SCOPE NEWSLETTER

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Phosphorus flows

Sewage treatment

Sources of phosphorus in municipal sewage

Estimating the amount of phosphorus of different source origins in municipal sewage is important for deciding and costing appropriate actions to reduce emissions to the environment

Sweden

Changes in phosphorus flows

A study in Linköping, Sweden, shows how per capita phosphorus flows have changed from 1870 to 1900 to today.

Phosphorus in surface waters

FATE

Impact of agricultural nutrients on the environment

The European Commission has published an assessment of nitrogen and phosphorus pressures on river basins in Europe, an "Atlas" of pressures from agricultural nutrient releases on eco-systems.

Shallow Mediterranean Lake

Obstacles to recovery from eutrophication

Despite sewage diversion and a resulting considerable reduction in phosphorus loads, Lake Pamvotis, Greece, remains eutrophic 8 years later.

England

Estimating phosphorus loads in rivers

Data from 17 UK catchments were used to assess the errors in river phosphorus loads resulting from different sampling frequencies and estimation methods

Illinois

Nutrients, chlorophyll and algae in streams

Chlorophyll and algal biomass are not related to nutrient concentrations in Illinois small rivers and streams. Agricultural nutrient run-off loads are mainly related to high flow events.

Website

Peak Phosphorus

Sustainable Phosphorus Futures

A new website presents the issue of finite phosphate resources and the need to move towards P-recycling.

Conferences

International Conference on

Nutrient Recovery from Wastewater Streams

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

Including technical visits to full-scale struvite recovery installations operating in municipal sewage works in Canada, USA, and to stream and reservoir fertilisation project.

Summary programme see back page.

Registration, full programme, etc:

www.phosphorus-recovery.tu-darmstadt.de

Covaphos III, Marrakech, 18-20 March 2009

Third International Conference on the 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 treatment

Sources of phosphorus in municipal sewage

The implementation of the EU Water Framework Directive (proposal of action plans) and of the EU Waste Water Treatment Directive (P-removal from sewage works serving conurbations of more than approx 6,000 population in potentially eutrophication susceptible areas) is requiring Member States to reassess nutrient management policies, and in particular municipal sewage works P-removal. In order to both define appropriate policies, and to assess their cost-effectiveness, it is important to apportion the phosphorus in municipal sewage to different sources, between human body emissions (faeces and urine), detergents, domestic food wastes, other household inputs, and small industry and commerce discharges into municipal sewers.

Figures from the UK water industry [1] indicate total phosphorus load to UK municipal waste water treatment plants of 143 tonnesP/day and average water consumption per capita of 245 litres/per capita/day, that is average total-P concentration in raw sewage of around 10 mgP/l and so **approx 2.4 gP/person/day total phosphorus in sewage reaching municipal waste water treatment works, or 2.6 gP if storm tanks are included**.

Apportioning sources of phosphorus

The 8 year work of the society of German chemists, published in the books edited by Bernhardt [13] (272 pages) and Hamm [9] (395 pages) concluded that 2.8 gP/person/day reach sewage works, of which 30% detergents in 1987 (the figure is significantly lower today), that is **a P-content in sewage of 1.96 gP/person/day** without detergents. This is excluding waste waters affected by commercial and industrial discharges. A similar figure of 1.9 g (without detergents) was obtained by measurements in new sewage connections in Berlin (same sources).

One difficulty in phosphorus source apportionment is the assessment how many households are really connected to the sewerage network, and of the “loss” of phosphorus in the sewerage network. The Béture Cerec study (6 catchments in France [18]) concluded that 37% of P coming out of households in sewerage did not reach the sewage works because of: houses not connected (eg. with autonomous treatment / septic tanks), misconnections, leakages out of sewer piping.

Geoplus [17] examined 4,112 data points from 3 water authorities covering half of France and a number of other administrations, assessing P from sewage works inflow data, number of connected population from census data, municipal connection data and then carrying out a verification by comparison with BOD (P/BOD ratio) data. They concluded, after subtracting known detergent phosphate usage, the following apportionment of phosphorus sources to municipal sewage:

- Human body emissions 1.2 – 1.6 gP/person/day
- Food wastes and other domestic (non detergent) 0.3 gP/person/day
- Loss in sewers and non-connection of households to sewerage: 37%
- Domestic sewage (non detergent) reaching sewage works, calculated from above = 0.9 – 1.2 gP/person/day
- Commercial and small industry phosphorus emissions arriving at urban sewage works 1.2 – 2 gP/person/day (compared to population)
- Total phosphorus reaching municipal sewage works (after 37% loss, and without detergents): 0.75 gP in rural areas, 1.95 – 2.75 gP/person/day in urban areas.

Phosphates from households

Phosphorus in sewage comes mainly from human body emissions (urine and faeces). However, phosphorus also comes from detergents (when these are phosphate based) and from other sources, in particular food wastes (food particles and traces removed in hand or machine washing of tableware and in preparation of food, liquid food wastes poured down the drain …).

Reliable figures are available for levels of **P in faeces and urine**. The total of these emissions from the body will correspond to available figures on P in human diets (approximately 1% is retained in the body on average [2]). Total emissions vary from 0.8 to 2 gP/person/day depending on the country being higher in developed countries Approximately 2/3 of human bodily phosphorus emissions are in urine and 1/3 in faeces. **A figure of 1.5 – 1.6 gP is generally accepted for Europe** (total faeces plus urine).

