SCOPE NEWSLETTER

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P-recovery

Sewage P-removal
Perspectives for biological nutrient removal

Current developments suggest that advances in biological nutrient removal make it possible to achieve very low phosphorus and nitrogen discharge levels at a low cost and a small footprint.

Germany
Working group on phosphate recycling

German Association for Water, Wastewater and Waste (DWA; formerly ATV-DVWK) assessment of the feasibility and potential of phosphate recycling from sewage.

Treviso, Italy
Demonstration struvite recovery plant

Further experience of the full scale pilot struvite recovery at Treviso municipal sewage works, Italy shows reliable and cost effective operation.

Eutrophication management

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Nutrient removal from septic tank effluent in soils

Soil samples from ten sites were tested for removal of nutrients and BOD from domestic septic tank outflow effluent, showing relatively good P removal but poor N and BOD removal.

Environmental costs
Economic damages of eutrophication

2.2 billion US$ per year is the estimated cost of eutrophication in the USA to property, recreation values, water treatment, biodiversity ...

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Nutrient criteria

Different methods of establishing nutrient criteria and acceptable algal growth levels for streams and rivers.

Agricultural phosphorus
Science for eutrophication management

Studies brought together by the British Society of Soil Science illustrate developments in understanding of agricultural phosphorus sources, their impact on eutrophication and their management.

Conferences

International Conference on

Nutrient Recovery

from Wastewater Streams

May 10th - 13th 2009

Vancouver,

British Columbia, Canada.

80 sessions and workshops. Plus May 14th technical visits to full-scale struvite recovery installations operating in municipal sewage works in Canada, USA, and to stream and reservoir fertilisation project.

***Details*, Registration, full programme:**
www.nutrientrecovery2009.com

Covaphos III, Marrakech, 18-20 March 2009
3rd International Conference on Valorisation of Phosphates and Phosphorus Compounds

Organised by RECHERPHOS (Researchers' Network on Phosphates) and CERPHOS. Topics: Geology of phosphates, Beneficiation of phosphates, Phosphoric acid, Fertilizers and fertilization, New uses of natural phosphates, Inorganic phosphate materials, Nanomaterials, Biomaterials, Organophosphorus molecules and materials, Phosphorus and environment, Safety, corrosion and Alloys. RECHERPHOS, 73 Boulevard Moulay Ismail, Casablanca, Maroc. Phone : 212 0 22 24 12 69. Fax : 212 0 22 24 64 41
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Phosphorus flows

Sewage P-removal

Perspectives for biological nutrient removal

This paper provides an overview of tendencies in nutrient removal technologies and operation, demonstrating the feasibility of increasing low levels of phosphorus and nitrogen discharge concentrations. Experience from a number of municipal waste water treatment works (wwtps) is presented where such performance is being achieved within upgrades of existing installations, and with a minimal use of space and of added chemicals.

Worldwide, wwtp operators are facing new nutrient discharge limits in areas not previously subject to such requirements, or **tightening discharge limits** as authorities implement policies to reduce surface water nutrient loads, for example under the 2001 USA EPA water quality criteria, or the EU 2000 Water Framework Directive.

Solutions using biological nutrient removal will be preferred in order to avoid chemical costs and related increased sludge generation, with operators looking for solutions which enable the use of existing installations and sites, and which use the sewage itself as a carbon source.

Biological nitrogen removal

Channel and carousel systems in combination with anoxic zones or as part of the Bardenpho system enable reliable biological nutrient removal down to around 3 mgN/l with milder temperature. Cost effective modification of existing secondary treatment wwtps to achieve biological nutrient removal can be possible, on a site by site basis, by modifications to partition anoxic zones in the treatment route.

Research and testing is currently underway to add various plastic media or materials to provide a fixed film surface to **improve process control** by fixing bacteria and reduce necessary residence times, and so plant size, especially in colder climates.

Bio P-removal

The authors emphasise that there is ample evidence that with mainly domestic waste waters, **excellent P-removal can be achieved biologically provided that the following conditions are fulfilled**:

- adequate readily bioavailable carbon (rbCOD) is available
- nitrates and oxygen are excluded from the anaerobic zone
- pH is near neutral
- the aerobic zone is sufficiently oxygenated
- release of phosphorus from sludge or from non aerated zones is avoided

Fermentation of primary or secondary sewage solids can supply the necessary rbCOD.

Annual average ortho-phosphorus discharges of around 0.1 mgP/l can be achieved using biological P-removal, at a cost not significantly higher than that of achieving 1 mgP/l. Levels of 0.03 – 0.07 mgP/l can be achieved using a low level of chemical P-removal as a finishing or “polishing” step.

Biological nutrient removal can also be combined with membrane systems to reduce inorganic nitrogen and phosphorus to very low levels with minimal use of space.

Biological phosphorus uptake allows for phosphorus recovery through struvite precipitation.

