THE CONSERVATION FUND

DENITRIFICATION 'WOODCHIP' BIOREACTORS FOR TREATMENT OF NITRATE

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Aquaculture Innovation Workshop
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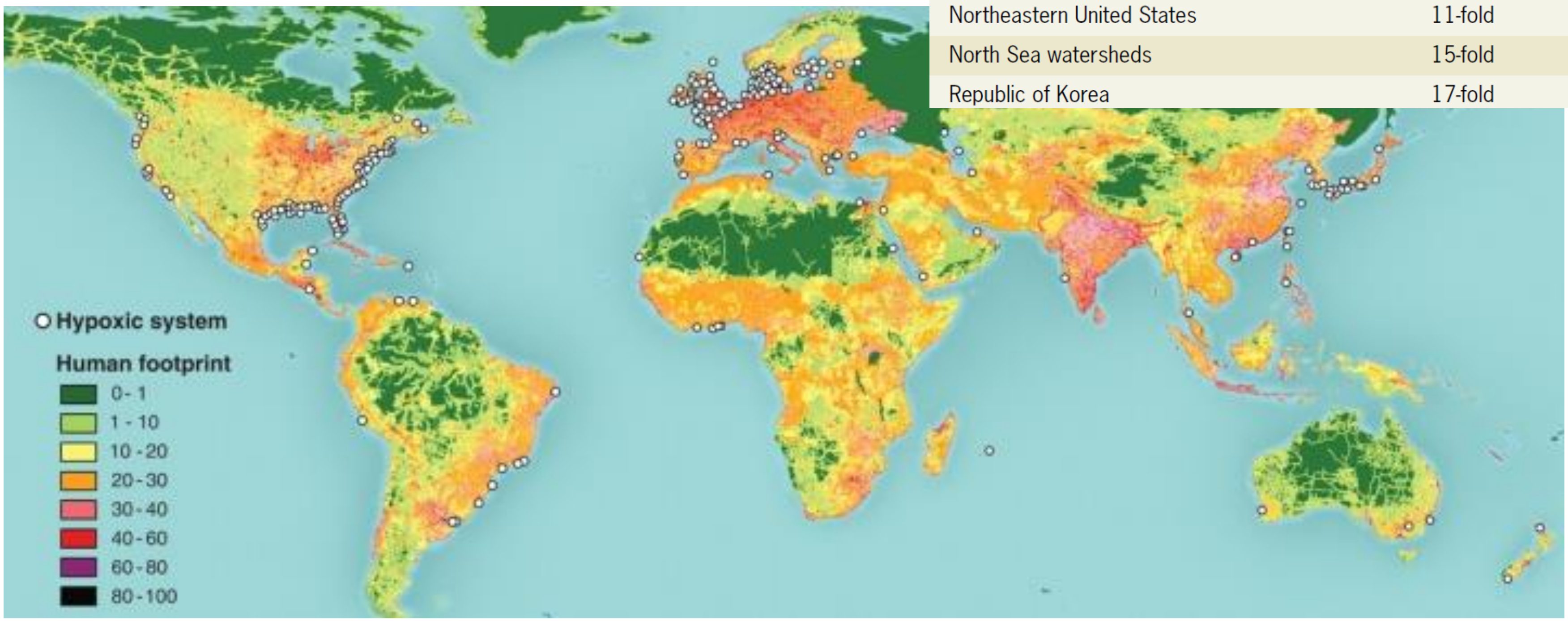
Wood-Based Enhanced-Denitrification

- Need to transform reactive nitrogen to reduce the global nitrogen cascade
  - Hypoxic zone
  - Human health

Table 4.1. INCREASE IN NITROGEN FLUXES IN RIVERS TO COASTAL OCEANS DUE TO HUMAN ACTIVITIES RELATIVE TO FLUXES PRIOR TO THE INDUSTRIAL AND AGRICULTURAL REVOLUTIONS (R9 Table 9.1)

Labrador and Hudson's Bay	no change
Southwestern Europe	3.7-fold
Great Lakes/St. Lawrence basin	4.1-fold
Baltic Sea watersheds	5-fold
Mississippi River basin	5.7-fold
Yellow River basin	10-fold
Northeastern United States	11-fold
North Sea watersheds	15-fold
Republic of Korea	17-fold

