
SCOPE NEWSLETTER

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Phosphate recycling

Phosphate recycling feasibility

UK committee recommends P-recovery investigation

UK Committee recommends that the feasibility of reusing phosphates recovered from sewage treatment plants should be investigated.

Spain - struvite

Struvite precipitation and biological P-removal

Successful struvite precipitation experiments and mass balance assessment in sewage works and sludge digesters show the potential of P-recovery for improving bio-P removal operation.

Fuzzy logic

Struvite recovery control

Innovative process control of pH shows potential to optimise struvite recovery in pilot-scale stirred reactor.

Spain - magnesite

Waste source of magnesium for P-recovery

Further experiments confirm the usefulness of a by-product of magnesium oxide production to precipitate struvite from sewage liquors for phosphate recycling.

Turkey

Natural source of magnesium for P-recovery

Natural magnesite mineral was tested for precipitation of struvite from landfill leachate.

Phosphorus flows

Peak phosphorus ?

Sustainable futures

Why phosphorus supplies, P-recycling, and global food security should now be on the world political agenda

Sewage and agriculture

Plant availability of P in sewage sludges

Plant availability of phosphorus in sewage biosolids depends on sewage works configuration, whether chemicals are used for P-removal, and sludge treatment processes.

Conference

REMINDER

International Conference on Nutrient Recovery from Wastewater Streams May 10th - 13th 2009 - Vancouver, British Columbia, Canada.

Speakers include:

Dr. James Barnard (2007 Clarke Prize),
Robert F Kennedy (Chief Prosecuting Attorney for the
Hudson Riverkeeper and President of Waterkeeper
Alliance)

May 14th 2009 – Technical visits

Including 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.nutrientrecovery2009.com

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www.ceep-phosphates.org

Correction

SCOPE Newsletter n°72 article: Montana, Wisconsin, Kansas – Nutrient Criteria

References should read:

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

<http://www.awra.org/jawra/>

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Eutrophication

European Union

Legal actions for failure to treat sewage

The EU Commission is maintaining pressure on Member States to implement sewage collection and treatment as required by the Urban Waste Water Treatment Directive 1991/271 (UWWT). At the same time, Member States are preparing the “Programmes of Measures” and “River Basin Management Plans” which must be finalised and published by December 2009 and which must ensure achievement of “Good” or “Good potential” quality status for all surface and groundwater bodies by December 2015 (except where delays are justified by specific local circumstances).

In late 2008, the EU Commission sent a second (final) written warning to Greece concerning 12 agglomerations of > 15,000 equivalent habitants. Such agglomerations should have been equipped with sewage collection and biological treatment by December 2000 (deadline fixed by the 1991 UWWT Directive). These agglomerations were already amongst 23 concerned by a European Court of Justice ruling against Greece in October 2007. After this final written warning, the EU Commission is empowered to take a Member State to the European Court of Justice a second time and to ask for financial penalties to be imposed.

Greece: Sewage works construction too slow, too late

Of these 12 agglomerations, five are not planning to complete sewage works building until 2013, despite EU financial support (Markopoulo, Artemida, Rafina, Koropi and N Makri), building is underway for 6 others (Malia, Litochoro, Edessa, Hyrsoupoli, Lefkimmi and Megara), and for the 12th, Tripoli, the construction is completed but no monitoring data have been submitted to the EU Commission.

In early 2009, the Commission sent a further final warning to Greece concerning the Thriassio Pedio area, for failure to build a sewage collection system and ensure tertiary treatment prior to discharge into the Gulf of Elefsina “Sensitive Area”. After being condemned by the European Court for the Thriassio Pedio situation in 2004, Greece has informed the Commission that the sewerage system and tertiary treatment will be in place by end 2010. The Commission considers this too late, given that the deadline fixed by the 1991 Directive for Sensitive Areas was end 1998 and that the construction of this wastewater treatment system is co-financed by the European Union.

The Commission has also sent two final written warnings to Spain concerning 343 agglomerations of > 10,000 e.h. discharging sewage into Sensitive Areas, or into waters which the Commission considers should be classified as Sensitive Areas, and 59 agglomerations of > 15,000 e.h. discharging into other areas. The 343 agglomerations in Sensitive Areas should have been equipped with sewage collection and treatment, including nutrient removal (tertiary treatment) by December 1998. The 59 other agglomerations should have been equipped with sewage collection and secondary treatment by December 2000 (same situation as in Greece above).

Spain: Failure to designate Sensitive Areas

In the first case, the EU Commission also considers, after carrying out an assessment, that **6 areas not currently designated should be designated as eutrophication Sensitive Areas**, as defined under the 1991 UWWT Directive.

If Spain fails to respond correctly to these written warnings within two months, then the EU

Commission is empowered to take the cases to the European Court of Justice.

Italy: 229 towns and cities without adequate sewage treatment

The EU Commission has also sent a final written warning to Italy, considering that 229 conurbations of > 15,000 e. h. are still not adequately collecting and treating their sewage following a first warning letter sent in July 2004. The EU Environment Commissioner Stavros Dimas stated: "“Untreated urban waste water is a danger to the health of European citizens and the environment. It is unacceptable that some eight years after the deadline, Italy is still failing to comply with this important legislation. We need to ensure that the level of treatment of urban waste water can be guaranteed throughout the European Union.”"

The EU Commission is also maintaining pressure on Member States concerning other aspects of water quality legislation. A final warning has been sent to Portugal concerning drinking water quality (1998 Drinking Water Directive), following a 2005 European Court of Justice decision against Portugal on this question. Again, this is the final step before the Commission may ask the European Court of Justice to impose financial penalties on Portugal.

Water Framework Directive

European Court of Justice decisions, and the pending risk of financial penalties for those Member States whose sewage treatment is still not conform to the 1991 UWWT Directive requirements, appears to be concentrating the attention of Member State authorities on this issue. **In France, which was condemned in 2004 by the European Court of Justice for inadequate designation of Sensitive Areas and corresponding inadequate sewage treatment**, State authorities have produced reports submitted to official stakeholders' committees (CODERST) listing the agglomerations which are still not conform to the different deadlines, and specifying that injunctions to comply have been sent to these cities' mayors who are legally responsible for waste water treatment.

The Water Framework Treatment, 2000/64, confirms that existing Directives remain

applicable (such as the 1991 Urban Waste Water Treatment Directive, the 1991 Nitrates Directive, the Drinking Water Directive, the Shellfish waters Directive ...), so that these legal procedures and the risk of financial penalties hanging over non-compliant Member States will continue. The Water Framework Directive however adds very major new obligations for Member States, in particular to define River Basin Management Plans and Programmes of Measures, covering all surface and ground water bodies, by December 2009. These programmes should specify how "Good" or (in morphologically modified water bodies) "Good Potential" quality status is to be achieved by the end 2015 deadline. Where specific local circumstances justify it only, this deadline can be extended by 6 or 12 years.

Member States are now concerned both to ensure finalisation and publication of these Plans and Programmes of Measures by the December 2009 deadline fixed by the Water Framework Directive, but also that failure to implement Measures defined will also be potentially subject to enforcement by the European Court of Justice, and consequently ultimately possible financial penalties.

EU Commission press releases

IP/09/140, 29th January 2009 "Greece: Commission sends final warning over wastewater case"

<http://europa.eu/rapid/pressReleasesAction.do?reference=IP/09/140>

IP/08/1825, 27th November 2008: "Greece: Commission takes legal action over lack of waste water treatment, waste landfill problems"

<http://europa.eu/rapid/pressReleasesAction.do?reference=IP/08/1825>

IP/08/1802, 27th November 2008: "Spain: Commission pursues legal action over breaches of environmental law"

<http://europa.eu/rapid/pressReleasesAction.do?reference=IP/08/1802>

IP/08/1804, 27th November 2008 "Environment: Commission sends Portugal final warning over drinking water":

<http://europa.eu/rapid/pressReleasesAction.do?reference=IP/08/1804>

IP/09/285, 19th February 2009 "Waste water treatment: European Commission sends final warning to Italy":

<http://europa.eu/rapid/pressReleasesAction.do?reference=IP/09/285>

Michigan

Sediment P, light and chlorophyll

To assess sediment phosphorus release, lake bed cores from three west Michigan lakes were incubated in aerobic or anaerobic conditions. Algal growth in the overlying water after incubation was tested to demonstrate that sediment P release can contribute to eutrophication symptoms. Data on land cover, inflow nutrient concentrations and pollution sources were used to estimate total lake nutrient loads and compare these with the estimated internal loads from sediment P-release derived from the above experiments. Results for the three lakes, Mona, Spring and White Lakes, which have different degrees of watershed urbanisation, were compared.

