PHOSPHORUS DYNAMICS & POLLUTION

(Source of some of the notes – Zaimes & Shultz 2002 – Phosphorus literature review Sharpley et al. 1999 – Agricultural phosphorus & eutrophication)

Introduction

• A major player in the eutrophication of inland water bodies – Lake Erie in the 1960’s – P pollution from phosphate detergents
  o Before pioneers – 4500 P/yr
  o 1968 – 28,000 P/yr
  o Now – 11,000 P/yr

• Very low P concentrations can cause eutrophication – 0.03 mg/L for dissolved P and 0.1 mg/L for total P (for lakes) – 
P not directly toxic
• N-based fertilizer application has led to over application of P – especially when manure application occurs

• Over-application over the years has increased the soil store of P – continued P problems even after controls has been put in place – Delaware & Maryland

• Problem with P – unlike N – it does not have a natural release mechanism by which excess nutrient can be removed from the soil system – what mechanism/process am I referring to?
Forms of P

Solution P (< 0.45μm filter)
• P in soil solution may be as low as 0.01% of the total soil P – rest of it may be in solid form!

• Soil solution concentrations typically very low – 0.001 mg/L to 1.0 mg/L - however, even low concentrations have potential for eutrophication

• Dissolved – inorganic and organic P

• Two inorganic forms of phosphate ions (orthophosphates) – HPO$_4^{2-}$ and H$_2$PO$_4^-$ [also referred to as Soluble Reactive P]

• H$_2$PO$_4^-$ is the dominant form in acid soils, whereas HPO$_4^{2-}$ dominates in alkaline soils

P forms associated with solids – Particulate P (>0.45μm):
• Organic P (30 to 65% of total soil P)
• Inorganic P (8 to 72%)
  i. Adsorbed to clay, Fe & Al oxides
  ii. Primary minerals (apatite – Ca$_5$(PO$_4$)$_3$F)
  iii. Secondary compounds:
    • Calcium-bound inorganic P
    • Iron- or aluminum-bound inorganic P
Table 6. The common chemical forms of P in soil and their characteristics and potential mobility.  

