SCOPE NEWSLETTER

NUMBER 62 **December 2005**

Linking landscape sources of phosphorus and surface water impacts

A thematic issue of Science of the Total Environment presents 18 papers addressing the ecology of nutrients in surface waters, assessments of nutrient sources and links between landscape sources of phosphorus and of sediments (suspended matter) to ecological impacts in surface waters, covering both Great Britain and Europe.

Editorial: new research approaches

The need for an interdisciplinary approach to understanding the links between diffuse phosphorus and sediment transfer from agricultural land and impacts on surface water quality.

Relative phosphorus contributions

A study of phosphorus sources to the Avon river, southern England, assesses the need for phosphorus removal in sewage works.

Risk based prediction of phosphorus losses

Three different geographic levels of data were used to estimate the risk of elevated phosphorus loads to lakes.

Nutrient discharges

Minnesota

Detailed assessment of P sources to surface waters

A study carried out for the Minnesota State authorities provides a breakdown of different phosphorus sources to waste water treatment plants and to surface waters, concluding that dishwasher detergents (all phosphorus based) represent less than 3% of phosphorus inputs to the state's surface waters.

Nutrients and ecosystems

Lake Peipsi

Modelling future nutrient scenarii

Nutrient loads to Lake Peipsi, from diffuse and point sources, are modelled for five different socioeconomic future development scenario

Soluble phosphorus

Nutrient availability

Soluble phosphate concentrations are orders of magnitude below concentrations estimated with standard methods

Danube catchment

Perspectives for water policies and economics

The regional conference on "Waste water treatment and implementation of the Water Framework Directive in CEE countries" looked at progress in waste water treatment over the last decade, costs and economics, and implications for the future in the international Danube and Black Sea catchments.

Book review

Importance of zooplankton in eutrophication control

"Eutrophication management and ecotoxicology" (Springer Verlag Berlin 2005) summarises current knowledge regarding the key role played by zooplankton grazing in controlling algal growth and presents some to date unpublished experimental results.

Linking landscape sources of phosphorus and surface water impacts

A thematic issue of *Science of the Total Environment* presents 18 papers addressing the ecology of nutrients in surface waters, assessments of nutrient sources and links between landscape sources of phosphorus and of sediments (suspended matter) to ecological impacts in surface waters, covering both Great Britain and Europe.

http://www.sciencedirect.com/science/journal/00489697

Editorial: new research approaches

In his editorial overview paper to this special edition *"Linking landscape sources of phosphorus and sediment to ecological impacts in surface waters"*, Phil Haygarth emphasises the need for an interdisciplinary approach to understanding the links between diffuse phosphorus and sediment transfer from agricultural land and impacts on surface water quality.

Phosphorus can reach streams, rivers and lakes in both soluble forms and in particulate forms, the latter often associated with sediment that has been transported in runoff. Sediment itself, as well representing a loss of soil from productive land and also acting as a carrier of phosphorus, can cause water quality deterioration by silting of gravel river beds.

European Water Framework Directive

The EU Water Framework Directive (2000/60) aims to restore all European surface waters to "good ecological status" by 2015, and requires specific actions to reduce and control nutrient releases.

Agriculture and rural land use is a major source of diffuse phosphorus inputs and of sediments to surface waters, but is very complex, and despite considerable recent research attention many questions remain concerning the links between landscape discharges of phosphorus and sediments and water quality. In particular, more attention needs to be given to landscape ecology, and to the relationship between land use change and how catchments respond.

This special issue of *Science of the Total Environment* brings together papers addressing modelling of landscape phosphorus releases, at different scales and degrees of information detail, results of mitigation strategies (in particular Bechmann et al., Norway, showing that long term policies addressing agricultural methods did effectively reduce phosphorus runoff), identification of the different phosphorus sources to given river systems, links between sediment runoff and ecological impacts. Key aspects addressed in a number of the papers are new approaches to bring together different levels of landscape and runoff models, and to link landscape and water quality research.

The author concludes that explicit linkages between landscape sources of phosphorus and sediments are difficult to isolate and that much research remains to do in this area.

Review

Phil Haygarth also co-authors the first paper in this special issue "The phosphorus transfer continuum: linking source to impact with an interdisciplinary and multi-scaled approach". This critical review looks at the continuum: phosphorus and sediments sources in the landscape, mobilisation of phosphorus in soil, delivery to surface waters, ecological impacts. Much research in the past has looked at just one of these levels, with most research being concentrated on the source and mobilisation tiers, and the challenge today is to link through the four levels to model final ecological impact on surface waters, and this despite the increasing uncertainty added at each tier. The authors conclude that this will require complexity based approaches and multidisciplinary research efforts, but that it is essential to provide practical management tools and information.

"Linking landscape sources of phosphorus and sediment to ecological impacts in surface waters", P. Haygarth, and "The phosphorus transfer continuum: linking source to impact with an interdisciplinary and multi-scaled

approach" P. Haygarth, L. Condron, A. Heathwaite, B. Turner, G. Harris, Science of the Total Environment, 344 (2005), pages 1-3 and 5-14 respectively.

P. Haygarth, Institute of Grassland and Environmental Research (IGER), North Wyke Research Station, Okehampton, Devon, EX20 2SB, England.
Phil.haygarth@bbsrc.ac.uk

Relative phosphorus contributions

A study of phosphorus sources to the Avon river, southern England, concludes that phosphorus removal in both large but also in significant small sewage works (<10,000 person equivalent = p.e.) is necessary if good ecological status is to be achieved as required by the EU Water Framework Directive.

The Avon catchment upstream of Evesham (2,200 km^2) was studied, with nutrient inputs (phosphorus, nitrogen) being evaluated by landscape runoff modelling and data from point sources, then compared with measured water concentrations. The effects of two scenarios of improved sewage treatment were evaluated: (a) implementation of a minimalist interpretation of the EU Urban Waste Water Treatment Directive 1991/271 (80% phosphorus removal in all sewage works > 10,000 person equivalent) and (b) as above plus 80% phosphorus removal from a range of 11 smaller sewage works (not necessarily the largest remaining works). In fact today phosphorus removal has probably been installed in a number of the catchment's sewage works, but the data set used in this study was produced in 1994-1996.

