Ecosystem Mass Balances and Models of Terrestrial Nutrient Cycling

OCN 401 - Biogeochemical Systems

21 September 2017

Reading: Schlesinger, Chapter 6

Outline

1. Ecosystem mass balances
   - The watershed concept
   - Hubbard Brook Forest: a classical ecosystem-scale study
2. Budgets
   - Chemical budgets for forests
   - Continental-scale budgets
   - Estimates of uncertainty
3. Models
   - From budgets to predictive models
   - Models that track mass fluxes through time

Ecosystem (Landscape) Mass Balances

The mass balance for any material in an ecosystem can be represented by a simple equation:

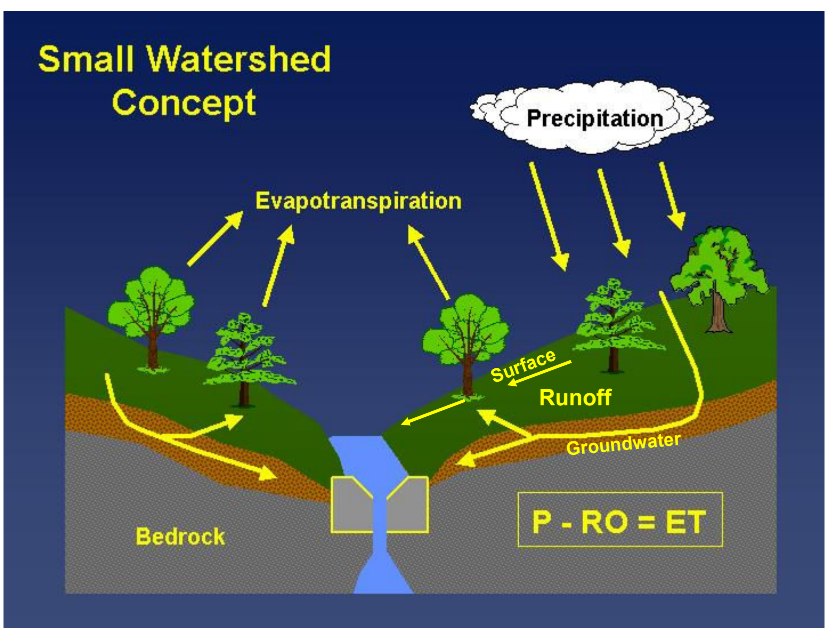
Input - Output = Change in Storage

Each of these terms (input, output, storage) can have multiple components

However, there is a fundamental controlling concept (Conservation of Mass):

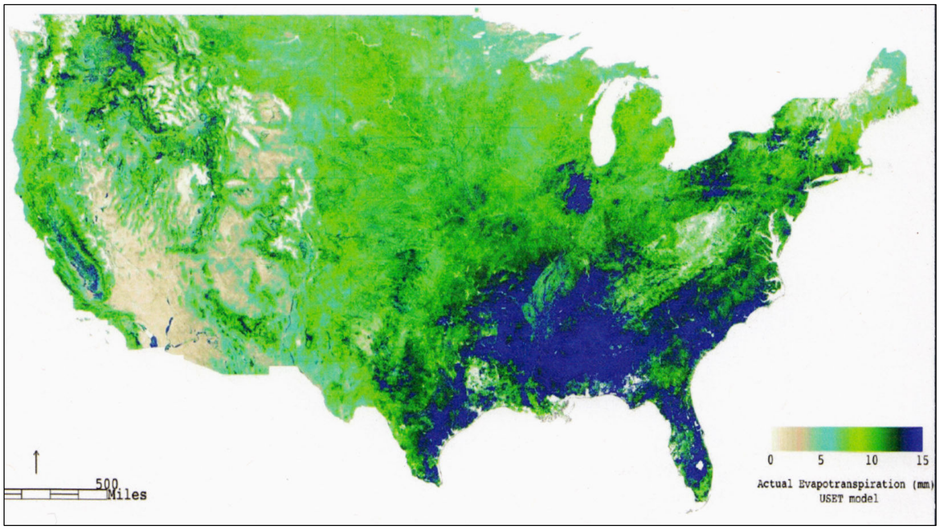
THINGS HAVE TO ADD UP!

