Model Analysis of Riparian Buffer Effectiveness for Reducing Nutrient Inputs to Streams in Agricultural Landscapes

Bob McKane[1], Bonnie Kwiatkowski[3], Marc Stieglitz[2], Feifei Pan[2], Ed Rastetter[3]

[1]*USEPA Western Ecology Division,* [2]*Georgia Institute of Technology,* [3]*Marine Biological Laboratory*

AGU 2006 Fall Meeting
Poster H41D-0435

Objectives

We developed a broadly applicable, process-based watershed simulator that links a spatially-explicit hydrologic model and a terrestrial biogeochemistry model. See Stieglitz et al. and Pan et al., Cheng et al. and Abdelnour et al. at this meeting, for details on the design and verification of this simulator.

Here we apply the watershed simulator to a generalized agricultural setting to demonstrate its potential for informing policy and management decisions concerning water quality. This demonstration specifically explores the effectiveness of riparian buffers for reducing the transport of nitrogenous fertilizers from agricultural fields to streams.

Questions

The interaction of hydrologic and biogeochemical processes represented in our watershed simulator allows several important questions to be addressed:

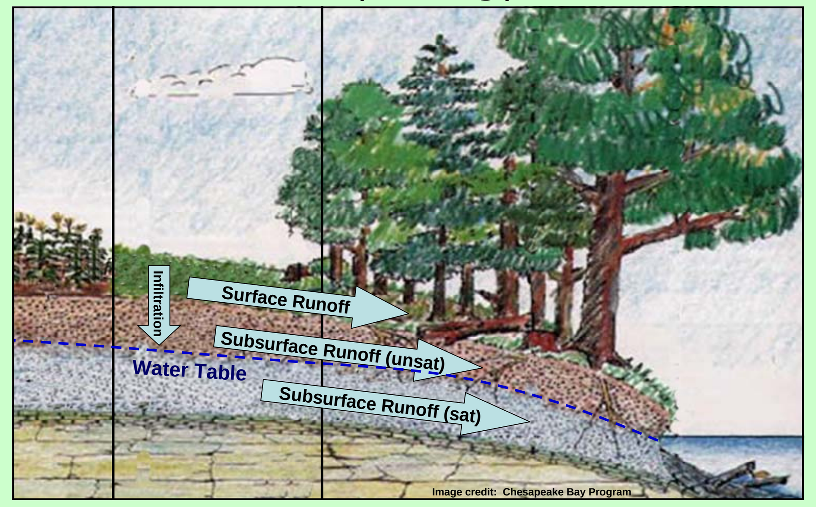
(1) *For a range of upland fertilization rates, to what extent do forest riparian buffers reduce nitrogen inputs to streams?*

(2) *Does buffer effectiveness change over time as the plant-soil system approaches N-saturation?*

(3) *How can buffers be managed to increase their effectiveness, e.g., through periodic harvest and replanting?*

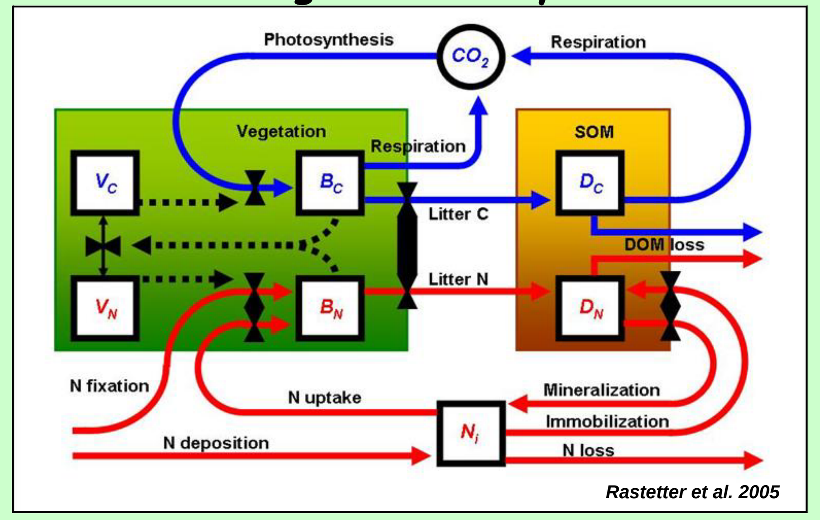
Process-based Simulator of Water & Nutrient Transport in Watersheds