<table>
<thead>
<tr>
<th>Form</th>
<th>Characteristics or Implication</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INORGANIC in solution</strong></td>
<td></td>
</tr>
<tr>
<td>Orthophosphate ((H_2PO_4))</td>
<td>Readily mobile but easily adsorbed/immobilized</td>
</tr>
<tr>
<td><strong>INORGANIC in the soil matrix</strong></td>
<td></td>
</tr>
<tr>
<td>Apatites</td>
<td></td>
</tr>
<tr>
<td>Hydroxyapatite ((Ca_{10}(PO_4)_6OH_2))</td>
<td>Very low solubility. Tend to be present more in nonacid soils than in acid.</td>
</tr>
<tr>
<td>Fluorapatite ((Ca_{10}(PO_4)_6F_2))</td>
<td></td>
</tr>
<tr>
<td>Sodium phosphates</td>
<td></td>
</tr>
<tr>
<td>Pyrophosphate ((Na_2P_2O_7\cdot H_2O))</td>
<td>Soluble. No known information on the implications</td>
</tr>
<tr>
<td>Polyphosphate ((Na_3PO_5)n)</td>
<td></td>
</tr>
<tr>
<td>Other calcium phosphates</td>
<td>Tend to form when fertilizers are added to nonacid soils.</td>
</tr>
<tr>
<td>Monocalcium phosphate ((Ca(H_2PO_4)_2\cdot H_2O))</td>
<td></td>
</tr>
<tr>
<td>Dicalcium phosphate ((Ca(HPO_4)_2\cdot 2H_2O))</td>
<td></td>
</tr>
<tr>
<td>Tricalcium phosphate ((Ca_5(PO_4)_2))</td>
<td></td>
</tr>
<tr>
<td>Octacalcium phosphate ((Ca_4H_2(PO_4)_6\cdot 5H_2O))</td>
<td></td>
</tr>
<tr>
<td>Aluminum phosphates</td>
<td>Tend to form when fertilizers are added to acid soils that have aluminum.</td>
</tr>
<tr>
<td>Variscite ((AlPO_4\cdot 2H_2O))</td>
<td></td>
</tr>
<tr>
<td>Taranakite ((H_4K_3Al_5(PO_4)_8\cdot 18H_2O))</td>
<td></td>
</tr>
<tr>
<td>Wavelite ((Al_5(OH_3)(PO_4))_2)</td>
<td></td>
</tr>
<tr>
<td>Iron phosphates</td>
<td>Tend to form when fertilizers are added to acid soils that have iron.</td>
</tr>
<tr>
<td>Vivianite ((Fe_5(PO_4)_2\cdot 8H_2O))</td>
<td></td>
</tr>
<tr>
<td>Strengite ((FePO_4\cdot H_2O))</td>
<td></td>
</tr>
<tr>
<td>Surface-adsorbed P</td>
<td>Adsorbed on calcium, iron and aluminum compounds.</td>
</tr>
<tr>
<td><strong>ORGANIC in soil matrix</strong></td>
<td></td>
</tr>
<tr>
<td>Phytic acid or Inositol hexaphosphates ((C_6H_9O_6)(PO_3)_6)</td>
<td>Not generally thought to be easily mobile except in sandy soils: maybe highly sorbed but have been noted in lake sediments</td>
</tr>
<tr>
<td>Phosphate diesters (nucleic acids, DNA, RNA, phospholipids)</td>
<td>Probably mobile but confirmation is required</td>
</tr>
<tr>
<td>Glucose P ((\alpha\text{-Glucose-6-phosphate; }\beta\text{-Glucose-1-phosphate})</td>
<td>Leaches through sandy soils</td>
</tr>
<tr>
<td>Phosphonates ((R-PO_3))</td>
<td>No known information on the implications</td>
</tr>
<tr>
<td>Polyphosphonates ((ATP,AMP))</td>
<td>No known information on the implications</td>
</tr>
</tbody>
</table>

*a* Haygarth and Jarvis (1999); Troeh and Thompson (1993); Anderson (1980); McClellan and Gremillion (1980); Sample et al. (1980).
Classification of P

<table>
<thead>
<tr>
<th>New classification</th>
<th>Established terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP (unf.)</td>
<td>Total P (TP) - from a unfiltered sample -</td>
</tr>
<tr>
<td>TP (&lt;0.45)</td>
<td>Total dissolved P (TDP), soluble P</td>
</tr>
<tr>
<td>TP (&gt;0.45)</td>
<td>Particulate P (PP), sediment-bound P, suspended P</td>
</tr>
<tr>
<td>RP (unf.)</td>
<td>Total reactive P (TRP),</td>
</tr>
<tr>
<td>UP (unf.)</td>
<td>Total organic P</td>
</tr>
<tr>
<td>RP (&lt;0.45)</td>
<td>Molybdate-reactive P (MRP), dissolved-reactive P (DRP), soluble reactive P (SRP), dissolved molybdate-reactive P, orthophosphate, inorganic P, phosphate</td>
</tr>
<tr>
<td>UP (&lt;0.45)</td>
<td>Dissolved organic P (DOP), soluble organic P (SOP), dissolved nonreactive P (DNRP)</td>
</tr>
<tr>
<td>RP (&gt;0.45)</td>
<td>Molybdate-reactive particulate P (MRPP), particulate reactive P</td>
</tr>
<tr>
<td>UP (&gt;0.45)</td>
<td>Particulate organic P</td>
</tr>
</tbody>
</table>

\(^a\) Modified from Haygarth and Sharpley (2000).