A Water Balance



Growing Season Evapotranspiration

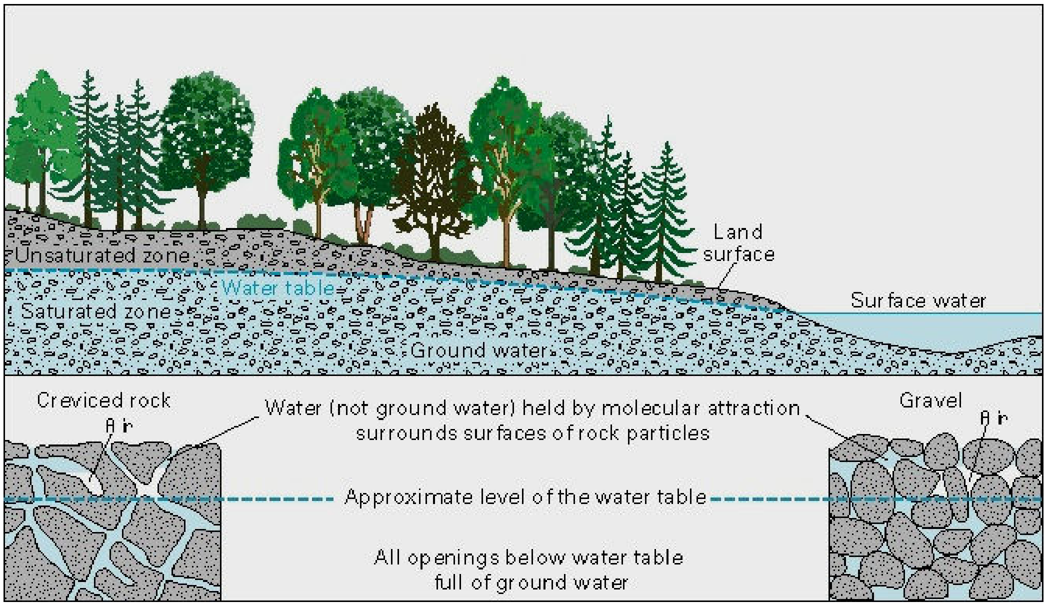
1 May – 30 Sept



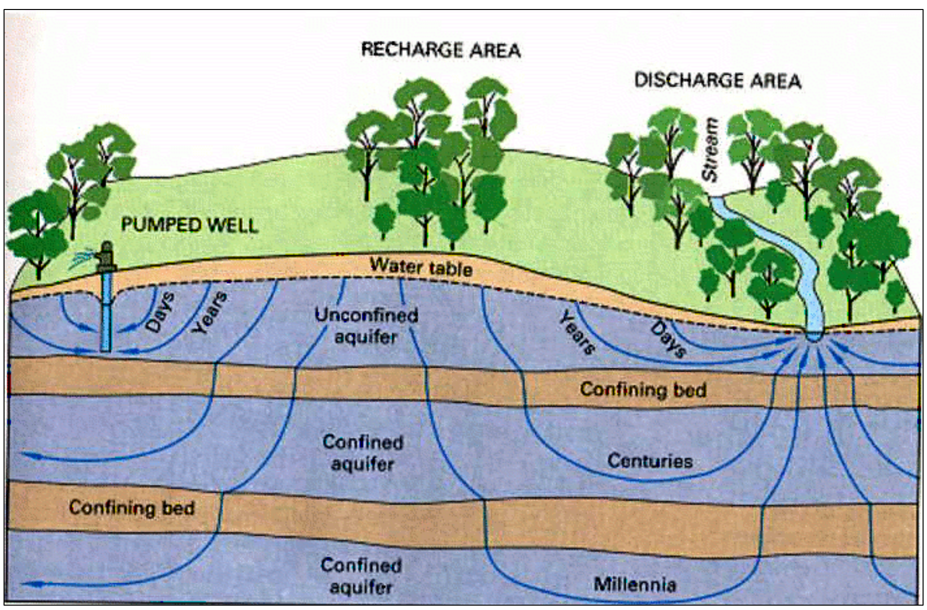
mm of ET per week (from *MODIS* satellite; B. Kamble, U. Neb – Lincoln)