Some published figures
for human metabolic phosphorus emissions:
In gP/person/day

- Henze [3] = 2 gP
- Eastham [4] = 0.5 – 1.5 gP in urine plus 0.4 – 0.8 gP in faeces.
- Gleisberg [5] = 1.6 gP
- Swedish default values [6] = 1.5 gP
- SNV [8] = 1.5 gP
- Hamm [9] = 1.6 gP
- Jönsson [7] (based on both measurements and Sweden diet figures) = 1.4 gP
- Hellström and Kärrman [11], analysed P in urine from 30 adults, showing an average of 1gP/person/day (in urine only). Based on other literature, they conclude a total (urine plus faeces) of 1.3 gP/day for adult women and 1.5 - 1.8 gP/day for adult men.
- Schmid Neset [2] indicates how the figure for Linköping city, Sweden, has increased from 1.17 gP/person/day in 1870 to 1.56 gP in 2000.
- Jönsson [10] indicates a range of figures for different countries across the world:
  - China 1.6 gP/person/day,
  - Haiti 0.8 gP,
  - India 1.1 gP,
  - South Africa 1.4 gP,
  - Uganda 1.1 gP

Detergents

The contribution of detergents to municipal sewage phosphorus will depend on whether phosphates are used or not, and their respective market share, in laundry and machine dishwashing detergents. Hand dishwashing liquids do not usually contain phosphates. This contribution is thus very different depending on local regulation and market, but is well known because the detergent industry has sales figures.

The EU detergent industry provided figures for per person consumption of phosphorus in detergents for each EU Member State in 2004 (published by the EU Commission [12]), with **an EU average of 0.36 gP/person/day from detergents**. Similar figures (0.3 gP/person/day) were submitted by the detergent industry during public consultation for the UK for 2008.

Food wastes and dirt from washing

Another significant but less well measured contribution of phosphorus to domestic sewage is from food wastes, dirt and soil on washed dishes, on washed clothes, and released during personal washing (in bath, shower and washbasin waters).

Bernhardt [13], in an 8 year study of phosphorus cycles and routes in Germany carried out by the German Water Chemists association, calculated that human foods (that is foods produced) contain 3.5 gP/p/day, of which 1.9 g goes to liquid wastes (total through the human body metabolism and in food wastes) and the remainder to solid waste streams. Given the figure of approx. 1.5 gP in human metabolism, this means **0.4 gP/person/day in food wastes going to sewage**.

Food wastes and washing soils: *In gP/person/day*

Henze [3]:
- 0.2 gP/person/day from kitchen liquid wastes
- 0.1 gP from dirt on laundry
- 0.2 gP from bathwater

Gleisberg [5]
- 0.3 gP/person/day from food wastes
- 0.2 gP from soil on laundry and household dirt

Metzner 2001[14]:
- 0.1 – 0.3 gP/person/day from food residues
- 0.1 gP from laundry soil

Hamm [9] :
- 0.3g from food wastes
- 0.1g from dirt from washing

Nelson (BARR) [15] (Minnesota, USA):
- 0.52 gP/person/day, of which 25% is from garbage disposal units, that is 0.4 gP/person/day if garbage disposal units are excluded.

Other domestic and municipal sources

Various authors suggest approx 0.1 gP/person/day from **other sources** including toothpastes, phosphate treatment of drinking water to prevent lead solubility (can be very significant locally where applied), background levels in drinking water, organic materials in run-off from roads and pavements in mixed rainwater / sewage collectors (in particular in animal urine and faeces).

Other municipal sources:
In gP/person/day
Metzner 2001[14]:
- 0.01 gP/person/day from drinking water treatment (national average for Germany)
- 0.07 gP from urban run off

Hamm [9]:
- 0.022 gP from drinking water treatment

Bernhardt [13]:
- 0.5 gP/person/day in Berlin 1969 (page 72)

Industry and offices

To the household sources cited above reaching municipal waste water treatment works must be added the phosphates in sewage from industries, offices, restaurants, hospitals etc. These include both phosphates from human metabolism (already accounted for above) and industrial discharges.

Large industrial phosphorus discharges (eg. fertiliser factories) are well identified and generally do not input into domestic sewage works.

Phosphorus inputs to domestic sewage from **small industries (in particular food preparation industries), offices, schools, restaurants … are however significant.**

Small industry and commercial phosphorus sources
- Bernhardt [13], page 74, estimated food industry and commercial discharges of P to sewage at 0.9 gP/person/day for Germany.
- Metzner [16] citing ATV-DVWK 2003 indicates 1.2 gP/person/day (updated from a figure of 0.3 – 0.5 in Metzner [14])
- Geoplus [17] indicate a difference of 1.2 – 2 gP/person/day, attributable to commercial and small industry connections, between loads arriving at urban sewage works with mainly domestic or significant industry connections, compared to smaller rural sewage works.

[1] Atkins Ltd, RPA, University of Abertay Dundee, 2007: "Interim report: draft impacts and sources of phosphorus to sewer", see table 6.5, page 35 and text page 34.

[2] T-S. Schmid Neset, 2008: "The flow of phosphorus in food production and consumption – Linköping, Swede, 1870-2000", Science of the Total Environment, 396, pages 111-120.

[3] M. Henze, 1998: "Waste design for households with respect to wastewater and solid waste", Asian conference on Water and Wastewater Management, Teheran 2-4 Marc 1998. Dept. Environmental Science, Technical University of Denmark, Lyngby, Denmark.

[4] R. Eastham, 1985: "Biochemical values in clinical medicine", 7th edition, ISBN 0 7236 0820 2.

[5] D. Gleisberg, 1995: "Zur Entwicklung des Phosphorentfernung aus Abwässern der Bundesrepublik Deutschland" (On the development of phosphorus removal from sewage in the Federal Republic of Germany), Korrespondenz Abwasser 6/95.

