

Denitrification in Engineered Systems: Applications, methods, modeling challenges

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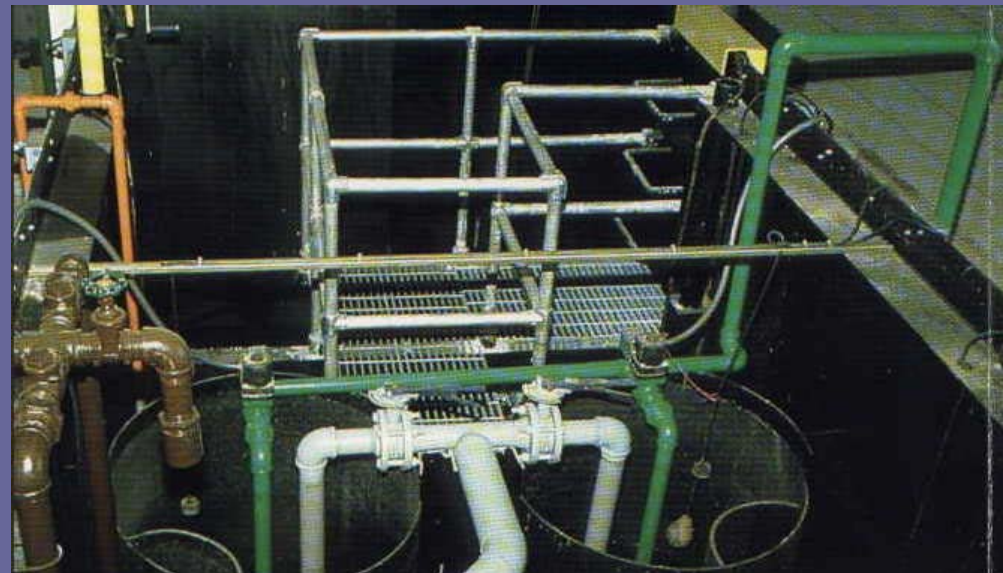
(Presented at: NSF Denitrification Research Coordination Network,
Denitrification Modeling Workshop. Nov 28-30,2006, Millbrook, NY)

Landscape Applications

- Groundwater Renovation:
 - Denitrification Walls
- Wastewater Treatment Wetlands
- Onsite Wastewater Disposal Systems (septic system applications)
- Agricultural Subsurface Drains
 - Controlled Drainage
 - Denitrification Barriers