www.youtube.com/watch?v=jUx9sscoCWA

Subsurface Hydrologic Zones

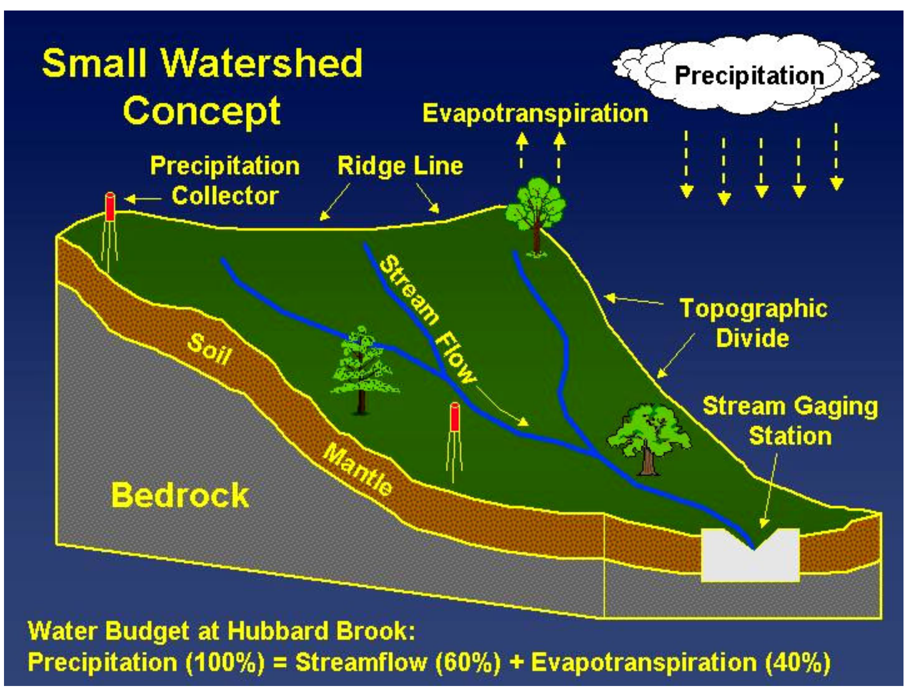


Groundwater Flow & Residence Times

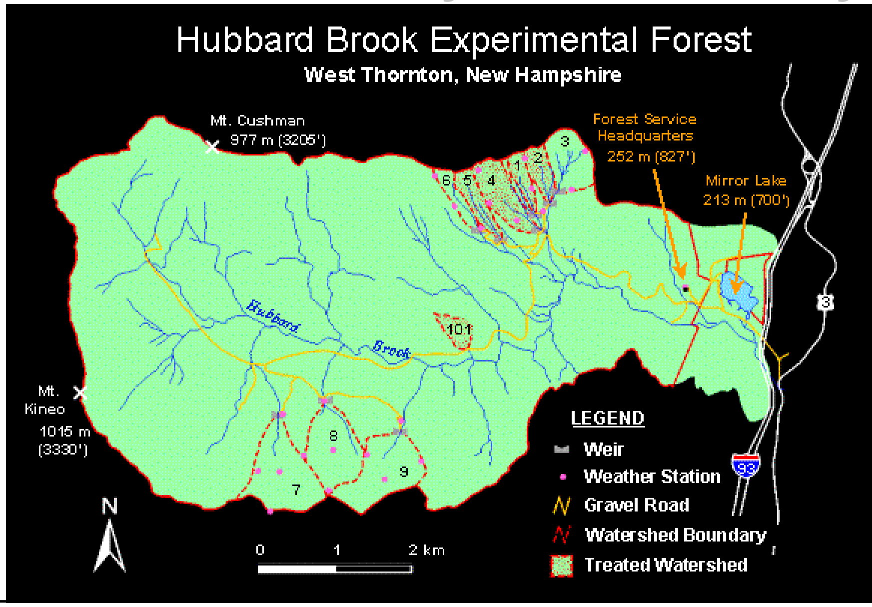


USGS circular 1139

www.youtube.com/watch?v=dUlAANVBYHM