“Where is biological nutrient removal going now?”, Water Science and Technology, vol 53, n°3, pages 155-164, 2006. http://www.iwaponline.com/wst/toc.htm

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Germany

Working group on phosphate recycling

The German Association for Water, Wastewater and Waste (DWA; formerly ATV-DVWK) has assessed the feasibility and potential of phosphate recycling from sewage. The association’s working group published its conclusions in 2003 in the specialist water industry magazine *KA Abwasser Abfall*. Considering that phosphates are a non renewable and essential resource whose price will inevitably increase, the group recommended that further R&D should be carried out and that incentives for P-recovery be put into place. The

DWA group AK1.1, led by Prof. Johannes Pinnekamp, (Director of the Institute for Environmental Engineering of RWTH Aachen University) brought together 17 specialists to work on phosphorus recovery.

Phosphorus is a key element for life. It can be extracted from the rocks in the earth's crust but its phosphate content of available rock is decreasing, and reserves are affected by substances such as cadmium. The 2001 world phosphate production was 128 million tonnes of phosphate rock, of which only 16.8 M t of P has been extracted. The prices have increased more than 4 times since the 60s, and are continuing to increase. Current world reserves are estimated at around 100 years of phosphorus consumption, but this could be extended to over 300 years if increasingly difficult to access phosphate deposits are used. **Worldwide, phosphates are used mainly as fertiliser (79%) and in animal feeds (11%) plus 7% in cleaning products and other industry and specialist applications**.

Phosphorus discharges from sewage works are regulated

European legislation limits the maximal amount of phosphorus in water leaving wastewater treatment plants in many parts of Europe (eutrophication sensitive areas). Phosphorus "removed" in waste water treatment is stored in the sludge. In many cases, sewage sludge is considered as a waste to be eliminated because agricultural utilisation is not possible, for example because of content of toxic products. Sewage sludge destined for use in agriculture has to fulfil the requirements of both the sewage sludge and the fertiliser regulation.

Phosphorus in waste waters

The working group estimates that in Germany phosphorus levels in domestic wastewater are nowadays between 1.6 and 2.0 g P/person/day (note: in Germany there is no use of phosphates in laundry detergents). The value used by the working group for its calculations is 1.9 g P/person/day. The phosphorus contribution to municipal wastewaters from industries etc. is hard to measure and is estimated to represent +40% in addition to this domestic production, bringing the annual total P input to German municipal sewage works to 72 100 t P/year. For 1998, the average total phosphorus concentration in municipal raw sewage was estimated to 7.5 mg P/l.

Phosphorus can be recovered in a solid form, either by chemical precipitation (iron / aluminium) or biological reaction (formation of poly-phosphates). The EU directive on waste water treatment is already well applied in Germany with clear water discharge of 0.9 mg P/l in 1999.

Waste water treatment plant model

A model of a municipal wastewater treatment plant was established to analyse the possible P-recovery in a typical process. Of 1.9 g P input, only 0.2 g P goes into the water discharged, and 1.7 g P go to the sludge. The physiological P demand of the micro organisms in the sludge can be estimated to consume 0.7 g P in conventional secondary treatment, leaving 0.8 g P requiring targeted elimination. This point is important for the choice of a phosphorus recovery technology. Treatment of the sludge containing 1.7 g P by digestion, dewatering and drying, then incineration produces ashes containing 6.5% $P_{dm.}$

In order to estimate the potential for P recovery, the group distinguished between P-recovery in liquors in the sewage works, with a potential of 0.8 g P or 42% of the incoming P load, and recovery from sludge streams with a potential of 1.7 g P or 89% of P load .

Principles of phosphorus recycling from the liquid phase

For magnesium ammonium phosphate (struvite) precipitation the pH value has to be increased to 8.5 – 9, but this process can avoid nuisance deposits of struvite in pipes or centrifuges. This process is potentially interesting for treatment of industrial waste water or sludge liquors.

The crystallisation of phosphates with the help of sand, calcite or Tobermorite as seed materials has less side effects and offers higher P contents in the end product. Sand seeded crystallisation of calcium phosphates allows the production of pellets of recovered phosphates, but requires prior acidification to lower the pH to 4.2 (CO_2 stripping), followed by alkali addition to then raise it to pH 9. Initial experiments using Calcite ($CaCO_3$) seeding suggest that there may be no need to modify the pH or to remove carbonate. This technique has only been used in industrial processes. A new Japanese seed material, Tobermorite ($Ca_5Si_6O_{16}(OH)_2 \; 4(H_2O)$) shows promising pilot scale results but raises the pH to > 9.5 which makes a neutralisation necessary.

Situating P-recovery in the sewage works

Mainstream: P is recovered as a last step after biological wastewater treatment, but this is technically problematic in municipal sewage works in Germany given the high volumes of water and the low phosphorus concentrations. Given the stringent phosphorus discharge limit values (approx. 1.0 mg/l), mainstream crystallisation is certainly not economically viable.

Liquor streams from sludge treatment: liquors from sludge digestion, sludge treatment side streams (Phostrip) or dewatering (filter press, centrifuge) have high P concentrations (> 50 mg/l) in low volumes, so that phosphate precipitation for P-recovery is feasible.

