
SCOPE NEWSLETTER

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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.

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CEEP
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Phosphorus recycling

Edmonton, Canada

Full-scale struvite recovery

A first large-scale struvite recovery demonstration reactor demonstration reactor has been built by Ostara Nutrient Recovery Technologies Inc, in Edmonton, Canada. This is based on the fluidised bed reactor technology developed by UBC (University of British Columbia) over recent years, presented in 3 other recent published papers summarised here (including pilots at Penticton, Annacis Island and Lulu Island) and previously in SCOPE Newsletters n° 56 and 60.

The €700,000 struvite recovery reactor at the Edmonton Gold Bar sewage treatment works (350 million litres/day) will treat around 500,000 litres per day of sludge lagoon supernatant. The reactor is expected to remove 75-95% of phosphate from the lagoon supernatant stream. If this pilot is successful, then in 2007-2008 a €1,800,000 facility will be built to treat 2,500,000 litres per day. This will involve five commercial scale reactors would cover the plant's full capacity, and enable recovery of up to 1,000 tonnes of phosphorus (as struvite) per year.

Cost benefit

The works has been spending €100,000 per year removing struvite build up in process equipment and the new reactor is intended to avoid these costs, as well as producing struvite (magnesium ammonium phosphate) which can be sold as a slow-release fertiliser: Branded as Crystal Green™, the product will be marketed as a slow-release environmentally-friendly to the turf (parks and golf courses, etc.), ornamental gardens and speciality agriculture markets. Initial trials on various types of turf have demonstrated that Crystal Green™ has certain distinct advantages over currently available commercial fertilisers in addition to being a sustainable product. As part of Ostara's contract with the City of Edmonton, the city will also will

receive a portion of the proceeds from the sale of the Crystal Green™ product.

The struvite recovery unit is a high-rate up-flow fluidised bed reactor, operating on the biological nutrient removal sludge digester / lagoon supernatant stream. Struvite is precipitated by adding caustic soda (to adjust pH) and magnesium chloride.

Ostara believe that their proprietary UBC reactor design offers improvements over those currently used in struvite recovery plants in Japan and Europe, with improved hydraulic mixing (proprietary liquor and chemical injection port design) and because of self-seeding (nucleated struvite crystals forming in the upper reactor fall to its base to serve as seeds for pellet growth, because of reactor shape, see SCOPE Newsletter n° 56). **The struvite pellets produced are thus >97% pure** (containing no foreign seed material, such as sand) and with diameters up to 6 mm are up to three times larger than those produced by the commercially operational reactors in Japan (see proceedings of the Second International Conference on Phosphorus Recovery at <http://www.nhm.ac.uk/research-curation/projects/phosphate-recovery/>).

Ostara estimates that around 1,000 sewage works operating in nutrient sensitive areas of North America and Europe, could in time be interested in struvite recovery, as a route for both avoiding struvite deposit problems, improving nutrient removal effectiveness, and recovering nutrients in a commercially valuable form.

Further development

Further development of the process are underway at a number of experimental sites, including the Hampton Roads Sanitation District's, Nansemond plant in Suffolk, Virginia and at Vancouver's Lulu Island sewage treatment plant. Trials of the reactor for struvite recovery from animal wastes also started in 2006 at the Agassiz Agricultural Research Farm, British Columbia.

Three recent papers present the detailed results of pilot scale struvite precipitation experiments, carried out in the laboratory (bench scale), at the

pilot scale using digester supernatant from the Annacis Island and Lulu island sewage treatment works (Greater Vancouver) and pilot trials on-site at the Penticton city sewage treatment plant (British Columbia). These follow the initial results presented in SCOPE Newsletter n° 56.

Bench scale experimental results

The bench scale experiments used a PVC 2m high, 2.5 litre volume fluidised bed struvite precipitation reactor and pure chemical solutions as feed, with liquor recycling through a 2 litre settling clarifier, at a range of phosphate concentrations 40 – 80 mgP/l. 21 different experiments, with runs of 2 – 12 days, were carried out, assessing struvite precipitation at different levels of pH, phosphorus concentration, magnesium:phosphate and nitrogen:phosphate ratios, temperature and liquor recycle ratios.

pH was found to be a very important operating parameter, effecting phosphorus removal efficiency (in one case, an increase of around +50% between pH 8.1 and pH 8.8), but if the pH was too high large amounts of fines (very small crystals) were formed, poor quality precipitates were formed in the reactor (dendritic/dentric), and fines and were carried out of the reactor (so that the precipitated phosphorus was not retained) and resulted in plugging of the reactor. The optimum pH depended on inflow phosphate concentrations, and would be uneconomically high (pH 9) for phosphate concentrations below 30 mgP/l (cost of pH adjusting agents).