\(^b\) May not necessarily be inclusive.
Phosphorus Cycling

The Phosphorus Cycle

- Animal manures and biosolids
- Plant residues
- Organic phosphorus: Microbial, Plant residue, Humus
- Crop harvest
- Mineral fertilizers
- Runoff and erosion
- Leaching (usually minor)
- Soil solution phosphorus: $\text{HPO}_4^{2-}$, $\text{H}_2\text{PO}_4^{-1}$
- Plant uptake
- Primary minerals (apatite)
- Mineral surfaces (clays, Fe and Al oxides)
- Secondary compounds (CaP, FeP, MnP, AlP)
- Immobilization
- Mineralization
- Weathering
- Adsorption
- Desorption
- Dissolution
- Precipitation
**P Inputs or sources**

• Weathering –
  o From the parent geologic materials – apatite
  o A minor source in agricultural landscapes

• Atmospheric deposition
  o Not a significant source
  o 0.05 – 0.40 kg/ha/yr

• Fertilizers
  o Largest source in agricultural landscapes
  o N-P-K fertilizers – application is N based! – which eventually leads to over application of P
  o As high as 75 kg/ha/yr
  o N-based application leads to a waste of P

<table>
<thead>
<tr>
<th>Country</th>
<th>Agriculture Share %</th>
<th>Reference Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Netherlands</td>
<td>24</td>
<td>1985</td>
</tr>
<tr>
<td>Italy</td>
<td>33</td>
<td>1986</td>
</tr>
<tr>
<td>Federal Republic of Germany</td>
<td>38</td>
<td>1987</td>
</tr>
<tr>
<td>North Sea catchment basin</td>
<td>25</td>
<td>1987</td>
</tr>
<tr>
<td>Sweden</td>
<td>16</td>
<td>1987</td>
</tr>
<tr>
<td>Denmark</td>
<td>70</td>
<td>1988</td>
</tr>
<tr>
<td>Norway</td>
<td>27</td>
<td>1988</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>35</td>
<td>1995</td>
</tr>
<tr>
<td>U.S.A.</td>
<td>84</td>
<td>1998</td>
</tr>
<tr>
<td>New Zealand</td>
<td>90</td>
<td>2000</td>
</tr>
<tr>
<td>Illinois River</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>All other rivers</td>
<td>67</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Percentage of NPS P inputs from agriculture to surface waters for different countries.

• Agricultural wastes/Manure
  o Lower N/P ratio – high P
  o Greater proportion of dissolved P
  o In several counties of NC – manure production exceeds crop needs by 500% !!!
  o P loss from manure application can be as high as 20% if rainfall occurs immediately after land application

• Municipal & industrial byproducts
  o Sewage
  o A factor for urban areas at the mouth of lakes/water bodies
  o However, can be subject to greater controls
Figure 5. A survey of agricultural soils analyzed by state soil test laboratories in 1997, shows a regional buildup of soil test P near P-sensitive waters (Fixen 1998).
Figure 8. Elevated soil test P levels (as Mehlich–1 P) are usually localized in areas of confined animal operations.
**P Outputs from soils**

Primary pathways –

- harvested plant biomass = 5 to 50 kg/ha/yr
- erosion – particulate P = 0.1 to 10 kg/ha/yr
- surface runoff – dissolved P = 0.01 to 3.0 kg/ha/yr
Soil P pools

Agriculture – inorganic P pools dominate
Forest land – Organic P pools make up most of the P

The Phosphorus Cycle
• adsorbed P pool – dependent on the soil type – sandy/silty/clayey

• highest P adsorption – soils high in clay (allopone clays) or Fe/Al oxides -- see figure of P retention with soil types

sequence of potential adsorption (increasing in order) –

2:1 clays < 1:1 clays < carbonate crystals < crystalline Fe, Al, Mn oxides < amorphous Al, Fe, Mn oxides, allopone

• sandy soils are susceptible to P leaching because of low P adsorption

• soils high in organic matter (peaty soils) – high P leaching – because adsorption surfaces are occupied by humic material --- see figure below

• Fixation highest at pH < 5.0 or pH > 8.0 (low pH or high pH).
• P retention in various soil types

