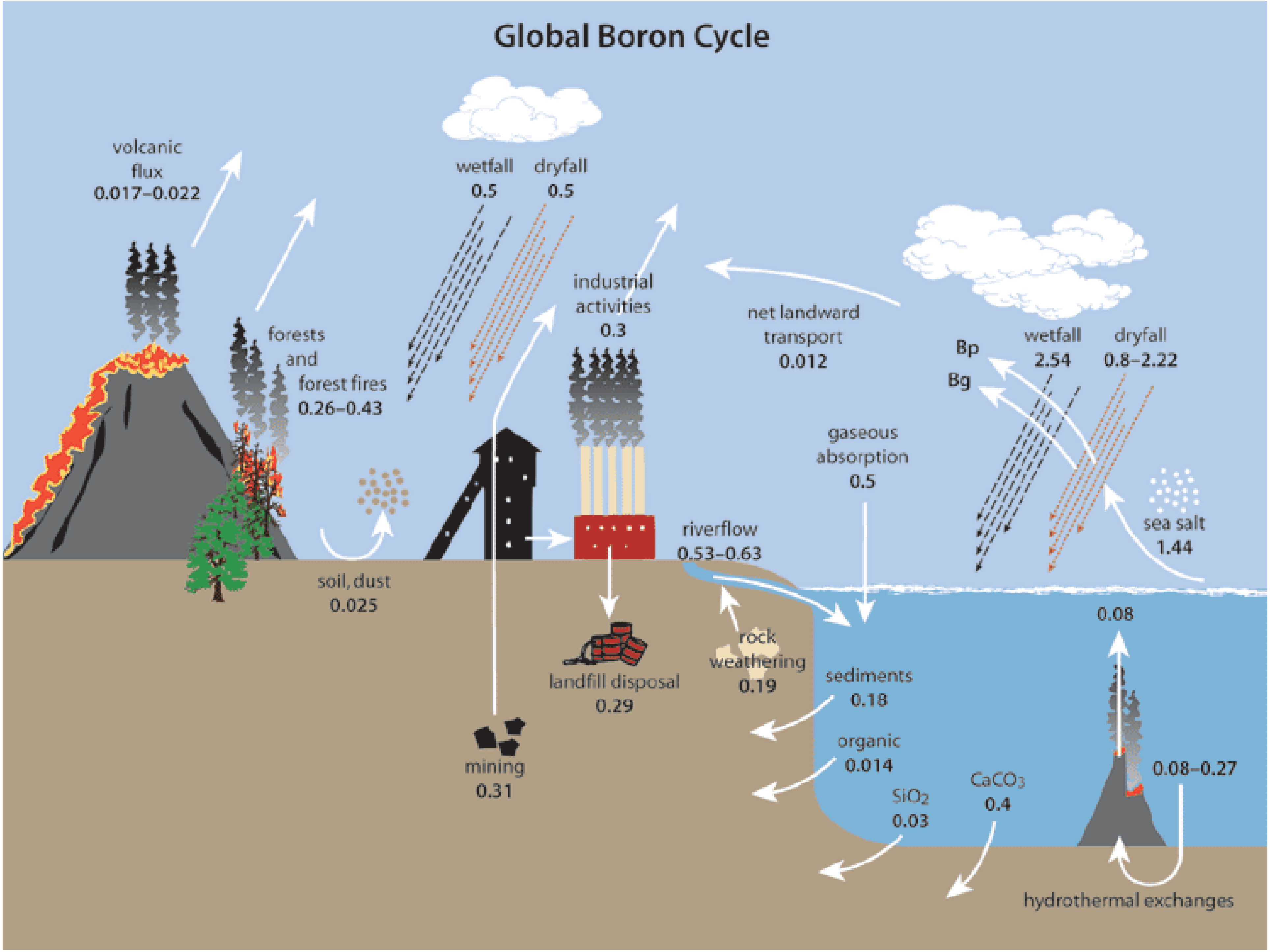
Chasing N Atoms:
The Global Nitrogen Cycle

Cary Institute of Ecosystem Studies

William H. Schlesinger, President

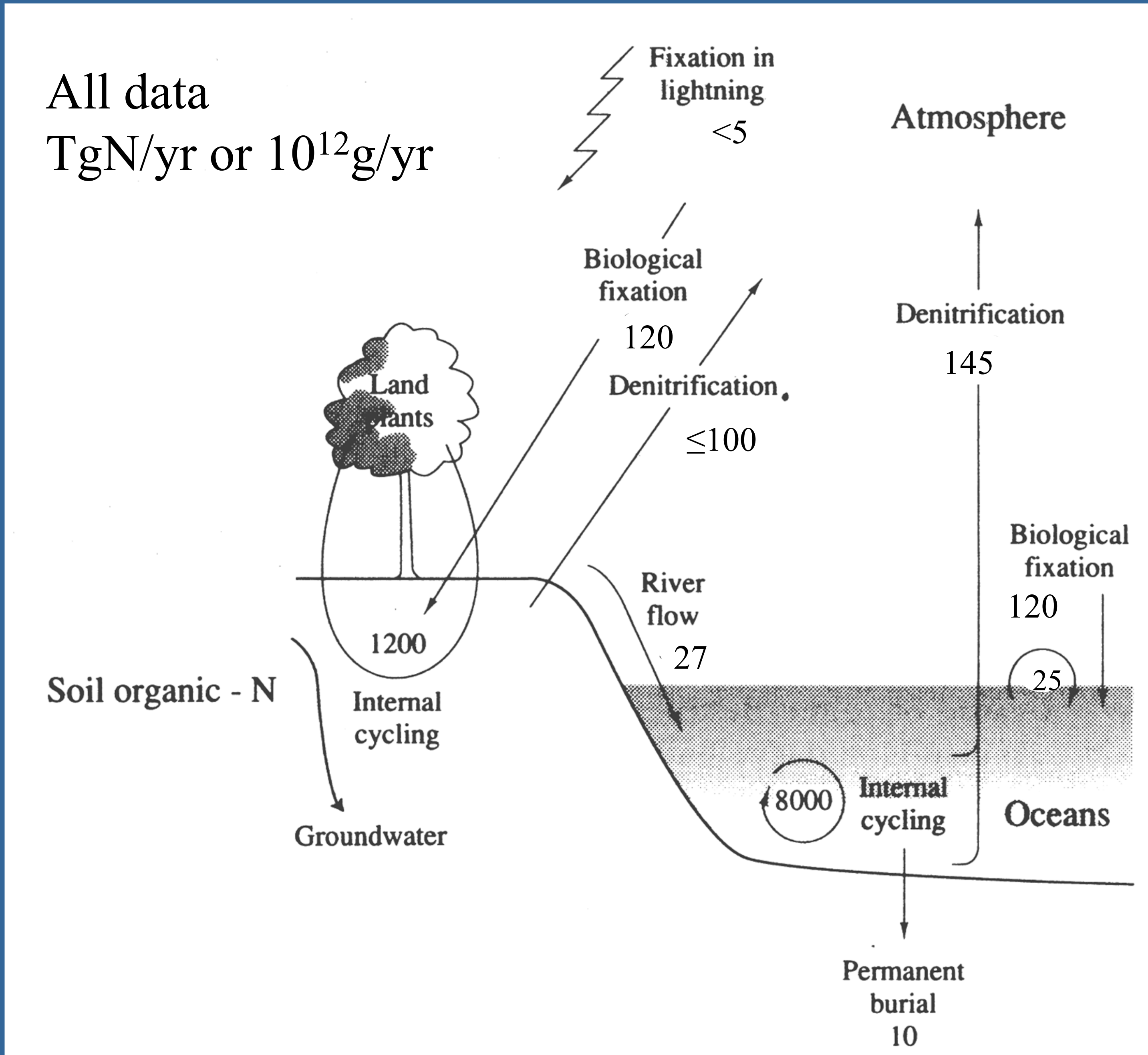


Global Boron Cycle
volcanic flux 0.017–0.022
forests and forest fires 0.26–0.43
wetfall 0.5
dryfall 0.5
industrial activities 0.3
net landward transport 0.012
Bp
Bg
wetfall 2.54
dryfall 0.8–2.22
gaseous absorption 0.5
sea salt 1.44
soil, dust 0.025
riverflow 0.53–0.63
0.08
rock weathering 0.19
landfill disposal 0.29
sediments 0.18
organic 0.014
mining 0.31
SiO_2 0.03
$CaCO_3$ 0.4
0.08–0.27
hydrothermal exchanges

