USDA

United States Department of Agriculture

Denitrifying Bioreactors
in Tile Drained Systems

Presented by:

Hamid Farahani, Ph.D. – Water Management Engineer – East National Technology Support Center

Ruth Book, Ph.D., P.E. – State Conservation Engineer – Illinois

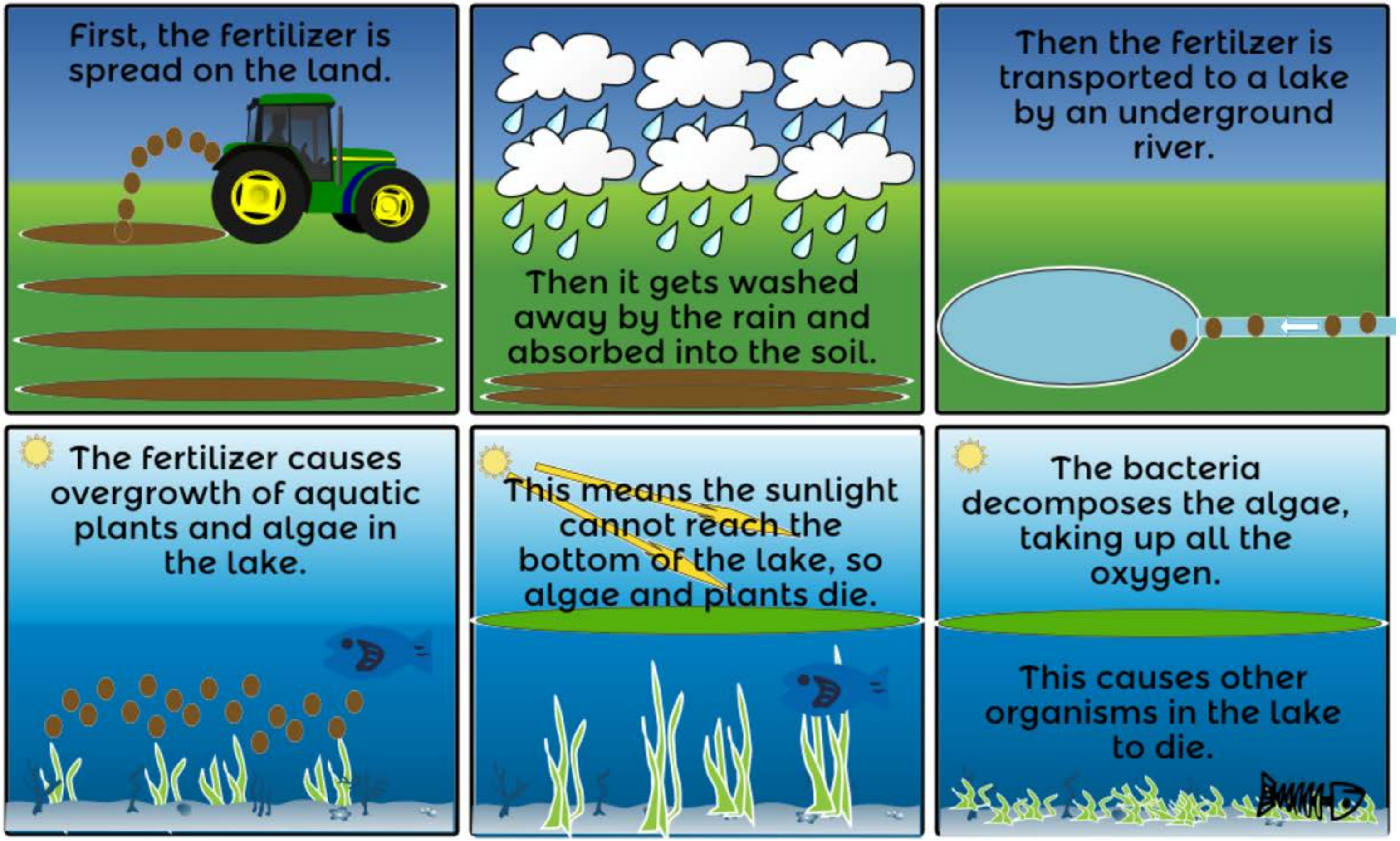
Bruce Atherton, P.E. – State Conservation Engineer - Ohio



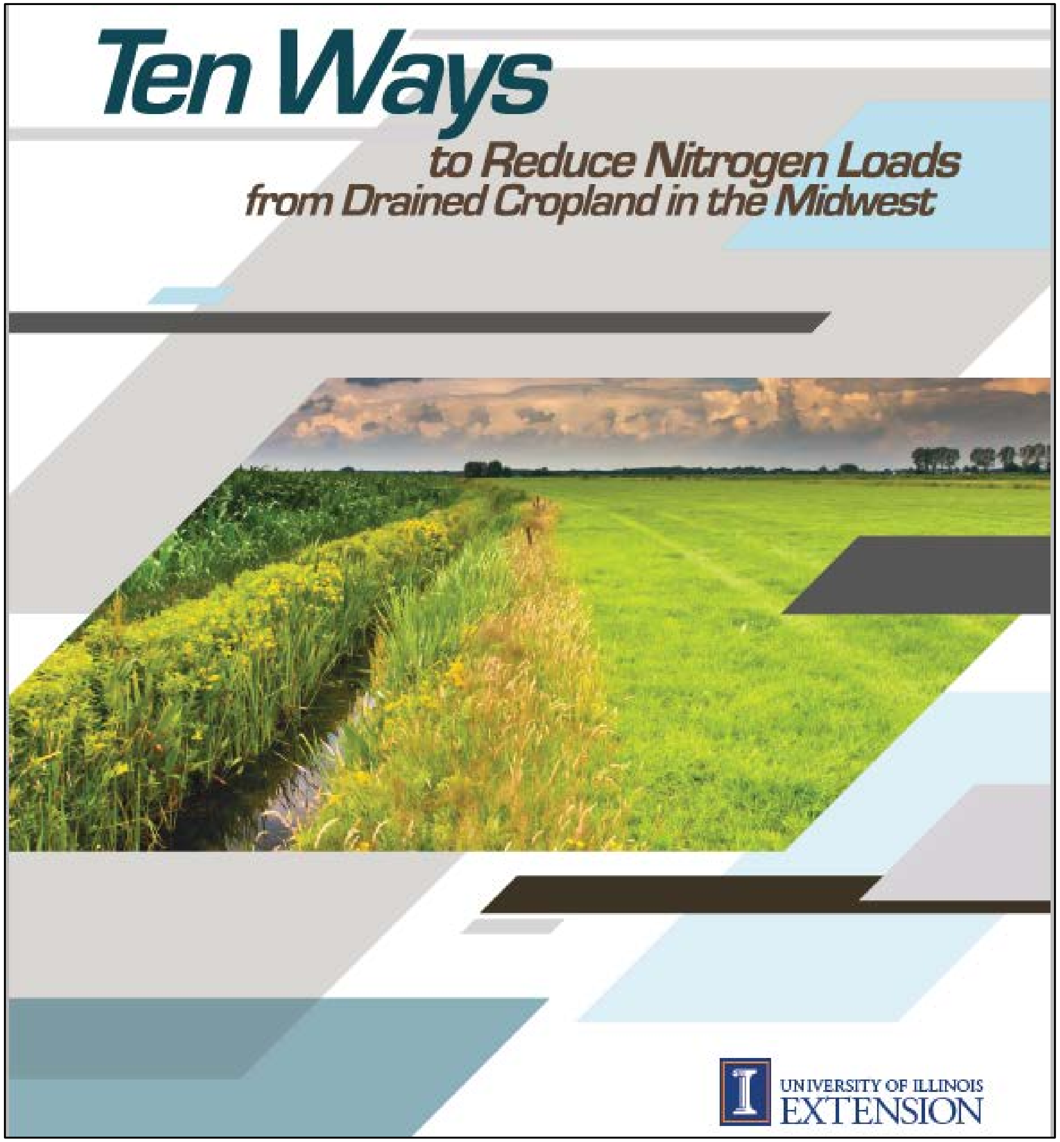
USDA United States Department of Agriculture

Problem – Water Quality

(Eutrophication & Hypoxia)