SOIL P Pools –

• LABILE

• NON-LABILE
P Transport Mechanisms

- Surface runoff or Overland flow
- Subsurface flow or interflow
- Vertical drainage or leaching
- Tile drainage
- Macropore flow or bypass flow
- Streamflow
- Erosion

P transport will be greater in flow paths -

Where water moves fast
Where the contact time with soil is the least
Figure 7. Phosphorus can be released from soil and plant material to surface and subsurface runoff water or lost by erosion.
Cultivated Ag landscapes –
- Erosion and surface runoff are the main pathways
- P in the top 2 cm interacts with overland flow
- Adsorption isotherms can be used to estimate the adsorption-desorption of P

E.g., Freundlich Isotherm

$$C_A = KC_s^{1/n}$$

Where $C_A$ – adsorbed conc., $C_s$ is the solution conc., and K and N are constants for the soil.
• P moving with sediment is associated with the finer clay fractions

• As sediment moves downslope the concentration of P in the sediment mass increases as the finer fraction of the sediment increases – **enrichment of P**

\[
\text{Enrichment ratio} = \frac{\text{conc. In sediment}}{\text{conc. In source soil}}
\]

• Factors that increase surface runoff and erosion will also increase P delivery

P transport in subsurface flow is low because of adsorption of P in the subsurface soil layers
  o Depends on the soil contact time
  o Soils with macropores may increase P delivery
Forest landscapes

- Surface runoff and subsurface flow are the primary hydrologic pathways
- Particulate organic P and dissolved organic and inorganic P are the main forms that are transported
Storm events versus non-storm periods

- *P exports increase with increase in watershed discharge*
- *P exports will be highest with high intensity storms (storms that generate surface runoff and erosion)*

### Table 5. Phosphorus concentrations in stream and drainage water under various flow regimes. Ranges are in the parenthesis when available.

<table>
<thead>
<tr>
<th>Flow regimes</th>
<th>TP (unf.) mg L⁻¹</th>
<th>TP (&lt; 0.45) mg L⁻¹</th>
<th>Land-use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stormflow</strong></td>
<td>1.5ᵃ</td>
<td>1.0ᵃ</td>
<td>0.15ᵇ</td>
</tr>
<tr>
<td>0.49 (0.14-2.37)ᶜ</td>
<td>0.15ᵇ</td>
<td>Pasture with dairy operations, stream water. Grassland, tile drains.</td>
<td></td>
</tr>
<tr>
<td>1.20 (0.16-4.30)ᶜ</td>
<td>0.15ᵇ</td>
<td>Pasture, stream water.</td>
<td></td>
</tr>
<tr>
<td>1.43 (0.50-5.21)ᶜ</td>
<td>0.15ᵇ</td>
<td>Riparian pine afforested 1, stream water.</td>
<td></td>
</tr>
<tr>
<td>0.46 (0.07-3.30)ᵈ</td>
<td>0.13 (&lt;0.01-0.36)ᵈ</td>
<td>Riparian pine afforested 2° stream water.</td>
<td></td>
</tr>
<tr>
<td><strong>Snowmelt</strong></td>
<td>0.27 (0.09-0.90)ᵈ</td>
<td>0.155 (0.02-0.45)ᵈ</td>
<td>Cropland (91%)</td>
</tr>
<tr>
<td><strong>Baseflow</strong></td>
<td>0.8ᵃ</td>
<td>0.4ᵃ</td>
<td>0.05ᵇ</td>
</tr>
<tr>
<td>0.18 (0.07-0.60)ᶜ</td>
<td>0.05ᵇ</td>
<td>Pasture with dairy operations, stream water. Grassland, tile drains.</td>
<td></td>
</tr>
<tr>
<td>0.20 (0.06-0.47)ᶜ</td>
<td>0.05ᵇ</td>
<td>Pasture, stream water.</td>
<td></td>
</tr>
<tr>
<td>0.32 (0.14-1.16)ᶜ</td>
<td>0.05ᵇ</td>
<td>Riparian pine afforested 1, stream water.</td>
<td></td>
</tr>
<tr>
<td>0.071 (0.02-0.61)ᵈ</td>
<td>0.031ᵃ (&lt;0.01-0.23)ᵈ</td>
<td>Cropland (91%), stream water.</td>
<td></td>
</tr>
</tbody>
</table>

ᵃ Shirmohammadi et al. (1997);ᵇ Stamm et al. (1997);ᶜ Smith (1992);ᵈ Culley and Bolton (1983).
P in aquatic systems

- Dissolved/particulate and inorganic and organic species of P are delivered to the streams and or lakes.