[6] B. Vinnerås, 2002: "Possibilities for sustainable nutrient recycling by faecal separation combined with urine diversion", Agraria 353, Acta Universitatis Agriculturae Sueciae, Swedish University of Agricultural Sciences.

[7] H. Jönsson, 2005: "Composition of urine, faeces, greywater and biowaste for use in the URWARE model", MISTRA Programme Report 2005:6

[8] SNV, 1995: Swedish NaturvardsVerket (Swedish EPA) "Vad innehaller avlopp fran hushall", rapport 4425

[9] A. Hamm, 1989: Auswirkungen des Phosphat-Höchstmengenverordnung für Waschmittel auf Kläranlagen und in Gewässern, conclusions of the Phosphates and Water committee of the Water Chemistry Group of the Society of German Chemists work from 1979 to 1987, published by Academia Verlag, St Augustin, ISBN

3-88345-377-3. Extracts at www.ceep-phosphates.org under Documents -> Environment.

[10] H. Jönsson 2004 : H. Jönnson, AR Stinzing, B. Vinneras, E. Salomon, Guidelines on the use of urine and faeces in crop production, Ecoscan report 2004-2

[11] D. Hellström, 1996: "Nitrogen and phosphorus in fresh and stored urine", Environmental Research Forum, vols. 5-6, pages 221-226, Transtec Publications Switzerland.

[12] B. de Madariaga, 2007: "Development of an European quantitative eutrophication risk assessment of polyphosphates in detergents", Spanish National Research Institute INIA, published by the EU Commission http://ec.europa.eu/enterprise/chemicals/legislation/detergents/studies/ceep_final_study_april_2007.pdf

[13] H. Bernhardt, 1978: "Phosphor. Wege und Verlieb in der Bundesrepublik Deutschland. Probleme des Umweltschutzes und der Rohstoffversorgung. Herausgegeben vom Hauptausschuss 'Phosphate und Wasser' der Fachgruppe Wasserchemie in der Gesellschaft Deutscher Chemiker im Auftrag des Bundesministeriums des Innern durch den Obmann des Fachausschusses Heinz Bernhardt" (Phosphorus. Flows and stocks. The problem of nutrient management and environmental protection. Report of the working team of the 'Phosphate and Water' Main Committee of the Society of German Chemists on request of the Federal Interior Ministry. Coordinated by Heinz Bernhardt.). Extracts translated at www.ceep-phosphates.org under Documents -> Environment.

[14] G. Metzner, 2001 and 2006: "Phosphates in municipal wastewater" Tenside surfactants detergent, 38(6) pages 360-367.

[15] N. Nelson, 2004: BARR Technical Memorandum, to Minnesota Pollution Control Agency, Project: 23/62-853 POTW 010, February 16th 2004, http://www.pca.state.mn.us/publications/reports/pstudy-appendix-b.pdf

[16] G. Metzner, 2006:"Phosphate aus Wasch- und Reinigungsmitteln im kommunalen Abwasser der Bundesrepublik Deutschland" http://www.gdch.de/strukturen/fg/wasch/had/phosphate.pdf

[17] Geoplus, 2000: "Etude du phosphore. Proportion du phosphore issu des détergents dans les eaux continentales. Phase 1.Réévaluation du ratio équivalent-habitant en phosphore"(Sources of phosphorus to surface waters: comparing calculated with measured P loadings for three French rivers). www.ceep-phosphates.org *under Documents -> Environment.*

[18] Béture Cerec, 1997: "Evaluation de la distribution des concentrations des substances composant les détergents dans les eaux superficielles", Comité Environnement-Détergents, France.). www.ceep-phosphates.org *under Documents -> Environment.*

Sweden

Changes in phosphorus flows

The cycling of phosphorus in agriculture, human diet, industry and in the different routes between these sectors is assessed for the Linköping area (South East Sweden, Lake Roxen and Baltic Sea catchment) for 1870, 1900 and today. In 1870, nearly all phosphorus contained in the human diet came from local agriculture and was recycled back to local agriculture, with a per capita dietary intake of 1.2 gP/person/day. In 2000, only around 20% of human dietary phosphorus is returned to agriculture (nearly 80% goes to landfill in sewage sludge). Dietary phosphorus intake has increased by >25% to 1.6 gP/person/day. 40% of food consumed in Sweden today is imported. The authors estimated that P-recovery from sewage could replace around one quarter of the mineral fertiliser necessary to produce food needs for the current average Linköping diet, or a higher proportion for a meat-free diet.

Linköping is today Sweden's fifth largest city with a population of over 130,000 persons, of which 94,000 are in the inner city, whereas in 1970 there were only 7,300 inhabitants. The study is based on **a wide variety of sources of phosphorus** including studies on hospital diets, local agriculture, sewage treatment, and various sources of Sweden statistics, with application of a dynamic model designed to take into account the wide error margin, particularly in the historic data, using the computer model SIMBOX and 85 parameters.

Changes in agriculture and diet

In 1870, the phosphorus flows from plant production to animal production in agriculture (crops used for animal feed = fodder) were 3.4 kgP/year/capita, and the flow from animal to plant production (farm recycling of manures) was 2.5 kgP. Loss of phosphorus from agriculture was estimated at 0.08 kgP, compared to atmospheric deposition on agricultural land of 0.25 kgP. Approximately 0.3kgP from local animal productions and 0.26 gkP from local plant production went into the human diet, with a very low input from imported foods, giving (after an average 1% retention in the human body) an estimated 0.43 gkP/person /year (**1.2 gP/person/day**) in human urine and faeces.

