

Thank you to everyone who provided comments and questions during the webinar. Because there was not enough time to answer all of the questions, this summary has been developed, with individual questions combined into like topics. Some of the topics go into much more depth than the scope of this awareness level webinar, and are best directed towards those conducting ongoing research in this relatively new field. The replay may be accessed at the following link: <http://www.conservationswebinars.net/webinars/de-nitrifying-bioreactors-in-tile-drained-systems>.

Comment/Question	Response
This is still treating the symptom rather than fixing the problem. Better understanding of soil health and keeping excess nutrients in organic form will greatly alleviate the problem.	We totally agree. Note the mention of nutrient management and cover crops in the presentation. Suites of practices implemented together can be very powerful. Dr. Laura Christiansen commented: "remember a significant percentage of nitrate loss in tile drainage is from the soil itself, not just from fertilizer N. We do not have a complete understanding of how increased soil N (due to increased soil health) will impact drainage N loss." As mentioned in the Q&A section of the webinar, there is some ongoing work in Illinois to demonstrate how cover crops and bioreactors work together. However, there are other soil health-related practices that have not yet been studied in this sense.
For flatter sites are landowners adjusting stoplogs like a DWM system and are bioreactors in this case going to still remove an adequate amount of nitrates? Do these also work in conjunction with drainage control structures?	Yes, the bioreactor control structures may need to be managed like a drainage water management (DWM) system. Depending on the site conditions and bioreactor outlet, there may be less nitrate reduction. The NRCS Conservation Practice Standard allows the bioreactor to be managed as with DWM when necessary to avoid crop damage, and considers the amount of nitrate removal to still be adequate. As mentioned in the Q&A section of the webinar, Drainage Water Management is a natural fit to pair with the Denitrifying Bioreactor in many cases.
Other than cost, why would this not be installed with a more permanent barrier, ie concrete pit, that could be refilled with chips and excavated out as needed? Could use a concrete box instead of lining with plastic.	The concept would work, as long as the designer ensures that the structure will not float. However, the cost would likely be prohibitive.

Can you control inflow remotely like in-line water control structures?	Remotely operated in-line water control structures are commercially available and could be used as the diversion structure for the bioreactor. The cost is significantly higher.
Does it matter what level the water comes in at?	Yes. When designing the bioreactor, two key parameters are the inlet and outlet stop log settings. These govern the hydraulic grade in the bioreactor chamber, and affect the flow capacity of the bioreactor. Also, the elevation of the tile line affects the available height that can be achieved to create the hydraulic grade, and also has the potential to affect the root zone of an adjacent crop, depending on topography.
Have you used bioreactors in conjunction with pumped tile outlets?	Not to our knowledge. One would need to carefully analyze the effects of the raised water table (needed to create a hydraulic gradient) on the adjacent cropland, and likely practice drainage water management. Also, since most pumped systems operate in a batch flow mode, the supply line would flow nearly full when the pump is running and be empty when the pump is not running. Each batch would send some water through the bioreactor and some would bypass the bioreactor; properly designed, the target percentage could still be achieved.
Is the plastic specified to be NON-BIO-DEGRADABLE with soil contact/burial?	Check out Illinois NRCS' set of standard design drawings and construction specifications (IL-ENG-131, 132, 133 and 134.) We specify 4 mil plastic, and have not encountered problems. https://www.nrcs.usda.gov/wps/portal/nrcs/main/il/technical/engineering/
Is the notch easily formed on the plastic board on site or does it have to be ordered like that?	The small notch (orifice) on the bottom of the downstream flashboard has typically been ordered that way. However, it could be fabricated using typical shop tools. On site fabrication would be difficult but not impossible.
Is the collector pipe "Filter Wrapped" (in a sock?)	Typically not. Instead, we try to limit the content of fine particles in the wood chip media, so the collection manifold will not become clogged.
Could a bioreactor be placed above the pool area of a pond site?	Yes, if a tile drainage system outlets into the pond. This has been done in Iowa.