- Dissolved inorganic P is immediately available for algal growth – referred to as *algal available P – AAP*

- Particulate or sediment associated P can deposit at the bottom of the waterbody and become a potential long-term source.
• Sediment P can be released under anaerobic (anoxic) conditions.

  o Under prolonged anaerobic conditions (wetlands, bottom sediments of lakes and streams) the Fe$^{3+}$ form of iron gets reduced to Fe$^{2+}$ --- increasing its solubility and leading to the release of P into solution!

• Fresh sediment in the waterbodies can act as a temporary sink for P (by adsorbing the dissolved forms) → this store could be released with large storms that can resuspend the sediment.
- *Erosion of streambanks can also release P* in aquatic systems.

- *It is important to control both dissolved and particulate P inputs to water bodies – What happens to P in aquatic systems has implications for watershed-scale budgets of P.*

<table>
<thead>
<tr>
<th>Location</th>
<th>% bioavailable</th>
<th>Total P g/kg</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Suspended sediment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Great lakes</td>
<td>0-47</td>
<td>0.5 – 1.4</td>
<td>De Pinto et al., 1985</td>
</tr>
<tr>
<td>Lake Erie</td>
<td>14-42</td>
<td>0.6-1.5</td>
<td>Logan et al., 1979</td>
</tr>
<tr>
<td><strong>Deposited sediment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Netherlands</td>
<td>0-41</td>
<td>0.4-4.8</td>
<td>Carigan &amp; Kalff 1980</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>60-95</td>
<td>0.6-3.9</td>
<td>Sagher et al., 1975</td>
</tr>
<tr>
<td>Great Lakes</td>
<td>27</td>
<td>0.4-1.4</td>
<td>Williams et al., 1980</td>
</tr>
</tbody>
</table>
**P yields from forested and agricultural watersheds**

P loads from agricultural watersheds are higher – and have a greater particulate fraction

Forest export = 33% dissolved & 77% particulate  
Ag export = 5% dissolved & 95% particulate
<table>
<thead>
<tr>
<th>Major land use</th>
<th>Soluble reactive P (mg L⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90% Forest</td>
<td>0.009</td>
</tr>
<tr>
<td>75% Forest</td>
<td>0.012</td>
</tr>
<tr>
<td>50% Forest</td>
<td>0.014</td>
</tr>
<tr>
<td>50% Range (remainder forest)</td>
<td>0.018</td>
</tr>
<tr>
<td>75% Range</td>
<td>0.037</td>
</tr>
<tr>
<td>50% Range (remainder agric.)</td>
<td>0.025</td>
</tr>
<tr>
<td>50% Agric.</td>
<td>0.037</td>
</tr>
<tr>
<td>90% Agric.</td>
<td>0.071</td>
</tr>
<tr>
<td>40% Urban</td>
<td>0.043</td>
</tr>
</tbody>
</table>

**P LOSS (g ha⁻¹ yr⁻¹)**

- **Soluble reactive P**
- **Particulate P**
P export from the Nomini Creek (agricultural) watershed located in the Coastal Plain region of Virginia (Inamdar et al., 2001)
Critical concentrations for P

Past studies have produced thresholds of P concentration for eutrophication.

