Denitrifying woodchip bioreactors: A view from the field

Dr. Laura Christianson
University of Illinois at Urbana-Champaign

Why do we need bioreactors in the U.S. Midwest?

- We have a long history of improving the land drainage.

Credit: Farm Mankato Free Press; https://www.mankatofreepress.com/news/local_news/special-report-day-farming-flourishes-with-drainage/article_4cec61fa-e721-52b5-9dc3-a75a2f72f945.amp.html; http://www.nejohnston.org/wej/120%20Years%20of%20Johnston%20Farming/120%20years%20of%20Johnston%20Farming.html

Why do we need bioreactors in the U.S. Midwest?

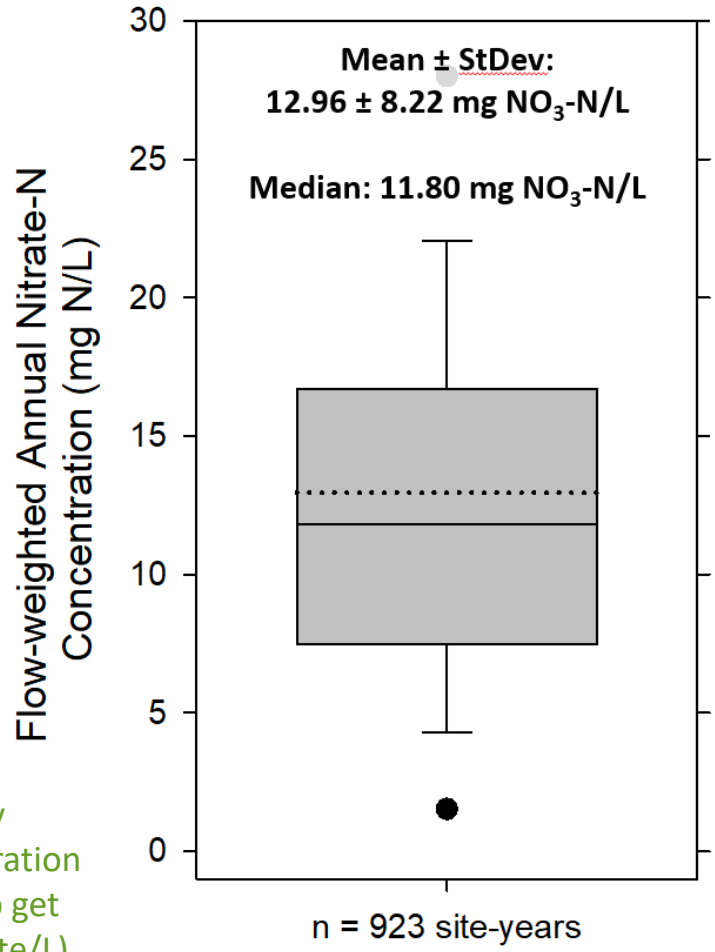
- We have a long history of improving the land drainage.
- Artificial drainage systems underpin our crop productivity.

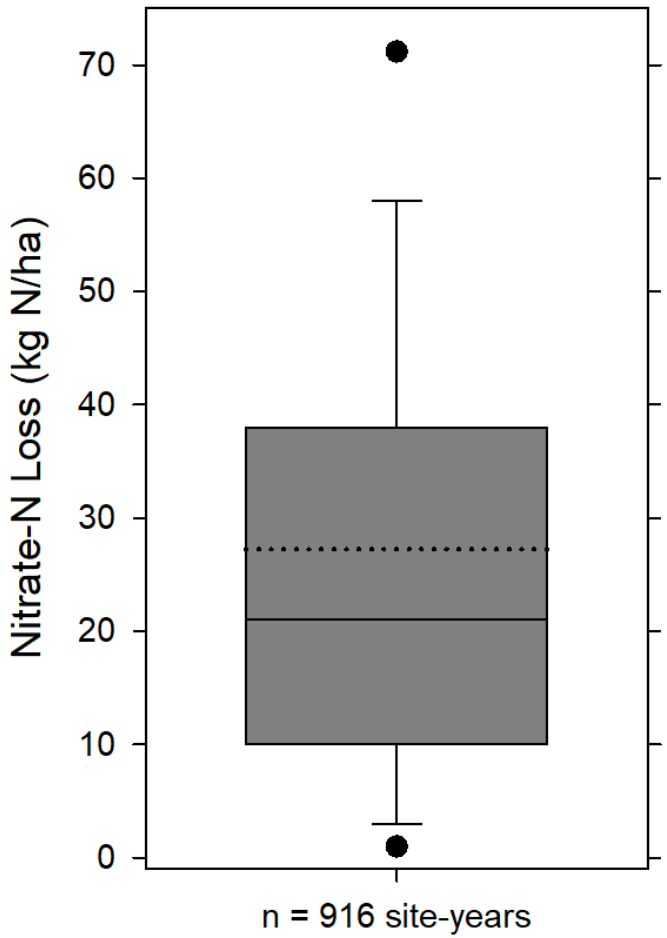
Clark Farm Drainage/Twitter

Why do we need bioreactors in the U.S. Midwest?

- We have a long history of improving the land drainage.
- Artificial drainage systems underpin our crop productivity.
- We have changed how water… and nutrients leave our fields.

Why do we need bioreactors in the U.S. Midwest?



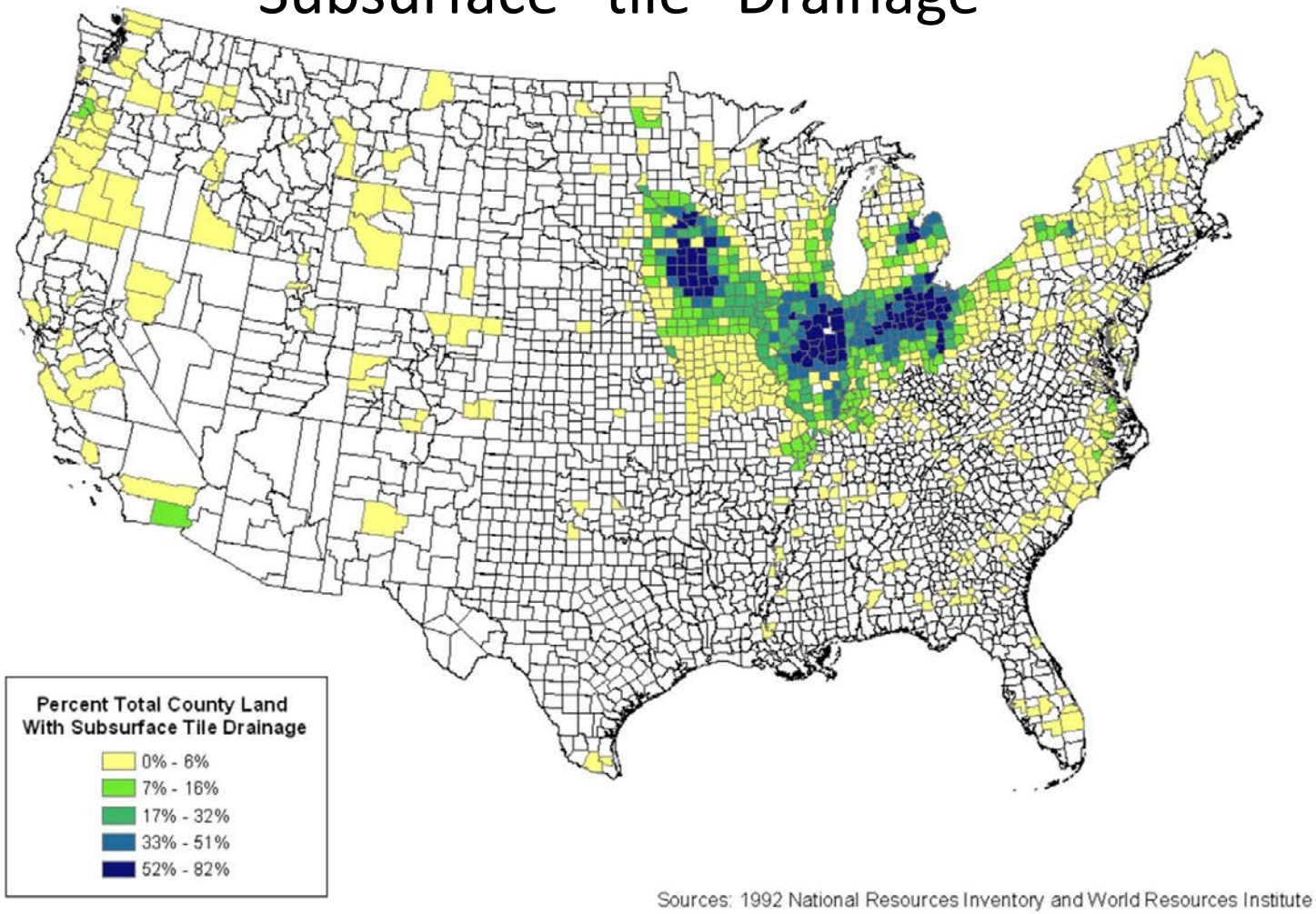


(multiply concentration by **4.4** to get mg nitrate/L)

MANAGE Database: DOI: 10.15482/USDA.ADC/1372907

Why do we need bioreactors in the U.S. Midwest?

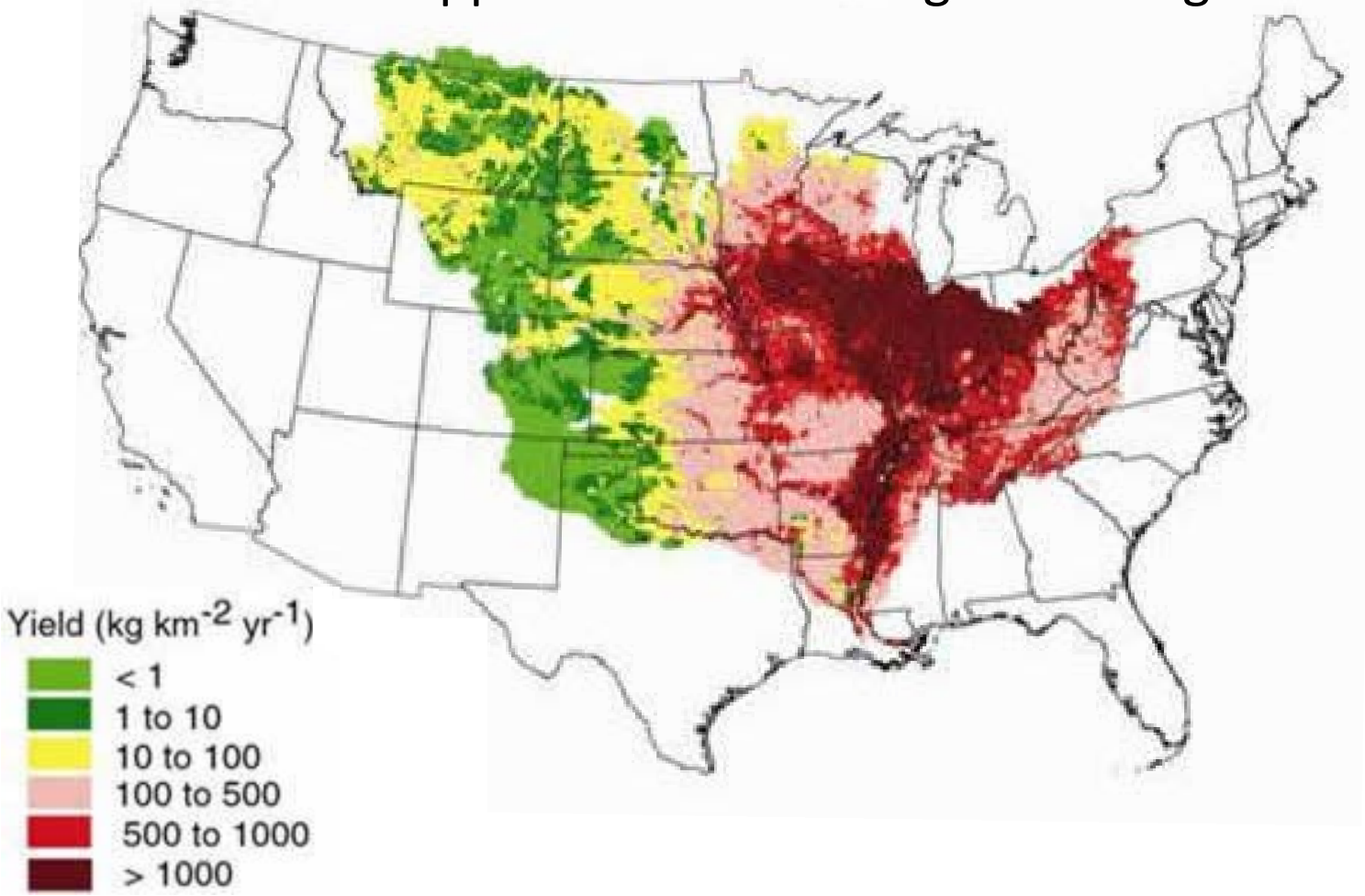
Subsurface "tile" Drainage



Source: Sugg et al., 2007

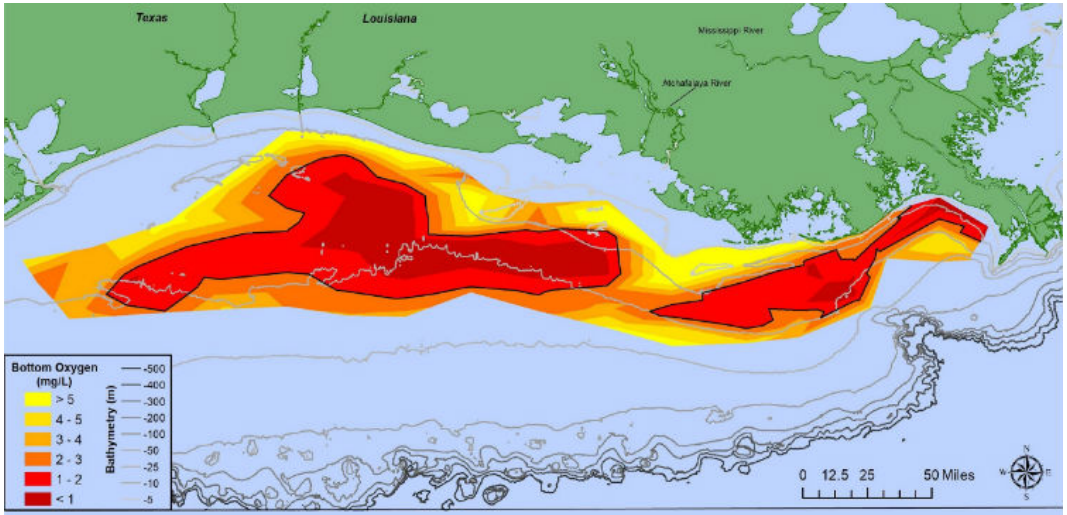
Why do we need bioreactors in the U.S. Midwest?

