Phosphorus in lakes - The old paradigm, a paradigm shift, and the future

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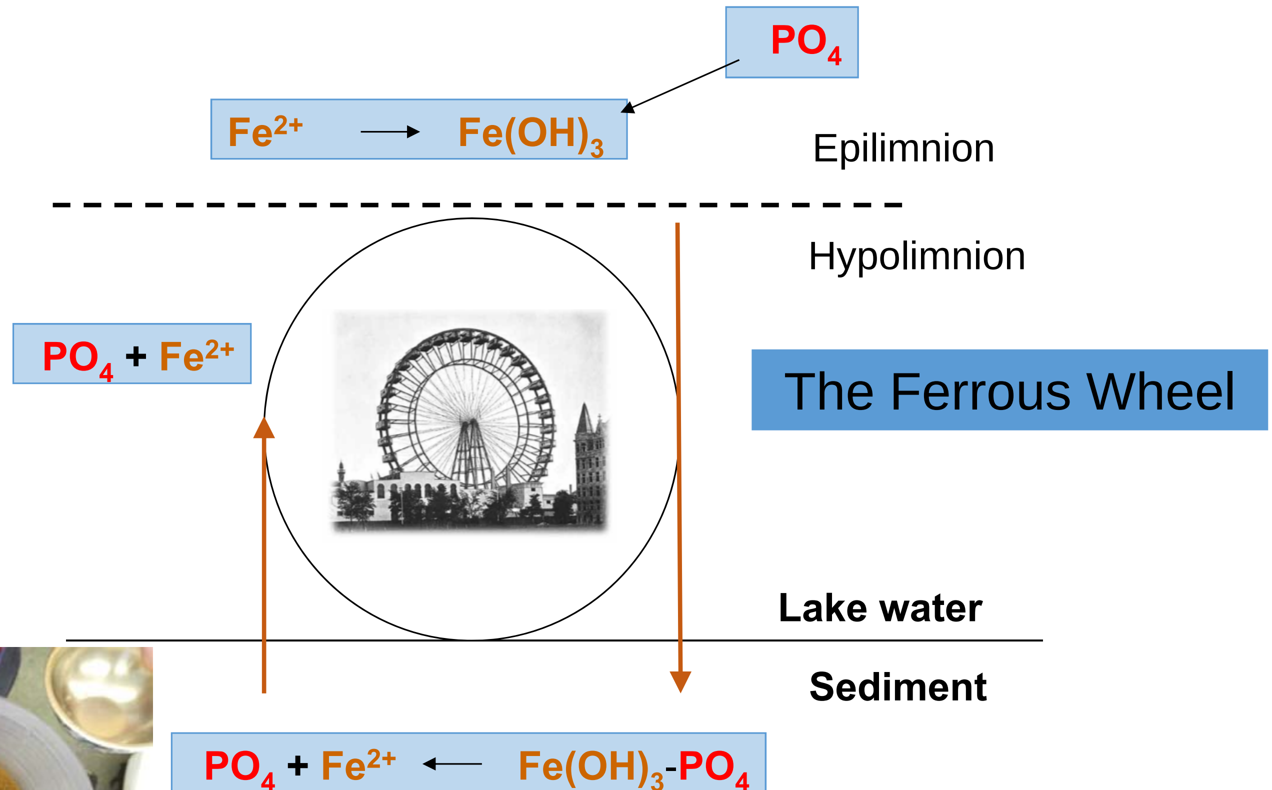
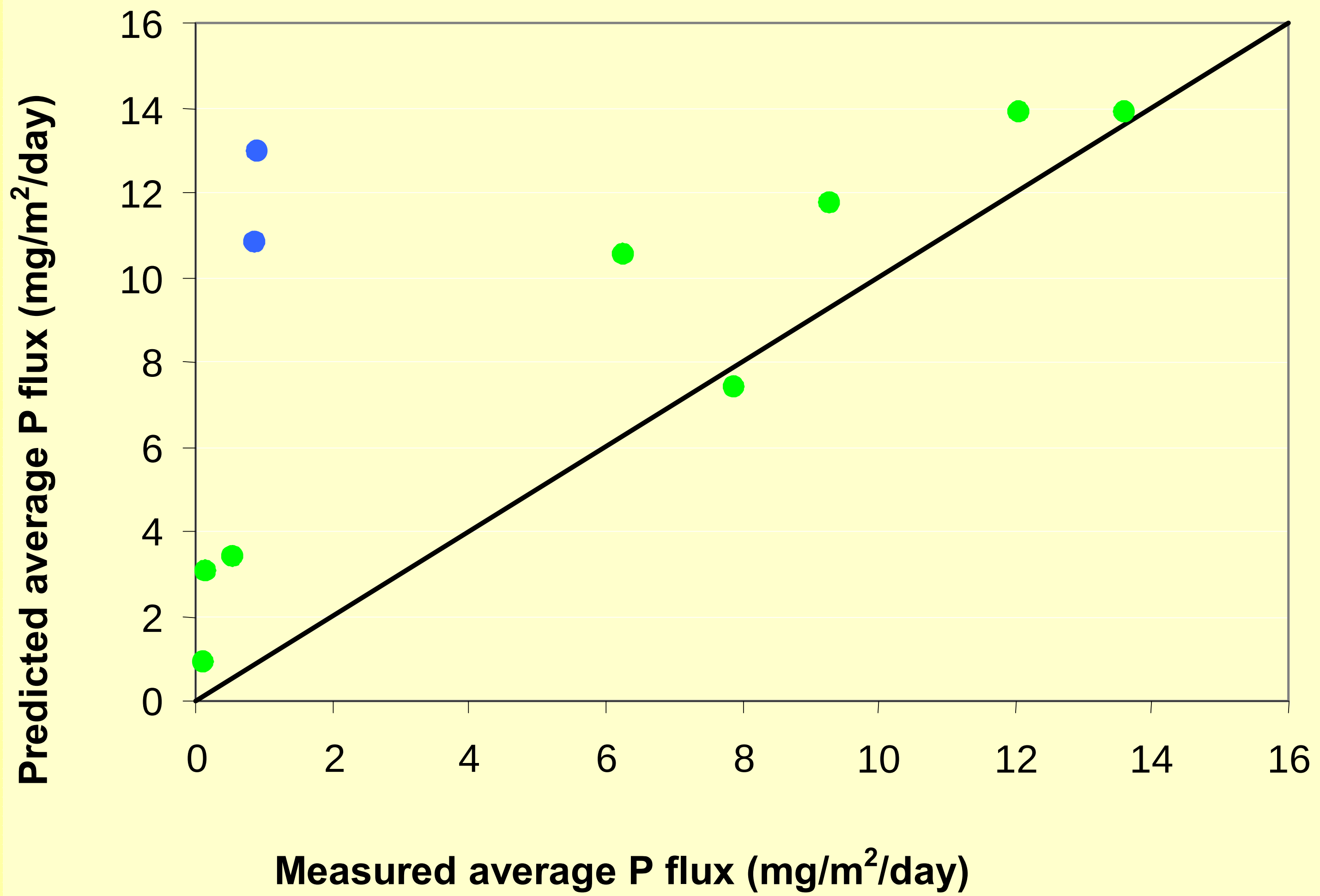
H = hydrogen, as in H_2O
C = carbon, as in CO_2
O = oxygen as in H_2O or O_2
Al = aluminum
P = phosphorus
Fe = iron