<table>
<thead>
<tr>
<th>Concentration (µg L⁻¹)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>TP (&lt;0.45) - critical concentration for lakes ¹,²</td>
</tr>
<tr>
<td>10-30</td>
<td>TP (&lt;0.45) - critical concentration for natural waters ³</td>
</tr>
<tr>
<td>100</td>
<td>TP (unf.) - critical concentration for streams ⁴</td>
</tr>
<tr>
<td>50</td>
<td>TP (unf.) - critical concentration for lakes ⁴</td>
</tr>
<tr>
<td>50</td>
<td>TP (&lt;0.45) - concentration allowed to enter Florida Everglades ⁵</td>
</tr>
<tr>
<td>10</td>
<td>TP (&lt;0.45) - target concentration allowed to enter Florida Everglades by the year 2000 ⁵</td>
</tr>
<tr>
<td>1000</td>
<td>Flow weighted annual TP (&lt;0.45) - proposed allowable limit for agricultural runoff ⁴</td>
</tr>
</tbody>
</table>

¹ Table adopted from Norflee (1998).
² Sharpley and Rekolainen (1997); ³ USA vs. South Florida Water Management District (1994); ⁴ USEPA (1986); ⁵ Vollenweider (1968); ⁶ Sawyer (1947).

• However, the susceptibility of water bodies to P pollution varies with soils, geology, regions, etc

• Therefore the current approach is to establish critical concentrations for different ecoregions

• EPA classified parts of the country into ecoregions – based on soils, geology, landuse type, ecosystem type, and nutrient conditions.
Figure 10. The fourteen ecoregions in the United States (Omernik, 2000). The ecoregions were differentiated based on geology, land-use, ecosystem type, and nutrient conditions.

Table 14. The EPA recommended critical TP (unf.) concentrations for some of the ecoregions. Ecoregions are shown in Figure 10. \(^a\)

<table>
<thead>
<tr>
<th></th>
<th>TP (unf.) (μg L(^{-1})) concentrations for eight ecoregions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>II</td>
</tr>
<tr>
<td>Rivers and</td>
<td>10.00</td>
</tr>
<tr>
<td>Streams</td>
<td>8</td>
</tr>
<tr>
<td>Lakes and</td>
<td>8.75</td>
</tr>
<tr>
<td>Reservoirs</td>
<td>0</td>
</tr>
</tbody>
</table>

\(^a\) USEPA (2001).
**Phosphorus Management**

**Source Management**

- Reduce off-farm inputs of P in livestock feed – decrease additions of P to feed

- Add digestive enzymes such as phytase to increase P (phytin) assimilation by livestock

- Reduce the amount of phytate (difficult to digest P) in feed (corn) and increase the inorganic P – via manipulation of genes controlling phytate formation in corn.
• establish environmental P thresholds and limit P application to these thresholds – see table and figure below

Table 3. Threshold soil test P values and P management recommendations (continued)

<table>
<thead>
<tr>
<th>State</th>
<th>Agronomic*</th>
<th>Environmental</th>
<th>Soil test P method</th>
<th>Management recommendations to protect water quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michigan</td>
<td>40</td>
<td>75</td>
<td>Bray-1</td>
<td>Below 75 ppm soil P: P application not to exceed crop removal. Above 75 ppm soil P: Apply no P from any source.</td>
</tr>
<tr>
<td>Texas</td>
<td>44</td>
<td>200</td>
<td>Texas A&amp;M</td>
<td>Above 200 ppm soil P: Amount of P applied should not exceed that taken up by the crop and removed as harvested produce.</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>20</td>
<td>75</td>
<td>Bray-1</td>
<td>Below 75 ppm soil P: Rotate to P-demanding crops and reduce P additions. Above 75 ppm soil P: Discontinue P applications.</td>
</tr>
</tbody>
</table>

SOURCE: Adapted from Sharpley et al. (1996).
Figure 10. As soil P increases, so does crop yield and the potential for P loss in surface runoff. The interval between the critical soil P value for yield and runoff P will be important for P management.
Manure management

- Determine manure and soil P content – do not apply manure where soil P contents are already high