Millenium Ecosystem Assessment, 2005

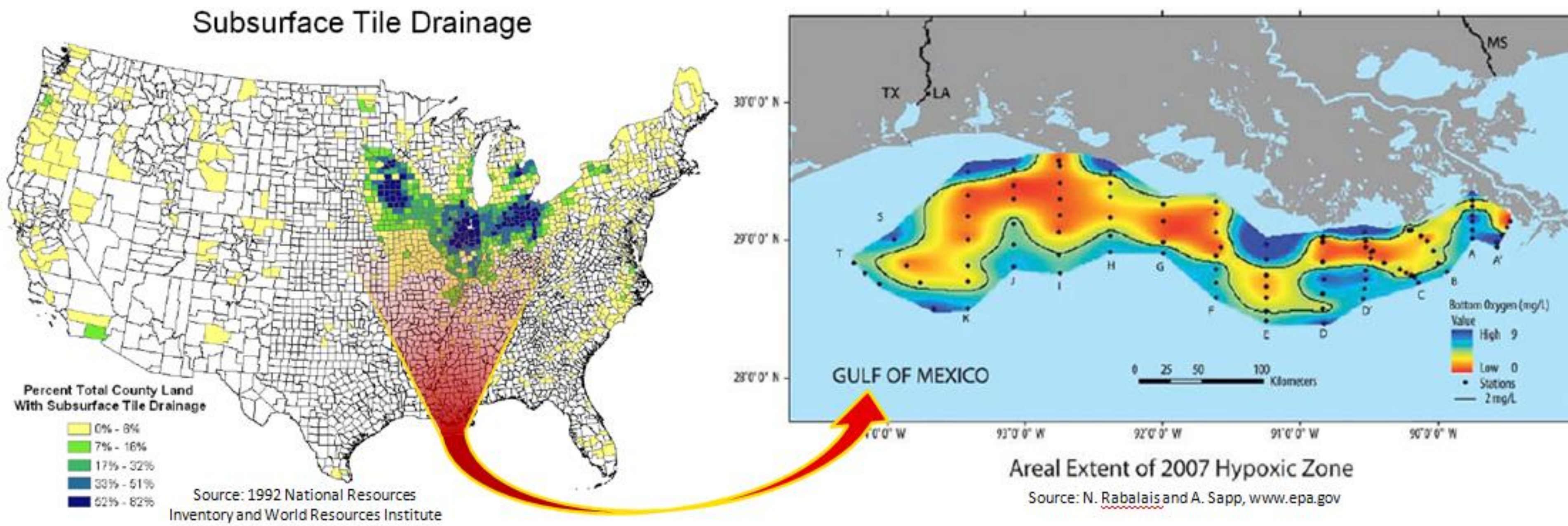


Diaz and Rosenburg, 2008

Wood-Based Enhanced-Denitrification

- Need to transform reactive nitrogen to reduce the global nitrogen cascade
  - Hypoxic zone
  - Human health
- Balance with food production

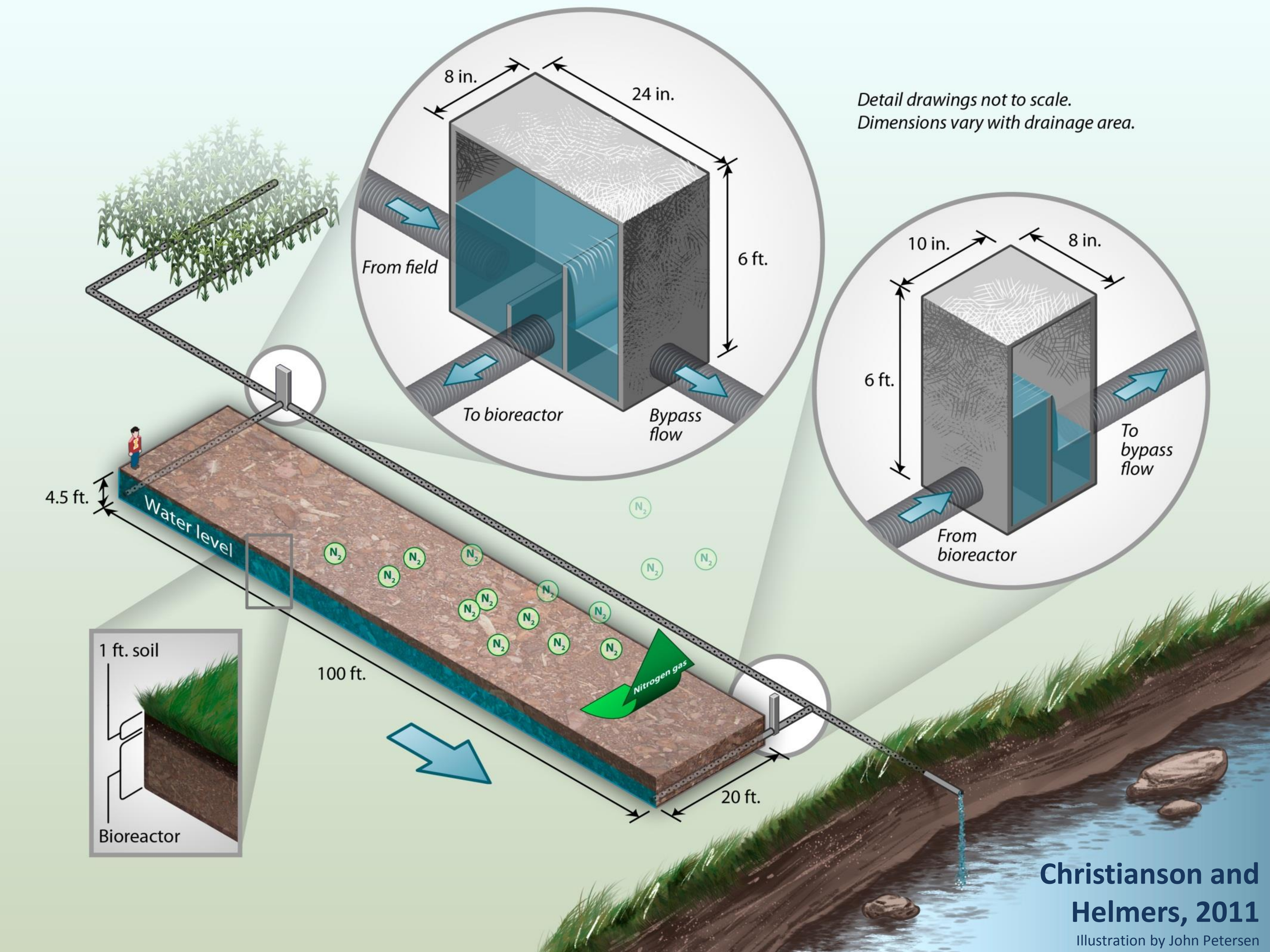
(Source: Matt Collins, Scientific American)



Wood-Based Enhanced-Denitrification

- Need to transform reactive nitrogen to reduce the global nitrogen cascade
  - Hypoxic zone
  - Human health
- Balance with food production
- Opportunity to enhance denitrification in the landscape
  - Carbon source
  - Anoxic conditions
  - Terminal electron acceptor: nitrate
- Novel wood-based designs in the 1990's

