SCOPE NEWSLETTER

*SCOPE N°37 - 06/2000 - Sewage sludge disposal*

# EU considers tighter sludge spreading rules

**The European Commission's "Working Document on sludge, 2nd Draft" (12/1/2000 ENV.E.3/LM) proposes to significantly tighten limits for heavy metals and other pollutants in sludge used for agricultural spreading or otherwise spread on soils. The objective is to maintain or improve rates of recycling of sludge nutrients and organic matter, thereby restoring public confidence and ensuring environmental compatibility of sludge spreading.**

However, there is a risk that **stricter regulations may, in the short term, push water companies to seriously consider other disposal options, in particular incineration**.

The Working Document not only proposes new limit values (for immediate, medium and long term application) for different contaminants in sludge, it also **defines how sludge can be applied to different types of crop/ land use and requires a certification process** for all sludge spreading, including laboratory analyses. The Document includes not only sludge from municipal sewage works, but also sludges from septic tanks as well as the food, paper and leather (where chromium is not used) industries.

## ======== Septic tanks ========

Septic tank sludges will not be permitted to be spread directly on land but will have to be transported to sewage works for treatment.

**All sludges will have to undergo a minimum processing regime before spreading**, involving either thermal drying, thermal treatment or composting, digestion or stabilisation at pre-determined combinations of temperature and time. A three-tier system of treatment classification is established, with spreading on certain crops or in certain situations requiring one of the higher standards of treatment. The spreading of sludge in natural forests and woods is no longer permitted.

Producers will ultimately be responsible for the quality of the sludge supplied, even where there are intermediaries ensuring marketing and spreading. The producers will have to **guarantee "the suitability of sludge for use"** (compatibility with EU requirements). They must also install an independently audited quality assurance system and carry out sampling and analysis of sludges (a table of frequencies and tests is set out in the working document) in a certified laboratory, authorised and monitored by the competent authority.

## ======== Limit values ========

The Working Document proposes **limit values** for :

- **soils** : spreading prohibited on soils which exceed these values for one or more heavy metals ; also spreading must not result in final soil values exceeding the limit values

- **sludges** : spreading not to take place if one or more sludge heavy metal or listed organic compound limit exceeded (limit values for immediate application are proposed, but also limits to be introduced progressively over the medium and long term)

- maximum annual quantities of **heavy metals** to be applied in sludge per hectare of soil

Limit values proposed by EU Commission working document for contaminants in sludges for use on land (sludge not to be used if one or more value exceeded).

| Contaminant | Directive 86/278 | proposed immediate | proposed medium term | proposed long term |
|---|---|---|---|---|
| Heavy metals (mg/kg dry matter) | | | | |
| Cadmium | 20-40 | 10 | 5 | 2 |
| Copper | 1,000-1,750 | 1,000 | 800 | 600 |
| Mercury | 16-25 | 10 | 5 | 2 |
| Nickel | 300-400 | 300 | 200 | 100 |
| Lead | 750-1,200 | 750 | 500 | 200 |
| Zinc | 2,500-4,000 | 2,500 | 2,000 | 1,500 |
| Organic compounds (mg/kg dry matter) | | | | |
| Sum of halogenated organics (AOX) | not addressed | 500 | | |
| Linear alkylbenzene suphonates | not addressed | 2,600 | | |
| Di(2-ethylhexyl phthalate | not addressed | 100 | | |
| NPE (certain nonylphenol and nonylphenolethoxylates) | not addressed | 50 | | |
| Sum of certain polycyclic aromatic hydrocarbons (PAH) | not addressed | 6 | | |
| PCB (sum of indicated polychlorinated byphenils) | not addressed | 0.8 | | |
| dioxins PCDD/ dibenzofuranes | not addressed | 0.1 mg toxic equivalent/kg | | |

## ======== Difficulties in meeting targets for UK ========

The UK's Environment Ministry (DETR) has released figures (see ENDS report 301) showing that the UK's 1996/97 90 percentile values are higher than the proposed long term limit values for cadmium, copper, mercury and lead, with mercury 90 percentile values already at the proposed initial limit value.

The UK would have difficulty meeting the limit values. Water companies would have to tighten trade effluent consents for industries, but this would not resolve the issue of copper levels, for which the main problem is copper from domestic plumbing piping.

The **proposed limits for dioxins and PCB's** of 0.1 and 0.8 mg/kg can be compared with new limits proposed by the US Environmental Protection Agency (EPA) in December 1999 of 0.3 mg toxic equivalent/kg for the sum of dioxins, furans and certain coplanar PCBs (see : http://www.epa.gov/ost/biosolids).

## ======== Realism or consumer confidence ? ========

The objective of the EU Commission's proposals is to **ensure a long-term future for sustainable agricultural use of sewage sludge (recycling or nutrients and organic matter)** by restoring consumer confidence through strict contamination limitation requirements. The risk is that water companies will find it so difficult to meet the stricter limits that they will instead choose to accelerate investments in other sludge disposal routes, in particular incineration.

Reacting to a first draft of the Commission's working paper, which included significantly stricter limits in the short Ð medium term, the UK's Environment Ministry suggested that it would lead to an increase in incineration from 17% of sludge in 1999 to around 35%.

**One possibility for avoiding this negative consequence of tighter environmental requirements for agricultural re-use, would be to set recycling targets as well as sludge quality limit values.**

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*The EU Directive 86/278 concerning sewage sludge spreading is available at : http://europa.eu.int/eur-lex/en/lif/dat/1986/en_386L0278.html*

*The EU Commission's "Working Document on Sludge" is available on request from envinfo@cec.eu.int.*

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SCOPE NEWSLETTER

*SCOPE N°37 - 06/2000 - Pot trials*

# Struvite proves a good fertiliser

**This study's aim was to look at the reaction products produced in soil by three commercial fertilisers and to study the solubility and fertiliser value of these products. Struvite (magnesium ammonium phosphate), which can be recovered from sewage and other phosphate containing waste streams, was detected as a soil reaction product for two of the fertilisers studied.**

The plant phosphorus uptake and growth for the different reaction products identified, which included struvite, were then assessed using 45-day pot trails of gram (Cicer arietinum L.).

Struvite ( $MgNH_4PO_4.6H_2O$ ) appeared as a soil reaction product for APP = ammonium polyphosphate and for DAP = diammonium orthophosphate fertilisers. The pot trials thus compared struvite with these two fertilisers, with SSP (single super phosphate fertiliser), and with three other soil reaction products (each laboratory prepared crystalline precipitates) :

- brushite : $CaHPO_4.2H_2O$
- variscite : $AlPO_4.2H_2O$
- strengite : $FEPO_4 . 2H_2O$

## ======== Pot trials ========

The pot trials used gram (var. H208), irrigated as required, and harvested 45 days after sowing. The trials used 5 gram plants per pot, with triple random duplication.

The soil used was collected from an upland area of Ranchi, Bihar, India. It was acidic (pH 5.2), loamy and low in organic carbon (0.37%).

At the commencement of sowing, 8mg/kg soil K (as KCl) and 9 mg/kg soil N (as urea) were applied.

The phosphate compound to be tested was added at sowing, in the soil, below the seeds at 6 and 12 mg/kg soil dosages.

## ======== Struvite as a fertiliser ========

**Struvite gave consistently better results for both plant P-uptake and growth** (measured as oven-dry plant mass at the end of the 45-day trials), when compared with the three other soil reaction products.

When compared with the three commercial fertilisers, struvite gave the results in Table 1. (see below)

The authors indicate that Lindsay and Taylor (1960) also reported that **struvite was a good source of phosphorus for crops, almost equal in efficiency to monocalcium phosphate.**

They conclude that **struvite "proved to be superior or equally effective" as a source of phosphorus** for gram plants compared to the three commercial fertilisers tested.

**Table 1**

| Product used | Plant dry weight (g/pot) | | Plant P uptake (mg/g in plant) | |
|---|---|---|---|---|
| Phosphorus dosage (mgP/kg soil) | 6 | 12 | 6 | 12 |
| **struvite** | **0.475** | **0.705** | **0.209** | **0.404** |
| APP ammonium polyphosphate | 0.665 | 0.683 | 0.167 | 0.393 |
| DAP diammonium orthophosphate | 0.590 | 0.645 | 0.218 | 0.376 |
| SSP single super phosphate | 0.605 | 0.616 | 0.197 | 0.338 |
| **control** | **0.406 at zero added P** | | **0.289 at zero added P** | |

*SCOPE Newsletter editor's note : the performance of struvite is probably dependent on soil pH, and may be better in the acidic soils used for these trials than in many temperate soils.*

**SCOPE would welcome any information, trial results or literature readers may have regarding the fertiliser value of struvite in different conditions.**

*KAP Ref: "Characterization of soil-fertilizer P reaction products and their evaluation as sources of P for gram (Cicer arietinum L.)", Nutrient Cycling in Agroecosystems 46, pp. 71-79, 1996.*
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SCOPE NEWSLETTER

*SCOPE N°37 - 06/2000 - Agricultural leaching*

# Phosphorus in tile drainage flows

**Phosphorus concentrations and forms were analysed in tile drainage waters at 27 sites underneath intensively cropped farmland in the Saint Lawrence lowlands area, southeast of Montreal, Quebec, Canada. The results suggest that flat, clayey soils of medium to rich P status may be particularly at risk of exceeding phosphorus concentration standards for surface waters.**

The 27 sampling sites were at drain outlets from underneath nine different neutral to slightly alkaline, poorly drained soil plots, mainly used for maize (Zea mays) and soybean (Glycine max) crop rotation. Tile drains in the area are usually located in the C-horizon, more than 90 cm below the soil surface. Samples were collected in the spring and the autumn of 1994, and in the autumn of 1995. Samples were tested unfiltered for total P (TP), soluble inorganic (reactive) phosphorus (SRP) and for dissolved organic carbon (DOC), and, after 0.45µm filtration, for total P and soluble inorganic phosphorus (SRP). Dissolved organic phosphorus was taken to be the difference, following filtration, between total phosphorus and SRP).