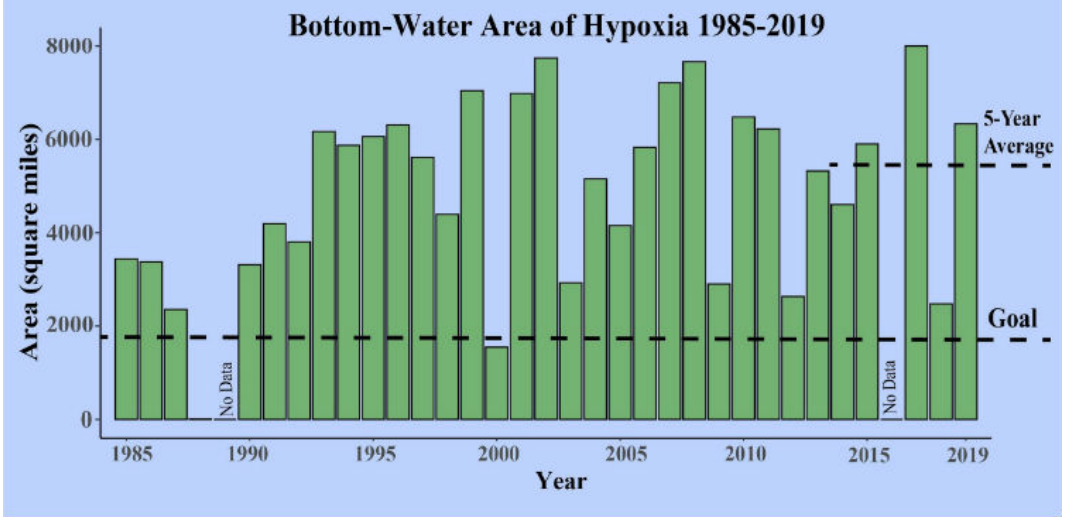
Mississippi River Basin Nitrogen Loading



Source: Alexander et al. (2008) *Envir. Sci. and Technology*

Why do we need bioreactors in the U.S. Midwest?





National Oceanic and Atmospheric Administration
U.S. Department of Commerce

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Large 'dead zone' measured in Gulf of Mexico

Hurricane Barry dampens initial size predictions

Oceans & Coasts | hypoxia

SHARE

August 1, 2019 —

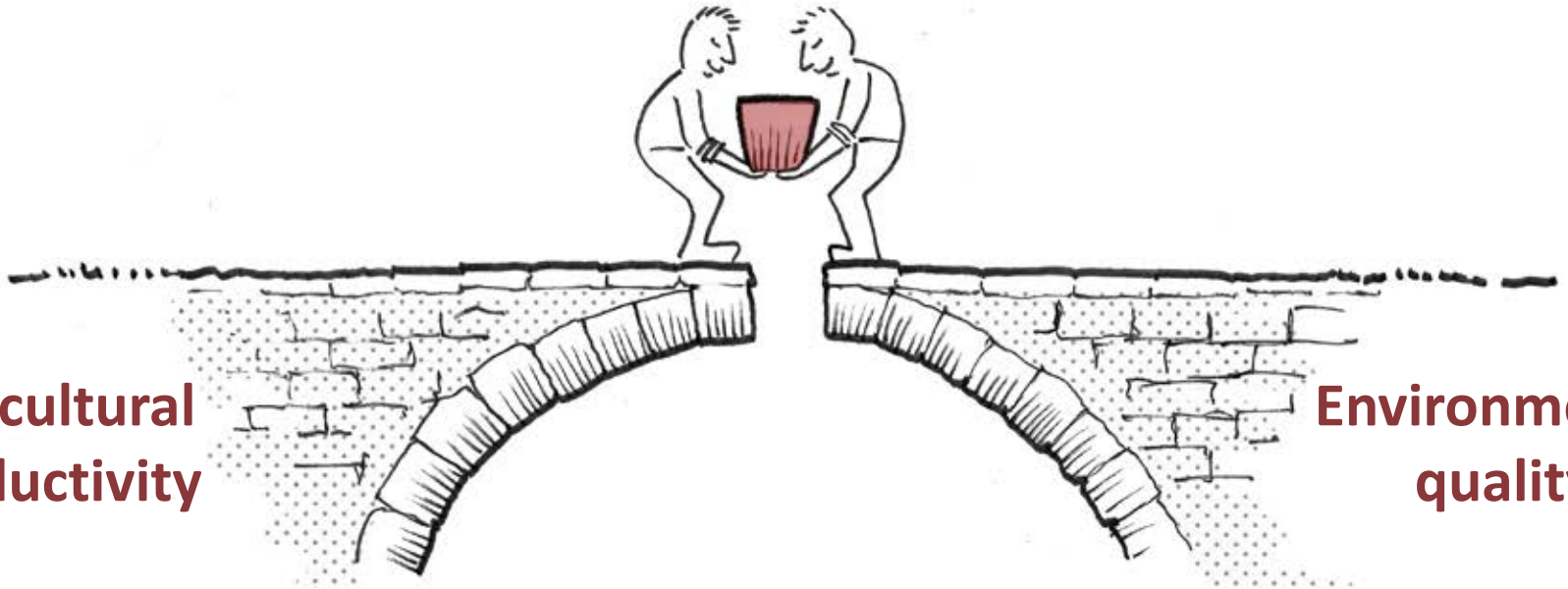
This year's Gulf of Mexico "dead zone"— an area of low oxygen that can kill fish and marine life — is approximately 6,952 square miles, according to NOAA-supported scientists.

The measured size of the dead zone, also called the hypoxic zone, is the 8th largest in the 33-year record and exceeds the 5,770-square-mile average from the past five years. The annual survey was led by scientists at Louisiana State University and the Louisiana Universities Marine Consortium (LUMCON) during a research cruise from July 23 to 29 aboard LUMCON's *R/V Pelican*.

Source: LUMCON/LSU

Why do we need bioreactors in the U.S. Midwest?

We need conservation solutions that allow continued excellence in agronomic productivity.



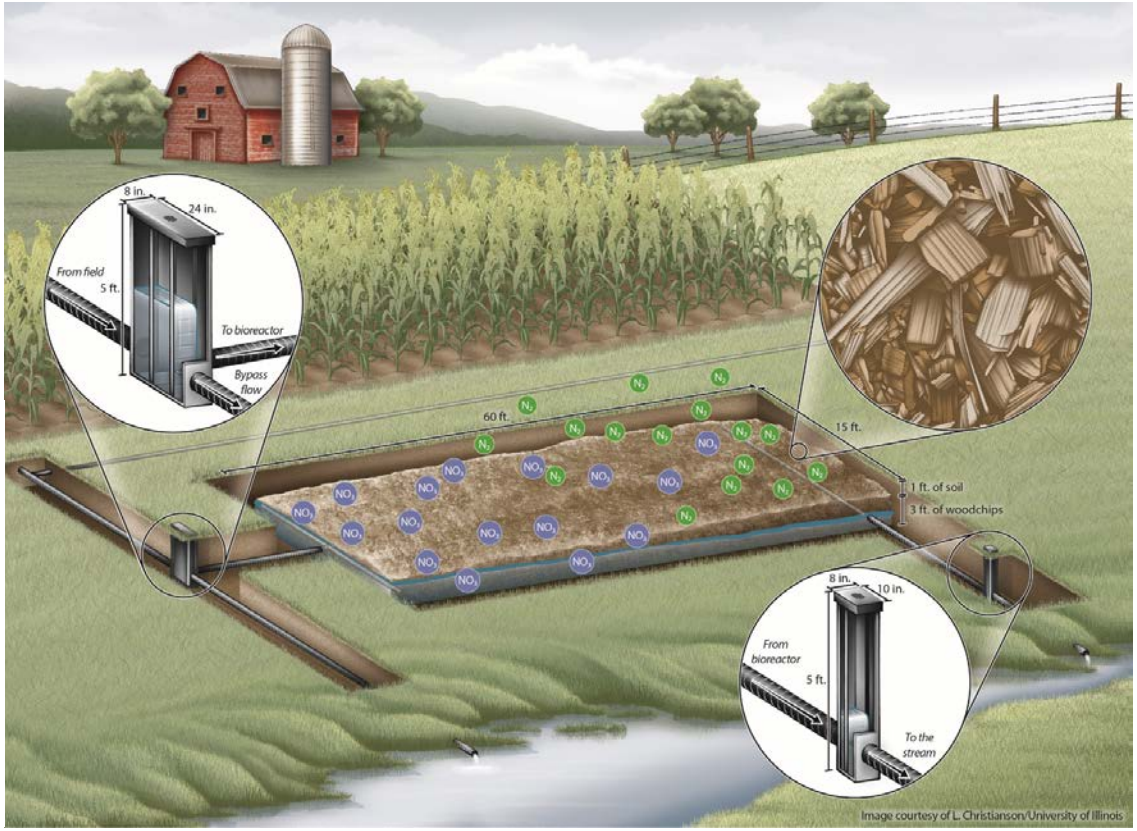
Agricultural productivity

Environmental quality

Denitrifying woodchip bioreactors

Denitrifying woodchip bioreactors

- Bioreactors are solid carbon-filled excavations used to enhance denitrification of nitrate-laden waters.



Denitrifying woodchip bioreactors

- Bioreactors are solid carbon-filled excavations used to enhance denitrification of nitrate-laden waters.
- Requirements:
  - **Available carbon**
  - Denitrifying bacteria
  - Nitrate
  - Anoxic conditions

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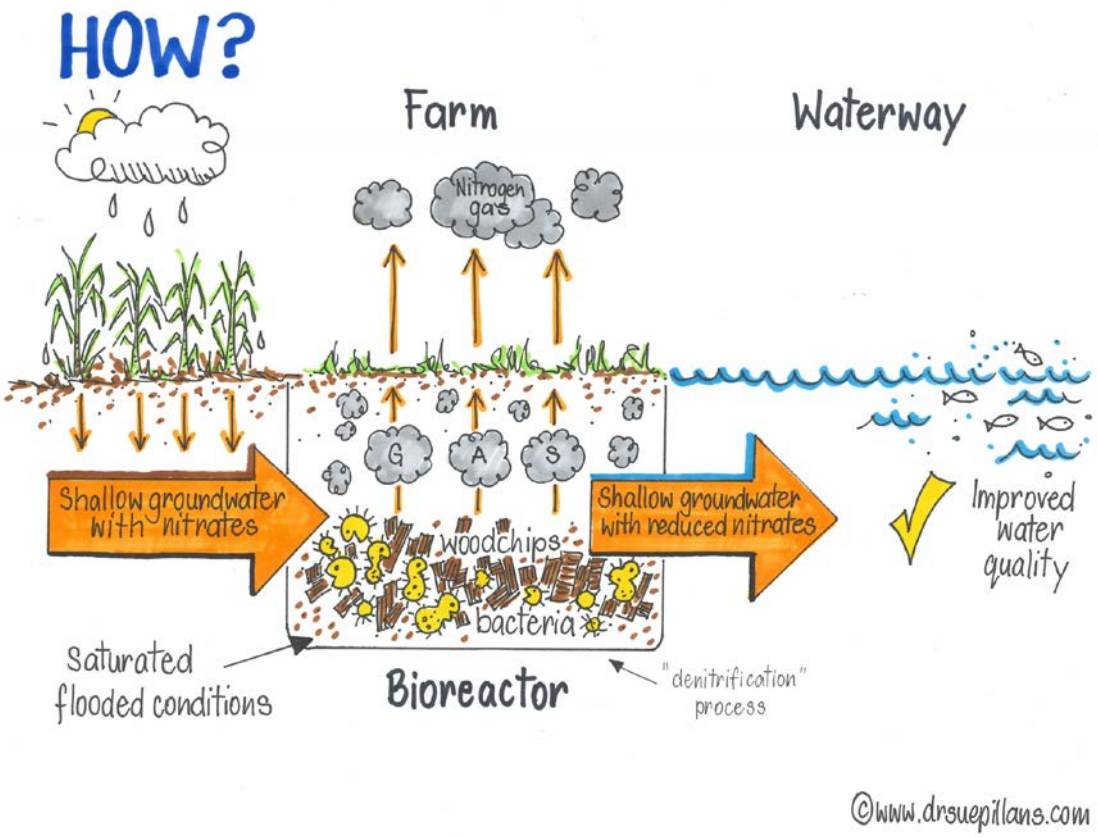

Source: https://terrain.org.au/wp-content/uploads/2018/10/Denitrification-Bioreactor-FINAL.pdf; ; Dr. Sue Pillans, www.drsuepillans.com; Wet Tropics Major Integrated Project, Queensland Government Reef Water Quality Program

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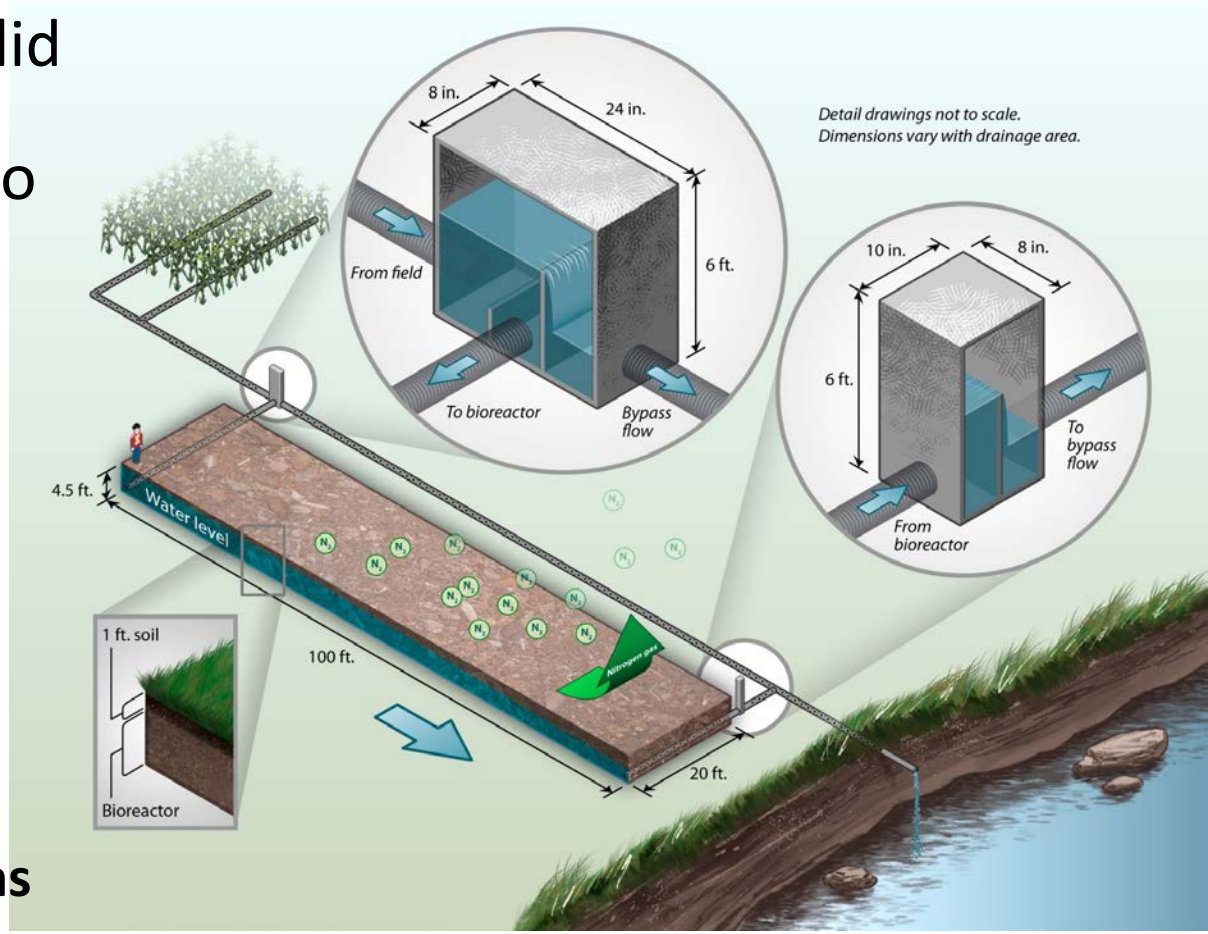