http://www. sciencedaily.com/releases/2010/11/101101151853.htm



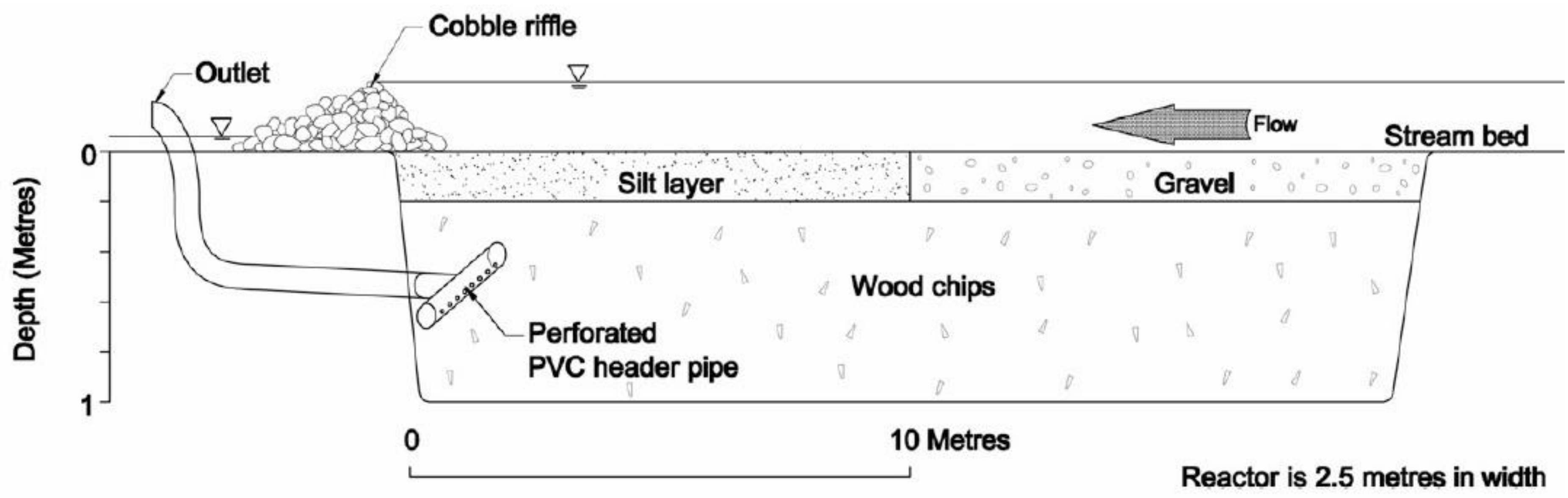
Christianson and Helmers, 2011

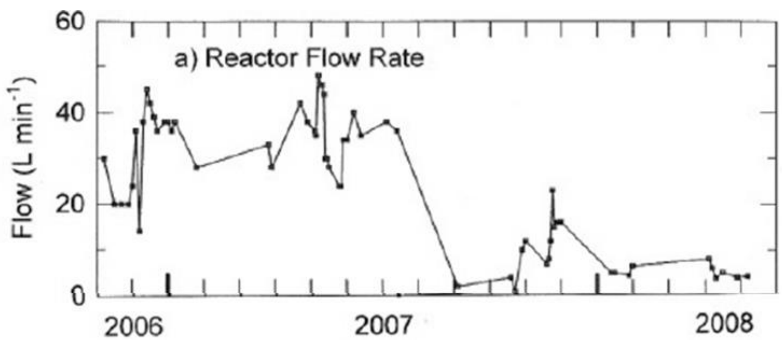
Illustration by John Petersen

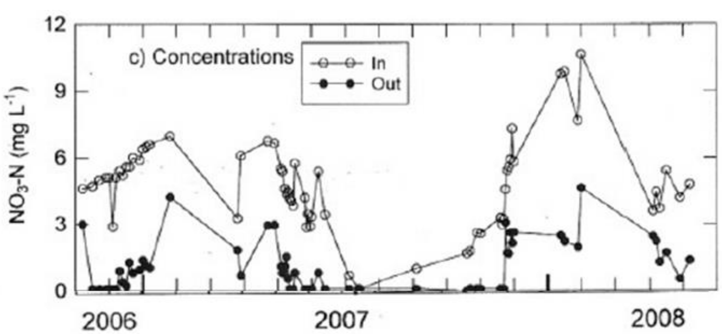
In-Stream Bioreactor for Agricultural Nitrate Treatment

W. D. Robertson* University of Waterloo
L. C. Merkley Upper Thames River Conservation Authority

Published in J. Environ. Qual. 38:230–237 (2009).







Other Wood-based Applications

Nitrate removal from three different effluents using large-scale denitrification beds

L.A. Schipper[a,*], S.C. Cameron[b], S. Warneke[a]

[a] Department of Earth and Ocean Sciences, University of Waikato, Private Bag 3105, Hamilt
[b] GNS Science, Taupo, New Zealand

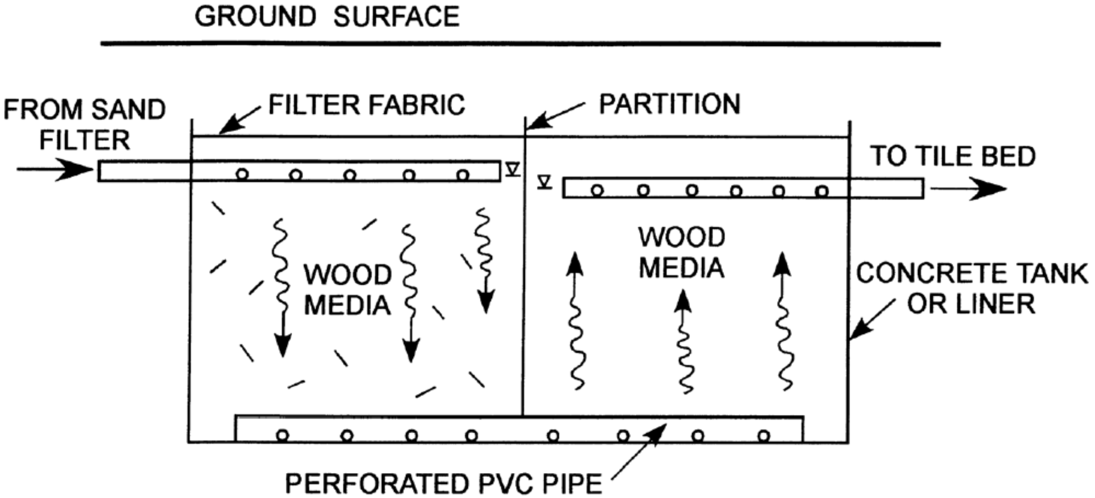
Ecological Engineering 36 (2010) 1552–1557