In 1870, 86% of this human P emission was estimated to be returned to agriculture, with 14% lost to surface waters.

By 1900, the situation had changed little. Dietary phosphorus had increased to 0.49 kgP/person/year, agricultural production had increased somewhat (fodder 3.9 kgP/capita) and some animal products were going to industrial processing such as dairies (0.4 kgP). Human dietary phosphorus continued to be mainly recycled to agriculture (nightsoil collection), but already the construction of a sewer system had started and 0.15 kgP/person/year was being lost to surface waters.

Sewage treatment

The largest changes occurred from the 1950s, when **centralised sewage treatment** was installed with collection of sewage from 90% of inhabitants. Dietary phosphorus had reached 0.53 kgP/person/year, of which 0.48 kg was now going to the local river Stanga, and then into Lake Roxen and ultimately the Baltic Sea.

By 2000, **P-removal was installed at the sewage works**. Per capita dietary phosphorus intake (and emission to sewage) had increased to 0.57 kg/person/year (**1.6 gP/person/day**) of which 0.43kgP/person/year goes to landfill (sewage sludge), 0.017 kgP only is lost to surface waters and 0.12 kgP only is recycled to agriculture.

Agricultural P flows have also changed considerably, with now 2 kgP/person input to agriculture from mineral fertilisers, 3 kgP fodder from plant production into animal production, and a return flow from animal to crop production (manure recycling) of only 1.8 kgP/person/year.

Food, diet and P-recycling

Whereas in 1870 and 1900 only an insignificant proportion of food consumed in Sweden (and so P in diets) was imported, by the 1950's some 14% of Sweden's food was imported, rising to **39% of phosphorus imported in 2000** (by % weight). If calculated instead by the agricultural area necessary to produce the food, then the proportion of imported food in 2000 is around 60%. Around 0.5 – 0.61 hectares are required in 2000 to produce one Linköping person's food needs.

The authors estimate that some 50 – 55 tonnes of phosphorus (P) could be recovered from sewage if P-recycling were developed, sufficient to replace around one quarter of mineral fertiliser consumed to produce Linköping's food consumption on the basis of the current average diet, or a higher proportion in the case of a meatless diet.

"The flow of phosphorus in food production and consumption – Linköping, Sweden, 1870-2000", Science of the Total Environment, 396, 2008, pages 111-120.
www.elsevier.com/locate/scitotenv

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Phosphorus in surface waters

FATE

Impact of agricultural nutrients on the environment

The maps of nutrient pressures on European eco-systems and the assessment of nitrogen and phosphorus sources to main European river basins, published by the European Commission, is the result of the FATE (Fate of Agrochemicals in Terrestrial and Coastal Ecosystems) research programme, carried out in the Rural, Water and Ecosystem Resources Unit (RWER) of the Institute for Environment and Sustainability (IES) within the European Commission's Joint Research Centre (JRC). A three tiered modelling approach is used to identify river basins with high nutrient losses, understand processes and pathways of nutrient loss, and elaborate appropriate farming practices to reduce nutrient load. The study identifies areas in Europe with high nutrient pressure, which include large parts of The Netherlands, Denmark, France, Ireland and Italy, and demonstrates the very wide range of nutrient surpluses in different intensive agriculture areas of Europe. A close link is shown between increased nutrient pressures and high-density livestock production.

The modelling of nutrient load is based on river characteristics, soil type, land cover and use (in particular arable crop type and area), meteorological data (precipitation, temperature), irrigation, and nutrient sources. Diffuse nutrient sources, and in particular agricultural fertilisers and manures, and point sources (sewage works, industrial discharges) are examined for both phosphorus and nitrogen.

Sewage works and scattered dwellings nutrients discharges were estimated from statistics on population density, population connected to waste water treatment, and the type of treatment installed (6). In both cases, this resulted in an approximate figure of kgN/hectare or kgP/hectare for 100km squares.

Agricultural nutrient pressure

In (2), an analysis of nutrient pressures from agriculture is developed, by spatialising official European statistics on agriculture: crop distribution (FSS Farm Structure Survey, CLC Corine Land Cover, LSU Livestock Units data), nitrogen and phosphorus mineral fertiliser application, manure application, N and P balances in soils.

Results show very variable gross nutrient balances per hectare (national averages): more than 270 kgN/ha/year The Netherlands and nearly 200 for Belgium, compared to below 60 for France, Austria, and the UK; over 25 kgP/ha/year for Belgium and The Netherlands compared to lower than 13 for other countries. However, because of country size Germany and France show the highest gross agricultural nitrogen balances (both over 1 500 000 tonnes N/year), and Spain and France the highest gross agricultural phosphorus balances (both over 200 000 tonnes P/year). European maps of N and P input per hectare in mineral fertilisers and in manure are provided, and maps of overall agricultural input and gross agricultural nutrient balance, calculated at the 10 kmx10km grid. Phosphorus and nitrogen source apportionment

In (1), the estimation of nutrient pressures starts from a model, developed by the EU JRC (GREEN: Geospatial Regression Equation for European Nutrient Losses). **This relates nutrient loads to spatially referenced point sources and to river basin characteristics**, and is based on the SPARROW model. The GREEN model is used as a screening tool to identify catchments with potentially high nutrient losses, susceptible to risk deteriorating water quality status.