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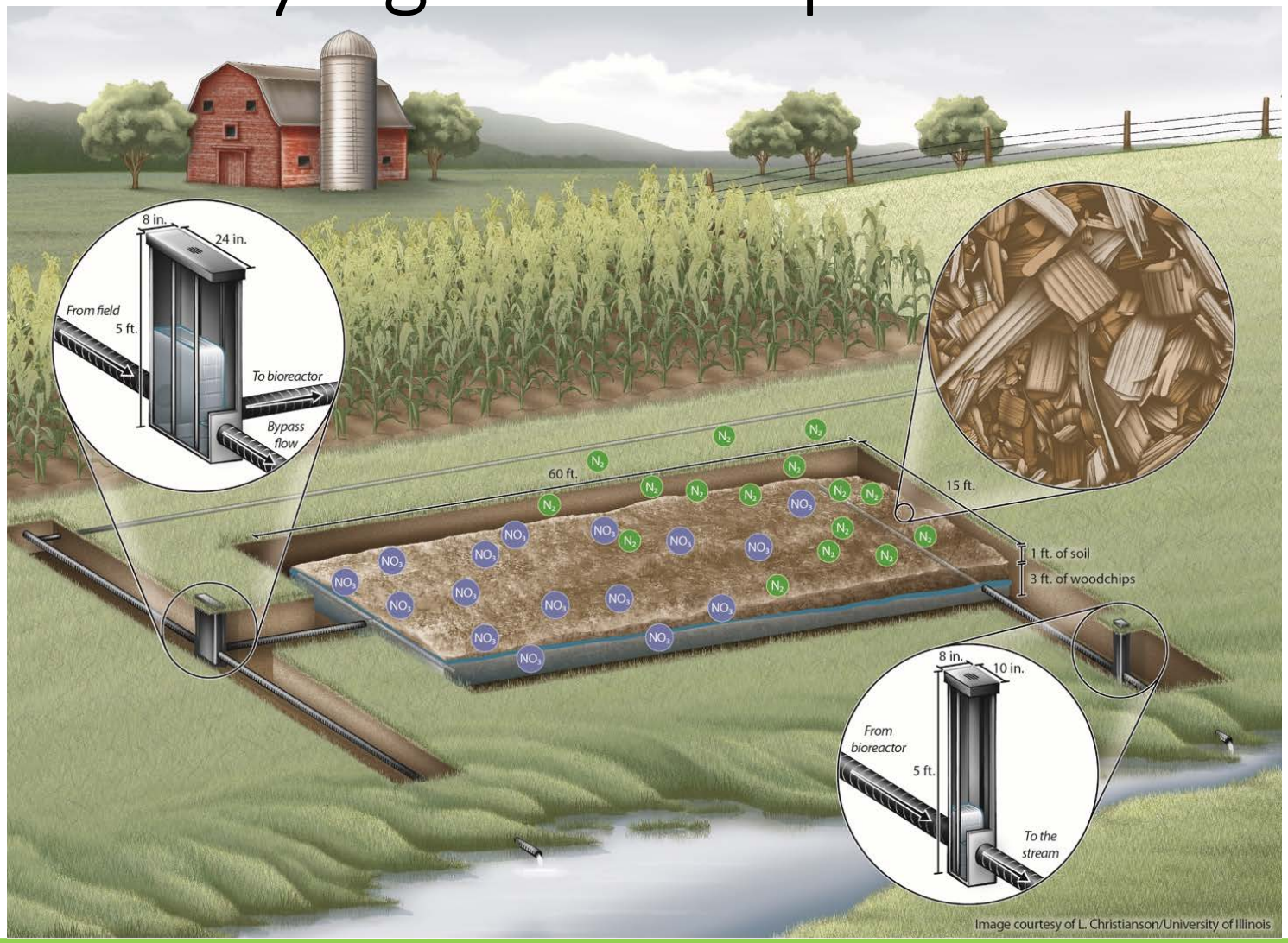

How do we build bioreactors?

1. Place the control structures

From: T. Sutphin and K. Kult, Iowa Soybean Association

How do we build bioreactors?

1. Place the control structures
2. Excavate the trench

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How do we build bioreactors?

1. Place the control structures
2. Excavate the trench
3. Line with plastic

ACES Dudley Smith Farm – bioreactor with baffles

Outflow manifold

Inflow manifold

From: T. Sutphin and K. Kult, Iowa Soybean Association

How do we build bioreactors?

1. Place the control structures
2. Excavate the trench
3. Line with plastic
4. Fill with woodchips

How do we build bioreactors?

1. Place the control structures
2. Excavate the trench
3. Line with plastic
4. Fill with woodchips
5. If using a soil cover:
   a. Install geo-fabric over chips

From: T. Sutphin and K. Kult, Iowa Soybean Association

How do we build bioreactors?

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How do we build bioreactors?

1. Place the control structures
2. Excavate the trench
3. Line with plastic
4. Fill with woodchips
5. If using a soil cover:
   a. Install geo-fabric over chips
   b. Cover with soil
   c. Re-seed

From: T. Sutphin and K. Kult, Iowa Soybean Association

How do we design bioreactors?

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:

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.

USDA United States Department of Agriculture

605-CPS-1

Natural Resources Conservation Service

CONSERVATION PRACTICE STANDARD

DENITRIFYING BIOREACTOR

Code 605

(No.)

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 drainage flow.

This practice does not apply to underground outlets from practices, such as terraces, where the drainage source is primarily from surface inlets.

CRITERIA

General Criteria Applicable to All Purposes

Notify landowner and/or contractor of their responsibility to locate all buried utilities in the project area, including drainage tile and other structural measures. The landowner is also required to obtain all necessary permits for project installation prior to construction.

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

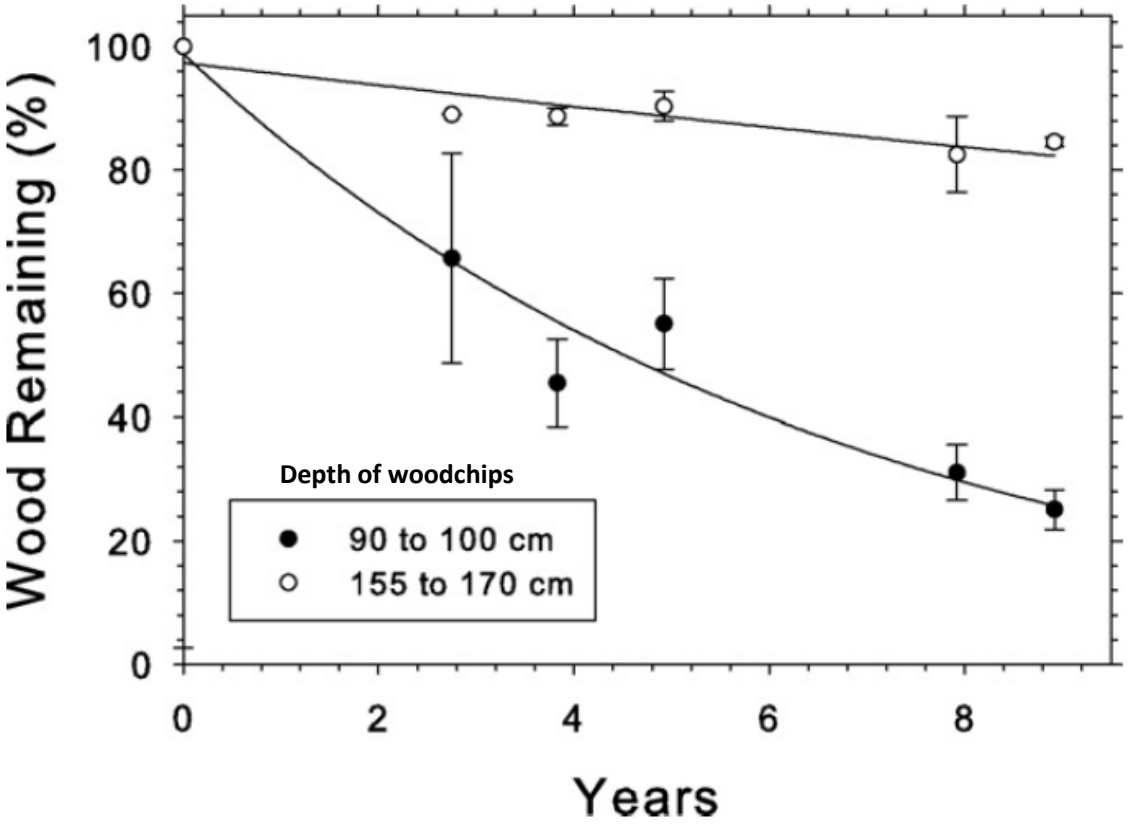
Design the bioreactor hydraulic retention time for a minimum of 3 hours at the peak flow capacity. Account for the porosity of the media and use the average depth of flow through the media. The effective volume of the reactor is calculated as:

Conservation practice standards are reviewed periodically and updated if needed. To obtain the current version of this standard, contact your Natural Resources Conservation Service State office or visit the Field Office Technical Guide.

NRCS, Illinois
December 2017

How long do the woodchips last?

- Practical life estimated at 7-15 years
- Just based on carbon availability: 20 to >50 yrs
- Wet chips last longer



Source: Moorman et al., 2010

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Source: Chris Hay, Iowa Soybean Association

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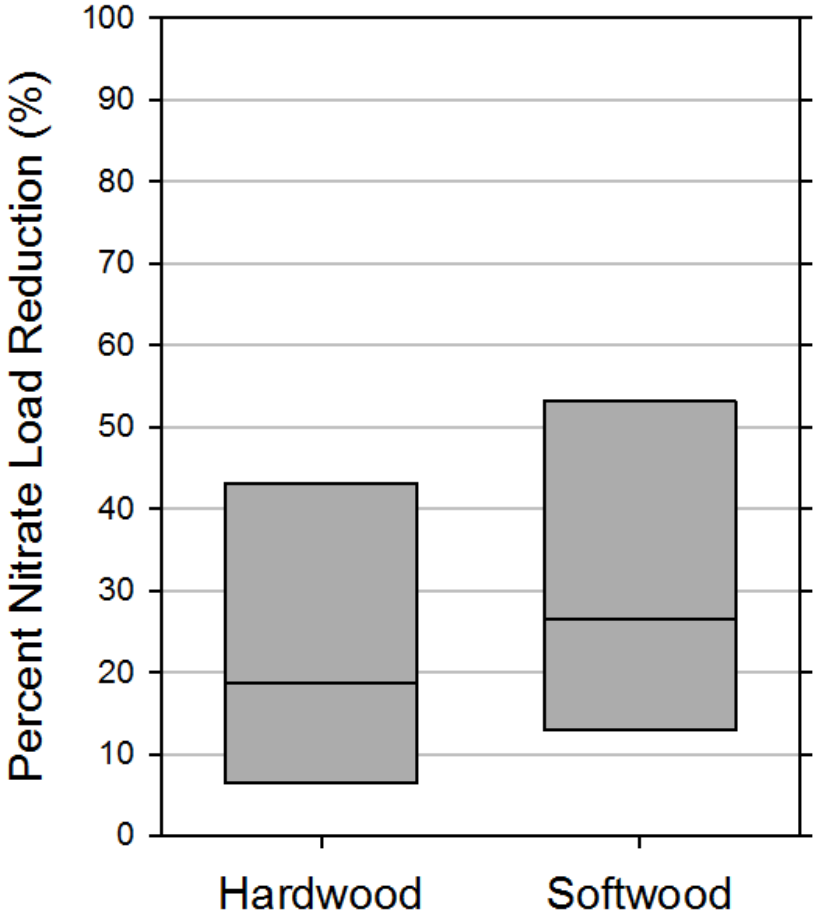
Photo Credit: Lowell Gentry, UIUC; IL LICA newsletter

Does the kind of woodchip matter?

- Short answer: No. There is no statistically significant difference between these two bars when comparing hardwood and softwood.



Adapted from: Addy, K., A. Gold, L. Christianson, M. David, L. Schipper, and N. Ratigan. 2016. Denitrifying bioreactors for nitrate removal: A meta-analysis. *J. Environ. Qual.* 45(3): 873-881.

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- Particle size and physical properties to end to matter more.

Good

Not as good

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CRITERIA

General Criteria Applicable to All Purposes

Media Chamber. Specify the carbon media that go in the chamber. Use a medium for the carbon source that is reasonably free from dirt, fines, and other contaminants. If wood chips are the media, specifically note that no high tannin content wood such as cedar or redwood are to be used. Oak chips may be used in the bioreactor if mixed with other allowable wood species and do not constitute more than 50% of the mix.[1] Do not use any wood that has been painted or treated. Avoid the use of sawdust, bark, leaf litter or other fine textured media in the wood chips. Distribute the media within the bioreactor to achieve a uniform flow path.

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How well are bioreactors working in the US Midwest?

Henry Co.

Bureau Co.

Mercer Co.

Peoria Co.