P-recovery from Sludge/ash

The highest P-recovery potential (90% of sewage work's inflow P load) is from sewage sludge or ash after mono-incineration of the sludge. By means of disintegration methods the phosphorus can be released from the sludge:

- Mechanical disintegration of sludge: setting P free from the cells, with potential release of 20 to 45% of P in sludge
- Thermal disintegration: potential release of 10 to 30% of P in sludge
- Chemical disintegration: up to 80% release from sludge at pH 2, or nearly 100% of P if combined with supercritical oxidation.

These routes can be combined with liquid stream recovery methods (precipitation or crystallisation) and a wide range of processes and R&D have been developed, including Krepo (sludge), Seaborne (sludge), Aqua-reci experiment (sludge), BioCon (ash).

Economic and environmental impact

The legal framework and the cost of P-recovery will have to correspond to the market price for implementation to develop. At present (2003), phosphates are sold at a price of 0.9 to 1 €/kg P for agricultural use. The costs of P recovered using current technologies are still higher than the market price, and closely related to the specific conditions at the wastewater treatment plant. **The P recovered by precipitation with calcium hydrate costs 7 to 16 €/kg P, calcium phosphate sand crystallisation costs 6 to 7 €/kg P and the Phostrip process allows lower the costs of 1.5 to 2.5 €/kg P** (all prices 2003).

The environmental life cycle assessment of P recovery must take into account the consequences regarding toxic elements in the wastewater and in mined phosphate rock replaced by recovered phosphates. P recovery also might reduce the Carbon footprint because the 2/3 of the footprint of phosphate production from mined rock is in transport. Recycling P also preserves the land that is mined, as P extraction destroys 10 to 15 times more land than brown coal mining.

Recommendations

In order to protect phosphate rock reserves as because mined phosphate prices will continue to increase as readily accessible high-grade reserves are depleted, the working group considers that P recovery for use in agriculture should be actively developed. Because current processes are not economically viable in today's market conditions, **the working group recommends to:**

- Increase research and testing of the economic and ecological feasibility of P recovery and plan the future in the context of expected increasing phosphate prices
- Initiate industrial scale implementation after R&D work, financing should not necessarily work via wastewater fees and economical incentives are needed

The recovered P should be given a special classification under fertiliser regulations, the plant fertilising effect of recovered P should be investigated and the phosphorus recovered should also be used as a raw material in the fertiliser industry which will also require R&D work

Separate disposal routes for ashes from mono-sludge-incineration should be established in order to enable P-recovery from these ashes (not possible if sludge is incinerated in cement works or coal-fired power plants)

Pinnekamp, J. et al. in ATV-DVWK Arbeitsgruppe, 2003. "Phosphorrückgewinnung", KA – Abwasser, Abfall 2003 (50) n° 6, pages 805-814 (in German)
Pinnekamp@isa.rwth-aachen.de

DWA, www.dwa.de *(German Association for Water, Wastewater and Waste) is a specialist technical and scientific organisation, promoting research and development, with 14,000 members (municipalities, institutes of higher education, engineers, public authorities and companies, experts and managers). In ten of the DWA main committees, the related sub-committees and working groups, an extensive range of topics are dealt with, resulting in technical rules and standards, training and education programmes, highly specialised publications, materials for public relations work in water-resource management, wastewater, waste and soil conservation.*

Treviso, Italy

Demonstration struvite recovery plant

Previous publications and reports, see in particular SCOPE Newsletters n°s 49 (diagram) and 55, present in detail the full scale pilot struvite recovery unit operating on anaerobic sludge digester liquor at the Treviso municipal sewage works, near Venice, Italy, and previous experimental work. The sewage works is a 70,000 pe plant operating biological nutrient removal. Following these previous publications, further experience of the full scale pilot struvite recovery unit is presented showing reliable and cost effective operation.

The **struvite recovery unit uses carbon dioxide stripping only to increase pH and cause struvite precipitation** in a simple fluidised bed reactor, with gravel in the reactor base ensuring mixing. The unit treats around 48 m^3/day of belt press dewatering liquor from the anaerobic sludge digester. A second reactor column used for CO_2 stripping (followed by a de-aeration column), on a recycle stream, enable the upflow in the fluidised bed reactor to be adjusted to ensure that the bed remains in suspension.

As indicated in SCOPE Newsletter n°55, the fluidised bed reactor was modified with installation of a Dortmund device to **limit flow-over of fines out of the top of the reactor**. The experience here presented also differs from the previous 2003 report in that struvite was used as a seed material (instead of sand).

Nine test runs

The supernatant effluent to be treated had average phosphate concentrations of 24 mgP-PO_4/l, 200 mgN-NH_4/l, 41 mg Mg/l and pH 7.4 – 7.8. Probably dilution with inadequately separated belt press wash waters were leading to dilution. In order to simulate conditions in other sewage works configurations, varying levels of magnesium and phosphate were added to the supernatant for the different runs giving concentrations from no addition up to 80 mgP-PO_4/l and magnesium from no addition to 100 mg Mg/l. Nine experimental runs were carried out, each at steady state, over a total time of 6 weeks (total volume of supernatant treated 650 m^3).

Removal of soluble phosphate in the reactor ranged from 69% (run without P or Mg addition) to 80%, and loss of precipitated struvite as fines ranged from 7% (no additions) down to zero. The precipitated product was made up of struvite (MAP) and calcium phosphate (hydroxyapatite HAP), with generally no detectable calcium carbonate (calcite). In the run without additions, the precipitate was 100% MAP.