- Manure additives – slaked lime, alum – reduce ammonia volatilization, decrease dissolved P loss \( \rightarrow \) thereby increase manure N:P ratio – favorable for plant uptake

- Manure transport from surplus to deficit areas

- Manure bank – that links manure-needy farmers to manure-rich poultry operators (as in Delaware)

- Composting of manure

Manure incorporation below the surface
**Transport Management**

Implement practices that reduce the delivery of P from landscapes to receiving waterbodies –

- Tillage practices
- Grass filter strips
- Riparian zones
- Settling basins or farm ponds

Conventional tillage in Georgia, USA
• conservation tillage reduces erosion and particulate P delivery but can increase the dissolved and organic fractions of P in runoff
Grass filters

- On-field filter strips are a good practice – will reduce the delivery of particulate P to the drainage channel or receiving stream

- However, these filter strips will have to be managed (raked up) after a period of 10 years or so to distribute the accumulating P back on the field.
Riparian zones

- Sediment deposition and P trapping in the vegetative mass
- P uptake by vegetation
- P buildup over time?
- P release from anoxic sediments?

Figure 15. Phosphorus movement in riparian forest buffers. Sediment and TP (>0.45) are filtered from overland flow and TP (<0.45) can be taken up by biota of the living filter (Schultz et al., 2000).
## Table 16. The effectiveness of different types of buffers with different widths in removing NPS P from overland flow.

<table>
<thead>
<tr>
<th>Country</th>
<th>Type</th>
<th>Width (m)</th>
<th>P form</th>
<th>Reduction (%)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark b</td>
<td>Grass</td>
<td>2</td>
<td>TP (unf.)</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td></td>
<td>97</td>
<td></td>
</tr>
<tr>
<td>Finland b</td>
<td>Grass</td>
<td>10</td>
<td>TP (unf.)</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>Norway b</td>
<td>Grass</td>
<td>5</td>
<td>TP (unf.)</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td></td>
<td>96</td>
<td></td>
</tr>
<tr>
<td>Norway b</td>
<td>Grass</td>
<td>5</td>
<td>TP (unf.)</td>
<td>51, 66</td>
<td>Results from two short-term experiments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td></td>
<td>67, 82</td>
<td></td>
</tr>
<tr>
<td>Sweden b</td>
<td>Grass</td>
<td>8</td>
<td>RP (&lt;0.45)</td>
<td>66</td>
<td>Short-term experiments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16</td>
<td></td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>Sweden b</td>
<td>Grass</td>
<td>5</td>
<td>TP (unf.)</td>
<td>-36</td>
<td></td>
</tr>
<tr>
<td>U.S.A. c</td>
<td>Grass</td>
<td>various</td>
<td>TP (unf.)</td>
<td>60</td>
<td>Captures only 20% of RP (&lt;0.45)</td>
</tr>
<tr>
<td>U.S.A. f</td>
<td>Grass</td>
<td>9.1</td>
<td>TP (unf.)</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.6</td>
<td></td>
<td>61</td>
<td></td>
</tr>
<tr>
<td>U.S.A. d</td>
<td>Forest</td>
<td>30</td>
<td>TP (unf.)</td>
<td>70-81</td>
<td>High inputs</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>24-50</td>
<td>Low inputs</td>
</tr>
<tr>
<td>U.S.A. b</td>
<td>Forest</td>
<td>Not stated</td>
<td>Not stated</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>50</td>
<td>TP (unf.)</td>
<td>80</td>
<td>3 kg TP (&lt;0.45) removed per 1 ha of riparian forest. TP losses divided evenly through surface and subsurface pathways.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TP (&lt;0.45)</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>Finland a</td>
<td>Vegetative (trees and grasses)</td>
<td>10</td>
<td>TP (unf.)</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Norway a</td>
<td>Vegetative (trees and grasses)</td>
<td>5</td>
<td>TP (unf.)</td>
<td>75, 97</td>
<td>Two short-term experiments</td>
</tr>
<tr>
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<td></td>
<td>10</td>
<td></td>
<td>97, 96</td>
<td></td>
</tr>
<tr>
<td>U.S.A. c</td>
<td>Switchgrass</td>
<td>3</td>
<td>TP (unf.)</td>
<td>40</td>
<td>Switch grass more effective then cool-season grasses</td>
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<td></td>
<td></td>
<td>6</td>
<td></td>
<td>35</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RP (&lt;0.45)</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>46</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cool-season grass</td>
<td>3</td>
<td>TP (unf.)</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RP (&lt;0.45)</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>U.S.A. a</td>
<td>Switchgrass</td>
<td>7.1</td>
<td>TP (unf.)</td>
<td>72</td>
<td>2-h rainfall simulation at 2.5 cm/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RP (&lt;0.45)</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Multi-species riparian buffer</td>
<td>16.3</td>
<td>TP (unf.)</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RP (&lt;0.45)</td>
<td>85</td>
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</tr>
<tr>
<td>U.S.A. a</td>
<td>Switch grass</td>
<td>7.1</td>
<td>TP (unf.)</td>
<td>46</td>
<td>1-h rainfall simulation at 6.9 cm/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RP (&lt;0.45)</td>
<td>28</td>
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<tr>
<td></td>
<td>Multi-species riparian buffer</td>
<td>16.3</td>
<td>TP (unf.)</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RP (&lt;0.45)</td>
<td>35</td>
<td></td>
</tr>
</tbody>
</table>