Group → / ↓Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo
		*	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
		**	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	



Concept from Einsele (1936) and Mortimer et al. (1941)

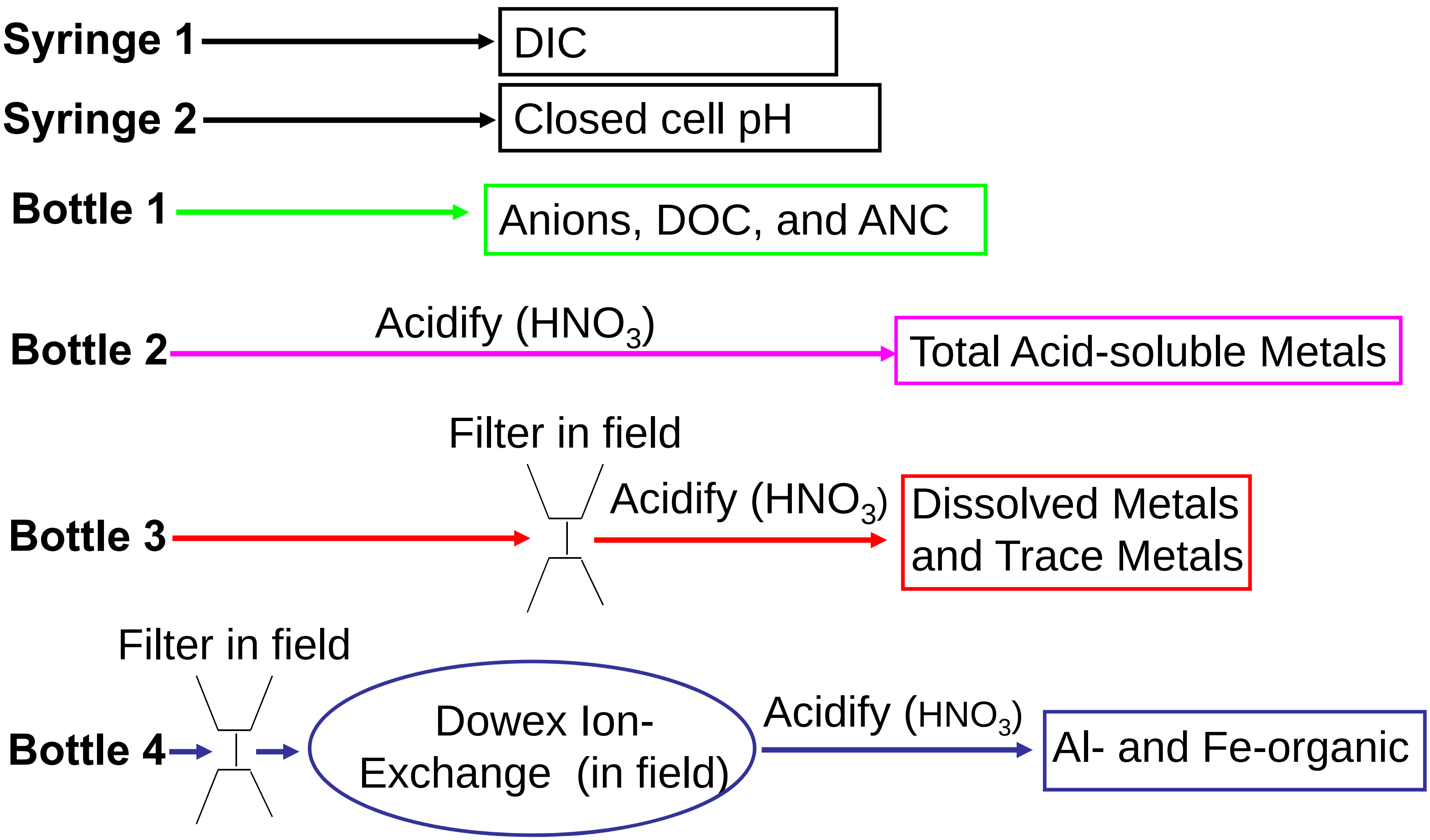
Insert courtesy of G. W. G. Ferris (1882)