Source: Eutrophication Süžeeskeem Poolt sloehr - StoryboardThat



Reduce Nitrate in Root Zone

1. Improve N Management
2. Incorporate Winter Cover Crop
3. Increase Perennials in the Cropping System

Reduce Nitrate Delivery to Field's Edge

4. Implement Drainage Water Management (Controlled drainage)
5. Reduce Drainage Intensity
6. Recycle Drainage Water

Remove Nitrate at Field Edge or Downstream

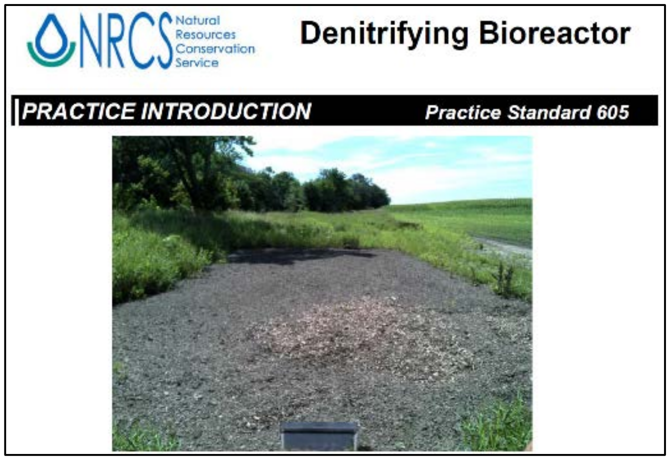
7. Bioreactors
8. Wetlands
9. Alternative Open-ditch
10. Saturated Buffers

Agenda

USDA

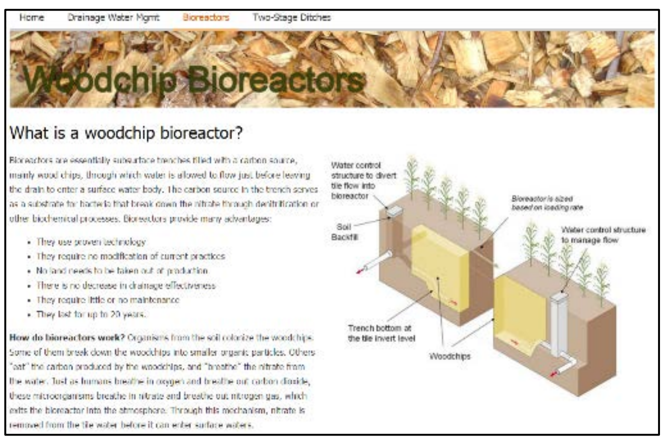
United States Department of Agriculture

Information Resources


NRCS Natural Resources Conservation Service

Denitrifying Bioreactor

PRACTICE INTRODUCTION — Practice Standard 605


Home | Drainage Water Mgmt | Bioreactors | Two-Stage Ditches

Woodchip Bioreactors

What is a woodchip bioreactor?

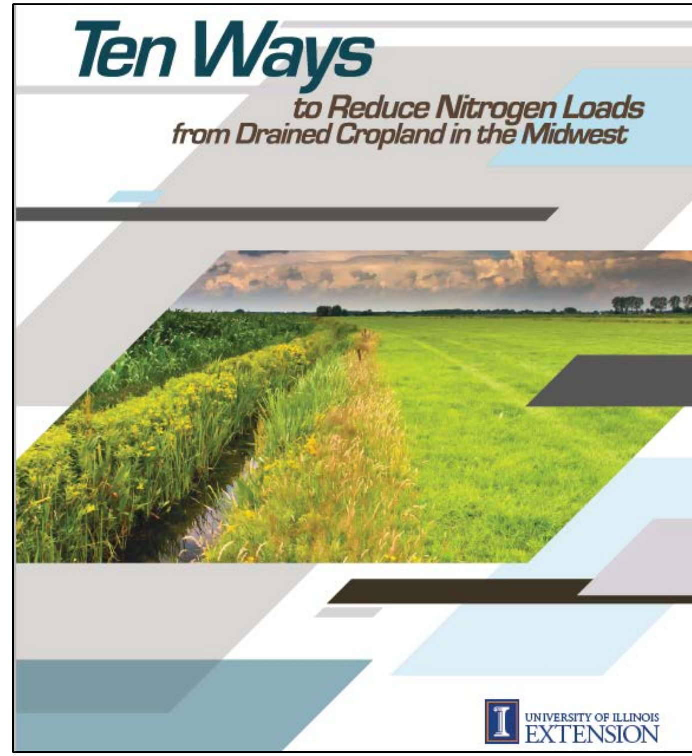
Bioreactors are essentially subsurface trenches filled with a carbon source, mainly wood chips, through which water is allowed to flow just before leaving the drain to enter a surface water body. The carbon source in the trench serves as a substrate for bacteria that break down the nitrate through denitrification or other biochemical processes. Bioreactors provide many advantages:

- They use proven technology
- They require no modification of current practices
- No land needs to be taken out of production
- There is no decrease in drainage effectiveness
- They require little or no maintenance
- They last for up to 20 years.

How do bioreactors work? Organisms from the soil colonize the woodchips. Some of them break down the woodchips into smaller organic particles. Others "eat" the carbon produced by the woodchips, and "breathe" the nitrate from the water. Just as humans breathe in oxygen and breathe out carbon dioxide, these microorganisms breathe in nitrate and breathe out nitrogen gas, which exits the bioreactor into the atmosphere. Through this mechanism, nitrate is removed from the tile water before it can enter surface waters.


Designing and Constructing Bioreactors to Reduce Nitrate Loss from Subsurface Drains.

Installing monitoring wells in a bioreactor in Illinois.


Ten Ways to Reduce Nitrogen Loads from Drained Cropland in the Midwest

University of Illinois Extension


Iowa State University

Home | Publications | News | Extension | Research | Staff | Facilities | Contact Us

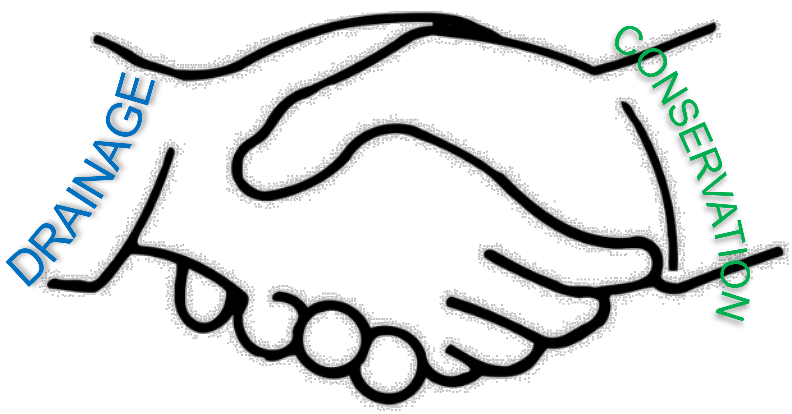
Ag Water Management Research Group

Denitrifying Woodchip Bioreactors

Process

A denitrifying bioreactor is a trench in the ground packed with carbonaceous material such as wood chips that allow colonization of soil bacteria that convert nitrate in drainage water to nitrogen gas. This project evaluates woodchip bioreactors as a cost-effective, farm-scale practice for nitrate removal from agricultural drainage. When placed strategically in drained watersheds, these bioreactors can reduce nitrate loadings to surface streams and help meet EPA's call for a >45% reduction in total N loads from the Upper Mississippi River Basin to the Northern Gulf of Mexico.These small foot-print, passive systems can treat drainage from 40 to 60 acres of farmland, require low maintenance, and have a life-span of 10 years or more. Ongoing research includes

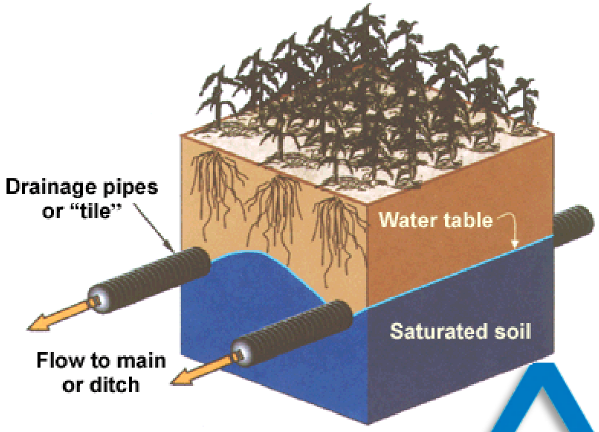
Agenda



Problem Statement

Drainage is needed for economical crop production in many agricultural fields.