GA Tech Hydrology Model



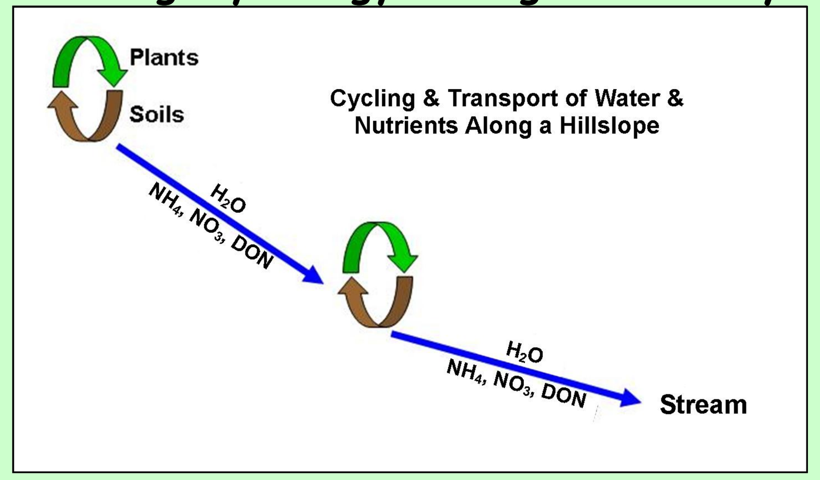
- Spatially explicit (flexible subcatchment size)
- Multiple soil layers
- Infiltration, surface runoff and subsurface runoff in saturated & unsaturated soil layers
- Spatial distribution of soil moisture
- Plots to watersheds, days to centuries
- Few parameters & forcing variables

MEL Biogeochemistry Model



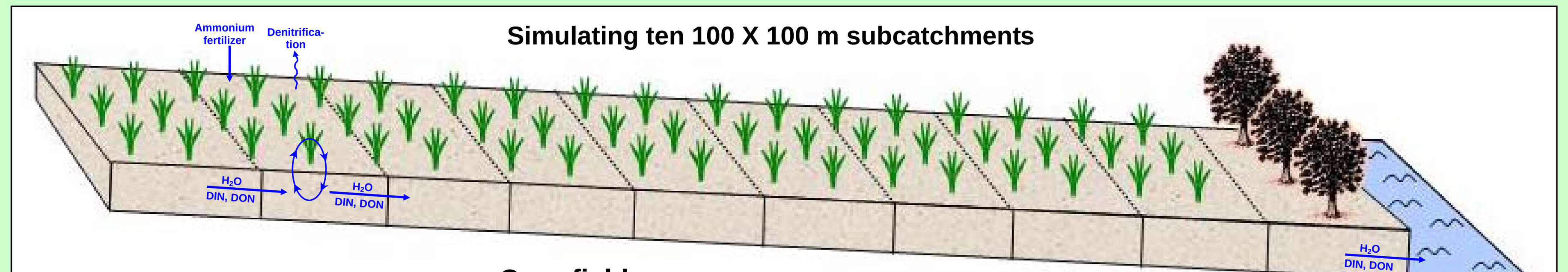
- Cycles simulated: C, N, P, & H_2O
- Resources simulated: H_2O, PO_4, NH_4, NO_3, DON, N fixation, CO_2, light
- Effects of land use, climate, chemicals & air pollutants on plants & soils
- Daily to century-scale responses
- Simulates grasslands, forests, tundra, ag systems, wetlands...