Reactor seeding was shown to have no significant effect, because the struvite crystals spontaneously formed could self-seed the reactor. Lower operating temperatures did appear to favour struvite crystal growth (15°C compared to 25°C). Increased magnesium concentrations did not appear to improve struvite crystal quality. Overall phosphorus removal rates of 12 – 56% were achieved.

Pilot scale experiments with supernatant from Annacis Island and Lulu Island

Results are reported of **extensive trials with two identical pilot fluidised bed struvite precipitation reactors**, similar to the laboratory design tested above and in previous work (see SCOPE Newsletters n°s 56 and 60). The reactors were again made of PVC, with this time a **height of approximately 5m, a volume of 19 litres**, and a through flow rate of 3.6 litres/minute (fluid residence time in total reactor = 5 minutes). As above, the reactors had a settling – clarifier tank in the liquor recycling stream.

The two reactors were operated in parallel, using both pure chemical phosphate solutions (synthetic wastewater) and anaerobic digester supernatants from the Annacis Island and Lulu Island secondary wastewater treatment plants operated by the Greater Vancouver Regional District, British Columbia. Average soluble phosphorus concentrations for these supernatants over the study period were respectively 133 and 84 mgP/l. The reactors were operated for four months.

Full details of the experiments carried out are to be found in two papers in print and H. Huang's MASc Thesis (University of British Columbia, 2003), referenced in the 2006 article cited (Environmental Technology vol. 27).

Better than 85% phosphate removal efficiency was reliably achieved by the reactors from both supernatants, under a variety of operating conditions (supernatant flow rate, liquor recycle rate, pH, magnesium:phosphate ratio).

The paper concentrates on the quality of the recovered struvite produced during this work. This shows 96.2% purity struvite for the Annacis supernatant. A slightly higher purity struvite, at 97.5%, was obtained from the Lulu supernatant which had lower levels of suspended solids.

The struvite crystals produced showed sizes of 1.5 – 3.4 mm diameter, with size (and so weight) increasing mainly with higher crystal residence time or higher levels of magnesium dosing. Crystal hardness also appeared to increase with these two factors. Under SEM (scanning electron microscope), the struvite produced appeared mainly to be in round, hard, fairly smooth particles, which when

examined more closely showed to be made up of tightly agglomerated fine brick and rod shaped crystals (see illustrations in article). These struvite particles were **easily separated and extracted** from the reactors.

Pilot plant at Penticton sewage plant

The two pilot struvite reactors, used in the experimental work above, were installed at the **City of Penticton Advanced Waste Water Treatment Plant** (AWWTP). This plant operates biological nutrient removal, and two-stage anaerobic digesters usually of primary sludge only. For this work, the composition of the digested sludge was modified to include waste activated sludge (WAS) in order to increase the phosphate content of the supernatant to 40-70 mgP/l.

The two reactors were operated in parallel for 3-4 months, using real anaerobic sludge digester supernatant.

Magnesium was added up to molar ratio for struvite compared to reactor inflow phosphate, and the reactors were controlled by adjusting pH or by adjusting the recycled liquor/new effluent ratio (and thus the phosphate concentration) to manage "SSR" (inflow supersaturation ratio).

Phosphate removal efficiencies of 70 – 90% were achieved for pH > 8, with a lower 40 – 60% efficiency for pH 7.6 – 7.8. It was shown that the reactors could be reliably controlled to achieve 90% phosphate removal.

The precipitated phosphates were nearly pure struvite (>99%) with traces of calcium and the diameters of the recovered particles crystals (in the reactor bed) increased from 0.5 to 1.8 mm over the duration of the runs. SEM photographs show that the struvite particles progress from apparently loosely aggregated crystals to tightly packed pellets with time.

The total struvite recovered, in the reactor bed, after 3 months, was around 13 kg in each reactor, representing over 90% of the phosphate removal – that is, **only a small proportion has been lost in fines**.