Human Perturbation of Global Cycles

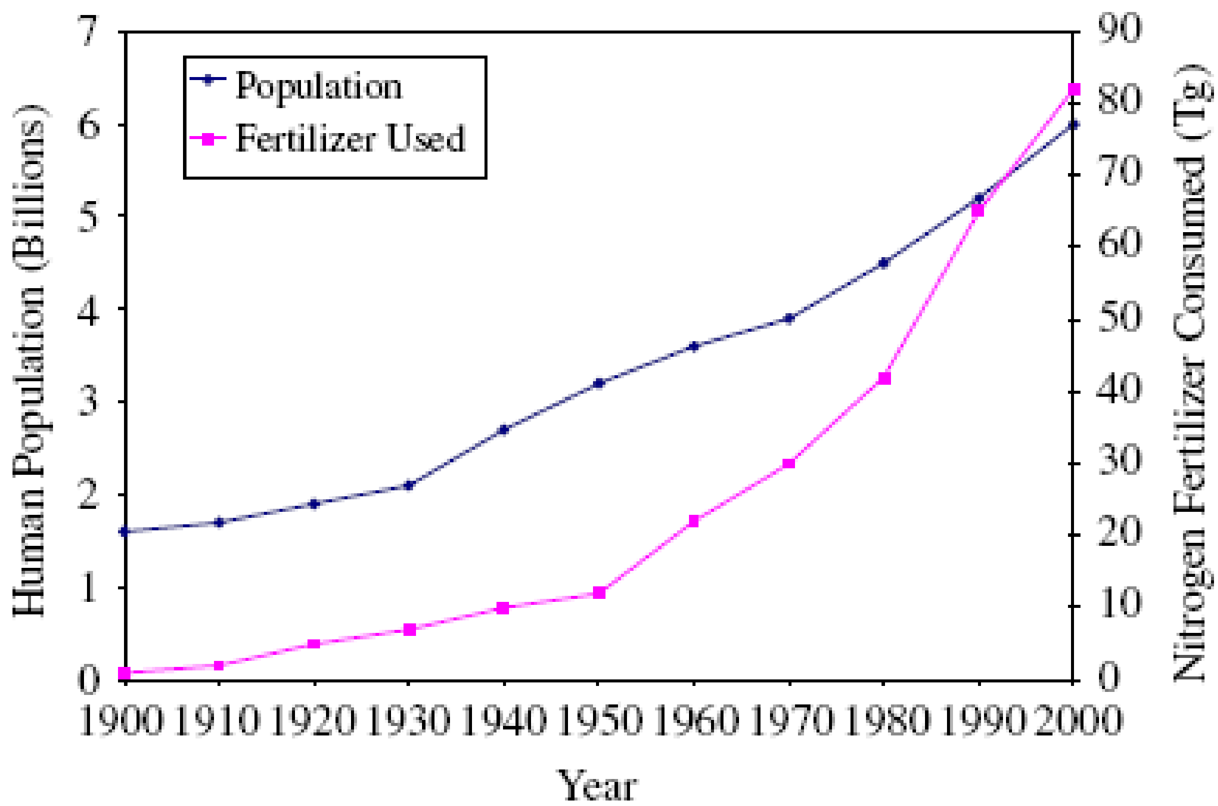
Element	Juvenile Flux	Chemical Weathering	Natural Cycle	Biospheric Recycling Ratio	Human Mobilization	Human Enhancement
	(1)	(2)	(3)	3/(1+2)	(4)	4/(1+2)
B	0.02	0.19	8.8	42	0.58	2.8
C	30	210	107,000	446	8,700	36.3
N	0.1	20	9,200	458	221	11.0
P	~0	2	1,000	500	25	12.5
S	10	70	450	5.6	130	1.6
Cl	2	260	120	0.46	170	0.65
Ca	120	500	2,300	3.7	65	0.10
Fe	6	1.5	40	5.3	840	112.0
Cu	0.05	0.056	2.5	23.6	11	104.0
Hg	0.0005	0.0002	0.003	4.3	0.0023	3.3

The Global Nitrogen Cycle - Pre-Industrial



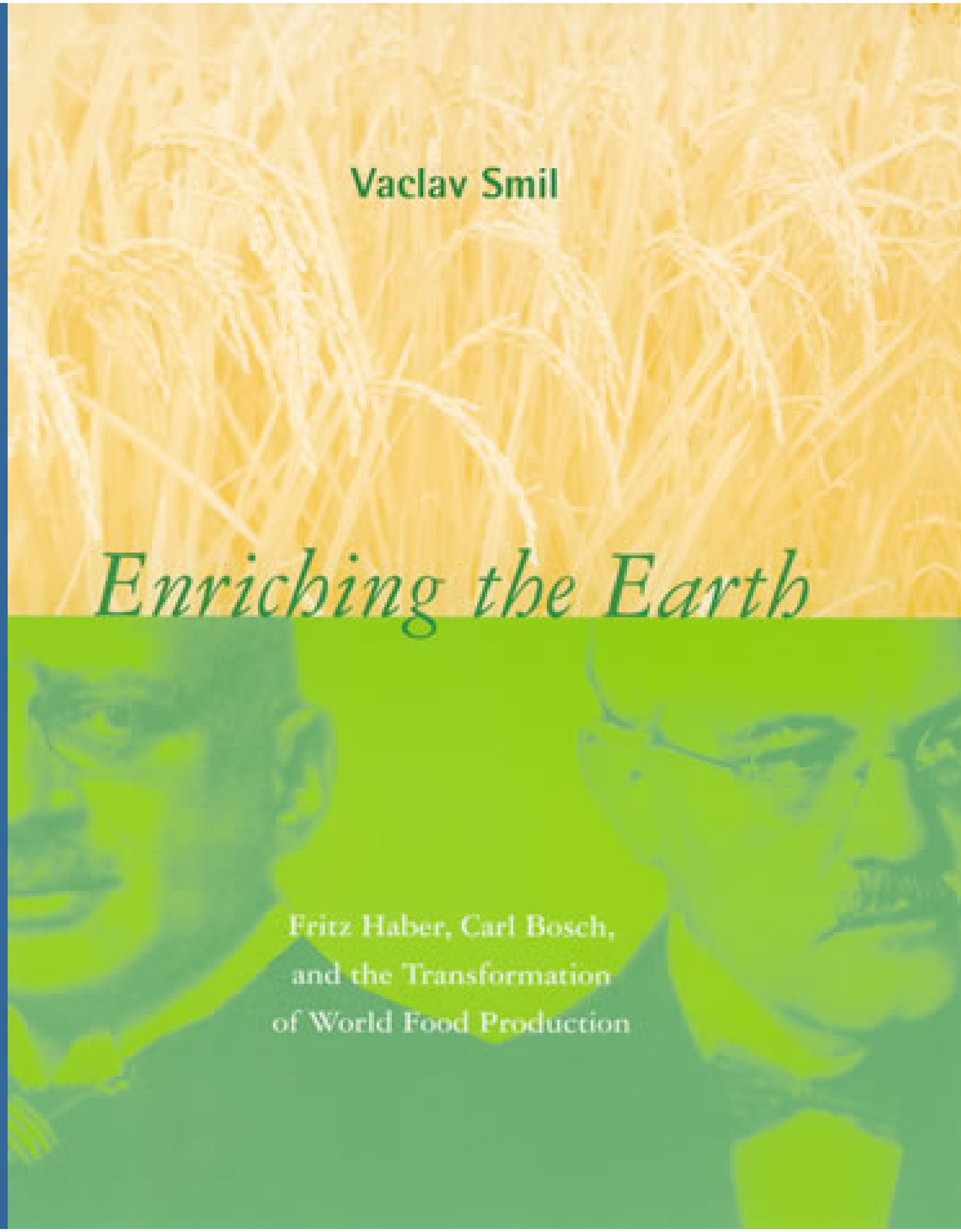

Growers Special™
12-6-6
GUARANTEED ANALYSIS
Total Nitrogen (N) 12%
1.86% Nitrate Nitrogen
1.28% Ammoniacal Nitrogen
8.86% Urea Nitrogen*
Available Phosphate (P_2O_5) 6%
Soluble Potash (K_2O) 6%
Boron (B) 0.02%
Copper (Cu) 0.05%
Iron (Fe) 0.25%
Total Manganese (Mn) 0.05%
0.05% Soluble Manganese
Zinc (Zn) 0.05%
Derived From Primary Plant Nutrient Sources: Nitrate of Potash, Ammoniated Phosphate, Urea Formaldehyde.
Secondary Plant Nutrient Sources Derived From: Sodium Borate, Copper Sulphate, Iron Sulphate, Manganese Sulphate, Zinc Sulphate.
*7.34% Slowly Available Nitrogen From Urea Formaldehyde.
370-2305
DIRECTIONS FOR USE
Hi-Yield® Growers Special™ is designed for controlled feeding of container plants, trees, shrubs, and lawns. The slow release formula in Growers Special™ reduces the risk of nitrogen burn and is chlorine free.
CONTAINER PLANTS: Apply one teaspoonful per 6 inch pot and 2 table-
spoons per square foot of soil surface in large containers