WOOD–BASED FILTER FOR NITRATE REMOVAL IN SEPTIC SYSTEMS

W. D. Robertson, G. I. Ford, P. S. Lombardo

Transactions of the ASAE

Vol. 48(1): 121–128



Aquacultural Application

Wood chips and wheat straw as alternative biofilter media for denitrification reactors treating aquaculture and other wastewaters with high nitrate concentrations

Willie Jones B. Saliling [b], Philip W. Westerman [a], Thomas M. Losordo [a,*]

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[b] Department of Agricultural and Biosystems Engineering, University of Southern Mindanao, Kabacan, 9407 Cotabato, Philippines

Aquacultural Engineering 37 (2007) 222–233

- Lab testing with synthetic aquaculture waste water
- Methanol added

Kaldnes media	Woodchips	Wheat Straw
1330±70 g N/m³-d	1360±40 g N/m³-d	1360±80 g N/m³-d

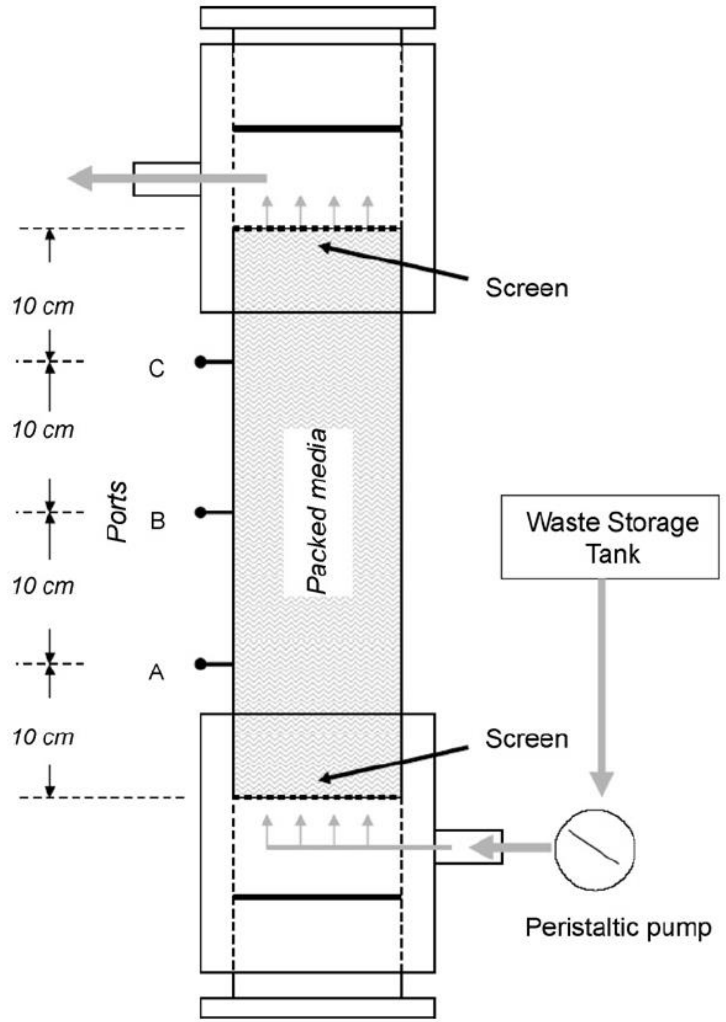

Fig. 1. Schematic diagram of an upflow packed bioreactor used in this study.

Three drainage bioreactors in Iowa

Bioreactor	Location	Installed	Drainage Area (ha)	Design Flow Rate (gpm)	L x W x D (m)	Vol. (m^3)	L:W
Greene Co.	Central Iowa	Aug. 2008	19.0 (47 ac)	90-130 gpm	15.2 x 7.6 x 1.1	127	2.0
Hamilton Co.	Central Iowa	June 2009	20.2 (50 ac)	40-90 gpm	30.5 x 3.7 x 0.9	102	8.3
Research Farm	Northeast Iowa	April 2009	14.2 (35 ac)	20-70 gpm	36.6 x 2.4 (bottom) x 1.0	128	15.3

Christianson et al., 2012 (*Trans. ASABE*)

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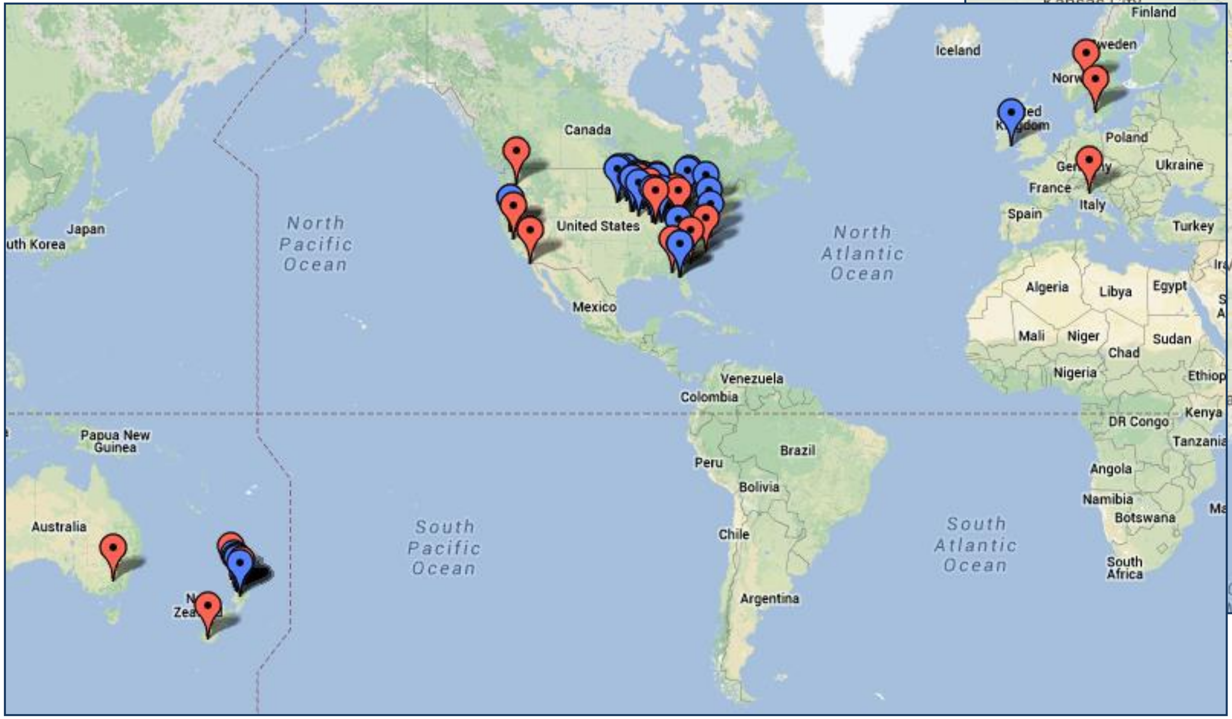
Christianson et al., 2012 (*Trans. ASABE*)

