SCOPE NEWSLETTER

SCOPE N°32 - 05/1999 - France - Vilaine River

Detergents contribute < 3% of surface water P

Total nitrogen and total phosphorus loads, from natural and anthropogenic sources, to the upper Vilaine river (above Rennes) were compared with export in the river water over a one year period 1994-5.

The section of river studied is 90 km long with a catchment of 902 km2. 78% of the land surface is agricultural. The area is one of France's main cattle production centres (1.93 heads/ha in 1988), with land use being predominantly grass, both temporary and permanent (the latter making up more than 40% of agricultural land use) and maze maze (around 30%), with some wheat (<7%).

The population is 60,000 persons, mainly in 40 small towns (the biggest, Vitré, has a population of 15,000). There are 20 municipal and 4 industrial sewage works.

River water was sampled for flow rate and nutrient concentrations at 20 different sampling sites on the Vilaine and on tributaries within the upper Vilaine catchment, enabling the contribution of subcatchments to be studied. Sampling was carried out every 2 weeks during periods of low flow, and more frequently during high flows. The river is typical of this area of France, with low flows during summer and autumn, and a relatively short period of high discharge (70% of the annual flow) from December to March.

Nutrient loads were calculated using data from point sources and estimates based on agricultural statistics and land use. Export from each subcatchment and from the whole catchment was calculated using measured concentrations and flow rates.

========= Nitrogen sources =========

Nitrates accounted for more than 86% of total nitrogen load. Sewage works were a significant source with the Vitré waste water treatment plant alone accounting for 1.5% of total catchment nitrogen.

The nitrogen export rate from land varied considerably between subcatchments, from 25.1 to 64.9 kg total N/ha/year. The highest export subcatchment showed the highest density of cattle and the highest % area of permanent grassland. Some nitrogen was retained in ponds and reservoirs: for example, 140 tonnes total N in the Haute Vilaine reservoir (7 million m3) over the year studied. 15% of total nitrate load was retained in the water bodies of the catchment.

Overall, non point sources contributed 95% of total nitrogen over the whole catchment.

========= Phosphorus sources =========

One of the main features of phosphorus movements was the large amount retained in the Haute Vilaine reservoir (28% of input load retained). **Overall, 15% of the total catchment phosphorus load was retained in the different reservoirs.**

Vitré appeared to have a more significant impact on total P than on total N. However, the quantity of total P input from the town’s industrial and municipal sewage plants was calculated (1.8 tonnes/year) as insufficient to account for the load measured, so that other local point sources may be occurring.

Overall, total P export from the whole catchment was around 100 tonnes over the year studied. As for total N, most of this export occurred during the high flow period (December – March).

P loss from land varied from 1.15 to 1.3 kg total P/ha/year.

Similarly to nitrogen, non point sources (agriculture) were highly dominant for phosphorus loadings: 90% of total P inputs.

SCOPE Newsletter editor's note: On this basis, taking detergent phosphates in France as 27% of sewage phosphates (IFEN "L’Environnement en France" 1999), it can be concluded that detergents represent less than 3% of the total P load to this surface water system (27% x 10%).

The total P outflow from the catchment for the 12 month period studied was 103 tonnes P.

SCOPE Newsletter editor’s note: This can be compared with detergent phosphate consumption for the catchment population, which can be estimated as (population = 60,000) x 0.348 kg/year (per person consumption of detergent phosphate as P, France 1996) = 21 tonnes. This corresponds to roughly 20% of total P outflow, so that only a small proportion of the expected detergent phosphates actually appear as surface water load, the remainder presumably being removed in sewage treatment or not reaching the lower river waters (adsorption to soils after septic tanks, transfer to sediments …).

The authors note that this study shows the significant buffer effect on nutrient loadings of stagnant waters, and the need for a better understanding of the exchanges of nutrients between sediments and water.

"Seasonal and spatial trends of nitrogen and phosphorus loads to the upper catchment of the river Vilaine (Brittany): relationships with land use". Hydrobiologia 373/374, 1998.

S. Moreau, G. Bertru, Laboratoire d'Evolution des systèmes Naturels et Modifiés, Université de Rennes I, France. C. Buson, Institut Scientifique et Technique de l'Environnement.

SCOPE NEWSLETTER

SCOPE N°32 - 05/1999 - Catchment management

Phosphorus loss from agricultural soils

Measurements of P losses from small subcatchments around the Rosemaund agricultural station in the River Lugg catchment area, UK, indicate significant variations between different land uses and drainage systems. The authors offer an overview of current research into agricultural P loss and emphasise the need for small-scale models which take into account P transfer mechanisms as well as export coefficient estimates.

The areas studied were the Belmont catchment (150 ha), two subcatchments within this (Jubilee 31 ha and Moorfield 6.3 ha) and a drained arable field area within Jubilee (Foxbridge 5.9 ha). All the Foxbridge measurements were taken in the field drain, thus indicating subsurface P runoff only.