New Holland

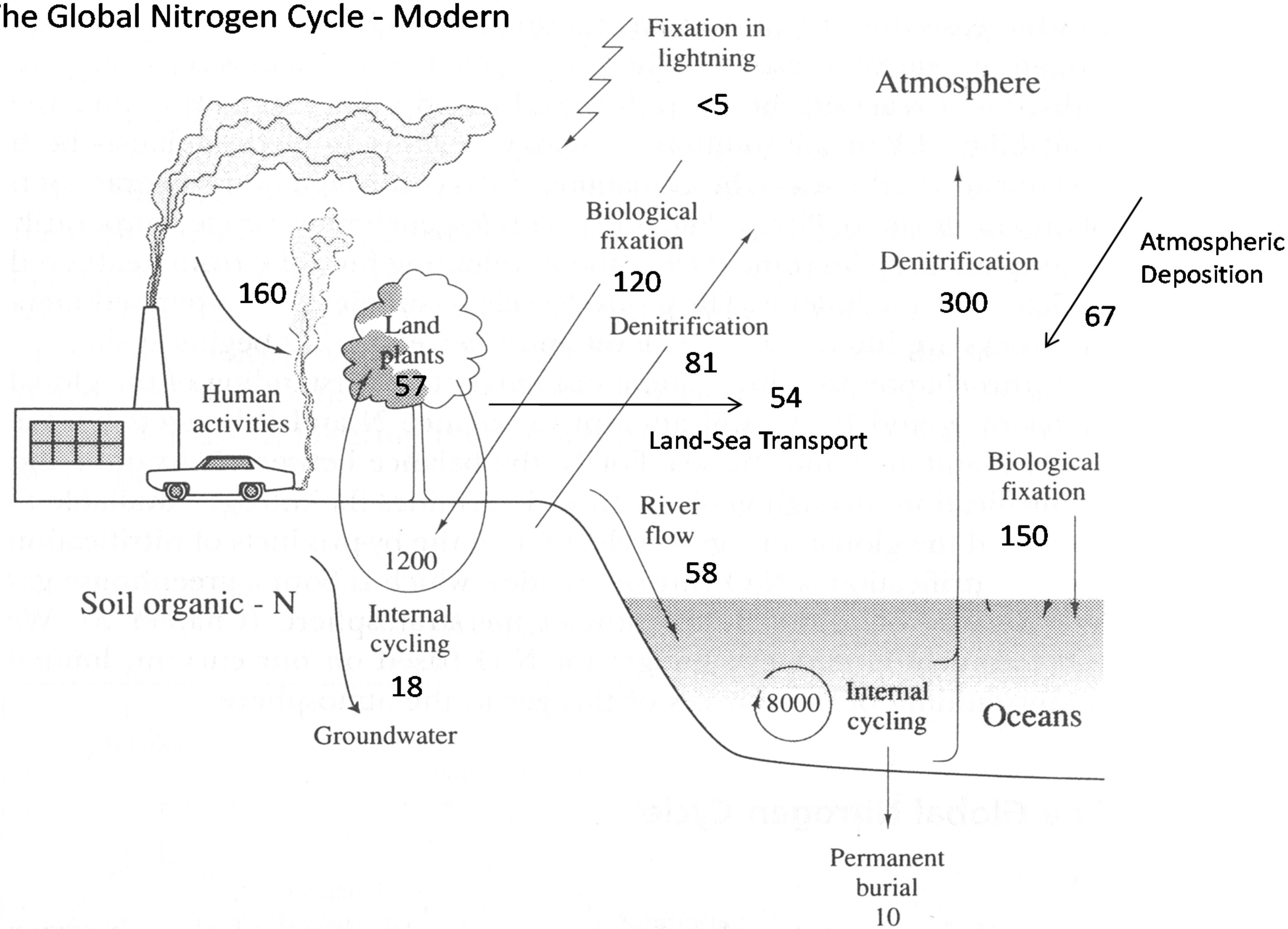


Population increase and use of nitrogen fertilizer from 1900 to 2000.

Aneja et al. 2008.


Vaclav Smil
Enriching the Earth
Fritz Haber, Carl Bosch,
and the Transformation
of World Food Production

The Global Nitrogen Cycle - Modern



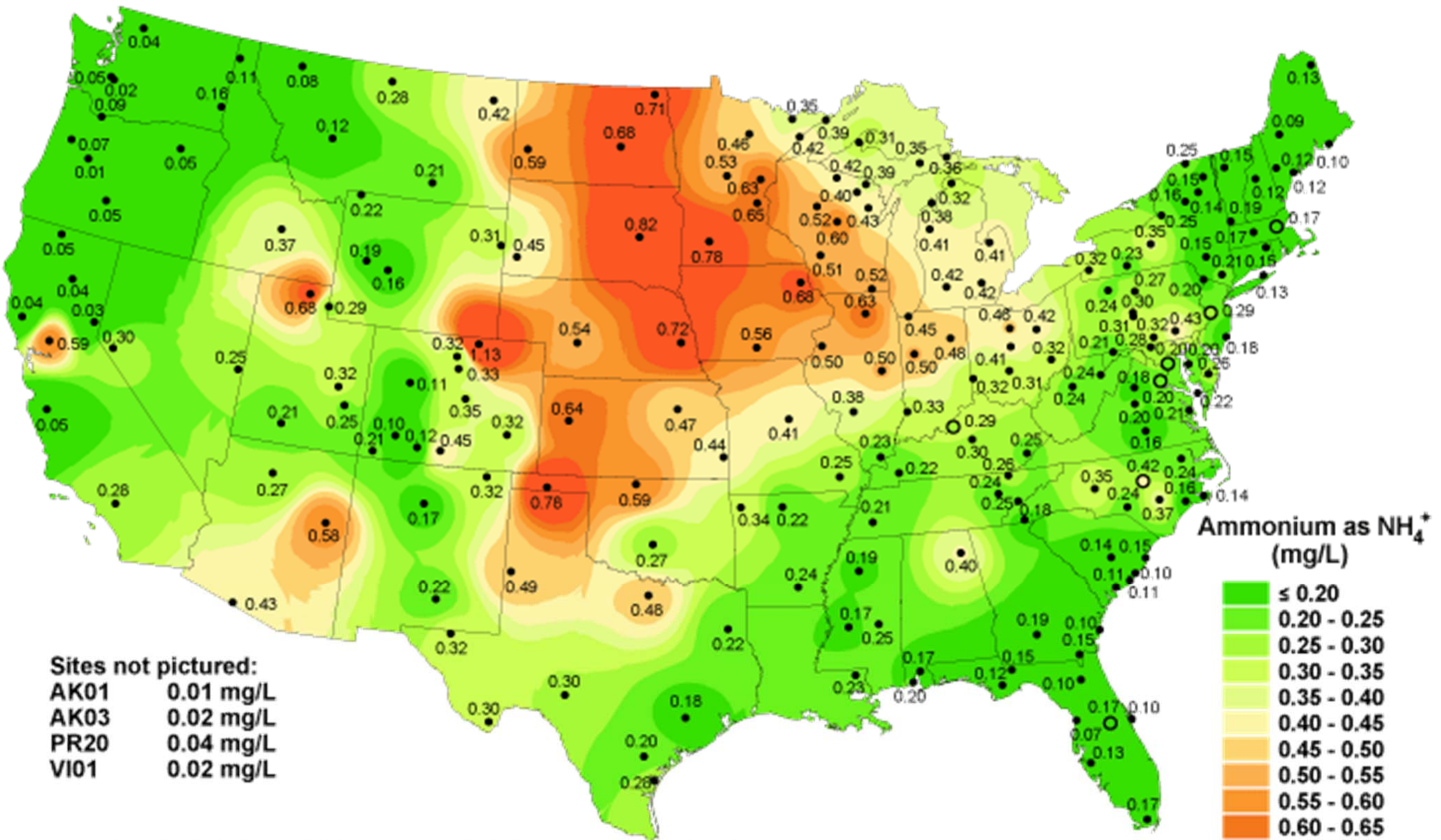
Where does this nitrogen go?

Table 6. Mass balance of ^{15}N-labeled fertilizer N as affected by long-term N application rate in continuous corn production. Values are 3-yr means of data collected annually at Monmouth, IL, from 1994 to 1996.

Form of N	Labeled N recovered	
	kg ha^{-1}	percentage of applied, %
		67 kg N ha^{-1}
Plant	20.7	31
Soil		
Inorganic	2.8	4
Organic	24.3	36
Total	47.8	71
N unaccounted for	19.2	29
		134 kg N ha^{-1}
Plant	45.2	34
Soil		
Inorganic	3.9	3
Organic	39.8	30
Total	88.9	66
N unaccounted for	45.1	34
		201 kg N ha^{-1}
Plant	74.6	37
Soil		
Inorganic	13.2	7
Organic	41.8	21
Total	129.6	64
N unaccounted for	71.4	36
		268 kg N ha^{-1}
Plant	94.9	35
Soil		
Inorganic	30.7	11
Organic	48.6	18
Total	174.2	65
N unaccounted for	93.8	35

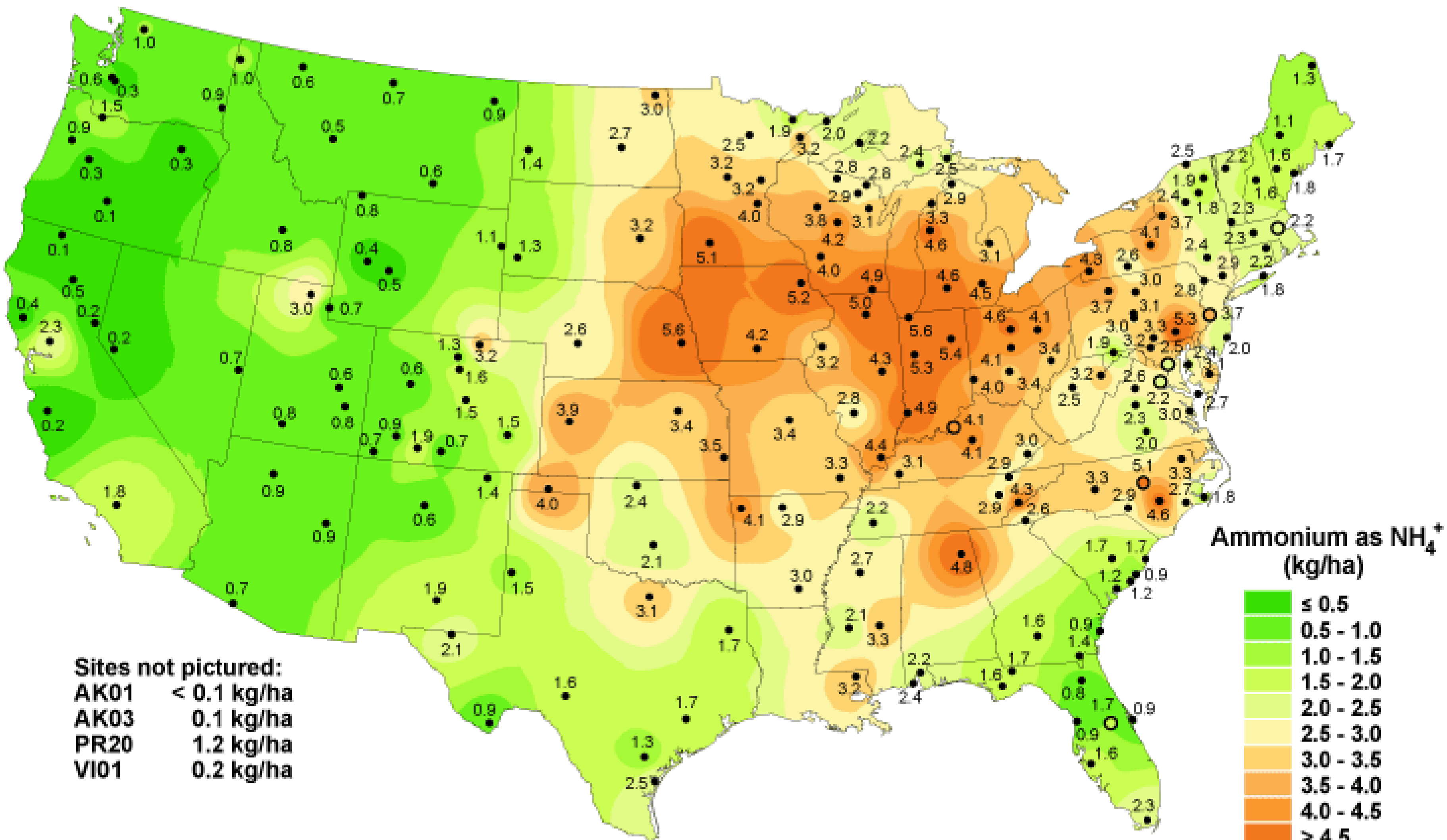
Stevens et al. 2005.