Per capita phosphorus in raw sewage was estimated to be 2.5 gP/person/day, before sewage treatment (based on OSPAR Guideline 4, 1999). Phosphorus removal levels of 20% for primary treatment sewage works, 30% for secondary treatment and 90% for tertiary treatment were used (based on EEA Dobris Assessment, 1995). Emission levels from scattered rural populations were estimated as 1.2 gP/person/day (OSPAR Guideline 5), that is approx. 50% of per capita P in raw sewage.

Nutrient discharges from industrial sources, paved and unpaved urban areas, scattered populations, atmospheric deposition, and diffuse sources related to manure and fertiliser application and to river basin characteristics were estimated.

Seven major river basins were modelled: the German part of the Danube, Rhine, Elbe, Weser/Ems, and the Meuse, the Seine and the Rhône. Municipal sewage was found to be the main source of soluble phosphate (PO_4-P) in all of these basins except for the Danube.

Phosphorus retention in the river systems was estimated as varying from 10-15% in the Elbe and Weser/Ems catchments, to around 20% in the Danube, and nearly 40% in the Rhône.

Modelling difficulties

Overall, the study found better modelling results for nitrogen than for phosphorus. **Diffuse phosphorus sources were underestimated by the model in the German river systems, except for the Danube**, possibly because the high level of P-removal installation in municipal sewage systems led to an overestimate of this source of phosphorus. In river monitoring data necessary for calibration is very difficult to obtain. Modelling data are generally scarce and non homogenous, and diffuse nutrient emissions vary in space and time. Also, the model does not take into account nutrient build up in soils.

Atlas and applications

The **parallel publications referenced below** provide (3) an atlas of European level maps of relevant catchment characteristics, such as fertiliser use, population density, catchments, rainfall, land use … ; (4) detailed application regarding nitrates in the Loire river and ground waters, France ; (5) application of the EPIC model to study the impact of future climate changes on crops water and nutrient requirements.

EU Commission press release IP/07/576 dated 26th April 2007:
http://europa.eu/rapid/pressReleasesAction.do?reference=IP/07/576&format=PDF&aged=1&language=EN&guiLanguage=fr

(1) Grizzetti B. and Bouraoui F. "Assessment of Nitrogen and Phosphorus Environmental Pressure at European Scale" EU JRC-IES 2006:
http://ies.jrc.cec.eu.int/fileadmin/Documentation/Reports/RWER/EUR_2006-2007/EUR_22526_EN.pdf

(2) Grizzetti B., Bouraoui F., Aloe A., " Spatialised European Nutrient Balance", EU JRC-IES 2007, not yet available in electronic format

(3) Mulligan D , Bouraoui F., Grizzetti B., Aloe A., Dusar J. "An Atlas of pan-European data for investigating the fate of agrochemicals in terrestrial ecosystems" European Commission Joint Research Centre – IES Institute for the Environment and Sustainability 2006.
http://ies.jrc.cec.eu.int/fileadmin/Documentation/Highlight/FATE_Atlas_compressed.pdf

(4) Bouraoui F., Grizzetti B.,,Mulligan D. "Fate of Agrochemicals in Terrestrial Ecosystems; An Integrated Modelling Framework: Application to The Loire (Fr)" EU JRC-IES 2006:
http://ies.jrc.cec.eu.int/fileadmin/Documentation/Reports/RWER/EUR_2006-2007/EUR_22518_EN.pdf

(5) Bouraoui F., Aloe A., "European Agrochemicals Geospatial Loss Estimation: Model Development and Applications" EU JRC-IES 2007, not yet available in electronic format

(6) Grizzetti, B., 2006. "Modelling nitrogen and phosphorus fate from point and diffuse sources at European scale". Thesis of Université Pierre et Marie Curie - Paris 6. Paris, France. pp.192.

Shallow Mediterranean Lake

Obstacles to recovery from eutrophication

Lake Pamvotis, near Ioannina, Western Greece, is a 23 km² shallow lake with an average depth of 4.3m and approximately 10 month hydraulic residence time, situated 470m above sea level on the flanks of the Pindus Mountains. The lake is an internationally important biodiversity conservation site under the EU Habitats Directive. The lake's trophic state deteriorated considerably during the late twentieth century as a consequence of sewage discharges from Ioannina (150,000 population), agriculture (40% of the lake catchment, with increasing intensification and high fertiliser use) and irrigation.

In the 1970's, submerged vegetation (mainly Myriophyllum spicatum and Potamegon sp) totally covered the lake bed. In 1986, several species of planktivorous and hervbivorous fish were introduced into the lake, and common carp (Cyprinus caprio) was also repeatedly re-stocked. In the 1990's, several studies showed a decrease in submerged plant (macrophyte) diversity, from 25 to 5 species, and of abundance.

20 year study

This paper is based on surface water sample analysis from the period 1985 – 2005, including nutrients (SRP, nitrate, nitrite, ammonium), chlorophyll and physico-chemical parameters, from five sampling stations, plus hydrological and morphological monitoring data.

Before sewage diversion in 1995-1996, dissolved inorganic nitrogen and phosphorus were respectively around 1.4 – 2 mg/l DIN and 0.8 – 2.8 mg/l SRP, suggesting nitrogen limitation.

The diversion of Ioannina's sewage away from the lake resulted in considerably reduced external nutrient loads. This was reflected in in-lake soluble phosphate concentrations which decreased by around

87% immediately after the sewage diversion, but rose again somewhat by 2005. Nitrates fell significantly after sewage diversion, and continued to do so through to 2005, and total dissolved inorganic nitrogen also showed a weak downward trend. Ammonium concentrations have tended to increase.