Total phosphorus runoff to surface water was assessed for each catchment using a combination of measured values (P concentration and outflow volumes) and estimates (based on literature values for runoff related to different land uses). **Total P export varied from 1.06 to 2.64 kg/ha/year between the different catchments**, with a molybdate reactive fraction of around 1/4 (higher for Belmont, which was influenced by the farm yard and a small sewage works serving the farm buildings and workers' houses).

========= Subsurface runoff =========

Foxfield showed a **loss of total P, in the subsurface drain, of 1.64 kg/ha/year, indicating the significance this type of runoff**. The low soluble fraction in this runoff (15% MRP) corresponds to subsurface transport of P adsorbed to suspended clay and silt particles.

P loss from the Jubilee subcatchment was the highest, despite having 30% grassland (near zero for Moorfield). This was thought to be related to differing seasonal runoff patterns : the duration of runoff flow at Moorfield was December – march only, compared to all year for Jubilee.

Total P runoff figures are compared to literature values given as (kg/ha/year):

- **arable land 3, but up to 30 in undrained clay-rich soils**
- **grassland 0.5**

- **woodland 0.02**

======== Scale of modelling ========

The authors offer an overview of soil phosphorus loss processes and of current research, underlining that both **soluble and particulate P loss to surface waters eventually become bioavailable in aquatic systems**, contributing to nutrient enrichment.

Phosphorus can be lost from soils to surface waters either attached to soil particles in subsurface drainage or surface runoff (erosion) or in a soluble form when soil P-adsorbtion capacities are saturated with intensive use of fertilisers or manure. Exchanges occur between surface, shallow subsurface and deep subsurface flow of phosphorus, depending upon soil P-saturation, slope of soil and permeability.

Surface P runoff in the UK is particularly related to soil erosion and downhill sediment transport during prolonged, intense rainfall events. The quantities of phosphorus transported by this pathway to surface waters depend on soil surface characteristics, soil properties and steepness of slope near water courses.

Subsurface drainage of grassland and arable farmland also provides a very effective pathway for the transport of phosphorus to surface waters. Where the upper layer of the soil’s P-adsorption capacity has been exceeded by fertiliser or manure application, or where downward movement is accelerated by macropore flow, subsurface drains can intercept vertical leaching of soluble phosphorus, bypassing existing soil adsorption capacities.

The long term agricultural application of phosphorus in excess to crop requirements leads to a **progressive saturation of soil P-adsorption capacities** along soil horizons. This also occurs downslope as P is continually transported from soils upslope. Although this process may be very localised, with saturation occurring along preferential P-transport channels (relating to water flow or soil structure), it still has a major influence on the quantities of phosphorus reaching surface waters, because of the transport of phosphorus along these preferential pathways.

Particulate phosphorus can also be transported below the surface of the soil by eluviation of fine soil particles. Selective adsorption of soluble P to fine soil particles can lead to a P-rich layer accumulating below the root zone or to lateral transport of colloidal P-rich material along rapid flow pathways through the soil, providing a further mechanism for transfer to surface waters.

Such conceptual models of P export provide useful understanding, but most experimental work has been carried out at the plot scale, under site specific conditions. These plot scale experiments, with careful hydrological isolation and drainage, allow accurate estimations of P transport along specific pathways.

To complete plot scale studies and conceptual models, the authors identify a clear need for research at the small catchment level (1 – 10 km2) to enable accurate estimations of P export from given land use and management systems.

"Phosphorus loss from agricultural catchments: pathways and implications for management". Soil Use and Management, 1998 – 14.

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SCOPE NEWSLETTER

SCOPE N°32 - 05/1999 - South Africa

P-reduction fails to bring benefits

The effects of a 1 mg/l ortho-P standard for sewage works releasing into the Vaal river, near Johannesburg South Africa, are assessed by comparing the 10 years prior to the decision with the 10 years after it. Although 40% of sewage works were not complying, average ortho-P emissions from works were reduced over 50%.

The Vaal rivers system studied flows into the 64 km long Vaal River Barrage, used by Rand Water for drinking water extraction. **The river system's water quality is heavily dependent on sewage treatment**, as it is fed by the Vaal river (releases from an upstream dam, 65% of flow), along with two rivers, the Klip (31%) and the Suikerbosrant (7%) which both flow through greater Johannesburg. In the case of the Kip river, 87% of flow is made up of sewage works outflow. Catchment land use is dominated by industrial, gold mining and domestic development.

Ortho-P emission values from the sewage works within the river system were collated over the 20 year period, as were ortho-P and chlorophyll concentrations in the upstream dam release water, the Kip and Suikerbosrant rivers and at the water extraction point in the Val River Barrage. Algal species composition was also monitored at the water extraction point.