Feasibility

Some pipe scaling in parts of the recovery unit were noted, but these were significantly less than in previous experiments reported, probably because in these runs the unit was operated near the saturation point for struvite (metastable) and not at supersaturation as for previous work.

The use of a high flow recycling rate **enabled clear precipitant grains to be obtained**, which can be easily washed, stood to run dry, then stored and used as an agricultural fertiliser. Agglomerated thin crystals were obtained in the fluidised bed zone, but a packed zone underneath the solids extraction device contained larger smoother grains which grew up to 2mm diameter. 280 kg of precipitated phosphates were produced over the 9 runs.

An assessment of operating costs is given, estimated at around 0.19 €/m3, cheaper than when quartz sand is purchased for use as a seed. The process is considered "feasible, easy to perform and to control".

"Auto-nucleation and crystal growth of struvite in a demonstrative fluidized bed reactor (FBR)", Environmental Technology, vol. 26, 2005, pages 975-982. http://www.environtechnol.co.uk/contents.htm

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Kentucky

Nutrient removal from septic tank effluent in soils

US EPA Guidelines require a minimum of 30 cm of soil between the bottom of a septic tank outflow drain and either an impermeable layer (bedrock, clay) or the water table. Undisturbed soil core samples (30, 45 and 60 cm depth samples) from 10 sites (4 different soil types) were tested over 15 days for removal of BOD, total nitrogen, ammonium, nitrate and total phosphorus from effluent collected regularly from an operating domestic septic tank.

The 15 day leaching experiments were done in 25 cm diameter tubes, the length of the different samples, with foam used to prevent direct flow between the outside of the soil sample and the inside of the tube. The septic tank effluent was collected every three days and applied to the surface of the vertical soil samples, using peristaltic pumps, at a constant rate, different for each type of soil and based on septic tank outflow design manuals (20 - 45 L/m^2/day). BOD and nutrients were analysed both in the effluent used and in the leachate coming out of each sample at the end of each leaching cycle.

The septic tank effluent concentrations of the different parameters studied were widely variable, for example from 1 – 72 mg/l total P (means 21 – 37 mgP/l for different soil samples). Nonetheless, the results in terms of both % pollutant removal and of % of soil leachate samples exceeding guideline values are considered by the authors as **indicative of real performance of a system consisting of a domestic septic tank plus 30 – 60 cm soil combination**.

Organic pollution

For the 30, 45 and 60 cm soil samples, daily compliance with the EPA recommendation of 30 mg/l BOD$_5$ ranged from 2% to 23% depending on soil types. That is, in all soil types, **over ¾ of samples were not compliant for BOD**, and in some cases up to 98% non compliant. For all soil types, the total average compliance (average of daily samples over the test period) was just 4% for 30 cm samples, up to 18% for 60 cm samples. Mean BOD removal ranged from 27 – 56% depending on the soil type.

Nitrogen pollution

For total nitrogen, the inflow concentrations ranged from 12 – 300 mgN/l (mean 118 mgN/l) and **only around one half of the samples achieved the 10 mg/l EPA MDL recommendation for total N**, again with statistically significant variations between different soil types. For ammonium NH$_4$, approximately one third of the samples achieved the EPA recommendation.

For nitrates, the situation was different. The septic tank effluent nitrate concentration was very low: 0.1 – 0.2 mg NO$_3$-N/l. Leachate nitrate concentrations were generally higher than this, showing nitrification in the soils, and only around 10% were higher than the EPA MDL.

Phosphorus

Total phosphorus inflow concentrations ranged from 1 to 71 mgP/l, with means 21 – 36 mgP/l for different soil types. Only 2 of the total 30 samples tested showed average effluent total P higher than the 5 mgP/l EPA MDL and **80% of the daily samples in the sandy soil and 95% in the silt-clay soil types respected this P guideline**.

The **phosphorus removal in the soil samples ranged from 56% in 60 cm sandy soil to 100% in 60 cm clay-silt soils**. This confirms as expected the inferior P-removal of coarse soils, due to the lower particle surface area.

The authors conclude that the 30 – 60 cm soil samples tested generally showed **inadequate BOD and nitrogen removal, with better levels of phosphorus removal.**

Nutrient removal from septic effluents as affected by soil thickness and texture, Journal of Water and Health, 04-2, 2006, pages 177-195, IWA Publishing.
www.iwaponline.com/jwh/

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Eutrophication management

Environmental costs

Economic damages of eutrophication

An estimation of the economic costs of eutrophication of freshwaters in the USA was established by examining EPA data for current observed nutrient concentrations, comparing these with reference values, assessing for a number of different uses the nutrient levels susceptible to result in loss of value, and estimating the lengths and surfaces of waters concerned. In particular, loss of recreational value (fishing and boating), lake property values, loss of biodiversity and drinking water treatment costs were assessed.

US Environmental Protection Agency data for each of the 14 EPA identified “nutrient ecoregions” show that % of rivers and the % of lakes and reservoirs in which current summer nutrient concentrations (total phosphorus, total nitrogen) exceed the reference median level (taken from Smith et al. 2003 estimates of background concentrations for rivers, corrected proportionally to derive estimates for lakes).