Phosphorus loads

This study is based on an Environment Agency dataset gathered from 58 water sampling sites in the Avon river system between 1994 and 1996. The study area had a population of around 0.7 million people = population density of 306 people km^2, (average UK population density of England was 377 people / km^2 in 2001) [and includes 100 municipal sewage treatment works, of which 7 are of capacity >10,000 p.e. 14% of land surface is urban or semi-urban, 44% cropland and 30% pasture.

SCOPE Newsletter editor's comment:

In fact, the EU Urban Waste Water Treatment Directive specifies that nutrient removal must be installed in sewage treatment works serving agglomerations of >10,000 p.e. (even if the sewage works are of lower capacity) discharging into "eutrophication sensitive" areas – in theory by end 1998! The Avon downstream was designated a "sensitive area" in 1990 following algal blooms during a low flow period, and the Directive's requirements on nutrient removal in sewage treatment are therefore applicable to the whole upstream catchment. However, the Directive does also specify that "appropriate" treatment should be installed at smaller sewage works, and the EU Water Framework Directive 2000/60 requirement to achieve "good ecological status" in surface waters by 2015 means that this must mean nutrient removal wherever nutrient emissions are an ecological issue. It should also be noted that sewage works operating either biological and/or chemical phosphorus removal can readily and reliably achieve P-removal rates significantly better than 80% using currently widespread technologies.

Data for estimating phosphorus loads came from :

- monitoring of the seven >10,000 p.e. sewage works and of 11 smaller sewage works,
- estimates for other sewage works, based on population served x 0.38 kgP/day.
- landscape runoff estimates based on GIS data for 17 types of land cover and phosphorus export coefficients
- estimates of livestock densities

These estimates for phosphorus loads were then compared to river data, for 44 monitoring sites for which annual loads could be estimated by multiplying measured river phosphorus concentrations by monitored flow rate. Because phosphorus runoff from land is known to be highly correlated to sporadic spate flow events (see e.g. "Illinois" in *SCOPE Newsletter n°58*), it was checked whether monitoring data included such events: 14 sites where it did not were removed from the dataset (58 – 14 = 44 sites as above). The estimated phosphorus loads showed very close agreement with the results from the monitoring at these 44 sites.

Impacts of sewage

Discharges from sewage works strongly increased river nutrient loads. For example, 7 of the 8 sites showing the highest river nutrient concentrations were <4 km downstream from one of the seven large sewage works.

High river nitrogen concentrations were spatially correlated to high phosphorus, but were also found in some small headland streams in the upper catchment.

One third of the monitoring sites showed sewage works as the majority source of phosphorus and the estimated proportion of phosphorus load coming from sewage works varied from 9 to 93%.

Near the outflow from the study catchment (Avon river near Evesham), average total phosphorus concentration was 1.7 mgTP/l with an estimated 76% coming from sewage works discharges.

The authors emphasise that the proportion of phosphorus coming from sewage works discharges is closely correlated to the river phosphorus concentrations. Of 45 occurrences of total phosphorus concentrations > 5mgTP/l over the study period at different sites, all but one were at sites with more than 2/3 of phosphorus load estimated to come from sewage works.

Also, the sites where a majority of phosphorus load came from sewage were those which showed the greatest seasonal variations in phosphorus concentrations, with sewage works discharges resulting in high summer concentrations (sewage works discharge is approximately constant year round, whereas phosphorus runoff from land is generally higher in the autumn and winter, when there is higher rainfall).

Nutrient removal

The two sewage works nutrient removal scenarios, as indicated above, modelled the effects (in terms of river total phosphorus concentrations) of (a) 80% P-removal applied in only the 7 larger sewage treatment works – total approx. 731,000 p.e. and (b) additionally, 80% P-removal in 11 of the 93 remaining sewage treatment works (53,000 p.e.). It should be noted that the total sewage works capacity expressed as p.e. (person equivalent) exceeds the actual population because of industrial and commercial effluents.

The 80% reduction at the 7 larger sewage works only resulted in an estimated 52% reduction in total catchment phosphorus load (378 tonnes/year in the river at Evesham), but the sampling sites with highest total phosphorus were still those with most phosphorus coming from sewage works discharges. The 80% P-reduction at a further 11 smaller sewage works only resulted in a further 4% decrease in total catchment phosphorus loads (river at Evesham), but resulted in 56 of the 58 monitoring sites showing an average phosphorus concentration below 1 mgTP/l.

The authors conclude that not only is it necessary to implement phosphorus removal at the larger sewage works (>10,000 p.e.) – as is in any case immediately obligatory under EU legislation, that phosphorus removal at targeted smaller sewage works is also necessary and effective, and finally that to achieve sufficient nutrient load reduction for "good ecological status" then reductions in diffuse phosphorus loads will also be necessary.

"The relative contribution of sewage and diffuse phosphorus sources in the River Avon catchment, southern England: Implications for nutrient management", Science of the Total Environment, 344 (2005), pages 67-81.

M. Bowes, J. Hilton, G. Irons, D. Hornby, Centre for Ecology and Hydrology (CEH), Winfrith Technology Centre, Dorchester, Dorset, DT2 8ZD, England
mibo@eh.ac.uk

Risk based prediction of phosphorus losses

Three different geographic levels of data were used to estimate the risk of elevated phosphorus loads to lakes.

For implementation of the EU Water Framework Directive 2000/60, the UK Environment Agency has defined an "interim eutrophication risk assessment" which aims to compare estimated phosphorus loads (to lakes) and resulting in-lake water total phosphorus concentration. The reference concentration is preferably defined according to the local ecological characteristics of each lake (site specific). Where adequate current water monitoring data is available, this can replace the estimated concentration derived from loads.