======== Reduction in reservoir ortho-P but not chlorophyll ========

Compliance with the 1 mg/l ortho-P emission limit increased from 6-13% to 52-60% of sewage works, and mean **ortho-P levels in sewage works emissions decreased from 8.63 to 3.49 mg/l along the Suikerbosrant, and from 4.37 to 1.98 mlg/l along the Kip river**. This decrease in emissions resulted in **very significant decreases in aquatic ortho-P concentrations:**

- **35%** in the Kip river
- **52 to –54%** in the Suikerbosrant and Vaal rivers
- **37%** at the water extraction point in the Vaal River Barrage.

These decreases in aquatic ortho-P did not, however, result in significant reductions in chlorophyll

concentrations at the water extraction point: median levels were unchanged and mean levels actually increased from 22.6 (SD = 24) to 25 µg/l (SD = 28).

The relative frequency of occurrences of chlorophyll > 30 µg/l decreased very slightly from 72 to 69% (this level is considered by Rand Water as the maximum possible for drinking water treatment).

========= N:P ratios and blue-green algal blooms =========

The reduction in aquatic ortho-P was accompanied by a very **considerable increase in the N(ammonium+nitrate): P(ortho-P) ratio**, from 2.5:1 to 13:1 at the Vaal River Barrage water extraction point. This was probably a result not only of ortho-P emission reductions, but also of increased nitrogen emissions due to increased sewage works outflows, inadequate maintenance and overloaded sewage works.

The algal species composition also changed: **Cyanophyceae (*Anabaena* and *Oscillatoria*) increased in dominance ten-fold** and Chlorophyceae (*Scenedesmus* and *Chlamydomonas*) doubled. This resulted in increased incidence of taste and odour problems, with concomitant possible toxic algal blooms.

========= Phosphorus not limiting =========

The authors conclude that phosphorus is not limiting in the system, that efforts should be made to continue to reduce the sewage works P-loadings (by achieving 100% compliance with the 1 mg/l discharge limit, and possibly by further tightening this limit) as well as **reducing nitrogen loads.**

"The implications of point source phosphorus management to potable water treatment". Water Science technology, vol. 37 n° 2, 1998.

R. Heath, M. Steynberg, R. Guglielmi, A. Maritz, Scientific Service, Rand Water, PO Box 54, Vereeniging 1930, South Africa.

SCOPE NEWSLETTER

SCOPE N°32 - 05/1999 - Gulf of Mexico

Estuarine algae and N+P co-stimulation

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18 litre microcosms filled with water from three sites in the Perdido Bay (Alabama – Florida, Gulf of Mexico) were used to assess the response of native phytoplankton assemblages to addition of nitrogen, phosphorus and the two nutrients together.

Experiments were carried out monthly, for a year (May 1990 – April 1991) at each site (12 x 3 experiments). Each experiment involved four treatments, each triplicated (12 microcosms): control, phosphate 10 µM above ambient, nitrate 50 µM above ambient, and finally combined phosphate and nitrate at these levels above ambient.

The three sites sampled were selected to represent a variation in estuarine conditions: upper, middle and lower bay areas. Perdido Bay has a total area of 130 km2 and an average depth of 2m. Exchange with the sea is limited by a narrow estuary mouth (Perdido Pass) so that the estuary tends to be stratified. The main sources of fresh water are the humic-rich Perdido river and Eleven Mile Creek (which carries paper mill wastes), both flowing into the upper bay.

Salinity at the three sampling sites showed a clear geographical gradient, varying from 0.2% (May) – 1.7% (October) in the upper bay, intermediate in the middle bay, and 0.3 – 1.4% higher than these values in the lower bay.

Surface water temperatures were similar between the three sites, varying from 28-31°C in June – September to 10°C in December.

The 18 litre microcosms were filled with bay water, filtered to remove zooplankton but not microheterotrophs (63µm mesh) and maintained in an outdoor water bath at temperatures similar to those of the bay water at the different seasons.

10% of the water volume of each mesocosm was replaced daily with new temperature adjusted water from the same site. Nutrient addition was carried out on day zero.

======== Response to simultaneous P and N addition ========

Phytoplankton response to nutrient addition, measured by chlorophyll-a concentration, fell into two main categories: primary N or P stimulation (ie. some growth with the addition of only one nutrient, enhanced growth with addition of both) and N+P co-stimulation (addition of both nutrients required to obtain a growth response).

Exclusive P stimulation occurred only once in the 36 experiments (ie. no additional growth with N+P compared with only P). Exclusive N stimulation was not detected.

As an overall pattern, primary P stimulation tended to occur during the cool season and at low salinity, whereas primary N stimulation occurred during the warmer months and at higher salinity.

As would be expected, primary P stimulation was generally associated with high ratios of dissolved organic nitrogen (DIN) to dissolved organic phosphorus (DIP): ratio range 18 – 288. Primary N stimulation was associated with DIN:DIP ratios in the range 8 – 46.

======== Frequent conditions near N+P co-stimulation ========

Examination of ambient nutrient and chlorophyll ratios produced contradictory and unclear indications. Whilst DIN and DIP concentrations and ratios suggested that P would be limiting most of the year, particulate organic nitrogen (PON): **particulate organic phosphorus (POP) ratios suggest N limitation.** PON: chl-a ratios, on the other hand, suggest N sufficiency.