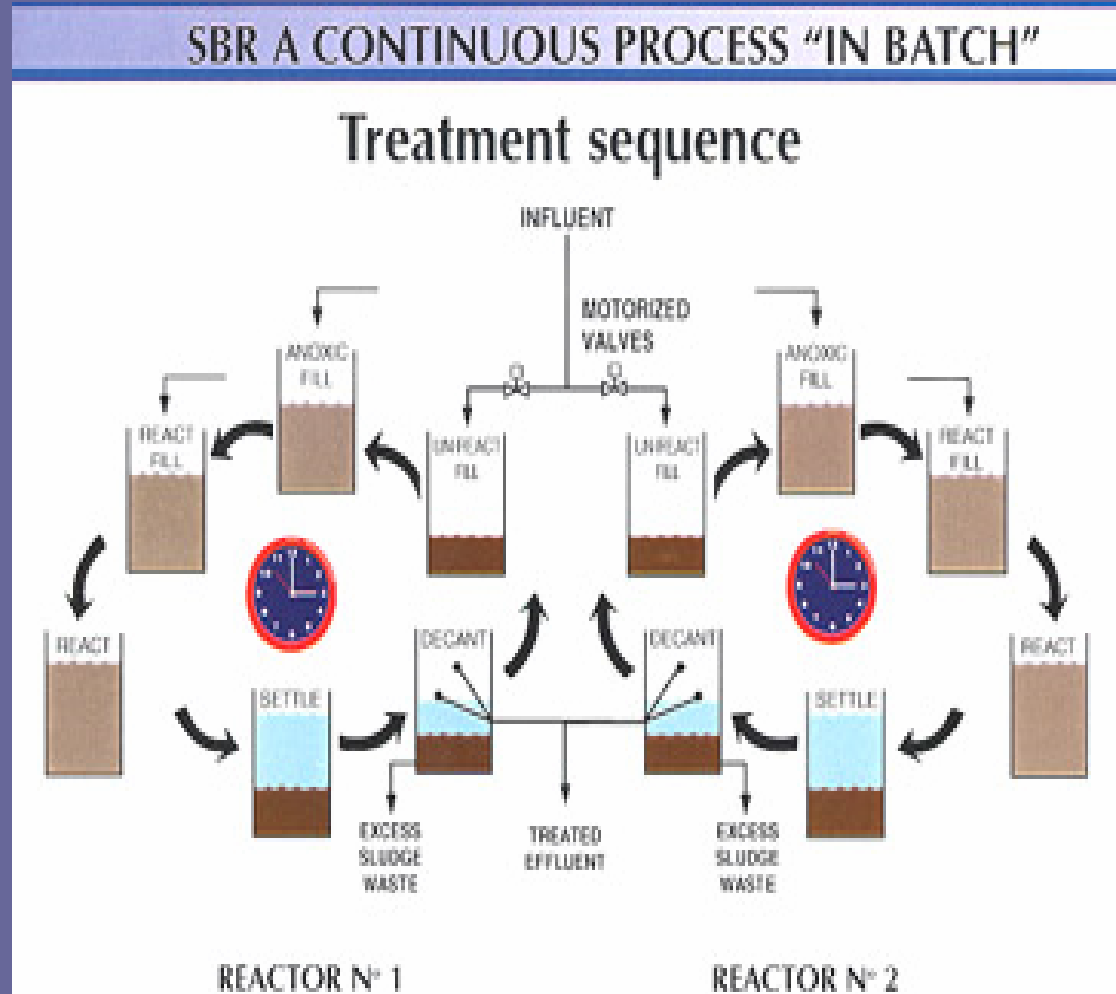
Modeling Classic Engineered Systems

- Controlled Pretreatment
- Well Defined Treatment Environments
 - Attached Growth Processes
 - Suspended Growth Processes
- Inputs well characterized
 - NO_3 Concentrations and Loading
 - Form and Dosing of Electron Donor