Bioreactor #1: Henry Co. Farm Bureau

Drainage area	2.8 ha
L x W x D (m)	9.8 x 1.8 x 0.9
Total volume	16 m^3
L:W ratio	5.4
Inlet tile size	15 cm

Image: Illinois Farm Bureau

L. Christianson, UIUC; Unpublished data

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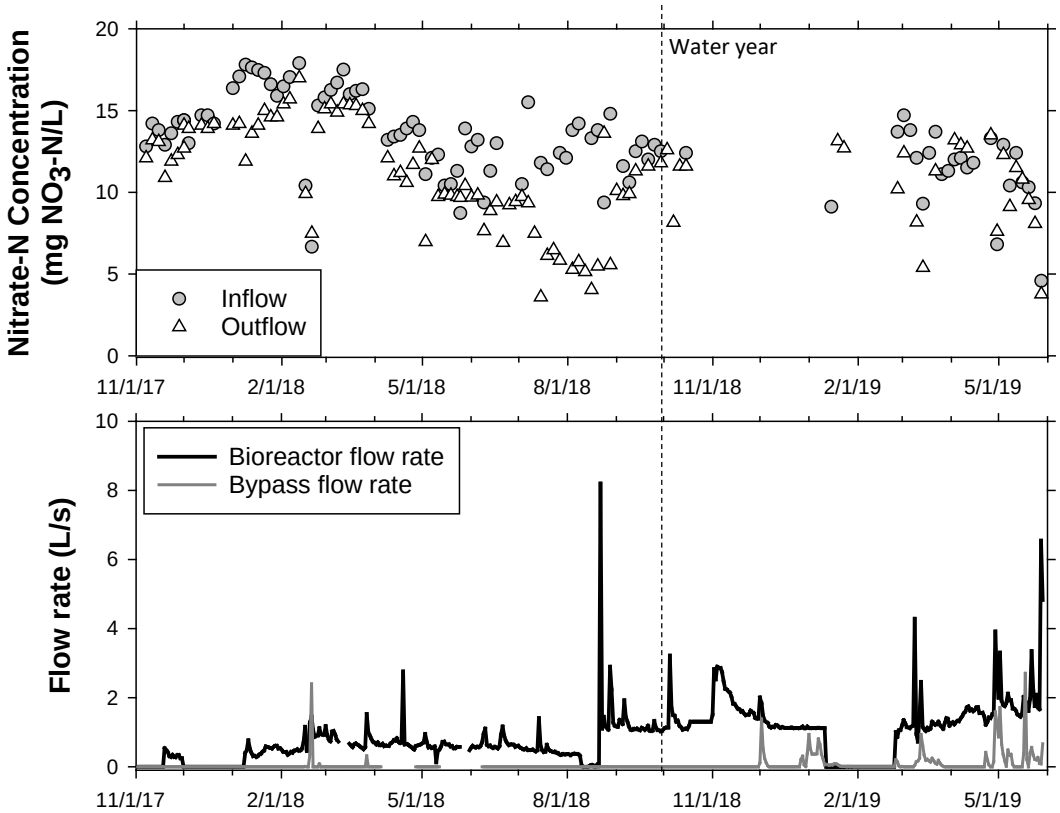
L x W x D (m)	9.8 x 1.8 x 0.9
Total volume	16 m^3
L:W ratio	5.4
Inlet tile size	15 cm
Flow into bioreactor	92-98%
N removal in bioreactor	12-49%
N removal at edge-of-field	**12-45%**
N removal rate	>5 g/m^3-d



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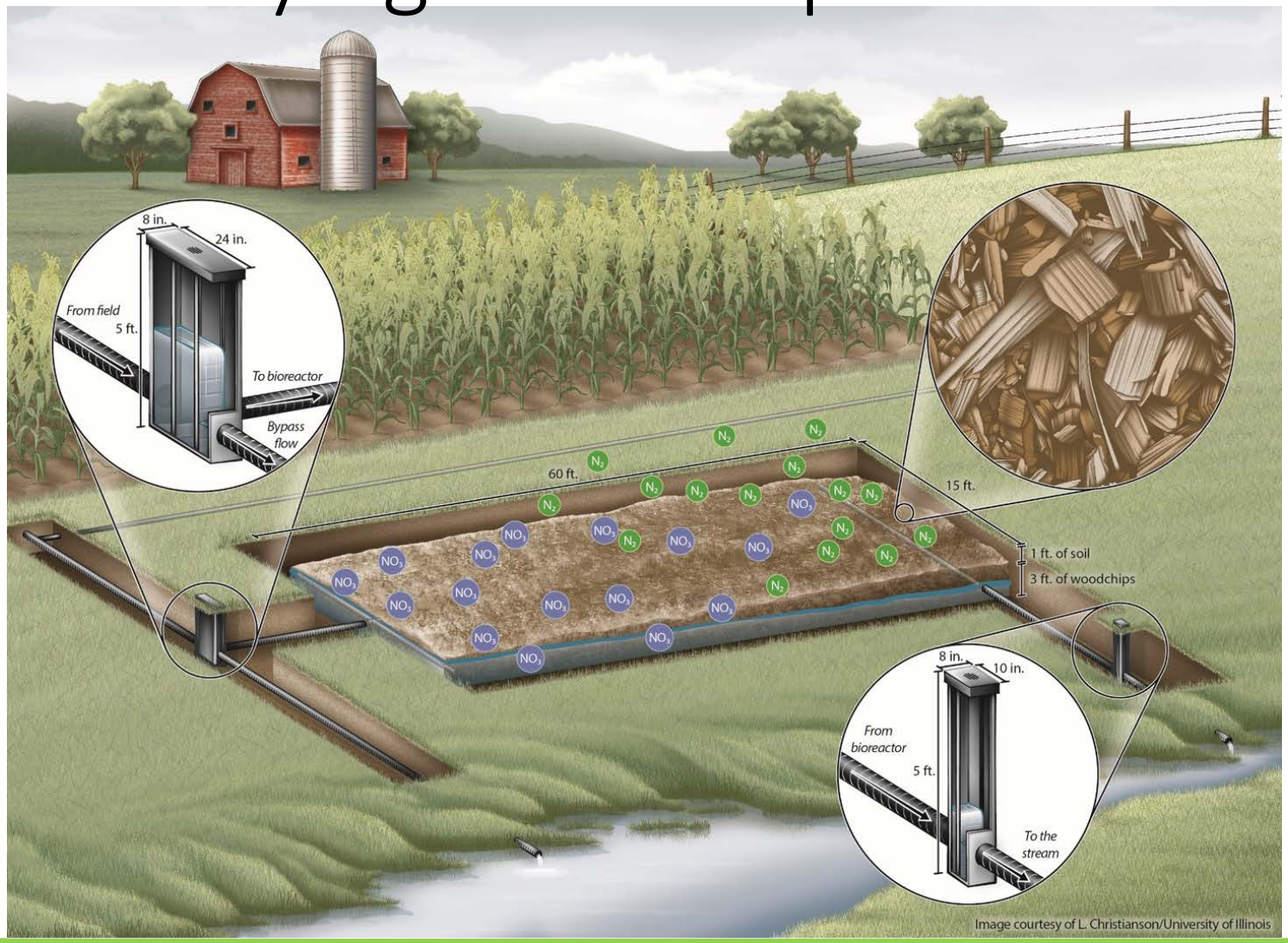
Denitrifying woodchip bioreactors



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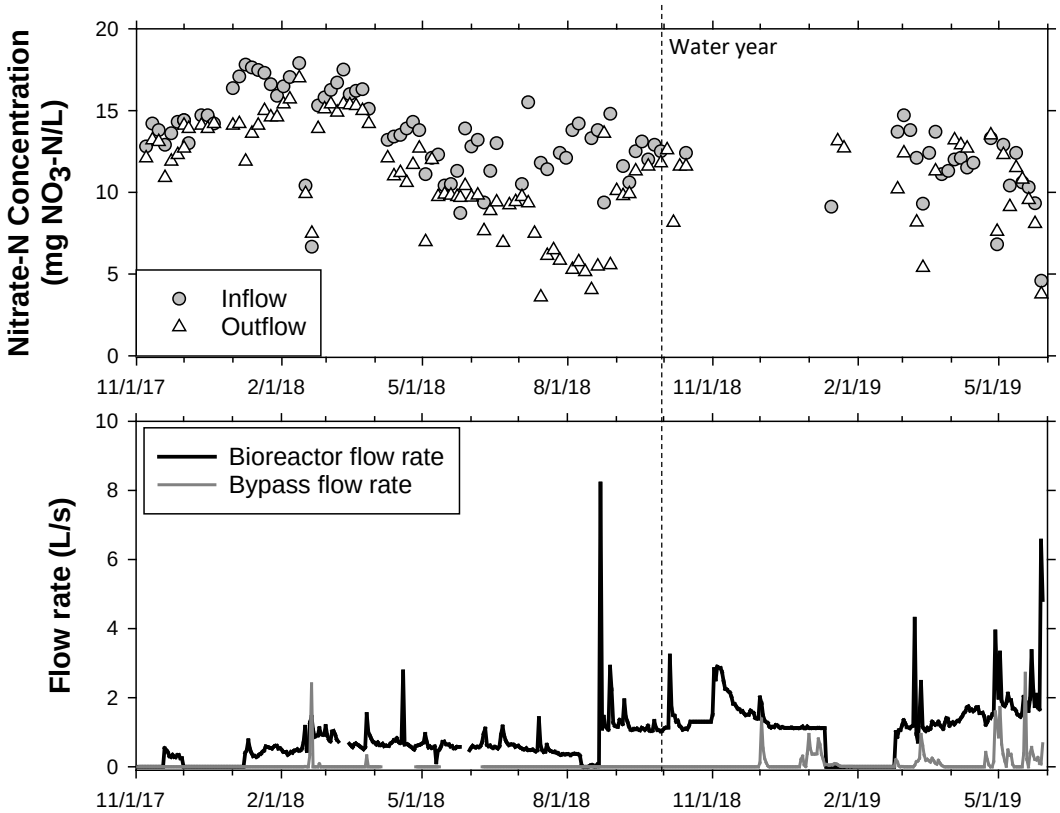


L. Christianson, UIUC; Unpublished data

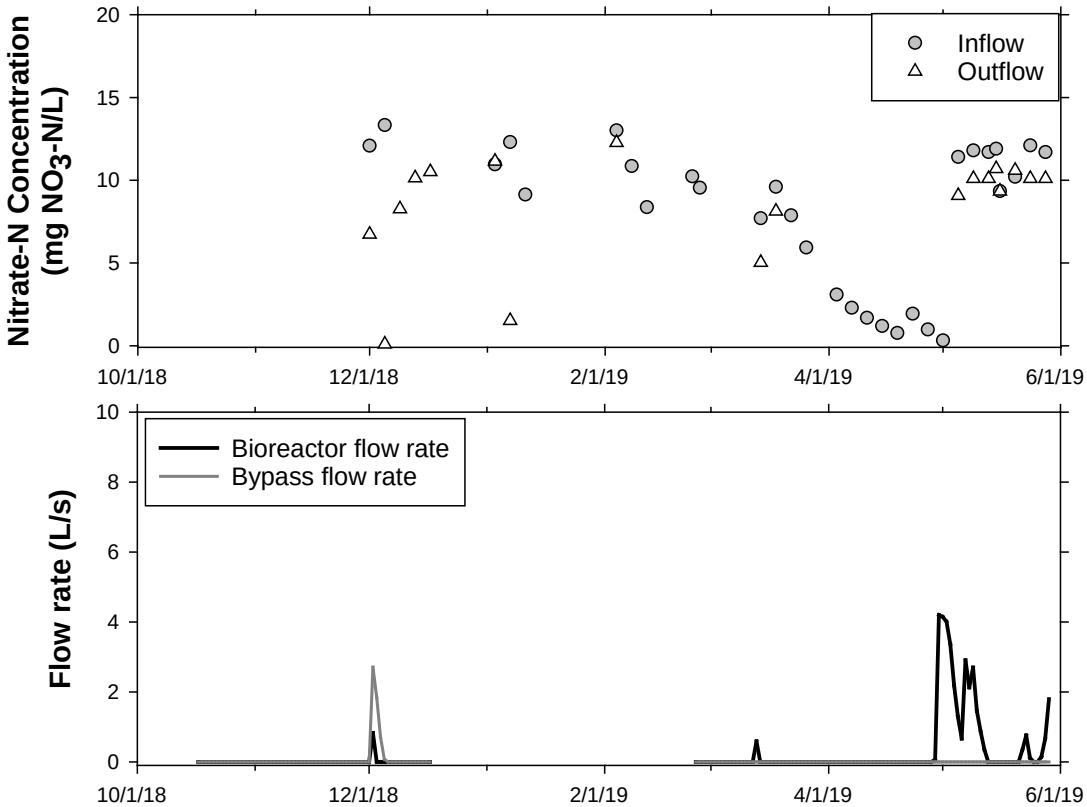
Bioreactor #2: Bureau Co. Farm Bureau

Drainage area	6.9 ha
L x W x D (m)	15 x 3.7 x 0.9
Total volume	51 m^3
L:W ratio	4.2
Inlet tile size	10 cm

L. Christianson, UIUC; Unpublished data

Bioreactor #2: Bureau Co. Farm Bureau

Drainage area	6.9 ha
L x W x D (m)	15 x 3.7 x 0.9
Total volume	51 m^3
L:W ratio	4.2
Inlet tile size	10 cm
Flow into bioreactor	86%
N removal in bioreactor	21%
N removal at edge-of-field	**17%**
N removal rate	1.1 g/m^3-d



L. Christianson, UIUC; Unpublished data

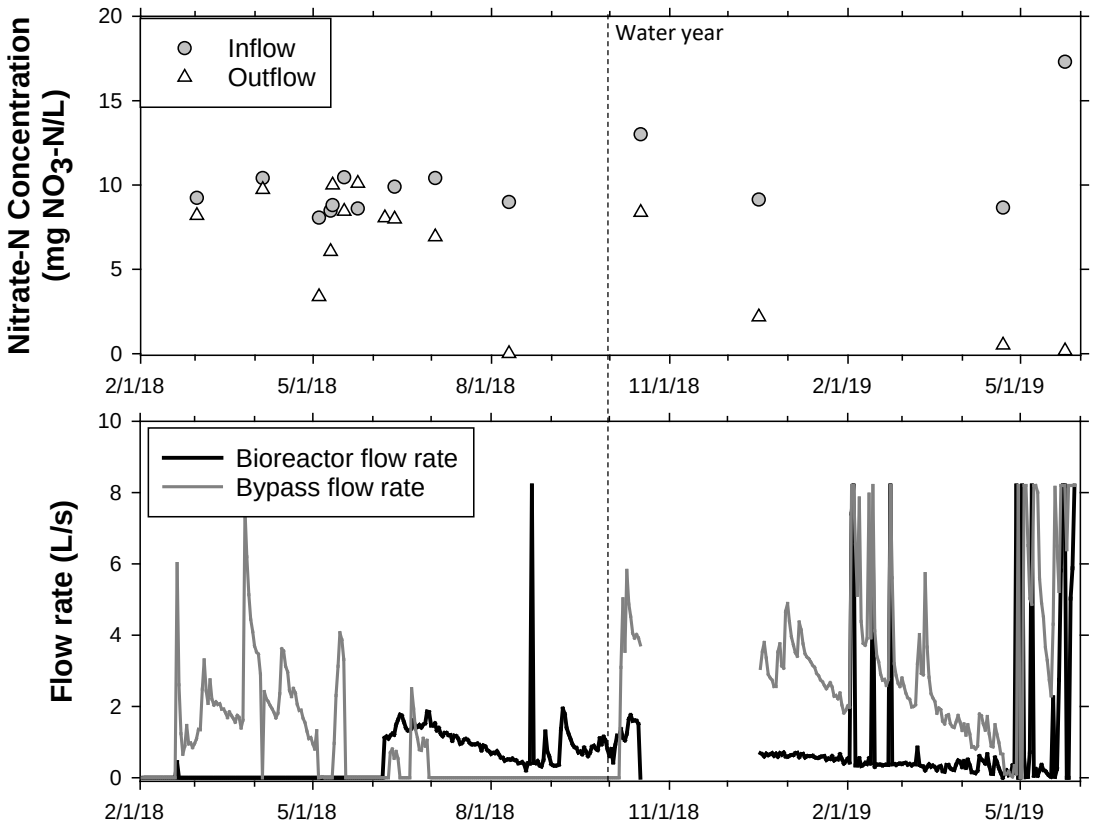
Bioreactor #3: Mercer Co. Farm Bureau

Drainage area	20 ha
L x W x D (m)	13 x 3.4 x 0.9
Total volume	41 m^3
L:W ratio	4.0
Inlet tile size	15 cm

L. Christianson, UIUC; Unpublished data

Bioreactor #3: Mercer Co. Farm Bureau

Drainage area	20 ha
L x W x D (m)	13 x 3.4 x 0.9
Total volume	41 m^3
L:W ratio	4.0
Inlet tile size	15 cm
Flow into bioreactor	27-28%
N removal in bioreactor	61-77%
N removal at edge-of-field	**18-22%**
N removal rate	>5.0 g/m^3-d