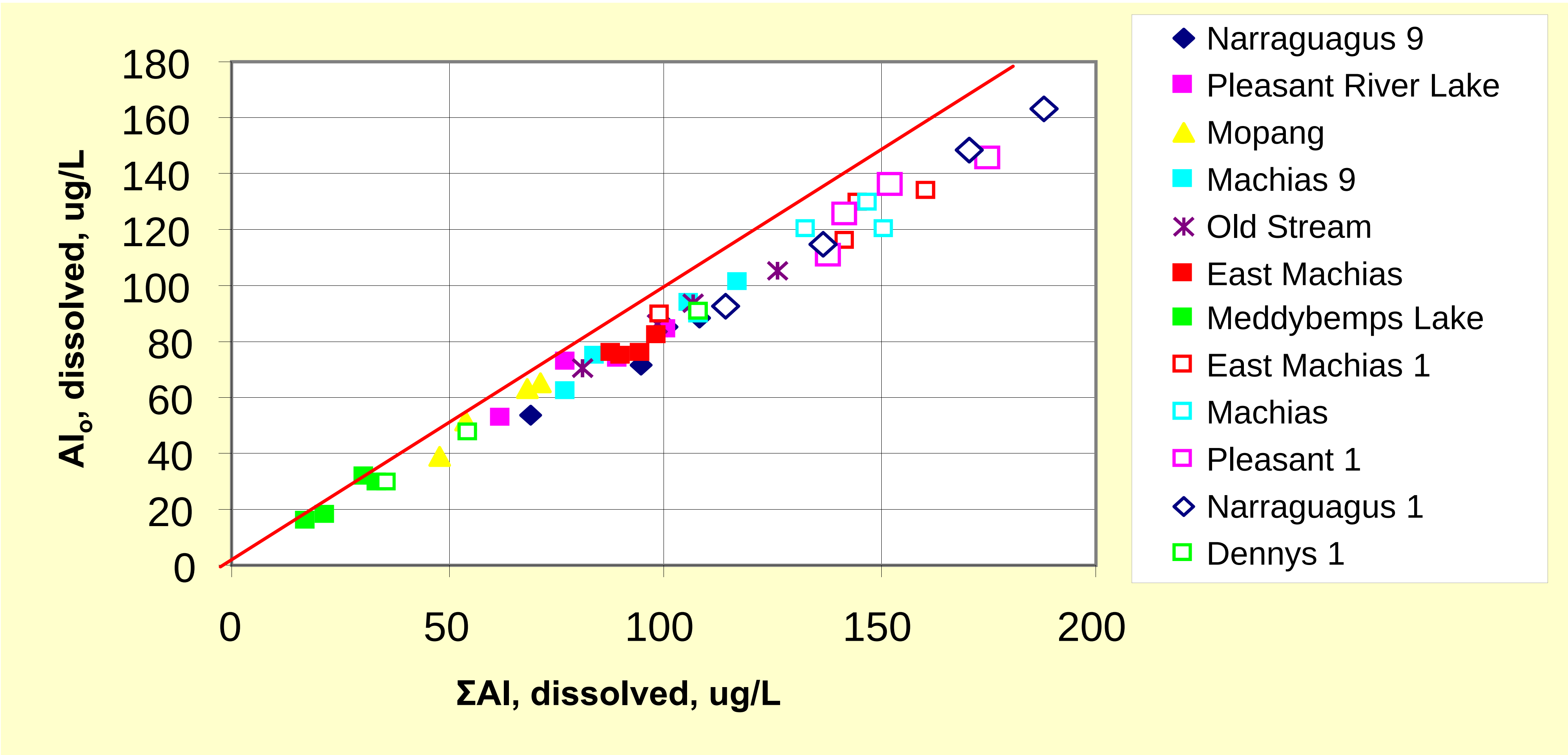


after Amirbahman et al. (2003)

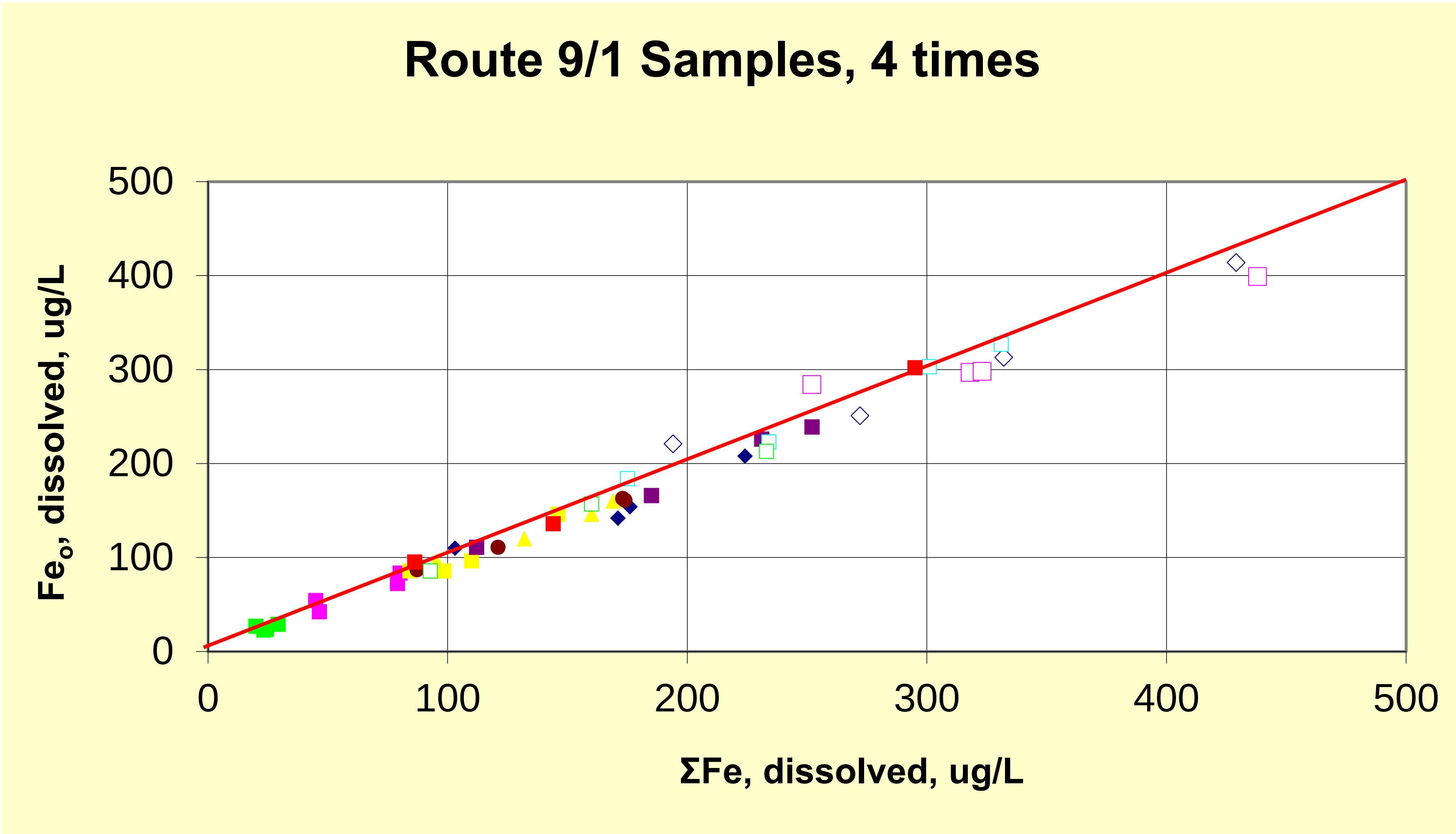
What broke the “ferrous wheel”?