Edmonton large scale pilot:

Environmental Science & Engineering Magazine, May 2006, pages 40-42, available at : www.esemag.com

Further information:

<http://www.businessedge.ca/article.cfm/newsID/11451.cfm>

Ostara Nutrient Recovery Technologies Inc.

www.onrti.com

Bench scale experiments:

"Preliminary investigation into factors affecting controlled struvite crystallization at the bench scale", *J. Environ. Eng. Sci.* 3, pages 195–202, 2004. A. Adnan, M. Dastur, D. Mavinic, F. Koch. http://pubs.nrc-cnrc.gc.ca/cgi-bin/rp/rp2_vols_e?jees

Pilot scale trials :

"Production, Characterization and Morphology of Struvite Crystals from a Pilot-Scale Crystallization Process", *Env. Technology*, 27(3), March 2006, 233-246. Huang, Mavinic, Lo & Koch.

<http://www.environtechnol.co.uk/contents.htm>

"Pilot-Scale Phosphorus Recovery through Struvite Crystallization – I: Examining the Feasibility of Applying the Process Technology", *J. Env. Eng. Sci.*, 2(5), September 2003, 315-324.

"Pilot-Scale Phosphorus Recovery through Struvite Crystallization – II: Applying In-Reactor Supersaturation Ratio as a Process Control Parameter for Struvite Crystallization", *J. Env. Eng. Sci.*, 2(6), November 2003, 473-483. A. Adnan, F. Koch, D. Mavinic,

"Small scale pilots at Penticton sewage works: Pilot-scale struvite recovery from anaerobic digester supernatant at an enhanced biological phosphorus removal wastewater treatment plant", *J. Env. Eng. Sci.* 4: 265–277 (2005) A. Britton, F. Koch, D. Mavinic, A. Adnan, W. Oldham, B. Udala

BCCWA Conference 2006, Morning of Tuesday 2nd May sessions: "Magnesium: The Key to Struvite Process Control", A. Forrest, D. Mavinic, F. Koch.

http://www.bcwwa.org/AGM/2006/BCWWA_Papers_2006.php

Previously summarised in SCOPE Newsletter n° 60 :

"The Effects of Magnesium and Ammonium Additions on Phosphate Recovery from Greenhouse Wastewater", *J. Env. Science and Health, Part B*, 40(2), March 2005, 263-374. Yi, Lo, Mavinic et al.

<http://www.tandf.co.uk/journals/titles/03601234.asp>

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<http://www.civil.ubc.ca/>

Alberta Canada

Struvite precipitation from cattle manure

This laboratory precipitation study was carried out using raw cattle manure collected from a feedlot in Alberta, Canada. The manure contained 10-12% solids. It was anaerobically digested in the laboratory with an average digester residence time of 14 days at 55°C, then centrifuged. The resulting liquor was used for batch struvite precipitation experiments carried out using 0.1 litre samples in beakers, shaken for 60 minutes, then 0.45 µm filtered. Soluble ions after filtration were measured using ion chromatography and the filtered solids by inductively coupled plasma mass spectrometry (ICP-MS).

Phosphorus removal was assessed at different pH (adjusted by sodium hydroxide addition), with and without added soluble phosphate, at different levels of magnesium addition (molar soluble magnesium:phosphorus ratio) and with the use of different magnesium salts for this addition.

The centrifuged digested manure contained relatively high levels of organic compounds and suspended solids: COD approx. 40,000 mg/l, total suspended solids 11,700 mg/l TSS. Concentrations of soluble phosphorus and ammonium varied from between digester batches: 100 – 350 mg PO₄/l (= 3.7 mmol soluble P- PO₄/l) and 220-2800 mg NH₄/l (= 12 - 155 mmol N-NH₄/l). Other ions included calcium at around 9 mmol calcium, 11 mmol magnesium and 70 mmol potassium. pH was 7.7 – 7.9.

Poor phosphate precipitation

Without magnesium or phosphate addition to the effluent, 20-30% of soluble phosphate was precipitated at pHs in the range 7.8 (liquor pH) – pH 9.

However, for very high magnesium addition ratios (4 x molar soluble phosphorus concentration) only low phosphorus precipitation efficiencies of around

40% were achieved. Even at very unrealistically high magnesium addition rates (20x molar P) only 60-70% were achieved at pH 9. This is considerably lower than levels achieved by other authors: often >90% phosphate precipitation efficiencies, even at Mg:P ratios < 1.5.

The authors suggest that this may be the consequence of high suspended solids in the liquor used (even after centrifugation) and/or to interference from other ions present.