Mona Lake sediment P-release

In the most recent paper (2008), lake bed cores with overlying water collected from Mona Lake, Michigan, were incubated for 24 days (in aerobic or anaerobic conditions). The characteristics of Mona Lake (surface 2.6 km²) and its water quality are fully presented in the 2006 paper, including estimates of external nutrient inputs. **Algal growth in the overlying water was then tested over 14 days under high and low light conditions.**

The experiment used 2x24 sediment samples, collected from 4 sites in Mona Lake (6 samples per site at each of two dates, April and June 2005). Each sediment core was 7 cm in diameter and approx 20cm in depth and included approx. 25 cm of overlying water.

The samples were incubated for 24 days in the dark at a temperature set to the mean lake bed temperature as measured at the time of collection (10-11 °C, depending on the site in April, 14-23°C in June). In half the samples, the overlying water was bubbled with oxygen to create aerobic conditions or, in the other half of the samples, with nitrogen (plus 330 ppm CO₂ to maintain pH) to create anaerobic conditions.

Algal growth

To test algal development, two 90ml sub-samples of overlying water from each of the incubated flasks were inoculated with 10 ml of algae collected from the lake using a 63 µm net. These 48 sub-samples were then incubated for 9 days (April samples) or 14 days (June samples) at the same temperature and on shaker tables (200 rpm). From each sample column, one sub-sample was given high light conditions and the other sub-sample low light.

This resulted, for each of the two dates, in 4 different treatments (aerobic / anaerobic incubation x high/low light) with 3 replicates for each of these treatments, that is 12 sub-samples per site x 2 dates.

Algal samples (GF/F filter) from each sub-sample were assessed for ash-free dry mass, chlorophyll_a, taxonomic composition, carbon (C), total phosphorus (TP).

The TP concentrations in the overlying water after the sediment sample incubation and the subsequent algal development were statistically analysed.

In the April experiments, average site TP concentrations in the overlying water after aerobic incubation were 23-34 µgP/l and 71-245 µgP/l after anaerobic incubation.

Interaction of P and light

The higher P levels resulted in significantly higher chlorophyll, lower algal C:P ratios and greater dominance by the chlorophyte genus *Scenedesmus*. Higher light also resulted in increased chlorophyll, but in higher C:P ratios, and increased biovolume of *Scenedesmus* and the diatom *Fragilaria*. The interaction between higher phosphorus and higher light was significant, with higher phosphorus levels showing a greater influence at high light than low light levels.

Similarly, for the June experiments, higher P resulted in increased algal mass (ash free dry mass), lower C:P ratio and increased *Pediastrum* biovolume. Higher light resulted in increased chlorophyll and algal mass, but increased C:P ratio and increased biovolume of *Scenedesmus*, *Fragilaria* and

Pediastrum. Again, interaction between phosphorus and light was significant, and the effect of increased phosphorus was higher in high light conditions.

Light and algal development

The comparison of algal biovolume showed that the **effect of changing light conditions (between the two conditions tested) was considerably higher than the effect of higher phosphorus** (for the two levels tested), both in April and June tests. Under low light conditions, the difference in algal biovolume between low and high P samples, at all 4 sites, was insignificant, whereas the high light resulted in much higher algal biovolume (2 – 100 x) than low light for both high and low P samples. At high light levels, algal biovolume was approx 2 – 5 x higher with high P than low P.

It can be concluded that sediment-derived phosphorus can stimulate phytoplankton growth in appropriate environmental conditions (in this case, high light), but that under the conditions tested light conditions modify algal growth more significantly than P.

Comparison of three different lakes

In previous papers, summarised below, the proportion of P coming from internal loading is assessed for three Michigan lakes.

Internal P-loading

Sediment P-release studies as above, and data on external P-loading, were used to assess the proportion of lake phosphorus loading coming from internal loading for three west Michigan lakes: Mona (as above), Spring (2003, 2006) and White (2008) Lakes. Spring and Mona Lakes have largely urbanised lakeshores and catchment, whereas White Lake has a less developed shoreline and a lower urban land cover and higher proportion of agricultural land in its catchment.

The initial total phosphorus in the sediment cores from White Lake (900 – 1280 mgP/kg sediment dry weight) were somewhat lower but of a similar order to those of Mona (1390 mgP/kg) and Spring (1280 mgP/kg). However, the P-release under anaerobic conditions for the White Lake samples was very

considerably lower than for Mona and Spring Lakes: 1.6 – 7.8 mgP/m²/day, that is approximately 2x lower than summer rates in Mona Lake and 4x lower than those in Spring Lake. In aerobic conditions the White Lake samples showed very low to negative P-release: -0.2 to 0.1 mgP/m²/day, showing that White Lake sediments can be a potential P-sink in this case.

There were **significant variations between the results from the four sample sites** studied in White Lake, corresponding to different geographic parts of the Lake.

From the data, total internal P-loading in White Lake (surface 10 km²) is estimated at 1.24 tonnes P/year. Compared to total estimated external loading, this suggests that internal P-loading makes up approximately 7% of total phosphorus loading to White Lake. This is much lower than estimates made similarly for Mona Lake (8 – 82%) and for Spring Lake (55 – 67%).

The authors conclude that management strategies for White Lake should focus on reducing the external phosphorus loading.

“Phytoplankton response to light and internal phosphorus loading from sediment release”, Freshwater Biology 53, Pages 2530-2542, 2008.

<http://www.wiley.com/bw/journal.asp?ref=0046-5070>

J. Cymbala, M. Ogdahl, A. Steinman, Annis Water Resources Institute, Grand Valley State University, Muskegon, MI, USA steinmana@gvsu.edu

“Spatial and temporal variability of internal and external phosphorus loads in Mona Lake, Michigan”, Aquatic Ecology, Vol. 43, n° 1, March 2009, pages 1-18

<http://www.springer.com/life+sci/ecology/journal/10452>

A. Steinman, X. Chu, M. Ogdahl, as above.

“An environmental assessment of an impacted, urbanized watershed: the Mona Lake Watershed, Michigan”, Arch. Hydrobiol. 166-1, Pages 117-144, May 2006

A. Steinman, R. Rediske, R. Denning, L. Nemeth, X. Chu, D. Uzarski, B. Biddanda, M. Luttenton, as above.

“An analysis of internal phosphorus loading in White Lake, Michigan”, Lake Pollution Research Progress ISBN: 978-1-60692-106-7, editors FR Miranda, LM Bernard, 2008.

See also *“Testing alum dosing to reduce internal P loading”* by some of the same authors in Scope Newsletter n° 61

Phosphate recycling feasibility

UK committee recommends P-recovery investigation

The UK's Advisory Committee on Hazardous Substances has published a review of the feasibility of recycling phosphates at sewage plants, concluding:

“Recovery and use of phosphorus as struvite also offers a number of major sustainable advantages, including natural resource protection of phosphate rocks and environmental enhancements through nutrient recovery / recycling and reduction in greenhouse gases.” ...

“Direct application of treated sewage sludge to agricultural / arable land represents a cost-effective way to recycle multi-nutrients to crops.”

The ACHS review looks at the **different possible routes for recycling P from sewage:**

- use of sewage works biosolids in agriculture, allowing recycling of all nutrients and organic content, but with problems of logistics (storage, transport of sewage sludge) and issues concerning contaminants
- use of dried sewage biosolids in agriculture, with the advantages above but with facilitated storage and transport, however with a significant energy cost for the drying
- P-recovery from sewage works, in particular as struvite precipitated in STPs operating biological nutrient removal

The committee indicates that **the UK water industry has spent to date some UK£900 million on installing nutrient removal in sewage works**, choosing mainly the chemical P-stripping process. However, a further investment of UK£500 million is now required to install nutrient removal in works situated in eutrophication 'Sensitive Areas' designated only recently under the 1991 EU Urban Waste Water Treatment Directive (1991/271).