Can this practice be installed in a soil with a seasonal high water table?	Yes. The Denitrifying Bioreactor is an edge-of-field practice that can typically be made to work just about anywhere, because we line the bioreactor chamber with plastic. The thing to avoid is surface flow flushing out the biofilm.
Any considerations for installing in an organic soil? Would you avoid Houghton Muck soils for a bioreactor?	We would not anticipate problems, but have no experience with this type of site yet.
Has any thought been given to backfilling tile lines with woodchips to treat inflow at the source?	Yes, Dan Jaynes did essentially this by installing a wood chip trench alongside an existing tile line to form a 'wall' the soil water would pass through. This did remove nitrates, but would be very expensive to do at the field scale. See Jaynes et al. 2008. <i>In situ bioreactors and deep drain-pipe installation to reduce nitrate losses in artificially drained fields</i> . J. Environ. Qual. 37, 429–436. Filling the tile lines with wood chips would be immensely unpopular for the landowner who has a drainage system in place to facilitate crop production. That's the reason that the typical implementation allows for overflow during periods of high drain flow. Remember that the biggest benefit that the landowner gets from implementing a Denitrifying Bioreactor is water quality benefitting the greater public, downstream of the site. The practice needs to be reasonable in cost and not negatively affecting crop production on the site.
You want wood chips with a high what content? Was it tannin content? Did Ruth say avoid woodchips with high tannins like oak?	You'll want to AVOID wood chips with a high tannin content (and also avoid treated wood). The carbon source needs to be something that will not negatively affect the activity of the denitrifying bacteria. To quote the NRCS Conservation Practice standard: "...specifically note that no high tannin content wood such as oak, cedar or redwood are to be used. Do not use any wood that has been treated for ground contact."
Is it ok to have wood chips mixed with leaves and significant amounts of bark? I was thinking about chips from parks and cities. There is a lot of this material, but is not as pure.	The NRCS Conservation Practice Standard requires the use of a medium for the carbon source that is reasonably free from dirt, fines, and other contaminants. Leaves would not be a good idea for several reasons. One is that they would tend to clog the distribution and collection pipes, and affect the hydraulic conductivity of the media chamber. Another is the much shorter life span that leaf pieces would have. Many of the wood chips that have been used in research installations have been from urban landscape recycling centers. The key is to minimize the amount of leaf litter and fine material.

Have you seen a significant difference between hard wood chips from oak etc. versus cottonwood, poplar and softer woods that may be more absorbent? Are there any studies on other tree species wood chips - pine, spruce, fir?

Most NRCS installations have been with mixed wood species. We have not seen studies referencing specific species.

What porosity and hydraulic conductivity values are used for wood chips in design?

The Illinois NRCS design spreadsheet uses porosity information provided by Dr. Richard Cooke at the University of Illinois. The porosity is dependent on the type of wood chips and the amount of soil overburden that is used in the design. Hydraulic conductivity is taken from studies by Van Driel et al. 2006. "*Denitrification of agricultural drainage using wood-based reactors*". Transactions of the ASABE 49(2): 565-573.

https://www.nrcs.usda.gov/wps/portal/nrcs/detail/il/technical/engineering/?cid=nrcs141p2_030572

The Iowa spreadsheet uses porosity = 0.7, hydraulic conductivity = 0.15 ft/s. It is unclear how much these values may vary in the field. HF: This study (http://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1589&context=abe_eng_pubs) from Christianson et al, 2010 concludes: "For one of the most common types of woodchips used in bioreactors, the porosity varied from 66% to 78% depending on packing density and the average saturated hydraulic conductivity was 9.5 cm/s. It was found that additions of pea gravel significantly increased the hydraulic conductivity of woodchips though additions of corn cobs did not."

Alternatively, one can use the "chipometer" device shown in the presentation to determine properties of the wood chips proposed for use in the installation.

Just contact your local tree service companies, many are willing to dump their wood chips at your farm to get rid of them and at the swine facilities for composting use.

Good idea, if there are trees in the area. It may be a good idea to avoid wood 'chips' that are more shredded than chipped. It is thought the hydraulic conductivity may suffer, but we know of no research into this issue.

<p>Do you run into problems with moving woodchips due to Emerald ash borer quarantines. How does this impact the invasive species special environmental concern?</p>	<p>Typically, it is not economical to transport wood chips more than about 50 miles. We have not encountered issues related to the emerald ash borer quarantine. However, this is a very good cautionary note.</p>
<p>How often do you have to replace wood chips? Would you be able to take a sample of effluent and test for nitrate levels in order to know when to replace the woodchips in your filter?</p>	<p>NRCS has set the practice life for the Denitrifying Bioreactor at 10 years; research sites have been in place for at least this duration without the need for wood chip replacement. If an installation is being monitored for research or demonstration, it will be much easier to know when the media need to be replaced. However, NRCS installs many bioreactors that are not research installations.</p>
<p>When the reactor is no longer useable, do you have to remove the spent chips/carbon source? Can you land spread it? Would the spent bark chips have to be treated as almost a hazardous waste due to high nitrates?</p>	<p>The wood chips would eventually break down to a material that would potentially have high value to composting operations, and could also be land applied as a soil amendment. The practice is new enough that this end of life treatment has not been encountered enough to fully study the process. NRCS typically recommends land application according to a nutrient management plan. There will be no significant nitrate contamination in the spent wood chips. The nitrates are denitrified and the result is nitrogen gas, which is released to the atmosphere.</p>
<p>What are some of the alternatives that can be used for a carbon source for the bioreactor? Why not use corn cobs? More readily available even though you have to replace them more often. Farmer may be more receptive to this than trying to find wood chips. Are corn cobs NRCS approved for use?</p>	<p>As mentioned in the webinar, wood chips are the preferred carbon source in the bioreactor. In laboratory studies, agricultural residues such as corn cobs consistently provide much higher nitrate removal rates than wood chips. However, they need to be replaced more frequently than wood chips. Also, the hydraulic conductivity may deteriorate more quickly. Corn cobs may be used, but will break down much sooner. The landowner would need to do significant operation and maintenance during the expected 10 year life span of the practice. There are quite a few available references on this topic.</p>
<p>How about switchgrass or other hay as a carbon source for open top bioreactors? More frequent replacement of material may not be an issue.</p>	<p>We are not aware of any studies involving switchgrass or other hay as bioreactor media, although the paper referenced below discusses the use of municipal yard waste (which is discouraged). In the absence of positive data, NRCS would discourage such use, because of the lack of information on longevity, hydraulic conductivity, porosity, and performance. See Christianson et al. 2012. "<i>The potential of municipal yard waste to be denitrification bioreactor fill</i>", Applied Engineering in Agriculture, Vol. 28(6): 853-859.</p>