Other factors

The experiments confirm work by other authors showing:

- increased struvite precipitation at **higher pH**, in this case continuing to increase up to pH 10
- increased struvite precipitation at **higher temperatures**, in the range 5 – 55°C
- the effectiveness of different magnesium sources was as follows : MgCl₂ > MgSO₄ > MgO > mg(OH)₂ > MgCO₃

Addition of phosphate and magnesium to increase the molar phosphate:ammonium ratio from an initial 0.01 to 1 showed that ammonium precipitation efficiency could be increased from 2% up to 52% (Mg:P ratio maintained at approx. 1.2). Potassium removal also increased from 2% to 10%.

K-struvite

Analysis of the precipitated solids (after filtration) showed that the phosphorus content was nearly 50% higher than the 1:1 molar ratio to ammonium expected in struvite, and 10-25% higher than the 1:1 expected molar ratio to magnesium. This confirmed that **a number of other phosphate products were also being formed**. Simultaneous precipitation of K-struvite was also studied. The low potassium content of the precipitated solids (5-10% molar of the phosphate content) suggested that K-struvite [MgKPO₄.6H₂O] had a lower tendency to form than struvite [MgNH₄PO₄.6H₂O].

“Nutrient removal from anaerobically digested cattle manure by struvite precipitation”, *J. Environ. Sci. Eng* 5, 285-294, 2006. <http://jees.nrc.ca>

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Experimental

Electrochemical struvite precipitation

Layers of struvite were precipitated from pure ionic solutions in laboratory beaker scale experiments by a three electrode system, indicating that this approach could be an applied in wastewaters.

Pure solutions of equimolar phosphate, ammonium and magnesium ions were used to test two different electrochemical precipitation set ups. 3.85 mmol were used, equivalent to 242 mgP-PO₄/l, comparable to concentrations found in animal wastewaters or sludge digester supernatants.

Preparatory experiments showed that **spontaneous struvite precipitation began to occur when the pH was increased to 8.2** (addition of sodium hydroxide), with minute needle-shaped crystals of struvite being produced.

The electrochemical system used a **working cathode onto which struvite was deposited**, integrated into a pH electrode, a reference electrode next to it, and as an anode a plate around the beaker. In one set up, the working anode was a gold grid on a flat end pH cathode. In the second set up, a rotating nickel disc was used as cathode (400 rpm).

Local pH was shown to increase with electrical potential (electrolysis of water to OH⁻), with the **local pH change being sufficient to cause the nucleation and crystal growth of struvite** on the cathode. It was shown that, in this pure ionic solution, no other compounds were deposited. SEM images show that the struvite was precipitated as needle shaped crystals, developing into a packed layer of less well formed crystals.

The authors conclude electrochemical precipitation could be an **alternative method for struvite**

recovery from wastewaters, without the addition of chemicals to adjust pH.

“Electrochemical precipitation of struvite”, *Electrochemical and Solid State Letters* 9(6), pages C97-C101, 2006. <http://ecsdl.org/ESL/>

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Calcium phosphate precipitation

A 250 litre upflow fluidised bed reactor was used to obtain detailed results for calcium phosphate precipitation in pure soluble phosphate solutions, with around 100 experimental reactor runs each of 6 hours. The objective was to obtain a large range of operating results, in order to open perspectives for industrial development of the process.

Around **100 reactor operating runs** assessed the phosphate precipitation reaction at different levels of pH, temperature, soluble calcium:phosphate ratio (the latter in the range Ca:P = 2 to Ca:P = 4,52). Pure orthophosphate solution (H₃PO₄ in demineralised water) was used as reactor feed liquor, at phosphate concentrations comparable to those found in sewage works digester supernatants (50 µgP/l). Reaction equilibrium constants and a chemical precipitation model were derived.

The fluidised bed reactor used was a 2m high glass column of 20mm diameter, with a wider section at the top intended to prevent carry over of fines. In the base of the reactor, the incoming phosphate solution flowed through a 20 cm deep bed of 4 mm glass balls, ensuring permanent upflow mixing and fluidity. Calcium chloride and potassium hydroxide solutions were injected in the lower column mixing zone to adjust pH and calcium:phosphate ratio.

The reactor was operated for 6 hour runs, at a liquor flow rate of 80 litres/hours (fluid residence time approx 4 hours) with 1 kg of sand as an initial bed (new sand for each run). This gave a depth of sand of 35 cm without upflow, and 75 cm fluidised bed depth (initial) increasing to 105 cm with time.

Stable reaction conditions

The reactor took approximately 30 minutes to reach stable reaction conditions at the start up of each run.