For each site, an A-horizon soil sample was analysed for available P (Meklich-III extractable P):

- 9 exceeded 112 mg $M^{III}$P/kg (excessive available P)
- a further 12 exceeded 53 mg $M^{III}$P/kg (adequate P fertility for maize and soybean).

## ======== High drainage water phosphorus levels ========

**Total phosphorus concentrations in the sampled drainage waters varied widely, from <0.01 to 1.17 mgTP/l**, with significantly higher levels in 1994 than in 1995, particularly for the sites sampled in the autumn of 1994 (when sampling came after a significant rain event following a dry month).

Background surface water phosphorus concentrations in the area are < 0.02 mgTP/l and a local “standard” for surface water for phosphorus is 0.03 mgTP/l.

**This 0.03 mgTP/l “standard” was exceeded in drainage waters for 14 out of 27 sites in 1994 and for 6 out of 25 sites in 1995** (2 sites could not be sampled in 1995 because the drain outlets were below the ditch water level). 10 of the 14 sites with total phosphorus drainage water levels above 0.03 mgTP/l (1994) were clayey soils.

The implications of these levels of agricultural phosphorus are relatively difficult to assess, particularly as data regarding phosphorus drainage from natural, undisturbed soils in the area are not available.

## ======== Forms of phosphorus in drainage water ========

The proportion of total phosphorus (TP) present as soluble reactive phosphorus (SRP = inorganic) and dissolved organic phosphorus (DOP) varied widely from site to site and between years. The proportion DOP/TP was however significantly lower in 1994.

Taking site averages from both years, **DRP/TP ranged from 0-59%, DOP/TP from 0-79% and particulate phosphorus from 2-96%**. The authors indicate that the proportion of particulate phosphorus tended to be higher when total phosphorus was high.

The concentrations of phosphorus present as particulates and soluble inorganic (SRP) showed significant variations between 1994 and 1995, whereas dissolved organic phosphorus did not. Also a weak logarithmic correlation was found between dissolved organic carbon and dissolved organic phosphorus. The authors suggest that this may be related to a **relatively constant background level of dissolved organic phosphorus in drainage waters**, attributable to a mobile form of phosphorus. This corresponds to Schoenau and Bettany (1987) who noted that a high proportion of organic phosphorus was associated with the mobile fulvic acid fraction, susceptible to leaching.

Ron Vas et al. (1993) also reported a **strong relationship between DOP and DOC** and suggested that DOP was mobile and might contribute significantly to phosphorus loss to groundwaters. Chardon et al. (1997) found that DOP was the largest fraction of phosphorus below 50 cm depth, even in soil receiving only mineral fertilisers, and that the addition of crop residues increased DOP levels and enhanced phosphorus leaching.

The authors suggest that DOP probably originates from native soil phosphorus fractions and is mobilised by soil microbial activity stimulated by carbon inputs. They conclude that **"the generalised assumption that most mineral soils are not at risk for P leaching needs to be refined. In medium to excessively P-rich, flat and tile drained soils, P loss in subsurface waters is very likely to contribute to the observed eutrophication of surface waters."**

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*"Forms and concentration of phosphorus in drainage water of twenty-seven tile-drained soils". Journal Env. Quality, 27 pages 721-728, 1998.*

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SCOPE NEWSLETTER

*SCOPE N°37 - 06/2000 - Lysimeters*
# Phosphorus leaching from soils

**20 1m wide, 1.25m deep lysimeters were used at the Falkenburg research centre, Germany, to test phosphorus leaching from two types of soil underneath grassland, winter barley/oats, winter wheat, sugar beet, maize, potato and alternated cultures with different levels of fertiliser application (manure and/or mineral phosphate fertiliser), as well as under fallow land and reforested land.**

Soil samples were used to calculate total soil phosphorus and amounts of sequentially extractable forms (total P, resin extractable labile P, $NaHCO_4$ extractable, NaOH extractable, $H_2SO_4$ extractable, residual P). Soil leachate water was collected and both the volume of leachate and the concentration of total phosphorus, were analysed monthly enabling annual phosphorus leachate loss to be calculated.

Soil phosphorus contents were in the range 435-1134 mg/kg, comparable to those of the soil parent material, indicating no significant anthropogenic phosphorus enrichment. The proportion of labile (resin adsorbed) phosphorus was 8-18%, similar to that reported in other German manured soils (Leibweiner, 1996).

## ======== Mobile phosphorus in soils ========

**Higher contents of very labile phosphorus forms (resin adsorbable) tended to occur under arable cultures whereas the content of relatively available phosphorus ($NaHCO_3$ extractable etc) followed the order grassland >arable land > fallow**. This may result from the intense root and rhizosphere effects of grass and larger microbial activity, leading to increased cycling of moderately labile forms of phosphorus.

**Soils receiving large mineral fertiliser application rates (25-60 kgP/ha) usually had higher labile phosphorus contents, although the relationship was not linear. Furthermore, as indicated later, this did not apparently result in increased phosphorus leaching.**

Overall, grassland on sandy soil and intensive root crop/grain crop rotations on loamy sand showed the largest amounts and percentages of soluble phosphorus fractions.

# ======== Phosphorus leaching ========

The **mean annual concentrations of phosphorus in the leachate waters collected in the lysimeters reached 0.8 mgP/l (total phosphorus)** in some cases, with an overall average of 0.16 mgP/l. This corresponded to total phosphorus losses of up to 3.2 kgP/ha/year, with an average for all lysimeters (with non zero leachate volume collected) of 0.3 kgP/ha/year.

These values are similar to those reported by Sharpley & Menzel 1987 but are lower than those modelled by Breeuwsma *et al*. 1995 for manured soils in Holland.

In lysimeters using the same soil type and culture, leachate losses did not relate to rates of mineral fertiliser application. However, **leaching was significantly related to the type of agricultural management**, but not in as might be expected. In order of decreasing observed leaching, the authors indicate the following comparison between different types of land management : grassland and arable cultures with mineral fertilisers > less intensively used soils with low fertilise inputs > arable cultures with organic and mineral fertilisers.

$NaHCO_3$ and acid oxalate extractable phosphorus contents of soils were positively correlated with the concentrations of phosphorus in leachates and leaching phosphorus losses.

No significant correlations were found, however, between DLP or $H_2O$ P and leaching losses, which supports doubts about the usefulness of soil P test values (as developed to assess the supply of phosphorus to crops) as a tool for predicting phosphorus leaching.

The authors conclude that **agricultural management which conserves soil organic matter and increases biological activity (such as permanent grassland or manure application) will increase the proportion of labile phosphorus in the soil, desirable for crop nutrition but more susceptible to leaching.**

The lysimeters which showed the lowest phosphorus leaching were those with intensive root crop/grain crop rotations with high phosphorus fertilisation rates. This means that any shift from intensive to extensive land use will need to be gradual and accompanied by management strategies if it is not to result in an increase in phosphorus leaching.

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*"Management effects on forms of phosphorus in soil and leaching losses". European Journal of Soil Science, n° 50, pages 413-424, Sept. 1999.*

P. Leinweber, K-U. Eckhardt, Institute for Soil Science, University of Rostock, Justus von Leibig Weg 6, 19059 Rostock, Germany. R. Meissner, J. Seeger, UFZ Centre for Environmental Research Leipzig-Halle GmbH, Institute of Soil Science

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SCOPE NEWSLETTER

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*SCOPE N°37 - 06/2000 - Manures on grassland*

# Phosphorus leaches to drains through rapid transport pathways

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**Flow rates and phosphorus concentrations and forms were studied in the tile drainage water flowing from underneath two sites in the Kleine Aa subcatchment of Lake Sempach, in the central Swiss plateau (altitude 505 - 670 m, slope 5-10%). The sites studied are permanent grassland, used for intensive dairy and pig farming (stock density of 3.0 dairy cow/ha equivalent) and are cut 5-7 times/year, with manure application following cutting.**

Tile drains were installed around 100 years ago 50Ð100 cm below the soil surface and the study looked at discharge waters flowing out of the drains into a brook. Whenever significant discharge occurred, samples were automatically collected every 15 minutes and mixed in pairs to give 30 minute averages. Discharge flows from the drains were measured and logged at 15 minute intervals. Precipitation was measured using a rain gauge located between the two sampling sites.

Phosphorus was analysed in the drainage water samples as follows :

- total phosphorus (TP) was assessed before filtration
- soluble reactive phosphorus (SRP, which is mainly inorganic) was measured after 0.45µm filtration
- total P after filtration was used to indicate total dissolved phosphorus (TDP)
- particulate phosphorus (PP) was calculated as the difference in total P before and after filtration
- dissolved organic phosphorus (DOP) was calculated as the difference between TDP and SRP

In one case, the inorganic phosphorus adsorbed to colloids was also assessed, by taking the difference between SRP in 0.45 µm and 0.05 µm filtrates.

The analysis of drainage waters was completed by assessments of the depth distribution of water extractable phosphorus in soils at the sites (these showed that phosphorus was mainly present in the upper 30 cm of soil) and by sprinkling experiments using blue dye to study water flow patterns and speeds within the soils.

## ======== Drainage flows and P discharges ========

Flows and phosphorus discharges were measured for seven rain events at site I and for 12 at site II, giving a total of 503 sets of 30-minute data. Drainage flow was continuous at site I, even during the driest periods of the year, whereas at site II, it generally stopped a few days after precipitation.

Measured **concentrations of SRP varied from 1.61 to 155 µmol/l, and were correlated with the flow rate for nearly all the discharge peaks**. At site II, which was managed by just one farmer, manure applications were noted and showed some influence on SRP concentrations: two rain events occurring within 1-2 days of manuring showed extremely high SRP concentrations, although other high SRP levels did not show an identifiable relationship to manure applications.

