650.1429 Denitrifying Bioreactor

A denitrifying bioreactor is a structure that may be incorporated into a subsurface drainage system to enhance the denitrification process in drainage water. It uses a carbon source to reduce the concentration of nitrate-nitrogen in the water. This results in improved water quality.

The discipline of bioreactor research, design, and evaluation is an evolving field. The assumptions and design guidance provided in this amendment are based on the best information available at the time of its writing. Modifications to the assumptions and design procedures may be necessary over time to reflect additional research and experience.

(a) Survey and data needed

A survey must be conducted at the proposed location that documents the size and profile of the tile drain that will be intercepted, ground elevations, and outlet conditions. Perform a topo survey of the area and shots on the tile for at least 200' to show the tile grade. This will provide a good plan view. Elevations at the top of the probed tile should be adequate, if some care is taken to get the probe on the center of the tile main. The size and material of the drain must be verified.

Obtain as much information on the tile system above the proposed bioreactor location as you can. A tile map to scale, ideally a GPS-derived map, will be very helpful. At a minimum, the following information is needed:

1. Acres drained by the main or submain that is being intercepted
2. Size, grade, and material of that main or submain
3. Future plans: For example, will additional tile be added in the watershed?
4. Are there any surface inlets? Discourage using bioreactors with these because of possible sedimentation or contamination issues.

The results from one or more recent water samples showing the expected nitrate-nitrogen concentration in the tile water will be helpful in the design process. The actual nitrate-nitrogen levels may affect the design considerations and selection of hydraulic retention time.

(b) Design capacity of the bioreactor

Design the capacity of the bioreactor to treat the base flow using either a minimum drainage coefficient of 0.125 inches from the serviced area, or a minimum of 15 percent of the calculated peak subsurface drain flow. Flow from surface inlets may be disregarded when calculating peak subsurface drain flow.

Experience has shown that using the 0.125 inches drainage coefficient criteria will result in a larger bioreactor than using 15% of the peak flow in the main. Use the 15% criteria whenever possible, but adjust the flow rate when necessary (using your best professional judgment) for mains that are larger than necessary as a result of surface intakes or steep slopes.

It is unrealistic to expect to treat the entire peak flow from the system. Research data indicates that capacity to treat 15% of the peak flow will result in treatment of 40-70% or more of the annual flow through the system.

It is best to avoid surface intakes in the system in order to minimize the influx of trash and other contaminants. Also, surface water generally contains a low concentration of nitrate-nitrogen.

The grade of the subsurface drainage main used in the design should be that grade which controls the capacity of the drain after the last lateral has entered the main. The grade of the main at the bioreactor location may be steeper than the controlling grade in some situations where there is quite a bit of fall to the outlet.

When using the drainage coefficient as the design criteria, a good tile map will be needed to document the actual area drained. Unfortunately, many older systems are not well mapped. Drain lines can sometimes be seen on aerial photography taken at the right time following a period of precipitation in the spring.

(c) Bioreactor size and shape

The size of the bioreactor will depend on the flow characteristics of the media and the desired hydraulic retention time. Generally we anticipate using wood chips. Researchers have reported the following characteristics for wood chips.

Parameter	Units	Suggested Values (ISU Research)	Reference	Other Values	Reference
Porosity	none	0.66 – 0.78	Christianson, 2010	0.7 0.53	Van Driel, et al. 2006 Greenan, et al. lab test
Hydraulic Conductivity	ft/s	0.31 (mean) 0.26 – 0.36 (range)	Christianson, 2010	0.039 0.088 – 0.160	Van Driel, et al., 2006 Chun et al., 2009

The following design parameters should be used unless other values can be justified.

- **K (hydraulic conductivity) = 0.15 ft/s (Laura Christianson, 2013.)**
- **Θ (effective media porosity) = 0.7**
- **HRT (hydraulic retention time) = 6 hours, with 4 hours minimum**

Initial designs used higher head drops, but it now appears a lower head drop – difference in elevation between the inlet and outlet water control structure stop board settings – will increase the retention time and result in a smaller bioreactor. Use higher outlet stop-board settings to decrease the head drop and increase the average depth of water flow through the bioreactor. In addition to reducing the retention time at peak flow, the deeper flow is less likely to result in preferential flow, thus maximizing water contact with the wood chips.

The design calculations are these:

Flow Rate (q, cfs) is based on Darcy's equation for flow through a porous media:

$q = KiA$ where

K = hydraulic conductivity (ft/s)
i = hydraulic gradient (head drop in length of reactor)
A = cross-sectional flow area perpendicular to flow (ft^2) [width x average depth of flow]

Hydraulic Retention Time (HRT, seconds)

$HRT = lwd\Theta/q$ where

l = length of bioreactor (ft)
d = average depth of flow in bioreactor (ft)
w = width of bioreactor (ft)
Θ = effective media porosity
q = flow rate (cfs)

At present, the desired hydraulic retention time (HRT) is 4-8 hours. A longer retention time will remove a greater amount of nitrate-nitrogen. However, if the nitrate is entirely removed, other products will be formed, and some may be detrimental to the water quality. A higher retention time may be justified where the incoming nitrate-nitrogen level is expected to be high. Designers tend to use the 4-hour retention time because it results in the smallest bioreactor. However, the retention time guidance may be increased in the future, so it is recommended that a 6+ hour retention time be evaluated. By treating a smaller proportion of the overall flow with a longer retention time, the nitrate reduction may be more efficient.

Porosity and hydraulic conductivity will vary depending on the woodchips and installation.

The calculations can be done using the Iowa NRCS Bioreactor spreadsheet.