The Phosphorus Index

- Developed under the realization that phosphorus pollution from watersheds is not generated uniformly.

- In some agricultural watersheds – 90% of AAP is generated from 10% of the watershed area – *this 10% of the area becomes very critical* – and we need to identify it.

- Remember for P pollution to occur = source + transport.

- P index was developed to identify the source areas which have a higher potential to transport P to the receiving stream/channel.

\[
P \text{ Index} = \sum [\text{weighting factor} \times \text{loss rating (value)}]
\]
### Table 4. The P index (continued)

<table>
<thead>
<tr>
<th>Site characteristic (Weighting factor)</th>
<th>Loss rating (value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None (0)</td>
</tr>
<tr>
<td>Source Factors</td>
<td></td>
</tr>
<tr>
<td>Soil test P (1.0)</td>
<td>N/A</td>
</tr>
<tr>
<td>P fertilizer application rate, lb P/acre (0.75)</td>
<td>None applied</td>
</tr>
<tr>
<td>P fertilizer application method (0.5)</td>
<td>None applied</td>
</tr>
<tr>
<td>Organic P source application rate, lb P/acre (1.0)</td>
<td>None applied</td>
</tr>
<tr>
<td>Organic P source application method (0.5)</td>
<td>None applied</td>
</tr>
</tbody>
</table>
Correction - **Transport Factors** – NOT – Transparent Factors

\[ \text{P Index} = \sum \text{[weighting factor} \times \text{loss rating (value)]} \]
<table>
<thead>
<tr>
<th>P index</th>
<th>General vulnerability to P loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 8</td>
<td><strong>Low</strong> potential for P loss. If current farming practices are maintained, there is a low probability of adverse impacts on surface waters.</td>
</tr>
<tr>
<td>8 to 14</td>
<td><strong>Medium</strong> potential for P loss. The chance for adverse impacts on surface waters exists, and some remediation should be taken to minimize the probability of P loss.</td>
</tr>
<tr>
<td>15 to 32</td>
<td><strong>High</strong> potential for P loss and adverse impacts on surface waters. Soil and water conservation measures and P management plans are needed to minimize the probability of P loss.</td>
</tr>
<tr>
<td>&gt; 32</td>
<td><strong>Very high</strong> potential for P loss and adverse impacts on surface waters. All necessary soil and water conservation measures and a P management plan must be implemented to minimize the P loss.</td>
</tr>
</tbody>
</table>
Figure 11. The principle of source-area management to more effectively target measures to reduce P export in surface runoff from watersheds.