L. Christianson, UIUC; Unpublished data

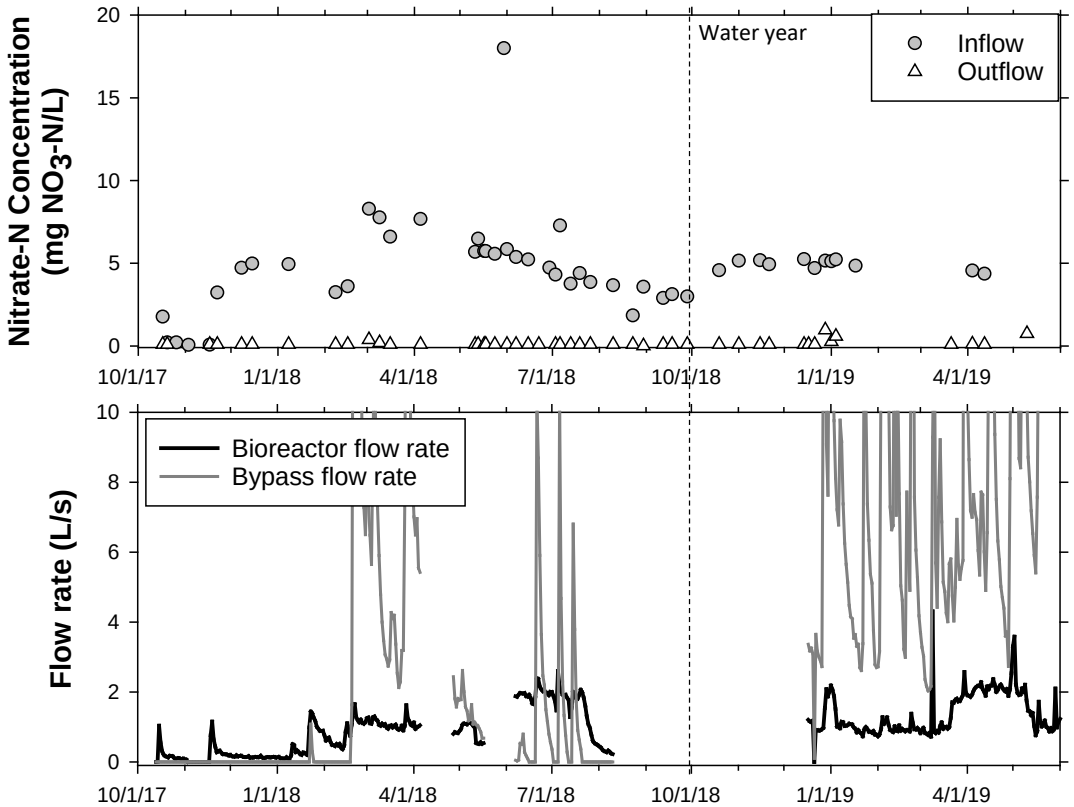
Bioreactor #4: Peoria Co. SWCD

Drainage area	20 ha
L x W x D (m)	23 x 5.8 x 1.1
Total volume	152 m^3
L:W ratio	4.0
Inlet tile size	25 cm

L. Christianson, UIUC; Unpublished data

Bioreactor #4: Peoria Co. SWCD

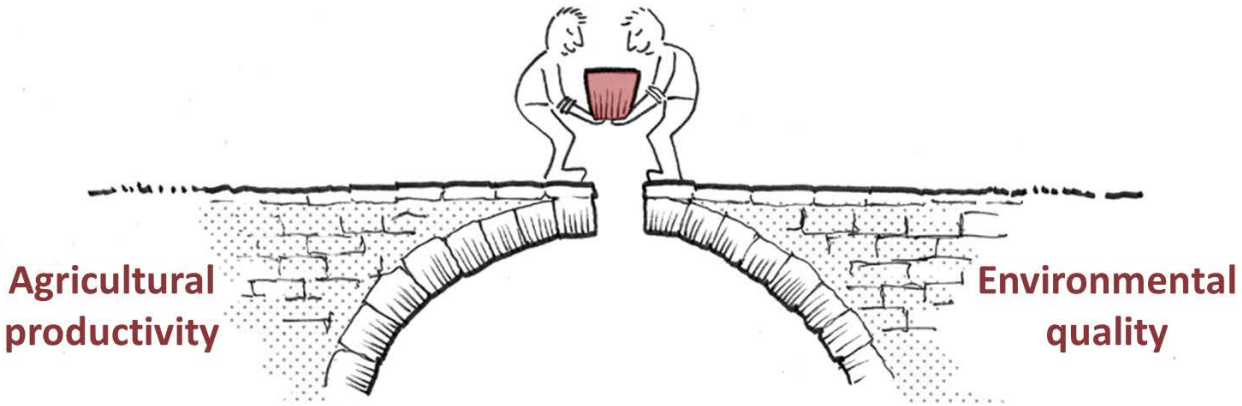
Drainage area	20 ha
L x W x D (m)	23 x 5.8 x 1.1
Total volume	152 m^3
L:W ratio	4.0
Inlet tile size	25 cm
Flow into bioreactor	15-32%
N removal in bioreactor	94-98%
N removal at edge-of-field	**15-25%**
N removal rate	2-4 g/m^3-d



L. Christianson, UIUC; Unpublished data

Denitrifying bioreactors offer…

- A realistic fit within current on-farm constraints
- Certainty for reductions in nutrient pollution
- Collaboration opportunities
- Opportunities to think and learn globally
- Opportunities to innovate due to design challenges that are not insurmountable



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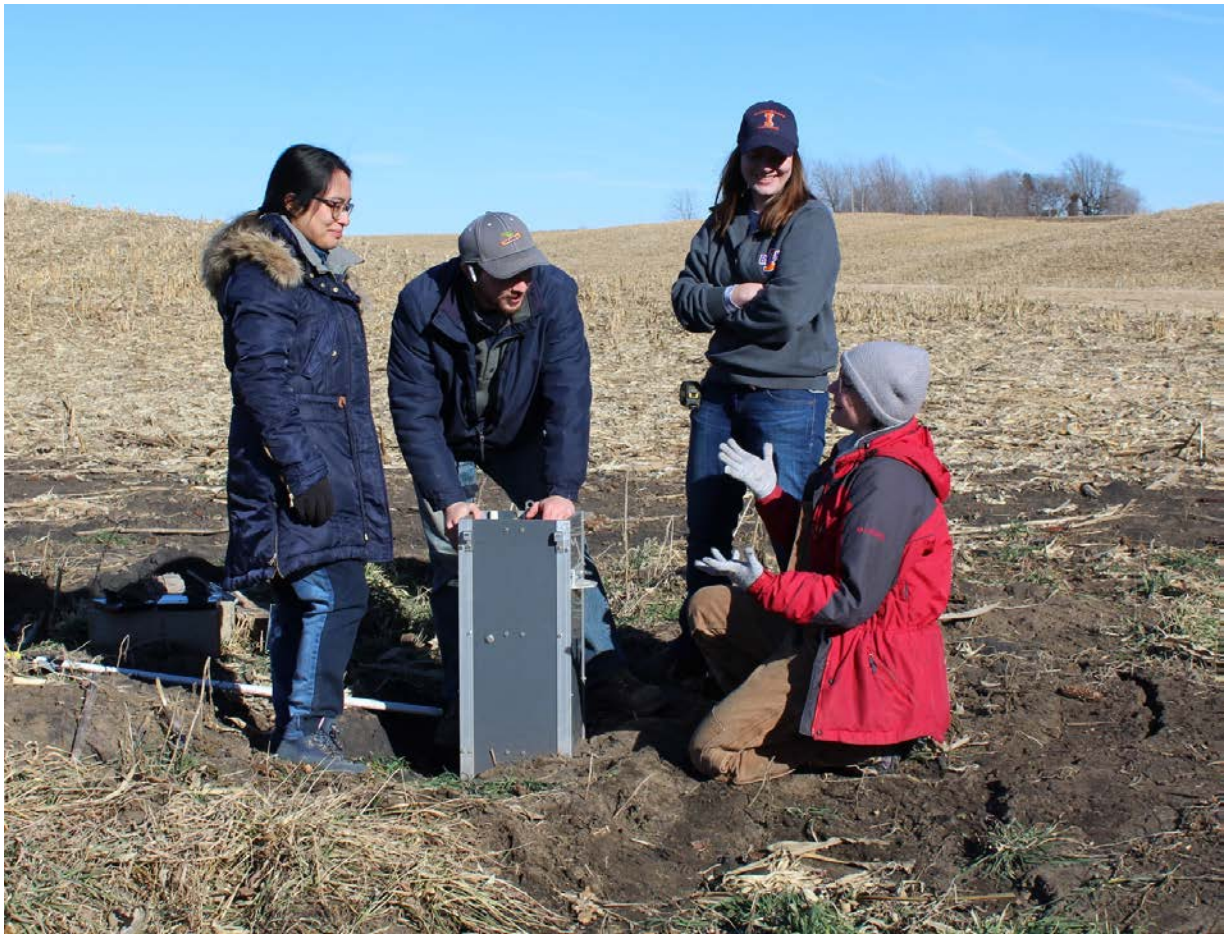

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Banana, pineapple, and sugarcane farms in Queensland, Australia

Credit: https://scorchinghotnews.com/bioreactor-improve-water-quality-great-barrier-reef/

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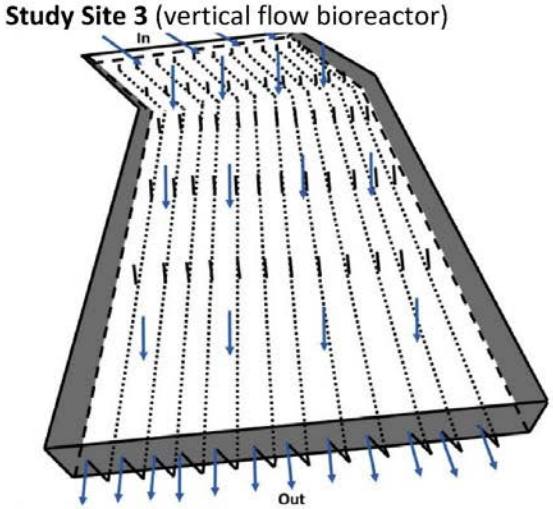
Aquaculture wastewater in Denmark



Source: Von Ahnen 2018 Aquacultural Engineering

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Agricultural ditch drainage water in Belgium

Source: PC Fruit - Belgium; K. Dhaese

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Saline agricultural outflows in Spain

Credit: Twitter @CanalMarMenor

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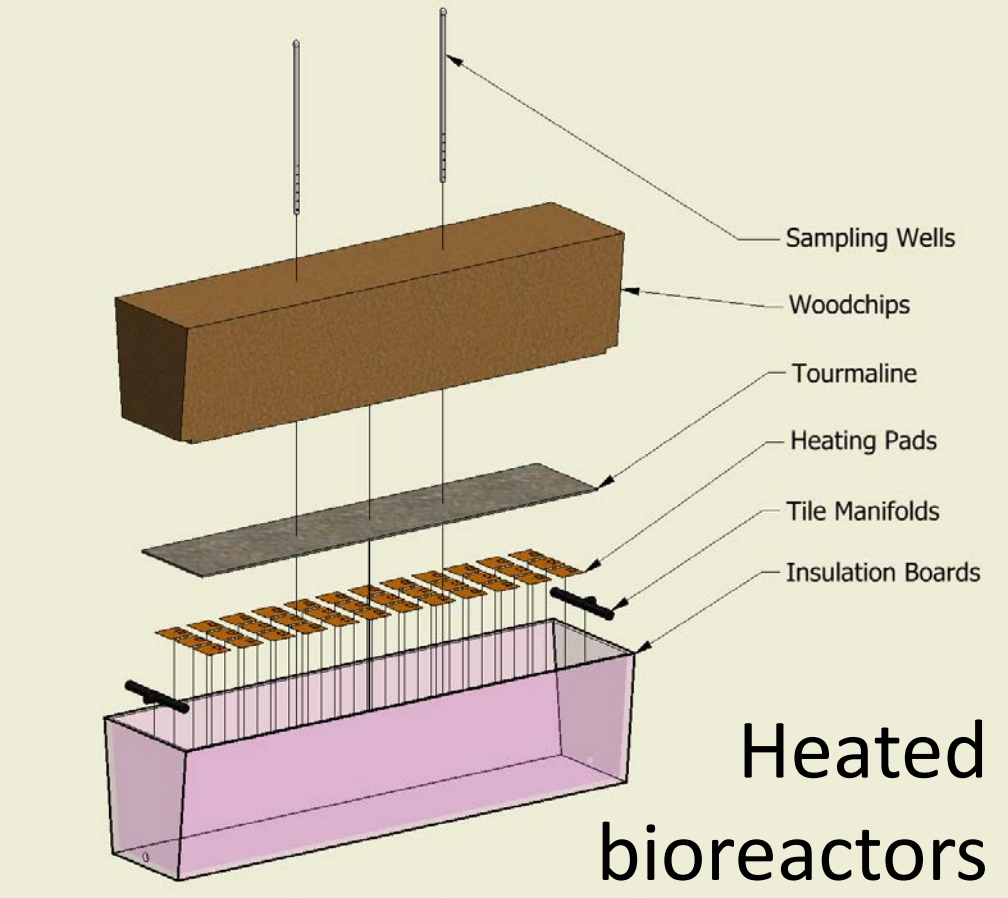

Challenges to bioreactor implementation

- Someone will have to pay for them.