## ======== Available phosphorus loads ========

**Soluble reactive phosphorus (SRP), which is the form most available to plants and so most susceptible to contribute to eutrophication, made up an average of 50% of phosphorus discharges at site I and 70% at site II.** Particulate phosphorus (PP) was also significantly present, whereas levels of dissolved organic phosphorus (DOP) were very small despite the regular manure applications. When colloidal phosphorus was assessed, this was found to make up an average of 12% of discharged phosphorus.

A base flow phosphorus discharge concentration of 1.6 µmol/l was estimated for site I. Total phosphorus load from the drainage discharges to the nearby brook was estimated, on the basis of the measured values for the recorded discharge events. This gave estimates of SRP leaching of 227 gP/ha over two and a half months at site I (May, June, October) and 1290 gP/ha at site II over the whole growing season (6 months), respectively arithmetically equivalent to **around 1300 and 2600 gP of SRP/ha/year**.

The figure for site I does not include the major flood event and the series of large discharges which followed it in May, because the site I instrumentation was damaged by this flood, whereas these discharges alone accounted for around 2/3 of all phosphorus losses from site II.

The 95% confidence levels for these estimates are very large, being 21% for site I and 36% for site II.

## ======== Rapid infiltration pathways ========

Dye sprinkling experiments, with irrigation at levels set to avoid run-off (5 mm/h at site I, 10 mm/h at site II, on 1.5 m x 1.5 m plots), showed that, although the dye only infiltrated 2-5 cm into the general bulk of the soil, a substantial proportion of the dye rapidly penetrated down to a depth of about 80 cm along preferential flow pathways at both sites. **Worm burrows (probably *Lumbricus terrestris L.*) were the dominant penetration pathway**. These were observed to be present in high densities everywhere throughout this area of grassland.

The fate of the dye penetrating these pathways differed between the two sites. At site II, after one day of sprinkling, many of the burrows were full of water, indicating little exchange with the surrounding bulk soil, but dyed water appeared in an open ditch 4.5 m downhill of the sprinkling plot less than two hours after the start of dye sprinkling. The dyed water emerged from pores with a diameter of 1-2 mm, situated below the water level of the ditch. By digging uphill, the lateral transport was shown to be occurring in the water-saturated zone of soil more than 1m below the surface, perhaps in preserved ancient root channels which are specific to the soils in this area.

At site I, on the other hand, large blue patches had developed in the bulk soil underneath the sprinkling plot after one day, showing s**ubstantial lateral transport.**

The authors conclude, as already suggested by Flury (1994), that **in agricultural soils vertical preferential flow is the normal case and not the exception**. The immediate response of SRP concentrations in drainage water to manure application at site II strongly suggests that some of these preferential flow channels are hydraulically connected to the drainage system, allowing phosphorus to pass rapidly from the topsoil to the tile drains.

The study sites are situated in the catchment of Lake Sempach, which is subject to eutrophication. Swiss water quality goals indicate that SRP losses from agricultural land in the catchment should not exceed 400 gP/ha/year on average. However, the authors emphasise that the observed values suggest that **these levels are largely exceeded by the drainage water on its own**, to which must then be added surface run-off.

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*"Preferential transport of phosphorus in drained grassland soils". J. Environ. Qual. 27, pages 515-522, 1998.*

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SCOPE NEWSLETTER

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*SCOPE N°37 - 06/2000 - Phosphorus cycle*

# Significance of atmospheric inputs

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**Dust and aerosols containing phosphorus are transported across the world, from erosion to of phosphorus containing soils, biological processes, combustion and other sources, accentuated by human activities (10-20% of atmospheric phosphorus). The evaluations of atmospheric phosphorus deposition in literature may often be inexact, because of difficulties in measurement or experimental method, but deposition is estimated at 0.04-2 kgP/ha/year.**

Atmospheric phosphorus can be found in both organic and inorganic dust particles. Particles of organic origin, such as pollen, will contain phosphorus as do all living organisms. Mineral dust will contain varying levels of phosphorus depending on its source: dust from the Atlas region of North West Africa, for example, contains 0.2%P. Other natural sources are volcanoes, meteorites and, to a limited extent, sea spray.

Phosphorus is also released into the atmosphere by microbial reduction processes which have been shown to generate volatile phosphorus compounds in sewage sludges, faeces, landfill, compost heaps and coastal sediments. Volatile gaseous products such as $PH_3$ or $P_2H_4$ may move into the atmosphere and become oxidised and airborne as aerosol droplets.

**The main anthropogenic sources of atmospheric phosphorus are probably combustion of coal and forest fires**, though certain industries such as concrete furnaces, phosphorus rock mining and intensive fertiliser use may also contribute to some extent.

## ======== Sampling errors ========

The assessment of the phosphorus content of air is very difficult because of the very small concentrations present and because the phosphorus is generally in aerosol form or associated with very small particles, often below 0.1 µm size. Concentrations in rain may often also be below the detection limit, necessitating concentration before analysis. **Errors in assessing phosphorus concentrations in rain water may also result from methodological differences** of filtering, as the phosphorus will be associated with aerosols and particles, or from errors in the molybdenum blue method resulting from silicate interference (eg. in dusts), or even from phosphate adsorption or release by laboratory glasswear in used sapling and analysis.

Phosphorus deposition needs to take into account both dry deposition and deposition in rain. This introduces further difficulties as dry deposition rates will be higher on a wet surface and the phosphorus content of rain may vary widely. **Fog water, for example, may contain up to ten times higher concentrations of phosphorus than most rain.**

## ======== Significance of atmospheric deposition ========

**The authors quote estimates for annual phosphorus deposition from the atmosphere (kgP/ha) of 0.04-0.1 for the central Amazon basin, 0.1-2 for tropical moist forests, 0.8 for German oak forest and 1 for New Hampshire hardwood forest.**

Rain can contribute a significant amount of phosphorus to the photic zone of the Mediterranean Sea during the summer (Bergametti et al., 1992). Atmospheric deposition compensates for 25% of phosphorus loss through sedimentation in some US lakes (Cole et al., 1990) and can contribute up to 30% of all phosphorus input to some Swiss lakes (L. Thšni, personal communication to the authors).

The authors conclude that a**tmospheric deposition is thus a critical input to both terrestrial and aquatic ecosystems**, at least for oligotrophic situations. However, special care in sampling and analysis methodology are necessary to obtain reliable data. Current values given in literature vary widely and some values may be questionable.

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*"The biogeochemical cycles of phosphorus: a review of local and global consequences of the atmospheric input". Technological and Environmental Chemistry, vol. 67, pages 171-188, 1998.*

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SCOPE NEWSLETTER

*SCOPE N°37 - 06/2000 - Lake Constance*
# Complexity of phosphorus - biomass relations

**This paper provides a full assessment of phosphorus fluxes in Lake Constance and examines interactions between different forms and sources of phosphorus and biological productivity (growth of algae, bacteria, zooplankton grazing). In particular, consideration is given to the exchanges between river inflows, surface waters (euphotic layer), deep waters and sediments, and to the biological cycling of phosphorus within the euphotic layer. The paper examines how these relationships have changed with re-oligotrophication of the Lake.**

The Lake Constance phosphorus loads have been reduced significantly over the past decade, so that, for example, the phosphorus load flowing out of this Lake in the Rhine has been reduced by 50% for 1985/6 to 1997.

73% of river phosphorus load entering the Lake was in particulate form (1985/86). The authors estimate that **80% of this particulate inflow settles directly as sediment in the Lake and is rapidly and irreversibly buried.**

Although the Rhine River makes the largest contribution to the Lake’s total phosphorus load (48%), this is mainly particulate, so that other rivers such as the Schussen carry as much dissolved phosphorus.

The Lake Constance phosphorus budget based on 1985/6 investigations (Wagner and Bührer, 1989) was (tonnes P):

| | |
|---|---|
| Total phosphorus 1985 | 2835 |
| + river particulate load | +1677 |
| + river dissolved load | +578 |
| + atmospheric load | +42 |
| - sedimentation losses | - 2086 |
| - outflow (Rhine) | - 406 |
| - other (drinking water extraction, fisheries …) | - 15 |

Total phosphorus 1986 2625

## ========= Sedimentation as a P sink =========

Sinking of phosphorus out of the euphotic layer into sediment is mainly caused by the loss of dead organisms, evidenced by the low proportion of living organisms found in the bottom waters. **Zooplankton grazing and then subsequent mortality was estimated to be the cause of 26% of phosphorus loss from the euphotic layer** to the sediment. Other main causes of phosphorus sedimentation were the breakdown of the spring algal bloom, calcite precipitation, and diatom sedimentation in autumn.

**Phosphorus sedimentation rates in the pelagic zones of the Lake were estimated as 2-6 mgP/m$^2$/day, representing per day up to 2% of the total phosphorus concentration in the euphotic layer in the summer** (during thermal stratification). Although this is significantly lower than the input to the Lake from rivers, the total phosphorus concentrations in the euphotic layer remain relatively stable, demonstrating that most of the river input is sedimented near the river inlets.

Considerable variations of river phosphorus loads flowing into the Lake have no apparent effect on concentrations in the euphotic layer, probably because of both intense horizontal mixing and the direct movement of river inflow phosphorus into the deep water layer with a reduced impact on the euphotic layer. Wagner and Wagner (1978) indicated that most of the phosphorus load from the Rhine and Bregenzer Ache rivers went into Lake water layers deeper than 10m.

Release rates of phosphorus from the sediments can reach 30-50% of the sedimentation rates and are fairly independent over the long term on whether the sediment surface is aerobic or anaerobic (although a change to anaerobic conditions can lead, in the short term, to an accelerated release). This phosphorus released from the sediments, however, will tend to stay in the deep waters and not reach the euphotic layer.