This does not include **further nutrient removal investment additionally necessary under the EU Water Framework Directive.**

In 2005, the UK produced over 1.1 million tonnes of sewage sludge (dry matter weight), of which around 70% was spread on agricultural land. **This corresponds in P content to approximately 40% of total UK phosphate fertiliser use.**

Iron phosphates – not recyclable

The review emphasises that **iron phosphates cannot be recycled:**

“Currently phosphorus can only be recovered from sludge with biological processes (e.g. EBPR) because the commonly used chemical precipitation of phosphorus involves addition of iron salts, therefore produces a product that cannot currently be recycled for industrial use.” and also that iron phosphate in sewage sludge may not be plant-available: “A preliminary analysis of the data submitted by the water companies to OFWAT indicates that both sludge phosphorus content and bioavailability need to be optimised to achieve truly sustainable phosphate use in agriculture ... direct application rates must take into account nutrient loads, to avoid runoff or excessive build up of nutrients in the soil.”

It is noted that :

“EBPR(= biological sewage nutrient removal) has the higher capital cost and lower operation and maintenance costs. Chemical treatment has the lower capital cost and higher operation and maintenance cost” but that “... the small proportion of the EBPR facilities in the UK might not necessarily be the most cost-efficient option and the current practices should be re-evaluated using methodologies such as those described in this report”.

Struvite – a positive solution

ACHS further considers that:

“Struvite can provide sources of phosphorus, nitrogen and magnesium to plants and its suitability as a slow-release fertiliser was demonstrated in some pilot- and full-scale productions in Japan, Canada and Australia and a Defra-funded project, which applied synthetic struvite to potatoes. Moreover, levels of contaminants, such as cadmium and lead in

phosphate recovered as struvite are significantly lower than the regulatory limit.”

ACHS recommends that a life-cycle and cost assessment of P-removal and P-recovery be carried out, to assist decision making on investments in sewage works where nutrient removal needs to be installed in coming years (in application of EU sewage treatment and Water Framework Directives). And that:

“Coherent data are needed to develop a phosphate flow diagram, which can help place phosphate recycling in the context of sludge reuse.”

The conclusion is that a key issue is the economics of P-recovery:

“For a given type of activated sludge system, the EBPR retrofit design and the choice of EBPR, EBPR with chemical treatment, or chemical treatment can vary depending on other site-specific factors. Wastewater characteristics have a major impact on the feasibility and economics of an EBPR retrofit for phosphorus removal.”

The economics of struvite recovery can be improved, as well as overall resource recycling, if industrial by-products are used as a magnesium source (see article on Spain in this SCOPE Newsletter). ACHS recommends that: *“The existence of such possible secondary Mg sources should be investigated in the UK.”*

ACHS thus reaches the following conclusion: *“It can be concluded that there are strong indications that the EBPR with struvite recovery can be an economically viable technology, however, further studies of the market availability and process economics specific to the UK conditions are needed to evaluate the feasibility of large-scale struvite recovery operations.”*

ACHS = Advisory Committee on Hazardous Substances
<http://www.defra.gov.uk/environment/chemicals/achs/>

30th January 2009: ACHS review of the feasibility of recycling phosphates at sewage treatment plants
<http://www.defra.gov.uk/environment/chemicals/achs/pdf/phosphates-review.pdf>

Spain - struvite

Struvite precipitation and biological P-removal optimisation

Ongoing work in Valencia, Spain, looks at the conditions in which struvite precipitation can occur and cause problems in sludge treatment processes at biological nutrient removal sewage works, and at struvite precipitation for P-recovery as a route for avoiding this and so improving enhanced biological nutrient removal (EBNR) works operation and sludge management. Phosphate mass balance and precipitation in the anaerobic sludge digester of an experimental pilot-scale bio-P plant and the sludge thickener and anaerobic digester at the Murcia Este BNR 100.000 m³/day sewage works. Experiments with a pilot-scale stirred struvite reactor looked at the feasibility of struvite precipitation, interactions between this and the sludge treatment processes, and optimisation using fuzzy-logic control systems.

This follows an initial report of first experiments in Scope Newsletter n° 57 and of work into phosphate precipitation and influence of calcium concentrations presented in Scope Newsletter n° 67 (Barat et al.). The results of the struvite precipitation experiments are presented in detail below.

The struvite precipitation experiments used the specifically developed 21 litre capacity stirred reactor developed by LAGEP Lyon with CEEP financial support (see Scope Newsletter n° 57) integrated into a **40 l/h innovative BNR pilot plant operated using fuzzy-logic** (see below).

Struvite precipitation in a sludge digester

Marti et al. 2007 (A) present studies of phosphate precipitation in a **160 litre (20 day reaction time) experimental anaerobic digester**, situated at the Carraixet waste water treatment plant, near Valencia, and fed a mixture of approximately half pre-fermented primary sludge from a pilot fermentation plant, and half waste activated sludge from a pilot EBNR plant at the same site. A range of parameters including total phosphorus, phosphate-P, calcium,

magnesium and potassium ions, total solids, COD, volatile fatty acids were measured.

Results showed that in the fermentation reactor soluble calcium and magnesium decreased, whereas potassium increased, and that soluble phosphate was higher in the outflow than in the inflow. Calcium, magnesium and potassium content of the organic matter were estimated based on data from previous work and solid matter concentrations. Because polyphosphate hydrolysis in the reactor would be expected to release potassium and magnesium (polyphosphate counter ions) but not calcium, and because potassium is not expected to precipitate in the reactor (high ammonium concentrations make K-struvite KMgPO_4 formation unlikely), the ratio between changes in K and Mg, and changes in Ca and PO_4 enable estimation of struvite and of calcium phosphate precipitation in the reactor, and thus mass balances to be carried out. The influences of reactor pH and soluble phosphate concentration were assessed.

Digester performance

A high reactor volatile solids and COD removal was noted (55 and 60%) attributed to the high level of mixing (agitator pump).

Results showed a high level of phosphate precipitation as struvite in the reactor, with some formation of calcium phosphates. Calcium carbonate was not expected to precipitate because of competition with phosphates. Phosphate precipitation was higher at high pH and high phosphate concentrations

Struvite precipitation

Results are presented in (B) of struvite precipitation experiments in the 21 litre continuous operation stirred precipitation reactor presented in the article on fuzzy logic control below. Continuous monitoring of pH, conductivity, temperature, and magnesium, chloride and sodium hydroxide flow rates enable data collection. Results were assessed for both precipitation efficiency (removal of soluble phosphate from solution = representative of thermodynamic process efficiency) and P-recovery efficiency (removal of total phosphate = also takes

into account crystal growth, as opposed to loss of “fines”).

Pure reagent solutions were used in 23 experimental runs, with influent soluble phosphate concentration around 80 mg/l P-PO_4 , Mg:P molar ratio around 1:1 and ammonium-N:P molar ratio around 2:1. Influent calcium concentrations were varied from 0 – 0.5 Ca:P molar ratio.

Struvite precipitation was highly pH dependent, with both precipitation and recovery efficiency increasing from 40 to 80% over the pH range 8.2 to 9.5.

Reactor fouling

Efficiency deteriorated in some runs when severe fouling of the reactor with struvite was noted, presumably because this reduced mixing efficiency.

In experiments with high influent calcium concentration, a higher loss of fines (reduced P-recovery efficiency) was noted. This also occurred when manual pH control was used (as opposed to fuzzy logic control). No significant differences were observed between hydraulic residence times of 2 – 11 hours (modified by adjusting influent through-flow rates). Experimental values of pK_{SMAP} (struvite solubility product) were calculated by comparing results with MINTEQA2 software predictions.