Different levels of information

Three different levels of model for predicting catchment phosphorus loads were compared, each based on phosphorus loss coefficients for different land use types, but at different levels of geographical detail:

- basic risk screening approach, based only on land use and animal stocking data which is available for each lake catchment : GB Lakes export inventory (GBL)
- pressure delivery risk screening (PDRS) matrix approach, which goes further by taking into account catchment characteristics in estimating what part of agricultural phosphorus loads (based on runoff land use coefficients) is susceptible to reach the lake
- phosphorus indicators Tool (PIT), which is based on three levels of information concerning activities (available phosphorus), mobilisation, connectivity of land to surface waters.

The relations between the three approaches were tested by applying the GBL approach to 50 lakes, and then the PDRS to 8 lakes and the PIT to 21 lakes.

Sufficient consistency

The GBL approach produced a fairly good log-log fit with actual measured lake phosphorus concentrations. The three approaches show some consistency in predicting which lakes are “at risk” of agricultural phosphorus causing eutrophication, and a table comparing rankings of different lakes by the different approaches is provided. The authors develop a step-wise approach for lakes, using the GBL and PDRS to define whether it is justifiable to undertake more detailed assessments using PIT, which requires more local data. The PIT approach is able to identify, at the 1 km^2 level, areas of catchments which show relatively high risks of phosphorus delivery to surface waters. This approach has been calibrated for five lakes identified as at risk.

The GBL approach, applied to all lakes in Great Britain of more than 1 ha area (>14,000 lakes), suggests that 51% of lakes in Great Britain (and 88% in England) are at risk of not meeting the “Good Ecological Status” objective of the EU Water Framework Directive because of agricultural phosphorus (diffuse) loads.

A map of lakes in Great Britain comparing the phosphate load eutrophication risk (derived by the PDRS approach) to other pressures (nitrates, sediment) was prepared.

The authors conclude that that the GBL approach is a relatively robust method for general risk assessment purposes across the whole of Great Britain. They recommend PDRS as a national tool for an assessment of pressures only. The PIT approach (not-calibrated or calibrated) provides much more detailed site-specific methods for understanding the main sources and pathways of nutrients within a catchment.

“A tiered risk-based approach for predicting diffuse and point source phosphorus losses in agricultural areas”, Science of the Total Environment, 344 (2005), pages 225-239

A. Heathwaite, Centre for Sustainable Water Management, The Lancaster Environment Centre, Lancaster University, Lancaster, LA1 4YQ, UK. R. Dils, Environment Agency, Evenlode House, Howbery Park, Wallingford, Oxon, OX10 8BD, UK. S. Liu, R. Brazier, Department of Geography, University of Sheffield, Sheffield, S10 2TN, UK. L. Carvalho, L. May, Centre for Ecology and Hydrology (Edinburgh), Bush Estate, Penicuik, EH26 0QB, UK. L. Pope, G. Phillips, Environment Agency, Kings Meadow House, Kings Meadow Road, Reading, RG1 8DQ, UK. M. Hughes, Environmental Change Research Centre, Department of Geography, University College London, 25 Bedford Way, London, WC1H 0A, UK. louise.heathwaite@lancs.ac.uk

“Risk Assessment Methodology for Determining Nutrient Impacts in Surface Freshwater Bodies”. UK Environment Agency R&D Technical Summary P2-260/09/TS, June 2004. Research Contractors: CEH, ECRC-ENSIS Ltd, University of Sheffield, University of Stirling. Summary available at: http://www.ceh.ac.uk/sections/sfe/projects/NUPHAR.html

Nutrients and ecosystems

Minnesota

Detailed assessment of P sources to surface waters

A study carried out for the Minnesota State authorities provides a breakdown of different phosphorus sources to waste water treatment plants and to surface waters, concluding that dishwasher detergents (all phosphorus based) represent less than 3% of phosphorus inputs to the state's surface waters.

Non-point sources are estimated to contribute 69% of total phosphorus inputs to Minnesota State's surface waters, of which 26% from cropland runoff, 13% atmospheric deposition and 11% stream bank erosion, according to a detailed report produced for the Minnesota Pollution Control Agency. Concerning point sources, the report estimates that non-ingested sources of phosphorus make up around 58% of total phosphorus inputs to publicly operated wwtps (waste water treatment plants): 26% from commercial and industrial waste streams, 16% from food wastes, 11% from dishwasher detergents and 5% from other sources. This estimate of 11% of phosphorus inputs to sewage treatment plants from dishwasher detergents thus corresponds to around 2.8% of total phosphorus inputs to surface waters.

The report however points out that point sources (31% of total State surface water phosphorus loadings for average flow) represent up to 45% of total P loadings during dry flow periods (down to 19% in wet = high flow periods), and represent 44% of bio-available phosphorus during average flow conditions and 57% during low flow conditions (page xiv).

The Agency's accompanying letter points out that phosphates "contained in many cleaning agents served a valuable purpose in increasing their overall effectiveness".

Basin by basin assessment

The report estimated total State-wide phosphorus loads by estimating phosphorus loads to each of the ten major river basins in the State. Data was collected for each basin from both literature and site-specific monitoring on population, land cover, land use, soil types. Data was also collected from waste water treatment facilities: population served, discharge permits, capacity, type of treatment, connected businesses and industries, flow and phosphorus discharge data where available.

Literature data was used to estimate the per capita loading of phosphorus into the sewage system (before treatment) from human faeces and urine, food soils, dishwashing water, and other products.