The authors conclude that the Perdido Bay phytoplankton assemblages may often be poised near a condition of joint N and P co-stimulation.

They suggest that DIN and DIP may be coupled to algal biomass production, whereas ambient PON and POP may be more influenced by the net effects of grazing by microheterotrophs and zooplankton, mineralisation and detritus.

"Seasonal growth stimulation of sub-temperate estuarine phytoplankton to nitrogen and phosphorus: an outdoor mesocosm experiment". Estuaries, vol. 21 n° 1, 1998.

D. Flemer, US Environmental Protection Agency, National Health and Environmental Effects Laboratory – Gulf Ecology Division, Gulf Breeze, Florida 32561 – 5299, USA. R. Livingston, S. McGlynn, Center for Aquatic Research, Florida State University, Tallahassee, Florida 32306, USA

SCOPE NEWSLETTER

SCOPE N°32 - 05/1999 - Holland

Sediment P and lake recovery

Lake Veluwe, Holland, was created in 1956, by the formation of polders. The lake received heavy nutrient loading resulting in eutrophication until 1979. At this time, P-removal was introduced at the local sewage plant in conjunction with a programme of winter flushing of the lake with low-nutrient polder water. This study looks at the recovery of the lake and the response of sediment P levels.

The lake has very particular hydrology. It was created between existing "old" land and newly recovered polder farmland (lying some 5m below sea level) in order to limit groundwater losses from the "old" land. The lake has a shallow, sandy-bottomed area bordering the "old" land (<1m depth), fed by an inflow of streams and infiltration of underground water, and a deeper area (1 – 3 m depth) with a silty base, from which water seeps out of the lake towards the polder.

In the first years after the creation of the lake in 1956 the water was clear with a rich animal and community. Macrophytes were dominated by Characeae.

The high nutrient loading began to effect the water quality in the 1960's. By 1970, the water had become turbid (Secchi depth < 20 cm), submerged macrophytes had disappeared and algae were dominated by cyanobacterai, in particular Oscillatoria agardhii.

A monitoring and restoration programme was launched in the 1970's and in 1979 P-removal was installed at the sewage works discharging into the lake and regular winter flushing with polder water (low in nutrients and in algae) was introduced.

Phosphorus loading to the lake was thus reduced from 3 to 1 gP/m^2/year and the average hydraulic residence time decreased from 0.45 to 0.2 years. Additional flushing from 1985 onwards further decreased the residence time to 0.15 years.

======== Immediate nutrient and chlorophyll response but ecological recovery only after a decade ========

Phosphorus and chlorophyll-a concentrations in the lake responded within a year, but the lake remained turbid.

Only in the early 1990's, more than 10 years after the reduction in nutrient loading, was the beginning of ecological recovery observed. Macrophytes reappeared, macrofauna and fish densities began to change and the water became transparent in much of the lake.

This **hysterisis effect**, whereby a shallow lake does not rapidly respond (in terms of ecological recovery) to reductions in nutrient loading, is thought to be related

to release of accumulated sediment phosphorus. The sediment P levels were modelled for Lake Veluwe and compared with measurements.

======== Sediment phosphorus and lake ecology ========

Phosphorus concentrations in the deeper lake sediment around 1979 were of the order of 0.5 – 0.6 gP/kg dry weight. Those in the shallower lake sediment were around 0.08 gP/kg.

Changes in the deeper lake sediment P can be related to changes in the lake's ecological condition. Initial levels are estimated to have been around 0.3 gP/kg. Modelling of sediment P levels suggest that the change from clear to turbid lake water took place when deeper lake sediment P reached 0.44gP/kg and that the change back from turbid to clear water occurred at 0.38 gP/kg.

The relatively rapid recovery of Lake Veluwe in response to nutrient loading reductions is probably the result of the particular hydrology: infiltration of "old" land groundwater into the lake through the shallow area sediment and seepage out of the lake through the deeper area sediment. This situation means that phosphorus build up in the shallow area sediment was limited during initial high nutrient loads, and that phosphorus tends to be moved towards the deeper area sediments. This latter effect is significantly reduced with the development of macrophytes in the shallow area following lake recovery.

The paper models sediment phosphorus changes as a function of infiltration, seepage, burial of suspended matter, precipitation of calcium phosphates and hydrology.

The model suggests that sediment P concentrations will return to the initial levels (as at the lake's creation) only in 2006. At this time, a balance will be reached between supply of P to the sediments and the P removal rate.

"Changes in sediment phosphorus as a result of eutrophication and oligotrophication in Lake Veluwe, the Netherlands". Wat. Res. vol. 12 n° 11 1998.

D. Van der Molen, R. Portlielje, P. Boers, Institute for Inland Water Management, PO Box 17, 8200 AA Lelystad, Holland. L. Lijklema, Ketsheuvel 33, 6871 EB Renkum, Holland.