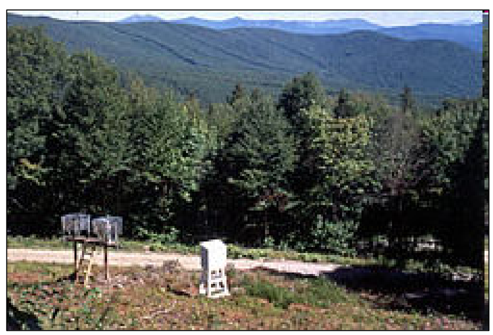


Hubbard Brook Forest: A Classical Ecosystem-scale Study

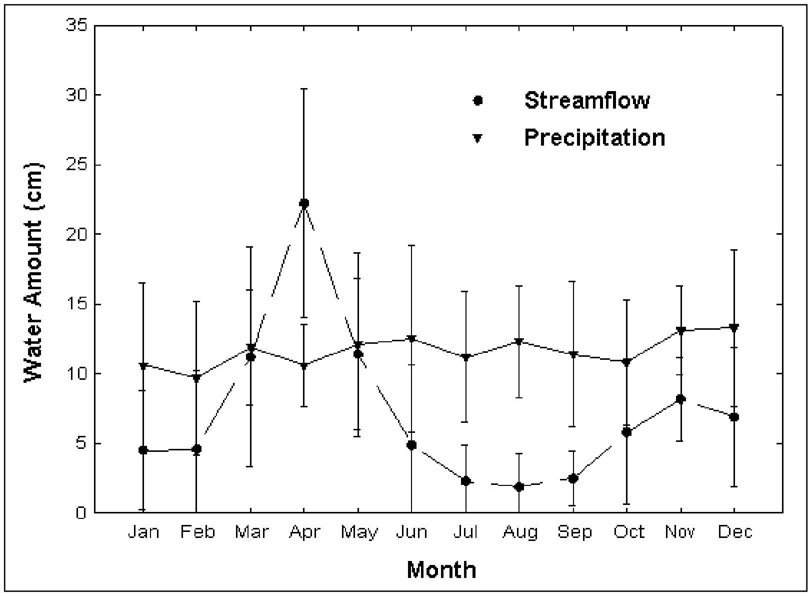


Example of a weir at Hubbard Brook:

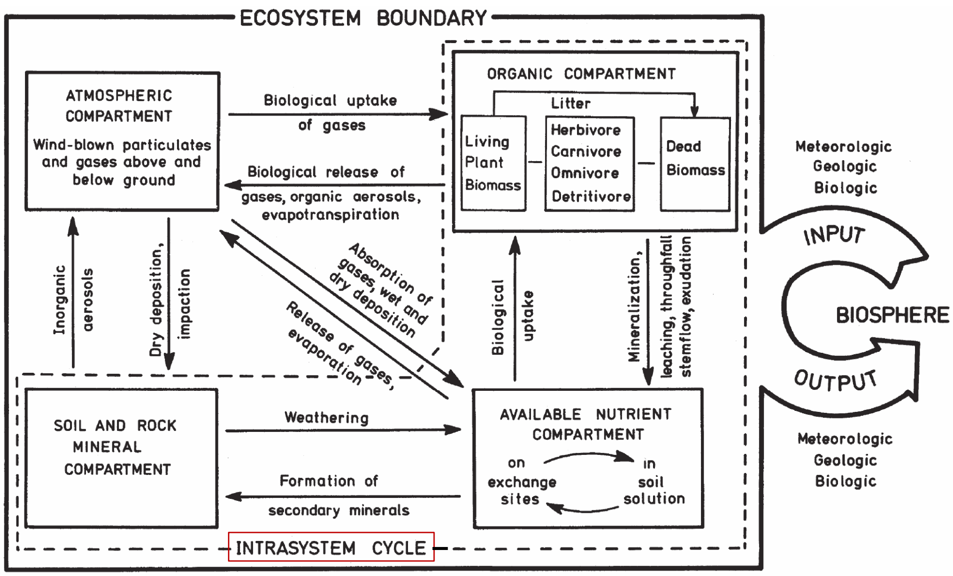
Weather station (note treated watersheds on ridge):