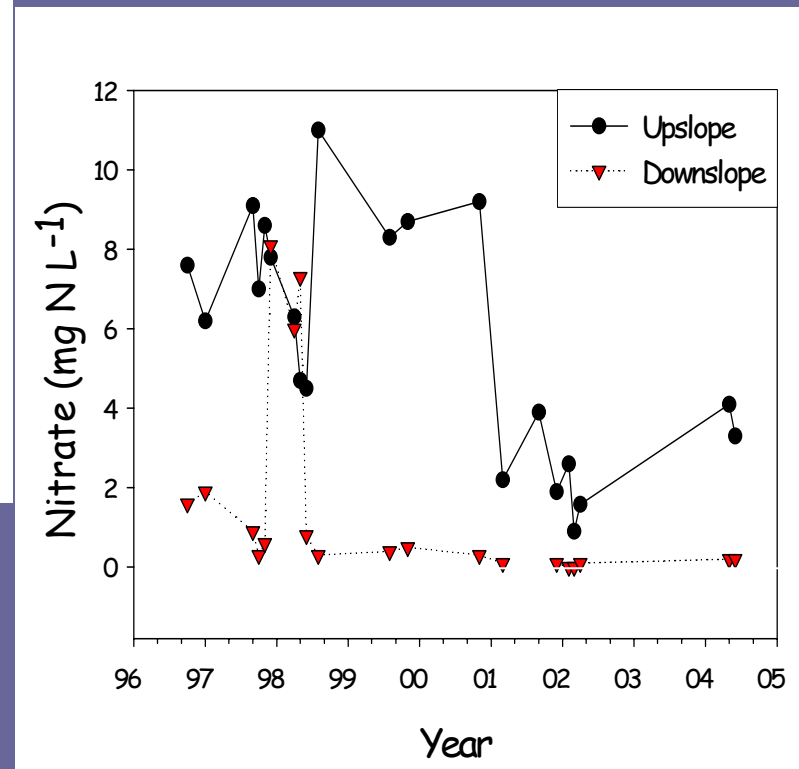
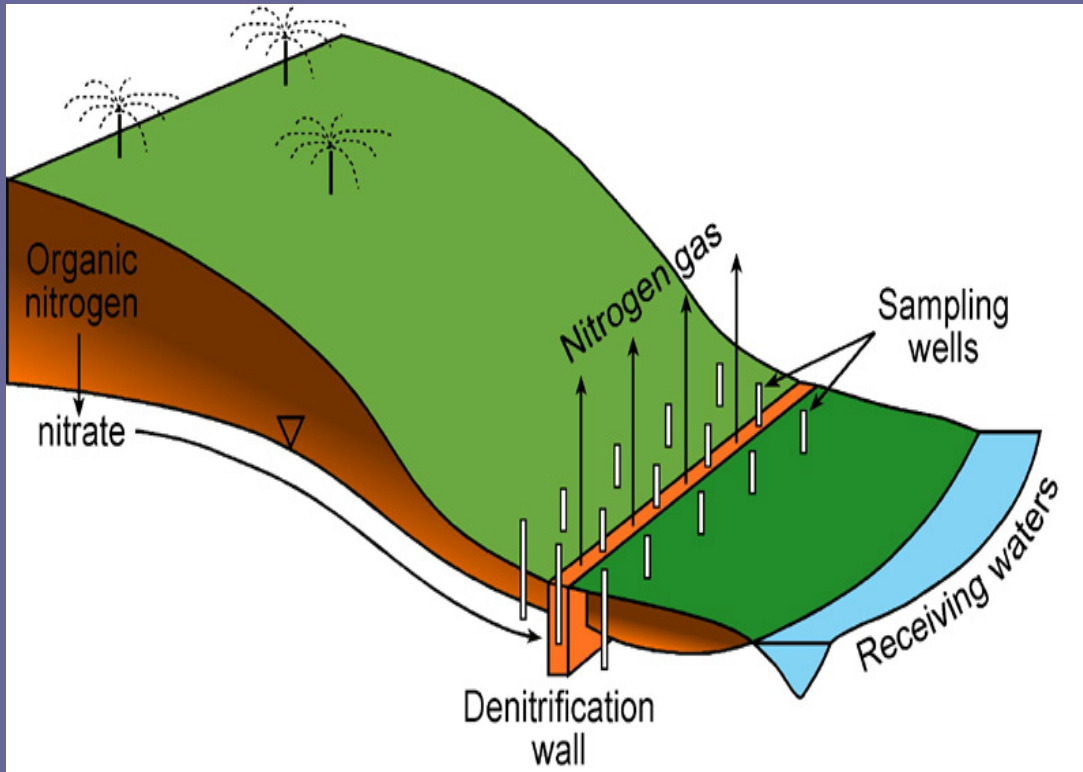


