Assessing and forecasting nitrate fluxes in agricultural aquifers

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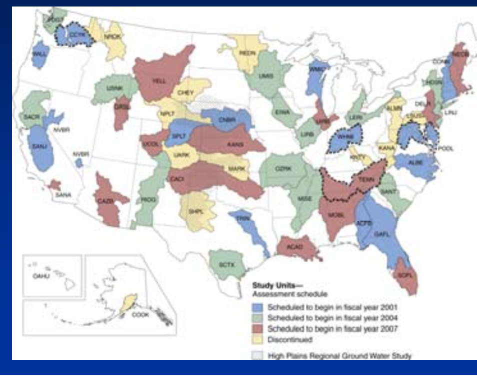
USGS NAWQA

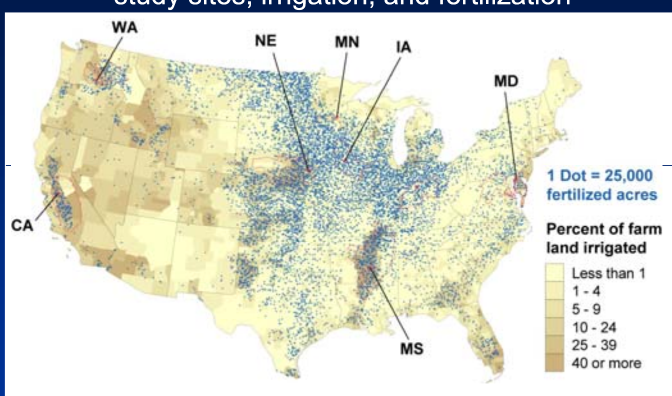
National Water-Quality Assessment Program

-Status and trends of groundwater and surface water quality in the US.

-Cycle 1 started in 1991, Cycle 2 in 2001, Cycle 3 in 2013



Agricultural Chemical Transport (ACT) study sites, irrigation, and fertilization



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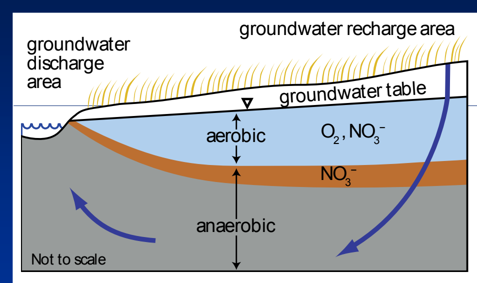
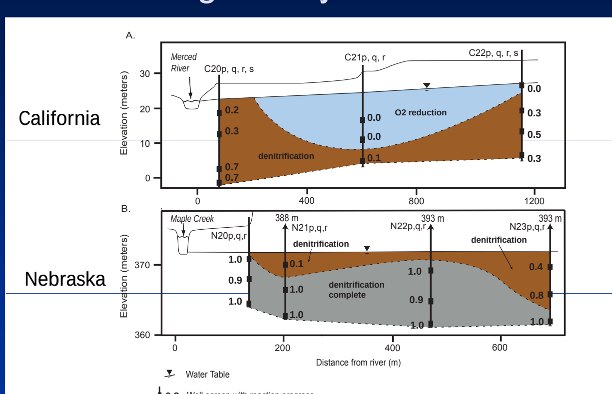
Flow system studies show common features in chemistry versus depth



Aerobic zone is underlain by denitrification zone, $NO_3 \rightarrow N2$
Denitrification zone is underlain by NO_3 free zone

What controls variability of nitrate depth among flow systems?



from Green et al., 2008

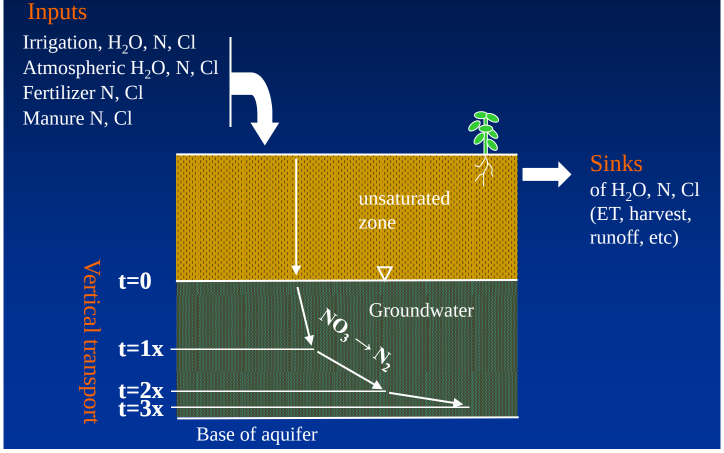
Sites can be divided by vertical extent of NO_3

