

A brief review of some aspects of phosphorus dynamics relevant to Lake Winnipeg remediation

Lake Winnipeg Stewardship Board
Selkirk, Manitoba
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Phosphorus facts

History

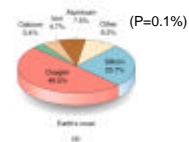
Brand (Germany 1669) discovered phosphorus in 1669 by extraction from urine.

Sources

Phosphorus is the 12th most abundant element in the earth's crust; because of the great reactivity of the element, it is always found in combined form, usually as phosphates (salts of H_3PO_4). Large deposits are found in Russia, in Morocco, and in Florida, Tennessee, Utah, Idaho, and elsewhere.

Uses

Phosphoric acids have become of great importance to agriculture and farm production. World-wide demand for fertilizers has caused record phosphate production.



Biological NB of P

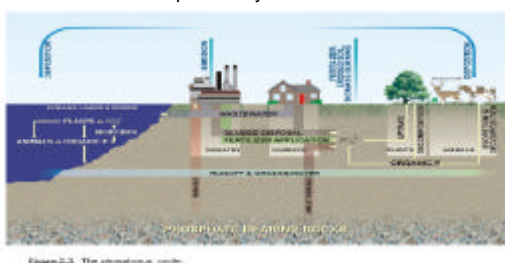
- Phosphorus essential ingredient of all cell protoplasm (RNA, DNA), nervous tissue, and bones
- A 91 kilogram (200 lb) person contains 1 kg of P. The ratios (SF) of the 8 main (of 22) elements in the body (H:O:C:N:Ca:P:S:Na) are:
375 : 132 : 85 : 6 : 2 : 1 : 0.2 : 0.1
- Note departure from ratio (106:16:1) proposed by Redfield (1934, 1942, 1958), for oceanic ecosystems. Current ocean data sets indicate moderate deviations from this formula. **Freshwater systems show very large differences from the RR.** (Sterner and Elster – Ecological Stoichiometry: The biology of Elements from Molecules to the Biosphere).
- Largemouth bass contain 3.8grams P/100 grams dry weight (3.8% P)



Phosphorus content of Lake Winnipeg commercial fish species

- 5 year mean (1994 – 1999) combined catch for whitefish, walleye and sauger in Lake Winnipeg = 3.73 M kg rd. wt.
- Estimated P dry wt. content of fish ~ 3.8% (Carlander 1977)
- Estimated total P in fish catch = 142 tonnes P/yr.
- Mean annual (1994 – 2001) Lake Winnipeg P load = 5597 T
- Commercial fish catches remove 2.5 % of P from lake.**

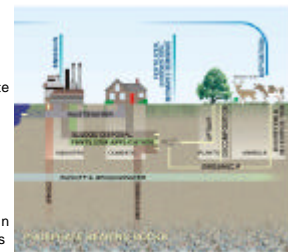
The Phosphorus Cycle Chambers et al. 2001



- P (unlike N) does not exist naturally in the elemental state
- Rock (apatite) and soil is the largest P reservoir
- All atmospheric sources of P derived from erosion, fertilizer drift, industrial emissions
- P exists in only one environmentally active form, PO_4^{3-} the orthophosphate ion.

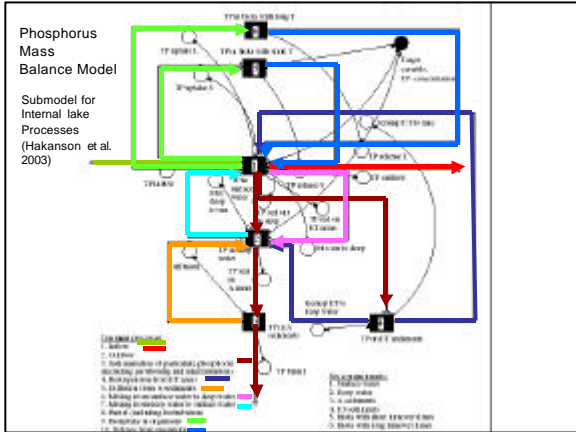
In the terrestrial compartment:

- P uptake as PO_4^{3-} into plants
- Plants grazed and animals excrete excess P as phosphorus salts in urine and faeces
- P converted from organic form to phosphate ion by bacteria, fungi
- PO_4^{3-} binds with many +ve ions (Fe, Al, Ca) forming insoluble compounds that are immobilized in terrestrial and aquatic ecosystems
- P added to agricultural soils in excess of natural weathering processes
- Municipal, industrial sources add P to water (wastewater), air (emissions), soil (landfills, sludge application)
- Land runoff in urban areas, forests, crop fields, provides P to vegetation



Aquatic phosphorus analytical forms:

- Total phosphorus (TP) is a measure of all forms of P in a sample of water including 1. **dissolved** [2 types- Total Dissolved P (TDP), and Soluble Reactive P, (SRP)] and 2. **particulate** forms (sediment, including plankton and suspended sediments)



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APPLIED ISSUES

A mass-balance model for phosphorus in lakes accounting for biouptake and retention in biota

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SUMMARY

1. A new mass-balance model was developed to predict phosphorus fluxes to, within and from lakes and lake concentrations of phosphorus.

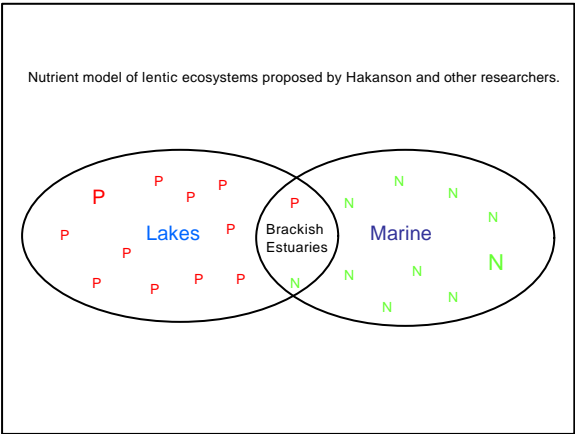
2. The model is driven by data easily accessed from standard monitoring programmes or maps, so it should be useful in many contexts of lake management.

3. The phosphorus model gives seasonal (weekly) variations and accounts for all fundamental abiotic/biotic interactions and feedbacks for lakes in general for phosphorus. The model has been developed within the framework of a more comprehensive ecosystem model, LakeWeb, which accounts for production values and biomass of nine functional groups of organisms (phytoplankton, bacterioplankton, herbivorous and predatory zooplankton, prey and predator fish, zoobenthos, macrophytes and benthic algae).

4. The LakeWeb-model has been critically tested in a wide limnological domain and shown to predict very well. By using this model, it is possible for the first time to predict realistic values of biouptake and retention of phosphorus in biota in lakes on a weekly basis.

Hakanson et al. 2003

- "...most (if not all) previous mass-balance models for phosphorus miscalculate the abiotic fluxes of phosphorus, and to compensate for such mistakes, it has been necessary to make even more mistakes to handle the retention of phosphorus in the given lake so that there is good correspondence between empirical data and modeled values"
- "Total phosphorus is the nutrient most likely to limit lake primary productivity (Schindler, 1977, 1978; Bierman, 1980; Chapra, 1980; Boynton, Kemp & Keefe, 1982; Wetzel, 1983; Persson & Jansson, 1988; Boers, Cappenberg & van Raaphorst, 1993)".
- "In contrast to phosphorus, nitrogen is generally recognised as the most likely limiting nutrient in marine areas. However, both elements are important in humic lakes, estuaries and brackish waters (Redfield, 1958; Ambio, 1990; Nixon, 1990)."