Controlled treatment environment

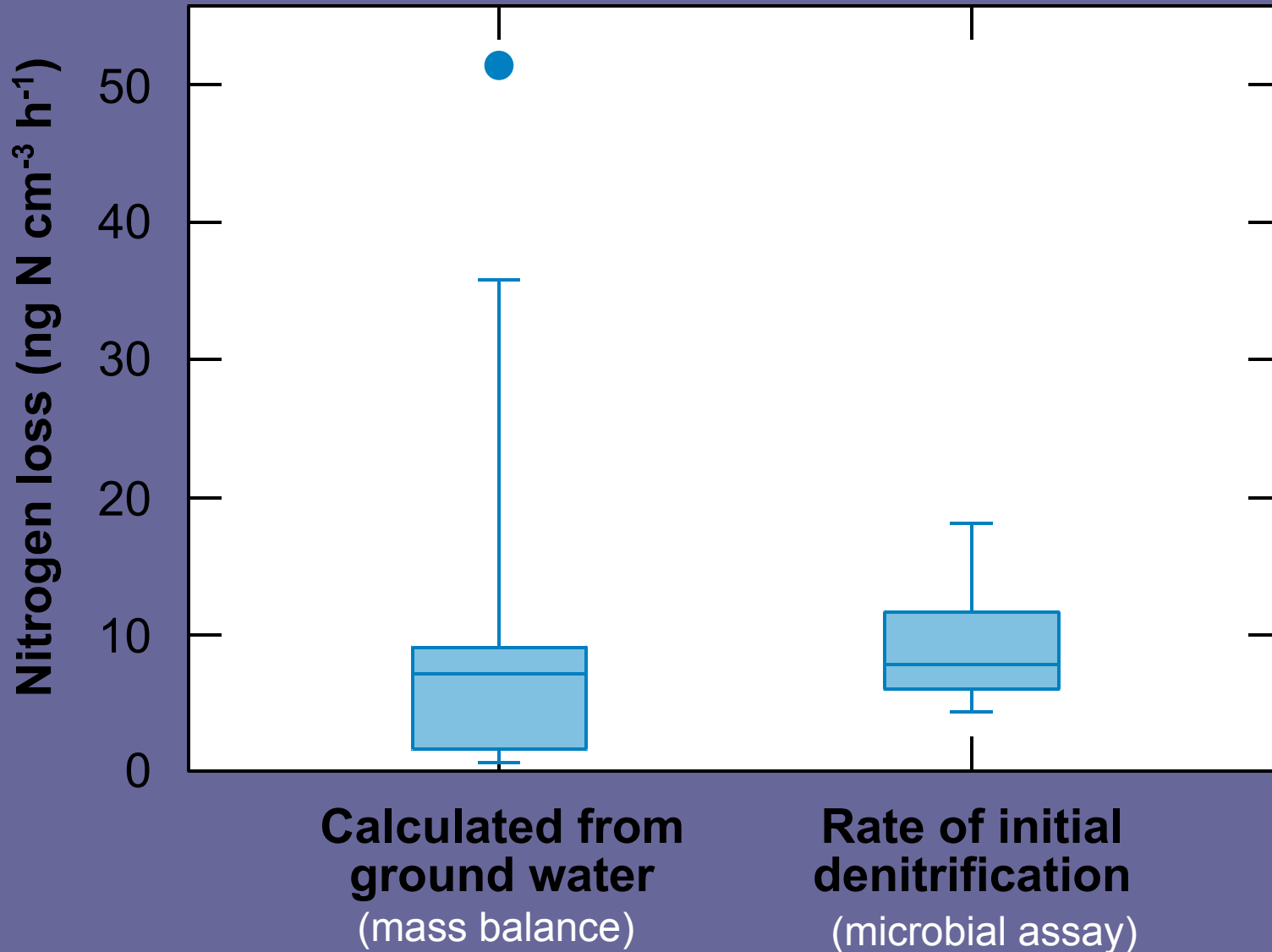
- Regulated flowpath and retention times
- Real time, component-based diagnostics



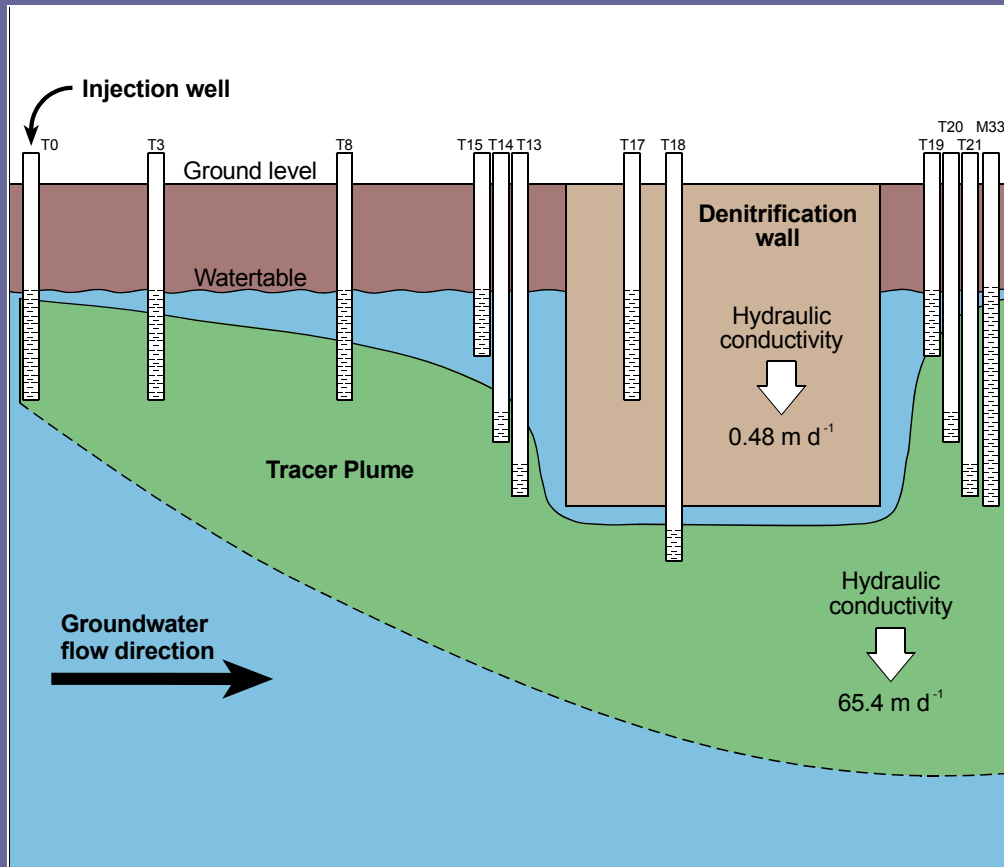
Denitrification walls: 60- 96% decline in NO_3 concentration (Robertson and Cherry, 1995; Schipper and Vojvodic-Vukovic, 1998)