SCOPE NEWSLETTER

SCOPE N°32 - 05/1999 - Shallow lakes

P storage in a prochlorophyte

The summer phytoplankton community of many shallow Dutch eutrophic lakes is dominated by large filamentous cyanobacteria such as *Anabaena, Aphanizomenon* and *Oscillatoria*. The Loosdrecht lake system, a series of shallow, hypertrophic lakes in the centre of Holland, is generally dominated in summer by another prokaryote, the prochlorophyte *Prochlorothrix hollandica.*

This species differs from cyanobacteria in its photosynthetic apparatus, which lacks the phycobilisomes present in cyanobacteria and contains chlorophyll-b.

The total P concentration in the Loosdrecht lakes' water is high, but summer concentrations of soluble reactive P can be very low. Phosphorus can be released from the sediment as distinct pulses by wind action. In this context, it was decided to compare the P uptake and storage capacities of *Prochlorothrix hollandica* (isolated from the Loosdrecht lakes) with those of a cycanobacterium (*Planktothrix agardhii*, formerly named *Oscillatoria agardhii*; originally isolated from Lake Veluwemeer, Holland).

Growth conditions were studied in 2 litre culture vessels at around 20°C with artificial light (approx. 40 µmol/m2/s photon irradiance).

Phosphorus concentrations were adjusted to 200 µgP/l to represent low P levels. Pulses of phosphorus were generated by adding 300 µgP/l at hourly intervals for several hours until the algal cells became P saturated.

The literature indicates that *Prochlorothrix* has a lower growth rate than *Planktothrix* (0.025 and 0.036 / hour, respectively).

The studies showed that *Prochlorothrix* has a significantly higher maximum P uptake rate. For both species, the P uptake rate decreases linearly as a function of cellular

P content, but this rate of decrease was slower in *Prochlorothrix*. Not only was the maximum cellular P content of *Prochlorthrix* much higher (11% of dry weight, compared to 4.2% for *Planktothrix*), the minimum cellular P content of *Prochlorthrix* was also lower, so that this species can accumulate much more cell phosphorus.

From the experimental results and modelling, it was calculated that in a steady state *Prochlorothrix* would develop with slightly lower cellular P levels (0.27% d.w. predicted, 0.31% observed, compared to 0.37% / 0.38% for *Planktothrix*), bringing the residual P concentration in the surrounding water (R*) down to 0.01 µgP/l, compared to 0.067, µgP/l for *Planktothrix.*

This value for *Prochlorothrix* is one of the lowest R* values ever reported for a phytoplankton species. Given the species' high P storage capacity, *Prochlorothrix* would appear to be amongst the best P competitors of freshwater phytoplankton. This is demonstrated by competition experiments between the two species studied, where *Prochlorothrix* dominated *Planktothrix* in steady state low P conditions, and less effectively in conditions with pulsed P additions. Models were developed to predict competition between the two species: the Droop model proved relatively good, whereas the Monod model, which does not take resource storage into account, did not provide useful predictions.

The question raised is therefore not so much "Why does *Prochlorothrix* dominate in the Loosdrecht lakes?" but rather "Why does it not dominate in most shallow lakes?".

The authors suggest that *Prochlorothrix* may have disadvantages for ecological factors other than P limitation. These may include grazing, sedimentation losses or competition for nitrogen.

"Competition between a prochlorophyte and a cyanobacterium under various phosphorus regimes : comparison with the droop model". J. Phycol. 34, 1998.

H. Debecou, J. Huisman, L. Mur, Lab. Microbiology ARISE, Univ. Amsterdam, Nieuwe Achtergracht 127, 1018 WS Amsterdam. R. Jonker, AquaSense, PO Box 95125, 1090 HC Amsterdam, Holland.

SCOPE NEWSLETTER

SCOPE N°32 - 05/1999 - Wastewater strategy

WWTP upgrading best option for the Danube

A study of 9* countries of the Danube basin compares the cost and environmental effectiveness of different investment scenarios for improving sewerage collection and urban waste water treatment.

> ** Austria, Bulgaria, Czech Republic, Hungary, Moldova, Romania, Slovakia, Slovenia, Ukraine. Because of the political situation, data from Bosnia-Herzegovia, Croatia and Yugoslavia were not available.*

The study was based on evaluations of emissions, water quality and waste water management costs assessed for the "Nutrient Balances for the Danube Countries" in the framework of the Environmental Programme for the Danube River Basin by experts from seven Danube countries.

The area of the Danube basin under consideration has a population of 58 million, 52% of whom live in conurbations of more than 10,000 people.

Within these, 75% of the population is connected to sewerage in, but only 20% outside them. An estimated 14 million p.e. of raw wastewater is discharged by industries not connected to urban sewerage (but this figure is probably underestimated).

Of the wastewater collected by sewerage, 33% is discharged either untreated or with only mechanical treatment. Only 20% of the wastewater collected undergoes some kind of tertiary treatment.