Hubbard Brook Forest



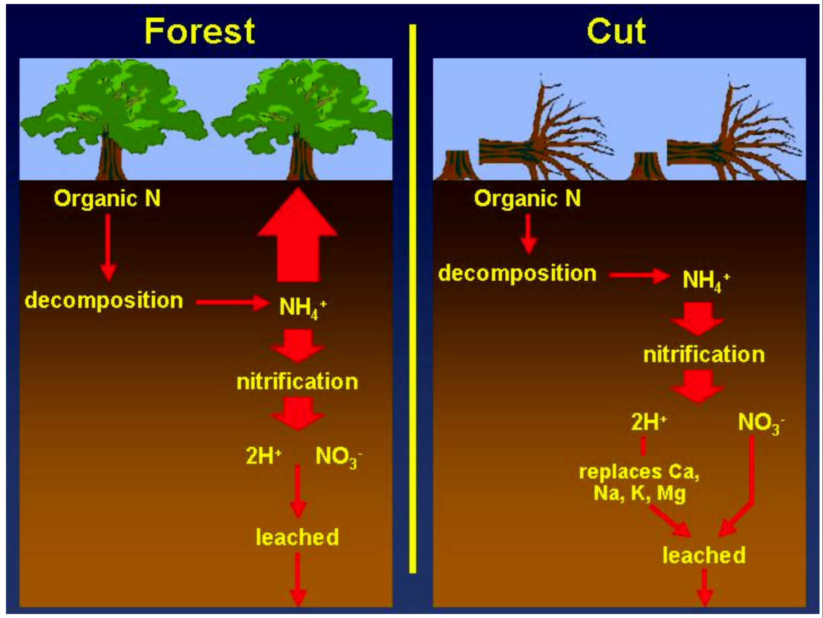
Mass-Balance Modeling at Hubbard Brook



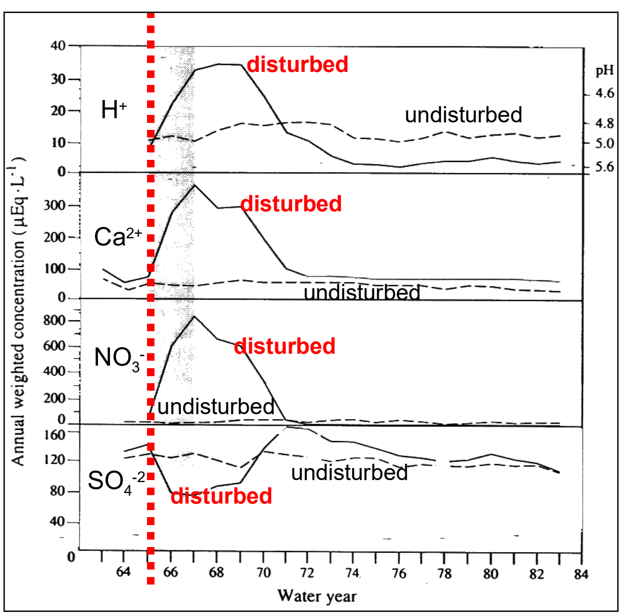
Input - Output = Change in Storage

Groffman et al. (2004) BioScience 54:139

Nitrogen: Pre- and Post-Cut



Element Concentration & Disturbance Over Time



Undisturbed system:
Constant output through time ("control")

Disturbed system:
Dramatic modification of output, then recovery back to behavior like undisturbed system

Sulfate removal may be due to increased adsorption onto soil solid-phase at lower pH

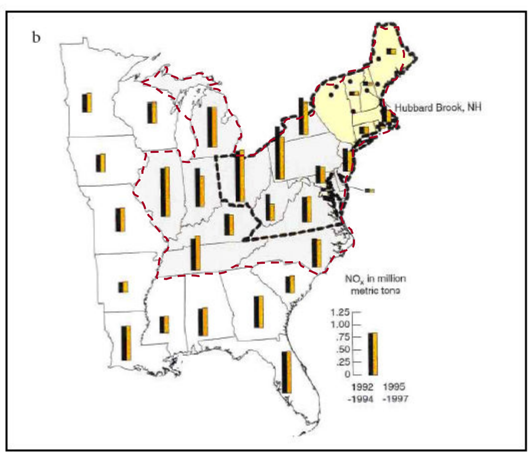
Chemical Budgets for Forests

	kilogram per hectare per year			
	(Stream loss minus atmospheric deposition)			
	Ca	**Cl**	**N**	**P**
British Columbia	15.8	2.9	-2.6	0.0
Oregon	41.2	---	-1.2	0.3
New Hampshire	11.7	-1.6	-16.7	0.0
North Carolina	3.9	1.7	-5.5	-0.1
Venezuela	14.2	-1.4	8.5	0.3

- If positive, then export of material
  (e.g., due to Ca release from weathering)
- If negative, then import of material
  (e.g., due to atmospheric input)

Where does the N input at Hubbard Brook come from?