	Vertical of NO_3 extent (m below water table)	Shallow NO_3 gradient (mg/L/m)	Maximum recharge NO_3 (mg/L)
Iowa	2	4	37
Mississippi	4	4	13
Nebraska	4	3	20
Minnesota	5	6	19
Maryland	12	-2	18
California	28	1	31
Washington	28	1	29

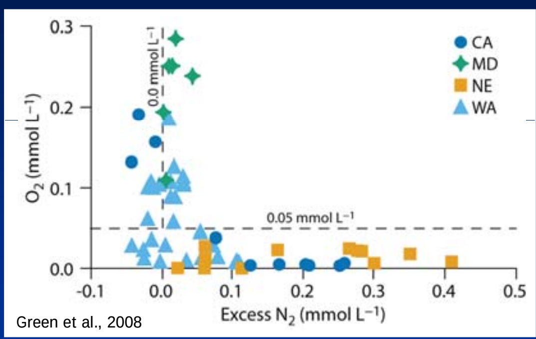
Scientific Questions

- What processes control the vertical extent of NO_3 (and associated redox processes) below agricultural fields?
  - Recharge (slower transport with low recharge)?
  - Denitrification rates (lower NO_3 with high rates)?
- How will land use changes (e.g. biofuels crops) affect the vertical extent of NO_3?

Vertical water and chemical fluxes in groundwater at recharge areas



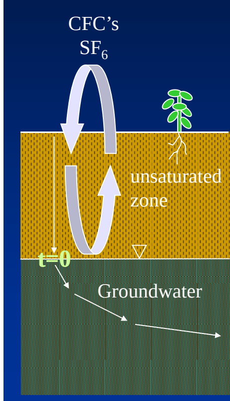
Denitrification produces "excess N_2" in anaerobic zones

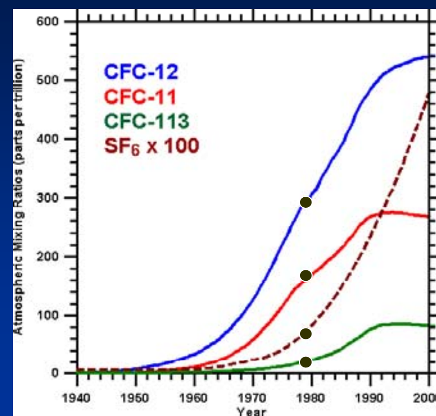


NO_3 + electron donor → $N_{2,D}$ + reaction products

$NO_{3,0} = N_{2,D} + NO_3$

Chlorofluorocarbon and Sulfur Hexafluoride Based Age Dating





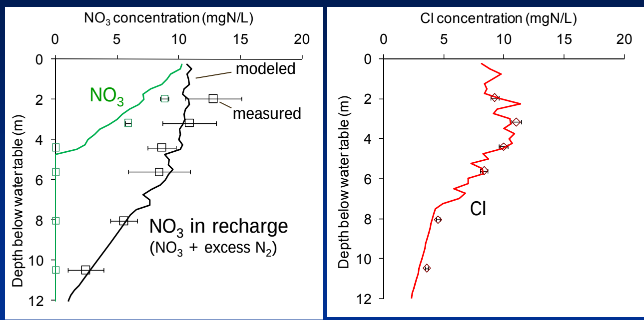
Mathematical model of N fluxes Background

- Estimates vertical flux of water and solutes through unsaturated zone and groundwater
- Parameters include:
  - Recharge rate
  - Unsaturated zone transport time
  - Fraction N leached/applied
  - Fraction Cl leached/applied
  - Denitrification rate
- Historical inputs of N and Cl are from US Dept. of Ag. and US Geol. Survey county estimates & local info where available

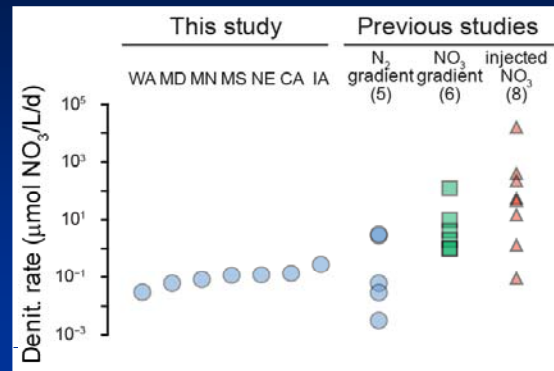
Mathematical model of N fluxes Implementation

- Calibrated to
  - NO_3,
  - NO_3 in recharge, $[NO_3]_0=[NO_3]+[\text{excess } N_2]$,
  - Cl,
  - atmospheric age-tracers (CFC's, SF_6, tritium)
- Calculated in spreadsheet
- Quick to implement and calibrate for multiple sites for comparisons and forecasts