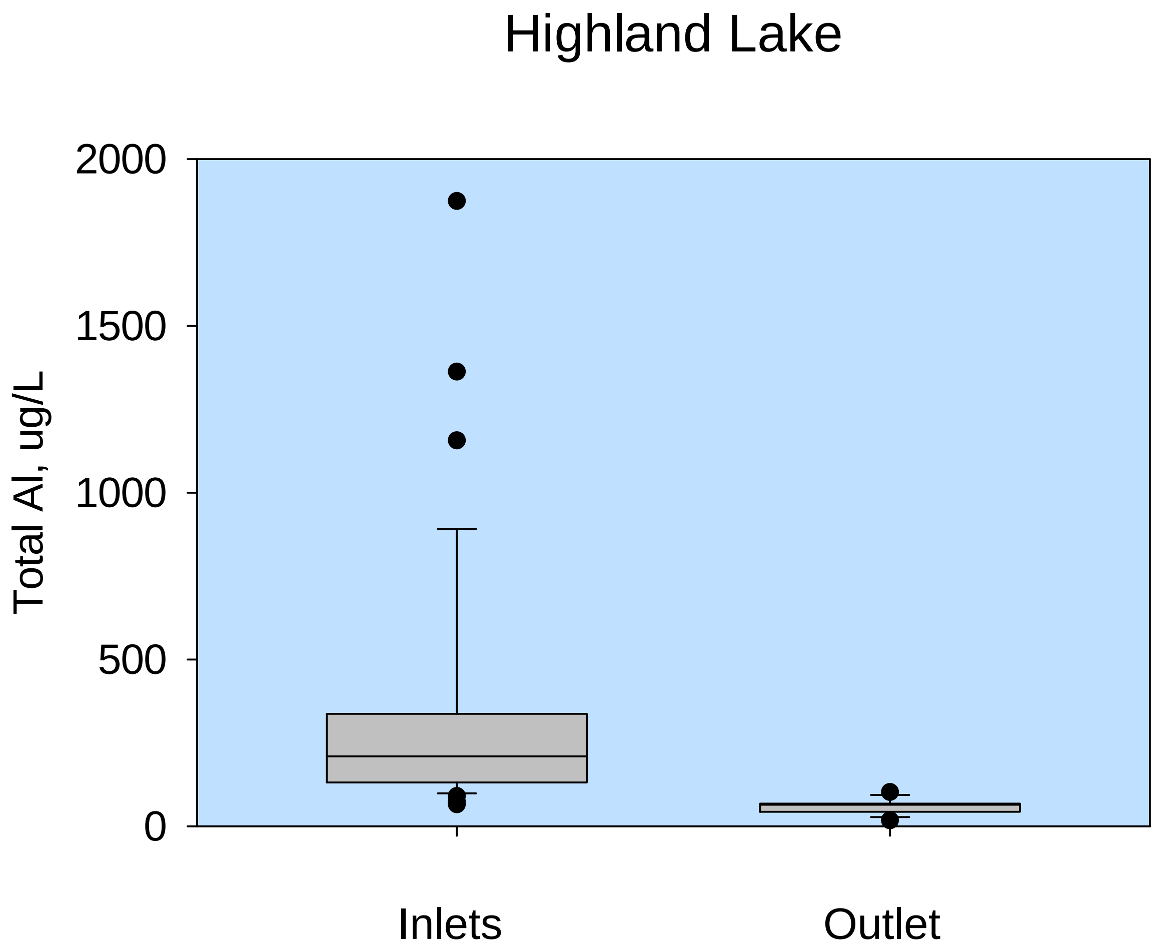
Sampling Method

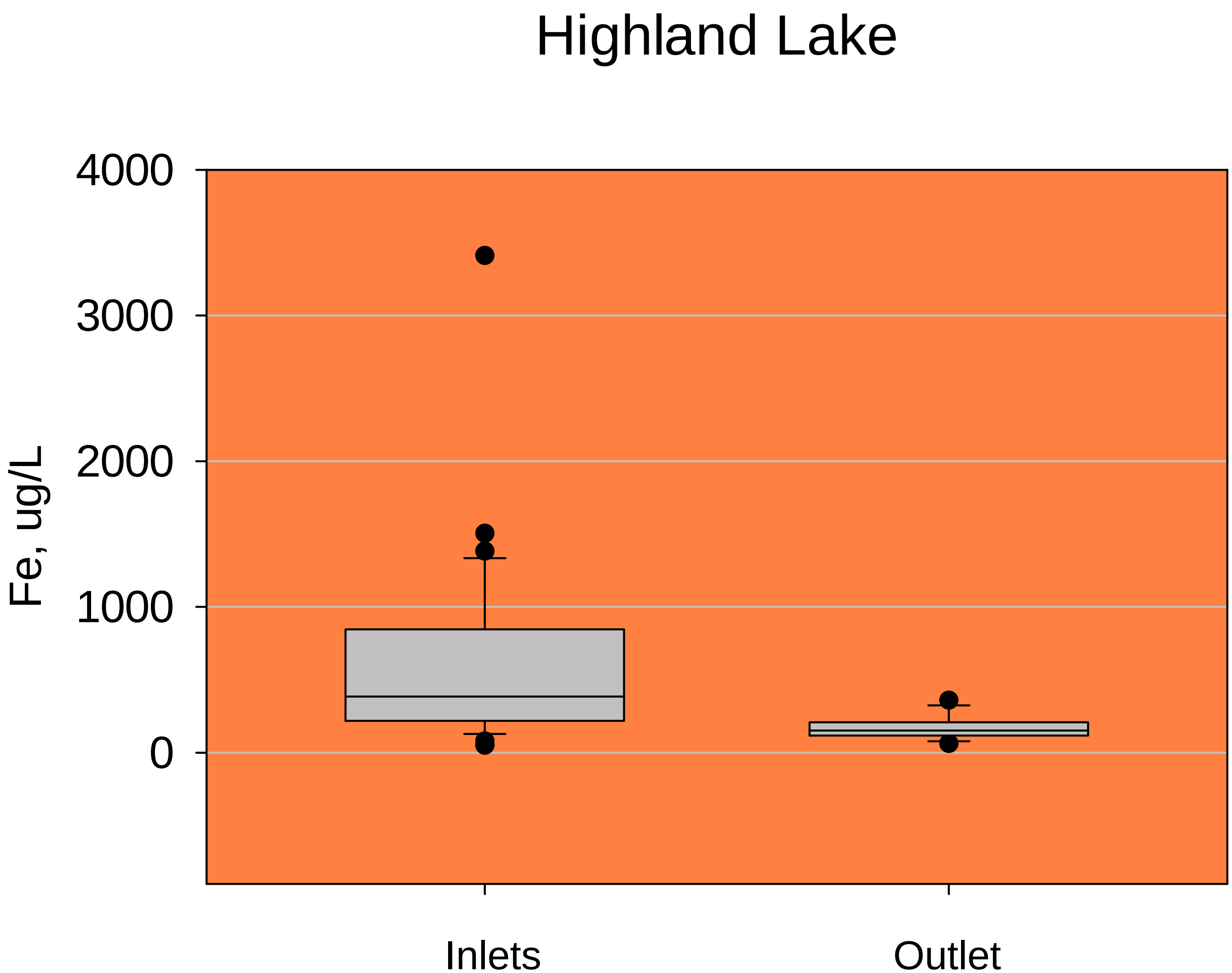


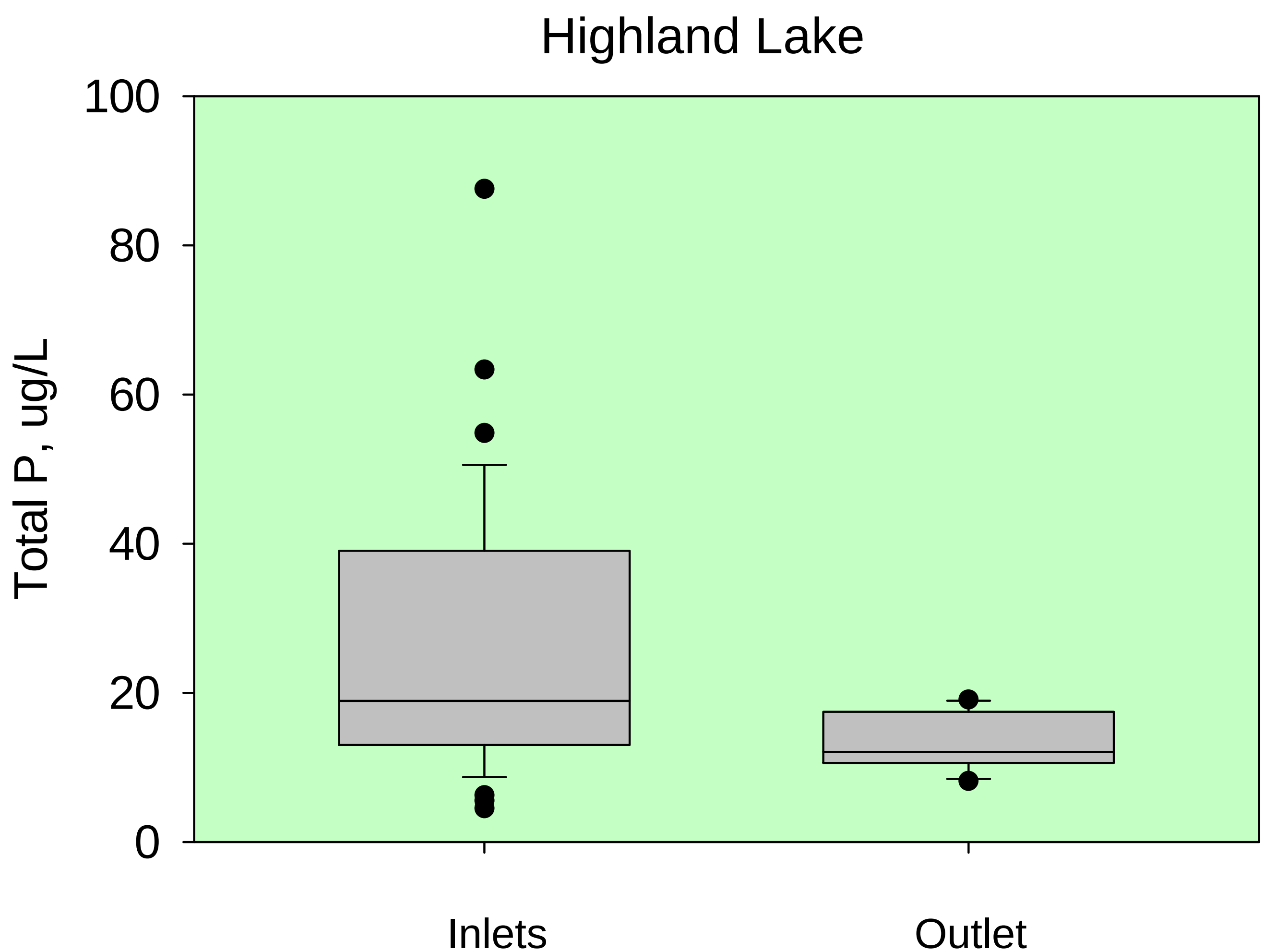


180
160
140
120
100
80
60
40
20
0
0
50
100
150
200
ΣAl, dissolved, ug/L
Al$_o$, dissolved, ug/L
Narraguagus 9
Pleasant River Lake
Mopang
Machias 9
Old Stream
East Machias
Meddybemps Lake
East Machias 1
Machias
Pleasant 1
Narraguagus 1
Dennys 1


Route 9/1 Samples, 4 times
Fe_o, dissolved, ug/L
0
100
200
300
400
500
0
100
200
300
400
500
ΣFe, dissolved, ug/L