<p>Can we use Biochar instead of woodchips? Will biochar be successful retaining both nitrate and orthophosphate?</p>	<p>Some suggest that biochar or activated charcoal should be used to supplement if not outright replace the wood chips as media in the bioreactor, and that the biochar may be able to retain both nitrate and orthophosphate. This is a very new field of research, and much more study is needed at the field scale to determine performance and design processes. See, for example, Bock et al. 2015. "<i>Enhanced Nitrate and Phosphate Removal in a Denitrifying Bioreactor with Biochar</i>", Journal of Environmental Quality, March 2015. Also see: Puer, et al. 2016. Controls Influencing the Treatment of Excess Agricultural Nitrate with Denitrifying Bioreactors. J. Environ. Qual. 45:772–778 (2016).</p> <p>We can comment that this approach would likely be significantly more expensive than the wood chip design, and thus less likely to be widely adopted by agricultural producers.</p>
<p>Could DDG's be used as a carbon substrate?</p>	<p>We are not aware of any studies using dried distillers grains (DDGs). This material may be used for a livestock feed, but would likely break down very quickly and require frequent replacement in a bioreactor. Also, we received a comment that the makeup of DDG tends to have too much nitrogen and not enough carbon. NRCS will await research results before using DDGs as media in the Denitrifying Bioreactor.</p>
<p>What about leaching of nutrients from crop residues? Would that not influence the effectiveness of the biofilter to reduce them?</p>	<p>The bioreactor is intended to treat a portion of the nitrates in the water flowing through the drainage tile. If nutrients leached from crop residues enter the drainage tile, the bioreactor would treat those nutrients. Although there has not been an extensive set of studies on this topic, the bioreactor design can handle significant fluctuations in nitrate concentration. For example - in Illinois, a good ballpark for concentration of nitrate in drainage water might be 12 mg/L. Even if you doubled that value, the bioreactor would still function properly. We do not anticipate a problem with leached nutrients from crop residues.</p>
<p>Has % treatment been evaluated seasonally - the high volume rains come in the spring when the fields are spread with manure, what % do they remove at what flows or seasonally?</p>	<p>There is a definite temperature effect. The bacteria work much more slowly when cold. See David et al. 2015. "<i>Temperature and Substrate Control Woodchip Bioreactor Performance in Reducing Tile Nitrate Loads in East-Central Illinois</i>." Journal of Environmental Quality. Also, typical annual flow distribution will vary by geographic area.</p>

By "breathing" the nitrogen, does that release N into the atmosphere? If so, what can be done to control or manage that so it doesn't become an air quality issue? If you put a plastic cover over the wood chips does it inhibit N gas release?	Yes, the bioreactor does release N, primarily in the form of Nitrogen gas (N ₂), although Nitrous Oxide (N ₂ O) can be temporarily produced until the denitrifying environment becomes significantly reducing. Since N ₂ makes up most of our atmosphere, it typically poses no problem. We have not tried a plastic cover over the wood chips.
Why would methyl mercury be produced? What is the source of the mercury?	The source of mercury in the bioreactor is atmospheric deposition, primarily as a result of fossil fuel combustion. See the Hudson et al handout for more details.
Given that phosphorous is the main driver of eutrophication and not nitrogen, what is the major benefit of focusing on nitrate removal rather than phosphorous?	High nitrate levels are a problem in many water supply systems. Water systems must deliver water with nitrate concentrations less than 10 mg/l. The City of Des Moines has a nitrate removal system that is expensive to own and operate. Nitrate levels in some of their source river water has exceeded 20 mg/l. Nitrogen is the main nutrient-related limitation in the Mississippi River Basin - leading to hypoxia in the Gulf of Mexico. Practices are needed to solve both concerns.
Does bioreactor reduce phosphorus? What kind of chips would reduce phosphorus?	The Denitrifying Bioreactor as presented is not intended to reduce phosphorus, nor is it expected to. Reducing phosphorus concentrations requires a different process. However, see the Goodwin et al handout for information on how phosphorus may be addressed in conjunction with the bioreactor. Iron slag or shavings are used to bind the reactive phosphorus. This is an active research area.
Could bark chips and steel slag or biochar be mixed together so nitrates and phosphorus both be reduced at the same time?	Possibly. This practice is still being researched.
Is there any safety concern of walking on the surface (similar to manure crust)?	Not at all. The wood chips form a firm, if spongy, surface on which a person may safely walk.