Dishwasher detergent phosphorus

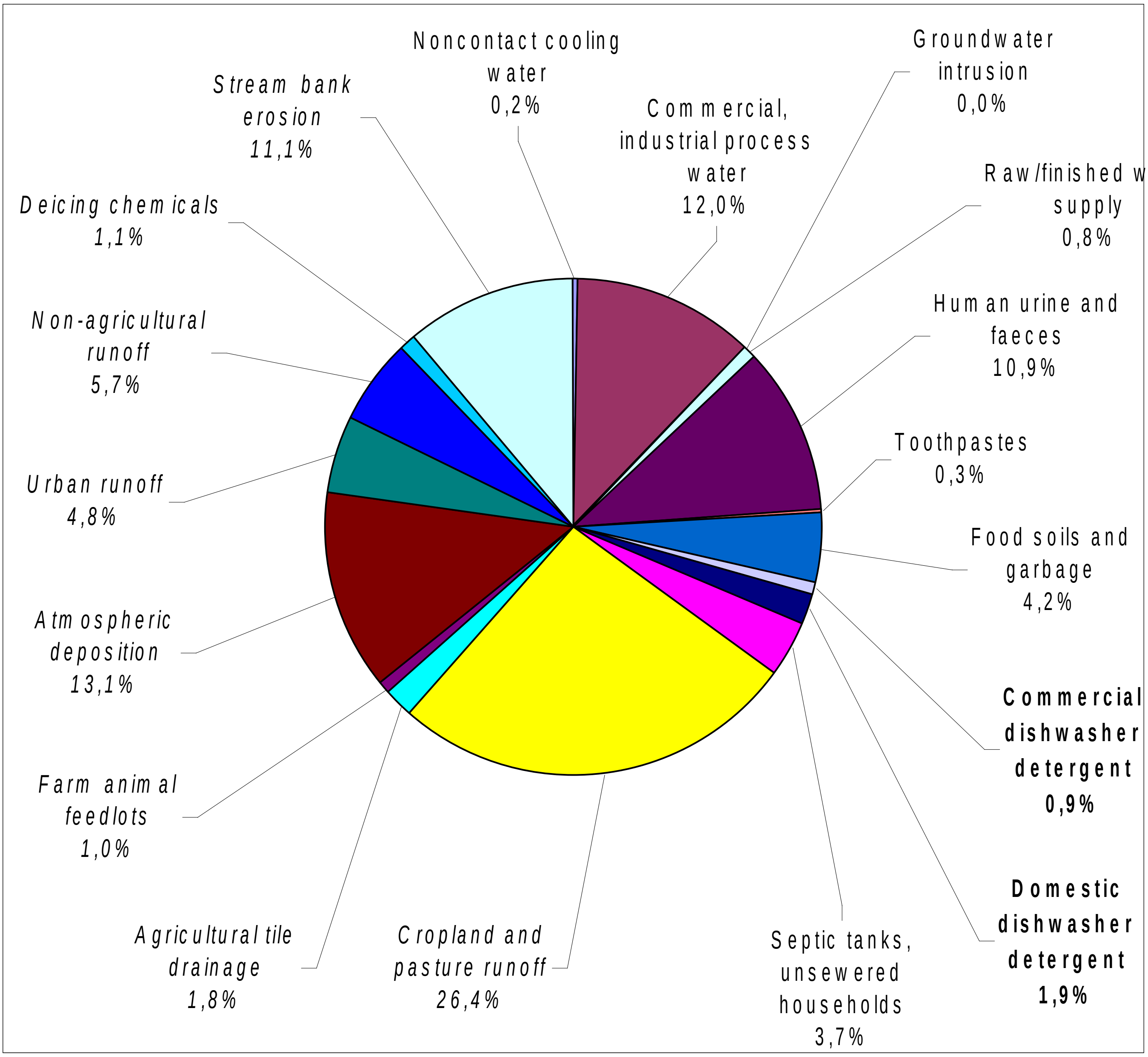
Dishwasher detergent phosphorus use per capita was estimated (page 20) based on 2000 data for total use in the USA of phosphates in domestic and commercial - industrial dishwasher detergent formulations (SRI Chemical Economics Handbook – Industrial Phosphates, SRI 2000) divided by the estimated total USA population, giving 0.085 kgP/person/year in domestic dishwasher detergents and 0.04 kgP/person/year in commercial – industrial dishwasher detergents. These per capita figures were then applied to the population served by each waste water treatment plant.

Phosphorus removal in sewage works

Data used were from 2001-2003. The report notes that, since then, phosphorus removal has been implemented at the MCES Metro wwtp, which alone (during the report years) contributed 74% of point source phosphorus loading to the Upper Mississippi River Basin and an estimated 40% of total State-wide point source phosphorus loadings (the Upper Mississippi contributes 34% of total average year State surface water phosphorus loadings). The report indicates (page viii) that the percentage of total State-wide phosphorus loading coming from point sources can be expected to have to have fallen from 31% to around 25%. This will mean that the % phosphorus load to surface waters coming from dishwasher detergents will have been reduced from around 2.8% to around 2.4% (assuming 80-90% phosphorus removal implemented at this wwtp).

Estimated total phosphorus contributions to Minnesota State surface waters

Average flow year (page ix and 118). *Italic = Non point sources = 69%.* Point sources = 31%
Total phosphorus loading estimated = 6 784 tonnes P / year



The report indicates (page xxiv) that efforts to reduce point source phosphorus loadings to surface waters should begin by implementing phosphorus removal at the larger waste water treatment works (public sewage works with capacity > 1 million gallons/day contribute 88% of point source phosphorus).

The report does not reach conclusions as to whether there would be any expected effect on water quality from removing a very minority source of phosphates such as dishwasher detergents.

Septic tanks

22% of the total Minnesota population of 4.4 million was estimated to be not connected to sewage works. Of this population, 12% were estimated to have partly operational septic tanks or autonomous sewage treatment systems, and 26% inoperative systems. 57% of phosphorus was assumed to be removed in septic tanks (figure from Tetra Tech, 2002, Minnesota River Basin Model, Model Calibration and Validation Report, for Minnesota Pollution Control Agency). Correctly installed systems were assumed to remove, in both the septic tank and soil retention, 80% (seasonal use) or 90% (residential use) of total phosphorus loading. Incorrectly installed systems were assumed to remove only the 57% indicated above.

Consequently, total phosphorus loadings from non sewerage connected households and septic tank systems were estimated at around 4% of total average year loads to surface waters. Domestic dishwasher detergents reaching surface waters via such households would thus represent < 0.3% of total surface water phosphorus loads.