Sludge thickening and struvite precipitation

The influence of different sludge treatment routes on struvite recovery was studied (C). This work studied **four separate pilot installations** at the Carraixet sewage treatment works (same pilots as indicated above), Valencia, Spain: an EBNR (enhanced biological nutrient removal) pilot, primary sludge fermentation and elutriation, sludge anaerobic digester, struvite precipitation reactor. Struvite precipitation experiments were carried out using two different feed liquors from sludge thickening lines: one from separate and one from mixed thickening of EBNR and primary sludges. In both cases, struvite precipitation was carried out after anaerobic digestion and centrifugation of the sludges, treating around 0.2 kg sludge per day. In each case, 5 experimental runs were carried out.

The mixing of the sludges before thickening resulted in reduced phosphate precipitation within the anaerobic digester and lower struvite reactor inflow soluble phosphate concentrations (P-PO₄) of around 40 mg/l and the separate thickening of around 150 mg/l. Although both experiments showed high phosphate removal and recovery efficiencies in the struvite reactor, phosphate recovery was significantly higher using the mixed thickening (2.5gP/kg sludge compared to 3.6 for the separate thickening stream).

The authors conclude that P-recovery as struvite requires not only optimisation of the struvite precipitation reactor but also optimisation of the whole sludge treatment system.

Case study: struvite precipitation in sludge digester

The Murcia Este municipal sewage treatment plant, Murcia, Spain, was commissioned in 2000 with a capacity of 100 000 m³/day, using an activated sludge process (A₂O configuration) for biological nitrogen and phosphorus removal. Primary sludges are concentrated in gravity thickeners and secondary in dissolved air flotation (DAF) thickeners, then mixed and anaerobically digested in three 6100 m³ digesters, before storage in a secondary digester and finally dewatering by centrifuge. The centrifuge supernatant liquor is returned to the input of the sewage works.

Plant operators have had continuous problems of precipitation fouling in the sludge line, in particular in the digestion and post-digestion processes, causing pipe blockages and difficulties with pumps and centrifuges. Despite high soluble phosphate concentrations in the thickened sludge, problem precipitation does not occur at this point in the sludge processing line because of low pH.

Detailed phosphorus, potassium, magnesium and calcium mass balances (D) were carried out by sampling at ten points in the main sewage treatment and in the sludge processing and return liquor lines, as well as in the organic matter of the primary and excess sludge. Approximately half of the available phosphate in the sludge digesters was found to be precipitating, approximately as struvite and (c. half the precipitate), as calcium phosphates (40%, mainly

hydroxyapatite) and partly by absorption to solids (9%).

The authors note that the struvite precipitation problems encountered in this plant may be accentuated by increased magnesium concentrations in influent wastewater (86 mg Mg/l), resulting from intrusion of seawater.

(A) "Struvite precipitation assessment in anaerobic digestion process", *Chemical Engineering Journal (Elsevier)*, Vol. 141, Issues 1-3, Pages 67-74, 15 July 2008: <http://dx.doi.org/10.1016/j.cej.2007.10.023>

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(B) "A pilot-scale study of struvite precipitation in a stirred tank reactor: conditions influencing the process", *Bioresource Technology (Elsevier)*, vol. 19, issue 14, pages 6285-6291, September 2008
<http://dx.doi.org/10.1016/j.biortech.2007.12.003>

L. Pastor, R. Barat, Dept. Ingeniería Hidráulica y Medio Ambiente, Universidad Politécnica de Valencia, Camino de Vera s/n, 46022 Valencia, Spain. A. Seco, see below. D. Mangin, Laboratoire d'Automatique et de Génie de Procédés (LAGEP), Université Claude Bernard Lyon I, bâtiment 308G ESCPE-Lyon 2^e étage, 69622 Villeurbanne Cédex, France.

(C) "Sewage sludge management for phosphorus recovery as struvite in EBPR wastewater treatment plants". *Bioresource Technology (Elsevier)*, Vol. 99, Issue 11, Pages 4817-4824, July 2008:
<http://dx.doi.org/10.1016/j.biortech.2007.09.054>

L. Pastor, N. Marti, A. Bouzas, A. Seco, as above.

(D) "Precipitation assessment in wastewater treatment plants operated for biological nutrient removal: a case study in Murcia, Spain", *Journal of Environmental Management (Elsevier)*, Vol. 90, Issue 2, Pages 850-857, February 2009:
<http://dx.doi.org/10.1016/j.jenvman.2008.02.001>

R. Barat, A. Bouzas, N. Marti, J. Ferrer, A. Seco, as above.

Fuzzy logic

Struvite recovery control

The nonlinear and time variant response of pH to the addition of base in struvite precipitation makes pH control by conventional methods difficult, but it is known that pH is critical in ensuring control to ensure struvite precipitation as crystal growth and avoid too rapid reaction resulting in the production of many small crystals. These “fines” are difficult to settle and therefore to recover and handle. Fuzzy logic control systems have shown their effectiveness in other processes and were here tested as a method of controlling a pilot scale stirred struvite precipitation reactor.

Seco et al. (2004) reported four months experiments on struvite precipitation using a **21 litre glass stirred reactor, developed at LAGEP Lyon, France**, for CEEP, (see Régy et al. 2002). This reactor was designed to have a perfectly mixed zone of 2.6 litres, with a three-blade vertical axis stirrer at 300 rpm and four vertical baffles to improve mixing, a poorly mixed zone of 2.3 litres, and a 16 litre wider zone for settling, to avoid flushing of fines over the top of the reactor. The reactor hydraulic residence time was 11 hours (calculated on whole reactor volume).

Six sets of experiments were carried out: five using pure chemical reagent solutions, testing different positioning of influent stream injectors, different pH, magnesium : phosphate ratio, and finally one experiment using anaerobic sludge digester supernatant.

Reagent injection

Ammonium chloride and ammonium dihydrogen phosphate solutions were mixed so that ammonium was largely in excess, as is the case in waste waters, and then magnesium chloride and sodium hydroxide added to provide magnesium and adjust pH. Soluble phosphate levels were around 90 mgP-PO₄/l throughout.

The first two experiments used a magnesium : phosphate ratio of 0.9 and a pH of 8.7. The site of the feed tubes of the reagents into the reactor was modified between these two runs. In they were situated above the stirrer, and this resulted in considerable fouling of the stirrer blades with precipitated struvite, thus reducing mixing. In this case, the reactor walls also showed fouling, probably because of the reduced stirring. In the five following

runs the injection site was modified, placing the reagent feed pipes below the stirrer, and thus obtaining reduced fouling and better mixing.

The third and fourth runs used the same **magnesium: phosphate ratio of 0.9** but with reduced pH, at 8.6 and 8.55. The fifth experiment tested an increased magnesium : phosphate ratio at 1.1 with pH again at 8.7. The sixth run used dewatering centrate from an anaerobic sludge digester from the Valencia Carraixet municipal sewage works, Spain, run at pH 8.6. This plant does not operate biological phosphorus removal, so potassium phosphate was added to bring phosphate concentrations up to 80 mgP-PO₄/l. This may have resulted in the production of K-struvite rather than struvite, but this is not examined by the authors.

Struvite production

In all cases the reactor was initially seeded with 9g of struvite crystals and phosphate recovery efficiency improved over the first 3-5 days, to reach then a near stable state, suggesting that this initial seeding was insufficient to consumer supersaturation.

In all runs, the struvite crystals removed from the reaction zone could be simply dried by placing on filter paper, and gave a non caking product, ranging from a rough powder of small crystals to pellets of aggregated crystals (1.5mm diameter).

The results showed that **60-90% of inflow phosphate was being removed in the reactor**, with lower removal at the lower pH values tested. In particular, 87% P-removal was achieved using the real sludge centrate.

Generally less than 10% of inflow phosphorus was being lost in the reactor outflow as fine crystals. However, when a temporary pH increase to 9.2 occurred (during the first run), a significant loss of fine crystals in the reactor outflow as observed (over 50% of total phosphorus in the outflow non soluble), showing the importance of accurate pH control.

The higher magnesium : phosphate ratio (run 5) did not appear to improve phosphorus removal, but this may have been due to a change in pH control system (to fuzzy logic, see below) for this run.