50% of the WWTP's (urban waste water treatment plants) are overloaded and 60% more than 15 years old.

In total, 75% of capacity will require reconstruction within the next 10 years.

======== Extension of sewerage? ========

Two scenarios were considered for investments in sewerage networks:

A. no construction of new sewerage (no extensions of networks); costs limited to maintenance and replacement of faulty and leaky sewerage (an estimated 10% of existing sewerage will require reconstruction by 2005).
B. realistic extension of sewerage networks, according to national legal requirements or development plans.

For each of these two sewerage system scenarios, four waste water treatment investment scenarios were considered:

(0) no improvement of sewage treatment; investments limited to operation and reconstruction where necessary of existing plants

(1) EC requirements for non-sensitive areas: ie. biological treatment (90% BOD, 75% COD removal) for all collected sewage

(2) EC requirements for sensitive areas: ie. as (1) plus nutrient removal (80%P, 70%N) for treatment plants serving more than 10,000 pe.

(3) treatment requirements defined as a function of water quality requirements (as regards BOD and NH4N – oxygen regime)

(4) scenario (3) enhanced to add **P-removal for all sewage works**

========= Economic burden of maintenance =========

The authors underline the very high cost faced by the Danube countries studied simply to maintain and replace as necessary existing sewerage and sewage treatment installations. The scenario "A0" (no extension of sewerage networks, no improvement of treatment works) alone implies a total cost of around 2 billion Euros/year.

The second conclusion is the very high cost of extension of sewerage networks: the scenario "B0" (development of sewerage according to existing plans) is 80% more costly than "A0", for a proportion of the population connected increased from around 50% to only 58%.

The costs for the most extensive improvement scenario for waste water treatment ("A2") are very similar to costs for developing sewerage ("B0"). However, **the effort on water treatment significantly decreases emissions to surface waters (overall 80% reduction in BOD from sewage works discharges, 20% reduction in total phosphorus emissions from all sources), whereas the development of sewerage ("B0") actually increases discharges to surface waters** (though infiltration to underground waters should be reduced).

========= 20 – 23% reduction in total P loading to surface waters =========

Removal of phosphorus at all sewage works (not only those serving >10,000 pe.) accentuates the achieved reduction in total P loading to surface waters: -20% for "B2", -23% for "B4" (reduction of all sources of P to surface waters).

Overall, P-removal is not one of the more costly investment decisions: P-removal at all sewage works compared to at no sewage works ("B4" vs. "B3") only increases total sewerage and sewage treatment costs by 4-6%.

On the basis of no P-removal at sewage works, the authors suggest that **the use of P-free detergents would reduce phosphate loadings by 8-10 %, compared to the 23% reduction achievable by sewage works P-removal.** Furthermore, the reduction offered by P-free detergents would be much smaller in a scenario where P-removal was introduced in a significant number of sewage works.

========= Necessity for nitrogen removal =========

The authors estimate that installing secondary biological treatment only in sewage works would not suffice to prevent increases in emissions to surface waters if sewerage collection is developed (scenario "B1"). Because of the low dilution in much of the basin, **advanced nitrification treatment will be necessary in many cases to ensure "good ambient quality water"** taken by the authors to be BOD < 9 mg/l and NH4-N < 1.5 mg/l).

The application of EC requirements for sewage treatment (scenario "B2": nutrient removal in works serving > 10,000 pe.) would reduce total nitrogen load to surface waters by around 15% (compared to the reduction of –20% achieved for P loadings).

The additional costs for nitrogen removal are 10 – 15% of total costs (compared to 4 – 6% for P-removal).

"Wastewater management in the Danube basin". Water Science Technology vol. 38, n° 11, 1998.

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SCOPE NEWSLETTER

SCOPE N°32 - 05/1999 - Biological nutrient removal

Upgrading of existing sewage works for bio- N and P removal

Upgrading of the 54,000 pe. Holten sewage works (Holland) was carried out in order to meet effluent requirements of <10 mg total N/l, <1 mg P/l and <10 mg suspended solids/l, whilst minimising investments, running costs (energy, chemicals) and maintaining a good sludge volume index. The method developed was then applied to other sewage works (6 presented).

The Holten WWTP originally consisted of two parallel aerated plug-flow activated sludge tanks. To upgrade to biological nutrient removal, these were put in series and compartmentalised into anaerobic (anoxic) and aerobic zones. A plug-flow anaerobic reactor compartment was added in front of the two tanks to prevent the introduction of nitrates into their anaerobic compartments.

After this anaerobic reactor, which acts as a selector as well as facilitating the hydrolysis of particulate COD, some hydrolysis products remain. Compartmentalisation of the anoxic zone is therefore necessary to achieve a good sludge volume index (SVI). At Holten, this compartmentalisation enabled SVI to be reduced from 150 to 80 mg/l.

======== Sludge retention time ========

In order to optimise nitrification and availability of CED for denitrification, sludge retention time (SRT) was maximised (up to 50 days). This tends to deteriorate bio-P removal effectiveness which is optimal with high sludge productions and low SRT.