"Detailed Assessment of Phosphorus Sources to Minnesota Watersheds", Barr Engineering Company for the Minnesota Pollution Control Agency www.pca.state.mn.u, *February 2004, 1140 pages including annexes. Full report available at:* http://www.pca.state.mn.us/hot/legislature/reports/phosphorus-report.html

Nutrients and ecosystems

Lake Peipsi
Modelling future nutrient scenarii

Lake Peipsi is one of Europe's five largest lakes, with a transboundary water basin draining some 44,000 km^2 in Russia (Chudskoe) 67%, Estonia 26% and Latvia 7%. Previous papers presented GIS-based modelling of diffuse and point source nutrient inputs to the lake and comparison with measured concentrations (see SCOPE Newsletter n°52 at *www.ceep-phosphates.org*). This further work presents modelling of future nutrient loads with five different social and economic development scenarii.

The scenario were based on high/low economic development and high/low levels of international cooperation (2x2 = 4 scenarii), plus a fifth scenario considering high economic development in the European Union (Estonia, Latvia) but low economic development in Russia. As a function of these basic premises, scenario for population, waste water treatment connection, fertiliser use, livestock numbers, crop yields, atmospheric deposition and agricultural land use were defined.

On the basis of each scenario, nutrient emissions (nitrogen N, phosphorus P) to Lake Peipsi were estimated using a GIS-based (Geographical Information System) model which simulates nutrient releases, transport and retention in drainage basins. This estimates and maps emissions from point source information, agricultural statistics and land use, then models hydrological fluxes and nutrient routing through the different soil, groundwater and river compartments.

Nitrogen and phosphorus

The results previously published showed that over the recent past both nitrogen and phosphorus loads to Lake Peipsi have decreased, as a result of reduced agricultural intensity and fertiliser use (mainly as a consequence of the economic and geo-political changes in the Soviet Union).

In the future modelling, both nitrogen and phosphorus loads are expected to decrease for all scenarii. The highest expected nitrogen loads occur in the "growth" high economic development + high international cooperation scenario, whereas the highest phosphorus loads occur in the "crisis" scenario (low economic development + low international cooperation). This is because nitrogen loads are dominated by diffuse sources (related mainly to the surface of land cropped used for cereal cultivation), whereas phosphorus loads are especially influenced by point sources. In the "crisis" scenario, wastewater treatment in Russia is assumed to collapse.

The authors conclude that the GIS-embedded nutrient model can provide plausible nutrient emission estimates and load simulations for a complete drainage basin, even where parts of the area have limited data available. They emphasize that strategies for nutrient load reduction should mainly focus on agricultural nutrient runoff, especially in the Russian part of the drainage basin, given that scenario II (economic growth and international cooperation) is the most likely one for the future.

"GIS-based quantification of future nutrient loads into Lake Peipsi/Chudskoe using qualitative regional development scenarios", Water Science and Technology, vol. 15, n°3-4, pages 355-363, 2005 http://www.iwaponline.com/wst/toc.htm *D. Mourad[1], M.*

Van der Perk[1], G. Gooch[2], E. Loigu [3] K. Piirimäe[3], P. Ståinacke[4]

Previous publications: see SCOPE Newsletter n°52 at www.ceep-phosphates.org and further details now published on: "Modelling nutrient fluxes from diffuse and point emissions to river loads: the Estonian part of the transboundary Lake Peipsi/Chudskoe drainage basin (Russia/Estonia/Latvia)", Water Science and Technology, vol. 49, n°3, pages 21-28, 2004. http://www.iwaponline.com/wst/toc.htm *D. Mourad[1], M. van der Perk[1].*

1: Dept. Physcial Geography, Utrecht Centre for Environment and Landscape (UCEL), Faculty of Geographical Sciences, Utrecht University, PO Box 80115, 3508 TC Utrecht, The Netherlands. 2: Dept. Management and Economics, Linköping University, Linköping University, 58183 Linköping, Sweden. 3: Dept. Environmental Engineering, Talinn Technical University, Järvevana tee 5, 19086 Talinn, Eesti. 4: Jordforsk (Norwegian Centre for Environmental Research), Frederik A. Dahis Vei 20, 1432 Ås, Norway.

Contact: d.mourad@geog.uu.nl

Past years' mean annual nutrient emissions in Lake Peipsi basin:

		Diffuse sources		*Point sources*		*TOTAL*
N: total nitrogen (tonnes/year)	1985-1989	417 000	99%	4 090	1%	421 090
	1995-1999	163 000	98%	3 410	2%	166 410
	2015-2019 Crisis scenario	109 000	97%	3 500	3%	112 500
	2015-2019 Growth scenario	488 000	99%	2 810	1%	490 810
P: total phosphorus (tonnes/year)	1985-1989	79 000	99%	1 130	1%	80 130
	1985-1989	18 000	95%	920	5%	18 920
	2015-2019 Crisis scenario	0	0%	980	100%	980
	2015-2019 Growth scenario	62 000	99%	800	1%	62 800

Soluble phosphorus
Nutrient availability

Soluble phosphate concentrations are orders of magnitude below concentrations estimated with standard methods

A new method for estimating phosphate concentrations in surface waters shows that available phosphate concentrations in ecosystems are significantly lower than has previously been thought, down to 27 – 885 picomolar. Soluble phosphate concentrations in aquatic ecosystems are under biotic control by pico- and nanoplankton, at least when the planktonic food web is limited by phosphorus and not by other nutrients, light or climate. This study presents a new method for assessing soluble phosphate concentrations by comparing uptake and release rates of phosphorus

In surface water layers, pelagic microorganisms rely on nutrient recycling to sustain productivity. Direct inputs of phosphorus to this water layer (either from external sources or from internal sources such as fish) are often small compared to microbial cycling.

Phosphate uptake cannot be directly measured, but the "uptake constant" can be accurately measured. By combining the uptake constant with a new method for estimating the rate of regeneration of dissolved phosphorus (total planktonic release), the authors were able to derive accurate estimates of aquatic soluble phosphate when assuming a "steady state" situation (this assumption is reasonable because the time scale of net planktonic biomass change is very long compared to that of phosphate cycling).