Source: United Soybean Board; Soybean Checkoff https://www.flickr.com/photos/unitedsoybean/9622304451/in/photostream/

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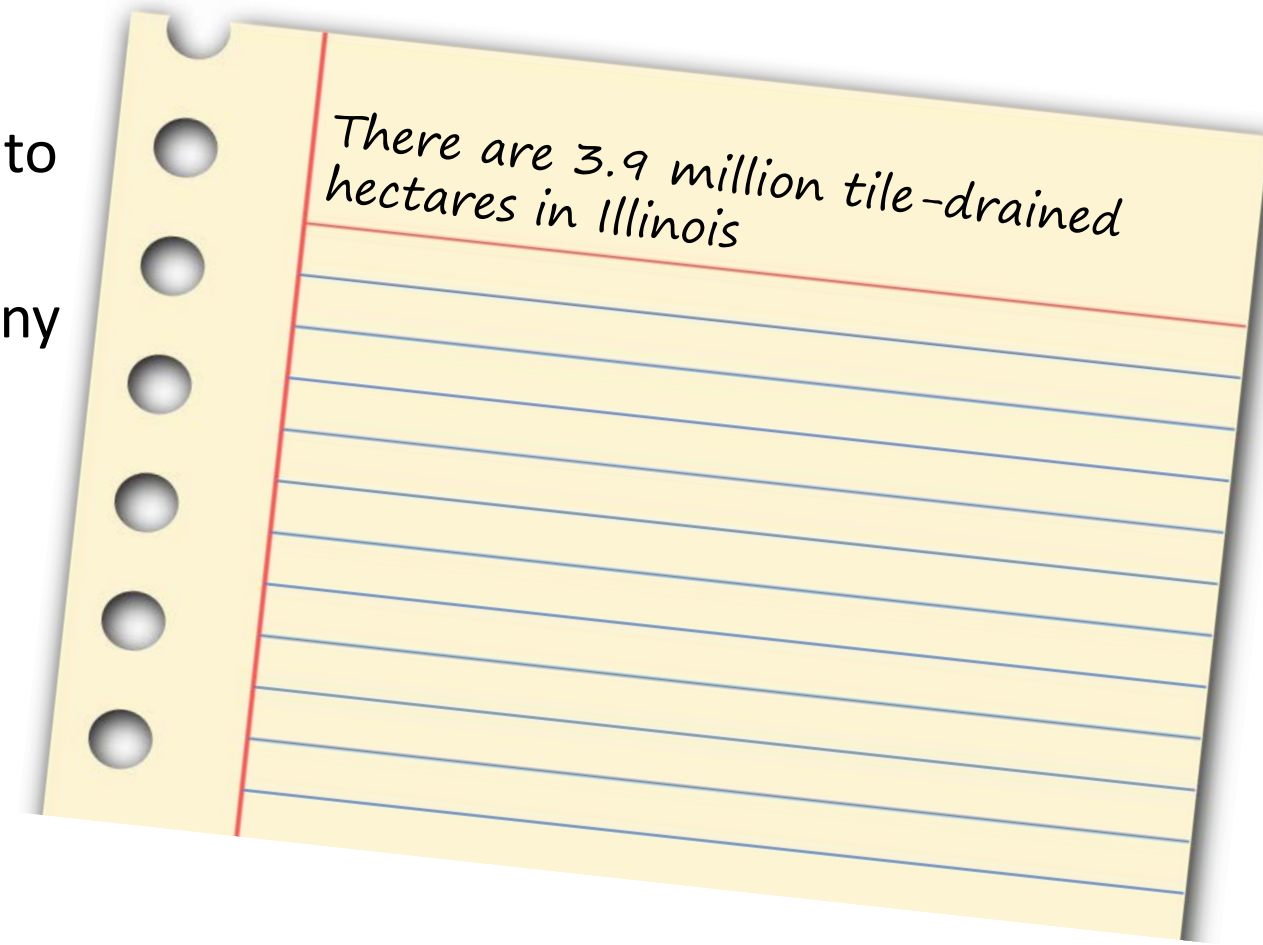
- We need many, many more…



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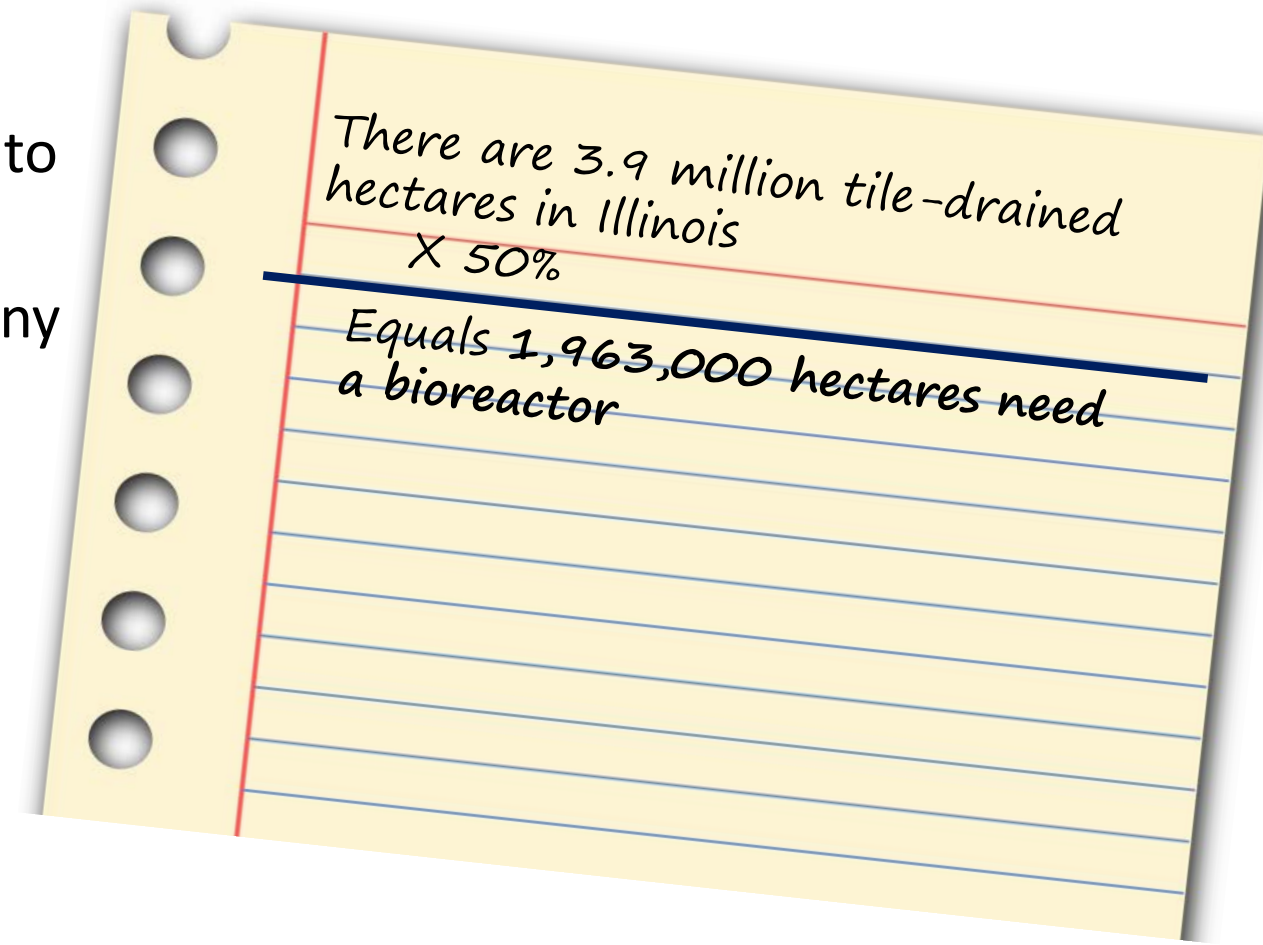

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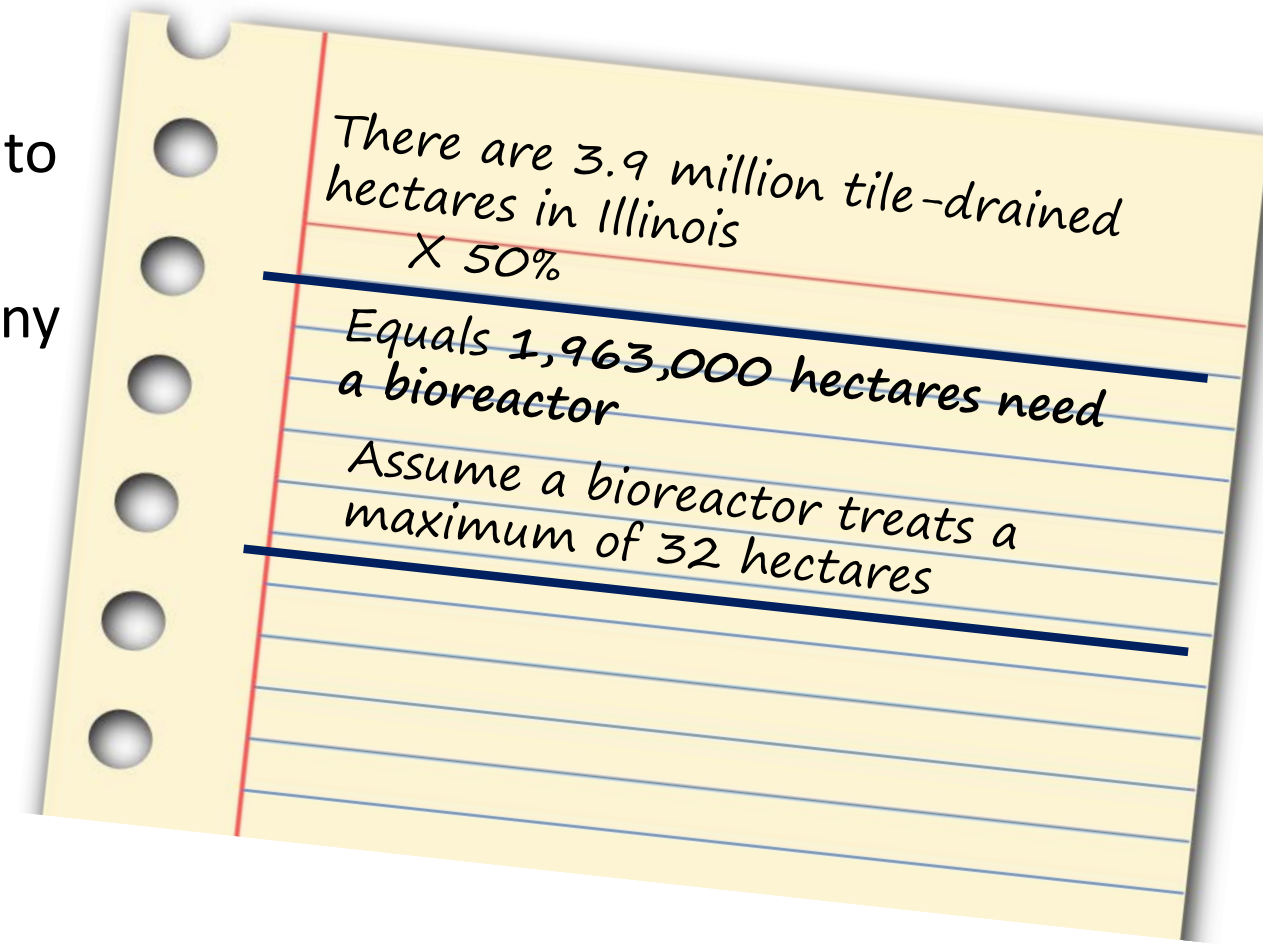

Challenges to bioreactor implementation

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There are 3.9 million tile-drained hectares in Illinois
X 50%

Equals **1,963,000 hectares need a bioreactor**

Assume a bioreactor treats a maximum of 32 hectares

Equals **more than 60,000 bioreactors are needed** in Illinois to meet Mississippi River Basin goals!

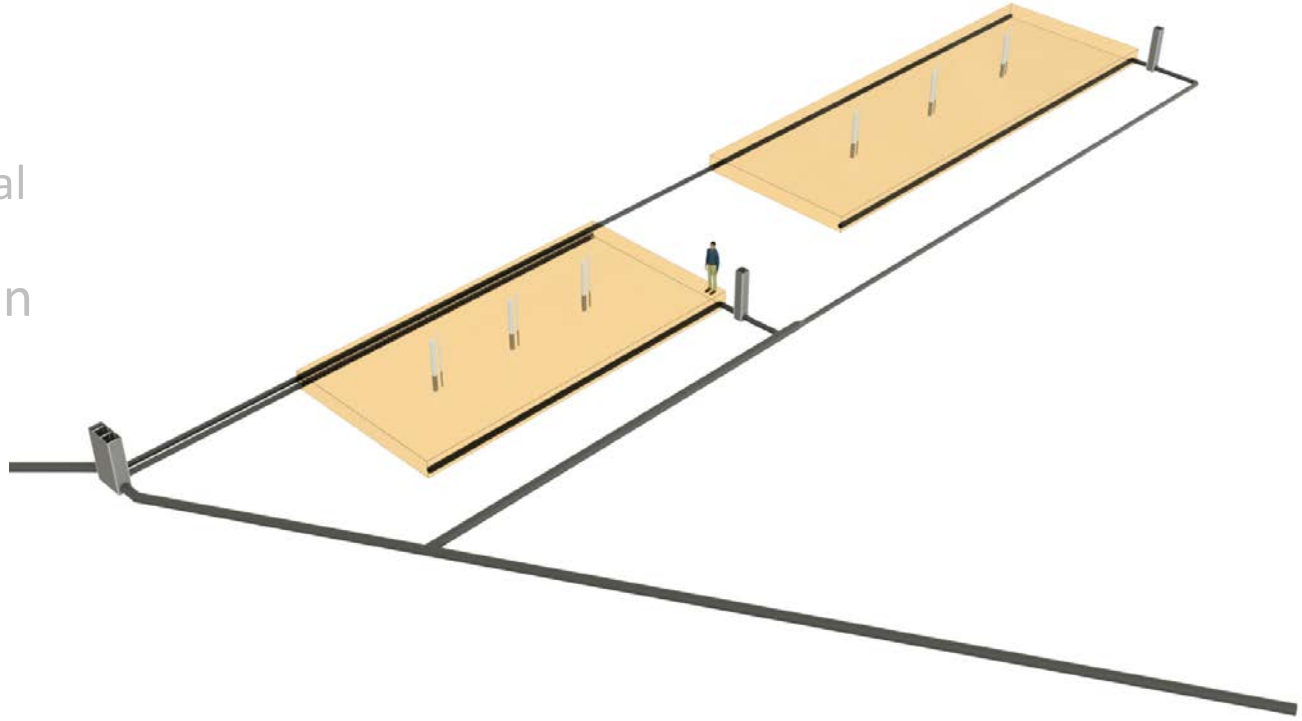
Challenges to bioreactor implementation

- Someone will have to pay for them.
- We need many, many more, or…
- We need to rethink scale.

Source: https://www.bridgewateruk.com/2016/08/working-large-company-vs-working-small-company-pros-cons/

How can we design bioreactors to scale?