Highland Lake
2000
1500
1000
500
0
Total Al, ug/L
Inlets
Outlet


Highland Lake
Fe, ug/L
4000
3000
2000
1000
0
Inlets
Outlet



Highland Lake
100
80
60
40
20
0
Total P, ug/L
Inlets
Outlet

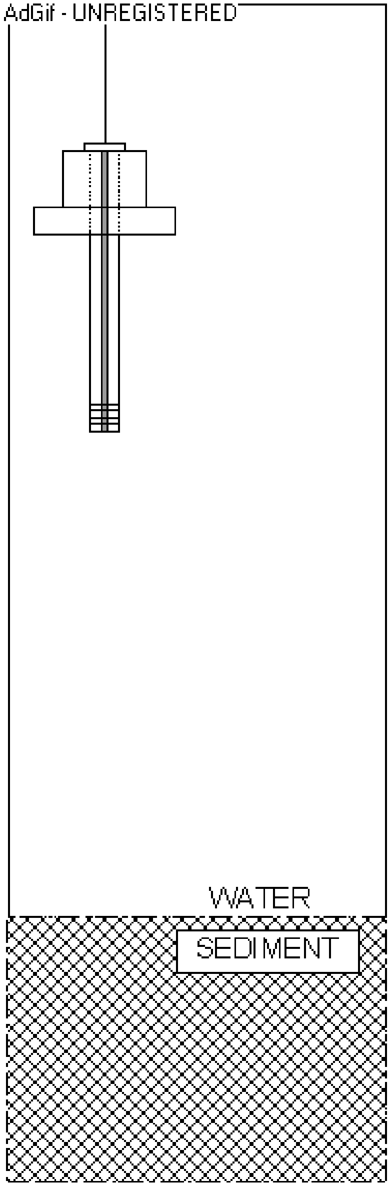
Al and Fe are quite insoluble in lakes with pH 5.5-8 (most of Maine lakes). How does all the Al and Fe get into lakes?

Al and Fe in soil + DOC $\longrightarrow$ dissolved Al-DOC + Fe-DOC in streams and lakes

So, how does the soluble Al-DOC and Fe-DOC get removed from lakes?

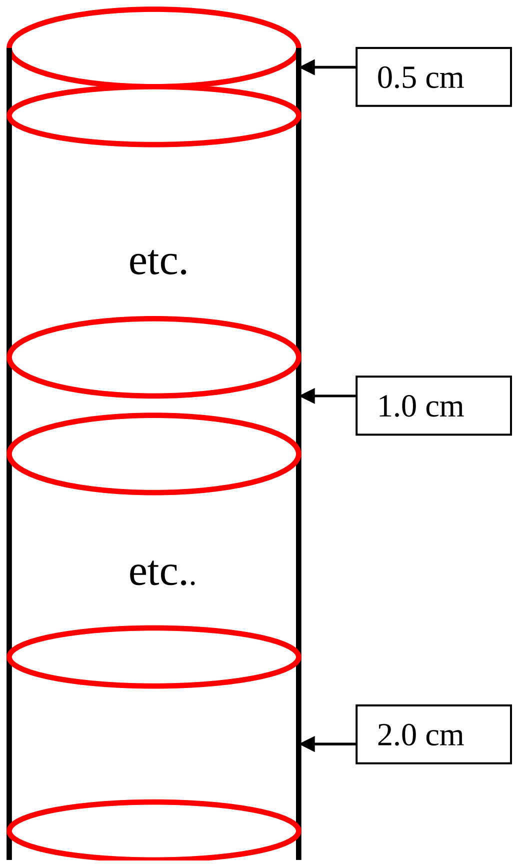
dissolved Al-DOC + Fe-DOC in lakes + sunlight $\longrightarrow$ dissolved Al + Fe, both of which then precipitate as $Al(OH)_3$ and $Fe(OH)_3$, both of which adsorb PO_4 from the water column

Coring (profile)