Where have wood-based enhanced-denitrification technologies been used?

http://www.artificialnsinks.org/

Legend:

Constructed wetlands (red marker) Denitrifying Bioreactors (blue marker)



Wood-based Denitrification Performance

Source	Site	Influent NO_3^--N Conc.	Percent Reduction	Nitrate-N Removal Rate
van Driel et al., 2006	Ontario, Canada	11.8 mg/L	--	2.5 g $N/m^2/d$
Jaynes et al., 2008	Central Iowa	19.1 to 25.3 mg/L	40% - 65%	0.62 g $N/m^3/d$
Woli et al., 2010	East-Central Illinois	2.8 to 18.9 mg/L	23% - 50%	6.4 g $N/m^3/d$
Christianson et al., 2012	Central Iowa	1.2 to 8.5 mg/L	22% - 74%	0.4-3.8 g $N/m^3/d$
Christianson et al., 2012	Northeast Iowa	9.9 to 13.2 mg/L	12% - 14%	0.9-1.6 g $N/m^3/d$
Christianson et al., 2012	Central Iowa	7.7 to 15.2 mg/L	27% - 33%	0.4-7.8 g $N/m^3/d$
Christianson et al., 2012	Central Iowa	7.7 to 9.6 mg/L	49% - 57%	0.4-5.0 g $N/m^3/d$

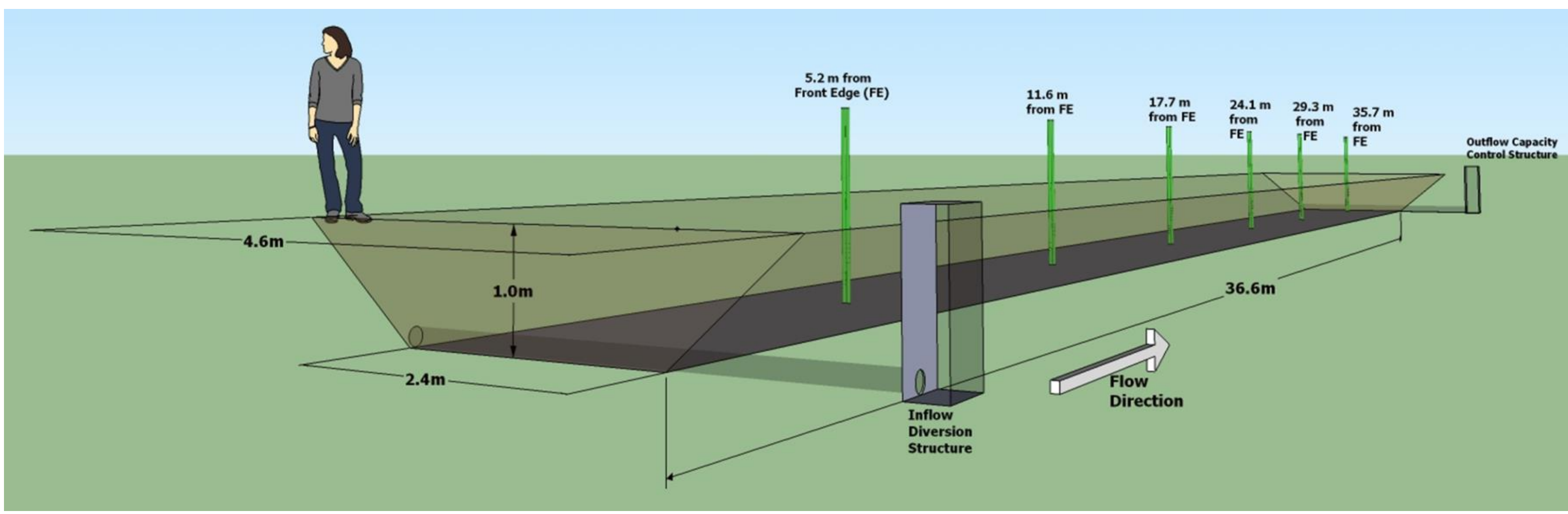
Christianson et al., 2012 (*Applied Eng. In Ag.*)

Factors affecting nitrate removal

Christianson et al., 2013
(*Eco. Eng. 52: 298-307*)

Sample Date	Flow rate (L min^{-1})	Retention time* (hours)	Water temp. (° C)	Inlet DO (mg/L)	N load reduction (% Mass)
May 17	43	5.3	8.9	3.39	10.8
May 30	59	4.1	10.1	6.27	7.16
June 29	46	4.6	13.9	5.77	11.1
July 28	6.0	22	16.9	4.97	69.5
August 24	2.9	44	17.1	2.65	100.0

*Modified based upon conservative tracer testing



Why woodchips?