## ========= Significance of littoral sediments =========

The rates of phosphorus inflow to the Lake are halved in summer, but epilimnetic phosphorus is not depleted. The authors suggest that this is largely related to the **release of littoral sediments** through wind resuspension and estimate that this source of phosphorus is comparable to river inflow. Phosphorus released from littoral sediments would mix rapidly within the euphotic layer.

## ========= Biological cycling =========

The authors note that the biological demand for phosphorus in the euphotic layer (calculated from the biomass of bacteria and algae and uptake rates) largely exceeds available phosphorus supply during growth periods (1500 mgP/m$^2$ compared to 360 mgP/m$^2$).

In this situation, **bacteria will tend to act as a phosphorus sink**, absorbing phosphorus from water which is then retained as they either sink to the sediment or are grazed by zooplankton. Hence bacteria can effectively compete with algae to take up scarce available phosphorus, rather than - as is often modelled - acting as a source of phosphorus by cycling phosphorus during decomposition.

Experimental observations suggest that **bacteria are superior competitors for phosphorus at low concentrations than algae** and that bacteria have a higher phosphorus content (P:C) ratio than algae.

This leads to a paradox: how can the high algal demand for phosphorus be effectively met during the summer in the Lake's euphotic layer? **Zooplankton grazing may be a key factor in influencing the outcome of this competition.**

## ======== Importance of biological cycling ========

The authors also indicate that **phosphorus regeneration by grazing of algae and bacteria is probably a very important factor**, perhaps accounting for up to 50% of estimated algal phosphorus demand (grazers excrete part of the phosphorus taken in with prey, only retaining phosphorus for their own growth).

Overall, 70-80% of the phosphorus required for algal biomass production must be provided by regeneration of organic materials within the euphotic layer.

Dissolved organic phosphorus, may be an important phosphorus source in the summer when dissolved inorganic phosphorus remains constantly below the detection limit. The authors note that more than 50% of the dissolved organic phosphorus pool could consist of nucleic acids, which are rather resistant to enzyme breakdown (resulting in a residence time in the water of 10-20 days), whereas concentrations of monomeric nucleotides such as ATP were two orders of magnitude lower (and showed very short turnover times in the water).

To conclude, the authors state that **the links between phosphorus fluxes and biological production is subject to complex biotic and abiotic interactions, so that biological productivity cannot be sufficiently predicted by simple phosphorus load approaches.**

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*"Phosphorus fluxes in Lake Constance". Arch. Hydrobiol. Special Issues Advanced Limnology n¡ 53, pages 505-544, 1998.*

H. Güde, Institute für Seenforschung, Untere Seestrasse 81, D88085 Langenargen, Germany. T. Gries, Limnology Institute, Konstanz University, D78457 Konstanz, Germany.

SCOPE NEWSLETTER

*SCOPE N°37 - 06/2000 - Japan*
# Algal control by shading

**Shading of 40-80% of the surface of small farm irrigation water reservoirs (1,000-1500 m2, approx. 3m maximum depth) was tested in the field as an approach for controlling algal blooms. Three reservoirs were tested using shading of 30-60% of the surface, with one left unshaded as a control, in 1998 and 1999.**

Shading was achieved using floating plastic or stick boards, either held together to cover one part of the reservoir, or distributed randomly as they floated over the water surface.

In 1998, after the appearance of the summer algal bloom, 50% shading was added resulting in a 50% drop in COD and water transparency improving to the extent of being able to see the reservoir bottom. In 1999, 30% and 50% **shading used before the appearance of the summer bloom completely prevented its appearance**. In both years, the control reservoir underwent a significant algal bloom, with scum developing on the water surface.

## ======== Blue-greens ========

In both years, the shading also resulted in an algal species shift from cyanobacteria in the algal blooms to diatoms. This is a very positive response where the reservoir water is intended for the water supply as it avoids risks due to toxins or odour problems.

The author notes that **the algal bloom was avoided both in the shaded and the unshaded areas of the reservoirs.** This does not appear simply to be the result of water mixing (meaning that all of the reservoir's water passes a proportion of its time under shading) since the growth rate of the algae in the unshaded areas of the reservoirs with partial shading was found to be one half to two thirds that of the algae in the control reservoir.

## ======== Loss of photosynthetic capacity ========

The author explains these results by referring to work by the late Prof. Ichimura, Tsukuba University, Japan, demonstrating that when samples of surface water from a eutrophic lake was stored in the dark or in low-light conditions for 1-5 days, the photosynthetic capacity becomes lower (on returning to light conditions after storage). The loss of photosynthetic activity is greater for longer storage periods and with darker storage conditions. This can be envisaged as a kind of shading memory effect.

In conclusion, the author suggests that up to 80% shading may be necessary to ensure very low algal concentrations necessary for the use of water for drinking supply, but that **40-60% shading would suffice to avoid algal bloom problems whilst maintaining some primary production**, considered necessary for fish production. Because this would imply relatively large areas of shading panels on any lake of significant size, the author suggests that the floating boards could be used to support photoelectric panels thereby also providing a source of renewable energy.

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*"Algal control of shallow lake by partial shading of surface". Tsukuba International Aquatic Environment Forum, February 1st 2000.*

S. Kojima, Central Research Laboratory, Nissuikon Co. Ltd., 7-107 Asahigoaka 4-Chome, Hino City, Tokyo 191, Japan.

SCOPE NEWSLETTER

*SCOPE N°37 - 06/2000 - Thin film gels*

# Measuring dissolved inorganic phosphorus

**Dynamic interactions of phosphorus species in natural systems may result in changes when samples are stored. The technique of diffusive gradients in thin films (DGT) can allow in situ measurements of dissolved inorganic phosphorus in natural waters, sediments or soils.**

The DGT technique is based on a simple device consisting of a **phosphorus binding agent fixed behind a thin hydrogel layer which acts as a well defined diffusion layer**. In the work presented in this paper, the binding agent is ferrihydrite fixed in gel behind a 0.8mm thick layer of polyacramide gel, itself behind a membrane filter for protection. A 10 cm x 1 cm window on larger sheets was in contact with the water to be tested.

Phosphorus accumulated by the ferrihydrite was measured by elution with sulphuric acid followed by spectophotometric analysis of molybdenum blue. The rate of diffusion of soluble inorganic phosphorus across the hydrogel layer was assessed experimentally using the diffusion cells and noting times taken to reach equilibration concentrations.

## ========= Field testing =========

The DGT devices presented were **field tested in a small, still eutrophic pond** on the Lancaster University campus (UK) in April 1997 (suspension for 8 hours) **and also in sediment cores** extracted from Esthwaite Water in June 1997 (24 hours contact time). In both cases, the soluble phosphorus calculated from them (FRP method) was compared with the concentrations in the pond and pore water measured by standard laboratory methods. Nine DGT devices were used in each case: triplicates of three different gel thicknesses.

For the pond water, the DGT-calculated soluble phosphorus concentration gave 100.8 +-3.3 µgP/l (95% confidence limits) and the FRP method 91.6 +-4.5 µgP/l. The 10% difference may be due to variations in the concentration in the water over the 8 hour exposure time (the sample for FRP was taken at one time only) and in any case is such that the **95% confidence limits overlap.**

In the sediment, the DGT device measurements need to be adjusted (equation given in paper) in order to take into account possible re-supply of soluble phosphorus from sediment particles in response to absorption from the pore water into the DGT device. The DGT results from the sediment core show a **well defined curve of increasing concentrations** from below the detection limit at the sediment surface to around 300 µgP/l at a depth of 50-60 cm in the sediment.

## ========= Interest of DGT method =========

The DGT method will indicate concentrations of soluble phosphorus species which are small enough to diffuse through the hydrogel layer (pore size 2-5 nm), so **that the DGT method will indicate genuinely soluble species only.**

Because the DGT device accumulates phosphorus over time, it can be **deployed for long time periods** (up to 50 days, subject only to problems of biological fouling), and can thus measure (as an average) very low soluble phosphorus concentrations (by accumulating phosphorus in the ferrihydrite) to concentrations measurable by standard laboratory techniques.

In soils and sediments, DGT can provide an indication not only of pore water soluble P concentrations, but, more interestingly, the **capacity of the soil to re-supply soluble phosphorus from particles.** More work is needed to assess the relationship between this DGT measurement of available phosphorus fluxes and possible plant uptake.

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*"In situ measurement of dissolved phosphorus in natural waters using DGT". Analytica Chimica Acta 370 pp. 29-38, 1998.*

H. Zhang, W. Davison, T. Kobayashi, Environmental Science, Lancaster University, Lancaster LA1 4YQ, UK. R. Gadi, ERD Kdmipe, ONGC, Dehradun-249001, India.

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SCOPE NEWSLETTER

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*SCOPE N°37 - 06/2000 - LaPlatte River, Vermont*
# Phosphorus storage

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**A three year study of the La Platte River (north west Vermont, USA, further details in article below) used a number of techniques to assess phosphorus stocks, phosphorus storage and exchange of phosphorus between different compartments.**

The study concentrated on phosphorus dynamics in two contrasting stretches of river:

- **Bacon Dr.**, around 6 km upstream from the mouth of the river (Lake Champlain), with a varied sediment river bed (sand, silt, clay and some pebbles and cobbles) and a macrophyte community covering 75% of the bed by late summer (dominated by *Elodea canadensis Michx* waterweed and two species of pondweed *Potamegon pectinatus L.* and *P. natans l.*)

- **Spear St.**, around 10 km from the river mouth, a quick flowing reach with a substrate mainly of cobbles with some boulders and a few small patches of gravely sand, silt and clay. The macrophyte community covered less than 1% of the river bed of this reach (same dominant species).