Some scrutiny of the reasoning given to control both N & P

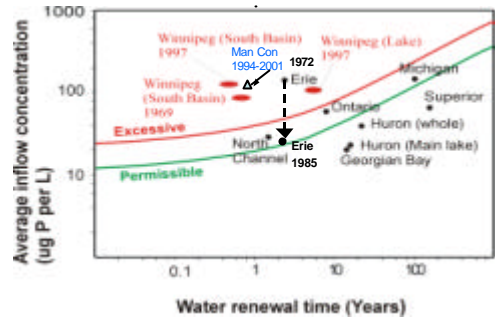
- US EPA approach. It was suggested that:
 - "recent studies show that nitrogen is limiting as often as phosphorus (Elsner et al. 1990)".
 - The concluding statement in this paper remarks "Finally, to the degree that some lakes can respond to N-reduction by increasing N₂ fixation (as in Lake Winnipeg), P-reduction will generally be a more reliable means to achieve lower algal standing stocks in the long term".
- European experience. It was suggested that:
 - "Commission of the European Communities requires control of both nitrogen and phosphorus from communities larger than 10,000 people.... (Directive 91/271/EEC)"
 - The Directive actually states:
 - "Table 2 of Annex I to Directive 91/271/EEC is replaced by the following text: Table 2: Requirements for discharges from urban waste water treatment plants to sensitive areas which are subject to eutrophication as identified in Annex II.A(a). One or both parameters may be applied depending on the local situation. The values for concentration or for the percentage of reduction shall apply."

Reasons for N and P removal (continued)

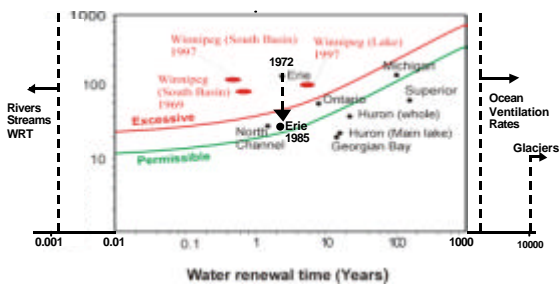
- New science in Prairie Regions
 "Assiniboine River study identified nitrogen being as important as phosphorus in limiting algal growth".

Granted that shallow prairie stream ecosystems may be regulated by N and P, nevertheless their structure and functioning cannot be compared to the much deeper and larger Lake Winnipeg ecosystem. Significant physical differences between lentic and lotic ecosystems result in dissimilar energy and nutrient pathways. Differences between stream/river/pond and large lake biological communities also lead to substantial variations in productivity and nutrient cycling.

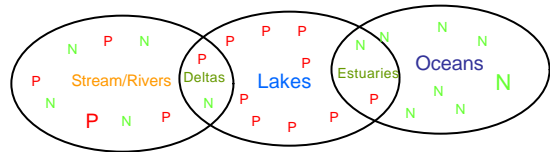
Phosphorous concentrations in inflowing water plotted as a function of water renewal time. Laurentian lakes data from the IJC, Vollenweider 1976. Lake Winnipeg data from Brunskill et al.1980, Patalas and Salki 1992, and Stewart et al. 2000.



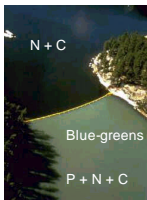
Water renewal times of hydrosphere compartments



Possible model of limiting nutrient in lentic and lotic compartments of hydrosphere



Recent findings relevant to nutrient control strategies for Lake Winnipeg

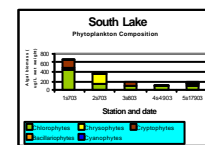
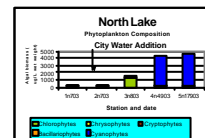