Ammonium ion concentration, 2006



National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

Ammonium ion wet deposition, 2006



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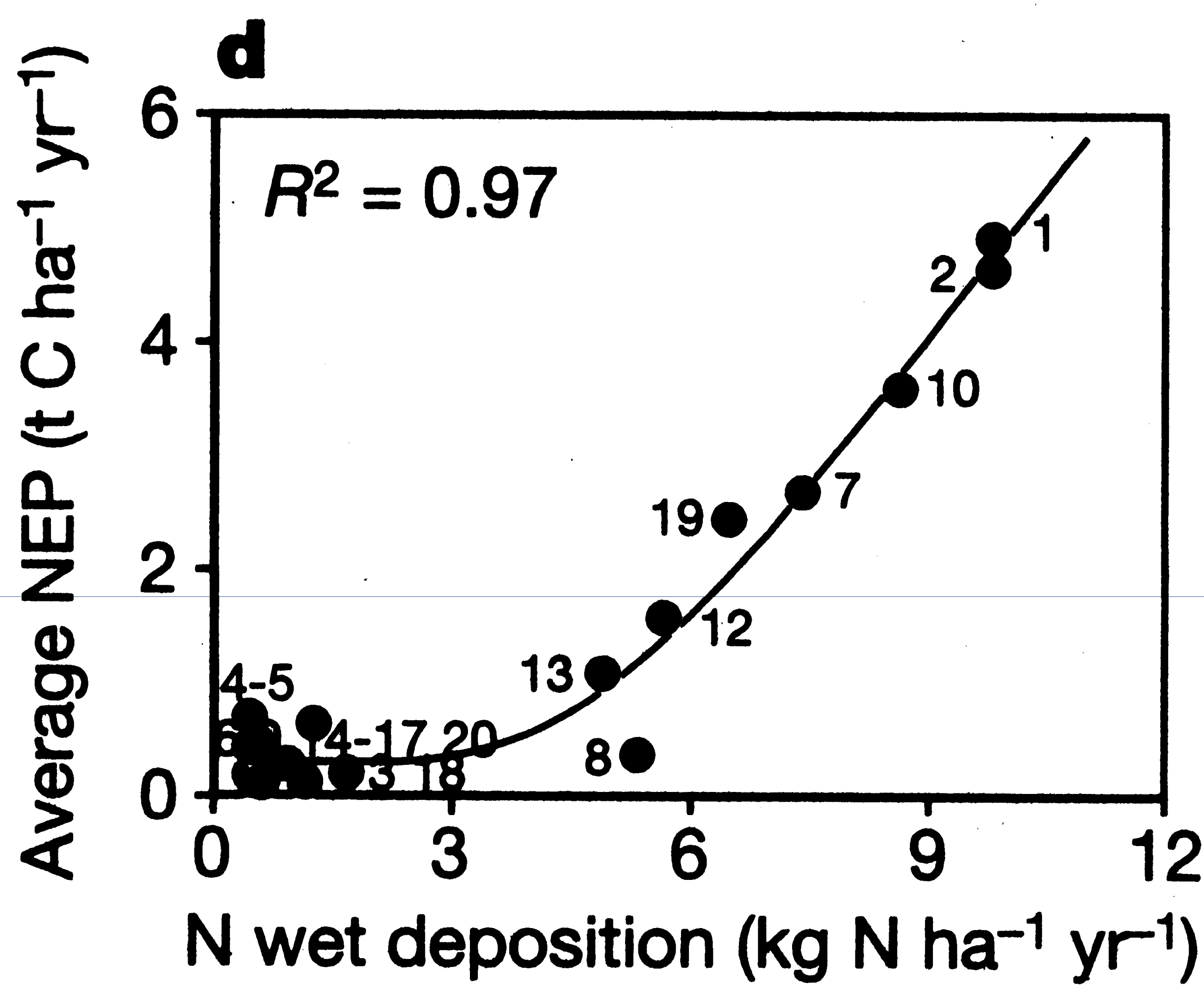


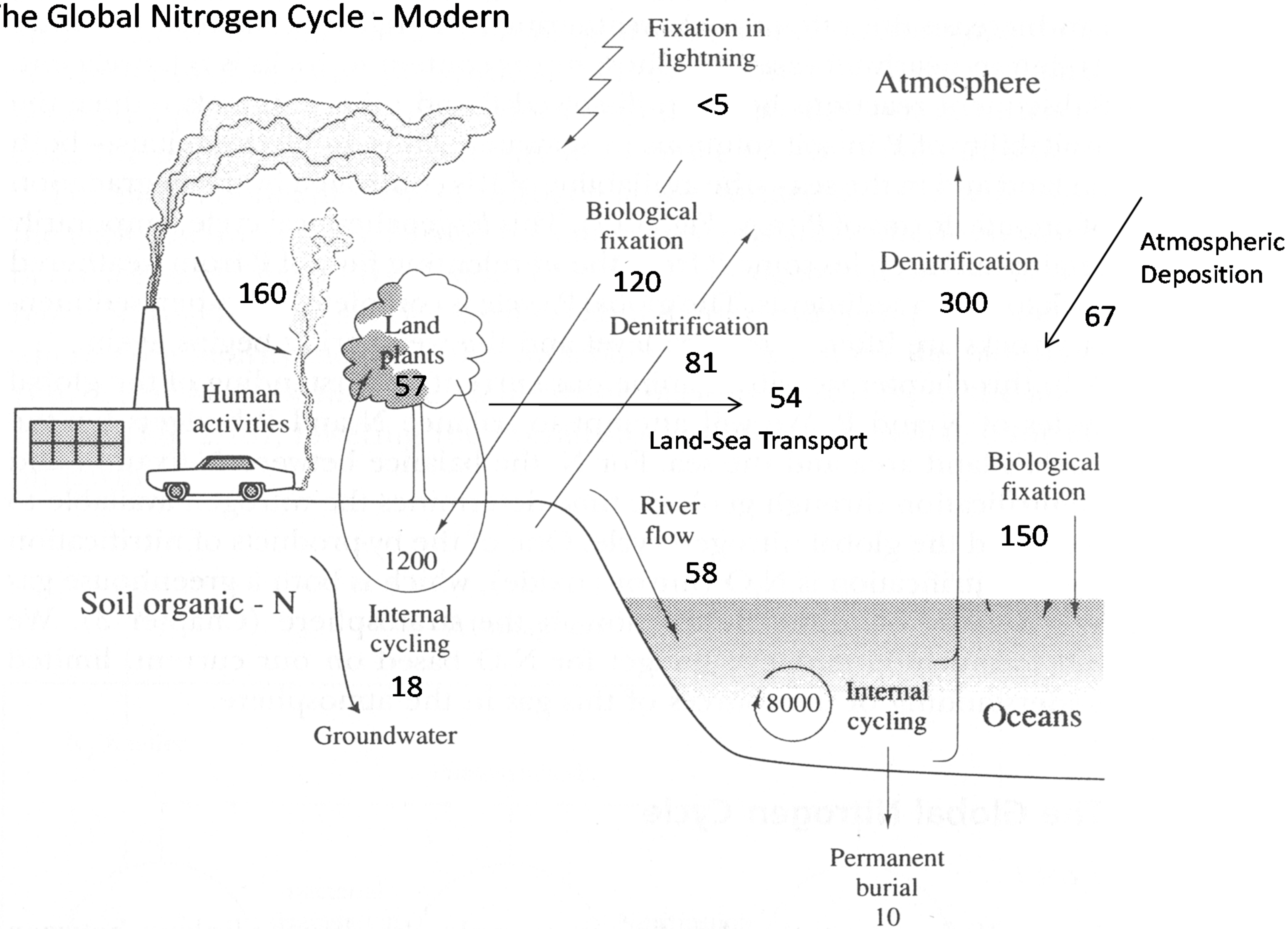
From: Magnani et al. 2007

Table 1.