Fuzzy logic pH control

Chanona et al. (2006) present the **development and application, to the struvite precipitation reactor above, of “fuzzy logic” pH control** to maintain an accurate pH during the recovery process of phosphorus. The authors observed that the highly non-linear response of pH value made manual pH control difficult. Therefore, software based on fuzzy logic control (FLC) was developed to maintain the pH at a set value, using computer software to adjust pH, via the frequency rate of the sodium hydroxide dosing pump. The fuzzy logic control system inputs were the difference between observed reactor pH and the objective pH, and rate of change of this difference.

The fuzzy logic system converts the numerical input values into a set of linguistic (or logic set) values, defines decisions using an inference engine based on this set, then converts the result back to a numeric value (in this case to control the pumping rate).

The authors demonstrated that the use of Fuzzy Logic Control (FLC) software allows a precise control of pH with high stability, optimizing the process, and minimizing the operator intervention.

“Nutrient recovery by struvite crystallization and improvement for enhanced biological phosphorus removal plants”, in proceedings of International Conference on Wastewater Treatment for Nutrient Removal and Reuse, Asian Institute of Technology, Thailand, 2-29 January 2004, pages 117-124

A. Seco, L. Pastor, R. Barat, J. Ferrer, D. Mangin.

“Application of a fuzzy algorithm for pH control in a struvite crystallisation reactor”, Water Science and Technology (IWA Publishing), vol 53, n°12, pages 161-168, 2006:

<http://www.iwaponline.com/wst/05312/wst053120161.htm>

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Spain magnesite

Waste material source of magnesium for P-recovery

Further experiments confirm the usefulness of a by-product of a magnesite calcination process for magnesium oxide production (BMP) to precipitate struvite from sewage liquors for phosphate recycling. In laboratory batch experiments, using real sewage sludge liquor, the effect of the different modes of the reagent BMP preparation were tested. This new text follows previous positive results assessing the potential of this by-product for struvite recovery, see Scope Newsletter n° 55.

The sludge liquor used for testing came from the Navalcarnero 70,000 p.e. bio-P sewage treatment works in the Madrid region, Spain. As in the previous experiments, from “Arroyo del Soto” sewage treatment plant, the liquor was collected from the filtrate from dewatering of digested sludge. Phosphate concentration was on average 64 mgP/l soluble P (2.1 mM/l), with 0.7 mM/l magnesium and 18 mM/l ammonium.

Air cleaning residue

The industrial by-product was the residue from an exhaust gas cleaning cyclone at a magnesite calcination kiln operated by Magnesitas Navarra SA. It was made up of around 68% MgO and 10% CaO, with >2% iron oxides, sulphate and silicate. The by-product as collected contained >80% particles < 0.1mm.

Five experimental runs were carried out, in each case with by-product dosed at Mg:P ratio of 1.6:1. This corresponds to the results of the previous work which shows that not all the magnesium in the by-product is readily available for struvite precipitation. pH was not adjusted, the previous work having shown that the by-product alone caused a sufficient pH increase for effective struvite precipitation.

In the five runs, different preparations of the by-product were tested:

- Added directly to the test liquor:
 - as collected
 - screened to particle size < 0.04 mm
 - milled to particle size < 0.04 mm
- Added after suspension / dissolving of Mg(CO₃H)₂ in tap water:
 - after mixing at 500 rpm for 30 minutes, then added directly
 - after mixing at 500 rpm with air injection for 28 hours, then settled for 4 hours and supernatant only used.

In batch run, 5 litre containers were used. The liquor was first aerated for 30 minutes, then the prepared by-product was added, and then the container was stirred for 3 hours at 120 rpm.

In all five cases, the phosphate concentration was reduced from around 70 mg/l to 10-20 mg/l. The preparation (5) above, that is with the longest suspension mixing time, showed to be the most effective, reducing phosphate to around 10 mg/l in 30 minutes (or less – concentrations not measured between time = 0 and 30 minutes). The other by-product preparations took longer to reduce phosphate concentrations, and gave levels slightly higher than for preparation (5) even after 3 hours.

These experimental results (this paper, 2004 paper summarised in Scope Newsletter n° 55) are completed by **detailed calculations of the reaction kinetics**, comparing the industrial by-product magnesium source and pure MgO (magnesium oxide), presented in the 2005 paper referenced below.

“Kinetics of phosphorus removal and struvite formation by the utilization of a by-product of magnesium oxide production”, Chemical Engineering Journal (Elsevier), 111 (2005), pages 45-52:

<http://dx.doi.org/10.1016/j.cej.2005.05.005>

M. Quintana, E. Sánchez, M.F. Colmenarejo, G. García, Centro de Ciencias Medioambientales (CSIC), C/Serrano, 115-Duplicado, 28006 Madrid, Spain. J. Barrera, Centre Europeen d'Etude des Polyphosphates, European Chemistry Council, Avenue E, Van Niewenhuyse 4, bât 2. B1160 Bruxelles, Belgium. R. Borja, Instituto de la Grasa

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“Removal of phosphorus through struvite precipitation using a by-product of magnesium oxide production (BMP): effect of the mode of BMP preparation”, Chemical Engineering Journal (Elsevier), 136 (2008), pages 204-209: <http://dx.doi.org/10.1016/j.cej.2007.04.002>

Same authors as above, plus L. Travieso, Centro de Ciencias Medioambientales (CSIC), Madrid.

Turkey

Natural mineral source of magnesium for P-recovery

Natural magnesite mineral from the Kutahya region of Turkey was tested as a magnesium source for P-recovery by struvite precipitation from landfill leachate. Experiments were carried out in 250 ml beakers, mixed rapidly for 5 minutes, followed by 15 minutes slow mixing with NaOH pH adjustment. Both synthetic solutions and real landfill leachate were tested. Finally the supernatant, after struvite precipitation from the leachate and settling, was fed to an anaerobic UASB reactor (used for biological treatment of the landfill leachate) to assess the impact on this reactor operation.

The landfill leachate used comes from the Odayeri Sanitary Landfill near Istanbul, Turkey, which produces around 1000 tonnes of litres per day, containing an average 43 mg/l total phosphorus, 20,000 mg/l COD and 2,700 mg/l ammonium. Previous work on P-recovery as struvite from this leachate is reported in Kabdasli et al., 2000, see Scope Newsletter n° 38.

Natural mineral

The magnesite mineral was supplied by Kütayha Magnesite Co. from the abundant natural deposits in this part of Turkey. It is composed mainly (98%) of magnesium carbonate MgCO₃ with a magnesium content of around 30% by weight, with traces of calcium, iron and silicate (<1%).

Initial experiments were carried out using synthetic solutions containing ammonium at concentrations comparable to those in the leachate, with phosphate (H_3PO_4) and magnesite addition to reach the same molar concentration as the ammonium, in order to assess optimal molar ratios and pH. Experiments were carried out to investigate how to obtain soluble magnesium bulk solutions from the poorly soluble magnesite (variation in molar concentration, time, pH). Solubility of the magnesite increased significantly when acid was added, with optimum being 2M HCl addition to 1M magnesite.

In real leachate the 20 minute batch reaction experiments (as indicated above) achieved around 90% ammonium removal.

Economics

An economic assessment indicates that the use of magnesite, taking into account the HCl cost, reduces the total cost of struvite recovery from 28 to 23 US\$/m³ leachate treated, compared to instead of commercial magnesium chloride (magnesium cost reduced from 40% to 4% of total cost). The principal cost remains the addition of phosphate up to the molar concentration of ammonium in the leachate.

The struvite precipitation causes an increase in salinity of the leachate from 4,500 to 18,500 mg/l (addition of phosphate and magnesite up to molar concentration of ammonium). It was therefore tested how this affected a UASB biological reactor treating the leachate. This showed no deterioration, and in fact **small improvements in removal of COD and BOD, and a significantly lower level of suspended solids in the reactor outflow** and reaction pH 8.6 and Mg:NH₄:PO₄ ratio of 1:1:1.

The authors conclude that natural magnesite mineral can be feasibly used as a low cost magnesium source for struvite precipitation.