Role of denitrification in Initial Experimental NZ Site

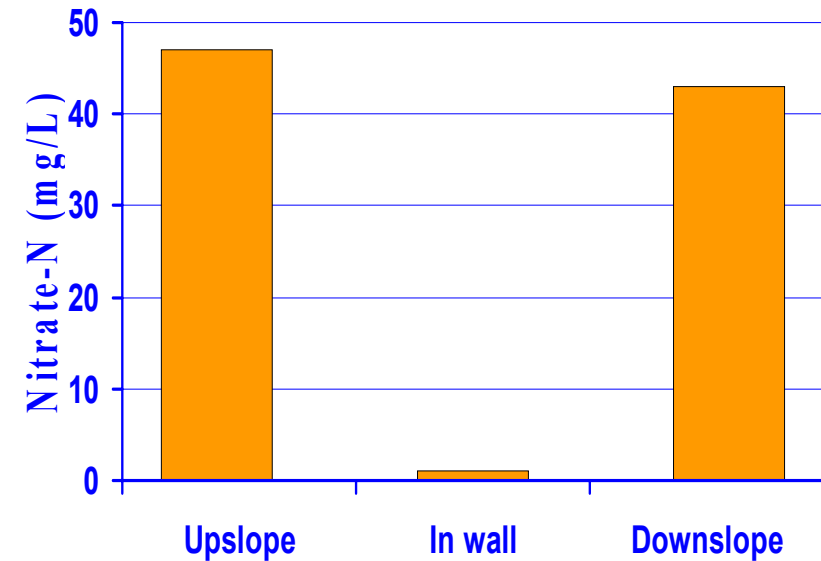


Hydrologic complexities (flowpaths):



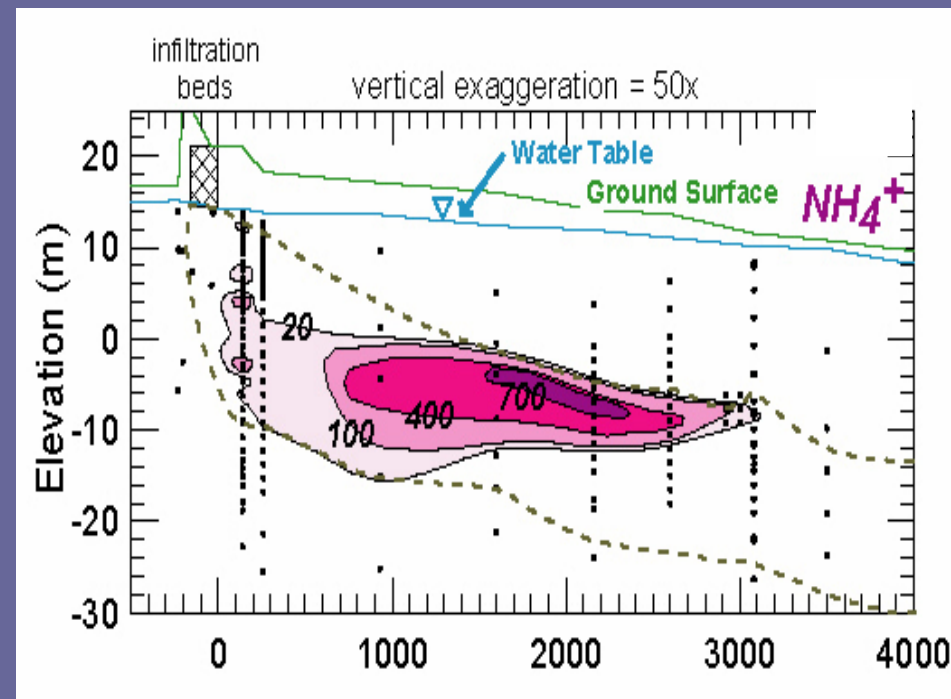
Nitrate plumes can bypass wall ecosystem