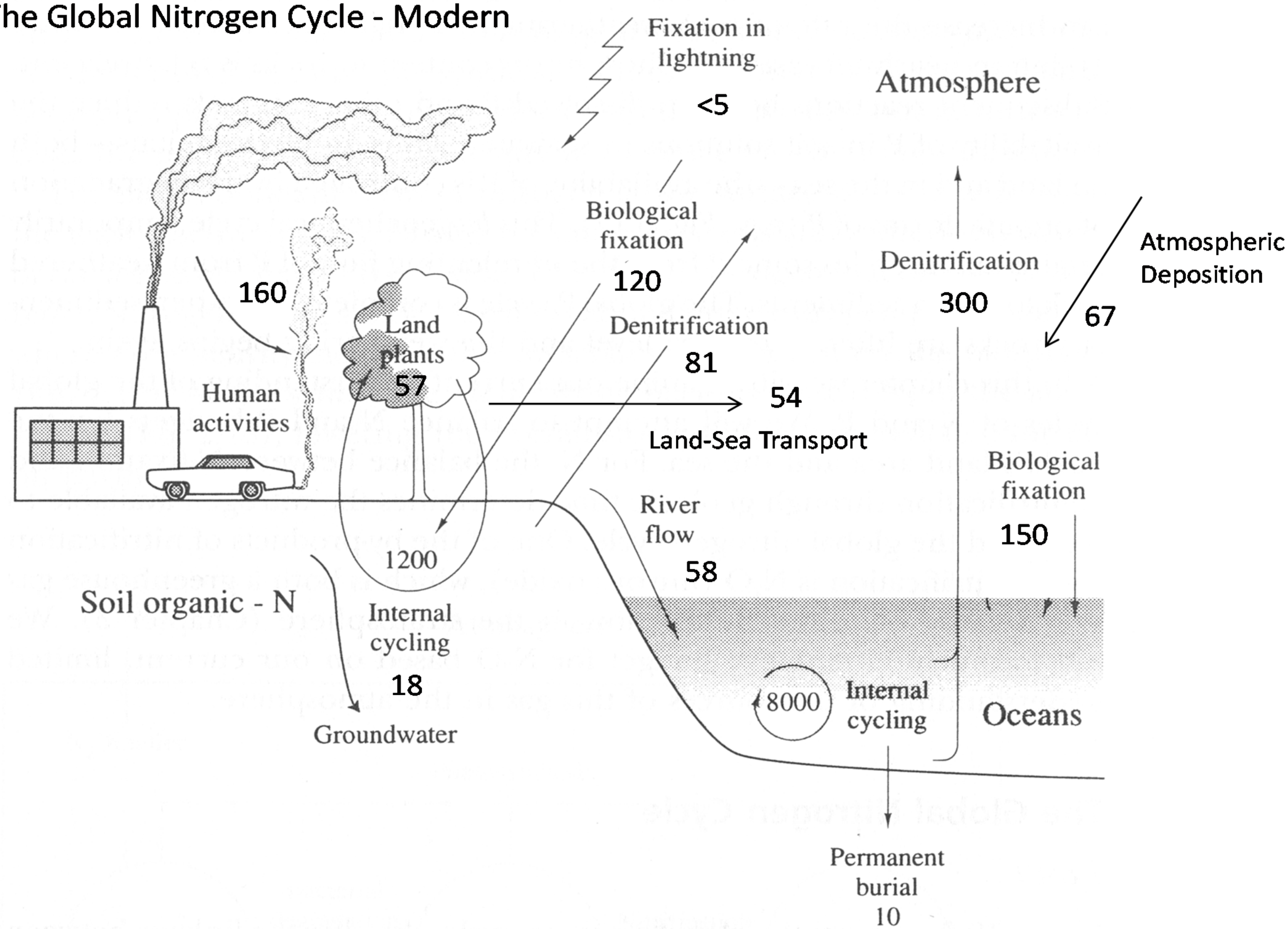
Ecosystem type	Age (years)	Method	Total application (kg N/ha)	Duration of study (years)	Percent recovery in: Plants	Litter	Soil: Inorganic	Soil: Organic	Leachate	Gaseous flux	Total measured recovery (%)	Reference
Pinus resinosa	50	(Treatement)–	276	6	21		1		1	Tr.	23	MaGill et al. (1997)
		(Control)	826	6	8		2		15	Tr.	25	
Mixed deciduous	50		276	6	20		1		2	Tr.	23	
			826	6	13		1		Tr.	Tr.	14	
Pinus contorta	11	$^{15}NH_4$	100	8	17	4	0	41			62	Preston and Mead (1994)
		$^{15}NO_3$	100	8	16	3	0	38			57	
Pinus elliottii	11	(Treatment)–	56	2	25	9		21			55	Mead and Pritchett (1975)
		(Control)	224		27	6		12			45	
Pinus radiata	16	(Treatment)– (Control)	922	9	15	5		21			50	Neilsen et al. (1992)
Pseudotsuga menziesii	35	$^{15}NH_4$	5	2	33	22		24	2		81	Koopmans et al. (1996)
			50	2	29	15		22	33		99	
Pinus sylvestris	45		5	2	10	46		20	10		86	
			50	2	17	21		16	17		71	

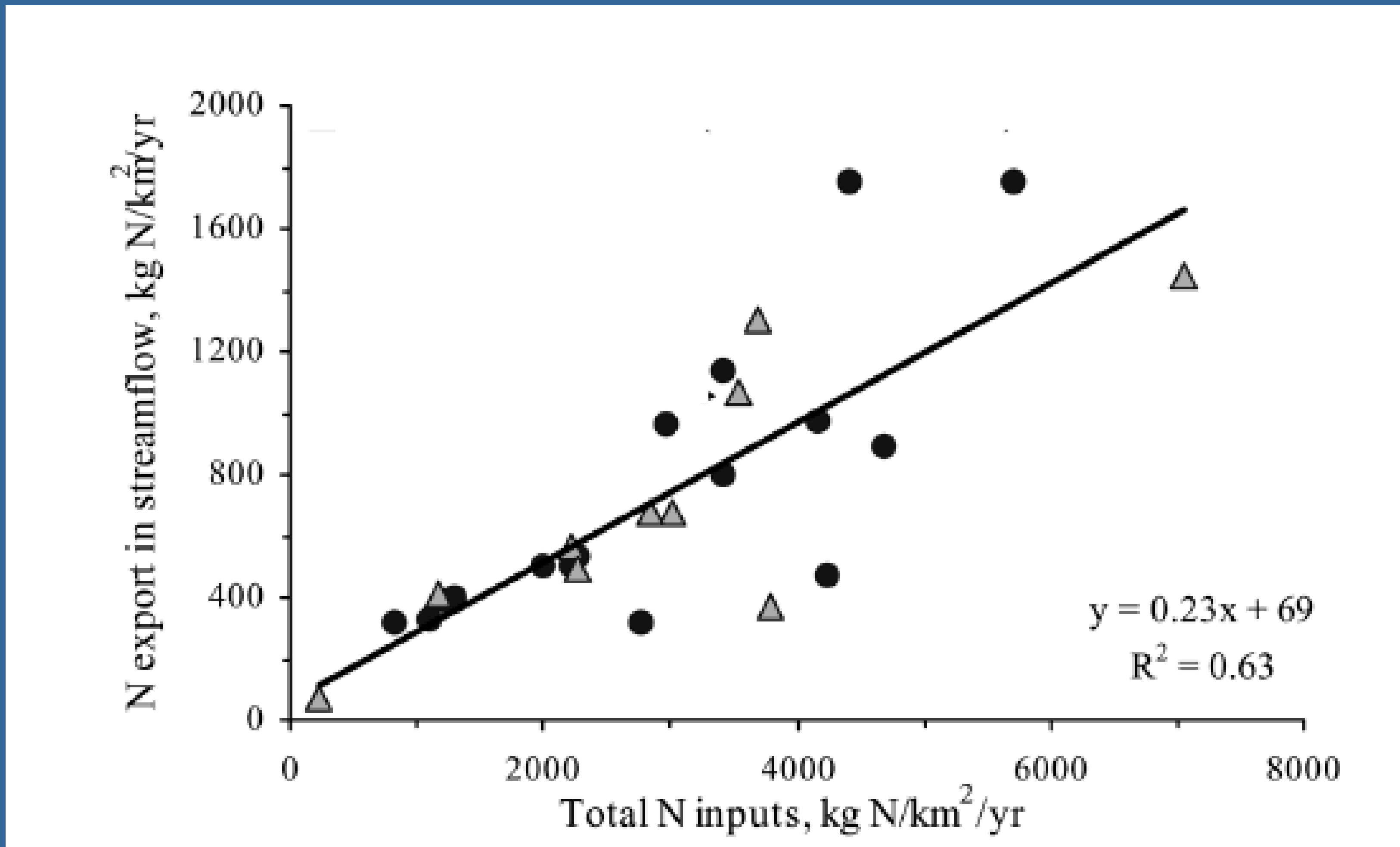
Schlesinger and Andrews. 2000. Biogeochemistry 48:7-20.