thanks to K. Coolidge

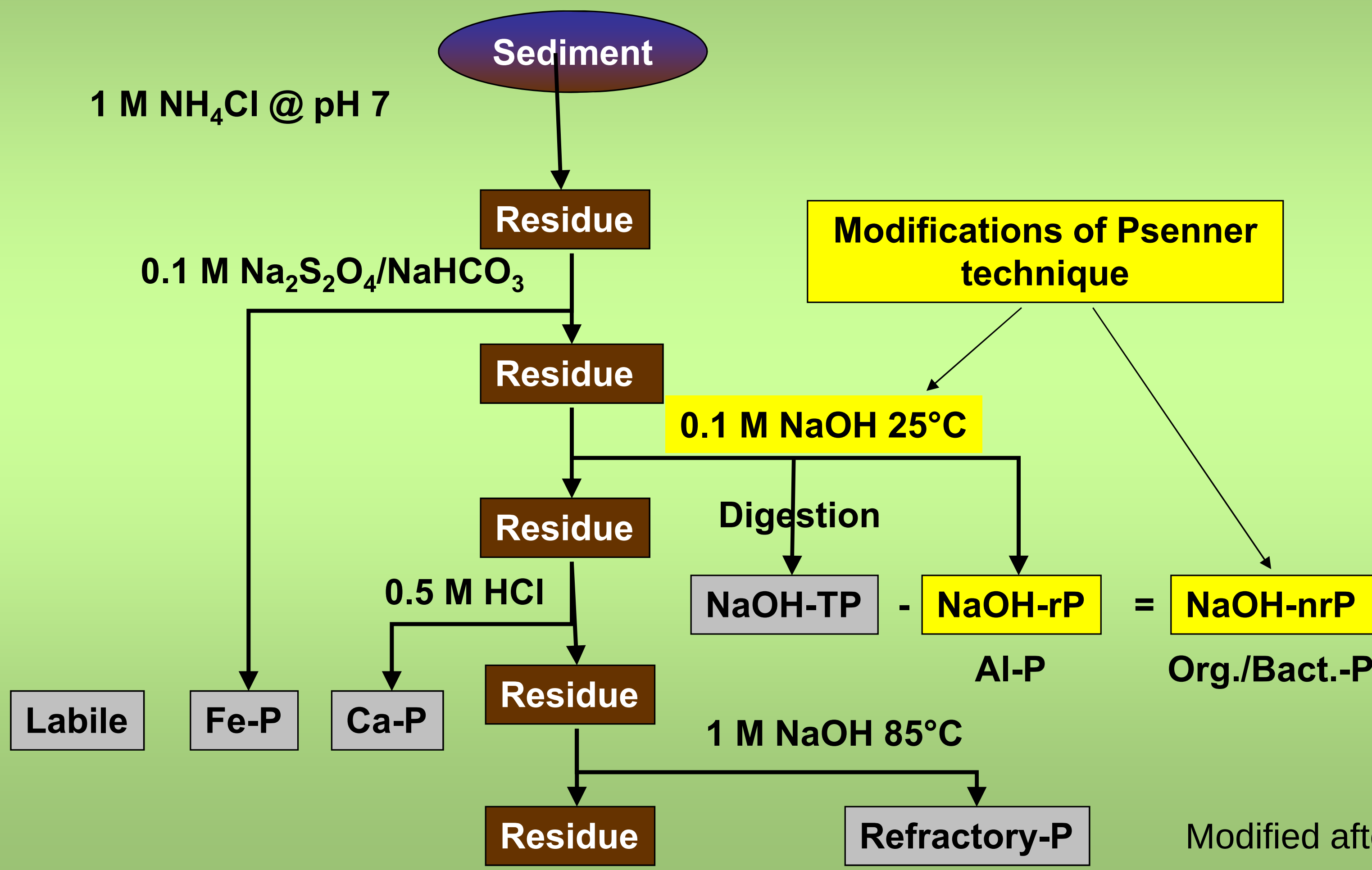
Dissecting the Core
Lake sediment



H_20 (%), 110°C
LOI (%) = % org., 550°C
Conc. = (ug Hg)/(g dry sed.)
^{210}Pb = Bq/(g dry sed.)
$t_{1/2}$ = 22 y
^{137}Cs (1963/4 maximum)
^{241}Am (1963/4 maximum)

Speciation of the elements of interest, including Al, Fe, and P

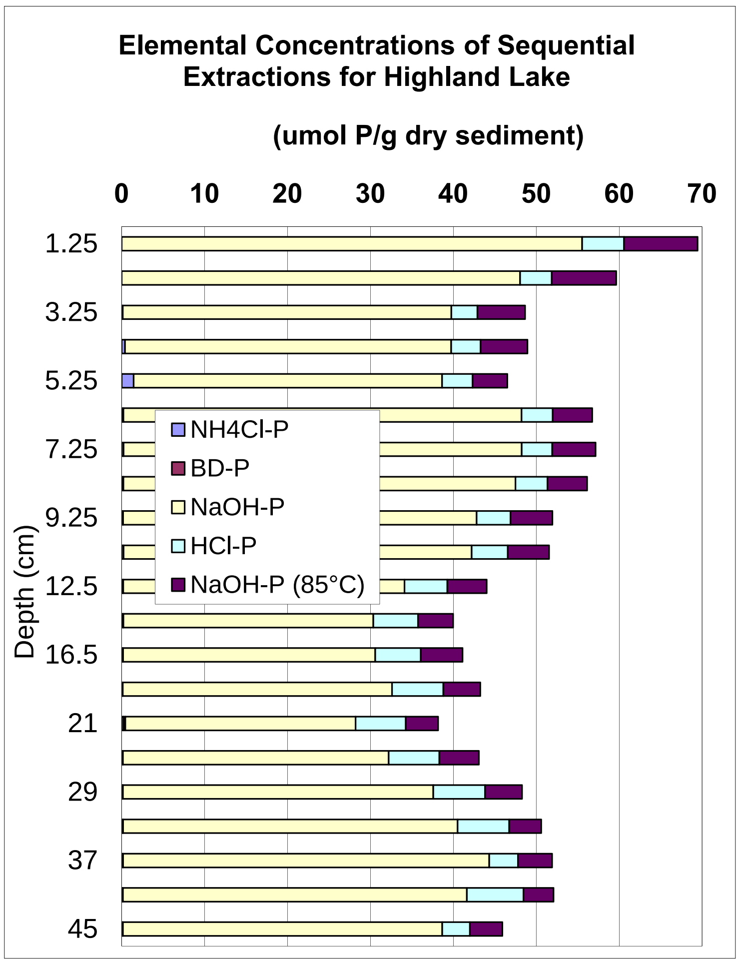
Sequential Extraction

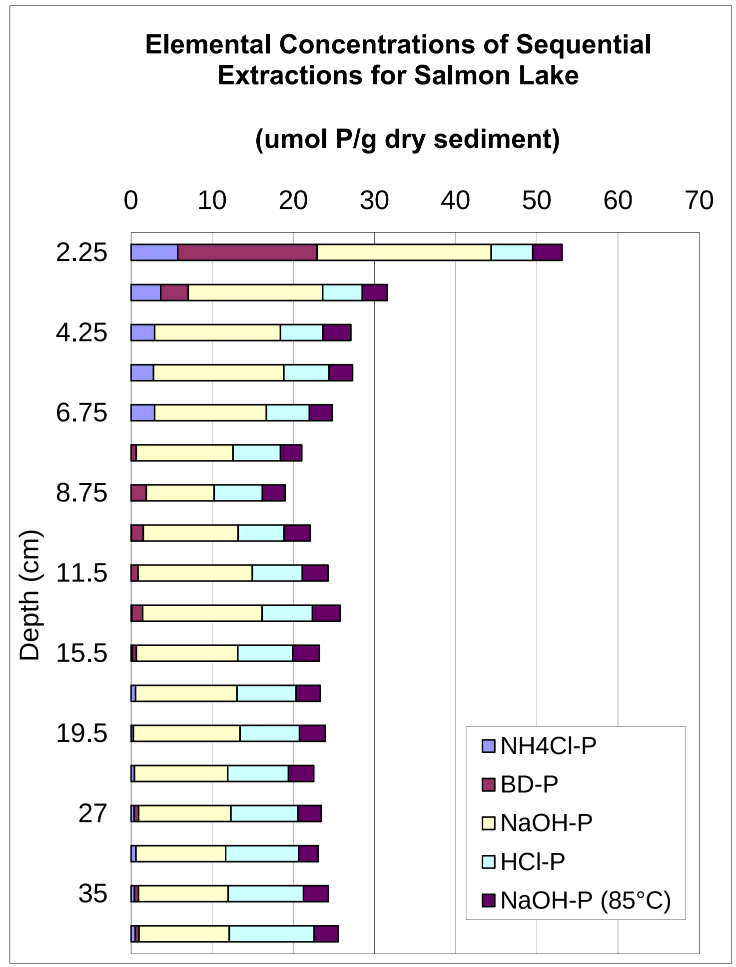


Modified after Psenner

P speciation in sediment of two Maine lakes

(data from K. Coolidge)