The paper summarises the results of the runs, showing phosphorus removal efficiency (% of inflow soluble phosphate precipitated and retained in the reactor) varying with pH, operating temperature, soluble Ca:P ratio. The results show a relatively stable calcium:phosphate ratio in the precipitated phosphates whenever the operating pH is above 7.4 and the authors conclude that the precipitate is then ACP (amorphous calcium phosphate) $\text{Ca}_3(\text{PO}_4)_2$. Below this pH, the phosphate precipitation efficiency depends on whether the reactor is initially operated with an increasing or decreasing pH, and the authors suggest that in this case a variety of calcium phosphates may be being precipitated, in particular DCPD (di calcium phosphate dehydrate) $\text{CaHPO}_4 \cdot 2\text{H}_2\text{O}$, and again ACP.

Phosphate precipitation efficiencies of 80% are achieved at an influent Ca:P ratio of 2 for pH 7.5 or higher. The authors conclude that further analysis of the reaction and process would be useful to improve control.

Pilot laboratory reactor

This work follows in 2 previous papers presenting experiments with a smaller glass column fluidised bed reactor and deriving precipitation models from these results. This reactor was (5 cm diameter, 200 cm height (that is 15 litres volume, 22 minutes hydraulic residence time), also using 50 mgP/l phosphate concentration inflow. In this case, the stabilisation time of the reactor phosphate precipitation efficiency and fluidised bed height was 7 hours, whereas pH stabilised after only 1 hour. The authors consider this is because of progressive saturation of the bed with fines.

A significant part of the precipitated phosphate was in this case carried over the top of the reactor (which did not have a wider top area), with over 95% removal of soluble phosphate from solution but only around 60% recovery in the reactor at pH 8.5. Analysis of the fines precipitated in the column and in the decanter after reactor-top carry over indicated a Ca:P ratio of 1.5 and a probable form of amorphous calcium phosphate (ACP).

The derived model suggests that a reactor of diameter 15 cm using 200 μm diameter sand would require an acceptable bed height of 40 cm sand (non fluidised height) to achieve 98% phosphorus recovery in the reactor, which would in theory enable EU sewage treatment directive discharge requirements for sensitive areas to be met at least using the pure reactant solutions (Directive 91/271).

“Experimental validation of calcium phosphate precipitation modelling in a pellet reactor”, L. Montastruc, S. Domenech, L. Pibouleau, C. Azzaro-Pantel, Environmental Technology, vol. 26, pages 683-693, 2005.

http://www.environtechol.co.uk/Contents_pages/volume_26n6.htm

In French, with summary in English: French title: “Validation expérimentale d’un modèle pour la précipitation de phosphates de calcium en lit fluidisé”.

Other publications:

“A general framework for pellet reactor modeling : Application to P-Recovery.” L. Montastruc, C. Azzaro-Pantel, B. Biscans, M. Cabassud, S. Domenech and L. Pibouleau, Transactions of the institution of chemical engineers Part A: Chemical engineering research and design, Vol.81, N°9, pp.1271-1278, 2003

“Some guidelines for pH control of a P-recovery pellet reactor” L. Montastruc, C. Azzaro-Pantel, B. Biscans, M. Cabassud, L. Pibouleau, S. Domenech, Phosphorus research bulletin, December 2004

“Use of genetics algorithms and gradient based optimization techniques for calcium phosphate precipitation.” L. Montastruc, C. Azzaro-Pantel, L. Pibouleau and S. Domenech, Chemical engineering and processing, Vol. 43, pp1289-1298, 2004

“A Systemic Approach for Pellet Reactor Modeling:Application to Water Treatment” L. Montastruc, C. Azzaro-Pantel, L. Pibouleau, S.

Domenech, *AICHE Journal*, Vol. 50, N°10, pp.2514-2525, 2004

In French, from the symposium "Cristal 2", Toulouse, 12-13 November 2003:

"Valorisation des phosphates dans les effluents par précipitation en lit fluidisé", F. Cabanes, L. Montastruc, M. Freche, J-L. Lacout, C. Azzaro-Pantel, M. Cabassud, L. Pibouleau, S. Domenech, B. Biscans

"Approche systématique pour la modélisation d'un lit fluidisé: application à la déphosphatation", L. Montastruc, C. Azzaro-Pantel, B. Biscans

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BCFS P-recovery

Enhancing bio-P removal by struvite recovery in BNR processes

The potential for improving biological nutrient removal operation by precipitating struvite from anaerobic supernatant is assessed by modelling, based on data from the Hardenberg 8,500 m³/day inflow municipal sewage treatment works, the Netherlands.