The Global Nitrogen Cycle - Modern



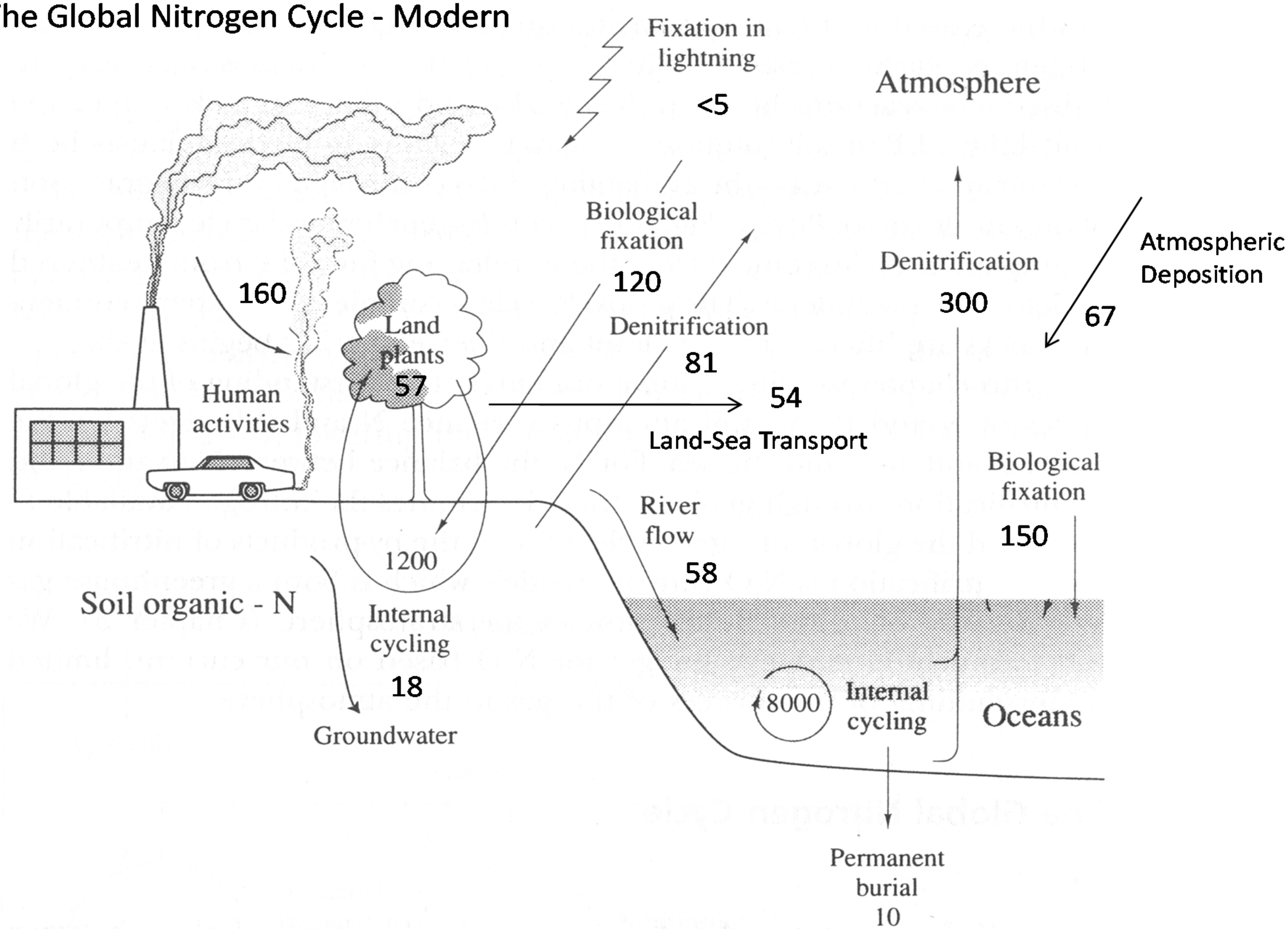
The Global Nitrogen Cycle - Modern

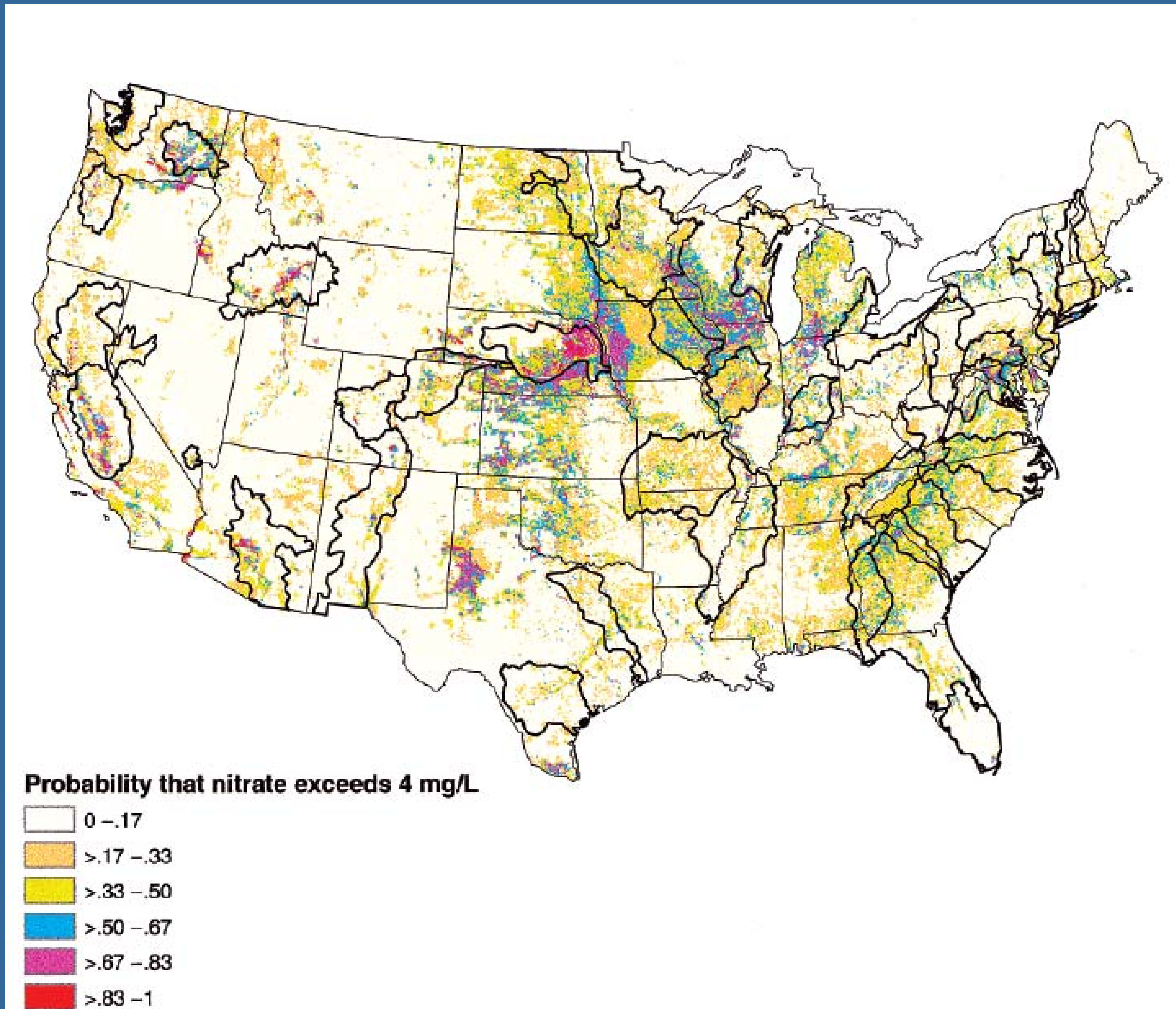




From Van Breeman et al. 2002

The Global Nitrogen Cycle - Modern





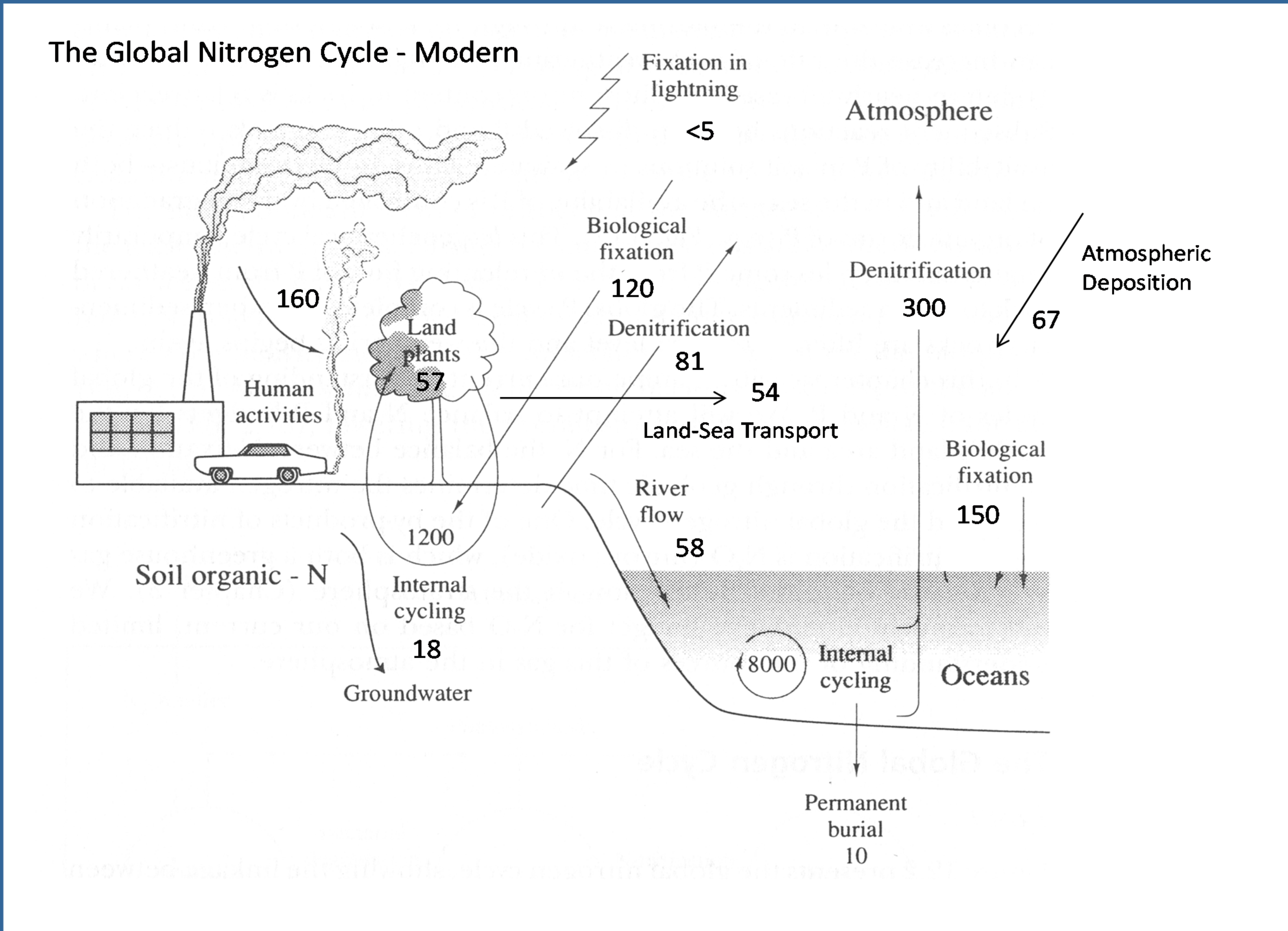
Nolan et al. 2002

Calculation of Groundwater Flux

$12{,}666\ km^3/yr \times 10^{12}\ l/km^3 \times 0.148 = 1{,}874\ km^3/yr$

$1{,}874\ km^3/yr \times 1.9\ mg/l = 3.6\ TgN/yr$ in N. America

$3.6\ TgN/yr\ /0.20 = 18\ TgN/yr$ globally



The Global Nitrogen Cycle - Modern
Fixation in lightning
<5
Atmosphere
Biological fixation
120
Denitrification
300
Atmospheric Deposition
67
160
Land plants
57
Denitrification
81
Human activities
54
Land-Sea Transport
Biological fixation
150
River flow
58
1200
Soil organic - N
Internal cycling
18
Groundwater
8000
Internal cycling
Oceans
Permanent burial
10