Linking Hydrology & Biogeochemistry



- Linkage of the GA Tech Hydrology & MEL Biogeochemistry models simulates lateral transport of water & nutrients within watersheds
- Predict spatially-explicit effects of land use, climate & non-point sources of nutrients on plant productivity, soil fertility and water quality & quantity.

Generalized Ag Setting for Simulating Riparian Forest Effectiveness



Corn field

- 1% slope
- 900 m X 100 m
- Ammonia fertilizer applied at 50, 100 or 200 kg N ha^{-1} on June 1 of every year for 20 years

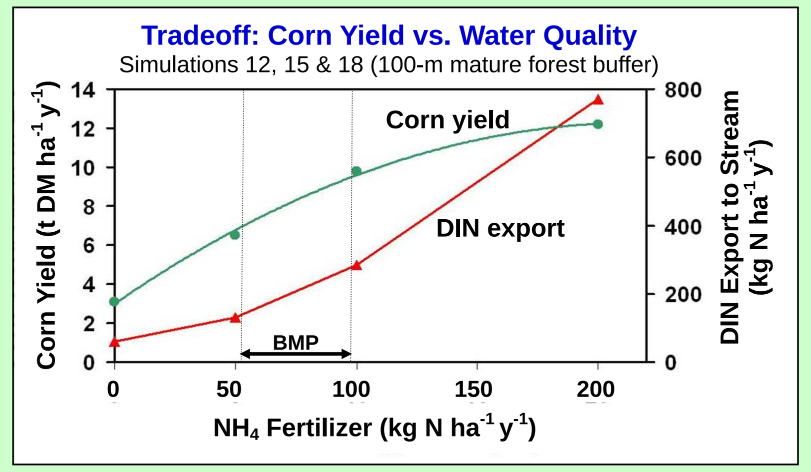
Riparian forest

- 0.1% slope
- Buffer width = 0, 50 or 100 m
- Age = 10 or 100 years

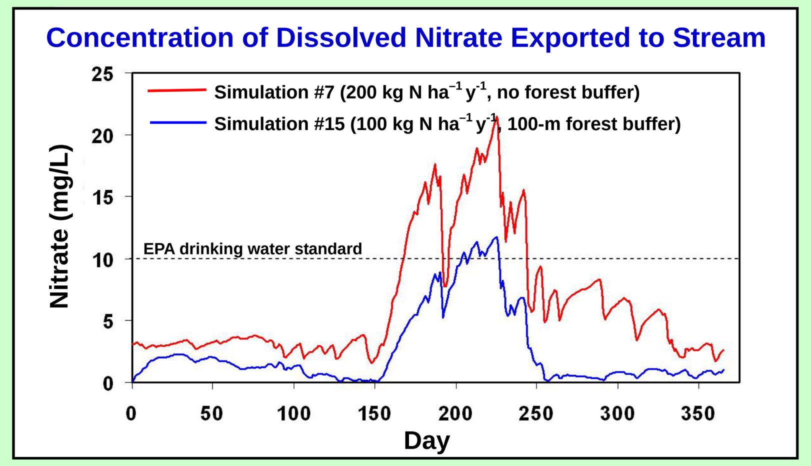
Simulation matrix: 2 forest ages X 3 forest widths X 3 fertilizer rates

Treatment:	Simulation # 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Forest Age, years																		
10		x	x		x	x		x	x									
100											x	x		x	x		x	x
Forest Buffer Width, meters																		
0	x			x			x			x			x			x		
50		x			x			x			x			x			x	
100			x			x			x			x			x			x
NH_4 Fertilizer Rate, kg N ha^{-1} y^{-1}																		
50	x	x	x							x	x	x						
100				x	x	x							x	x	x			
200							x	x	x							x	x	x
Model Results:																		
Corn Yield, t DM ha^{-1} y^{-1}	6.5	6.5	6.5	9.8	9.8	9.8	12.2	12.2	12.2	6.5	6.5	6.5	9.8	9.8	9.8	12.2	12.2	12.2
N Export to Stream, Kg N ha^{-1} y^{-1}	270	200	130	460	411	362	940	898	855	270	200	130	460	373	285	940	855	770
Best & Worst Mgmt Practices							WMP	WMP	WMP			BMP WQ, Yield			BMP Yield, WQ	WMP	WMP	WMP