The plant operates the patented **BCFS© biological nutrient removal (BNR) process**, see summary of a previous article by the same authors in SCOPE Newsletter n° 54. This includes a phosphate precipitation step operating on the anaerobic tank's supernatant, where phosphate concentration is relatively high at 20 – 40 mgP/l. This reduces soluble phosphate loads into the anoxic and aerobic tanks which enhances biological nutrient removal performance and relatively increase the influent COD:P ratio required to achieve discharge phosphorus concentrations.

Previous modelling suggests that such a system can convert approximately one third of influent carbon into methane gas (energy) and **recover up to half of inflow phosphorus as struvite** (magnesium ammonium phosphate MAP, which can be sold as a fertiliser). The modelling in this paper intends to answer questions about how operating parameters

such as phosphorus and nitrogen discharge concentrations, oxygen consumption, and overall P-recovery rate are affected by different rates of side-stream and of phosphate precipitation in the side-stream supernatant.

COD : P ratios

The modelling indicated that the phosphate precipitation (struvite recovery) enabled effluent phosphate levels to be reduced from <1 to <0.1 mgP/l. The latter performance is achieved in reality by the Hardensberg plant operating phosphate precipitation in the aerobic tank's supernatant.

Increasing the rate of side-stream supernatant up to 20% could increase overall phosphorus recovery rates (as struvite). Increasing beyond this percentage did not bring significant improvements.

At this side-stream rate, the supernatant phosphate precipitation enabled the plant's discharge consent of < 1 mgP/l to be met according to modelling at a COD:P ratio of 10, whereas a ratio of 20 would be necessary without phosphate precipitation. At this lower COD:P ratio, around one third of total plant inflow phosphorus would be recovered as struvite.

The effects of **varying plant loads (variations in COD:P ratio over the day)** were modelled. The effluent phosphate discharge limits continued to be met, but process optimisation was possible.

"Model-based evaluation of struvite recovery from an in-line stripper in a BNR process (BCFS©)", Water Science and Technology, vol. 53, n°3, pages 191-198, 2006.

<http://www.iwaponline.com/wst/toc.htm>

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Phosphorus management policies

England

Humber Estuary not eutrophic

The Humber is Britain's largest catchment (26 000 km², approximately 1/5th of the area of England. The catchment is lowland, with a population of 11 million including the cities of Birmingham, Bradford, Leeds and Sheffield amongst others. Its estuary tidal area is 62 km long, including the tidal parts of the Trent and Ouse rivers, with an average flushing time of 20 days in winter to 160 days in summer.

The Estuary's natural levels of organic materials are high, in particular because of releases from wetlands (salt marsh, reedbeds ...). Along with high tidal variations (5m average height) which give strong tidal currents, this results in natural high turbidity (5 - 14 g/l solids) and a characteristic brown coloration.

Turbidity

This natural turbidity attenuates light, limiting algal growth, and also accelerates oxidation of organic matter (bacteria attached to suspended particles) thus depressing water oxygen levels.

This study compared water monitoring data ; information on land use ; sewage, agricultural and industrial discharges ; historical and current information concerning a variety of water quality parameters.

Organic matter input to the Estuary is estimated to come 17% from sewage works discharges (treated sewage) and 15% from sewage works storm overflows (2001 figures, current figures will be somewhat lower because of sewage works investments underway). 65% of total phosphorus inputs and 33% of total nitrogen inputs are from treated sewage, plus 7% and 3% respectively from storm overflows (2001, same remark).

Not a "Sensitive Area"

Analysis of water and ecological quality indicators showed however that in nearly all cases **there are at present no symptoms of eutrophication**: no known occurrence of algal blooms or filamentous algae growth ; only very sporadic mat formation ; no significant oxygen depletion. The authors conclude that the Estuary is not currently "eutrophic" as defined by the Urban Waste Water Treatment Directive 1991/271.

The consequences of possible designation as a "Sensitive Area" under this Directive are examined, requiring investment in nutrient removal in sewage works > 10 000 p.e., as well as designation as a Nitrate Vulnerable Zone under the Nitrates Directive 1991/676, requiring agricultural management plans. These measures would result in a 17% reduction in total nitrogen inputs and a 43% reduction in total phosphorus inputs to the estuary.

Given the high turbidity and high organic matter levels in the estuary, the authors consider that **"it is not likely that the area will become eutrophic"**. Current levels of organic matter from sewage discharges appear, in fact, to balance reductions in organic matter levels resulting from the loss of wetlands (50% of the intertidal area has been lost since the 1700's).