Example Results - Mississippi

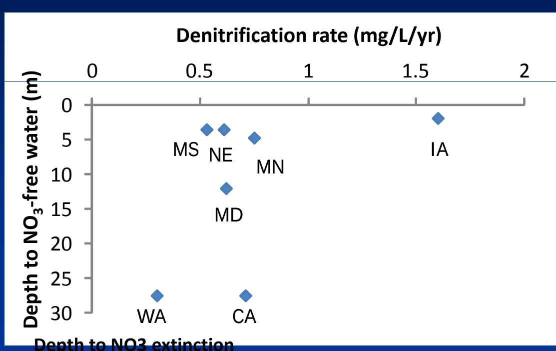


Denitrification rates are relatively uniform among these sites

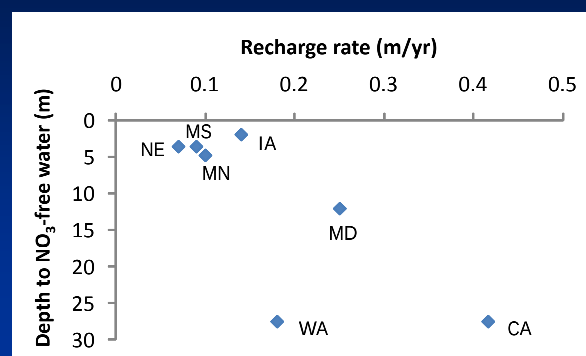


(rates are 0.3 to 1.8 mg/L/yr)

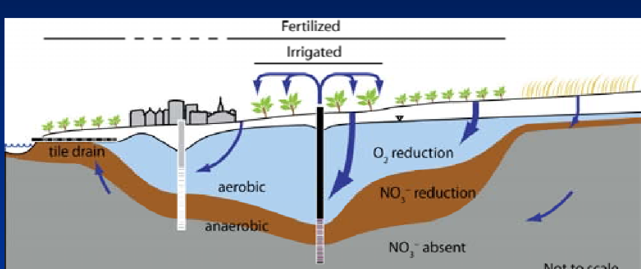
Rates show weak or no correlation with depth of NO_3



Recharge correlates with depth of NO_3

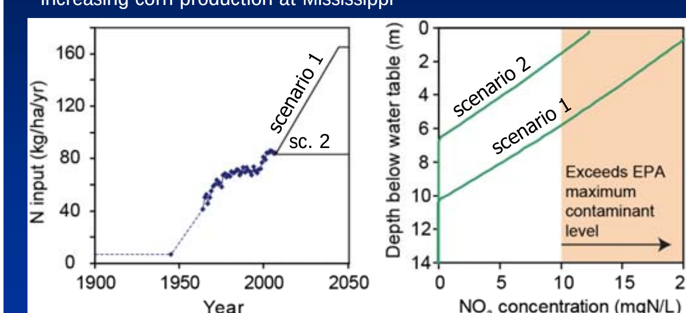


Groundwater modifications affect distribution of NO_3 and chemistry



Future Work – land use changes and biofuel production

Example – hypothetical scenarios
increasing corn production at Mississippi



Key scientific findings

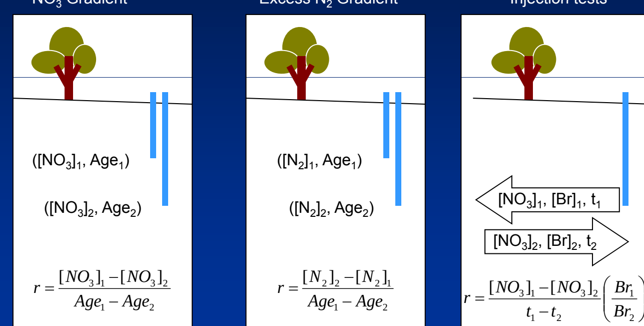
- Denitrification rates affect vertical extent of NO_3 at a minority sites (IA, WA)
- Recharge rates are more strongly correlated with vertical extent of NO_3. Hydrology may dominate NO_3 distributions at many agricultural sites.