- Bioreactors operating in parallel during high flow
- Wider bioreactors to be able to receive more flow
  - Use baffles to avoid preferential flow paths
- Place bioreactors in ditches
  - Paired ditch designs
- Bioreactors designed for the small watershed-scale



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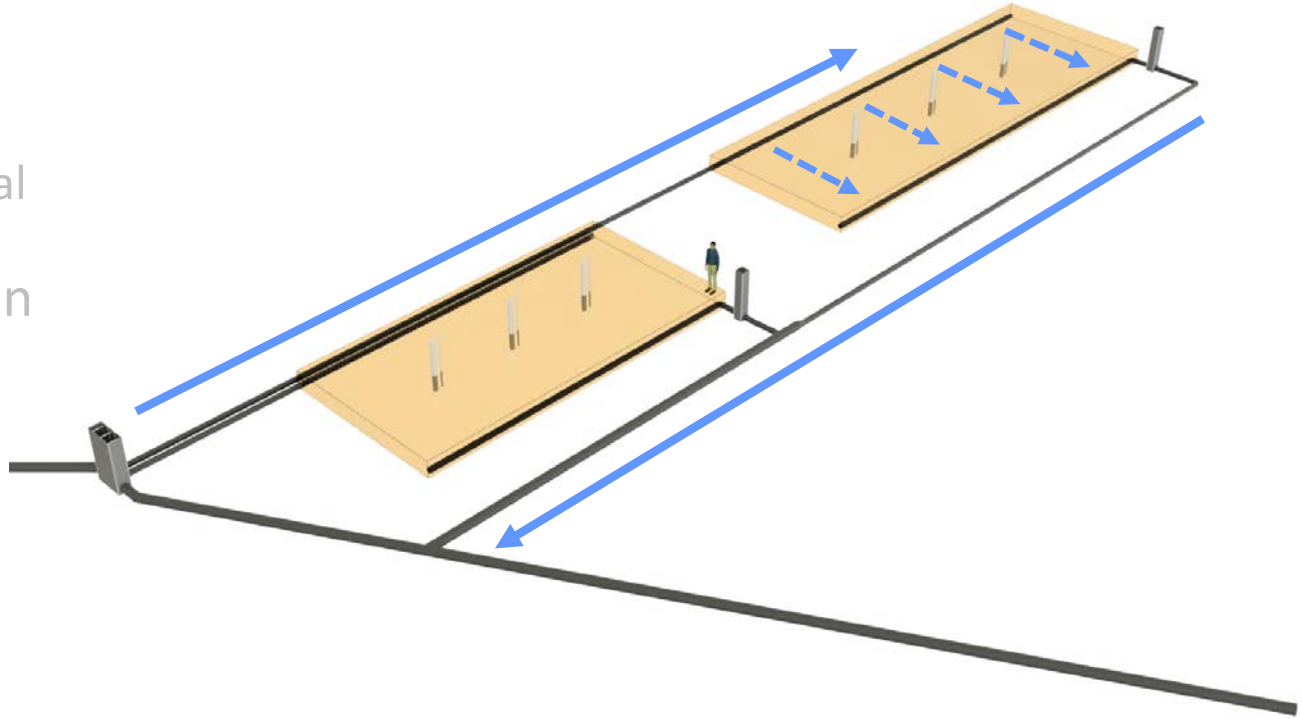

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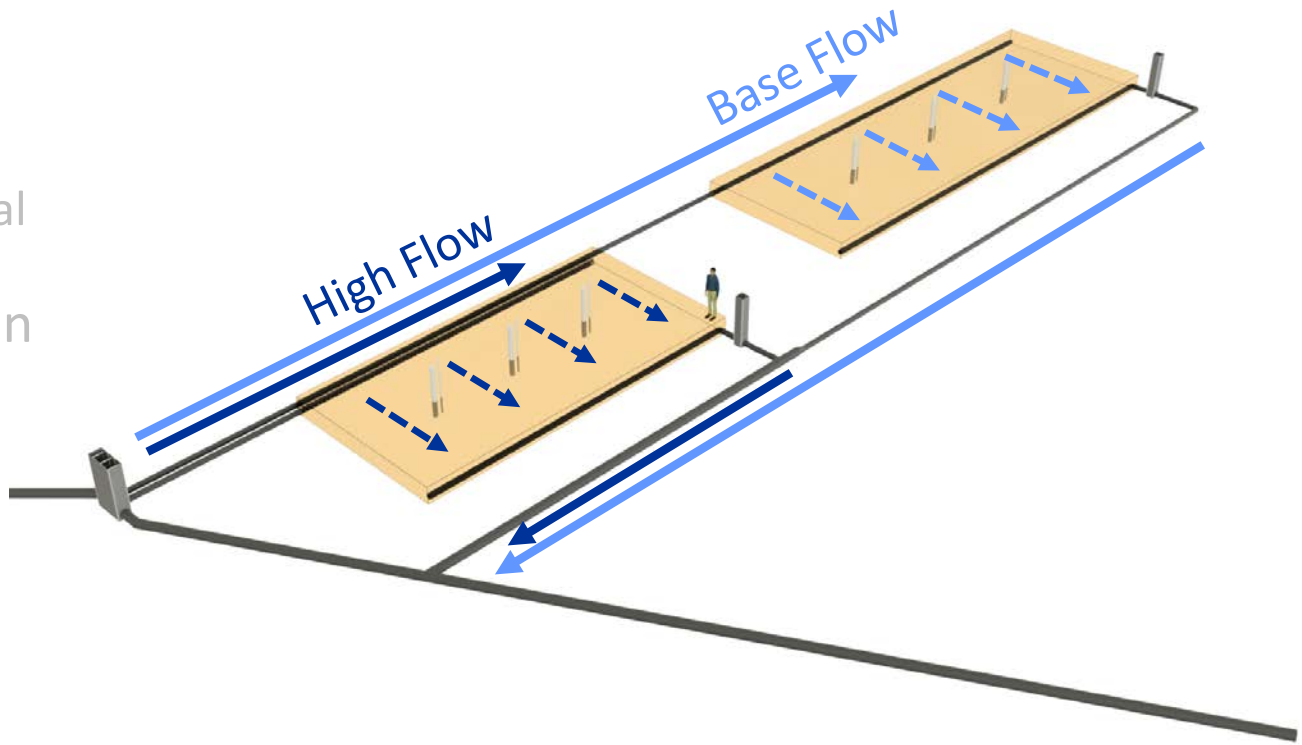

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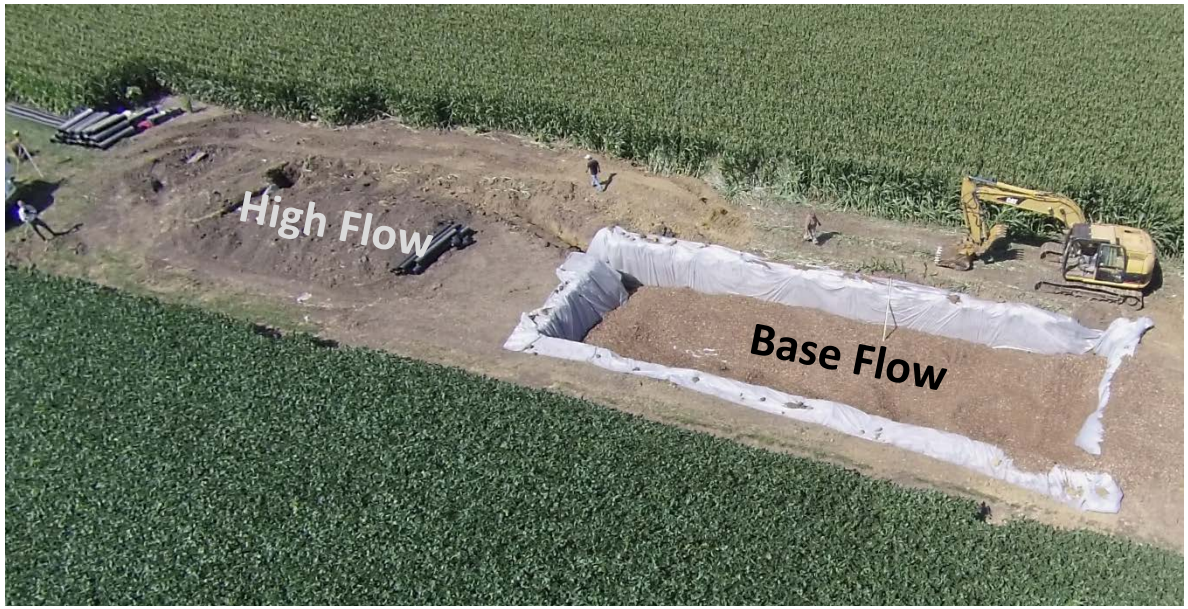

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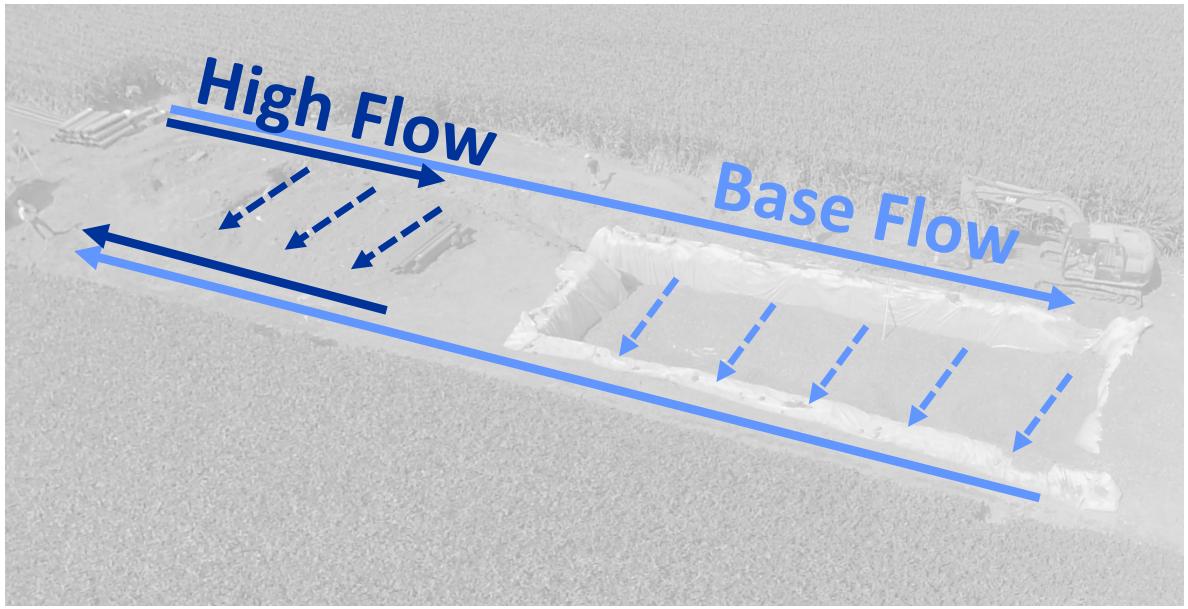

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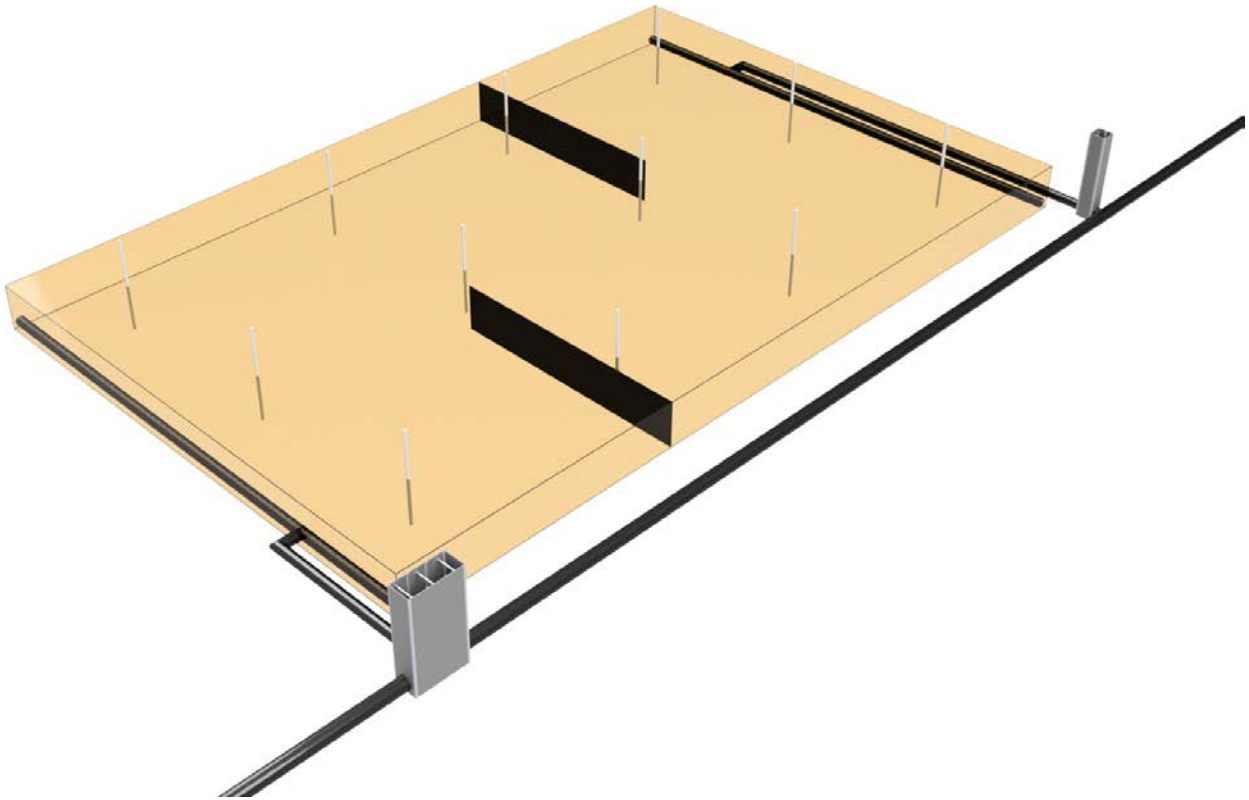

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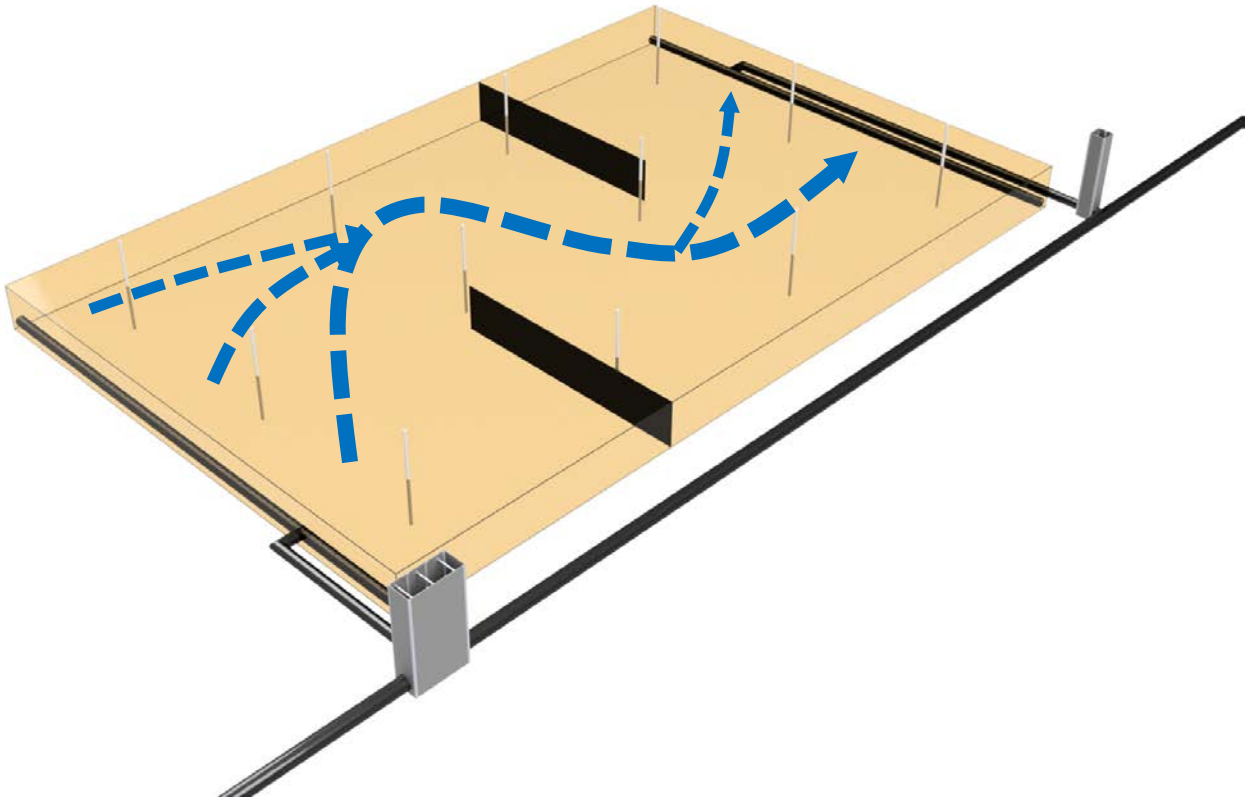