- Many organic carbon sources have been trialed:
  - Shredded newspaper
  - Cardboard fibers
  - Almond and walnut shells
  - Barley straw
  - Wheat straw
  - Corn cobs
  - Corn stover
  - Date palm leaves
  - Rice husks
  - Pine bark
  - Pine needles
  - Mulch/compost/green waste
- Woody media:
  - Low cost
  - Physical, chemical, and biological properties
  - Durability



http://www.gardeningblog.net
http://news.cals.wisc.edu/energy/2011/11/16/forage-know-how-gives-wisconsin-farmers-an-edge-in-growing-biomass/
http://www.notimeforflashcards.com/2009/11/walnut-shell-turtles.html
http://www.ohnuts.com/buy.cfm/bulk-nuts-seeds/almonds/raw-in-shell
http://www.needhamag.com/innovative_product_sales/residue_management_solutions.php
http://www.delange.org/PalmPhoenix/PalmPhoenix.htm
http://green-earth-aerogel.es/photos.htm
http://www.mushroomsource.ca/shredded-cardboard-for-mushrooms.html

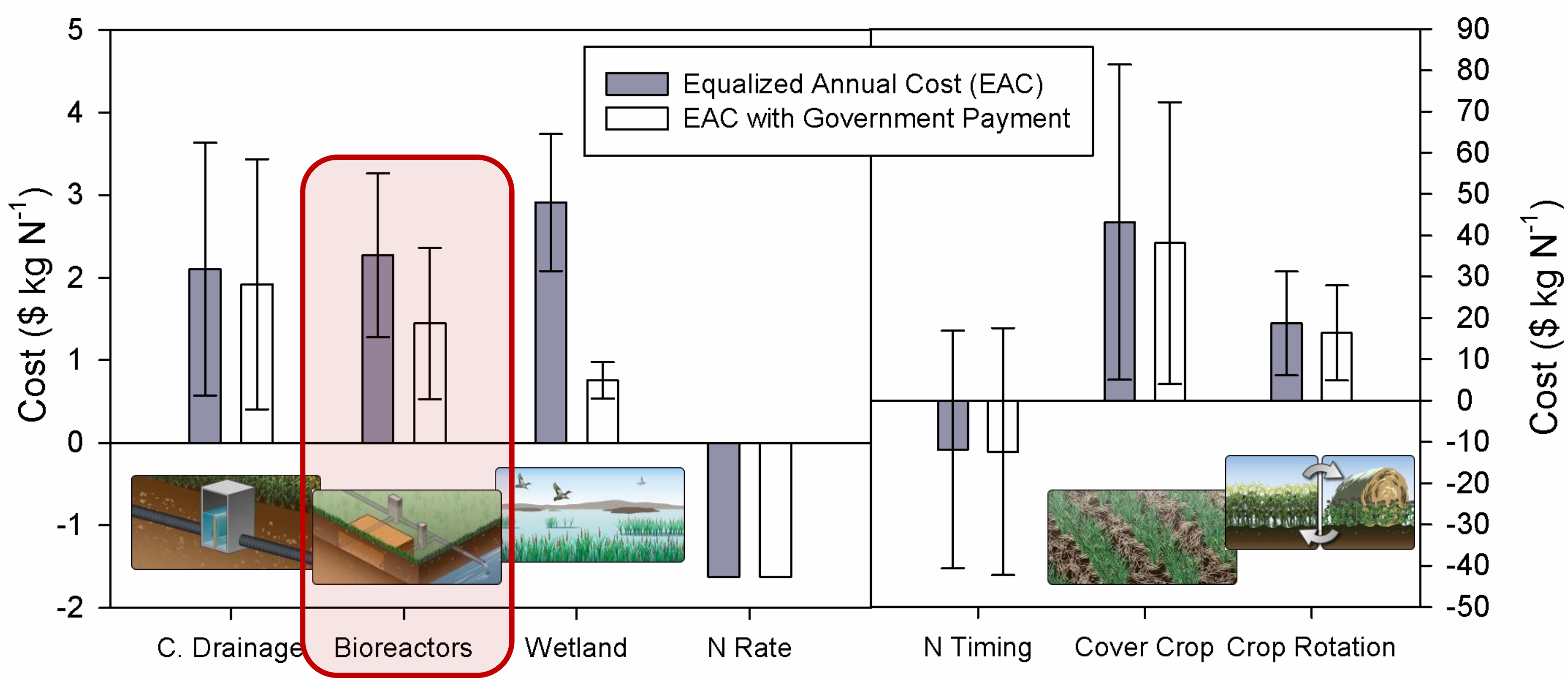
What do bioreactors cost?

	Structure	Contractor	Woodchips	Supplies	Total	$ total/ha drained
Greene Co.	$2,750.00	$5,250.00	$1,245.00	$500.00	$9,745.00	$512.35
Hamilton Co.	$1,640.00	NA†	$2,400.00	$350.00	$4,390.00	$216.96
Iowa 1	$1,970.00	$1,800.00	$3,350.00	$560.00	$7,680.00	$316.30
Iowa 2	$1,270.00	$1,890.00	$3,000.00	$780.00	$6,940.00	$428.73
Iowa 3	$1,640.00	$5,030.00	$4,650.00	$500.00	$11,820.00	$194.72
Iowa 4	$1,480.00	$2,710.00	$2,520.00	$400.00	$7,110.00	$585.64

†contractor time donated

Christianson et al., 2012 (*Trans. ASABE*)

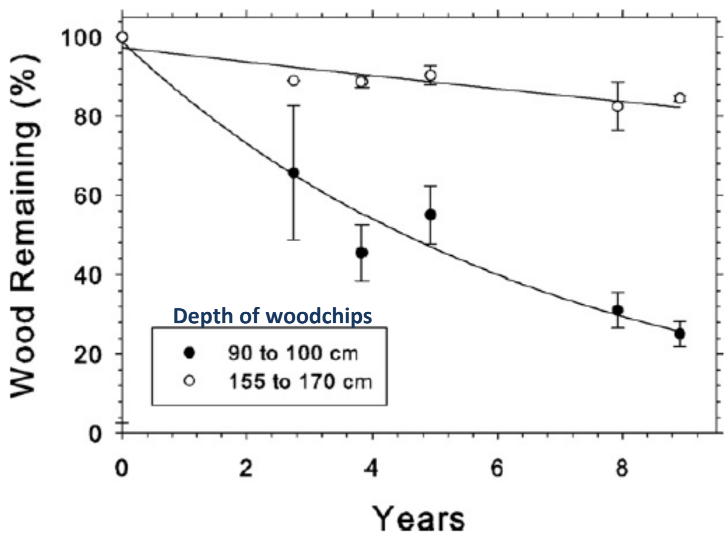
Average: $152.07/ac



Christianson, 2011

What is the life?

