Phosphorus Legacy: Overcoming the Effects of Past Management Practices to Mitigate Future Water Quality Impairment

Andrew Sharpley, et al. 2014

Presented by Eric Moore
Sub-disciplines in Ecology

BIOGEOCHEMISTRY
ECOSYSTEM ECOLOGY
CHEMICAL ECOLOGY
COMMUNITY ECOLOGY
PHYSIOLOGICAL ECOLOGY
POPULATION ECOLOGY
BEHAVIORAL ECOLOGY

BIOTIC FOCUS
(Systematics, Genetics, Physiology)

ABiotic Focus
(Meteorology, Geology, Hydrology)

(Taken from ideas discussed at the Institute of Ecosystem Studies, Millbrook, NY 1991)
Three Types of Legacy Phosphorus

- **Terrestrial** - effect of land and nutrient management on the buildup of soil P beyond crop needs. Includes land use changes that affect connectivity of sources to rivers/streams
  - Controlled mostly by adsorption/desorption, precipitation/dissolution, mineralization/immobilization

- **River** - retention and remobilization of P through cascades and spirals, in drainage channels from the edge of fields to receiving standing water. Account for 10-80% of annual P flux
  - Deposition of particulate P as sediments, sorption of dissolved P onto sediments, uptake from water column by plants and microbes

- **Standing water** - (in lakes and reservoirs) deposition and remobilization of inorganic and organic P as functions of ecosystem drivers (residence time, water depth, extreme climate events)
  - Over the long term, sediment storage capacity can diminish, converting from sink to source
Lag time influenced by various processes

~1/2 year to many centuries
Approaches to Tracing Legacy P

- **cascade (transport)** of P from soil, to rivers/streams, then to oceans/coastal zones
  - occurs as a result of erosion, with soils losing P mostly as particulate (solid) P
  - Hotspots of Legacy P often found downslope, where water velocity slows and sedimentation increases

- **biogeochemical spiraling** (i.e., cycling during cascade) as water and sediment move “downslope and downstream”
  - Retention of dissolved P in wetlands, riparian/hyporheic zones, lakes, groundwater
Background

- Monitoring of water quality began decades ago in certain regions
- Some watershed management practices 20-30 years old
- $24 billion invested in conservation measures in the between 2005-2010
- No “instant gratification” - **eutrophication** and **water quality worsened**
- Why?
Early land managers did not consider the importance of dissolved P transport via runoff/subsurface flow.

Sorption potential of P and amount of total P in most soils is much greater than dissolved P.

As saturation increases, P is then released.
The Effect of Macronutrient Decoupling

- Increased Carbon inputs
  - Higher rate of Microbial Respiration
    - Degradation of organic matter releases P, depletes $O_2$
      - Dissolution of Fe oxyhydroxides, releasing sorbed P
Case Study 1 - Terrestrial
Legacy of Poultry Litter Management: Maryland

- High soil P as a result of 20+ years of poultry litter additions
- From 2000-2010, applications of three P-based rates of poultry litter were tested (no added P, crop P requirement, crop N requirement)
- Surface runoff monitored for first 5 years, soil sampled for entire duration
- No significant differences were detected for any measure of P (loss or extractable)
- Results seem to indicate that even with crop harvest and reduced application of P in fertilizer, it will take decades for soil to recover
Case Study 2 - Terrestrial Hydrologic Mobilization of P on Hillslopes: Pennsylvania

- 2 year study of P losses in surface runoff
- Soil P in upslope row crops was 3x higher than required, while soil P in the riparian zone was near optimum
- Runoff volume of riparian zone was ~30 times greater than upslope, with ~3x more P load, BUT
  - Riparian zone runoff P concentration was nearly 6x less than upslope
- Riparian zone represented 6% of total area, but produced Legacy P yield equivalent to ~75% of watershed P loss
- Site hydrology can ultimately convert small amounts of P into major P loads
Case Study 3 - River
Legacy of Land Management P Export: Lake Erie Basin

- P loads in 2 watersheds (Maumee and Sandusky river watersheds) since 1975; predominantly row-crops
- Conservation tillage and nutrient management planning adopted and studied
- From 1975-1995, mean annual flow-weighted dissolved P decreased 86%, and total P concentrations decreased 44%
- Since 1995, annual flow-weighted dissolved P concentrations have increased, but particulate and total P have declined
- Attributed to changes in rainfall distribution, legacy of chronic excess of P, a buildup of P at the soil surface after conversion to no-till methods, and increased manure application without incorporation into the soil during fall/winter
- Since 2005, tile drainage and legacy P input to Lake Erie has increased
- In 2010, dissolved P load was the highest it had been in 35 years
Authors characterize the Lambourn River as a “relatively low-energy” stream.

The river had been exposed to a point-source input of P, which was “suddenly and dramatically” reduced.

River-reach mass balance and the sediment equilibrium P concentrations (EPC₀) were measured along 2.5 km of the river, before and after the point-source reductions.

Around 6 months after the point-source reduction, bed sediment EPC₀ values declined to equilibrium values of the rest of the river.

A higher flowing river with more active erosion would be expected to have a lag time shorter than 6 months, with more rapid removal of sediment as well.
Case Study 4 - River
Short-term In-channel Fluvial P Legacies: River Lambourn, United Kingdom

a) Mass balance measurement, showing net loss of dissolved reactive P (DRP) in the water, due to net uptake of DRP by sediments; following reduction of P input, there is net release of DRP from sediments

b) EPC₀ measurements showing that bed sediments were net sinks during point-source P inputs, then became net sources of legacy DRP after point-source P reduction
Case Study 5
Legacy P and Lake Recovery after Remediation: Loch Leven, United Kingdom

- Shallow lake with a mean depth of only ~4 m, and a history of eutrophication
- Between the late 1970s and early 1990s, external P inputs were reduced by around 60%, by reducing inputs from a nearby mill (Phase 2), upgrading sewage treatment plants (Phase 3), and encouraging farmers to use less fertilizer and better management.
- Winter total P concentrations in-lake fell by 75%, and spring concentrations initially fell by 60%, compared to pre-management levels. However, summer concentrations increased.
- The lowered winter, spring, and fall P concentrations, together with the increased summer P concentration, indicates a switch from external P loading to internal P loading (release of P from bed sediments the water column).
Case Study 5
Legacy P and Lake Recovery after Remediation: Loch Leven, United Kingdom

(a) Changes in the mean monthly TP concentration during different Phases

(b) Change in cumulative monthly downstream delivery of TP, post-management and pre-management. Positive values indicate losses from the lake

(c) Long-term variation in monthly TP concentration from 1970-2010
Best Management Practices

- Discourage the loss of nutrients by retaining eroded soil, sediment, water, and nutrients within the landscape.
- Decrease the amount of P delivery to downstream environments and lessen the impact on water quality.

- However, they can create long-term, continuing sources of Legacy P to receiving downstream environment.
  - What’s better than a “Best” practice?
Questions for Discussion

- The Conowingo Dam in Pennsylvania has seen a 2 to 3-fold increase in P concentration in recent discharges, compared to similar discharges from the past, and is also 85% full with sediment. When dams like this are decommissioned, what impact do they have downstream, and how is this mitigated? What role do large tropical storms play?

- If the world suddenly decided to eliminate all excess P and fertilize plants based on their specific P requirements, which environments would improve the quickest, based just on Legacy P?

- How would Loch Leven have responded if it were significantly deeper than 4 m?