Consequences for policy

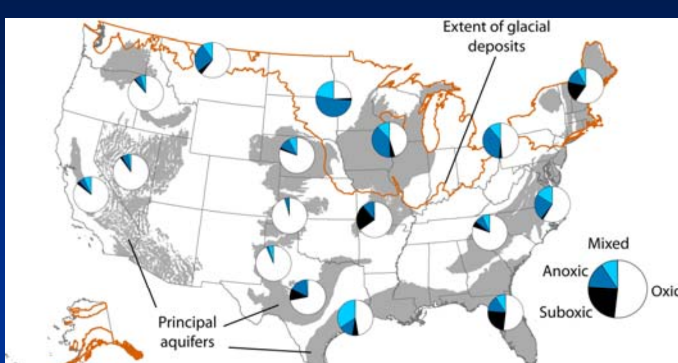
- At agricultural sites, fluxes of N are high and rates of natural attenuation are generally low.
- Monitoring the concentration at one depth does not reveal the extent of contamination nor give a sense of the fluxes of NO_3.
- Water quality and quantity are inseparable. Drainage, pumping and irrigation will all affect the extent of NO_3 contamination.

Methods for estimating in-situ denitrification rate, r, in ground water

NO_3 + electron donor -> N_2 + reaction products

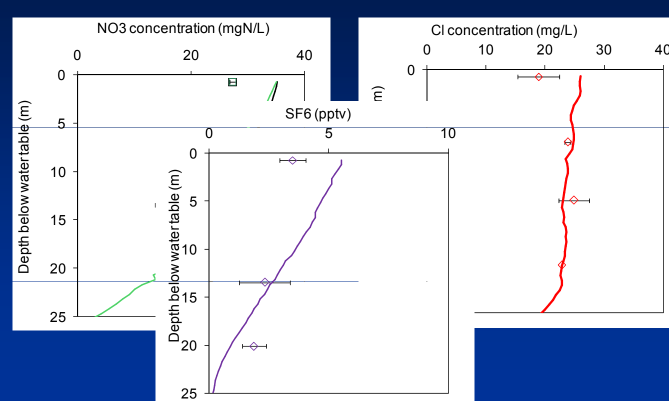


Aerobic groundwater in USA aquifers indicates limited e^- donor reactivity

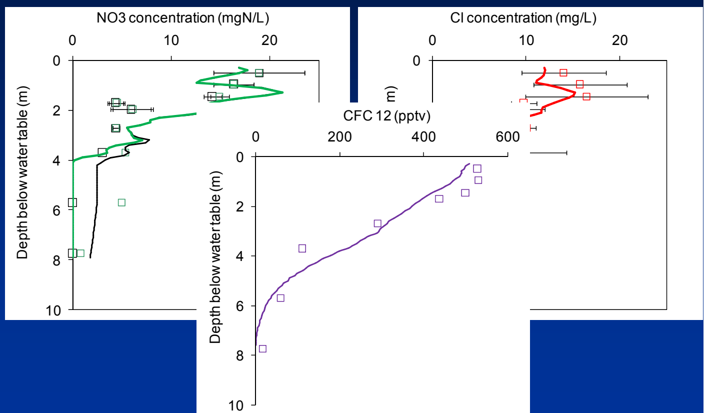


From McMahon and Chapelle, Ground Water

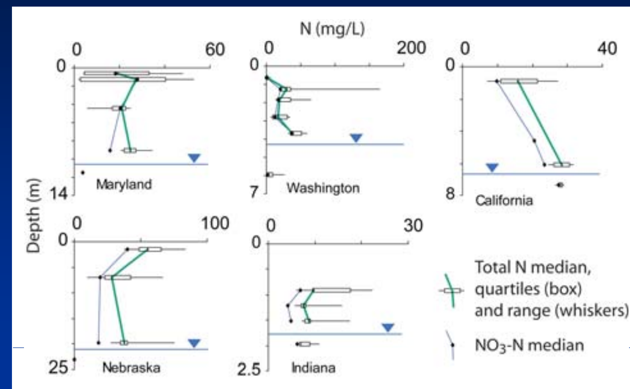
Example results - California



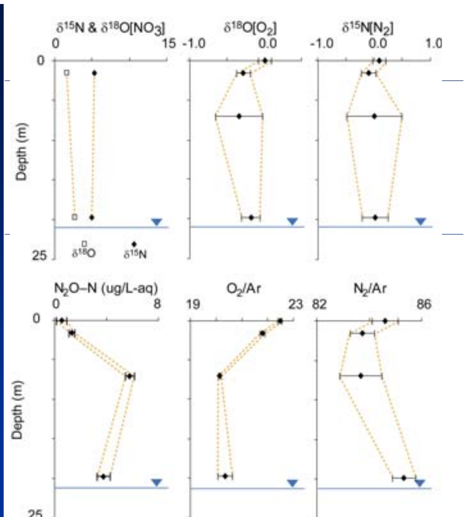
Example results - Minnesota



Unsat zone profiles indicate minimal NO_3 attenuation



Nebraska gas and stable isotope profiles indicate minimal denitrification



N leaching is higher in sandy unsaturated zones (CA and MD)