Identifying Best Management Practices (BMPs)

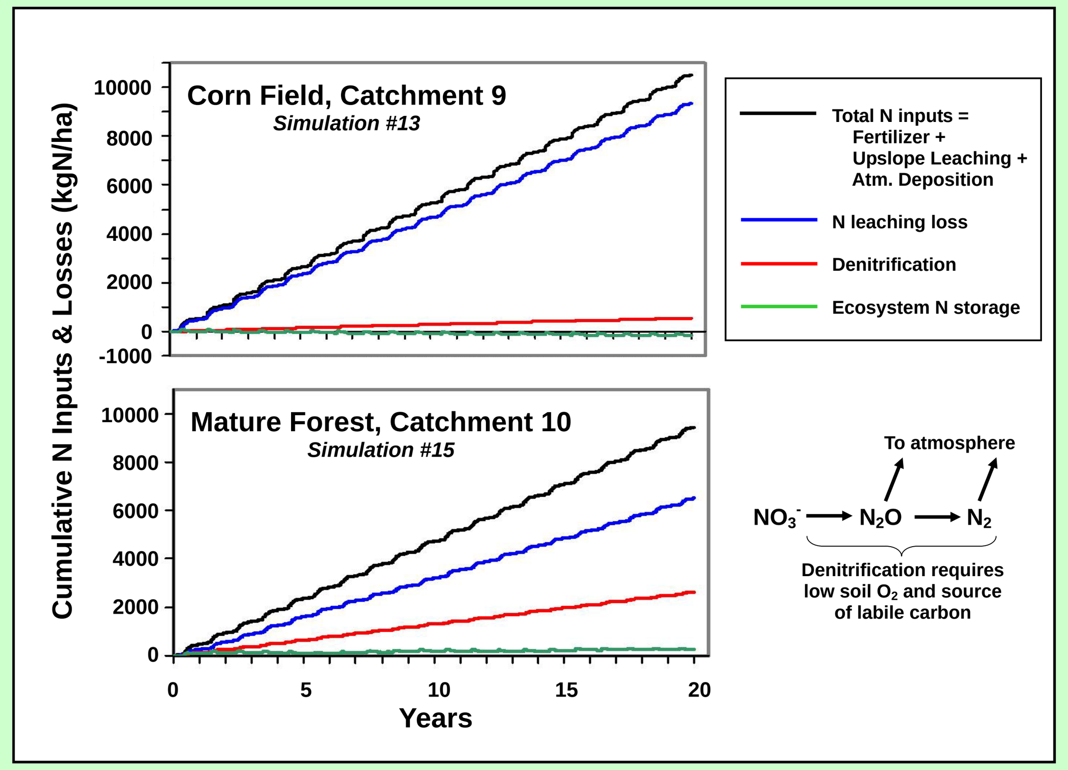


- Fertilizer N increases corn production, but with diminishing returns after 100 kg N ha^{-1} y^{-1}
- Export of DIN (dissolved inorganic N) to stream increases rapidly at higher rates of fertilization
- Best Management Practices must optimize tradeoff between corn production & water quality (see below)