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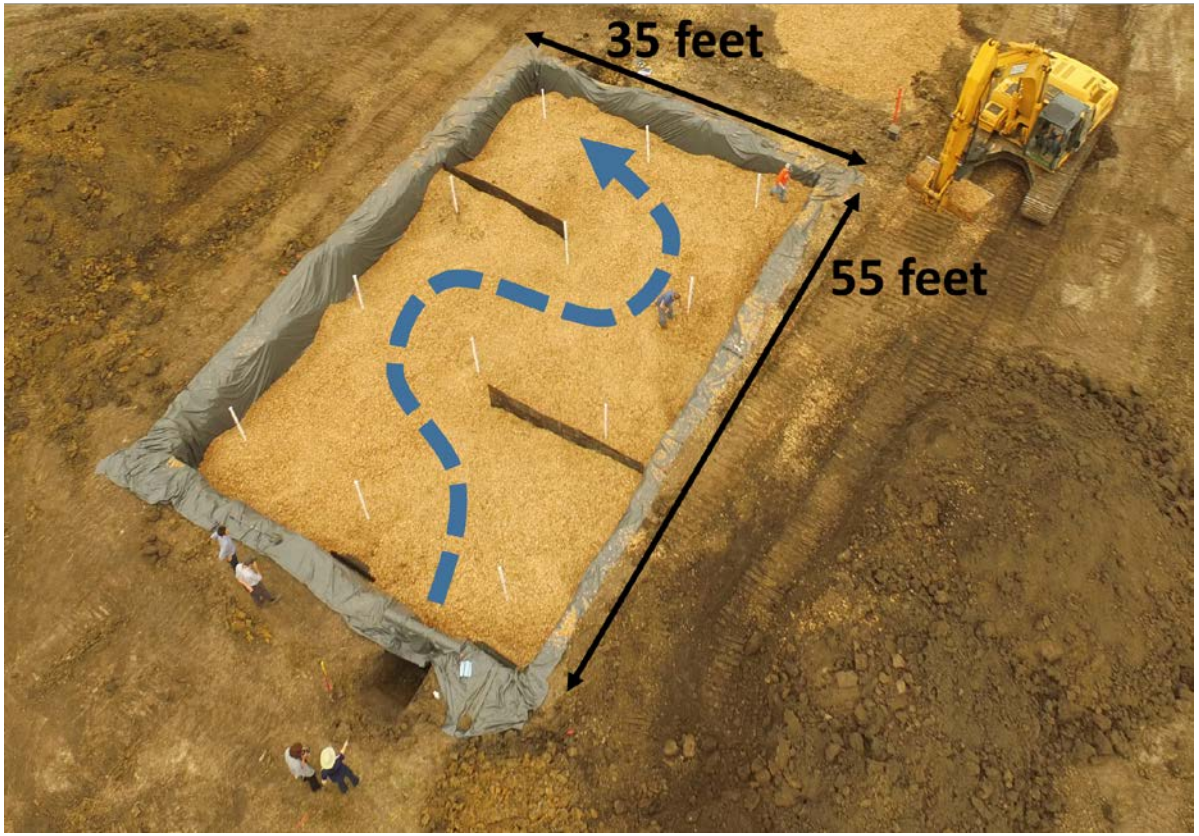

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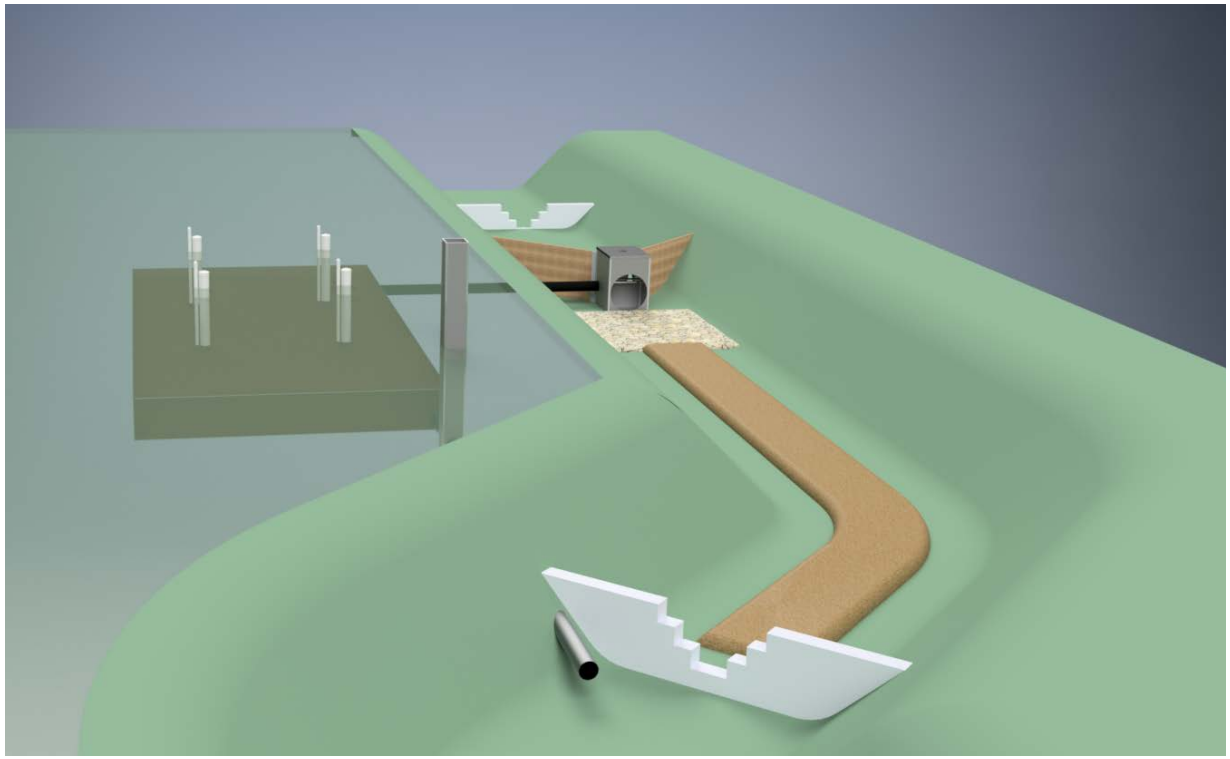

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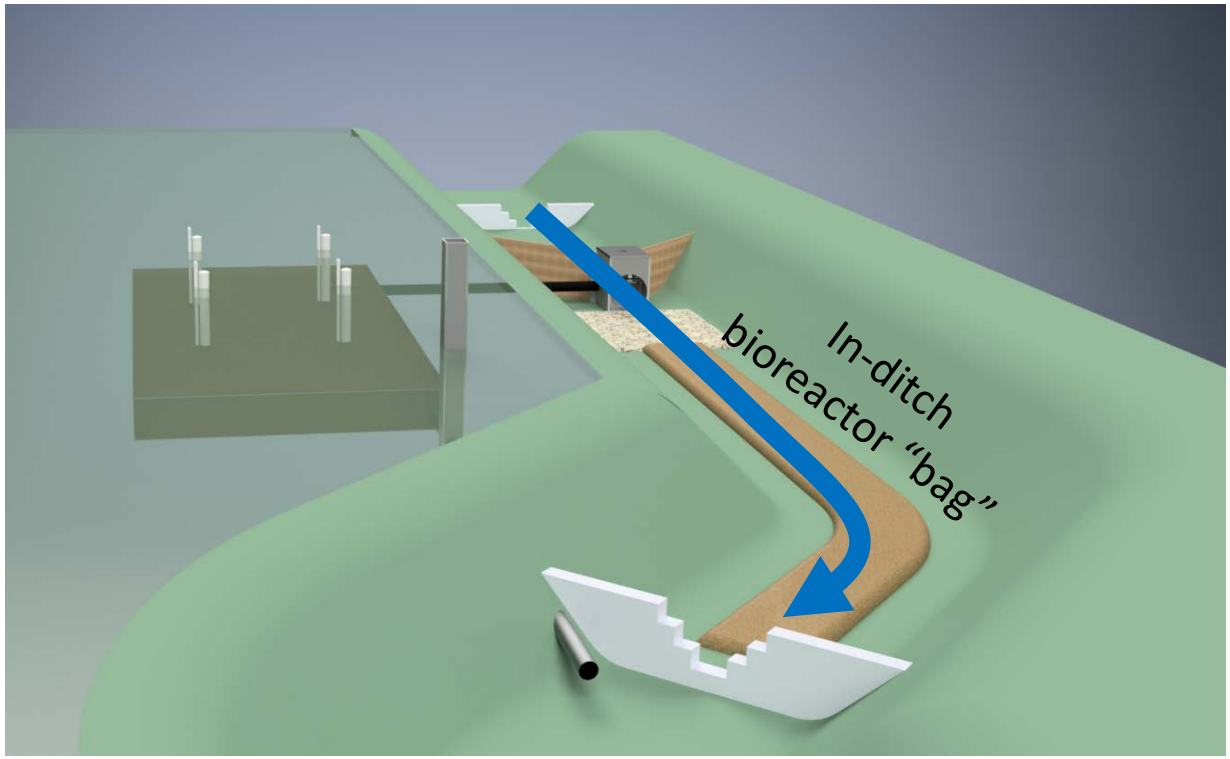

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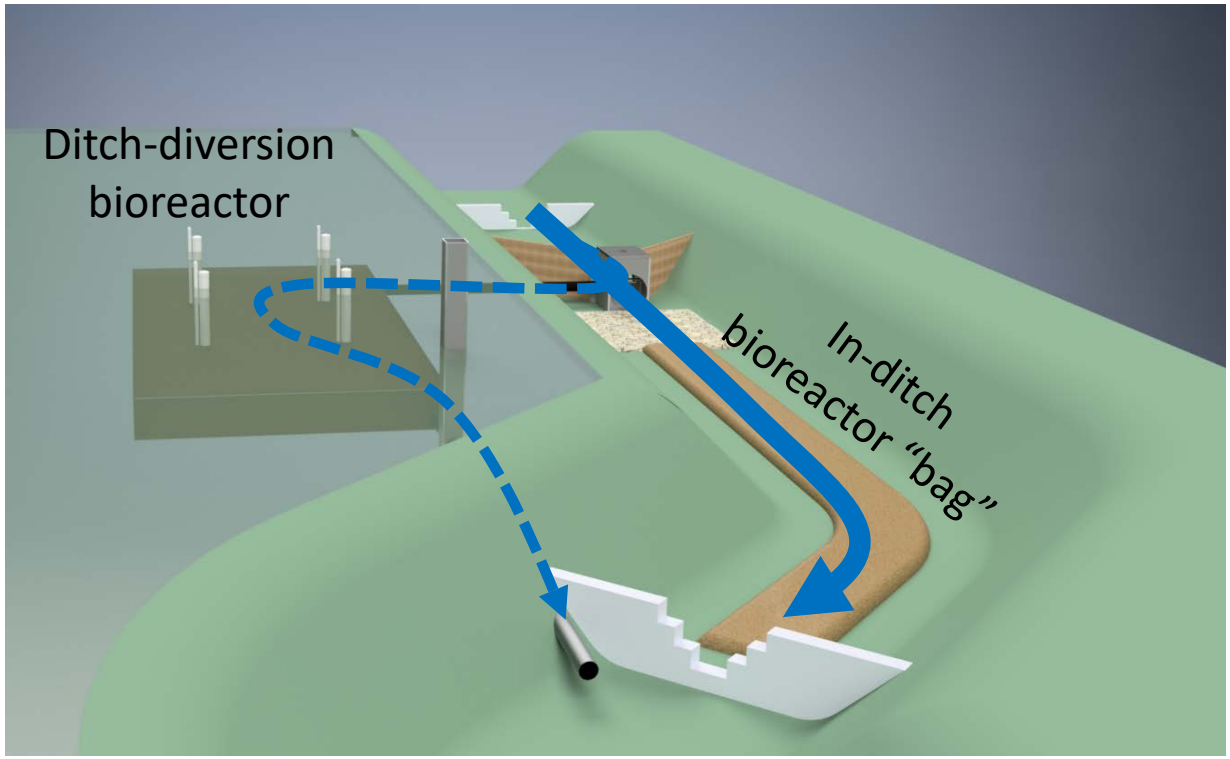

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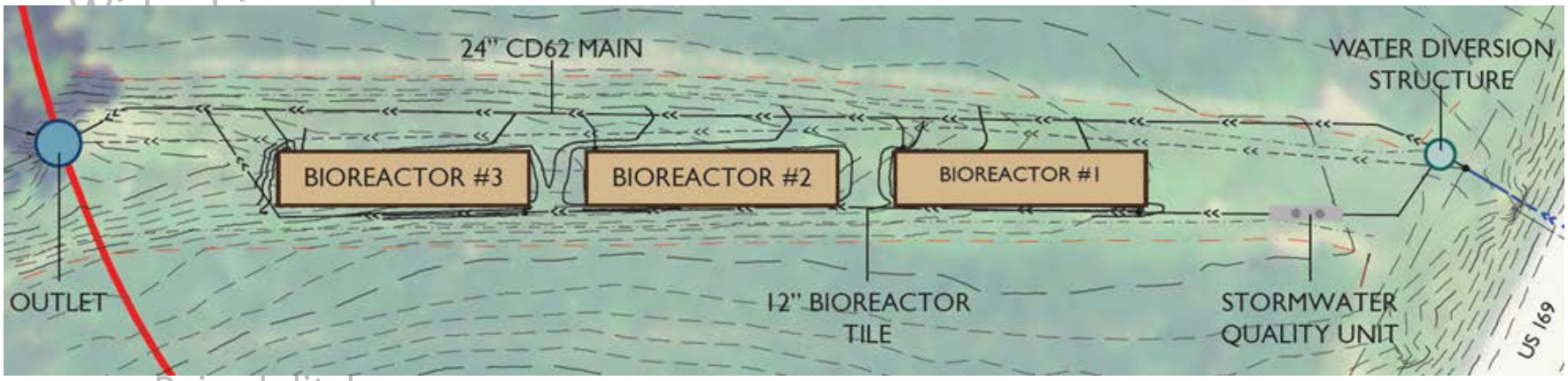
- Bioreactors operating in parallel during high flow

Faribault County, Minnesota
280 ha (700 ac) watershed



- Paired ditch designs

- Bioreactors designed for the small watershed-scale

- Each bioreactor is 41 x 7.6 x 1.5 m (135 x 25 x 5 ft)
- ≈$200,000
- ISG Consultants; Faribault County SWCD; G. Feyereisen

I could give you 100 bioreactor facts or… 1 emotion

Carol (3 years)
and
Sylvia (1.5 years)
Christianson

USDA
United States Department of Agriculture
National Institute of Food and Agriculture

USDA United States Department of Agriculture
Natural Resources Conservation Service

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

IWRC ILLINOIS WATER RESOURCES CENTER

ILLINOIS
College of Agricultural, Consumer & Environmental Sciences

ILLINOIS NREC

FFAR

ILLINOIS FARM BUREAU
Farm. Family. Food.™

The Fertilizer Institute
Nourish, Replenish, Grow

ADMC
Agricultural Drainage Management Coalition

Also: Dr. Richard Cooke; Illinois LICA; Peoria County SWCD; Christianson IDROP Water Quality Lab Team

Thank you for your time and interest in bioreactors.