## ========= Phosphorus mass balance =========

Phosphorus dynamics in the river reaches were examined using seasonal stock assessments to estimate uptake and release from the five compartments: water, sediment, epilithon, macrophytes and epiphytes, detritus. Additional experimental assessments of uptake rates were made using radioactively labelled phosphorus in laboratory conditions, and retention rate assessments were made in the river using phosphorus spike and dye addition (see article below).

A phosphorus dynamics simulation model was built and parameters assigned using both the experimental results and map data covering the river basin morphology.

## ========= Stock assessment =========

Phosphorus stocks for each of the studied compartments were assessed for each season from August 1993 to April 1995. At both reaches, a number of samples were taken from random locations for each compartment and total phosphorus was calculated using chemical analysis along with the calculation of plant matter, detritus weight and suitable epilithon and sediment area.

As might be expected, **the plant and sediment rich Beacon Dr. reach showed significantly higher standing phosphorus stocks** than the Spear St. reach (25-29 compared to 2 - 4 $gP/m^2$ on average). In both reaches, most of the phosphorus stock was in the sediment (97% and 71% respectively).

**Phosphorus uptake rates were estimated by comparing the maximum differences between consecutive seasonal stock estimates, giving 96 and 11 $mg/m^2/day$** respectively for Beacon Dr. and Spear St.

## ========= Sediment exchange =========

Nearly all of the exchange of phosphorus between sediments and other compartments concerned the **upper layer of sediments** only. The variation in phosphorus concentrations in the upper 0-2 cm of sediment was high (range 0.25 mgP/g sediment = 44% of the mean value) whereas the variation for the remaining 3-5 cm of sediment studied was only 0.07 mgP/g sediment.

In laboratory sediment sorption experiments, the river sediments reached equilibrium with a 1 mg/lP soluble phosphorus solution after 12 hours, with half of the total absorption occurring within one hour. This demonstrated that the **sediments were far from phosphorus saturated under ambient conditions.**

## ========= River phosphorus dynamics =========

The uptake rates estimated from laboratory radioactive phosphorus experiments (river microcosms with all of the different studied compartments and with epilithon) were consistent with those estimated from the seasonal stock variations in the river, suggesting overall phosphorus uptake rates of 10-100 mgP/m2/day over the year. The rates at the upper end of this range would occur in summer when biologically available phosphorus concentrations are higher and at sediment and plant-rich reaches such as Beacon Dr.

The extrapolation of these phosphorus uptake rates to the whole river (51 ha of river surface) yields a range for **phosphorus uptake between seasons of 600-4,500 kgP**. This is somewhat lower than the estimated annual flux of phosphorus from non-points sources from the LaPlatte River into Lake Champlain (7,600 kgP/year).

Extrapolation of phosphorus stock estimates suggest that the **stock in all compartments of the LaPlatte river lies between 1,400 and 14,000 kgP, with a likely figure being around 8,000 kg, giving a**

**load:stock ratio of around one.**

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*«Lake Champlain in transition : from research toward restoration». Water Science and Application, vol. 1, pages 205-223 (American Geophysical Union).*

D. Wang, School of Natural Resources, University of Vermont, Burlington, Vermont, 05405 USA. Email : deane.wang@uvm.edu. S. Levine, D. Meals, J. Hoffmann, J. Drake, E. Cassell (addresses see next article).

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SCOPE NEWSLETTER

*SCOPE N°37 - 06/2000 - Nutrient ecology*

# River phosphorus retention

**Spikes of dissolved phosphate (orthophosphate) and of dye added to a stretch of the LaPlatte River, north west Vermont , USA (flow 0.2-20 m3/s) showed that over one third of the phosphorus was temporarily retained (not carried downstream after 2.5 hours) in both December and September. However, whereas nearly all the added phosphorus was released during the next 12 hours on 20th December (under ice cover, with minimal biological activity), nearly 40% was still retained 48 hours later on 3rd September when plant growth was abundant.**

The LaPlatte River drains a watershed of nearly 14,000 ha and is 24 km long, flowing into Lake Champlain from its headlands in the Green Mountain foothills. Around 20% of the catchment is forested headland area, the remainder being agricultural and suburban, with agricultural land accounting for 47% of the catchment area, mainly dairy farming.

**The river has historically experienced heavy agricultural and point source (Hinesburg urban wastewaters) nutrient and sediment loads.** Annual average total phosphorus (TP) and soluble reactive phosphorus (SRP) concentrations were 420 and 310 µgP/l respectively in the 1980's. In 1992, the Hinesburg sewage works was upgraded, resulting in significant reductions in phosphorus concentrations in the river waters at low flow (to 20-140 µgP/l TP and 10-100 µgP/l SRP) although annual average phosphorus loads in the river water at its outflow into the lake have not changed significantly.

The phosphorus spiking experiments were carried out in a 3 km long 3rd order pool and riffle reach of the LaPlatte River near the town of Shelbourne. The pools had a macrophyte community with typically dominant species of Elodea and Potamogeton. Riffles had abundant substrates for epilithic periphyton, with cobbles, boulders and patches of sand, silts and clays. At this point the river was around 10-12 m wide with depths varying from 2m in the pools to <0.3m in riffles. River water flow rates were 0.58 m3/s in the December experiment and 0.24-0.25 m3/s in the September experiment.

The river was spiked both with relatively large doses of phosphorus (890 g of phosphorus in winter, 300g in autumn calculated to give the same concentration in the river as a function of the flow, both as orthophosphate) and Rhodamine WT (a red dye considered to be not significantly absorbable to plants or clays at the doses used). Following spiking and for the first 20-48 hours, samples of the river water were taken 3 km downstream at 10 minute intervals. The first samples gave the background level of phosphorus before spiking, whilst samples, starting with the arrival of the first traces of dye, enabled the phosphorus retention in the river system to be assessed by comparing the distributions over time of concentration and flux of phosphorus and of the dye.

## ========= Delayed phosphorus transport =========

In the December experiment, when the river was largely covered in ice, the dye pulse was first detected 3 km downstream 380 minutes later (average velocity of leading edge 0.13 m/s) and dye continued to be detected for a further 230 minutes, corresponding to a “plume” length of 1.8 km in the river. Phosphorus, however, although first detected nearly concurrently with the first detection of dye (the small difference was compatible with errors resulting related to differing detection sensitivity), was still detectable above background levels in the last sample taken 550 minutes after its first detection. By extrapolation, the phosphorus plume was calculated to have continued for 830 minutes, corresponding to an overall plume length in the river of 6.5 km.

Background phosphorus levels were 47 µgP/l total phosphorus (TP) and the maximum concentration reached in the sampling 3 km downstream of the spiking was 216 µgP/l.

The flux of phosphorus above background levels leaving the experiment reach was estimated, using measured discharges and comparisons with dye concentrations, as 93% of the mass of phosphorus added in the spike. The 7% “loss” was most probably due to minor errors in estimations of flows and concentrations, so it was deduced that all or nearly all the added phosphorus had been carried out of the experimental reach after the 830 minutes (13 hours), indicating **negligible phosphorus retention in December.**

## ========= Phosphorus retention =========

In the September experiment, when water temperatures were in the 15-17 °C range, flow rates were significantly lower as was the average velocity of the leading edge of the dye plume, at 0.9 m/s. This resulted in the dye first reaching the lower end of the experimental reach 560 minutes after spiking and continuing to be detectable for a further 670 minutes, giving a 3.6 km long dye plume (three times the length of the dye plume in December).

The first detection of phosphorus above the background level was again concurrent with the first detection of dye, but, unlike for the December experiment, phosphorus concentrations returned to background levels only shortly after the end of dye detection (760 minutes after detection), giving a **phosphorus plume length of 4.0 km, considerably shorter than the phosphorus plume in December.**

Background phosphorus concentrations were in this case 58 µgP/l total phosphorus (TP), and the maximum concentration reached at the sampling point 3 km downstream of the spiking was 98 µgP/l.

When the phosphorus concentrations had returned to background levels (accuracy of measurement 1 µgP/l), it was calculated that **only around 62% of the spiked phosphorus had actually flowed past the sampling site, corresponding to 38% retention in the river system after 48 hours.**

## ======== Abiotic and biological P retention ========

**In both the December and September experiments, the short-term retention of phosphorus was demonstrated**, with the phosphorus plume being longer than that generated by the spiked dye. The authors suggest that this is probably due to **the temporary sorption of phosphorus to sediments**, resulting from the relatively higher phosphorus concentrations in the water due to spiking, followed by release as the water P concentration decreases again as the plume moves downstream. The fact that this effect occurred more noticeably in December (longer phosphorus spike) may have been because the phosphorus concentrations resulting from the spiking were in this case higher (concentration below spiking point after initial mixing 13.5 mgTP/l in December versus 10.0 mgTP/l in September).

The shorter phosphorus plume and the significant level of P retention (38%) in September suggest, on the other hand, that the dominant mechanism in this case is **active biotic phosphorus uptake, probably by macrophytes and epilithon**. This was compatible with laboratory measured phosphorus uptake rates for the LaPlatte River epithlon, estimated at 66 mgP/m2/day (Hoffmann et al. 1996).

The authors note that their results are difficult to extrapolate to general conclusions about phosphorus retention in river systems, in particular because the P-spiking method necessarily implies concentrations significantly above natural levels in the river waters, and these are, in turn, susceptible to result in non typical ecosystem responses. They do, however, conclude that **the experiments confirm the capacity of a relatively short stretch of river (in this case a eutrophic river already subject to high nutrient loads) to retain a very considerable proportion of input phosphorus during the growth season**, that is at exactly the time of year when receiving waters (in this case a lake) would be most sensitive to nutrient inflows.