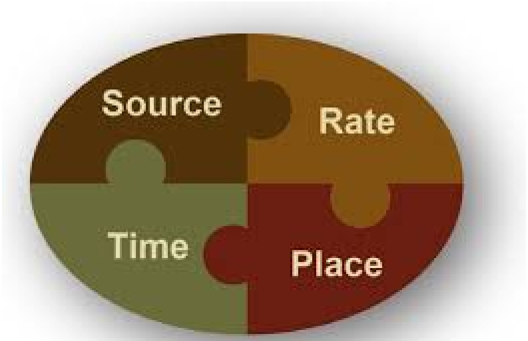
Tile drainage water is a primary source of nitrate to surface water



Conservation Drainage Practices

- ❑ Drainage Water Management
- ❑ Denitrifying Bioreactors
- ❑ Saturated Buffers
- ❑ Constructed Wetlands
- ❑ Two-Stage Ditches

...etc



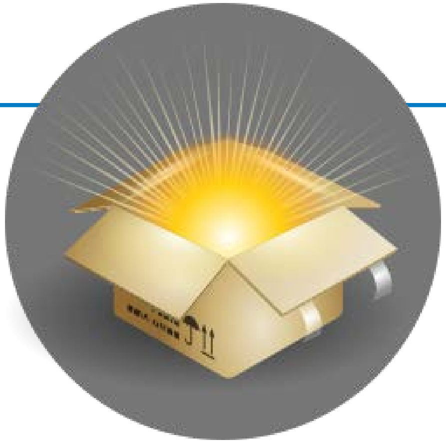
Nutrient Management

Cover Crops

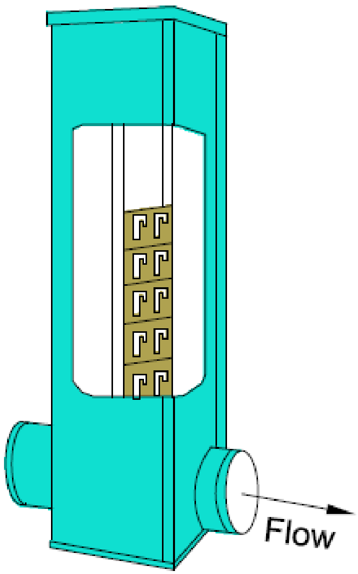
Denitrifying Bioreactor

- Organisms “eat” the carbon in the wood chips and “breathe” the nitrate from the water
- Let natural denitrifying bacteria “clean” the tile water
- Works on steeper ground

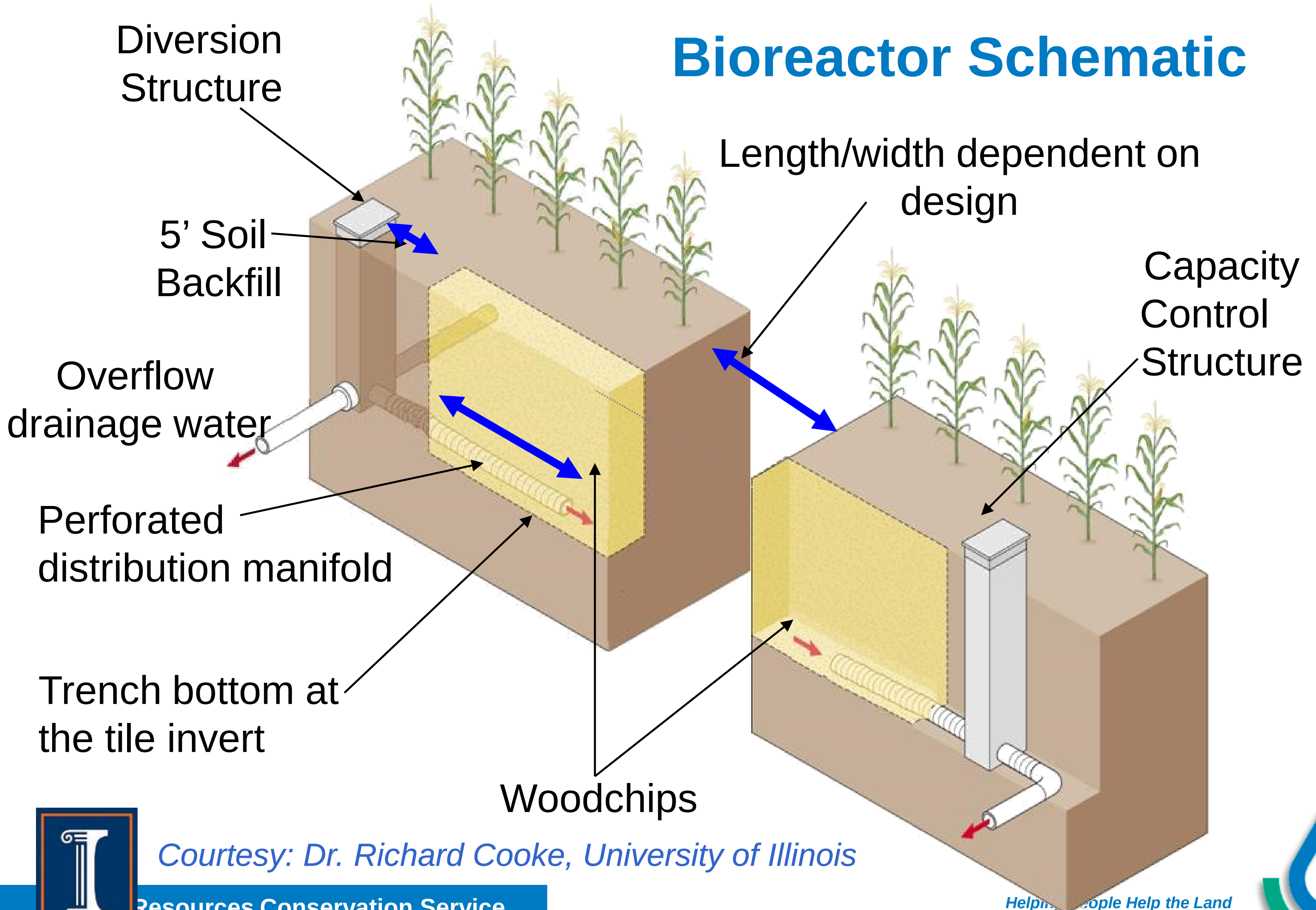
Bioreactor Contents



- A hole in the ground *(at the end of a tile line)*
- Plastic lining *to prevent seepage before treatment*
- Wood chips *(need a good supply!)*
- An upstream (diversion) structure *to bypass high flow and control inlet elevation in bioreactor*
- Distribution manifold plumbing
- A downstream (capacity) structure *to control treatment level and allow drain down of the bioreactor*