Source: Schipper and Barkle



Hydrology and Site Constraints Limit Capacity to Generalize Denitrification Wall Models

- Construction constrains wall depth to upper 1 – 1.5 m of groundwater
 - Many nitrate plumes move at deeper depths
- Plumes are often narrow
 - **Piezometers** in Waquoit Bay **10 meters apart**:
25 fold differences in nitrate concentrations
(Source: Lomardi Assoc.)



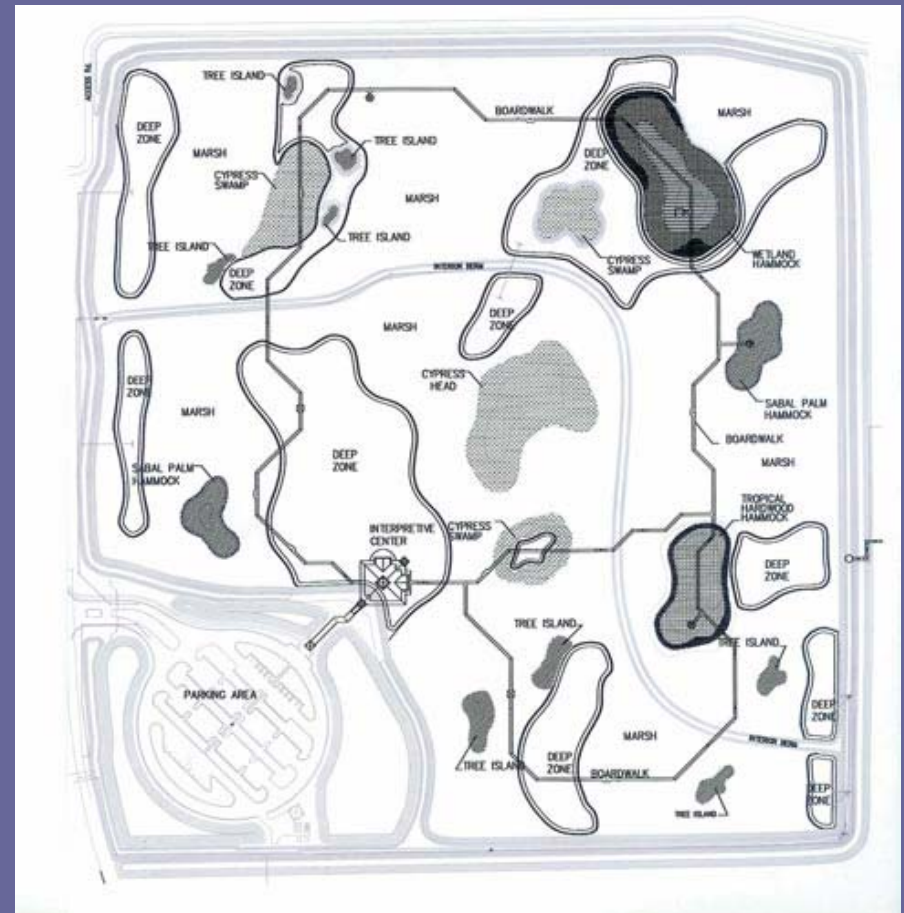
Source: Bohlke et al. 2006

Modeling Denitrification Walls

- Denitrification rates remain high for > 8 years (Source: empirical data)
- Darcian flow estimates (aquifer property maps) and dimensions provide retention time
- Nitrate loading rates: Very site specific
 - Less uncertainty in aquifers with shallow aquicludes

Wastewater Treatment Wetlands: Complex systems, varied designs

- Nitrification models required for anoxic primary effluent
- Attached Growth WW Treatment models often used
- But ... multitude of subsystems, retention times, flow paths and processes “overwhelm” assumptions for tank devices. (Kadlec and Kadlec, 1996)