90% of rivers in 12 out of the 14 ecoregions showed nutrient levels considerable higher than reference, on average 5.5x higher for nitrogen and 3x higher for phosphorus.

For **fishing and boating recreation use losses**, lakes were assumed to be closed for such activities for 1-3 months (see below) if summer total phosphorus exceeded 100 µgP/l, because blue-green algal blooms were considered very likely to occur at such P concentrations. Calculations were then based on lake area, number of lakes and nutrient concentrations separately for each ecoregion. The economic loss was estimated by assuming as lost average per-trip expenditure only (travel, lodging, fuel, food, fishing bait).

For **lake properties**, data from 37 lakes in the Mississippi River headwaters region was used to derive a relationship between Secchi depth and the value of private lakeside properties: 16% loss in property value per metre Secchi depth. This was then multiplied by the total lake frontage, using different estimates for the % of private shore ownership (see below), and the estimated loss in Secchi depth due to nutrient concentrations in each ecoregion.

For biodiversity, it was estimated that 25% of threatened aquatic species in the US are in part at risk because of eutrophication, and so the total cost of eutrophication in the USA was estimated as 25% of total costs of US Federal Endangered Species Act plans addressing aquatic species.

Drinking water costs were estimated based on the estimate of money spent on bottled water to avoid taste and odour problems in tap water, resulting from eutrophication (algal blooms) in surface waters used for drinking water extraction. 28% of people purchasing bottled water indicated in a 2000 survey that this was because of taste and odour problems, and it was assumed that this was attributable entirely to surface extracted water. Drinking water treatment costs were not taken into account.

Recreational economic losses were estimated at 0.4 to 1.2 billion US$/year (b$), depending on whether 1 to 3 months closure were assumed. Property value losses were annualised at 0.3 – 2.8 b$/year, depending on whether 5% - 50% of lake shores were assumed to be valued private property. Biodiversity (species management) costs were estimated at 0.04 b$/year and bottled water costs at 0.8 b$/year.

Underestimations

The authors note that **many of the calculations will result in underestimations of costs**. For example, recreation losses were calculated for the months of closure assuming that activities are spread over the year, whereas in fact most water recreation is concentrated in summer when algal blooms are more likely to occur, and the estimated losses do not include equipment purchases and other lost spending. No account was taken of losses of fish, wildlife or livestock due to algal blooms. Costs of dealing with excessive plant growth were not accounted, although the authors did estimate that removal of macrophytes from 1% of principal US waterways would cost 1.2 b$ mechanically or 0.1 b$ using herbicides.

The costs estimated cover US freshwaters only, and do not include estuaries or marine impacts.

"Eutrophication of US freshwaters: analysis of potential economic damages", Environmental Science & Technology, 43(1), pages 12-19, 2009
http://pubs.acs.org/journal/esthag

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Montana, Wisconsin, Kansas

Nutrient criteria

Several papers look at different methods of establishing criteria or reference levels for nutrient concentrations in rivers and streams in Montana, Wisconsin and Kansas in the USA.

Montana: public perception

Suplee et al., 2008, present results of a survey of nearly 1,000 people aiming to establish what is a desirable or acceptable degree of benthic (surface) algal development for recreational uses of a river. 563 recreational users were interviewed, and a postal mailing survey of the general State population (389 completed returns, 22% response rate) used 8 photos of rivers with different levels and types of algal growth. These ranged from nearly no visible algae, through (photo F) significant algal cover of rocks and the river bed but with only short filaments, to generalised 30 – 50 cm long filamentous algae. These corresponded to mean benthic algae increasing from 40 to >1,000 mg $\text{Chll}_{\text{-a}}/\text{m}^2$.

In both surveys, recreational desirability decreased with increasing benthic chlorophyll. The **appearance of long filamentous algae** (> 1 cm long), corresponding to chlorophyll levels of 150 – 200 mg $\text{Chll}_{\text{-a}}/\text{m}^2$, was a clear cut-off point between desirable and undesirable status.

The authors note that this is coherent with the limit of 200 mg $\text{Chll}_{\text{-a}}/\text{m}^2$ proposed by Dodds et al., 1998, see below.

Suplee et al., 2007, compared two methods for defining nutrient criteria as proposed by the US Environment Protection Agency (EPA): the 75th percentile of "reference" (unpolluted or good quality status waters) and the 25th percentile of all waters. The comparison was based on Montana State Department of Environment quality data (MT-DEQ STORET). The data was separated into ecoregions and seasons for comparison, using for example flow and biological data to distinguish between seasons rather than simply dates (seasonal distribution dates differ significantly between mountain and plain streams).

A number of reference streams in Montana were identified (see Suplee 2005). These were identified on the basis of expert opinion plus water quality data, but NOT including nutrient concentration data. Various other pollutants and land use and riparian vegetation were also taken into account. Sites were considered as "reference" only if all criteria were considered as in reference condition.