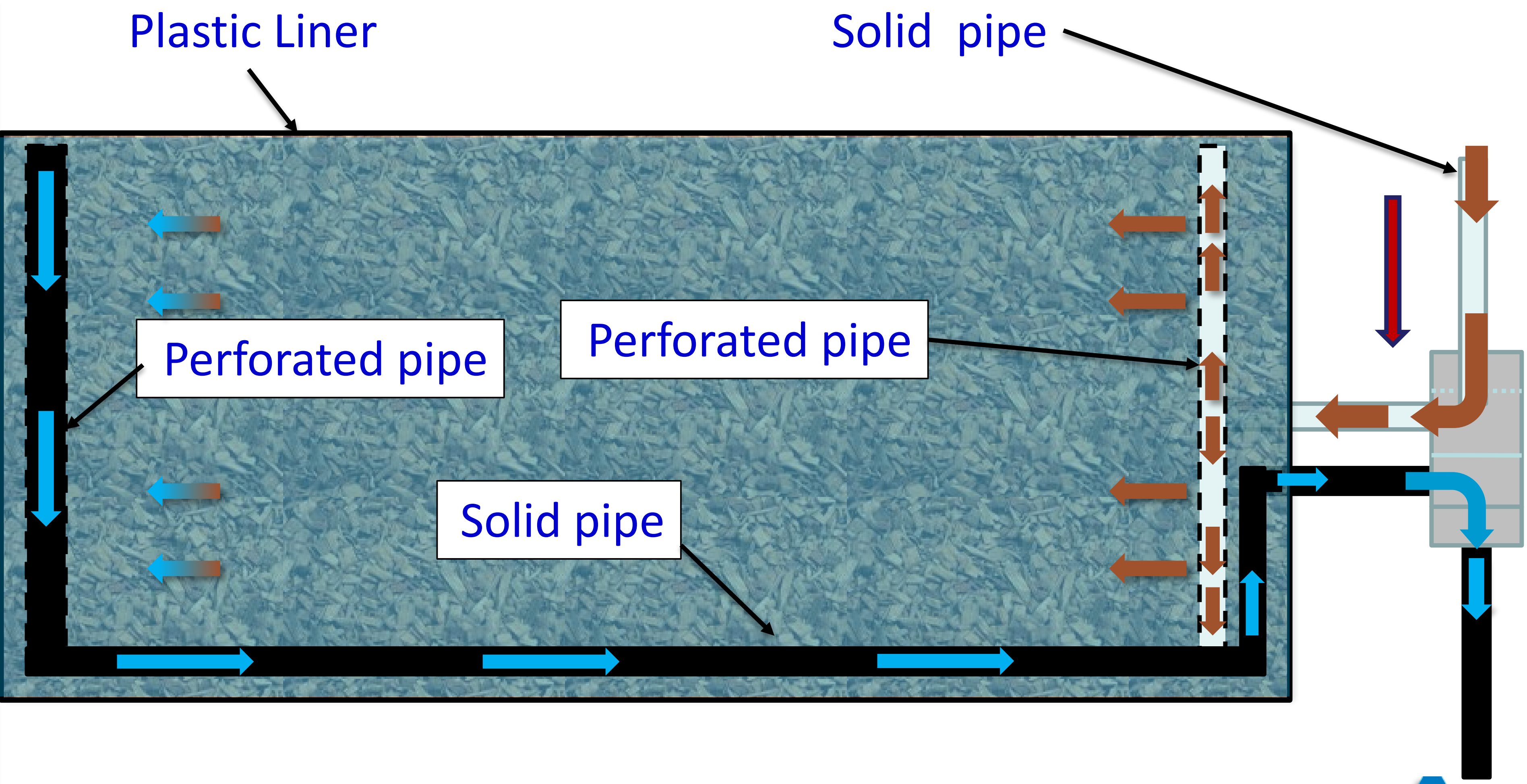
Bioreactor Schematic



Courtesy: Dr. Richard Cooke, University of Illinois

United States Department of Agriculture

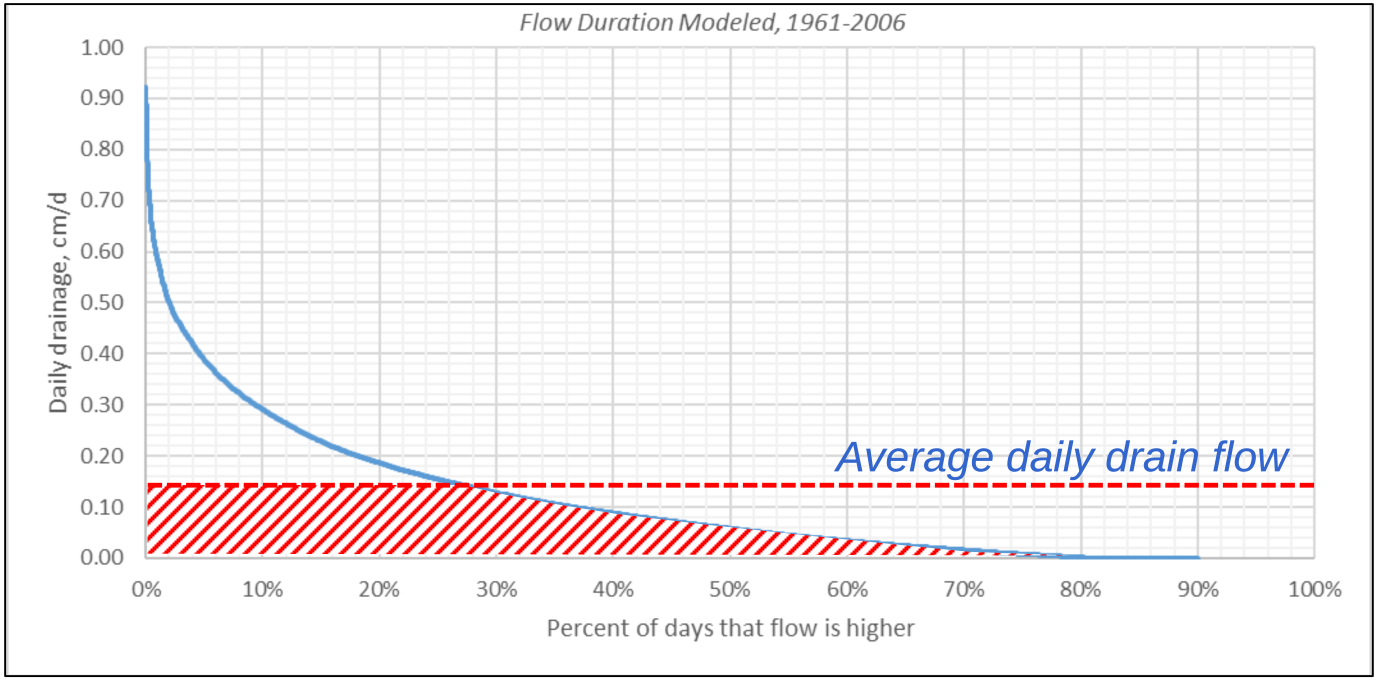
Bioreactor Plan View



Courtesy: Dr. Richard Cooke, University of Illinois

Bioreactor Performance

- Bioreactors are designed to treat a reasonable percentage of the water coming from the subsurface drain system.
- Example: treat 15% of the capacity of the subsurface drainage system.



Bioreactor Cost Efficiency

In-field management practices   Edge-of-field structural practices   Land use changes

Nitrogen loss reduction practices	Cost per acre	Cost efficiency in $ per lb N saved
Reducing N application rate from the background rate to the rate giving the Maximum Return to Nitrogen on 10% of acres	–$8*	–$4.25
Nitrification inhibitor for all fall-applied fertilizer on tile-drained corn acres	$7	$2.30
Split N application to 50% fall and 50% spring on tile-drained corn acres	$17	$6.20
Split N application to 40% fall, 10% pre-plant, and 50% side dress	$17	–
Spring only N application on tile-drained corn acres	$18	$3.20
Cover crops on all corn/soybean tile-drained acres	$29	$3.20
Cover crops on all corn/soybean non-tiled acres	$29	$11.00
Bioreactors on 50% of tile-drained acres	$17	$2.20
Wetlands on 35% of tile-drained acres	$61	$4.00
Buffers on all applicable cropland	$294	$1.60
Perennial/energy crops equal to pasture/hay acreage from 1987 (tiled and non-tiled acres)	$86	$9.30
Perennial/energy crops on 10% of tile-drained acres	$86	$3.20

*Cost savings

Source: Illinois Nutrient Loss Reduction Strategy

Agenda

- Introduction
- Basics of Denitrifying Bioreactors
- NRCS Conservation Practice Standard 605
- Bioreactors in Practice

NRCS Standard: Denitrifying Bioreactor

United States Department of Agriculture

Natural Resources Conservation Service

CONSERVATION PRACTICE STANDARD

DENITRIFYING BIOREACTOR

Code 605

(Ea.)

DEFINITION

A structure that uses a carbon source to reduce the concentration of nitrate nitrogen in subsurface agricultural drainage flow via enhanced denitrification.

PURPOSE

This practice is applied to achieve the following purpose:

- Improve water quality by reducing the nitrate nitrogen content of subsurface agricultural drainage flow.