Monod Wetland Nitrification Model

J_{NITR} = Nitrification Rate (gm NH₄-N m⁻² yr⁻¹)

$$J_{\text{NITR}} = U_{\text{NITR}} * V_{\text{NITR}}$$

U_{NITR} = Nitrification rate (gm NH₄-N gm⁻¹ yr⁻¹)
= Growth rate * Yield⁻¹

Yield = gm nitrifiers per gm NH₄-N nitrified

Growth rate = f ([NH₄-N]; T; DO; Alkalinity; pH)

***** Calibration to treatment wetland data has not been attempted.**

V_{NITR} = Effective nitrifier mass per area (gm m⁻²)

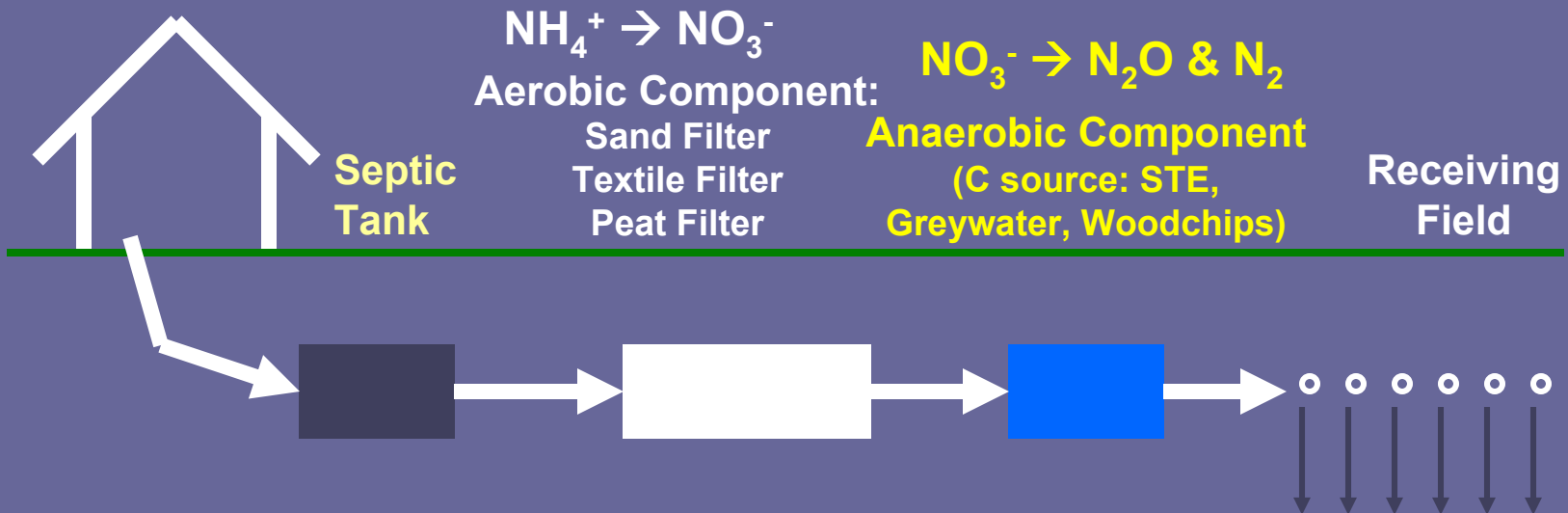
***** Difficult to obtain, little data; one average estimate of 0.05 gm m⁻².**

(Kadlec and Kadlec, 1996)

Wetland Treatment Models

- New paradigms needed to describe short-circuiting and spatial distributions of vegetation and multitude of N transformation processes. (Bastviken, 2006)
- Current models focus on empirically derived first-order NH_4^+ and NO_3^- “disappearance”