Figure 1. Study region for the analysis of acidic-deposition effects on forest and aquatic ecosystems is indicated by the shaded area. Solid circles designate the location of Hubbard Brook Experimental Forest and other National Atmospheric Deposition Program sites in the study region. Solid bars show state emissions of (a) SO_2 and (b) NO_x for the eastern United States for 1992–1994. Shaded bars are for 1995–1997. The emissions source area for the study region, based on 15-hour back trajectories, is indicated by boldface dashed lines. The emissions source area, based on 21-hour back trajectories, is indicated by lighter shading (as calculated from Butler et al. 2001). **(thin dashed line)**



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Many Budgets Contain Estimates of Uncertainty

Table 7. A budget for atmospheric NH_3. — Global estimates

Inputs:	'Best' estimate (TgN/yr)	Potential range (TgN/yr)
Domestic animals (Table 4)	32	24—40
Sea surface (text)	13	8—18
Undisturbed soils (Table 3)	10	6—45
Fertilizers (Table 6)	9	5—10
Biomass burning (text)	5	1—9
Human excrement* (Warneck 1988)	4	
Coal combustion* (Warneck 1988)	2	
Automobiles* (Warneck 1988)	0.2	
TOTAL INPUTS	75	50—128
Outputs:		
Wet deposition on land (Warneck 1988)	30	
Dry deposition on land (Warneck 1988)	10	
Wet deposition on sea surface (Duce et al. 1991)	16	
Reaction with OH radical (Warneck 1988)	1	
TOTAL OUTPUTS	57	

* incremented to represent current human and automobile populations.

Tg = teragram = 10^{12} g

Budgets Can Lead to Predictive Models

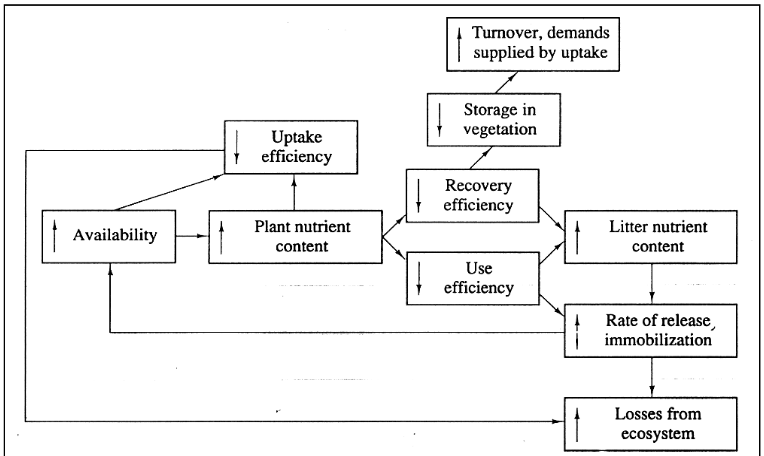


Figure 6.22 Changes in internal nutrient cycling that are expected with changes in nutrient availability. From Shaver and Melillo (1984).

Higher nutrient availability

...leads to

higher plant nutrient content

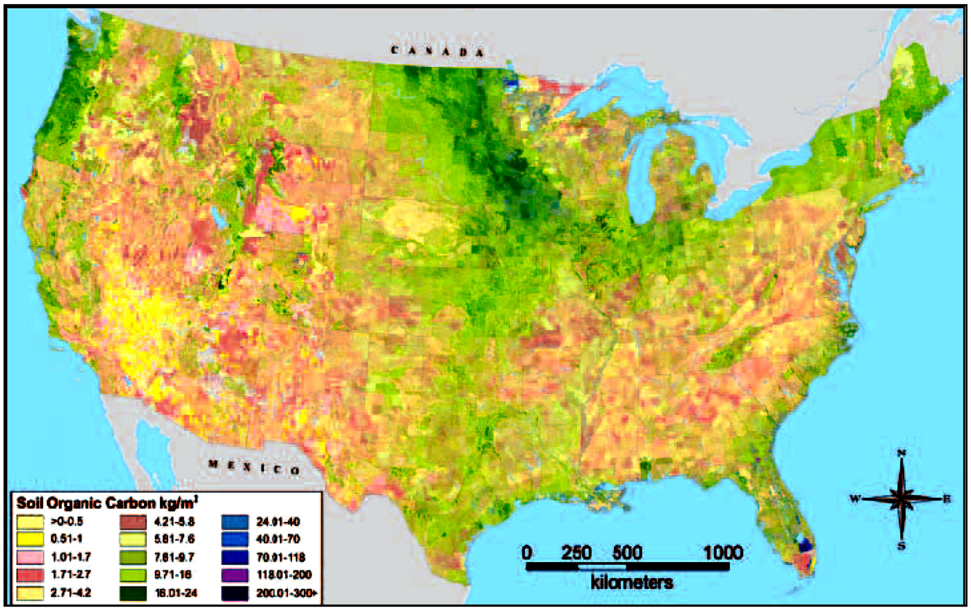
...leads to

lower nutrient reabsorption before leaf-fall

...which reflects

lower nutrient-use efficiency

Example: Modeling of Soil Organic Carbon Content



Soil organic C (kg/m^2)