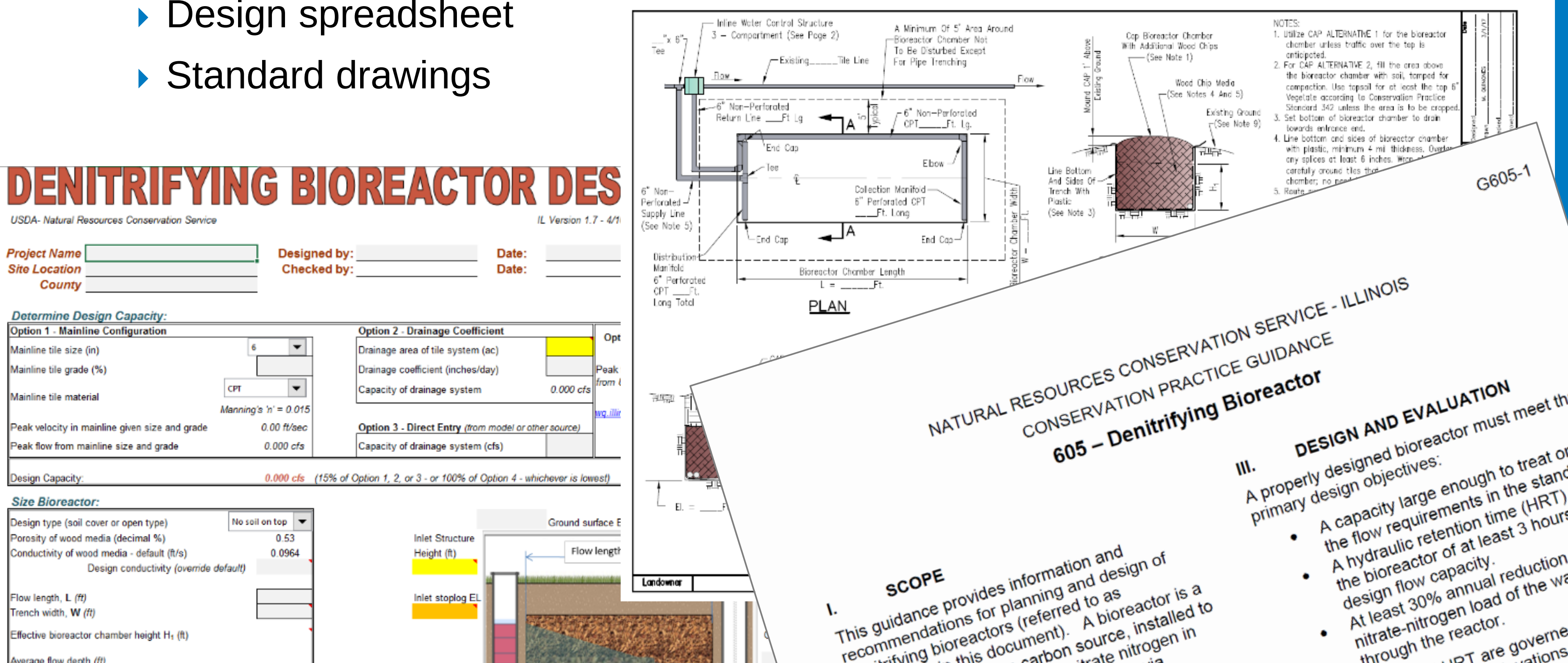
CONDITIONS WHERE PRACTICE APPLIES

This practice applies to sites where there is a need to reduce nitrate nitrogen concentration in subsurface

United States Department of Agriculture

Design Guidance and Tools

- Each State Conservation Engineer determines process for that State.
- For reference: *https://www.nrcs.usda.gov/wps/portal/nrcs/main/il/technical/engineering/*
  - Illinois FOTG, Section IV – Conservation Practice Guidance
  - Design spreadsheet
  - Standard drawings



Bioreactor Design

Media Chamber. Use a medium for the carbon source that is reasonably free from dirt, fines, and other contaminants. Distribute the media within the bioreactor to achieve a uniform flow path.

Use geotextile or plastic lining for the bottom, sides, and top of the bioreactor as needed to prevent migration of soil particles into the bioreactor and minimize bypass of treatment flow by leaching from the media chamber.

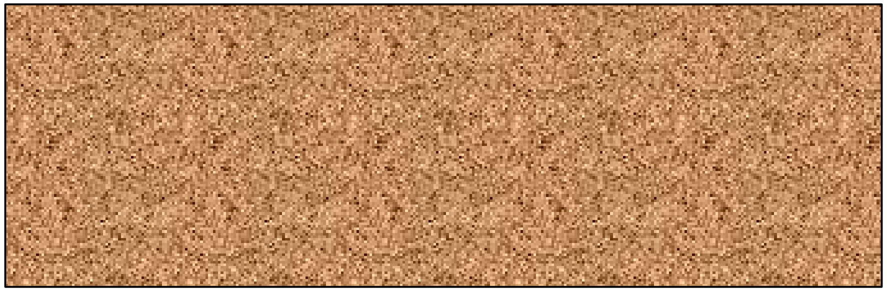
Design the bioreactor media for an expected life of at least 10 years. To create a longer lifespan, provide provisions for periodic renewal of the media.

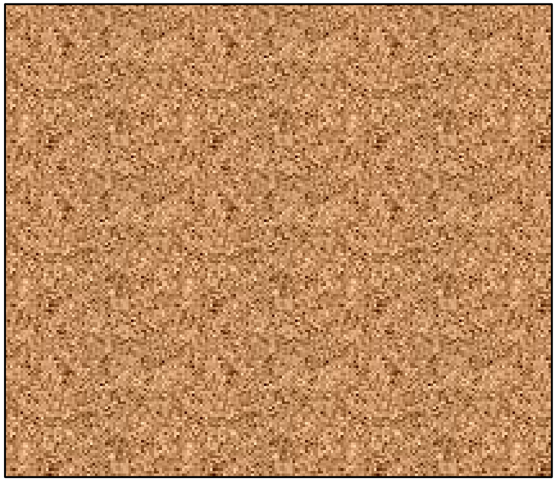
Design the media chamber to prevent development of preferential flow pattern. For a media chamber with a length to width ratio of 4:1 or greater, use a perforated distribution pipe at the chamber inlet and a perforated collection pipe at the chamber outlet. For wider chambers, design a multiple-header distribution system so that the width served by each header is no greater than 25 percent of the chamber length.

Specify the carbon media that goes in the chamber. If wood chips are the media, 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.

Designing a Bioreactor

- L:W ratio 4:1 or greater, or use special design for distribution pipe
- Be able to drain in 48 hours during no-flow periods (avoid stagnant water)
- Protect from surface flows (might flush out established biofilm)





Carbon Source

- Wood chips are widely used as the carbon source
  - Have structure and will last a while
  - Acceptable hydraulic conductivity

Carbon Source

- Bioreactors require a lot of wood chips. Here is a 100 cu. yd. truck load.

Carbon Source

- Good wood chips for a denitrifying bioreactor

Design Capacity

CRITERIA

General Criteria Applicable to All Purposes

Performance and Capacity. Design the capacity of the bioreactor based on one of the following:

- Treat peak flow from a 10-year, 24-hour drain flow event.
- Treat at least 15 percent of the peak flow from the drainage system.
- Treat at least 60 percent of the long-term average annual flow from the drainage system using locally proven criteria (e.g., drainage coefficient).

Disregard flow from surface inlets when calculating design subsurface drain flow for capacity purposes.

Design the bioreactor hydraulic retention time for a minimum of 3 hours at the peak flow capacity. Account for the porosity of the media and use the average depth of flow through the media. The effective volume of the reactor is calculated as:

$$V = L \times W \times (d_{in} + d_{out})/2 \times P$$

Where:

V = effective volume of media (ft^3)

L and W are the length and width of media chamber (feet)

d_{in} and d_{out} are the depth of the inlet water and outlet water (feet)

P is the porosity of the material (decimal percentage)

Design the bioreactor to achieve at least a 30-percent annual reduction in the nitrate nitrogen load of the water flowing through the bioreactor.

If reducing conditions may result in the production of methyl mercury, make additional provisions to ensure that stagnant conditions do not develop in the media chamber.

Design Criteria in 605 Standard

Criterion 1 – Treat peak flow from a 10-year, 24-hour drain flow event

This criterion is used for other standards such as the grassed waterway

Determine this event from:

- Analysis of long term flow data
- Analysis of output from a drainage model – DRAINMOD

Design Criteria in 605 Standard

Criterion 2 – Treat at least 15 percent of the peak flow from the drainage system.