Results were obtained for 56 lakes (from the Rocky Mountains, Interior Plains and Canadian Shield areas of North America). Three lakes were identified as outliers and were removed from the data set; they were weakly phosphorus limited. For the 53 remaining lakes, soluble phosphate concentrations of 27 – 885 picomolar were estimated. Interestingly, soluble phosphate concentrations did increase with lake total phosphorus concentrations, but not on a 1:1 basis (log soluble P relates to approx. 0.75 x log total P).

Orders of magnitude

These estimates were compared to soluble reactive phosphorus concentrations (SRP) from the literature for the same study lakes. The new estimates of soluble phosphate were 2 - 3 orders of magnitude lower than standard SRP measurements. Despite the continued use of SRP, the SRP procedure is known to greatly overestimate phosphate. This was understood since Rigler's seminal papers in the 1960s on the phosphorus cycle, but the degree of overestimation was poorly understood. The SRP procedure causes significant overestimates because of the release of soluble phosphorus due to the damaging of cells during filtration (causing the release of cellular phosphates) and to the use of acidic reagents prior to colorimetric determination of soluble phosphorus. Multiple Rigler bioassay estimates of soluble phosphate in two of the study lakes also gave results 2 orders of magnitude higher than the new "steady state" method.

The picomolar soluble phosphate concentrations derived by the new method are the lowest concentrations of phosphate ever reported for an aquatic ecosystem, but are comparable to concentrations estimated for micronutrients (e.g., iron, manganese and zinc in the open ocean). These low concentrations are confirmed by a handful of other published studies which have used innovative methods to estimate aquatic ecosystem soluble phosphate concentrations: Fisher and Lean 1992 (concentrations of soluble phosphorus around 500 picomolar), Dodds 1993 (concentrations of 80 – 140 picomolar). Recent modifications of this new method for measuring phosphate at picomolar concentrations are also available in a recent paper by the authors (Hudson and Taylor 2005).

"Phosphate concentrations in lakes", Nature, vol. 406, 6th July 2000, Pages 54-56.
http://www.nature.com/nature/journal/v406/n6791/abs/406054a0_fs.html

J. Hudson[1], W. Taylor[2] and D. Schindler[3]

[1]Dept. Biology. University of Saskachewan, Saskatoon, Saskatchewan, S7N 5E2, Canada.
jeff.hudson@usask.ca

[2] Dept. Biology, University of Waterloo, Waterloo, Ontario, N2L 3G1, Canada.

[3]Dept. Biological Sciences, University of Alberta, Edmonton, Alberta, T6G 2E9, Canada.

Hudson, J. and W. Taylor. (2005). Rapid estimation of phosphate at picomolar concentrations in freshwater lakes with potential application to P-limited marine systems. Aquat. Sci. 67:316-325.

Fischer, T. and D. Lean, "Interpretation of radiophosphate dynamics in lake waters", Can. Fish. Aquat. Sci. 49, 252 – 258, 1992.

Dodds, W. "What controls levels of dissolved phosphate and ammonium in surface waters", Aquat. Sci. 55, 132-142, 1993.

Danube catchment
Perspectives for water policies and economics

The 19 countries in the Black Sea catchment show massive variations in per capita GDP, from around 25,000 €/person/year to around 1,000 € in Herzia, Bosnia Herzogovina, Yugoslavia, Bulgaria … Over the past years, important new tools for inter-state cooperation have been established with the creation of the International Commission for Protection of the Danube River (ICPDR) and the Black Sea Commission.

Laszlo Somlyody, Budapest University of Technology and Economics, explained that today only 56% of households in CEE countries are connected to sewerage and around 33% of total wastewater is adequately treated. This is particularly true in rural areas, which cover 30-40% of the region's populations. Consequently needs for investments in sewerage and sewage treatment are estimated at around 100 billion €. Because of the variations in GDP, to achieve this over 10 years, this would mean up to around 40% of national GDP invested in water treatment.

Investment cost challenge

Dr. Somolyody emphasised that despite the huge investments already made and planned, there is little learning from previous technical and administrative experience. Also, the administrative and institutional organisation is very complex in each country and is an obstacle to efficiency.

Elsewhere, the Global Water Partnership has indicated that even today, expenditures for water and wastewater range from nearly 7% of household income in Romania to around 1% in Slovakia (non EU-accession states not presented).

Affordability and financing are thus key issues for achieving objectives in waste water treatment in the Danube basin.

Jiri Wanner, Prague Institute of Chemical Technology, presented the example of the concerted management of the Elbe River, between the Czech Republic and Germany, through the Elbe River Commission.

Ivan Zavadsky, UNDP/GEF Regional Programme Director for the Danube and Black Sea areas, emphasised the ambition of the projects for improving water quality in the Danube and the Black Sea, and the international support for this. He indicated that the four key challenges are reducing agricultural pollution, investing to improve sewage treatment, prevention of industrial pollutant releases and developing a transport policy which respects the river's natural morphology.

Sustainable sludge management

Matthias Zessner, Vienna University of Technology, presented the issues of sustainable sludge management. Municipal waste waters contain 19,000 tonnesP/year of phosphorus, compared to a total of around 200,000 tonnes being cycled in Austria in sewage, manure, fertilisers and imported animal fodder. The proportion in municipal waste waters is higher for both nitrogen and for potassium, but the part retained in sewage sludge is much lower.

For phosphorus therefore, Dr Zessner concludes that phosphorus in sewage sludge, where phosphorus removal is installed in sewage works, are a significant potential resource for substituting mineral fertilisers (a limited primary resource). Nitrogen recycling could be possible through separative urine collection, but this is controversially appreciated.

The optimal route for sustainable sludge management is agricultural re-use of the sludge. In this case, the phosphorus limits the rate or application, that is the sludge should be treated as a P-fertiliser, and its value should be assessed by the ratio between phosphorus and contaminants. This emphasises the need to reduce contaminant levels in sewage sludge, in particular by reducing heavy metals in sewage. Where this has been pursued, eg. in Austria, then sludge application to agricultural soils will result only in very slow increases of heavy metals to soils, much less significant than inputs from other sources such as traffic deposition. An issue remains however with “unknown risks” from organic micro pollutants. No objective risks have been identified, but there is strong psychological opposition.