“Use of magnesite as a magnesium source for ammonium removal from leachate”, Journal of Hazardous Materials (Elsevier) Vol. 156, Issues 1-3, 15 August 2008, pages 619-623. <http://dx.doi.org/10.1016/j.jhazmat.2007.12.067>

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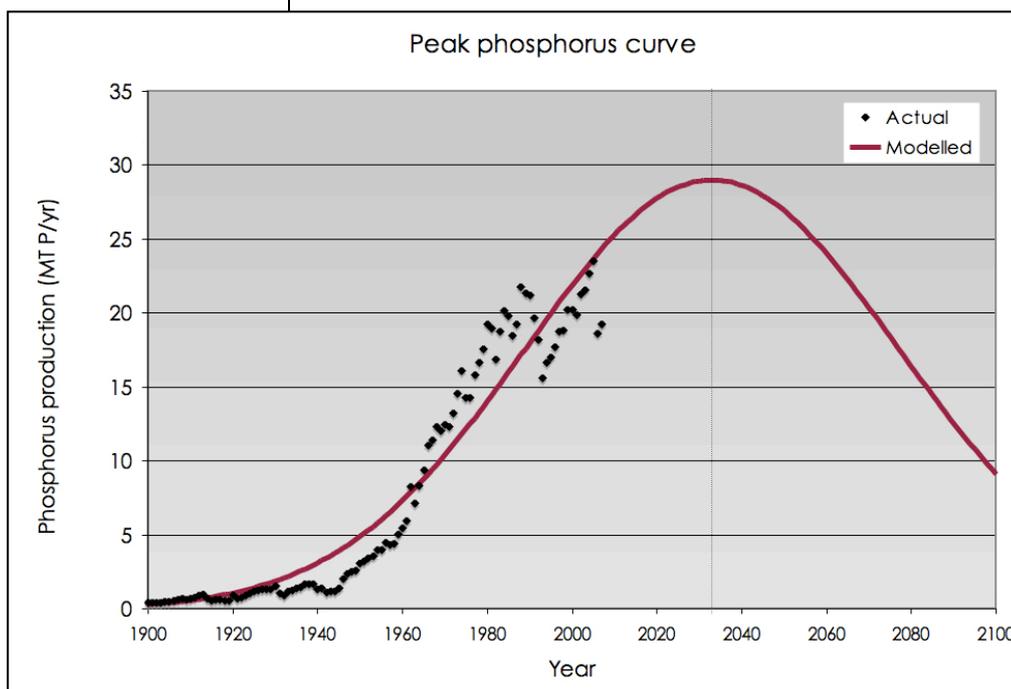


Figure 1: global peak phosphorus curve based on industry data of reported world phosphate reserves in 2007

Phosphorus flows

Peak phosphorus ?

Sustainable futures

Modern agriculture is dependent on continual inputs of phosphorus fertilizers to sustain high crop yields and replace the soil with nutrients lost in each harvest. Yet the main source of phosphate fertilizers – phosphate rock – is a non-renewable resource and high quality global reserves may be depleted in 50-100 years.

While demand for phosphorus worldwide is expected to increase over the next 50 years, a peak in production is predicted to occur around 2030 (figure 1).

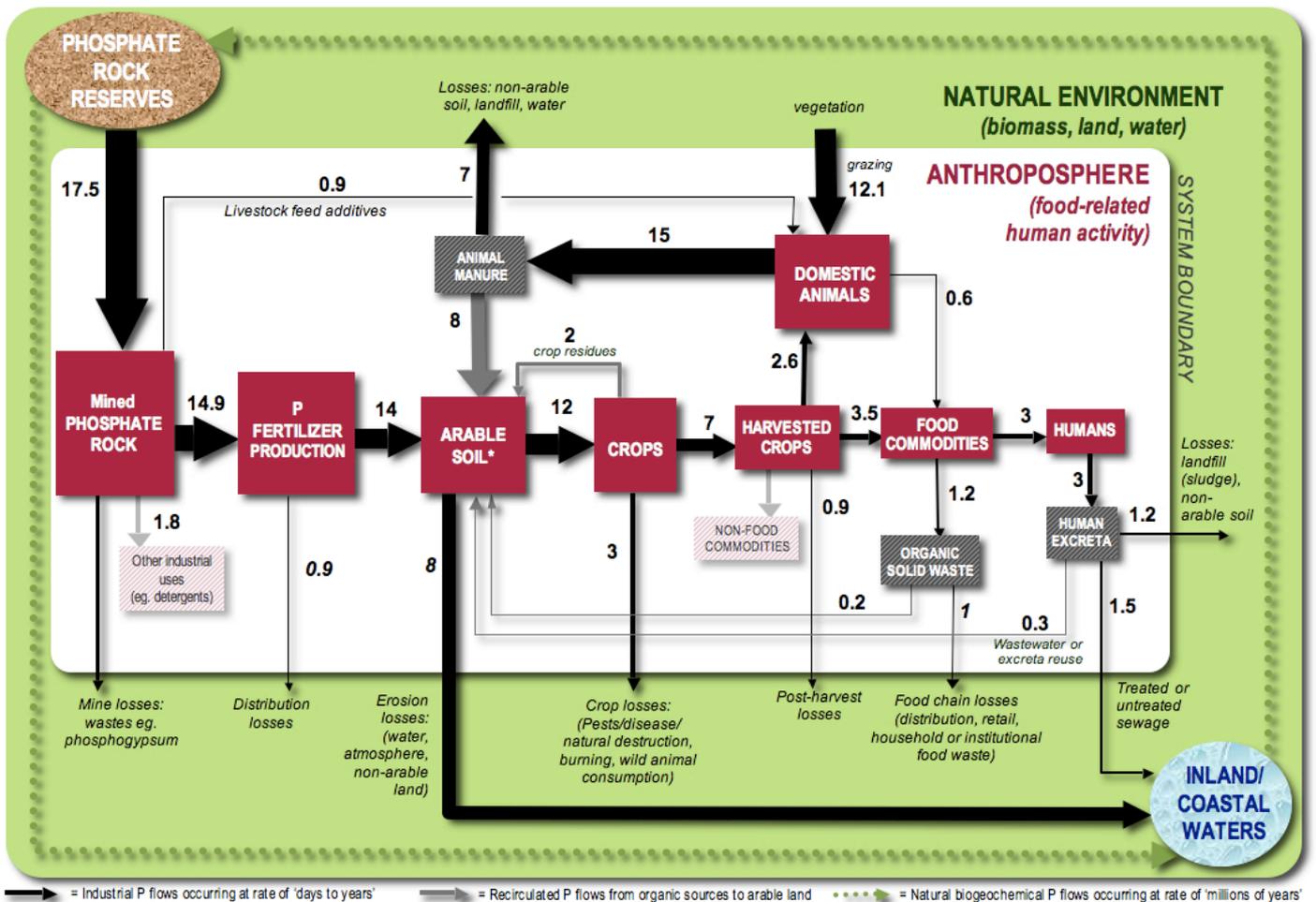
While the exact timing of peak phosphorus may be disputed, the fertilizer industry acknowledges that the quality of remaining reserves is declining, and costs are increasing. The increased demand worldwide for meat and dairy products and biofuel crops has put upward pressure on phosphate fertilizer demand. This contributed to the 800% price rise of phosphate rock from US\$50/tonne to over US\$400/tonne between 2007-2008.

The reserves that remain are in the control of just a handful of countries, including China, the US and Morocco. China imposed a 135% export tariff on its reserves last year, effectively stopping exports to secure domestic supplies. The US has approximately

25 years left of reserves and already imports large quantities of phosphate rock from Morocco to maintain its position as the world's largest producer of phosphate fertilizers. Morocco occupies the Western Sahara and controls its high-grade phosphate rock reserves, a strategic situation which is seen by the authors as a potential source of conflict.

The mining, production and global trade of 30 million tonnes of phosphate rock each year bears an ever-increasing environmental cost. Every tonne of phosphate generates 5 tonnes of phosphogypsum – a by-product that, in general and except where specific processing and valorisation routes are developed, has to be stockpiled because it is too radioactive to reuse.

Figure 2: key phosphorus flows through the global food production and consumption system, indicating phosphorus usage, losses and recovery at each key stage of the process. Units in million tonnes per year.



Processing and particularly transport of phosphate rock and fertilizers has until now relied on cheap oil. With growing concern about peak oil and climate change there is a need to reconsider the current production and use of phosphorus.