Denitrification

$$5CH_2O + 4H^+ + 4NO_3^- \rightarrow$$

$$2N_2 + 5CO_2 + 7H_20$$

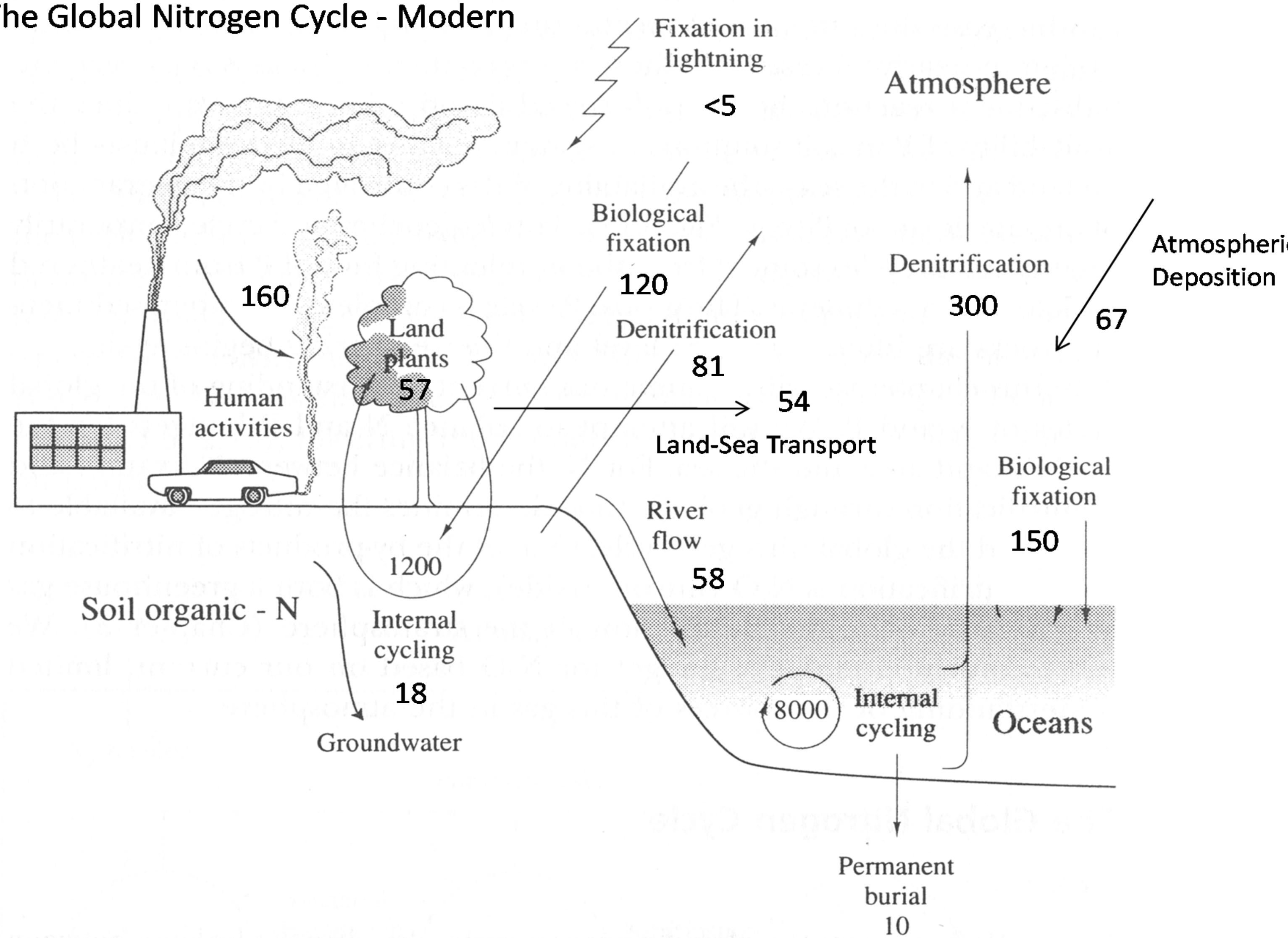
Have you thanked a wetland today?

TABLE 1. Denitrification of land-based N sources based on spatially distributed estimates.

System	Denitrification (Tg N/yr)
Terrestrial	
Soils	124 (65–175)†
Freshwater	
Groundwater	44 (>0–138)‡
Lakes and reservoirs	31 (19–43)
Rivers	35 (20–35)
Subtotal	110 (39–216)
Marine	
Estuaries	8 (3–10)
Continental shelves	46 (>0–70)§
Oxygen minimum zones	25 (>0–30?)¶
Subtotal	79 (3–145)