Results showed that stream nutrient concentrations generally varied significantly with season, as would be expected. The comparison of the two EPA methods showed **wide differences**, with the upper 75th percentile of reference streams corresponding to general stream population percentiles ranging from 4th to 97th, with particularly large discrepancies in the mountainous ecoregions. That is: general stream nutrient concentrations in mountainous regions were comparatively much higher than reference streams in these regions, whereas in prairie ecoregions reference and general nutrient concentrations were much more similar.

Only in 11% of cases did the two EPA methods give similar results (within 5 percentiles).

Kansas: interpolation from land use relationships

Dodds and Oakes, 2004, estimate reference nutrient concentrations by deriving relationships between % urban land use and % agricultural cropland and measured nutrient concentrations. The analysis is based on:

- for Kansas: Department of Health and Environment (KDHE) stream and river nutrient concentration data for 2000-2003 from four ecoregions and over 1,700 nutrient data points from 1994-2001 from a pristine stream watershed (4 sub-basins of King's Creek, Konza Prairie)
- for the whole USA: USGS nutrient data for 1970-1983.

Statistical analysis of the Kansas data for total phosphorus (TP) showed no significant ecoregion differences (within the State) but a **log-correlation to both % of cropland and to % of urban land**. Interpolation then allows an estimate of the TP concentration corresponding to zero % urban and zero % cropland, that is to "reference" conditions. Similar calculations were made for total nitrogen, except that in this case significant ecoregion differences necessitated a separate calculation for each of the 4 State ecoregions.

For both TP and TN this method suggested reference concentrations significantly higher than the upper 75th quantile of the King's Creek data (first EPA method indicated above) but close to those given by the second EPA method indicated above (lower 25th quantile of all data).

For the whole USA data, % cropland upstream of the sampling point showed the strongest relationship to phosphorus concentrations (TP), with urban land and population both also significantly related. % cropland upstream was also the best predictor of total nitrogen (TN) in most ecoregions.

Reference conditions were generally predicted as < 50 µgP/l (TP) and < 600 µgN/l (TN). The authors conclude that this method generally gives results comparable to those from the two EPA methods indicated above, that each method has its own weaknesses and strengths, and that reference levels derived as > 60 *GP/l or > 600 µgN/l should generally be considered as suspect.

"How green is too green? Public opinion of what constitutes undesirable algae levels in streams", Journal of the American Water Resources Association (JAWRA), vol. 45, n°1, February 2009, Pages: 123-140
http://www.awra.org/jawra/

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"Developing nutrient criteria for streams: an evaluation of the frequency distribution method", Journal of the American Water Resources Association (JAWRA J05187), vol. 43; n° 2, pages 453-472, April 2007.
http://www.awra.org/jawra/

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"A technique for establishing reference nutrient concentrations across watersheds affected by humans", Limnology and Oceanography: Methods 2, 2004, pages 333-341. http://www.aslo.org/lo/

W. Dodds, R. Oakes, see above.

"Identification and Assessment of Montana Reference Streams: A Follow-up and Expansion of the 1992 Benchmark Biology Study" (2005)
http://www.deq.mt.gov/wqinfo/Standards/Refsites_writeup_FINALPrintReady.pdf

M. Suplee, R. Sada de Suplee, D. Feldman, T. Laidlaw

Suggested classification of stream trophic state: distributions of temperate stream typoes by chlorophyll, total nitrogen and phosphorus, Water Research, vol. 32, n° 5, pages 1455-1462, 1998.
http://www.sciencedirect.com/science/journal/00431354

W. Dodds, J. Jones, E. Welch.

Agricultural phosphorus

Science for eutrophication management

Number 23 of « Soil Use and Management » presents 16 studies concerning agricultural inputs of phosphorus to surface waters, relations between these inputs and eutrophication (in particular, between total, particulate and soluble forms of phosphorus and water quality) and potential, feasibility and experience of agriculture P-release reduction policies.

The papers cover North, West, Central and Eastern Europe, showing the considerable variation between national and local situations, depending on climate, hydrological, soil and physical catchment conditions, as well as on agricultural practices and the relative importance of agriculture compared to other phosphorus sources (particularly municipal sewage discharges).

Ulen et al. compare the **significance of agriculture as a P-source for eutrophication in Norway, Sweden, the UK and Ireland**. Despite the geographical proximity and climate similarities (Atlantic influence), variability in local situations is very high.

Forms of agricultural phosphorus

Most P-loss from agriculture is generally considered to be as particulate P, but **dissolved P can nonetheless make up 9 – 93%**. High levels of agricultural soluble phosphorus can result from desorption from particles following storm flow events or snow melt, loss from fertiliser or manure applications, or from decomposing vegetation. The proportion of dissolved P will also be higher if particulate P losses are lower, because of permanent pastures or soil "sieving" which retain particles, or if erosion prevention measures are taken.

Subsurface drainage can contribute 12 – 60% of agricultural P-losses and surface erosion 40 – 88%. Total P export for small agricultural stream catchments for the four countries considered vary from 0.3 to 6 kgP/ha/year. P-loss is particularly high in Norway where historic landscape modifications result in a high risk of soil erosion.