Chlorophyll$_{-a}$ concentrations fell significantly following sewage diversion, but rose again by 2005 to levels even higher than in the 1980's. **No significant correlation, over the whole period, was found between chlorophyll$_{-a}$ and dissolved phosphate concentrations**.

Internal loading

SRP concentrations in Lake Pamvotis are 3 – 4 x higher in summer than in winter, indicative of **internal recycling of phosphorus** from sediments and biomass to the water column. This is accentuated by **resuspension of sediments** induced by wind and by lake bottom currents.

The **introduced and restocked fish** are largely bottom feeding, and contribute to internal loading by direct recycling of nutrients, by stirring up sediments, and by destruction of lake bed vegetation which stabilises sediments.

The authors note that Lake Pamvotis remains eutrophic / hypereutrophic. This may be because in-lake phosphate concentrations remain high enough to not effectively limit algal development, despite sewage diversion, because of internal loading, and because of nutrients from agriculture. **Lake recovery ("switch" to good water quality conditions) may be prevented by the fish populations.**

Certain interventions to reduce internal loading are rejected by the authors as probably not feasible. The introduction of piscivorous fish (to control herbivorous and planktivorous fish populations) would pose unknown risks for endangered endemic species important for biodiversity. Sediment removal could worsen the situation because of resulting resuspension of sediment nutrients during works. They propose a significant removal of carp as an action to be considered to try to instigate a "reverse switch" to lake recovery and to enable the re-establishment of submerged vegetation. They also emphasise the possibly significant impacts of climate change for this Mediterranean lake.

"Long term changes in the eutrophication process in a shallow Mediterranean lake ecosystem of W. Greece: response after the reduction of external load", J. Environmental Management 87 (2008), pages 497-506.
www.elsevier.com/locate/jenvman

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England

Estimating phosphorus loads in rivers

Modelling of impacts of nutrients on the environment, and of relative impact of different nutrient sources and consequences of management actions, requires estimates of phosphorus loads being carried by rivers (nutrient flux). These estimates are generally derived by multiplying sampling concentrations by estimated total water flows. This study shows that such methods can produce widely varying estimates of river P-load, depending on the sampling frequency used and on the mathematical model used to derive the estimate from the data.

Sampling data from 17 UK river catchments, with a total of 39 site-years (water years), were used, each with daily sampling data (total phosphorus concentration, river flow). These data were artificially segmented to generate 7 different "weekly sampling" data sets (each of 52 data points per year, one set for Mondays, one for Tuesday, etc); 30 different "monthly sampling" data sets (each with 12 data points per year, one set for the 1st day of each month, etc), and 7 "stratified" data sets (daily samples taken into account for the 10% highest flow samples, weekly samples otherwise). For each of the sets of data points thus generated, and for the original complete set (all daily samples), **8 different mathematical model methods were applied to give total river phosphorus load estimates**.

Consideration was also given to the underlying catchment characteristics susceptible to affect nutrient flows and load estimates (the proportion of nutrient inputs and river flow coming from agricultural and land run-off, human populations, and the relative proportion of baseflow from groundwater evident in the river flow data), and to the relationship between soluble phosphate loads and total phosphorus loads.

Spate flow events and phosphorus transport

In the case of infrequent sampling (less than daily), then extreme flow events tend to be missed, and concentrations of soluble phosphate reflect baseflow and not real conditions. **For total phosphorus, a significant part of river load can occur in low-frequency, extreme flow events**.

In most of the catchments studied, 5-10% of the total phosphorus flow was carried in 5 highest flow events per year, but in around half over 15% and even up to 45% of total flow occurred in the 5 highest flow events per year.

Estimation methods

The 8 mathematical methods used to estimate total phosphorus flow, from the complete daily sampling data set, did not give consistent results. Estimates varied depending on the mathematical model used from 45% to 225% of the "best estimate". Estimates appear particularly unreliable for methods based on interpolation and on log-log ratings. The different methods generally give closer results for catchments in which a high baseflow constitutes a high proportion of total river flow.

Estimations based on lower sampling frequency data sets (weekly or monthly instead of daily) show considerable variations from the "best estimate" of total river P-load, giving errors often of the order of 2 (50 – 200% of best estimate) for weekly samples, and of an order of up to 5 for monthly samples. The stratified data sets gave results generally significantly closer to the "best estimate".

The most reliable estimates for total P loads (based on weekly data) were given by multiplying the sampled total P concentration by the **mean flow between sampling dates** rather than by the instantaneous flow rate at the sampling time (method 3). However, a method taking into account the mean flow of the sampling period may reduce bias (method 5).

Estimates were generally more reliable in lowland rivers with a high baseflow, and unreliable in catchments with high contributions from human and point discharges or with "flashy" flow regimes (that is significant occurrence of brief, high-flow events). The author notes that even daily sampling results can give unreliable estimates in such catchments.

Recommendations

The author offers the following recommendations:

- all sampling programmes should **measure both total and soluble phosphorus**
- monthly frequency of sampling gives very unreliable P-load estimates and should not be relied upon for the purposes of catchment management
- certain calculation methods (3, 5) are the more reliable than others
- for catchments with a high baseflow and/or low population density, **weekly sampling may give reliable results**
- **relationships between P-concentration and river flow, and in the ratio of soluble to total P, vary significantly** from one year to another in some catchments, so that interpolation is not reliable
- if daily sampling is not considered to be feasible in routine water quality monitoring programmes, **stratified sampling** combining sampling of the 35 highest flow days in the year with weekly sampling at other times should be considered as the next most reliable approach to load estimation

"Uncertainties in annual riverine phosphorus load estimation: impact of load estimation methodology, sampling frequency, baseflow index and catchment population density", Journal of Hydrology n° 322, pages 241-258, 2007. www.elsevier.com/locate/jhydrol

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Illinois

Nutrients, chlorophyll and algae in streams

Three studies from Illinois, USA Midwest, look at the mechanisms of nutrient run-off from 3 agriculture watersheds; relationships between nutrients, chlorophyll and dissolved oxygen in 5 streams in agricultural watersheds; and at nutrient – algal biomass relationships for >100 streams and small rivers.