Because of this opposition to agricultural sludge reuse and current poor economic viability of phosphorus recovery for recycling, Dr Zessner recommends mono-incineration of sewage sludge (not mixed with other wastes) in order to generate an ash which can have up to 8% P-content, and can be landfilled separately and thus safeguards the P-resources for possible future recovery.

Achieving WFD objectives in Austria and Germany

Helmut Zoiss, Vienna University of Technology, presented the state of EU Water Framework Directive implementation in Austria. Today, 97% of Austria's population are connected to sewerage and to sewage treatment and Austria's water law dating from 1959 already set key public interest quality objectives.

A key issue placing many surface waters at risk of not achieving Good Ecological Status is that of river morphology, and funds are now being made available for river morphology restoration.

Regarding sewage treatment, after the upgrading of the Vienna sewage works, currently coming on line, little construction of sewage works capacity remains to be built in Austria, except for small sewage works.

Key issues appear as costs of operation, with important work already launched into cost benchmarking and training of sewer and sewage plant operators. Operating costs are 2-3 x higher per capita for small sewage works (<12,000 pe) than for large plants (>50,000). For larger plants, only a small part of costs is related to treatment mode, and around one third of costs are for sludge treatment and disposal and one third for administration and monitoring of the plant.

Austria has required phosphorus discharge limits of 1.5 mgP/l for small sewage works (>1,000 pe) since 1996, 1 mgP/l for larger plants.

Jens Jedlitschka, Bavaria State Ministry for the Environment, indicated that in Germany also water law dates back many years, to 1957. In the Danube catchment, 93% of the population is connected to EU-legislation conform waste water treatment, including phosphorus removal in all plants >10,000 pe: although this territory is not classified "sensitive area" the phosphorus removal is in any case obligatory under existing German legislation. Two large sewage works in the catchment in Germany are not yet conform to requirements for phosphorus removal, but this will be resolved within 1-2 years.

In the Danube basin part of Germany, approximately one third of water bodies are at risk or possibly at risk of not achieving Good Ecological Status because of nutrient enrichment, mainly because of diffuse nutrient emissions from agriculture, compared to 2/3 at risk or possible risk because of morphological modifications.

Total investment in sewage treatment in Bavaria over the last 50 years represent around 30 billion €. Some investment needs to continue to be made in small sewage works and in improvement of separative storm overflows, as well as in improvement of control and maintenance of autonomous domestic waste water treatment systems (septic tanks).

Erno Fleit, Budapest University of Technology and Economics, estimated at 4 billion € the investments needed in sewage treatment in Hungary. At present, only around 60% of the population is connected to sewage treatment, and only around one third of collected sewage is treated conform to EU legislation.

Domestic water pricing has increased by around 10x since the early 1990s with consequently a near halving of domestic water consumption. This reduction has led to technical issues including increased residence times in sewers, overcapacity of sewage works or designs not adapted to increased waste water concentration.

Miloslav Drtil, Slovak University of Technology, summarised the situation in the Slovak Republic. Sewage treatment with nutrient removal is required in the whole country for all agglomerations > 10,000 persons by 2010, conform to classification of the whole territory as a "sensitive area". This corresponds to the request by the ICPDR to classify the whole Danube catchment as a "sensitive area" and to remove both nitrogen and phosphorus. However, today only approximately half of the population is connected to sewage treatment, and at least half of existing sewage works will need upgrading or reconstruction by 2010 to achieve this. Total cost is estimated at 2.5 billion €, of which 65% is expected to be covered by EU funding.

Necessity and cost of "sensitive area" classification

In concluding remarks, several speakers emphasised that the whole Danube catchment must be classified as a "sensitive area" under the EU Waste Water Treatment Directive 91/271, in that both the lower Danube in Romania and the Black Sea are nutrient "sensitive areas", at least when Romania enters the EU (the Directive obliges classification as a "sensitive area" of waters flowing across a national border from one Member State into a "sensitive area" in another Member State).

The relatively low cost of ensuring nutrient removal in sewage works, compared with overall sewerage and sewage treatment compliance costs, was underlined. Dr Zoiss estimated nutrient removal as 5-10% of operating costs (including annualised capital costs) for large sewage works, and as a negligible additional cost for smaller sewage works (where best practice treatment implies configurations where nutrient removal can be included).

"Wastewater treatment and WFD implementation in CEE Danube countries", ACE – EWA – IWA – Global Water Partnership Conference, Bratislava, 1-2 December 2005.
http://www.acesr.sk/kalendar.aspx?id=133
Contact: jan.derco@stuba.sk

Book review

Importance of zooplankton in eutrophication control

"Eutrophication management and ecotoxicology" (Springer Verlag Berlin 2005) summarises current knowledge regarding the key role played by zooplankton grazing in controlling algal growth and presents some to date unpublished experimental results. It is increasingly recognised that the reaction of ecosystems to nutrient loadings is very variable, and that grazing of algae (phytoplankton) by zooplankton (in particular cladocerans such as daphnia) plays a key role. A healthy population of grazer zooplankton can convert increased primary production (algal development) "up" the food chain to increased fish production, without detrimental environmental impacts, whereas damage to the grazer zooplankton population (because of excess stocking of small fish, loss of macrophyte plant shelter, or poisoning by pollutants) can cause algal blooms to develop in an ecosystem which has previously been balanced. In particular, factors affecting zooplankton grazing can cause a step change (switch) in a water body from a situation with good water status to one with manifest symptoms of eutrophication (algal blooms, turbidity), for which restoration can be difficult (see previous literature by Moss et al. SCOPE Newsletter n°29)

The 122 page book "Eutrophication management and ecotoxicology" (Scholten *et al*., Springer Verlag Berlin 2005) presents a summary of knowledge regarding eutrophication and ecosystems (in particular trophic cascades), distinguishing between "eutrophication" *senso alto* (eutrophicated or eutrophied), that is surface waters showing quality status deteriorations (algal blooms, ecosystem unbalance …) and eutrophication *senso stricto* (eutrophic waters), that is waters receiving increased nutrient loadings, showing that eutrophic waters are more likely to become eutrophied but not certain to do so (shift in probability distribution). The "Vollenweider" model (OECD) developed for deep upland lakes is presented: this has in the past been used to show a link between increased phosphorus concentrations and eutrophication symptoms, but in fact shows a broad variation in the relationship between the two parameters (factor of 10 at 99% confidence even on a log scale). Many eutrophic waters exist with low algal densities, and vice-versa.