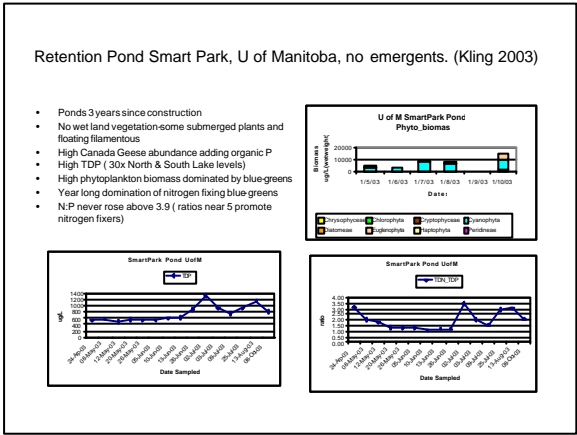
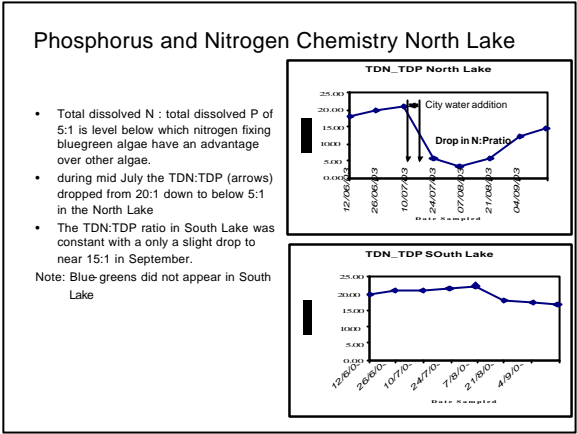
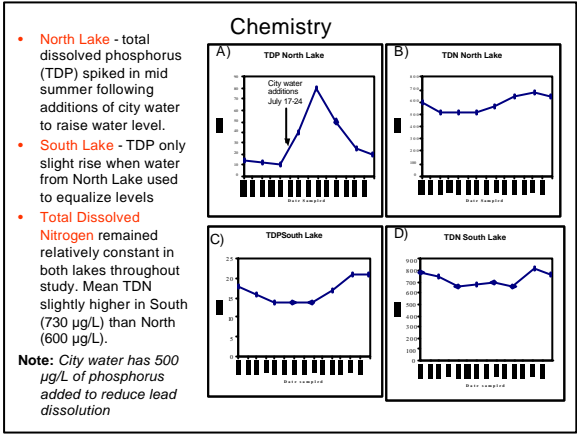
Lake 226 Nutrient Addition Experiment provided convincing evidence to regulators that phosphorus alone stimulated blue-green algal development in Boreal Shield lakes

Do we have a comparable example from aquatic ecosystems in sedimentary prairie areas?

Phytoplankton development in North & South Lakes, Greater Winnipeg area, during summer 2003 (Kling 2003)

- **Initial algal biomass** - each lake < 1000µg/L (<1000 µg/L indicative of low nutrient conditions, >10000 µg/L considered high nutrients, eutrophic)
- **Initial composition** dominated by small green, brown and yellow algae indicative of clean low nutrient water
- **Early August** - North Lake showed small increase N₂ fixing bluegreens indicating N deficiency in this pond.
- **September** North Lake high biomass of N₂ fixers indicates source of high P without corresponding source of N
- **South Lake August to September** Decreased biomass and balanced species composition indicates good water quality with low nutrients in this lake.
- Explanation for large increase in the North Lake?





Manitoba Clean Environment Commission Report on Public Hearings August 2003

Among the CEC recommendations:

Nutrient Management Strategy

- The priority for nutrient removal is phosphorus followed by nitrogen
- Province to complete and implement nutrient management strategy and provide suitable guidance for phosphorus and nitrogen removal

Environmental Research and Monitoring

- A co-operative (federal, provincial, municipal), cost-shared research and monitoring program is required to define baseline conditions, address information deficiencies and provide answers to questions about the impact of municipal wastewaters and other sources of pollution on the environment and human health.

The proposed winter sampling of Lake Winnipeg can fulfill this latter recommendation