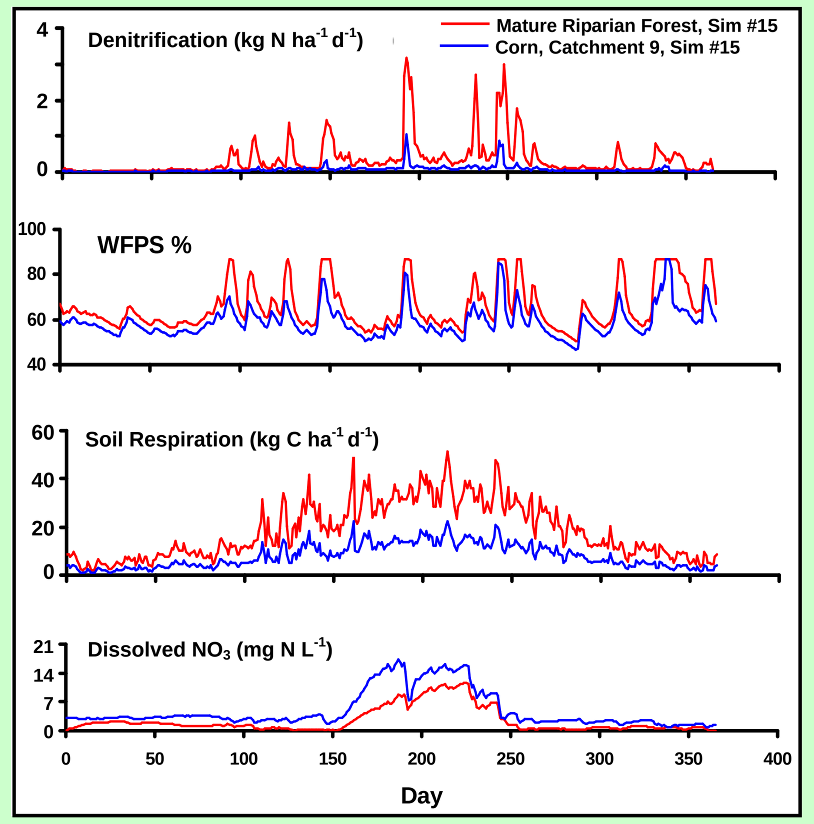
- Simulated stream nitrate concentrations exceed EPA water quality standard when fertilizer is applied at high rate (200 kg N ha^{-1} y^{-1})
- Best Management Practices may include reducing fertilizer rate, adding a riparian forest buffer or increasing its width, or some combination

Reduction in Stream NO_3 Due Mainly to Riparian Denitrification



- (Top) Without a riparian forest buffer, 90% of total N inputs to corn field were leached to stream
- (Bottom) Denitrification in mature riparian forest reduced N leaching to stream by 1/3
- Denitrification in corn & young forest (not shown) was 20% & 80% of that in mature forest
- Sequestration of N in plants & soils, in any cover type, did not significantly reduce N leaching to stream

Riparian Denitrification Strongly Controlled by Carbon Availability



- Based on Del Grosso et al. (2000), denitrification in MEL is controlled by the availabilities of oxygen (water filled pore space), labile carbon (soil respiration), and nitrate
- The overall pattern of denitrificaton was closely correlated with water-filled pore space (WFPS)
- However, the amplitude of denitrification was determined by carbon availability, reflected in rates of detritus production & soil respiration
- In this system, carbon limited denitrification more strongly than nitrate

Key Points

- In these generalized simulations, denitrification in riparian forests reduced leaching losses of N fertilizer to streams by up to 1/3. Increased uptake & storage of N in forest vegetation & soil was comparatively insignificant.
- Because mature forests produced more detritus (decomposable carbon), they were more effective than young forests in denitrifying upslope inputs of nitrate and protecting stream water quality.
- Nonetheless, for the conditions simulated here, riparian forests did not sufficiently reduce N leaching to streams where fertilization rates approached those typically used for intensive agriculture (e.g., 150-200 kg N ha^{-1} y^{-1} for corn in the U.S.A. Midwestern states).
- Future work will focus on testing model performance against measured data for agricultural systems representing a variety of climates, soils types, topography and cropping systems.