Determine 15% of the peak flow:

- Based on capacity of tile main
- Based on the area drained and the drainage coefficient
- Analysis of long term flow data
- Analysis of output from a drainage model - DRAINMOD

Drainage System Capacity – Option 1

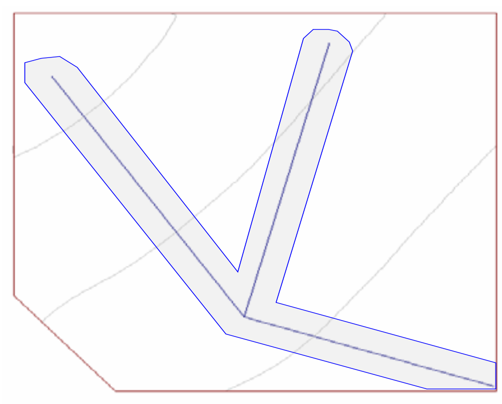
- Mainline configuration
  - Tile size and diameter
  - Tile grade

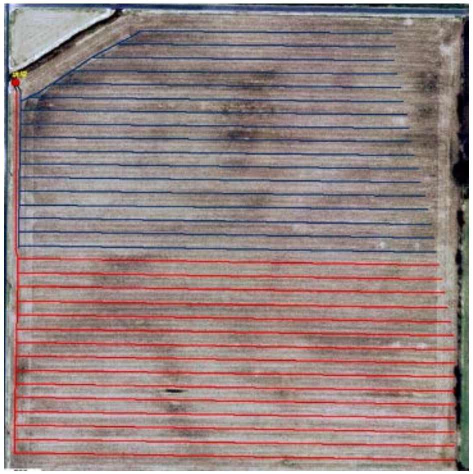
$$Q = \frac{1.486}{n} A\, R^{\frac{2}{3}} S^{\frac{1}{2}}$$

- Tends to be conservative

Drainage System Capacity – Option 2

- Drainage Coefficient method
  - **With tile map** – determine drained acres same as with DWM
    - Find the drain spacing for the soil type and estimated depth, from the Illinois Drainage Guide, and divide in half (**½S**)
    - Delineate drained acres by drawing a line around the tile system, **½S** on each side of the tile.
  - Then multiply drainage coefficient times drained acres *(with units conversions)*



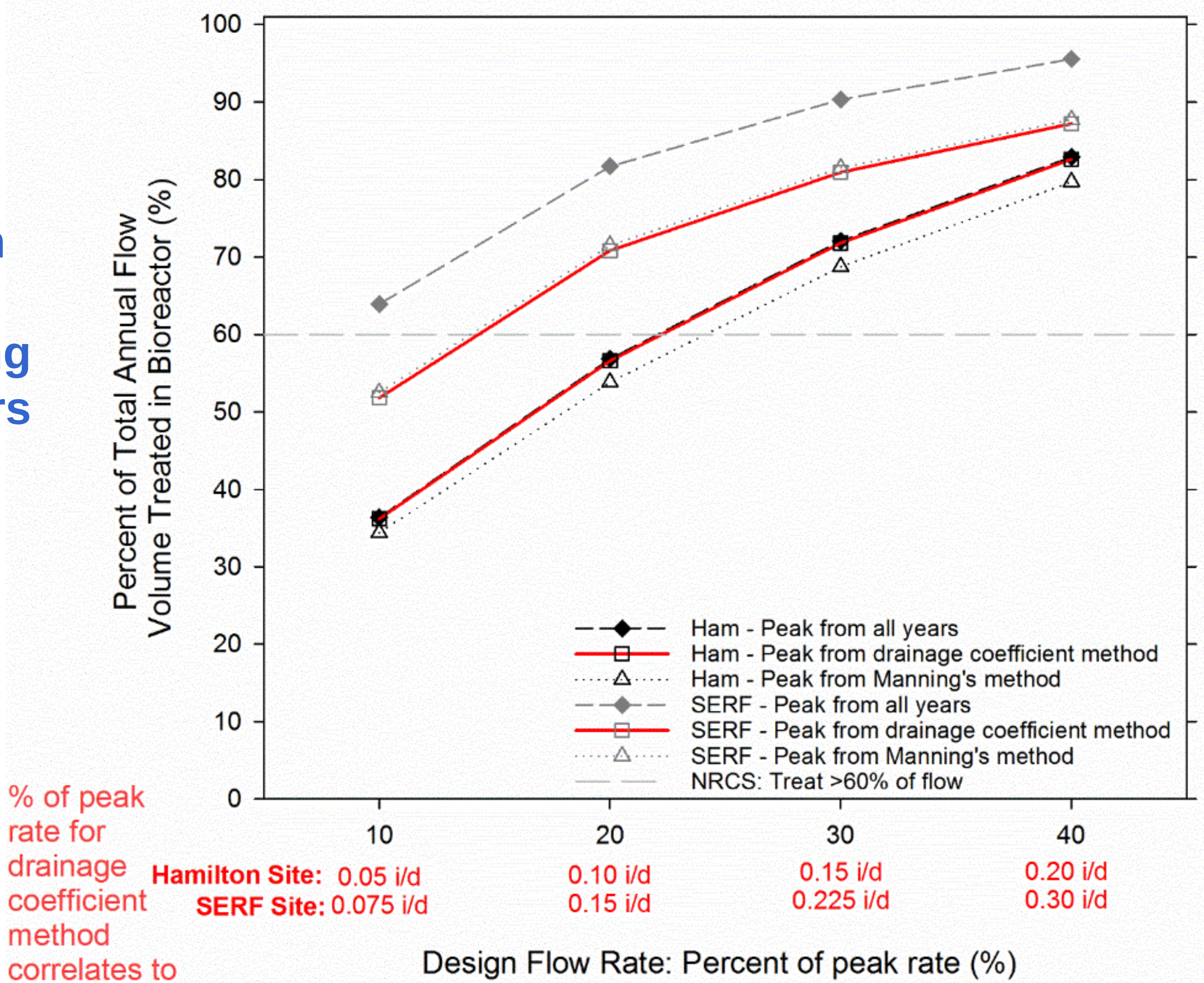


Design Criteria in 605 Standard

Criterion 3 – Treat at least 60 percent of the long-term average annual flow from the drainage system using locally proven criteria (e.g., drainage coefficient).

- Analysis of long term flow data
- Analysis of output from a drainage model - DRAINMOD

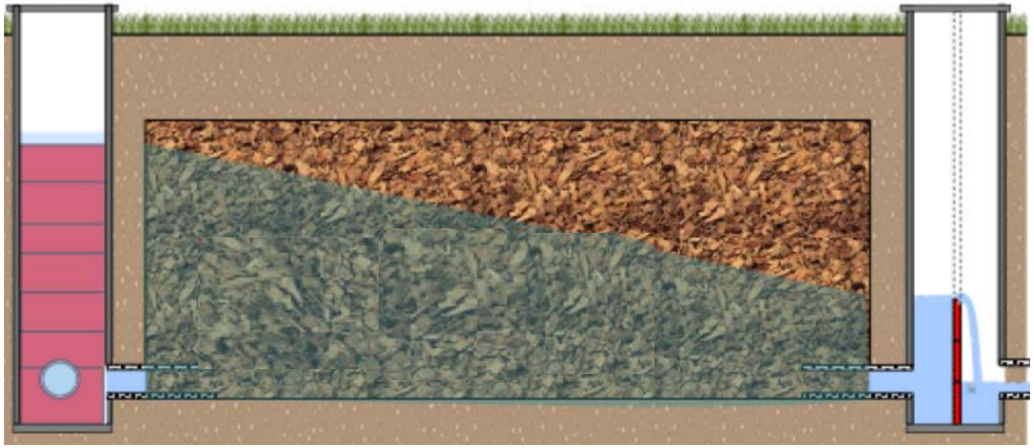
Graph showing peak flow rates from two Iowa denitrifying bioreactors compared to NRCS design criterion