Yorkshire Water, who funded this study, have estimated at **> 2 billion Euros over 20 years** the costs of upgrading sewage treatment if the estuary were to be classified as a "Sensitive Area".

"Organic matter and nutrient inputs to the Humber Estuary, England", Marine Pollution Bulletin 53 (2006), pages 136-143.

www.sciencedirect.com/science/journal/0025326X

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Lowland rivers

Sewage phosphorus inputs

A study of 54 UK lowland river monitoring sites suggests that sewage phosphate inputs are critical factors for eutrophication, and that action to reduce emissions from smaller sewage works discharging to ecologically sensitive tributaries may well be necessary.

An analysis of water quality data from 54 UK lowland river monitoring sites was carried out by Helen Jarvie and Colin Neal of CEH Wallingford, a leading centre of eutrophication and water quality research in the UK, and Paul Withers of ADAS, the agricultural management consultancy. The study covers the Tweed, Wear, Humber, Wye, Great Ouse, Thames and Avon catchments, draining about a fifth of Britain.

Previous studies, based on annual phosphorus mass loads have estimated that approximately 50% of total phosphorus loads to UK waters come from agricultural sources. However, annual phosphorus mass loads cannot be directly used to assess ecological risks. This is because river eutrophication (excessive growth of aquatic plants, particularly algal blooms) is mainly related to concentrations of soluble phosphorus during spring and summer low-flow periods, when increased water residence times, long daylight hours and higher water temperatures promote aquatic plant growth. Retention and/or release of phosphorus by sediments, plants and biofilms on the river bed can however render the situation more complex. Control of sources of soluble phosphorus at times of greatest eutrophication risk is of high priority to help improve the ecology of many lowland rivers.

Boron tracer indicates dominant effluent source of riverine phosphorus

The rivers were sampled on a weekly basis for periods of 1 – 8 years from 1993 to 2004. Soluble phosphorus, total phosphorus (soluble+particulate) and boron were monitored. Boron is a chemically conservative element, and in rivers is essentially derived from detergents (P-based and/or P-free), so

providing a tracer of sewage inputs. **Strong positive correlations were shown between river concentrations of boron and soluble and total phosphorus**, suggesting that that inputs controlling soluble and total phosphorus concentrations in these rivers are closely linked to effluent sources of boron. Soluble phosphorus and boron concentrations were diluted as river flows increased, which is also strongly indicative of sewage effluent, rather than agricultural runoff sources. Summer soluble phosphorus concentrations were thus generally significantly higher, as a result of reduced effluent dilution, and agricultural runoff contributions during summer were relatively low. In a river without direct sewage works discharges (Chitterne, a small rural chalk stream), both soluble phosphorus and boron concentrations increase with river flow, indicating flushing of sewage into the river as groundwater levels rise and intercept floodplain septic tanks and effluent soakaways. Relatively low soluble phosphorus : boron ratios in river water, compared with sewage effluent, suggest that there are no significant additional sources of soluble phosphorus in relation to the dominant effluent inputs, but that there are substantial in-stream losses of soluble phosphorus.

River sediments help to mitigate soluble phosphorus in rivers

The study also assessed the role of river bed sediments (derived from erosion of agricultural land) as a potential source of soluble phosphorus to the river water. However, under stable low flows and times of greatest eutrophication risk, 80% of sediment samples showed a net capacity for phosphorus uptake. Therefore, rather than being a source of phosphate pollution, **river sediments were in fact helping to remove soluble phosphorus from the river water.**

Quality objectives

The authors conclude that the data indicate greater risk for river eutrophication from effluent point sources than from agricultural diffuse sources, even for rural/agricultural areas. Sewage phosphorus releases from small settlements can be particularly significant in rural headwater

catchments. P-removal from effluents discharging from larger sewage works (under the Urban Wastewater Treatment Directive) has been effective in substantially reducing river water P concentrations. Nonetheless, even after P-stripping, river P concentrations can remain well above levels required to achieve control of eutrophication, as a result of the cumulative influence of smaller sewage works upstream. **Reduction of emissions from smaller sewage works and septic tanks systems** are therefore likely to be necessary to achieve EU Water Framework Directive quality obligations.

Sewage-effluent phosphorus: a greater risk to river eutrophication than agricultural phosphorus ?”, Science of the Total Environment 360 (2006), pages 246-253.