Zooplankton

The introductory section then explains how zooplankton grazing of algae (top down control), with balanced food chains, can be a key factor in enabling waters to remain in good quality status, with high transparency and without algal blooms, even when nutrient concentrations increase. Cladocerans such as daphnia are particularly effective grazers in controlling eutrophication symptoms, because of their large size and indiscriminate grazing, and because they contribute to reducing phosphorus available for algal growth (cladocerans have a relatively high body N:P ratio and are effective are thus retain phosphorus, also their excrement is solid and will tend to sediment so removing phosphorus from the available water cycle).

A chapter summarises knowledge of daphnid grazing ecology, including both literature information and previously unpublished experimental results showing daphnid grazing rates on algae and illustrating how, in aquatic systems, effective daphnid grazing can control development of algae whereas algal blooms can result in the absence of daphnid grazing with the same nutrient levels.

The experimental results published are from work carried out by TNO The Netherlands, University of Alicante Spain, and Université de Savoie France.

In 3000 litre enclosures in a Spanish reservoir and in laboratory mesocosm and microcosm assays, for example, daphnids were able to effectively limit algal development (chlorophyll increases). In some cases, development of algae could clearly be seen to be inversely proportional to the number of daphnids. In other cases, the algal development showed to be faster than the grazer response, with 5-10 days being necessary for the daphnids to bring chlorophyll levels back down after an initial algal bloom (in this case at 0.15 mgP/l, N:P ratio of 22).

Effects of toxic pollutants

Toxic pollutants reaching surface waters may thus enable algal blooms or development of eutrophication symptoms, by eliminating zooplankton grazer populations. Cladocerans are in particular considered to be sensitive to a wide range of pollutants.

A number of literature sources suggest that in sub-lethal concentrations, toxicants may not only inhibit daphnia reproduction, but also may reduce feeding rates (toxic anorexia). Experimental results are presented (TNO The Netherlands) showing that in some cases sublethal concentrations of toxicants added to mesocosms can result in increased algal development (presumably because of effects on daphnia grazing), despite their toxic effect on the algae (the daphnia are more sensitive to the toxicant than are the algae).

Grazing in two lakes

Data from two similar lakes in The Netherlands are presented: Lake Geestmerambacht and Lake Amstelmeer. Despite similar nutrient levels and daphnid presence in both lakes, algal development in the two lakes has been very different, with Geestmerambacht showing clear water and Amstelmeer showing algal blooms. The authors suggest that the different lake response to nutrients is related to sublethal inhibition of daphnid grazing in Amstelmeer, possibly resulting from pesticide contamination or from slight salinity in this lake.

Water management

The authors suggest that a better appreciation of zooplankton grazing, in particular cladocerans, provides a "new dimension for lake eutrophication management". Sublethal levels of toxic pollutants at levels susceptible to impact daphnia, occur in many surface waters, in particular pesticides, and should be taken into account in management. Reduction of grazing can enable a switch (hysteresis) to a eutrophicated state (turbidity, algal blooms), which then feeds back to effects such as loss of macrophytes which make recovery difficult.

"Eutrophication management and ecotoxicology", M. Scholten, E. Foekema, H. Van Dokkum, N. Kaag, R. Jak, TNO-MEP, PO Box 57, 1780 AB Den Helder, The Netherlands h.vandokkum@mep.tno.nl *. Including results from experimental work by TNO The Netherlands, G. Blake andn B. Clément, Université de Savoie (ESIGEC) France and D. Prats, P. Hernandez, J-C Asensi, M-J. Navarro, L. Rull, University of Alicante Spain, funded by CEEP (Cefic).*

Springer Verlag, Berlin, Germany, 2005 (Environmental Science series). 122 pages. ISBN 3-540-22210-3 www.springeronline.com

Summaries of previous studies concerning zooplankton control of algal development in SCOPE Newsletters on www.ceep-phosphates.org *:*

n°61, page 6, Mazumder & Havens

n°48, page 8, Kasprzak et al., Schoenberg et al.

n°45, page 15, Elser et al.

n°39, page 8, Grigorsky et al.

n°33, page 6, Spencer and page 6, Murdoch et al.

n°30, page 3, Foekema et al

n°29, overview 45 pages, "Shallow lakes biomanipulation and eutrophication", Moss

n°26, page 5, Norfolk Broads Authority, UK

The Scope Newsletter

The SCOPE Newsletter is produced by the Centre Européen d'Etudes des Polyphosphates, the phosphate industry's research association and a sector group of CEFIC (the European Chemical Industry Council).

The SCOPE Newsletter seeks to promote the sustainable use of phosphates through recovery and recycling and a better understanding of the role of phosphates in the environment.

The SCOPE Newsletter is open to input from its readers and we welcome all comments or information. Contributions from readers are invited on all subjects concerning phosphates, detergents, sewage treatment and the environment. You are invited to submit scientific papers for review.

The SCOPE NEWSLETTER is produced by CEEP - a sector group of CEFIC,
avenue E. Van Nieuwenhuyse 4, bte 2, B1160, Bruxelles - Belgium.
Tel: (32) 2 6767211 Fax: (32) 2 67673 01 E-Mail: cja@cefic.be *www.ceep-phosphates.org*
The SCOPE Newsletter is circulated, free of charge, electronically :
to receive it or to unsubscribe: *http://www.ceep-phosphates.org/subscribe.htm*

cefic

CEEP
Centre Européen d'Etude
des Polyphosphates