Designing a Bioreactor

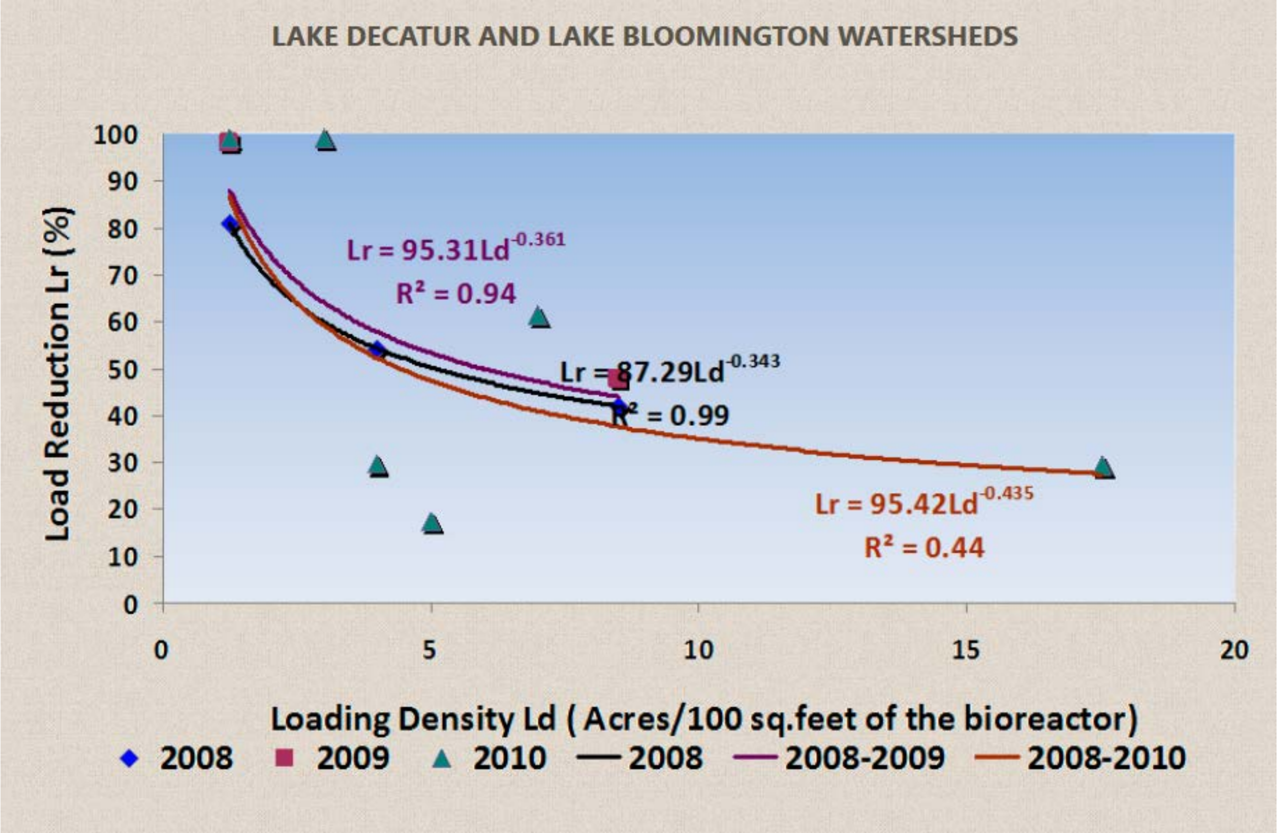
- Hydraulic retention time
  - At least 3 hours

$$HRT = \frac{Volume}{Flow\ Rate} = \frac{(Length)(Width)(Average\ Depth)(Porosity)}{Flow\ Rate}$$



Designing a Bioreactor

- Reduce annual load of Nitrate-Nitrogen by at least 30%



Operation and Maintenance

OPERATION AND MAINTENANCE

Provide an operation and management (O&M) plan and review this with the land manager. Specified actions should include normal repetitive activities in the application and use of the practice, along with repair and upkeep of the practice. The plan must be site specific and include, but not be limited to, a description of the following:

- Planned water level management and timing.
- Inspection and maintenance requirements of the bioreactor and contributing drainage system, especially upstream surface inlets.
- Requirements for monitoring the status of the bioreactor media and replacement/replenishment of media as needed.
- Monitoring and reporting criteria that demonstrate system performance.
- Monitoring information to improve the design and management of this practice as needed.

Operation and Maintenance

OPERATION AND MAINTENANCE

Provide an operation and management (O&M) plan and review this with the land manager. Specified actions should include normal repetitive activities in the application and use of the practice, along with repair and upkeep of the practice. The plan must be site specific and include, but not be limited to, a description of the following:

- Planned water level management and timing.
- Inspection and maintenance requirements of the bioreactor and contributing drainage system, especially upstream surface inlets.
- Requirements for monitoring the status of the bioreactor media and replacement/replenishment of media as needed.
- Monitoring and reporting criteria that demonstrate system performance.
- Monitoring information to improve the design and management of this practice as needed.

United States Department of Agriculture

Agenda

- Introduction
- Basics of Denitrifying Bioreactors
- NRCS Conservation Practice Standard 605
- Bioreactors in Practice

Planning Considerations

Legal description or other way to locate site
County and project (client) name
Aerial map with property boundaries and location of proposed practice.
Is the proposed site currently in permanent vegetation? What is growing there now, and how far does it extend from the receiving channel? (photographs could help)
Tile map (preferred), or at minimum tile diameter, depth and grade at the location where the bioreactor is proposed
Any surface intakes in the drainage system?
Topographic map of site (LiDAR 2’ contours, if available)
Watershed delineation (surface area that drains to the tile outlet location), with acres of the different soils summarized
Information about elevations of the proposed bioreactor site relative to adjacent crop fields; also crops grown (including cover crops)
Information about the receiving channel (ditch or stream) – particularly elevation of baseflow, and whether it appears to flood out regularly (photographs could help).
Preference of the client – should we plan to leave the top open (so more wood chips can be added later, if needed) or should we plan for the bioreactor to be covered with soil and revegetated?
Preference of the client – will s/he be willing to adjust the level of the stoplogs periodically? If so, how about doing drainage water management along with the bioreactor?
Will this installation be used for monitoring/research?
Information about any program that the land might be under (ie, CRP status). Note that even if a site isn’t eligible for CRP, it may be for EQIP. This new CRP special project just gives us more options for funding.

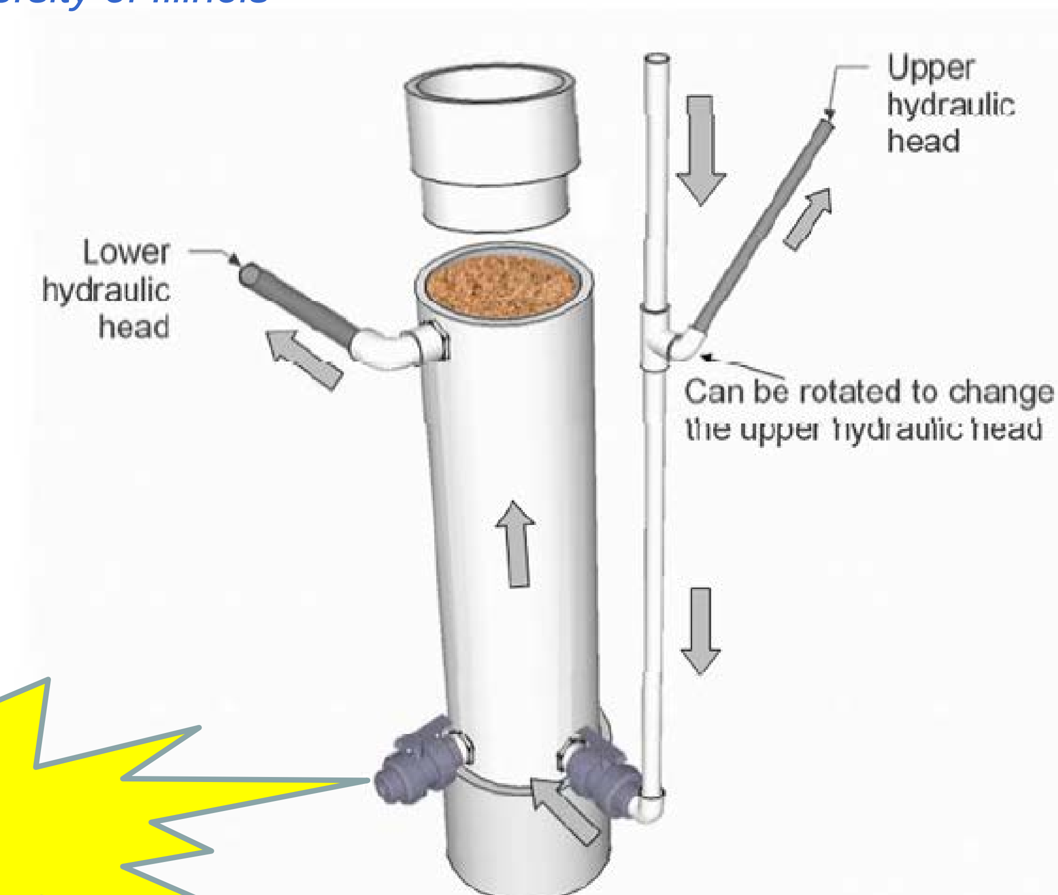
Installing a Bioreactor

Challenges

- Getting enough wood chips
- Keeping surface water out

Testing your wood chips…

Courtesy: Dr. Richard Cooke, University of Illinois



The “Chipometer”

- Hydraulic Conductivity (cm/sec)
- Drainable Porosity (%)

Screening your wood chips?