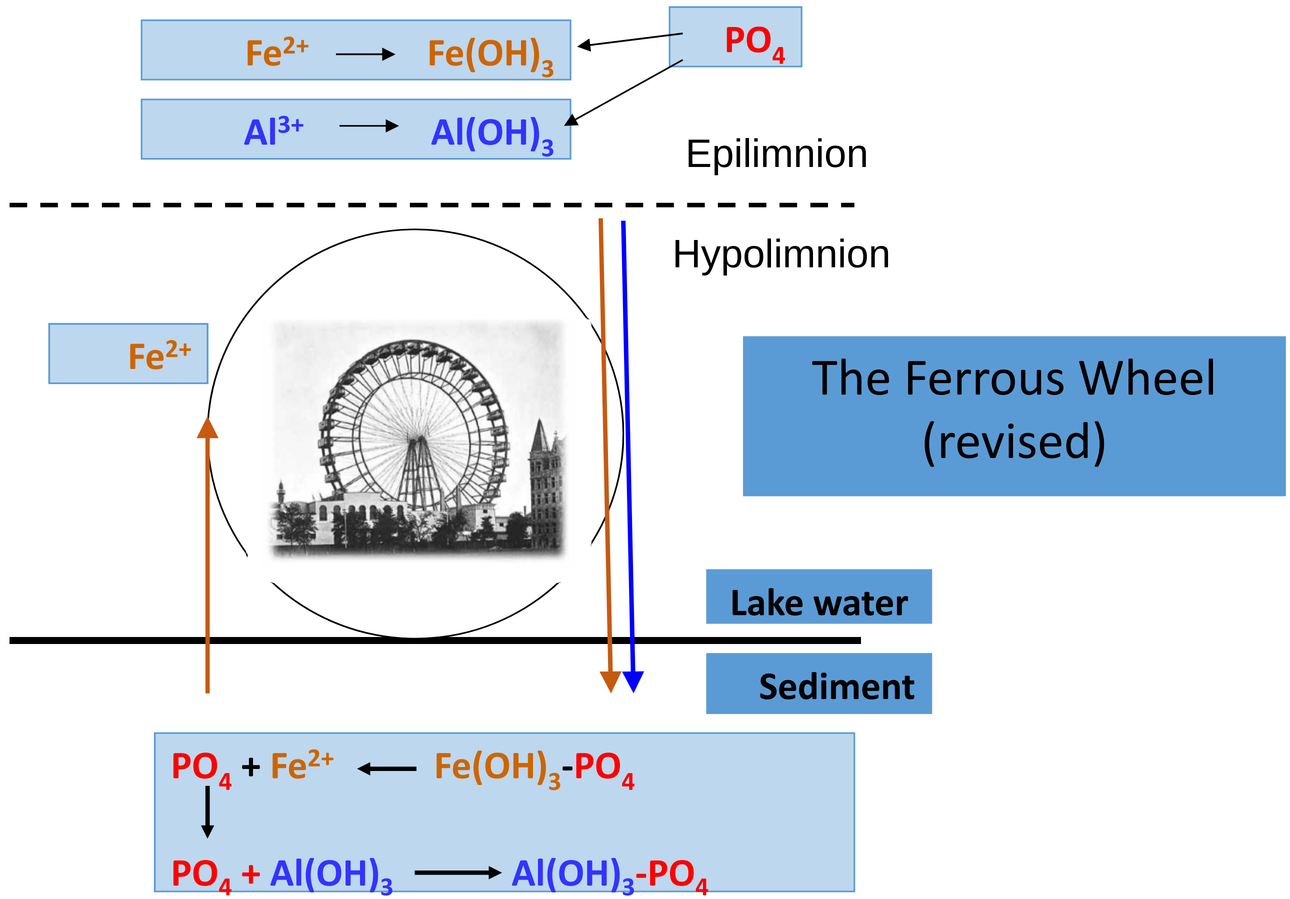
The magic numbers!

If extractable $Al(OH)_3$:$Fe(OH)_3$ > 3, there is little release of P

If extractable $Al(OH)_3$:$Fe(OH)_3$ < 1, = P release is substantial if ….

If extractable $Al(OH)_3$:$P_{(Fe\text{-}associated)}$ > 25, there is little release of P

for example, Lake Auburn…….



$Fe^{2+} \rightarrow Fe(OH)_3$
$Al^{3+} \rightarrow Al(OH)_3$
PO_4
Epilimnion
Hypolimnion
Fe^{2+}
The Ferrous Wheel
(revised)
Lake water
Sediment
$PO_4 + Fe^{2+} \leftarrow Fe(OH)_3\text{-}PO_4$
$PO_4 + Al(OH)_3 \rightarrow Al(OH)_3\text{-}PO_4$

Thinking ……………………………………….


Sargent Mountain Pond, Maine

Assembling the pieces of a biogeochemical problem

- Water in streams and lakes
- Speciation of the chemistry of water
- Speciation of the chemistry of sediments

and now to the future…..

Engaging citizen scientists to evaluate potential for water quality decline in Maine lakes

Senator George J. Mitchell Center for Sustainability Solutions

University of Maine

FY16 Sustainability Research Grants

A focused study of 24 Maine lakes to: (1) develop a lake *Vulnerability Index* that combines stakeholder engagement parameters with physical and chemical indicators (all with VLMP help) to predict which lakes are more susceptible to deterioration in water quality, (2) identify, through surveys and interviews, the underlying factors that result in successful collaborations among VLMP monitors, homeowners, and lake associations on lake stewardship activities, and (3) use the data to develop a blueprint of activities that can positively influence stewardship behavior among the public.

citizen involvement \ trophic state	low		high
high	Thompson (4400*) Emden (1568) Hopkins (442)	Long (2700) Great (8240) Messalonski (3500) North (2900)	Salmon (666)/McGrath (486) East (1823)
	Pleasant in Casco (1312) Clearwater (750) Pleasant in Caratunk (1120)	Damariscotta (4400) Mousam (900)/Square (840) Taylor (650) Meddybemps (6765)	Sabbatus (1960) Unity (2500) Webber (1200)
low	Tunk (2010)	Auburn (2260)	China (3844)

* Numbers are lake surface area in acres

Who is involved?

A consortium of Maine D.E.P., U.Maine, U.S.Maine, VLMP, and VLMP monitors

What are we doing?

1. Targeted sampling and characterization of sediment and water samples (2X). First round complete.

2. Written surveys from, and interviews with, VLMP volunteers and lake associations. "In the mail".

3. Workshops with Lake Associations and volunteers on how lakes function

4. Compiling metrics about lakes and their watersheds

5. Development of a *Vulnerability Index* capable of predictive power for water quality in a changing physical and chemical climate

Why bother?

Better understanding of social and scientific dynamics related to lake protection, leading to better protection of Maine's aquatic gems