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*"Retention of spike additions of soluble phosphorus in a northern eutrophic stream". J. N. Am. Benthol. Soc. 1999 18(2) pages 185-198.*

D. Meals (dmeals@wcvt.com), S. Levine, D. Wang, E. Cassell, D. Pelton, H. Galarneau (School of Natural Resources), J. Hoffmann (Dept. of Botany), J. Drake, A. Brown (Geology Dept.), Vermont University, Burlington, Vermont 05405 USA.

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SCOPE NEWSLETTER

*SCOPE N°37 - 06/2000 - Rhine and Elbe rivers*

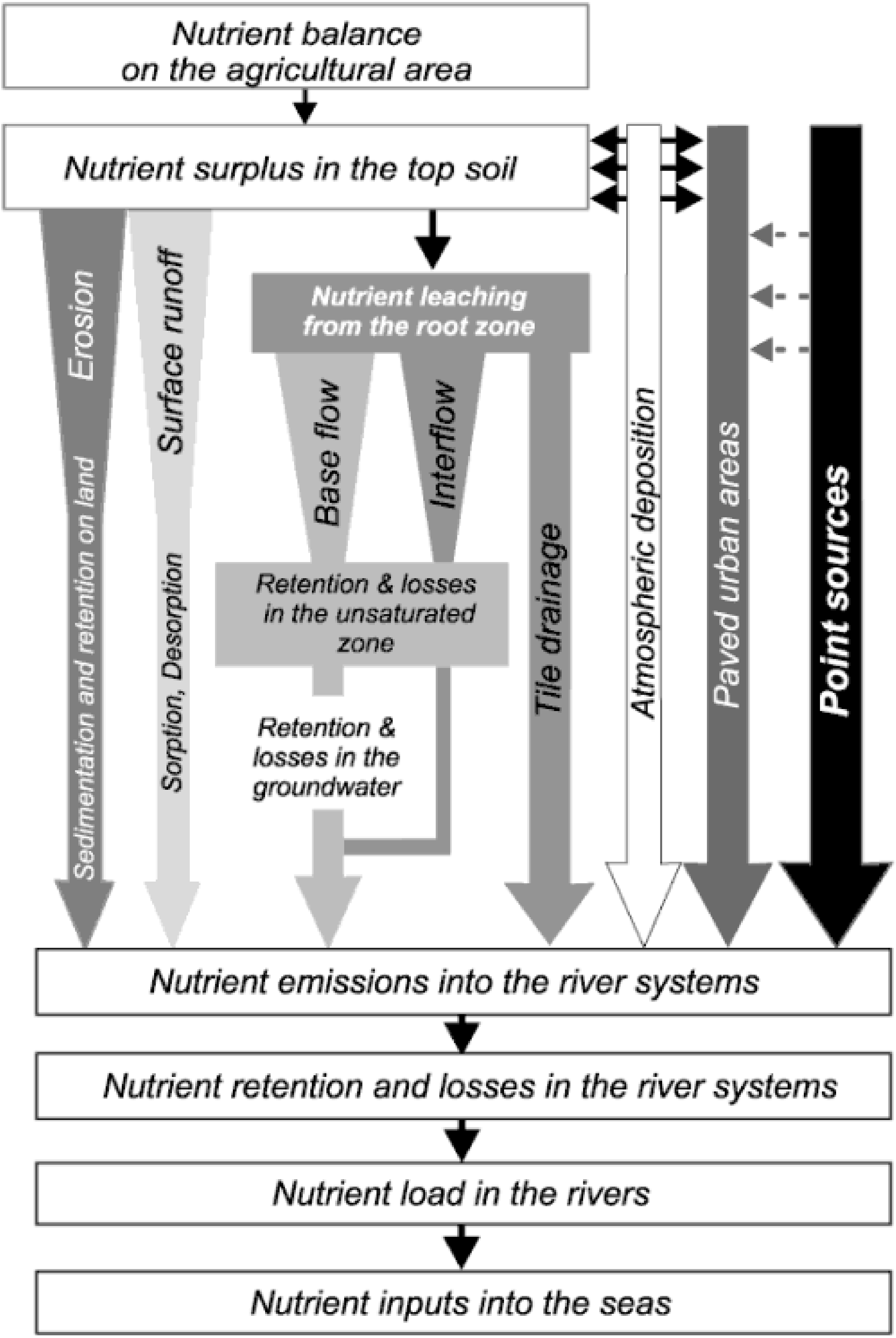
# Trends in nutrient loads to German rivers

**Both nitrogen and phosphorus inputs to the Rhine and Elbe rivers have been significantly reduced over the last fifteen years, mainly as a consequence of reductions to point source emissions (nitrogen removal in sewage works).**

One of the main objectives of the International Geosphere - Biosphere Programme core project LOICZ (Land - Ocean Interactions in the Coastal Zone) was to determine fluxes of nutrients to coastal areas. Most nutrients are carried by medium and large rivers. The MONERIS (Modelling Nutrient Emissions in River Systems) model has been developed to estimate point and diffuse source nutrient inputs into German rivers - see diagram opposite.

The MONERIS model was applied to more than **200 different German river basins** and summarised for the Rhine (159 700 $km^2$ upstream of the Lobith monitoring station where it flows out of Germany into Holland) and the Elbe (134 900 $km^2$ upstream of the Zollenspiker monitoring station, the last station not influenced by tides). A detailed description of the model is published in Behrendt, H., Huber, P., Kornmilch, M., Opitz, D., Schmoll, O., Scholz, G. & Uebe, R. (1999): NŠhrstoffbilanzierung der Flu§gebiete Deutschlands. UBA Text 75/99, 288S.

Nutrient inputs from the river basins and nutrient loadings as carried in the river water at the downstream monitoring stations were compared for the periods 1983-1987 and 1993-1997. (see table below)


Nutrient balance
on the agricultural area
Nutrient surplus in the top soil
Erosion
Surface runoff
Nutrient leaching
from the root zone
Base flow
Interflow
Sedimentation and retention on land
Sorption, Desorption
Retention & losses
in the unsaturated
zone
Retention &
losses in the
groundwater
Tile drainage
Atmospheric deposition
Paved urban areas
Point sources
Nutrient emissions into the river systems
Nutrient retention and losses in the river systems
Nutrient load in the rivers
Nutrient inputs into the seas


***Pathways and processes within the MONERIS model.***

## ========= Nitrogen loads =========

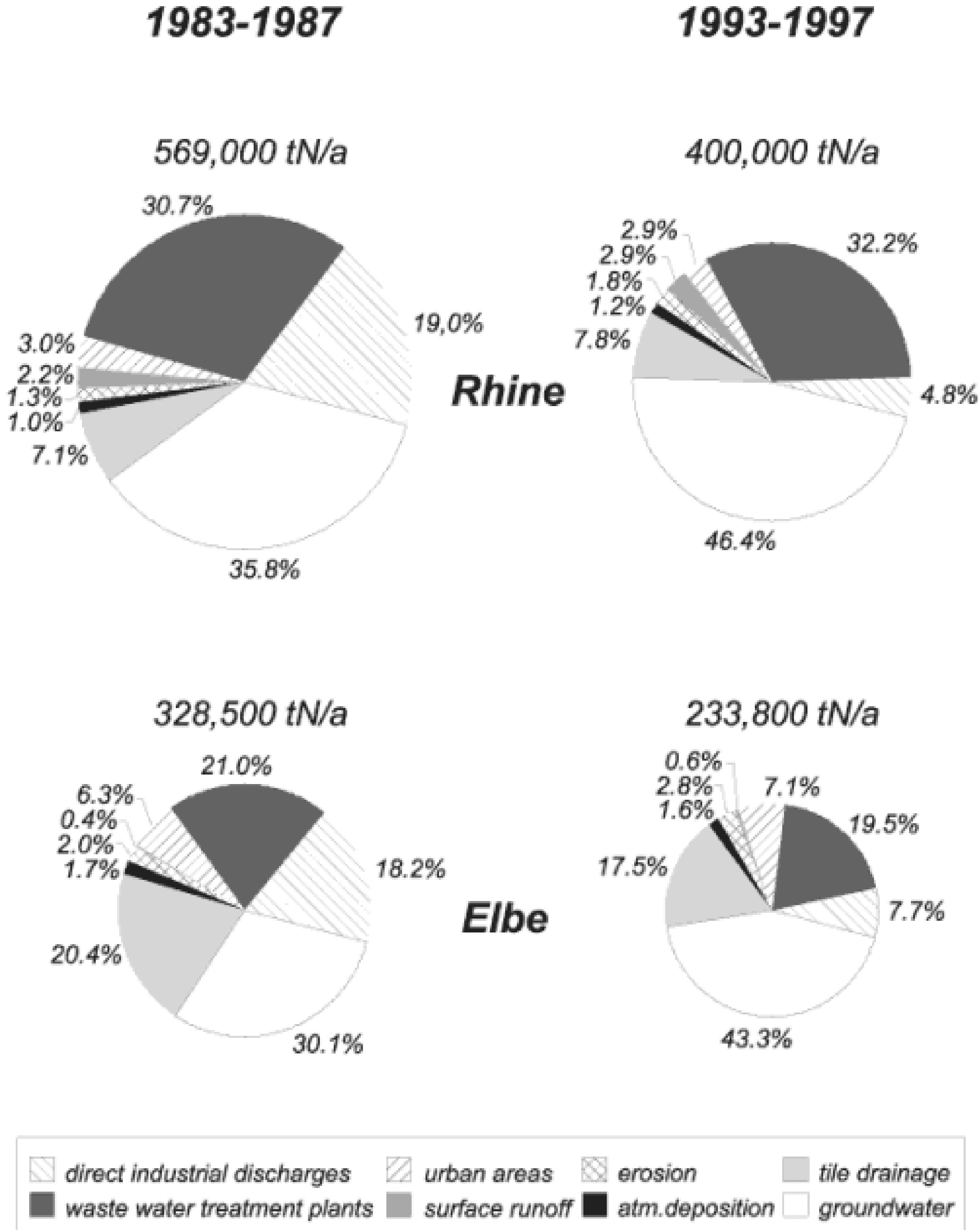
The 1990's total nitrogen input to the Rhine was 400 000 tonnes N/y, 28% lower than in the 1980's. **46% of this nitrogen input comes from groundwater**. The reduction results in particular from lower industrial discharges (down to only 4.8% of inputs in the 1990's) and improved sewage treatment.