From: Seitzinger et al. 2006

The Global Nitrogen Cycle - Modern

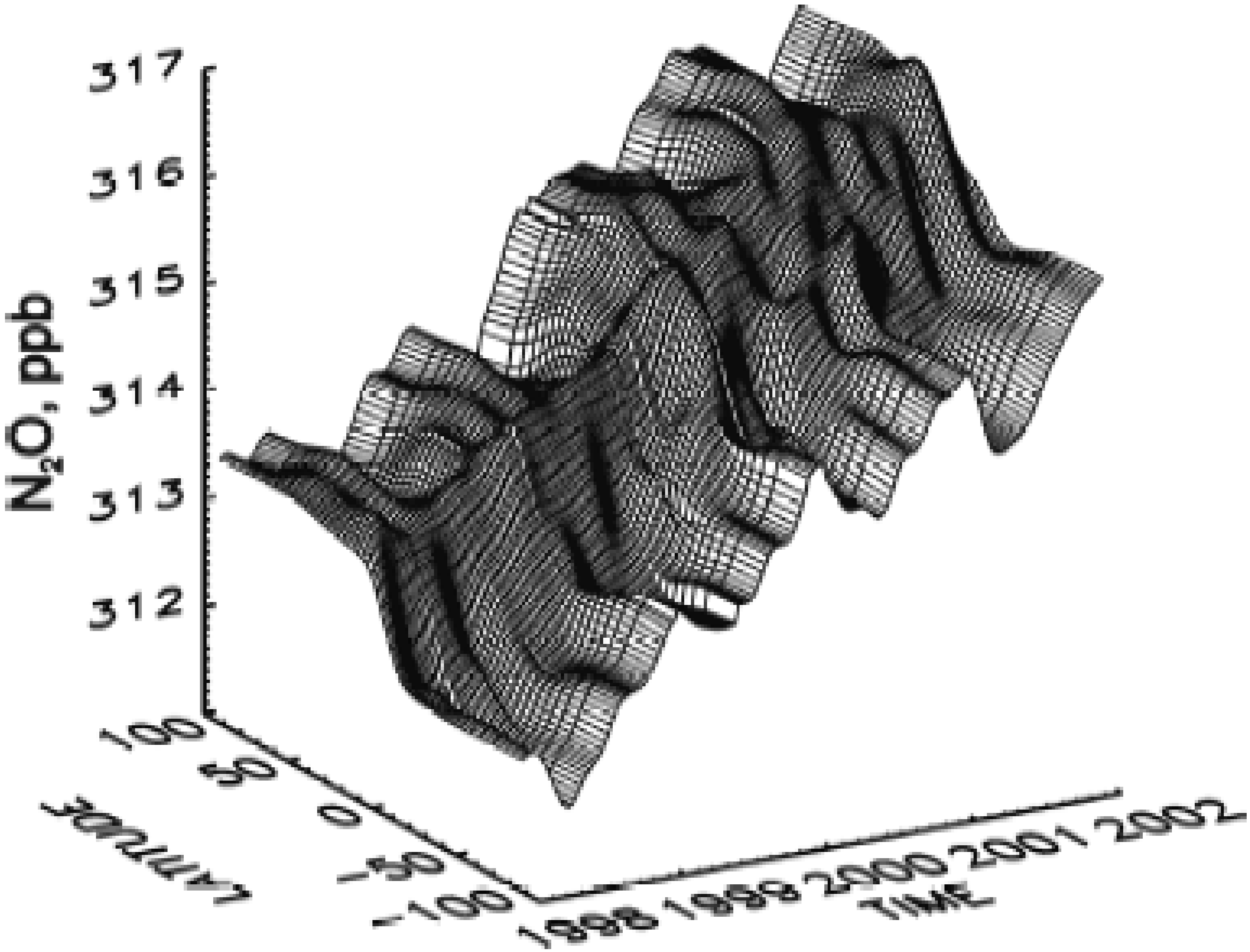


Denitrification

$$5CH_2O + 4H^+ + 4NO_3^- \rightarrow$$

$$2N_2 + 5CO_2 + 7H_20$$

Intermediates include NO and N_2O



Hirsch et al. 2006

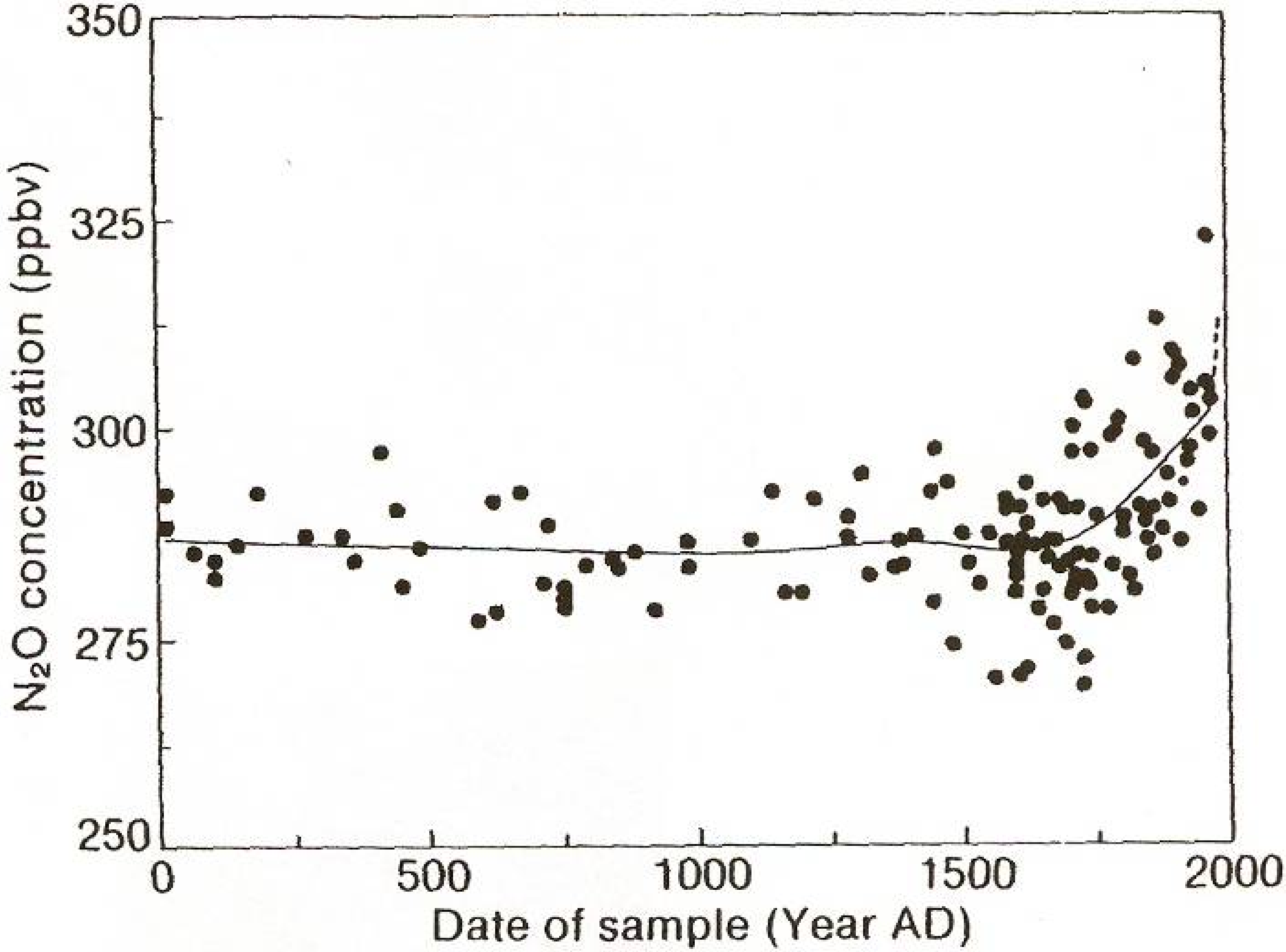


Figure 12.5 Nitrous oxide measurements from ice-core samples, as compiled by Watson et al. (1990).

$$\frac{\Delta N_2 0}{\dfrac{N_2 0}{N_2 + N_2 0}} = \textbf{TOTAL}$$

Table 2. Mean N_2O-yield values from various laboratory and field studies of denitrification

Ecosystem	N_2O-N/(N_2+N_2O)N
Agricultural soils	0.375 ± 0.035 (SE)
Soils under natural or recovering vegetation	0.492 ± 0.066 (SE)
Freshwater wetlands and flooded soils	0.082 ± 0.024 (SE)

Full dataset is available as Table S1.

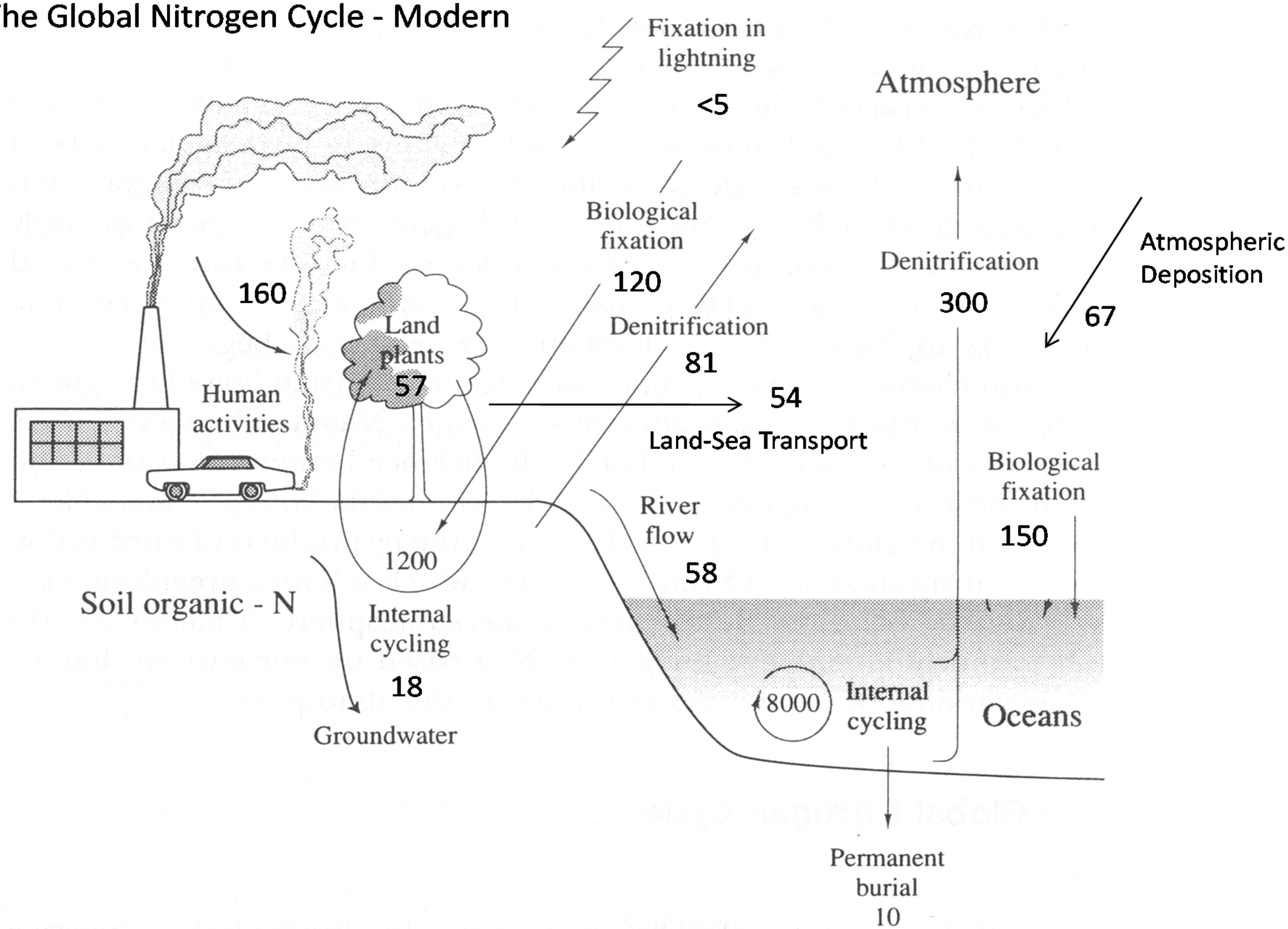
Schlesinger 2009

Calculation of change in denitrification from N_2O

$$124\ \mathrm{Tg}\ (0.37) + 110\ \mathrm{Tg}\ (0.082) = 234\ \mathrm{Tg}\ (0.246)$$

$$4\ \mathrm{TgN_2O/yr}\ /\ 0.25 = 17\ \mathrm{TgN/yr}$$

The Global Nitrogen Cycle - Modern



Mass-balance for nitrogen on the Earth's land surface. All values are in TgN/yr (=10^{12} g N/yr)

Inputs	Preindustrial	Human derived	Total
Biological N fixation	60[a]	60[b]	120
Lightning	5	0	5
Rock weathering	20[c]	0	20
Industrial N fixation	0	136[d]	136
Fossil fuel combustion	0	25	25
Total	85	221	306
Fates			
Biospheric increment	0	9	9
Soil accumulation	0	48	48
Riverflow	27	31	58
Groundwater	0	18	18
Denitrification	27[e]	17	44
Pyrodenitrification	25[f]	12	37
Atmospheric land–sea transport[g]	6	48	54
Total	85	183	268

Schlesinger and Bernhardt. 2013. Biogeochemistry, 3rd Edition.


Marsh between RR and upland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