Courtesy: Mark Dittrich, MN Dep't of Agriculture

Q & A: When to replace wood chips?

- Typically 10 years
- No known test at this time
- Settlement allowance (about a foot)

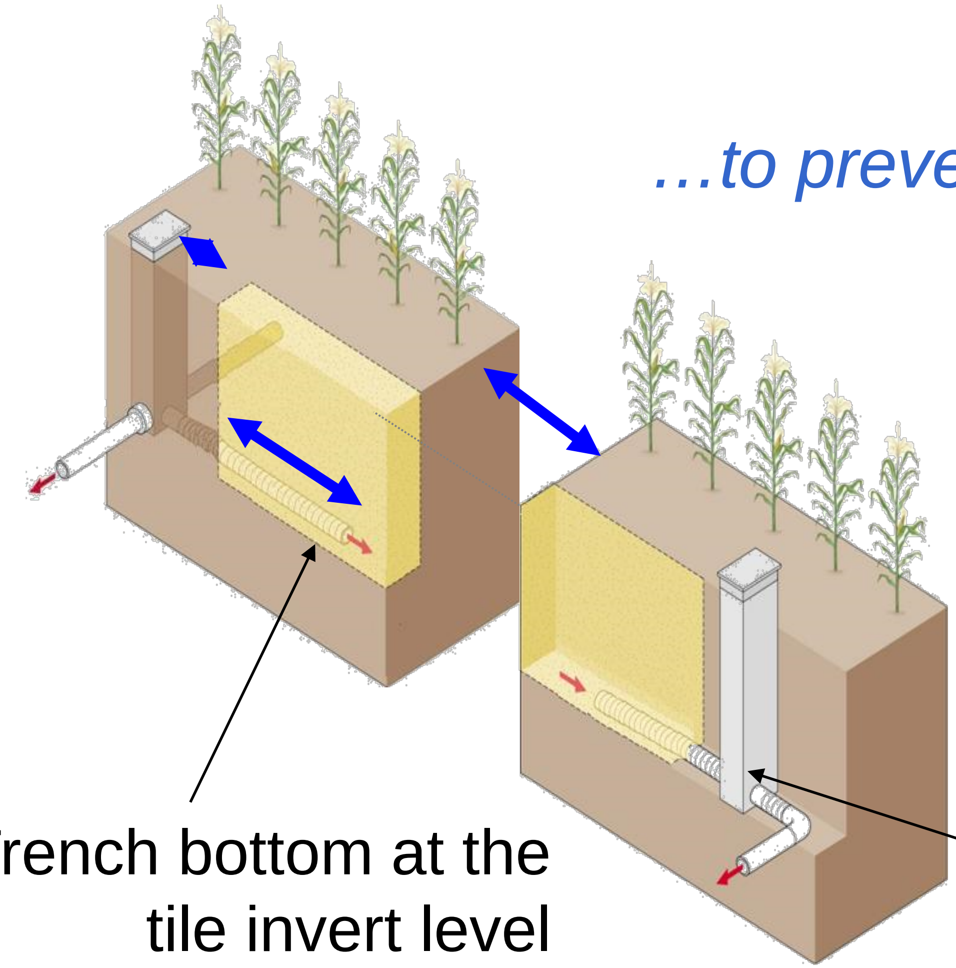
Q & A: Soil cover vs open top?

- Tradeoffs:
  - Soil cover
    - excludes surface water (good for sites adjacent to grassed waterways)
    - protects from burrowing animals

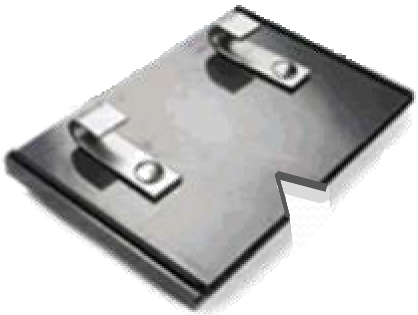
  - Open top
    - means smaller footprint (less compaction → better hydraulic conductivity through wood chips)
    - helps if it's a demonstration site
    - allows for easier replenishment of wood chips if needed

Drain Bioreactor During Low Flow

…to prevent stagnant conditions which lead to methyl mercury



Trench bottom at the tile invert level



Drain the capacity valve

Q & A: New or existing drainage systems?

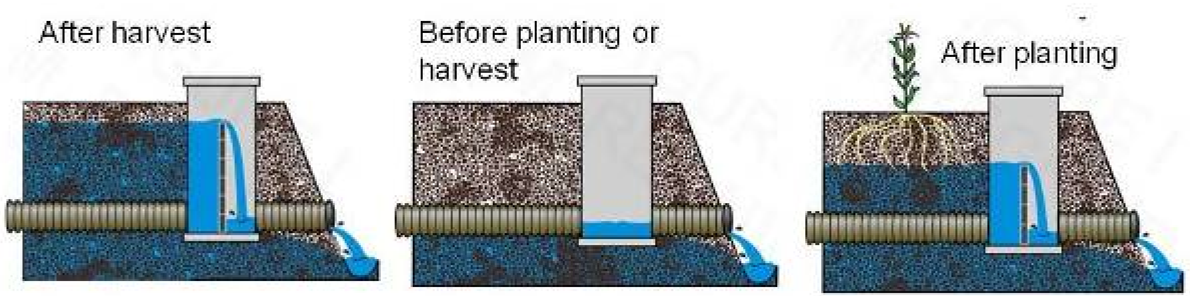
- Both!
- Existing is more typical.
- We can provide technical assistance and perhaps even financial assistance on a bioreactor associated with a new drainage system.

Q & A: Soil types to avoid?

- Not that we've found.
- Line the bioreactor chamber with plastic for separation.
- Clear plastic helps the contractor ensure proper overlap at splices.

Q & A: Can you do DWM with the bioreactor?

- Yes!
- Suites of practices are highly recommended.
- If the site is relatively flat, some measure of DWM will likely be required.
- *May be able to hold back water and nutrients for crop production.*



Q & A: What setback from outlet ditch?

- No rule (perhaps 20-30 ft would be a good guideline)
- Avoid bank stability problems

Ongoing Research

- Enhanced Nitrate removal with iron upstream of wood chips
- Soluble Phosphorus (orthophosphate) removal with iron downstream of wood chips

Hamid Farahani, Ph.D. – Hamid.Farahani@gnb.usda.gov

Ruth Book, Ph.D., P.E. – Ruth.Book@il.usda.gov

Bruce Atherton, P.E. – Bruce.Atherton@oh.usda.gov

Equal Opportunity

The U.S. Department of Agriculture (USDA) prohibits discrimination against its customers. If you believe you experienced discrimination when obtaining services from USDA, participating in a USDA program, or participating in a program that receives financial assistance from USDA, you may file a complaint with USDA. Information about how to file a discrimination complaint is available from the Office of the Assistant Secretary for Civil Rights.

USDA prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex (including gender identity and expression), marital status, familial status, parental status, religion, sexual orientation, political beliefs, genetic information, reprisal, or because all or part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.)

To file a complaint of discrimination, complete, sign and mail a program discrimination complaint form, available at any USDA office location or online at www.ascr.usda.gov, or write to:

USDA
Office of the Assistant Secretary for Civil Rights
1400 Independence Avenue, S.W.
Washington, D.C. 20250-9410

Or call toll free at (866) 632-9992 (voice) to obtain additional information, the appropriate office or to request documents. Individuals who are deaf, hard of hearing or have speech disabilities may contact USDA through the Federal Relay service at (800) 877-8339 or (800) 845-6136 (in Spanish). USDA is an equal opportunity provider, employer and lender.

Persons with disabilities who require alternative means for communication of program information (e.g., Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD).