptacek, C. J., & Cherry, J. A. (2000). Long-term performance of in situ reactive barriers for nitrate remediation. *Ground Water*, *38*(5), 689–695. https://doi.org/10.1111/j.1745-6584.2000.tb02704.x

Robertson, W. D., & Merkley, L. C. (2009). In-stream bioreactor for agricultural nitrate treatment. *Journal of Environmental Quality*, *38*(1), 230–237. https://doi.org/10.2134/jeq2008.0100

Robertson, W. D., Feng, D., Kobylinski, S., Finnigan, D. S., Merkley, C., & Schiff, S. L. (2018). Low cost media can filter particulate phosphorus from turbid stream water under short retention times. *Ecological Engineering*, *123*, 95–102. https://doi.org/10.1016/j.ecoleng.2018.08.015

Schipper, L. A., Robertson, W. D., Gold, A. J., Jaynes, D. B., & Cameron, S. C. (2010). Denitrifying bioreactors-An approach for reducing nitrate loads to receiving waters. In *Ecological Engineering* (Vol. 36, Issue 11, pp. 1532–1543). https://doi.org/10.1016/j.ecoleng.2010.04.008

Schipper, L. A., & Vojvodić-Vuković, M. (2001). Five years of nitrate removal, denitrification, and carbon dynamics in a denitrification wall. *Water Research*, *35*(14), 3473–3477. https://doi.org/10.1016/S0043-1354(01)00052-5

Van Driel, P. W., Robertson, W. D., & Merkley, L. C. (2006). Denitrification of agricultural drainage using wood-based reactors. *Transactions of the ASABE*, *49*(2), 565–573. https://elibrary.asabe.org/abstract.asp?aid=20391

van Driel, P. W., Robertson, W. D., & Merkley, L. C. (2006). Upflow Reactors for Riparian Zone Denitrification. *Journal of Environmental Quality*, *35*(2), 412–420. https://doi.org/10.2134/jeq2005.0027

Yep, T., Saunders, M., Merkley, C., Finnigan, D., & Mutus, B. (1925). Application of Red-Sand/Chitosan Hybrid Filtration System for Phosphate Removal from Agricultural Wastewater. *Journal of Applied Biotechnology & Bioengineering*. https://doi.org/10.15406/jabb.2016.01.00005

Online Resources:

Christianson, L. E., & Helmers, M. (2011). Woodchip Bioreactors for Nitrate in Agricultural Drainage. *Iowa State University Extension Publication PMR 1008.*, *October*, 1–4. http://lib.dr.iastate.edu/extension_ag_pubs/85%0Ahttp://www.leopold.iastate.edu/sites/default/files/pubs-and-papers/2011-11-woodchip-bioreactors-nitrate-agricultural-drainage.pdf

Christianson, L. (2018). *Woodchip Bioreactors*. University of Illinois. Retrieved from http://draindrop.cropsci.illinois.edu/wp-content/uploads/2019/12/Christianson-et-al_2018_Woodchip-Bioreactor_2pg-Factsheet.pdf

Farm and Food Care. (2013, October 30). Woodchip Biofilter to Treat Greenhouse Runoff Water. *YouTube.* Retrieved from https://www.youtube.com/watch?v=xuG1FQFbJnw

Gleason, T. (2017, September 27). Woodchip Bioreactor Installation Day. *YouTube.* Retrieved from https://www.youtube.com/watch?v=J3Tw-EsTA6g

Illinois Crop Sciences. (2021, April 12). 1. Woodchip bioreactor water monitoring: Where the magic happens. *YouTube.* Retrieved from https://www.youtube.com/watch?v=fvrSH9yYUNM

Ohio State University Extension. (n.d.). *Wood Chip Bioreactor (NRCS 605)*. Retrieved from https://agbmps.osu.edu/bmp/wood-chip-bioreactor-nrcs-605

Ontario Ministry of Agriculture, F. and R. A. (2015, March 15). Nutrient Recovery Woodchip Biofilter. *YouTube.* Retrieved from https://www.youtube.com/watch?v=6kDcEw_NJ5o

Purdue University College of Engineering. (2021). *Woodchip bioreactors*. https://engineering.purdue.edu/watersheds/conservationdrainage/bioreactors.html

University of Illinois. (2020, July 2). Bio WHAT?! Woodchip bioreactors for tile drainage. *YouTube.* Retrieved from https://www.youtube.com/watch?v=lYCGhbesFmA

Woodchip suppliers in Southern Ontario

	Price $/yd (fob or delivered)		
Sawmills	Woodchips[1]	Woodchip Mulch[2]	Sawdust[3]
Edgewood Lumber, Hawksville, ON (519) 699-4616	$15/yd	$13	$12
Townsend Mills, Tillsonburg, ON (519) 842-8234	$25	$20-35	
Kitchener Forest Products, Kitchener, ON (519) 696-2713; kitchenerforestproducts.com	$18	$15	$20
Gro-Bark, Brampton, ON (905) 846-1515		$25[4]	
Lakeshore Forest Products, Thedford, ON (519) 296-2105		$14	$14
Chisholm Lumber, Thomasburg, ON (613) 477-3920		$22[5]	
Landscape and Garden Suppliers (most local suppliers have woodchip mulch)			
Super Soils, Barrie, ON 1-844-7267645; simcoesoils.ca		$17	
London Landscape Supply, London, ON (519) 630-9974		$55	
Stone Landscapes, Waterloo, ON (519) 888-9992; stonelandscape.ca		$54	
D&J Paton Brothers, Arva, ON (519) 266-6943; patonsoils.com	$42	$42-53	
Tree Tech, Mitchell, ON (519) 301-2058; treetech.ca	$25	$60	
V&P's Topsoil & Landscape Supplies, London, ON (519) 690-0003; vnptopsoil.com	$42	$52-65	

**Prices as of 2019. Check with your local supplier for up to date costs.*