All four countries are currently developing **measures to reduce agricultural P-losses, in response to the EU Water Framework Directive obligations to achieve "Good Quality" status in surface waters**. Average phosphorus concentrations in South Swedish streams have shown reductions of 2% per year since 1993, following measures to reduce soil erosion and improve waste water treatment from isolated households. However, climate change may increase P-losses (more frequent freezing-thawing of the soil, more frequent snowmelts and more episodes with extreme flow rate) and this will be a challenge for each of these countries.

Central and Eastern Europe

Csatho et al. Examine the situation in the « new » EU Member States in Central and Eastern Europe (CEE). Here, there is significantly less data available, whereas agriculture is currently undergoing rapid and considerable changes whilst at the same time **implementation of urban waste water treatment is considerably reducing the phosphate input to surface waters from sewage**.

Intensive fertiliser use started much later in the CEE countries, and lasted less long than in Western Europe, so that only 10 – 50% of agricultural surface currently has adequate soil P and current agricultural P-balances (excess of supply over agronomic need) are generally low, or even negative. However, significant soil erosion does affect considerable areas of certain CEE countries, in particular the former Yugoslavia, Bulgaria, Romania, Hungary and the Czech Republic, but also parts of Poland. Erosion related diffuse P is considered to be the main cause of the 92,000 tonnes P/year agricultural input to the Danube catchment (1.4 kgP/ha/y), that is 52% of total P input to the Danube.

Eutrophication quality of small rivers in the CEE countries is generally very good (as judged by chlorophyll levels), but larger rivers show significant eutrophication problems, often related to municipal sewage discharges. However, data quality and availability is very poor, and variability makes comparison difficult. Reductions in river nutrient levels are being observed, usually resulting from P-removal in municipal sewage works, and consequently the relative contribution of agricultural phosphorus is increasing.

Actions to reduce soil erosion, such as conversion of cropland to forest or permanent pasture are seen by the authors as the most important route for controlling agricultural P-losses in Central and Eastern Europe, but these must be combined with measures to ensure appropriate agronomic, rural and economic development.

Catchment modelling and data

Kronvang et al. present the results of monitoring and modelling of agricultural phosphorus losses from 35 micro (< 30 km^2) Nordic – Baltic catchments, 17 European macro-catchments (250 – 11,000 km^2) and 10 large European catchments (> 50,000 km^2). Annual average P loss was highly variable for the micro- and macro-catchments (0.1 – 6 kg/ha/y), despite the fact that the micro-catchments were all from the Baltic / Northern Europe region, with lower variability for the larger catchments. **P-loss was not related to short term phosphorus application surplus, but was related to soil erosion and high levels of surface water run-off.** The proportion of P-loss in the form of soluble phosphate showed a very high variability (10% - 90%), as did the N:P ratio (10 – 300).

The MONERIS model was used to estimate **apportionment of total phosphorus loads for the 17 European macro-catchments**, again showing very high variability. The average results were:

- **18% of total P load from waste water treatment plants** (range 5 – 39%)
- 10% from scattered dwellings (2 – 39%)
- **53% for soil erosion and surface run-off**
- 14% for groundwater
- 3% for drainage
- and 1% for atmospheric deposition.

Agriculture was the main P-source in 12 out of 17 macro- and 3 out of 10 large catchments, but with the proviso that agricultural P run-off is often underestimated by the periodic monitoring from which this data is derived (large P losses during spate flows are not adequately accounted). The key factors affecting P loads in the large catchments appear as run-off intensity, population density and surface area of water bodies, but not the % agricultural land use. This may be because of the importance of P-retention mechanisms in rivers and surface waters.

The authors conclude that P-loads, the proportion of agricultural phosphorus and the forms of P (soluble, particulate) are **highly variable**, depending on local situations, so that defining result-orientated actions as required by the EU Water Framework Directive, will necessitate a catchment by catchment approach.

Edwards and Withers summarise the issues in linking phosphorus sources to eutrophication impacts. They emphasise that **not only phosphorus load must be taken into account, but also the specific ecologic conditions of the receiving water bodies**, both at the site of discharge and also further downstream, and as a function of these conditions, the different forms of phosphorus discharged (in particular its bioavailability over different time periods) and the temporal patterns of its release.

P-discharge from diffuse sources is often closely related to rainfall and run-off flows, which may result in its being of lower eutrophication significance (release at periods of higher dilution, or at times of the year when algae are less susceptible to develop), whereas point sources such as sewage works will generally discharge phosphates all year round, including at low river flow, high algal growth periods. However, some diffuse sources such as households not connected to sewerage will not be rainfall dependent. **Impacts will also depend on how P is discharged**, directly into surface waters, via run-off, or through groundwater.

Various tables show overview data on source apportionment of phosphorus, bioavailability of P from different sources, P-concentrations compared to population densities, hydrological / catchment conditions relating to phosphorus transport.

The authors conclude that **targeting one phosphorus source group, without evidence of directly associated impacts, is unlikely to deliver objective improvements in water quality**, and that consideration of temporal linkages between phosphorus discharge from different sources and eutrophication risk (algal growth periods) will be necessary, at the catchment level, to define the phosphorus management actions required for EU Water Framework Directive implementation.