Given the importance of phosphorus for global food production, it is of concern that phosphate scarcity is not on the priority agenda in any political discussions on global food security.

An analysis of global flows of phosphorus from mine to field to the dinner table and to the toilet can help in locating and quantifying phosphorus losses in the system and thus assist in identifying potential recovery points. **Figure 2 tracks the annual tonnes of phosphorus through each key stage in the food production and consumption system** - including mining, fertilizer production and application, crop harvesting and food processing, consumption by humans and animals and excretion. While humans eat approximately 3 million tonnes of phosphorus

in food each year, depending on diet (meat and dairy products consumption in particular) five times this amount is mined for food production. The remainder is lost during fertilizer production and application, as crop residues or in livestock manures and food waste. Further, we excrete 3 million tonnes of phosphorus in our urine and faeces each year. More than half of this is generated in cities and most of this is effectively lost in sewage sludge or ends up in waterways if not intentionally recovered and reused. This analysis tells us that an integrated approach is required to simultaneously address phosphate scarcity and water pollution due to phosphate leakage both from agriculture and from municipal waste waters.

In addition to improving fertilizer use efficiency and reducing the demand for phosphorus through influencing diets, reusing locally available and renewable sources of phosphorus from excreta, manure, food waste and other organic sources is likely to play a critical role in securing future food production for a growing world population.

Urine is essentially sterile and contains all the plant nutrients (N,P,K) in the correct ratio. According to some studies in Sweden and Zimbabwe, the nutrients in one person's urine are sufficient, if combined with recycling of animal and soil

phosphorus, to produce most of a person's food requirements. Urine can be easily collected separate from faeces via a dry or wet urine-diverting toilet (see figure 3).



Figure 3: a) a urine-diverting dry squat toilet from India (photo: S.Vishwanath www.rainwaterclub.org); b) a urine-diverting dry toilet from Sweden (photo: Dana Cordell).

Where urine is not separately collected for recycling, then the recycling of phosphorus from sewage is one important route, either by effective reuse of treated sewage biosolids as a fertiliser, or by nutrient recovery in sewage works where biosolids spreading is not feasible or accepted.

As Victor Hugo wrote in *Les Misérables*:

Science, after having long groped about, now knows that the most fecundating and the most efficacious of fertilizers is human manure. The Chinese, let us confess it to our shame, knew it before us. Not a Chinese peasant – it is Eckberg who says this – goes to town without bringing back with him, at the two extremities of his bamboo pole, two full buckets of what we designate as filth. Thanks to human dung, the earth in China is still as young as in the days of Abraham. Chinese wheat yields a hundredfold of the seed. There is no guano comparable infertility with the detritus of a capital. A great city is the most mighty of dung-makers. Certain success would attend the experiment of employing the city to manure the

plain. If our gold is manure, our manure, on the other hand, is gold.

Despite the imminence of a global phosphorus crisis, phosphate scarcity is missing from the priority agenda in discussions on global food security and global environmental change. Further, there are no existing institutional arrangements or international organisations responsible for ensuring the long-term security of phosphorus for food production. Significant institutional and physical changes will be required in the future to achieve global phosphorus security and hence food security.

"The story of phosphorus: global food security and food for thought", *Global Environmental Change* (2009): doi:10.1016/j.gloenvcha.2008.10.009

Full paper at:

http://www.sciencedirect.com/science?_ob=PublicationURL&_toctype=%23TOC%236020%239999%2399999999%23999999%23FLA%23&_cdi=6020&_pubType=J&_auth=y&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=9c6df98a0ba30d3de206d5f71b2f76c9

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Phosphorus futures website: www.phosphorusfutures.net

Sewage and agriculture

Plant availability of phosphorus in sewage sludges

Agricultural application of sewage biosolids is an optimum solution for recycling not only phosphorus, but also nitrogen, organic values and other elements. However, phosphorus can only be considered to be effectively recycled if it is applied in response to crop needs (effectively replacing the use of mineral or other fertilisers) and if the P-content is bio-available to plants. Various studies in the past have shown that the plant availability of phosphorus in sewage sludge is very variable (see eg. Römer et al., in SCOPE Newsletter n°67). Recent work confirms this, and also assesses the question of to what extent agricultural application of sewage sludge can contribute to an accumulation of phosphorus in soils, and whether this P becomes plant available in following years.

Krogstad et al. tested five different sewage sludges in greenhouse pot trials with rye grass in moraine and clay soils, comparing growth, plant P content and soil P content to application of a mineral fertiliser (at control = zero plus three different fertilisation levels). A combination of sludge plus mineral fertiliser was also tested. The five sludges were a biological P-removal sludge, two aluminium dosing P-removal sludges and two iron dosing P-removal sewage (of which one with lime treatment). Sludge sanitisation and post-treatments were different for each sludge.

Soil pH

The different sewage sludges each affected soil pH, which is liable to directly impact the plant availability of both phosphorus and other elements.

The results show the complexity of relations between sewage and sludge treatments, and plant availability and uptake of sludge phosphorus. **The authors conclude that the bio-P sludge showed the highest amount of plant available phosphorus**, and that sludge from works using iron or aluminium precipitation showed low fertilisation values. Application of such sludges in combination with water-soluble inorganic phosphates appeared to

increase the plant availability of the sludge phosphorus.

The paper also assessed the “repercussion value” of sludge P, that is **the amount of plant-available phosphorus left in the soil after a crop** (at the end of the growing season). This value is generally deducted from the phosphorus fertiliser need considered necessary for farmers to supply to crops for the next season, so that phosphorus present in this way can be effectively available for crops in year N+1.

The authors conclude that the repercussion value decreased dramatically for sewage sludges treated with iron or aluminium flocculating agents. They also note that although the phosphorus in soil after application of such sludges is not necessarily plant available, sludge application nonetheless increases total soil phosphorus by 50 – 95%, posing a possible risk of contributing to eutrophication if this excess phosphorus is transferred to surface waters by soil erosion or run-off, and if the phosphorus then becomes bio-available through water or sediment processes.

Sludge treatment routes

Guivarch’s thesis looks at **P availability in a range of different sewage sludges**, based on pot trials, analysis of different forms of phosphorus in soils and sludges, and a number of previous sludge fertilisation studies in literature. A key aim is to identify reliable indicators of the plant availability of sludge P: a one month sludge incubation test is proposed as a potentially reliable protocol. However, this indicates availability for immediate plant uptake, and the residual P availability (“repercussion value” above) must also be questioned.

From previous literature, the short term fertiliser value of phosphate in sewage sludges appears 74 – 107 % VF, and sludges treated with iron salts as 62 – 85% (Frossard, 1996)

80 sludges from French municipal waste water treatment plants were collected for analysis, of which 20 were from plants operating phosphate removal (9 bio-P removal, 11 combined bio-P plus chemical dosing). 16 of these sludges were used in pot trials of rye-grass (5 from works with iron addition, 11

without), in which plant phosphorus uptake was analysed using radioactive P tracing and total plant P-content analysis.

The author concludes that anaerobic digestion, composting, heat treatment, and iron or aluminium dosing all decrease the plant available proportion (RPA) of phosphorus in sewage sludges, which is also affected by the soil or soil/sludge pH. The water soluble phosphorus in sewage sludge is reduced to 2% in sludges where iron salt dosing has been used, compared to 25% of total sludge phosphorus where iron salts have not been dosed.

She notes that current recommendations for the agricultural application of sewage sludges result in an accumulation of P in soils, and that the use of sludge “RPA” values (available phosphorus) must be developed to enable better sludge management.

Zhang (1991) previously measured the **availability of phosphorus in three different municipal sewage works sludges: heat dried, coagulated and aerobically digested**. 63% of the phosphorus in the heat dried sludge was present as calcium phosphates, and the phosphate in this sludge was poorly plant available and had little effect on the soil available P or the plant P uptake (1/4 – 1/3 of the effectiveness of MCP fertiliser). 40% of the phosphorus in the aerobically digested sludge was water or NaCH₃ soluble, and this sludge had a high phosphorus efficiency for plants (42 – 71%). The coagulated sludge showed intermediate results. The author concludes that sewage sludge phosphorus is less plant available than mineral fertiliser, with the availability being strongly dependent on the sludge treatment applied.