Brown et al. 2010 *Eos*

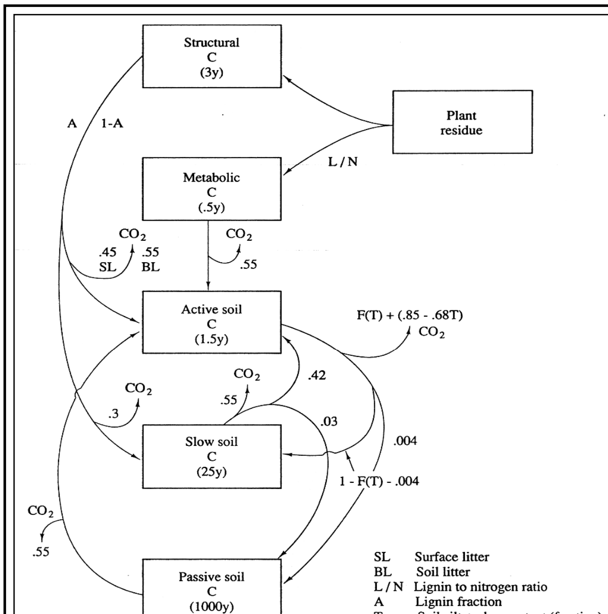


Figure 6.25 Flow diagram for carbon in the CENTURY model. The proportion of carbon moving along each flowpath is shown as a fraction, and turnover times for reservoirs are shown in parentheses. From Parton et al. (1988).

Models, As Well As Budgets, Often Track Mass Fluxes Through Time

The CENTURY model describes grassland soil development:

- Boxes = pools of plant C residue in soil
- Arrows = C transfers between soil pools
  - Each arrow is represented by an equation describing the transfer
- Turnover times ranges from 0.5 y (fresh metabolic C) to 1,000 y ("passive soil")

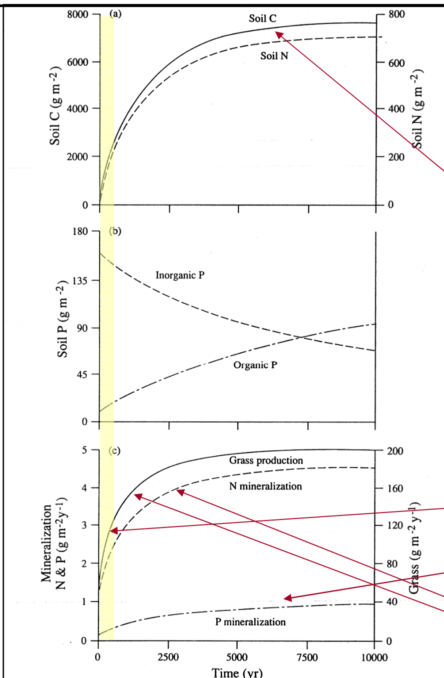


Figure 6.22 Simulated changes in soil C, N, and P during 10,000 years of soil development in a grassland, using the Parton et al. (1988) model.

The model simulates the time-course of grassland soil development over 10,000 years

Grass production and soil C accumulation is closely linked to P availability during the first 800 yr

After that, they are related to increases in soil N mineralization

Lecture Summary

- Material fluxes at the ecosystem scale are integrating measures of ecosystem function -- thus we determine ***Ecosystem Mass Balances***
- ***Budgets*** are descriptions of material flux from one reservoir to another
- ***Models*** may be superficially similar to budgets, except that simultaneous equations are used instead of purely descriptive data to describe the time course of material flux through a system
- With both budgets and models there is often added insight by the simultaneous examination of fluxes of several linked materials (*e.g.*, C, N, P) through the system

The Next Lectures:

"Wetlands, biogeochemical redox reactions in aquatic systems"

This will mark a transition in the course from terrestrial to aquatic systems

Although we have already discussed redox reactions, these lectures will include a more comprehensive coverage of these important processes

Hint: a review of your old chemistry texts may be in order!