Simplified Onsite Wastewater Treatment Train: “Denitrification” System



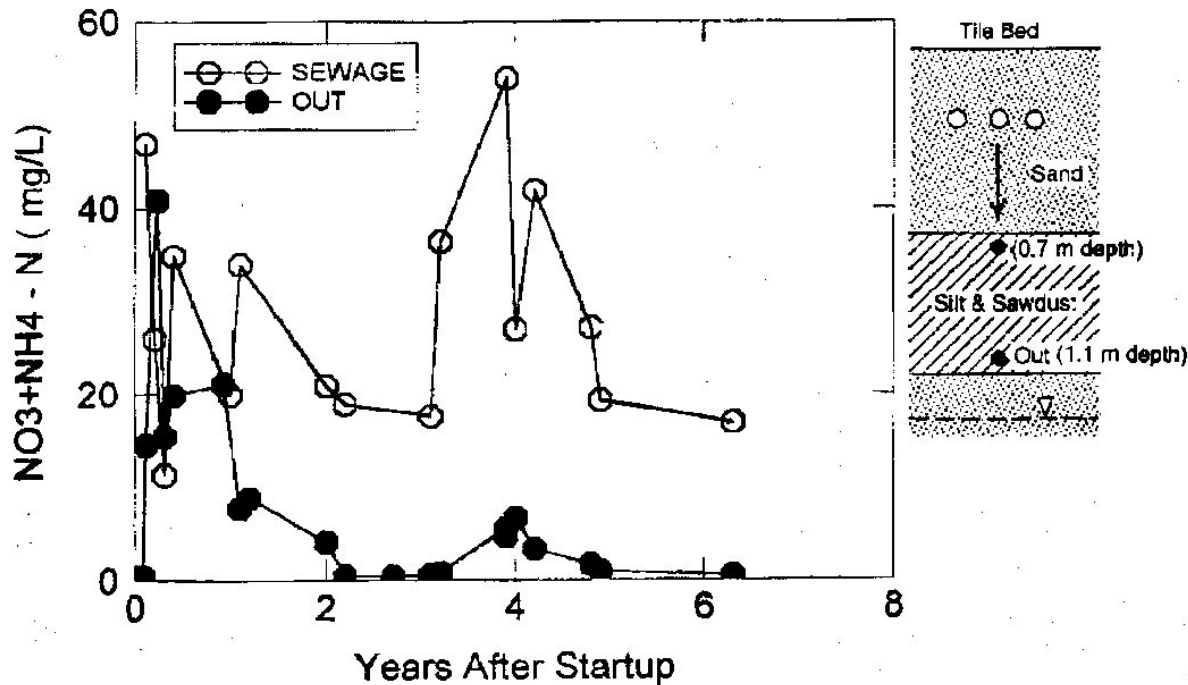
- Long term removal = 40 – 85% of TN
- Most removal likely to be denitrification
 < 5% TN remains in septic tank sludge

Horizontal beds Septic tank effluent

Robertson et al., 2000
University of Waterloo

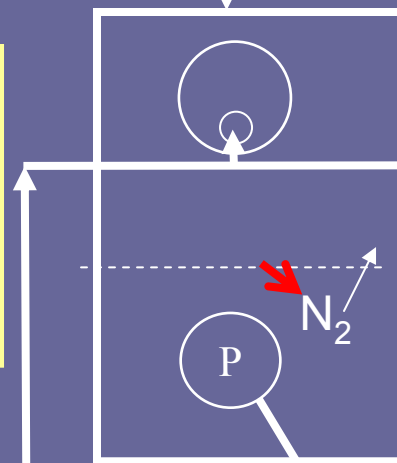


b) Borden Layer



Household Influent
(O-N, NH₃, NH₄⁺)

Recirculation
Septic Tank
(Nitrified effluent
mixes with anaerobic
influent)



Pressurized Drainfield

P

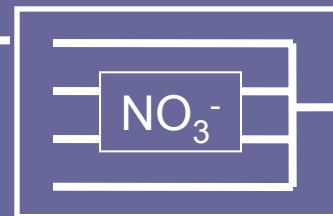


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N₂

TN removal: 30 – 60%; Multiple constraints

Final effluent dominated by either NH₄ (lack of nitrification) or NO₃.



Media Filter (Aerobic)

Loomis et al., 2005

Septic Tank serves as C source, denitrification zone

Septic System Denitrification:

Suited for Empirical Models??

- Treatment environment and waste stream well defined
- Sensors and pumps can regulate flows and retention times
- Monitoring studies limited to evaluation tests – even those generate data suitable for Black Box Models. Lack of data isolating input and output characteristics of individual components.

Summary

- Denitrification models in many engineered landscape systems are confounded by uncertainty surrounding factors associated with classic WW treatment:
 - Complex vs. well defined systems
 - Complex vs. well defined flowpaths and retention times
 - Sporadic vs. real-time diagnostic monitoring and management

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