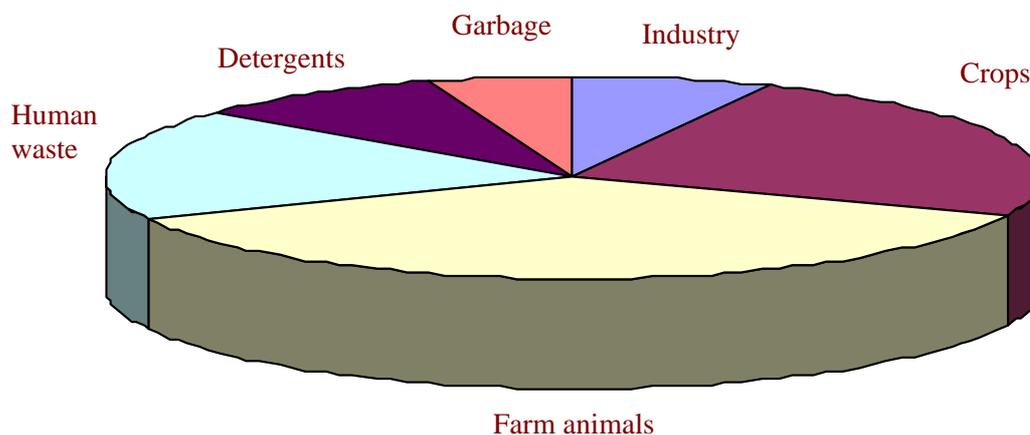
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China

Phosphorus flows and public policies

A Wageningen University thesis looks at phosphorus flows and at the extent of eutrophication of surface waters, and assesses policies to control phosphorus inputs in China. In particular, the experience of the Dianchi Basin (Yunnan Province, Southwest China) is examined, where a number of major investments have been made to address eutrophication, as well as a regional detergent P-ban.

China has some 2,300 lakes > 1 km² and a population of 1.3 billion, of which around one third in towns and cities.



Phosphorus loads to surface waters in China

Phosphorus flows

Total phosphorus use in China is estimated at 3,024,000 tonnesP/year, going mainly to fertilisers. Inputs to surface waters are estimated at 1,106,000 tonnesP/year, of which:

Agriculture - soil	17,0%
Agriculture - livestock, manure, composting	62,6%
Detergents	10,0%
Food and food industry	10,0%
Other industry	0,4%

The Dianchi Lake has a surface of around 300 km² and a catchment area of nearly 3,000 km² and a population of 310 million. It includes phosphate rock ore reserves. Just over half of the Lake phosphorus input 1998 was estimated to come from urban (33.6%) and rural populations (28.5%), a very small fraction from industry, and the remainder from agriculture.

Policy assessment

The study looks at the effectiveness of possible public policies to reduce phosphorus inputs to surface waters, addressing livestock production units, detergent phosphates, and sewage treatment.

Concerning detergent phosphorus bans, experience concludes that **“none of these current local P detergents ban programs resulted in a significant improvement of surface water quality in China”**

The bans have however resulted in **“social and economic impacts ... additional cost ... low acceptability of P-free detergents due to their poor washing performance ... the challenge of market supervision and enforcement”**.

Chinese detergents performance tests are quoted as “consistent with international ones ... of 20 brands of P-free laundry powders ... only one achieved the washing quality requested by the national standard”.

In the Dianchi Basin (Jiangsu Province), the first area to instigate a P-ban in China in 1996, field surveys showed:

- **many consumers insisted on using P-based detergents, because of lower price and better performance**

- many “P-free” products contained high levels of phosphates or did not match the national quality standard

- many rural shops do not sell P-free products

- “the local P detergent ban measures have not produced a reliable environmental effectiveness”

- the ban led to a 16-25% reduction in P concentrations in sewage works inflows, but P concentrations in streams and lakes did not respond (more increases than decreases).

Studies on Taihu Lake (Shu), Xihu Lake (Zhejiang Province), urban waterbodies (Shanghai) also justify this conclusion.

Consideration of sewage treatment shows that **China is considerably behind its objectives in terms of sewage treatment installation for large municipalities**, and suggests that in many areas decentralised sewage treatment and source separation are a more realistic way forward. Treatment of nutrient releases from intensive livestock production units appears as the most cost-effective public policy to address phosphorus.

*“Phosphorus flows in China – physical profile and environmental regulation”, Yi Liu, PhD thesis Wageningen University The Netherlands, 2005. ISBN 90-8504-196-1. yi.liu@mail.tsinghua.edu.cn
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