In order to improve bio-P removal, sludge is recycled through anaerobic and anoxic conditions, with presettling of influent before the anaerobic reactor (minimising accumulation of inerts and heterotrophs). Chemical P-removal in the sludge line is applied (addition of iron in the sludge digester).

The presettling stage produces a primary sludge which, when mixed with the secondary sludge, improves digestion, thus increasing methane energy production and decreasing sludge generation. Bypassing the presettler and inputting raw sewage to the anaerobic reactor improved bio-P removal (increased COD substrate) and also increased N removal (the nitrogen, however, was not denitrified, but simply transferred to the increased sludge volume produced). After assessment, it was decided to maintain the presettler: the lower nutrient removal efficiency (with presettler) was considered less important than the decreased energy and increased sludge production.

======== In-line P-stripper ========

The operation with a long sludge retention time limits the phosphorus being removed to sludge, so that some chemical P-stripping was necessary to ensure that P effluent levels remained below discharge consents. Addition of P-stripping chemicals in the main reactor tanks would result in accumulation of precipitants in the sludge, reducing nitrification activity. It was nonetheless wished to avoid construction of a new and separate P-stripping tank. As a solution, **baffles were added in part of the anaerobic zone, creating a settling area from where a P-rich clear liquor can be decanted.** This liquor (on average 10% of through-flow) is then transferred to the sludge digester where P-striping chemicals are dosed.

This specific combination of in-line bio-P removal and off-line P-precipitation minimises new investments and is denoted the BCFS© process (Biologische Chemishe Fosfatt Stikstof verwijdering).

Process control is very important for the biological nitrogen and P removal, and to adjust chemical P-stripping. This is ensured by redox probes in the anoxic and anaerobic zones which control the recycling of mixed liquors and withdrawal of P-rich liquor from the in-line settling area.

"Upgrading of waste water treatment processes for integrated nutrient removal – the BCFS© process". Water Science Tech. Vol. 37 n°9, 1998.

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SCOPE NEWSLETTER

SCOPE N°32 - 05/1999 - Sewage sludge digestion

Differing availability of phosphorus and metals

Extraction and speciation methods for phosphorus and different metals (Fe, Ca, Mg, Cu, Zn, Mn, Cr, Ni) were tested on model compounds then applied to anaerobic digesters fed with high-P sludge from plants operating chemical (iron precipitation) and biological phosphorus removal.

As an initial experiment, extraction of the different metals from carbonate, sulphate and phosphate model compounds was tested using the Stover et al method (1976). Phosphate extraction from calcium phosphate, magnesium phosphate and iron phosphate was tested using different extractants and the Uhlmann et al method (1990).

As a second stage, availability of phosphorus and of the different metals was tested in anaerobic digesters treating high-phosphate content sewage sludge:

A. sludge from a plant operating chemical P-removal (CPR) using iron precipitation: 37.9 g total P/kg dried sludge
B. sludge from this plant during shutdown of the P-precipitation process: 13.3 gP/kg
C. sludge from a plant operating biological P-removal (BPR) on a part of works throughflow: 11.0 gP/kg
D. sludge from a plant without P-removal: 9.1 gP/kg

======== Low P-availability after chemical P-stripping ========

Total phosphorus was divided into soluble, water extractable, NaOH total P extractable (organic), NaOH phosphate extractable (inorganic), HCl extractable and aqua regia digestion P (residual).

Not surprisingly, phosphorus was significantly less readily available in the digester treating CPR sludge, with only 3.2% soluble or water-available P (compared to 22.5% and 16.8% in digesters B and C).

The proportion of organic phosphorus in the different reactors, at around a quarter of total P present, was very similar.

========= Struvite precipitation =========

Reactors B and C had higher HCl extractable P levels (24% and 23%) suggesting that, in the absence of iron and in the presence of hard water (Ca, Mg) the alkaline earth metals render insoluble a significant proportion of total P.

It could have been expected that the low redox conditions in the anaerobic digesters would cause an increase in soluble phosphates in digester A (CPR) by reduction of the ferric precipitate ion. This did not occur, the authors suggest because of re-precipitation in the form of Fe3(PO4)2 = vivianite (cf. Singer 1972, Thomas 1966).

In the absence of sufficient ferrous ions, re-precipitation as struvite (magnesium ammonium phosphate or magnesium potassium phosphate) is probable and the formation of struvite in sludge digesters downstream of biological P-removal plants has been widely reported (Borgerding 1972, Rabonowitz and Barnard 1995). The P-extraction results are compatible with this hypothesis, with a high NaOH inorganic fraction in reactor A (fraction in which vivianite should be found) and a high HCl and residual fractions in B and C (fractions in which struvite should be found).