The 1990's total nitrogen input to the Elbe was 233 800 tN/y. The reduction since the 1980's (29%) was very similar to that for the Rhine, and was again the result of reduced industrial discharges and improved nutrient removal from sewage.

Nitrogen input to the Elbe from agricultural drainage (17.5%) is significantly higher than for the Rhine because of the higher proportion of land with tile drainage.

The decrease in agricultural nitrogen surplus only caused a very limited reduction in nitrogen load during the 1990's, because of the long residence time of nitrates in the water table, but is expected to lead to a slow decrease in nitrogen inputs from groundwater after 2000.

## *Nitrogen Emissions*



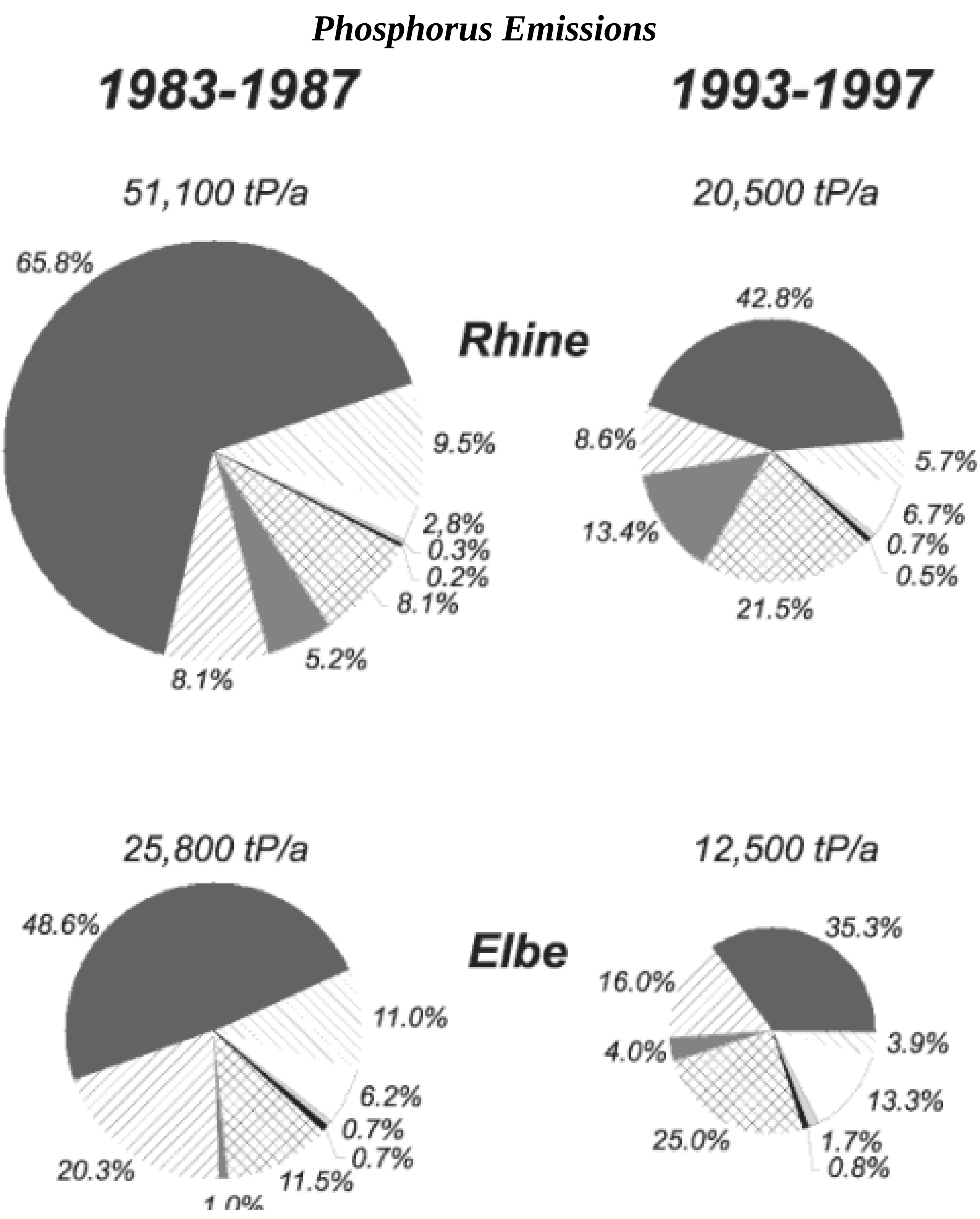

## ========= Phosphorus loads =========

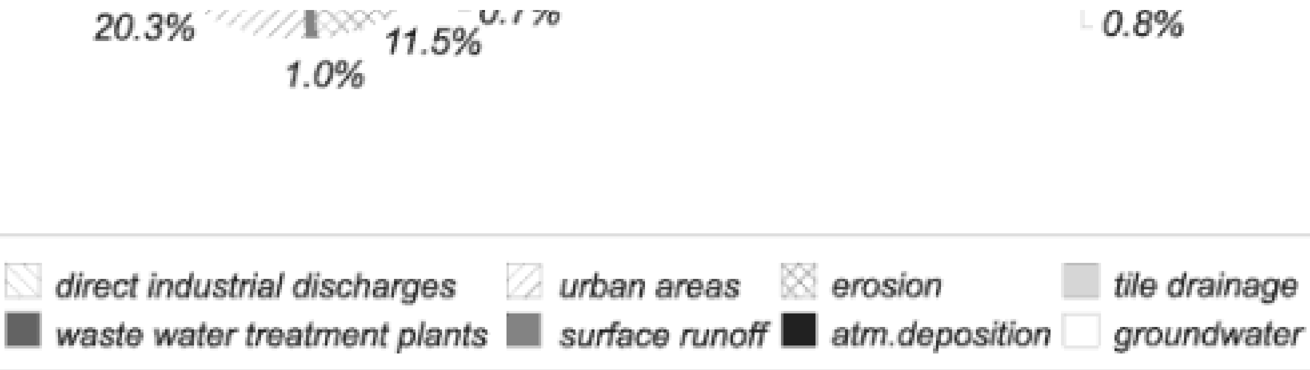
Total phosphorus inputs into the Rhine were very considerably reduced from the 1980’s to 20 500 tP/y in the 1990’s (60% decrease), mainly as a result of **reduced inputs from sewage works (nutrient removal**

**installation)**. This source still accounted for 42.8% of total P inputs in the 1990's, however. Industrial discharges also decreased.

For the Elbe, the total phosphorus input of 12 500 tP/y in the 1990's was a 52% reduction from 1980's levels, again mainly resulting from reduced emissions from sewage works (64% reduction).

In both the Rhine and Elbe, by the 1990's, d**iffuse sources were the main inputs of phosphorus** (51.5% and 60.8% respectively).






## ========= Nutrient inputs exceed outflows =========

**The observed nutrient loads carried in the river outflow (average concentrations x flow at downstream monitoring stations) are significantly lower than the total inputs to the river : 30-40% lower for both N and P in the Rhine, 50-65% in the Elbe.**

However, the reduction in observed loads of both nutrients in the river waters at the monitoring stations is comparable to the reductions in nutrient inputs.

The author suggests that the significant differences between nutrient inputs and monitored river loads are the result of **retention and loss processes in the river** (denitrification, sedimentation, adsorption) - ***see other papers reviewed in this Newsletter.***

The author concludes that, beyond nutrient removal from point sources, additional **measures to reduce diffuse nutrients will be necessary** to meet the target of 50% coastal zone load reductions set by Helcom and Osparcom. Nutrient retention near to or within surface waters should be increased by using **buffer strips and wetland restoration or reconstruction.**

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*"Estimation of the nutrient inputs into medium and large river basins - a case study for German rivers", LOICZ Newsletter n¡ 12, September 1999.*

H. Behrendt, Institute of Freshwater Ecology and Inland Fisheries, Müggelseedamm 310, D-12587, Berlin, Germany.

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SCOPE NEWSLETTER

*SCOPE N°37 - 06/2000 - Nutrient retention*

# Phosphorus loads in rivers lower than inputs

**Three recent papers compare inventories of point and diffuse nutrient inputs to different river basins/ sub-basins with observed nutrient load.**

Previously, a small number of authors had already **published figures indicating that monitored nutrient loads in rivers were lower than would be expected from total inputs**. Billen *et al.* (1982, 1985) found nitrogen losses between upstream and downstream points of 48% in the Meuse and 73% in the Escaut rivers in Belgium. For phosphorus, Svendson and Kronvag (1993) measured P retention in a small river in Denmark at around 20% and the International Commission for the Protection of the Rhine (1992) found monitored phosphorus loads around 20% higher than total inputs.

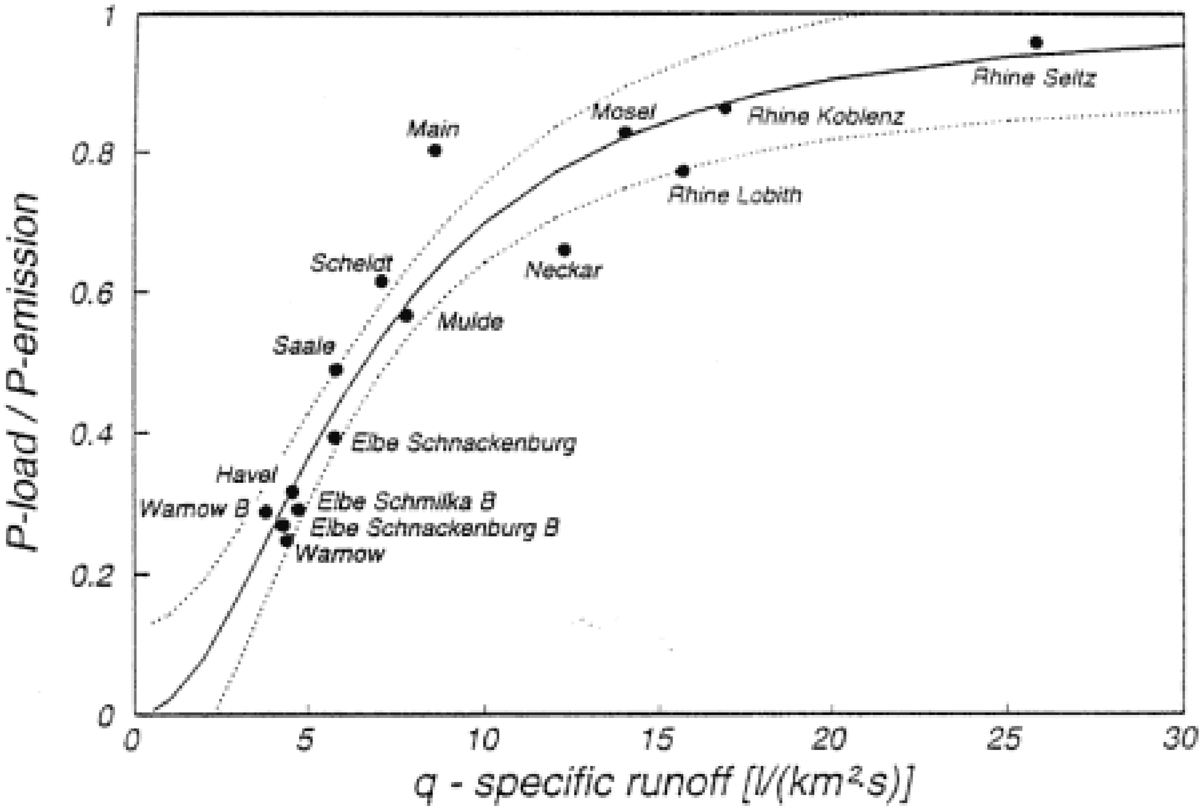
In 1996, Behrendt (ref. below) compared estimated total N and P inputs into the German rivers Rhine and Elbe and their tributaries, and into the smaller river Warnow in North-East Germany.

## ======== P retention related to run-off ========

The author found significantly larger differences between nutrient inputs and river load for the Elbe river system than for the Rhine and its major tributaries (Mosel, Necker, Main). He suggested a strong inverse relationship, for both nitrogen and phosphorus, between nutrient retention and **specific runoff (average river flow l/s per km$^2$ river basin).**

Rivers with a relatively low specific runoff (around 5 l/s/km$^2$) showed phosphorus retention of 60-80% and nitrogen retention/loss of 40-80%.

The author suggests that differences between nutrient inputs and monitored loads cannot be explained by errors in estimates of inputs, although diffuse sources may be overestimated in some cases. He concludes that although nutrient retention mechanisms may not be significant in the small river basins often used for studies, they may be considerable in larger basins.




***Dependency of the (phosphorous transported/total emissions) ratio on specific runoff for diffrent Centre European Basins.***

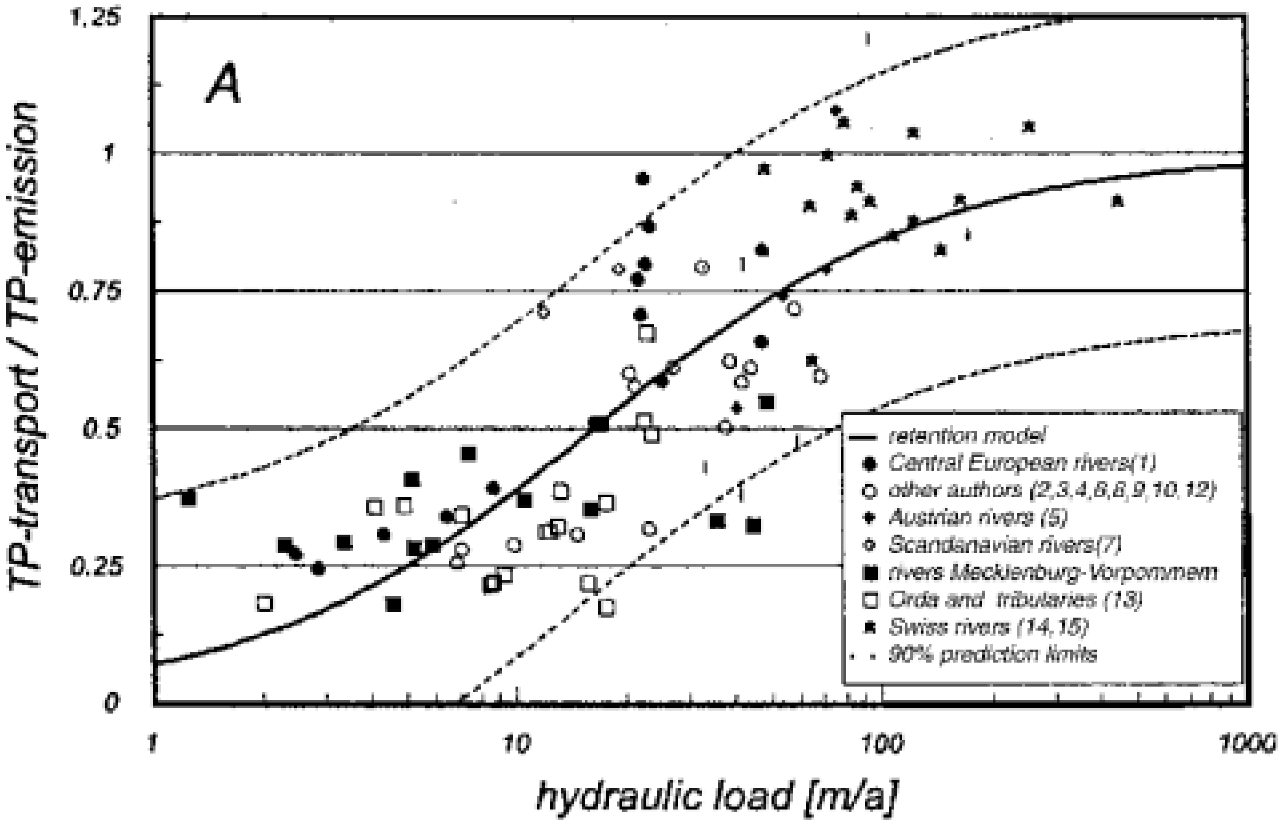
## ========= 100 river basins =========

In a further study in 1999, Behrendt and Opitz compare nutrient inputs with monitored river load for 100 European river basins with catchments varying from 121 to 194 000 km$^2$. They showed that the **observed transport of phosphorus is lower than total inputs** for nearly all except five of the river catchments considered, and was often considerably lower.

The authors examined the dependence of the % phosphorus retention (difference between inputs and transport) on two indicators of river system hydrology : the specific runoff (litres/second per km2 catchment area) and hydraulic load (annual average value of the height of water column flowing over one m2 of the river system water surface).

Around 80% of the variation in phosphorus retention is explained by variation in specific runoff, whereas only 61% is explained by hydraulic load. For nitrogen the results are different, with 51% of the variation in N loss/retention only being explained by specific runoff and 65% by hydraulic load. No statistically significant dependence on catchment basin size was found.

The authors derived a statistical model of nutrient loss/retention as a function of specific runoff, water surface area and basin size.




***Dependency of the (phosphorous transported/total emissions) ratio on hydraulic load for diffrent Centre European Basins.***

## ======== 40-50% phosphorus retention ========

In a further paper in 1999, Behrendt considers different methods for estimating diffuse source nutrient inputs into rivers. Seven methods of assessment were examined for 14 river basins in North East Germany.

This demonstrates the **difficulties involved in estimating diffuse sources of phosphorus** : the standard deviation for the results of the seven different methods applied to these basins is 60% for phosphorus, compared to only 27% for nitrogen.

The results demonstrate that **methods which assume "zero phosphorus retention" must be excluded**. An overestimation of point sources and underestimation of transported loads for phosphorus is indicated by the statistical analysis, but a large difference between inputs and transported phosphorus nonetheless remains. The authors conclude that river retention processes result in around 40-50% of phosphorus inputs not reappearing in the transported nutrient loads. This retention is clearly dependent on specific runoff.

## ======== 3/4 of nutrient inputs to the Odra river do not reach the sea ========

In another 1999 paper, Behrendt *et al.* examine nutrient inputs and transport in the Odra river, one of the largest transboundary rivers in Central Europe. The catchment studied is that upstream of Krajnik Dolny : more than 110 000 $km^2$ with a population of around 15.5 million. Specific runoff is relatively low at 4.5 $l/s/km^2$.

Point sources dominate phosphorus inputs in the basin (73%) with a trend of reductions over the study period 1991-1994.

Compared to nutrient inputs, river transport is low, with an average of around 43-55% of nitrogen and **75% of phosphorus retained / lost in the river system**. River transported phosphorus loads make up less than 50% of identified point source P inputs, even if diffuse sources are ignored !

The authors indicate that the target of a 50% reduction in nutrient load to the Baltic Sea can be achieved for the Odra river for phosphorus if point sources alone are reduced by 70%, which is possible by nutrient removal installation in sewage works.

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*H. Behrendt : "Inventories of point and diffuse sources and estimated nutrient loads - a comparison of different river basins in central Europe", Wat. Sci. Tech. vol. 33 n¡ 4-5 pp. 99-107, 1996.*

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