The bioreactor design will be an iterative process to achieve a size and shape that will provide the estimated flow rate at the desired HRT.

Early bioreactor designs have utilized a rectangular cross-section, but at least one is using a trapezoidal cross-section to provide less cross-sectional area during low flow. The trapezoidal cross-section may have merit, but no advantage has been shown to date in Iowa.

The bottom of the bioreactor should be level or at a low gradient from the inlet to the outlet. The bottom gradient should be accounted for in the design depth of flow in the bioreactor.

Avoid length to width (L:W) ratios less than 4:1. For large drainage areas (large mains), this may mean having more than one bioreactor. This is to reduce the chance of preferential flow path development.

(d) Wood Chip Specifications

Wood chips shall meet the following specifications:

1. Material shall be chipped, not shredded. The chips should be in the 1-2” range.
2. Wood chips shall be 30-120 days old. Decomposed or partially decomposed wood chips shall not be used.
3. Wood chips shall be free from objectionable material such as dirt, fines, stones, etc.

As there are no standard tests for wood chips, the engineer or technician will have to make a judgment call as to whether the wood chips are acceptable. This should be done prior to delivery to the site.

(e) Inlet

A water control structure (see NRCS Conservation Practice Code 587) will be used in the subsurface drain main to divert a portion of the peak flow into the bioreactor. Typically a two-compartment control structure with a single set of stop boards will be appropriate. The stop boards will raise the water in the drain to provide the head needed for flow through the system. Some of the bioreactors installed by the Iowa Soybean Association project have a three-chamber water control structure, but this may not be necessary. Non-perforated pipe at least 10 feet long should be used at the inlet and exit from water control structures. Also, less flexible pipe such as PVC or dual wall HDPE may be advantageous to ease installation and maintain grade.

The pipe or tubing at the upper end of the bioreactor needs to have the capacity to deliver the design flow rate under the assumed head conditions. The flow rate will depend on the size of the pipe and the size and number of the perforations. At present, the expected flow through the inlet pipe and outlet pipe has not been well documented. Early installations are using perforated drain tubing the same size as the main. Perforated PVC pipe, or perhaps perforated dual-wall pipe, may be a good choice within the bioreactor to provide better control of grade and ease of installation than perforated corrugated plastic tubing.

Head loss through perforated drain pipe has not been documented. It may be advantageous to specify pipe with larger holes to minimize the head loss at both the inlet and outlet.

(f) Outlet

A perforated pipe is laid at the outlet end of the bioreactor to intercept the flow from the bioreactor. As with the inlet pipe, the capacity should be sufficient to convey the design flow rate. Perforated drain tubing has been used at the outlet end on some initial bioreactors, but the same considerations apply as for the inlet pipe. A less flexible pipe such as perforated PVC or perforated dual-wall pipe may allow better control of grade and may provide less head loss. This pipe would be routed through a second water control structure, and then to an outlet. The outlet could be the original main or a ditch.

The second water control structure will be used to control the head on the system.

A single, multiple-chamber control structure serving as both the inlet and outlet has been proposed as an alternative to using two separate control structures. To date, this has not been tried in Iowa. It would require excellent grade control to avoid stagnant water conditions.

Stagnant water conditions in the bioreactor must be avoided. If the topography allows, install the outlet water control structure a few tenths below the bioreactor outlet. This will provide room for a stop board to be left in the structure while allowing the bioreactor to drain completely.

An alternative that has been tried in Iowa is to construct a 1” diameter hole (orifice) in the lowest stop board to allow the bioreactor to drain. During high flow conditions, water flows over the stop boards, and low flow can still drain out. The flow through this orifice should be accounted for in the design.

(g) Operation and Maintenance

A majority of the flow in Iowa occurs in the April-June period when low temperatures may reduce the denitrification rate in the bioreactor. During this time the outlet should be set high. Later in the summer, under low flow conditions, the outlet stop boards should be lowered or removed to limit the residence time. Having an orifice in the lower stop board may reduce the management needed.

The owner should note any hydrogen sulfide smell at the outlet as this indicates that all of the nitrates have been reduced and the potential for methyl mercury production exists. If that smell is noted, all stop-boards in the outlet structure should be removed until higher flow rates occur.

(h) References

The following references were used in the development of this Iowa Amendment:

Christianson, L., A. Castello, R. Christianson, M. Helmers, A. Bhandari. 2010. Hydraulic property determination of denitrifying bioreactor fill media. *Applied Engineering in Agriculture.* 26(5): 849-854.

Christianson, L., A. Bhandari, and M. Helmers. 2012. A Practice-oriented review of woodchip bioreactors for subsurface agricultural drainage. *Applied Engineering in Agriculture*. 28(6): 861-874.

Christianson, Laura, Alok Bhandari, Matthew Helmers, Keegan Kult, Todd Sutphin, and Roger Wolf. 2012. Performance evaluation of four field-scale agricultural drainage denitrification bioreactors in Iowa. *Trans. ASABE.* 55(6):2163-2174.

Chun, J. A., R. A. Cooke, J.W. Eheart, and M. S. Kang. 2009. Estimation of flow and transport parameters for woodchip-based bioreactors: I. laboratory-scale bioreactor. *Biosystems Eng.* 104(3): 384-395.

Van Driel, P.W., W.D. Robertson, and L.C. Merkley. Denitrification of agricultural drainage using wood-based reactors. *Trans. ASABE* 49(2): 565-573.

NRCS Conservation Practice Standard 605, Denitrifying Bioreactor. https://efotg.sc.egov.usda.gov/references/public/IA/Denitrifying_Bioreactor_605_STD_2015_10a.pdf