Could partially or fully submerged wood chip "cribs" be used along stream channels to remove nitrate?

Potentially so. The implementation would need to be different from what was presented in this webinar, because of the need to keep the wood chips from floating away, and because there would need to be a way to ensure adequate hydraulic retention time to accomplish the denitrification. See Elgood et al. 2010. "*Nitrate removal and greenhouse gas production in a stream-bed denitrifying bioreactor*", *Ecological Engineering* 36(2010) 1575-1580.

Why would we "Disregard flow from surface inlets when calculating design subsurface drain flow for capacity purposes." This water can also enter the bioreactor impacting capacity even if the water contains little nitrate. Please provide more information about the implications of having surface tile inlets in the watershed. Should we be using a bioreactor in tile systems with surface tile inlets?

Surface inlets tend to introduce a high volume flush of water during surface runoff events. The bioreactor is designed to treat a prescribed portion of the DRAINAGE water (not surface water). We allow the high surface flow to bypass the bioreactor through structural means. Contributions of flow from surface inlets are not included when designing the bioreactor, since the water from surface inlets would typically contain relatively low nitrate concentration as compared to the subsurface drainage water. As mentioned in the webinar, the Conservation Practice Standard does not specifically prohibit surface inlets in the drainage system supplying the bioreactor. However, the planner needs to ensure that the line will not be subject to excessive sedimentation or debris accumulation, which could plug the bioreactor.

Could the box be used in conjunction with a WASCOD structure?

Water from the underground outlet of the water-and-sediment-control-basin (WASCOB) typically would mainly be surface water with few nitrates, and is not the target of the Denitrifying Bioreactor. Also, since the WASCOB is designed to dewater at a specific rate given the hydraulic grade of the underground outlet, it would be inadvisable to add the bioreactor structure because it would raise the outlet level and potentially cause the WASCOB basin to overtop.

Do you have any case studies based upon actual installations of these bioreactors and their installation costs & operational costs and a measurement of their effectiveness? How does a landowner get a return on a \$17,000 investment like this? Seems like this is a very new technology so I am looking for more info. Thanks

The denitrifying bioreactor is an edge-of-field practice: treating drainage water before it leaves the field. As such, the water quality benefits accrue mostly to the general public rather than specifically to that landowner. If and when regulations are put into effect, the return on investment will have more meaning. For now, landowners' return is to know that they are doing their part to keep excess nutrients from leaving their field through drainage tile. As mentioned, an approximate average cost to install might be about \$17,000. NRCS provides significant financial assistance for the Denitrifying Bioreactor, which can reduce this by 50-75%. Remember that every site is different, so these are just ballpark numbers. Also, check out the Illinois Nutrient Loss Reduction Strategy (as shown on one of the slides): the bioreactor has been estimated to cost \$2.20 per pound of nitrate-nitrogen removed over the lifespan of the practice. As noted, this is a relatively new practice. Case studies will become more available as more work is done.

How do these compare in functionality to saturated buffers?

The saturated buffer is very similar to the denitrifying bioreactor, essentially using the in situ soil in place of the bioreactor media (ie, wood chips). The design process is similar; however, the saturated buffer is only feasible on certain soil types, whereas the bioreactor can be built just about anywhere. Also, because the saturated buffer uses in situ soils instead of wood chips, it takes a much longer distribution manifold to treat the same volume of drainage water, because the soil's hydraulic conductivity is much less.

Would a saturated buffer complement a bioreactor by handling the overflow?

Possibly. However, the saturated buffer also is designed to treat just a portion of the total flow. It would be impractical for a bioreactor or a saturated buffer to treat all of the flow from the drainage system - they would need to be very large indeed and costs would be prohibitive.

How many of these structures have been installed to date?

A significant percentage of the bioreactor installations to date have been research sites. Over the past few years, NRCS has provided financial and technical assistance to design and install denitrifying bioreactors as well - first under Interim Conservation Practice Standard 747 and now under Conservation Practice Standard 605. Without sending a data call nationwide, it is difficult to say exactly how many have been built; however, it is probably safe to say that the sum total is less than 50 in the United States.