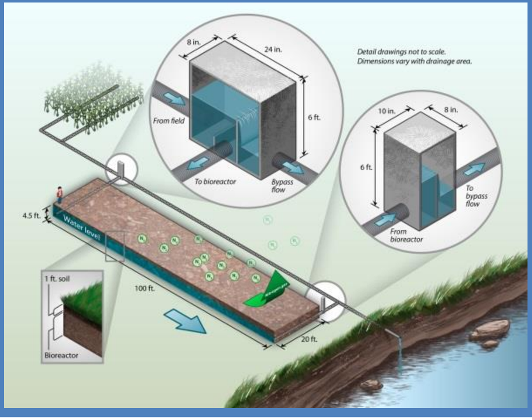
- Life estimated at 10 to 20 years
- Stoichiometric estimates: 20 to >50 yrs
- Empirical evidence:
  - Robertson et al., 2008: 15 yr septic treatment wall
  - Long et al., 2011: 14 yr sawdust groundwater wall
  - Moorman et al., 2010: 9 yr woodchip drainage wall

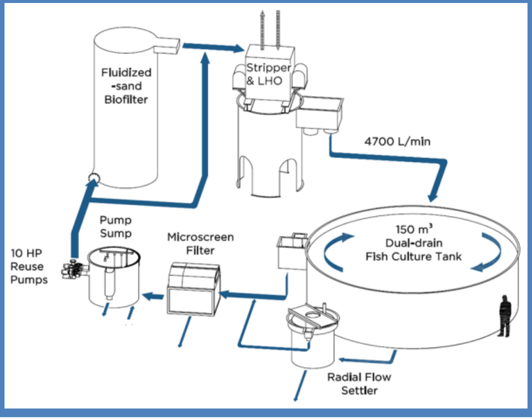


Moorman et al., 2010

http://smithmeadows.com/farm/daredevil-farming-3/

Woodchip Bioreactors for TCFFI Effluent Treatment





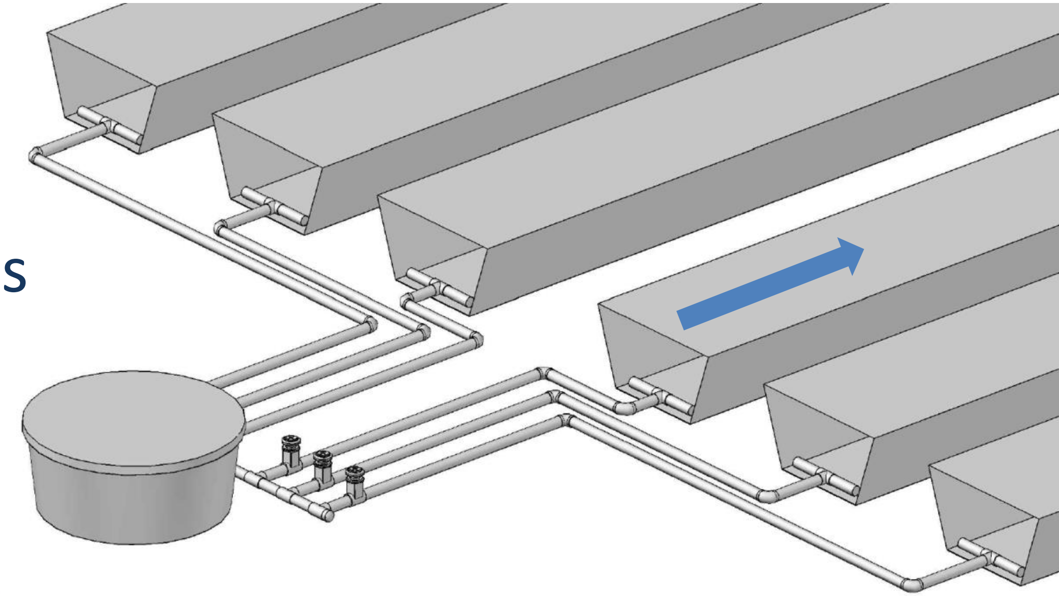
	Typical tile drainage[1]	Typical aquaculture effluent at TCFFI[2]
Flow rate (Design flow rate)	≈360 gpm (30-80 acres) (Design: 60 gpm)	≈300 gpm (Design: 60 gpm)
Nitrate-N	10-20 mg NO_3-N/L (average range)	1-5 mg NO_3-N/L (average range)
Temperature	<3 (winter) - >15°C (summer)	11.6-15.5°C
Dissolved oxygen	<3 (summer) - >8 (winter) mg DO/L	8.2-10.9 mg DO/L
Total susp. solids	<1 mg TSS/L	<1 - 10 mg TSS/L
BOD	2 mg BOD/L	1.4 – 8.2 mg BOD_5/L