Too much or too little?

Webber (2003) assesses the **implications for Quebec soils of application of sewage sludge containing iron or aluminium resulting from chemical P-removal**. The amorphous iron or aluminium oxides present in such biosolids, after repeated long-term application to soils, can either result in an increase in soluble soil phosphorus with resulting risks of eutrophication of surface waters, or in reduced soil phosphorus availability leading to crop P deficiency, depending strongly on soil type and pH.

Iron and aluminium salts added in municipal waste water treatment form amorphous oxides on contact with water, offering a large surface area, enabling fixation of phosphates and other suspended matter. These flocs are then settled out into sewage sludges. Past literature cited indicates that phosphorus in sewage sludge is less plant available than that in fertilisers, and that this is particularly so for sludges where iron or aluminium salts were used.

The author estimates that for a sludge aluminium content of 1.5% or iron content of 4%, **two thirds of the sludge phosphorus would be readily available**, whereas this proportion falls to 44% for 3% aluminium or 8.5% iron.

For non-calcareous soils which are near neutral in pH, the availability of soil phosphorus depends strongly on the P-saturation of the amorphous oxides, that is $SP_{M34} = P_{M3} / Al_{M3}$ (where M3 = mg/kg soil).

The author estimates levels of soluble soil phosphorus SP_{M34} (0.025 for heavy soils and 0.04 for light soils) below which crop phosphorus deficiency is susceptible to occur and values above which phosphorus loss to surface waters is a risk ($SP_{M34} = 0.075$ for heavy soils and 0.15 for light soils).

“Influence of chemically and biologically stabilized sewage sludge on plant-available phosphorus in soil”, *Ecological Engineering* 25, pages 51-60, 2005.

www.elsevier.com/locate/ecoleng

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“Valeur fertilisante à court terme du phosphore des boues de stations d’épuration urbaines”, Thesis by A. Guivarch, Institut National Polytechnique de Lorraine : Institut National de la Recherche Agricole (INRA) Bordeaux Unité d’Agronomie, June 2001,

www.bordeaux.inra.fr/tcem/document/Guivarch_these.PDF

“Valorisation agricole des biosolides municipaux : revue de littérature et recommandations concernant l’impact des sels d’aluminium et de fer sur la disponibilité du phosphore du sol », M. Webber, *Agrosol*, octobre 2003,

vol. 14, n°1, pages 22-28 (text in French, summary in English).

“Caractérisation et biodisponibilité du phosphore de trios types de boues d’épuration urbaines”, Thesis at the Institut Polytechnique de Lorraine / INRA, I. Zhang, July 1991.

J. Webber, Environmental Consultant, 590 Barons Court, Burlington, Ontario L7R 4E4, Canada, mdwebberenvironmental@cogeco.ca

“The fate of sludge phosphorus in soil-plant systems”, E. Frossard, S. Sinaj, L-M. Zhang, J. Morel, *Soil. Sci. Soc. Am. J.*, 60, pages 1248-1253, 1996.

E. Frossard, S. Sinaj, Institute of Plant Sciences, Swiss Federal Institute of Technology (ETH), Eschikon Research Station, Eschikon 33, CH 8315, Lindau, Switzerland. L-M. Zhang, J. Morel, ENSAIA, Vandoeuvre les Nancy, France frossard@ipw.agrl.ethz.ch

International Conference on Nutrient Recovery from Wastewater Streams

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

c 100 speakers and posters

Sunday May 10 th	19:00	Welcome Reception
Monday May 11 th	08:30	Conference Opening and Welcome Address
	11:00	Keynote Address: Dr. James Barnard (2007 Clarke Prize) Special Guest: Robert F. Kennedy
	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 12 th	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 13 th	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 14 th :		Technical tours and visits – see below and http://www.nutrientrecovery2009.com/showcontent.aspx?MenuID=606

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

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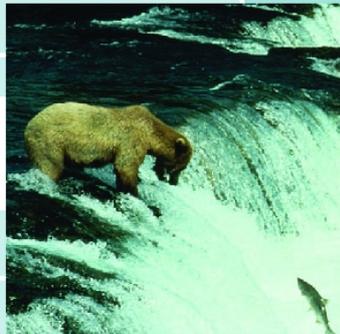
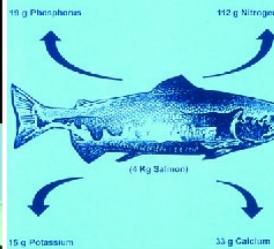
International Conference on Nutrient Recovery from Wastewater Streams

May 10-13, 2009

The Westin Bayshore Hotel and Resort
Vancouver, British Columbia, Canada

Editors:

Ken Ashley,
Don Mavinic
and Fred Koch



Conference news and update

Special guest: Robert F. Kennedy

On May 11, 2009, special guest Robert F. Kennedy Jr. will address the conference delegates. Mr. Kennedy serves as Chief Prosecuting Attorney for the Hudson Riverkeeper and President of Waterkeeper Alliance. He is also a Clinical Professor and Supervising Attorney at Pace University School of Law's Environmental Litigation Clinic and is co-host of Ring of Fire on Air America Radio. Mr. Kennedy has worked on environmental issues across the Americas and has assisted several indigenous tribes in Latin America and Canada in successfully negotiating treaties protecting traditional homelands. He is credited with leading the fight to protect New York City's water supply. The New York City watershed agreement, which he negotiated on behalf of environmentalists and New York City watershed consumers, is regarded as an international model in stakeholder consensus negotiations and sustainable development. He helped lead the fight to turn back the anti-environmental legislation during the 104th Congress.

Technical tours programme Thursday, May 14, 2009

See: <http://www.nutrientrecovery2009.com/showcontent.aspx?MenuID=606>

Fraser Valley stream channels and reservoir fertilization

08:00-16:30. Participants will travel by bus to visit two fisheries restoration programs being coordinated by the BC Ministry of Environment. The first stop is the Chilliwack Experimental Channels, a series of nine replicate experimental channels, where Ministry staff conducts experiments with struvite and various forms of organic and inorganic nutrients to determine the dosage and timing to increase the growth and survival of native salmonids. The results from the experimental channels are then transferred to full sized rivers and streams for routine treatments. The bus will then travel to Alouette Reservoir, near Maple Ridge, where Ministry biologists are fertilizing the reservoir to restore its productivity and rebuild native fish populations. The bus trip, which includes a box lunch, will take approx. 8 hours. Please bring hiking shoes, warm clothing and rain gear, as the weather can be unpredictable in these mountain valleys.

Lulu Island WWTP R&D struvite recovery set-up

08:00-12:30 Lulu Island WWTP, Richmond, BC-This secondary wastewater treatment plant is the home of two identical, pilot-scale, struvite recovery research reactors, operated by UBC. Each reactor is fully instrumented, for data collection and process optimization, and each reactor is equipped for carbon dioxide stripping, for pH control.

Portland, Oregon (USA) full scale Ostara struvite recovery (possible Visa required)

04:30-20:00 (flight Vancouver – Portland must be booked separately). Durham Treatment Facility, Portland, Oregon WWTP, USA. This advanced wastewater treatment facility is the home of North America's first multi-reactor, struvite recovery(Crystal Green) system, built and constructed by the Ostara corporation. This plant will be the first in the US to employ the next generation of Ostara's technology, incorporating instrumentation and feed-back loop control systems currently under development by the UBC research team. Please note that special Visa requirements may exist for certain delegates wishing to enter the United States. This is an all day tour.

Edmonton, Alberta (Canada) Goldbar full scale Ostara struvite recovery

06:30-20:00 (flight Vancouver – Edmonton must be booked separately). Edmonton Goldbar WWTP, AB-This site is the home of North America's first full-scale, struvite recovery system, installed by Ostara, Inc. and managed jointly by Ostara and the City of Edmonton. This facility treats approximately 20% of the plant capacity and the recovered product is marketed commercially as Crystal Green. Eventually, a total of five reactors will be built and operated at this site. No special Visa requirements are required for this site visit. This is an all day tour.

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