Agricultural watersheds of the Midwest are the principal source of nutrients to the Mississippi and to the Gulf of Mexico. Development of nutrient standards is underway on a State by State basis. However, nutrient standards (TDML) tend to focus on concentrations during summer low-flow periods, whereas most nutrient discharge in fact occurs during high-flow periods. Furthermore, nutrient standards are only possible if a relationship can be shown between N and P concentrations and the achievement of water quality required for designated uses. This does not appear to be the case in small streams and rivers, where **no relationship was found between nutrient concentrations, chlorophyll and algal biomass**.

Agricultural phosphorus run-off

A study [1] of three mainly agricultural watersheds in Illinois looked at nitrate-N, total phosphorus and dissolved reactive phosphorus (DRP) export over 8-12 years, based on long-term and intensive monitoring. The watersheds (Embarras, Kaskaskia and Sangamon) had areas of 101, 386 and 481 km^2 and land coverage of 86 – 91% row-crop agriculture, mainly corn and soybean, and largely tile drained. Most of the land was wetland and mesic prairie before drainage and cultivation. Nitrogen losses, at 20 – 50 kg total-N per hectare per year are amongst the highest in the Mississippi river basin.

Stream flow was measured hourly or every 15 minutes. Nutrient concentrations were generally sampled weekly, but with hourly or even more frequent sampling during flood events and periods of rapid flow change.

Results showed that nitrate discharge was principally related to underground tile-drain flows, whereas phosphorus discharges (particularly as particulate P) was largely related to surface run-off. In-stream nutrient concentrations were higher during the winter and spring periods of higher flows. Nearly all nutrient discharge occurred when flows were higher than the median level, with extreme flow events (>90th percentile) accounting for >50% of nitrate and >80% of phosphorus exports.

Proposed **TDML (Total Mean Daily Load) nutrient criteria** are generally based on nutrient concentrations during low flow periods, because these occur in the summer when peak algal productivity occurs. However, this study shows that **reducing nutrient loads by as much as 50% during low flow periods would have no effect on the annual watershed nutrient export**, which is the significant factor for addressing eutrophication and hypoxia problems in the Gulf of Mexico.

Nutrients, chlorophyll and dissolved oxygen

A study [2] of five streams in Illinois (situated in the Embarras, Kaskaskia and Vermilion watersheds) compared dissolved nutrients, algal abundance and dissolved 0_2 over the spring – autumn period (March – November) 2004. The catchments ranged from 25 to 777 km^2 and in all cases had land cover or 74 – 91% row-crop agriculture. Stream depth was 32 – 93 cms. Water sampling was carried out weekly, with more frequent samples during high flows. Algal abundance was in each case assessed in five equidistant transects along a 40m section of stream, sestonic algae (water column suspended algae) by filtration of collected water samples, periphyton (algae growing on stream bed surfaces) by analysis of scrapings of defined areas from collected rocks, filamentous algae by visual assessment of covered area and biomass of samples. Discharge was calculated from records of nearby USGS stations (US Geological Survey).

This followed sampling [4] in 2003 of 18 streams, and a detailed study of algal development on natural substrata and on unglazed ceramic tiles. The 18 sites were situated in five East – Central Illinois watersheds: Salt Creek, Sangamon River, Vermilion, Kaskaskia River, Embarras). Periphytic and sestonic chlorophyll$_{-a}$, nutrients, temperature, turbidity and dissolved oxygen were measured and USGS monitoring data used for flow rates. Additionally, unglazed ceramic tiles were placed at each of the 18 sites for 4 weeks in mid-Summer for analysis of periphytic algal growth. At four sites in the Embarras River (2 shaded, 2 unshaded) 25 small unglazed tiles were sampled every two weeks from July to December 2003. For these small tiles, filamentous algae were included in the chlorophyll$_{-a}$ analysis because of difficulty in separating them.

This study concluded that sestonic chlorophyll was low, that **filamentous algae were an important component of the algal communities**, and that periphytic algae was not generally related to the concentration of N or of P in the water column, but tended to be limited by light (turbidity) in unshaded streams.

Sestonic chlorophyll levels were low (<5 µg/l chl$_{-a}$) and showed no significant differences between shaded and unshaded sections of stream, and no correlation to periphyton either onsite or upstream. Periphyton levels were higher at unshaded sites, ranging from 0 to 40 mg chl$_{-a}$/m^2. Higher periphyton levels occurred in low flow periods, and was correlated to DRP but not significantly to nitrate, total P or turbidity. Filamentous algae coverage was significant (up to 40% of area, > 30 mg dry mass / m^2) but unrelated to flow rate, turbidity or nutrient concentrations.

Dissolved oxygen concentrations sometimes fell at night below the Illinois Pollution Control Board standard of 5,000 µg/l, with low levels appearing to be **principally related to filamentous algae**.

The authors conclude that sestonic algae is a poor criteria for assessing nutrient related problems in these streams. Filamentous algae accounted for 64% of variation in dissolved oxygen but was not nutrient related. Hydrology and light conditions, rather than nutrients, appear to be the principal factors controlling algal abundance. Furthermore, the authors consider that **it may not be possible, in this agricultural landscape, to reduce nutrient emissions sufficiently to limit filamentous algae development**.