Urban wastewater treatment and reactive phosphorus concentrations

Foy compares statistics for installed P-removal in urban sewage treatment to data for reactive phosphorus concentrations in rivers for 10 West European countries, comparing in particular five countries with near 100% population coverage by P-removal (Austria, Denmark, Finland, Germany, the Netherlands, Sweden) with countries with much lower levels of P-removal implementation, in the range 2% - 56% (Belgium, France, Ireland, the UK). Reactive phosphorus can be considered as more indicative of potential eutrophication problems that total phosphorus, because it is immediately available to algae.

He concludes that mean reactive phosphorus (RP) concentrations, and also the % of rivers with RP concentrations > 100 µg/l, are **closely correlated to population density corrected for P-removal, but not to simple population density**. Agricultural factors (% cropland, application of nutrients in fertilisers or manures) were not correlated to mean or median RP concentrations, but were negatively correlated to the % of rivers with low RP concentrations (< 25 µg/l).

"Agriculture as a phosphorus source for eutrophication in the north-west European countries, Norway, Sweden, United Kingdom and Ireland: a review". B. Ulén, Division of Water Quality Management, Swedish University of Agricultural Sciences, Box 7014, SE 750 07 Uppsala, Sweden, and M. Bechmann, J. Fölster, H. Jarvie, H. Tunney. Barbro.Ulen@mv.slu.se

"Agriculture as a source of phosphorus causing eutrophication in Central and Eastern Europe", P. Csatho, Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences, Budapest, Hungary, and I. Sisak, L. Radimszky, S. Lushaj, H. Spiegel, M. Nikolova, P. Cermak, J. Klir, A. Astover, A. Karklins, S. Lazauskas, J. Kopinski, C. Hera, E. Dumitru, M; Manojlovic, D. Bogdanovic, S. Torma, M. Leskosek, A. Khristenko, csatho@rissac.hu

"Phosphorus losses at the catchment scale within Europe: an overview", B. Kronvang, Dept. Freshwater Ecology, National Environmental Research Institute, Vejlsovej 25, 8600, Silkeborg, Denmark, and N. Vagstad, H. Behrendt, S. Larsen, bkr@dmu.dk

"Linking phosphorus sources to impacts in different types of water body", A. Edwards, Nether Backhill, Ardelie, by Peterhead, Aberdeenshire, AB42 5BQ, UK t.edwards@btinternet.com *and P. Withers, Catchment Management Group, ADAS Gleadthorpe, Meden Vale, Mansfield, Nottingham, NG20 9PF, UK.*

"Variation in the reactive phosphorus concentrations in rivers of northwest Europe with respect to their potential to cause eutrophication", R. Foy, Agri-Environment Branch, Agri-Food and Biosciences Institutes, Newforge Lane, Belfast, BT9 5PX, UK. Bob.foy@afbini.gov.uk

Soil Use and Management (Blackwell Publishing), 23 (suppl. 1), 2007
http://www.blackwellpublishing.com/journal.asp?ref=0266-0032

International Conference on

Nutrient Recovery from Wastewater Streams

May 10th - 14th 2009 - Vancouver, British Columbia, Canada

Draft programme – 80 sessions and workshops

Sunday May 10th	19:00	Welcome Reception
Monday May 11th	08:30	**Conference Opening and Welcome Address**
	11:00	**Keynote Address:** Dr. James Barnard (2007 Clarke Prize)
	13:00	Parallel Sessions : Global perspectives on nutrient use and recovery / Struvite chemistry and recovery I / Modelling nutrient recovery
	15:30	Parallel sessions : Economics of phosphorus recovery / Struvite chemistry and recovery II / Utilisation of recovered nutrients I
Tuesday May 12th	8:30	Parallel sessions : Agricultural nutrient recovery I / Struvite chemistry and recovery III / Phosphorus recovery from WWTPs I
	10:30	Parallel sessions : Agricultural nutrient recovery II / Struvite chemistry and recovery IV / Phosphorus recovery from WWTPs II
	13:00	Parallel sessions : Agricultural nutrient recovery III / Struvite chemistry and recovery V / Phosphorus recovery from WWTPs III
	15:30	Parallel sessions : Agricultural nutrient recovery IV / Nutrient recovery processes / Phosphorus recovery from WWTPs IV
	19:00	**Evening Dinner Harbour Boat Cruise** (optional)
Wednesday May 13th	8:30	Parallel sessions : Agricultural nutrient recovery V / Small scale and rural nutrient recovery / Nutrient recovery chemistry I
	10:30	Parallel sessions : Utilisation of recovered nutrients II / Nitrogen removal and recovery / Nutrient recovery chemistry II
	13:30	**Plenary Session and Expert Panel Discussion**, Q&A session.
	15:30	**Poster Session** Wine and Cheese
Thursday May 14th Technical tours (optional)	**- Fraser Valley stream and reservoir fertilisation project** **- Lulu Island WWTP R&D struvite recovery set-up** **- Edmonton, Alberta (Canada) Goldbar full scale Ostara struvite recovery** **- Portland, Oregon (USA) full scale Ostara struvite recovery** (overnight, USA visa required)	

For further details, conference registration, fees, full programme:
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