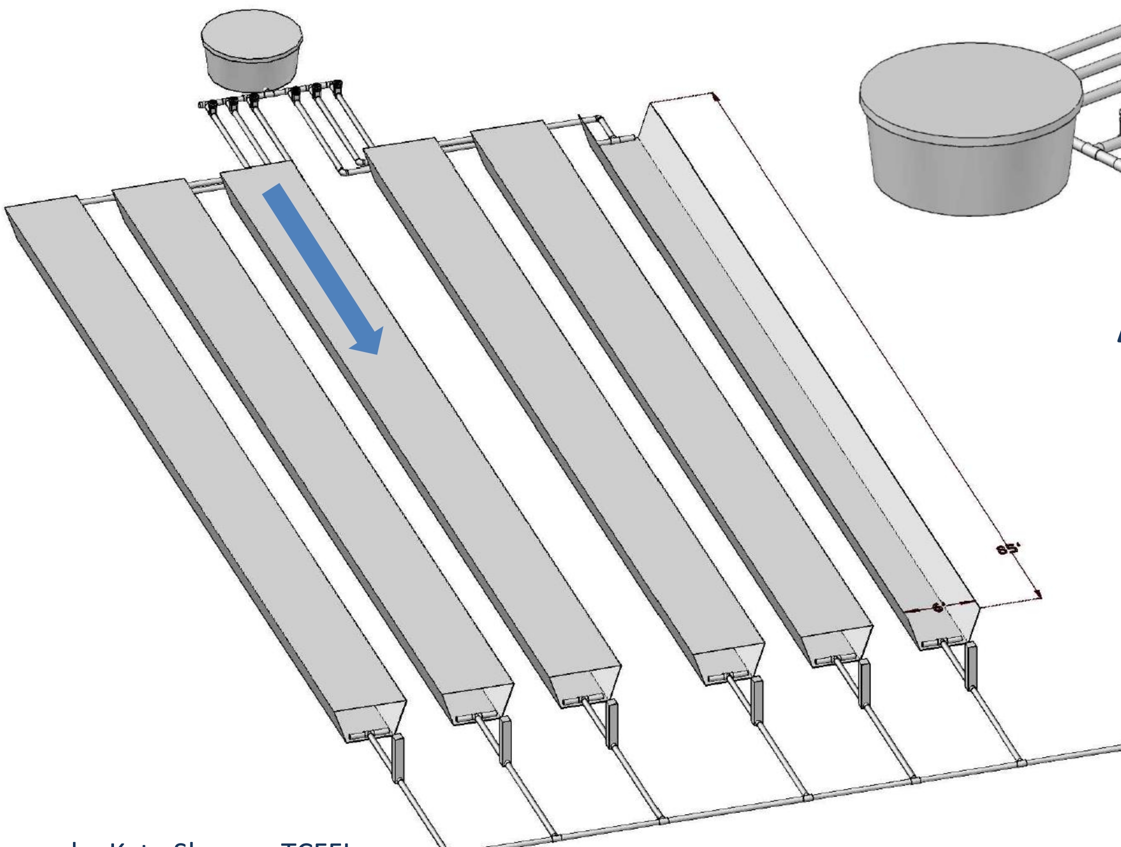
[1] From Christianson et al. (2012) and van Driel et al. (2006)
[2] From Per. Comm. Karen Shroyer; Davidson et al. (2008); Summerfelt et al. (2013)

Woodchip Bioreactors for TCFFI Effluent Treatment

Replicated design

- 26 x 1.8 (top) x 0.91 m
- Constant head tank
- Outlet control structures





Ability to test

- Different hydraulic retention times
- Media longevity
- Start-up flushing losses
- Coliform transport and fate
- P removal design options

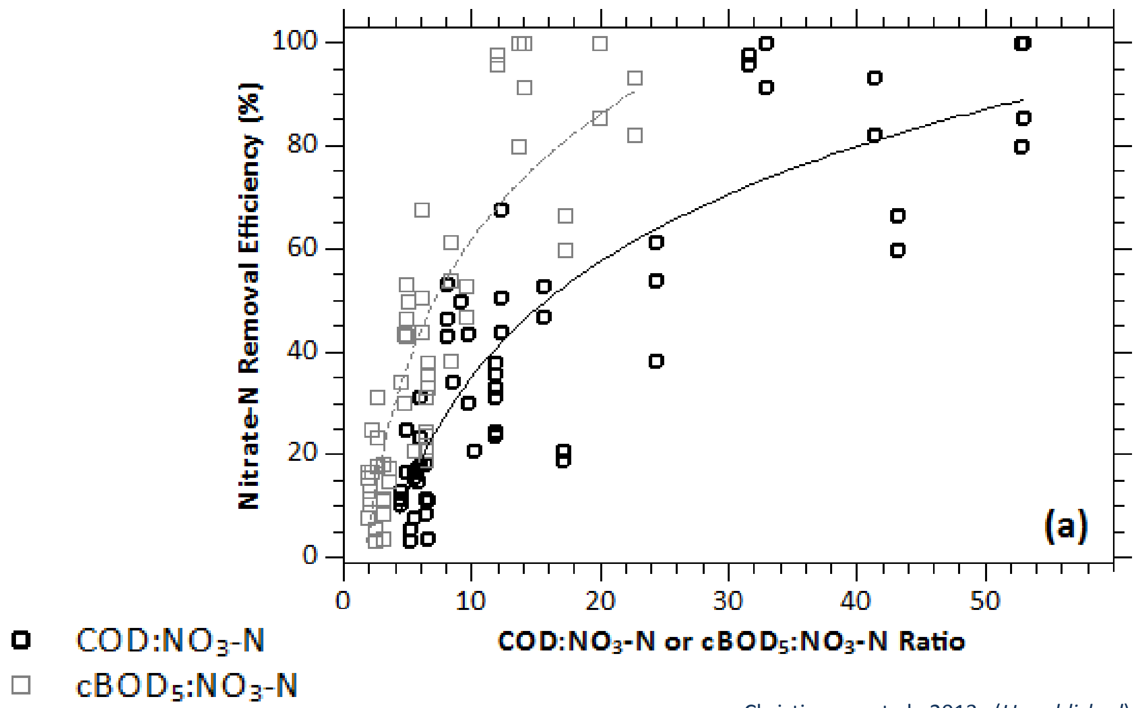
Drawn by Kata Sharrer, TCFFI

Other TCCFI Research on Novel Denit. Technologies

Fluidized Biofilters: Phase I

Sand and endogenous carbon source

- 27% NO_3-N removal treating effluent
- 402 g NO_3-N/m^3 biofilter-dy



Christianson et al., 2013a (*Unpublished*)

Other TCCFI Research on Novel Denit. Technologies

Fluidized Biofilters: Phase II

Sulfur-based autotrophic denitrification

- Reduced sulfur as the electron donor
- Preliminary work evaluating a range of elemental S particles sizes

$$1.0\,NO_3^- + 1.10S + 0.40CO_2 + 0.76H_2O + 0.080NH_4^+ \rightarrow 0.080C_5H_7O_2N + 0.50N_2 + 1.10SO_4^{2-} + 1.28H^+$$

Christianson et al., 2013b (*Unpublished*)

Acknowledgements

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  - Agriculture's Clean Water Alliance
  - The Sand County Foundation
- Coldwater Palmer Watershed Association

More information

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