Forms and pathways of agricultural phosphorus

Ten years of sampling data for phosphorus concentrations and forms and for precipitation and stream flows were assessed [4] for three sites (1994-2003): Embarras river, Lake Fork of Kaskaskia river and Big Ditch of Sangamon river. Annual flow-weighted mean total phosphorus concentrations exceeded 0.1 mgTP/l.

Both soluble phosphorus (DRP) and particulate phosphorus concentrations increased with stream flow and total loads were greatly affected by particulate P carried in high flow, overland runoff events. High levels of DRP (up to 1.25 mgDRP/l) were associated with precipitation following phosphate fertiliser application on frozen soils. However, even if such incidents are avoided, under-field tile drainage would remain an important contributor of DRP from late autumn through to early Summer.

Overall, soluble phosphate represented 41 – 73% of total phosphorus loads to the three streams, considered typical of agriculturally dominated watersheds in the US Corn Belt. Total export of phosphorus was in the range 0.46 – 0.75 kgP/ha/year.

Nutrient standards

The Federal Clean Water Act requires the States of the USA to identify impaired water bodies and develop plans to reduce impairment. Nutrient standards are thus developed with the objective of preventing or reversing impairment due to eutrophication symptoms (eg. excessive algal biomass or low dissolved oxygen), in order to achieve water quality compatible with "identified uses". Chlorophyll$_{-a}$ (chl$_{-a}$) levels are often used as a proxy measurement of algal biomass.

In order to support the **development of State nutrient criteria for Illinois**, a state-wide assessment [3] of relationships between nutrients and chl$_{-a}$ was carried out. This included surveys of 138 stream and river sites from May to July (summer) in 2004, including sampling of sestonic and benthic chl$_{-}$

$_a$, estimation of canopy cover (shading), water sample analysis for total P, DRP, organic P, total N, nitrate-N, ammonia-N, organic N and dissolved silica, temperature, pH, turbidity, specific conductivity. Flow data from the USGS was used. 109 sites were revisited in September at base flow rate. Further assessment of some of the State's larger rivers was carried out in 2005.

Median total P concentrations were 0.185 mgP/l at low flow and 0.168 mgP/l at higher flows. Nitrogen concentrations were high, reflecting the heavily fertilised agricultural land use, with total N concentrations generally > 1 mgN/l (median 5.6 mgN/l at higher flows).

Median sestonic chlorophyll$_{-a}$ concentration was low 5 µg/l (90% of sites < 35 µg/l) with no statistical relationship between sestonic and benthic chl$_{-a}$. In general, there was no relationship between sestonic chlorophyll$_{-a}$ and total phosphorus, except for in unshaded sites with total P < around 0.2 mgP/l, where a threshold of 0.07 mgP/l appeared to limit sestonic algae. **There was no relationship between benthic chl$_{-a}$ accrual and nutrient concentrations, or indeed any other environmental factor**.

The authors conclude that in many Illinois streams and rivers nutrient concentrations are not the limiting factor for algal biomass, because of high nutrient concentrations from agriculture, and the effects of other factors such as river bed substrate conditions and turbidity.

[1] "Timing of riverine export of nitrate and phosphorus from agricultural watershed in Illinois: implications for reducing nutrient loading to the Mississippi River", Environ. Sci. Technol. N°40, pages 4126-4131, 2006. http://pubs.acs.org/journals/esthag/index.html

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[2] "Relationships among nutrients, chlorophyll-a, and dissolved oxygen in agricultural streams in Illinois", J. Environmental Quality, vol. 35, July-August 2006, pages 1110-1117. http://jeq.scijournals.org/

A. Morgan, University of Illinois at Urbana-Champaign as above. T. Royer, M. David, L. Gentry. as above.

[3] "Assessment of chlorophyll-a as a criterion for establishing nutrient standards in the streams and rivers of Illinois", J. of Environmental Quality, vol. 37, March-April 2008, pages 437-447.

T. Royer, M. David, L. Gentry, as above. A. Mitchell, K. Starks, University of Illinois at Urbana-Champaign as above. T. Heatherly II and M. Whiles, Dept. Zoology and Center for Ecology, Southern Illinois University, Carbondale, IL 62901, USA.

See also: "Nutrient loading assessment in the Illinois river using a synthetic approach", SCOPE Newsletter n°58.

[4] "Phosphorus transport pathways to streams in tile-drained agricultural watersheds", J. Environmental Quality 36, 2007, pages 408-415. http://jeq.scijournals.org/

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Peak Phosphorus

Sustainable Phosphorus Futures

Unlike oil, which is lost once used, phosphates can be recovered and recycled. However, phosphorus cannot be replaced once resources begin to be depleted: there is no substitute. At present, 80% of phosphate mined is lost in fertiliser production, field application, food processing, and does not reach the food we consume. Worldwide, mankind emits 3 million tonnes of phosphorus annually in faeces and urine, with even more in animal manures. Human emissions represent more than 10% of phosphate rock production. Recovery and recycling of phosphorus offer an important opportunity to reduce dependency on mined phosphates and make food production more sustainable.

The Phosphorus Futures website presents information and proposals for sustainable phosphorus management. The initiative is based at Linköping University, Sweden and part of the Global Phosphorus Research Initiative. *http://phosphorusfutures.net*

See also the P-recovery website: www.phosphorus-recovery.tu-darmstadt.de

International Conference on

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

Draft programme – 93 speakers and posters programmed to date

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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