Jardin and Popel (1994), for example, concluded that **nearly all the magnesium and 54% of the P released during digestion of BPR sludge precipitated as struvite.**

========= Release of organic polyphosphates from BPR sludge =========

Polyphosphates intracellularly accumulated during BPR processes are known to be released under anaerobic conditions. Also, it is known that BPR micro-organisms fix phosphates on the cell surface in high concentrations and that these phosphates can be released by washing in water (Steichan and Schon 1991).

These phenomena could explain the relatively higher soluble and water available P in reactor B. However, these fractions are not great enough to account for all released polyphosphates.

BPR phosphate uptake is known to be accompanied by uptake of Mg and K and their release to be accompany polyphosphate release. **The authors suggest that this mechanism could facilitate struvite precipitation** in reactor B.

========= Availability of metals in CPR sludge =========

Comparisons of metal extractability show that the different metals are somewhat more easily available in the CPR sludge digester (A). Residual and nitric acid extractable metal fractions dominate for chromium and nickel in reactors B and C, whereas these metals are mainly Na4P2O7 or KF extractable in reactor A.

Residual fractions for Fe, Mg, Cu, Zn and Mn are also higher in reactors B and C.

The authors suggest that **increased chromium availability in reactor A** may be the result of the association of chromium with the organic fraction of sludge as a result of flocculation during P-precipitation.

"Metal and phosphate speciation during anaerobic digestion of phosphorus rich sludge". Wat. Sci. Tech. vol. 36 n° 6-7, 1997.

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SCOPE NEWSLETTER

SCOPE N°32 - 05/1999 - Ecological nutrient removal

Using fish and periphyton for P and N removal

Tanks containing periphyton and algal-grazing fish were tested as ecological systems for nutrient removal, enabling recovery of the nutrients for recycling: in the mucous-bound fish feces which accumulate in collectable sediment and in the production of harvestable fish biomass.

Various authors have demonstrated the potential of periphyton as an ecological nutrient removal system. Periphyton can take up both N and P from wastewaters at a very high rate, they naturally adjust growth and nutrient uptake rates to nutrient concentrations, and they are well adapted to high water through-flow rates. However, the periphyton communities have to be harvested in some way in order to effectively remove the fixed nutrients, otherwise they tend to senesce or slough off, returning nutrients to the water. Effective and clean methods for harvesting the periphyton are often not economically viable: rotating discs, vacuum systems, harvesting by hand... **This paper presents experiments testing the use of algal-grazing fish as a simple nutrient harvesting system.**

The principal experiment reported involved a four month outdoor (Spring – early Summer) run with 24 cascading mesocosm tanks (influent flowing through the tanks in series), each with around 35,000 cm2 of 0.64 cm mesh plastic screen acting as a substrate for periphyton growth. **The tanks contained two algal-grazing fish:** the cichlid *Tilapia mossambica* and the minnow stoneroller *Campostoma anomalum*. Altogether (for the 24 tanks), 712 fish were stocked (average fish wet mass/tank 250 g).

Artificially polluted water was made by adding agricultural fertilisers to reservoir water to bring nutrients up to concentrations typical of domestic sewage: average 0.39 mg TP/l and 1.09 mg TN/l.

After a period of system stabilisation, nutrient removal rates of over 50% were achieved, with outflow TP concentrations generally below 0.15 mg/l and TN below 1 mg/l.

Total phosphorus removal rates by fish growth (transfer of P into fish biomass) were around 27 mg/day/m2 mesocosm water surface area, and removal by sedimentation of feces around 21 mg/day/m2.

The periphyton biomass at the end of the experiment was mainly filamentous green algae (in particular *Cladophora glomerata*) as well as association diatoms such as *Cyclotella meneghiniana, Gomophoneam* *subtile and Nitzschia amphibia.*

The authors conclude that such fish/periphyton systems could provide a useful ecological method for removing nutrients from wastewaters, with the fish being a valuable product either for consumption or river restocking. The fish would, however, tend to assimilate toxicants present in the wastewaters: this could provide a useful quality indicator, but would limit their value for consumtion.

The authors consider that the nutrrient remvoal rates can be improved (for example by better feces drainage) but point out that, even if efficiency is doubled, removal of 1 mg P/l from an effluent volume of 1,000 m3/day would require a water surface area of 10,000 m2.

"Ecologica water treatment system for removal phosphorus and nitrogen from polluted water". Ecological Applications 7(2) 1997 (Ecological Society of America).

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SCOPE NEWSLETTER

SCOPE N°32 - 05/1999 - Scandinavia

Zeolites increase sewage sludge and deteriorate filterability

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A study by Tampere University Finland and the Swedish Royal Institute of Technology assesses the effects of detergent zeolites on sewage sludge characteristics.

Zeolites are the most widely used partial substitute for phosphates in laundry detergents. The effects of two zeolites (Doucil-P and Doucil-A24) in concentrations of 10 – 30 mg/l were tested in sludge from a full scale sewage plant, sludge from a pilot unit fed with synthetic waste water, and in the nitrification-denitrification system of a pilot plant fed with synthetic waste water.

The paper reports estimates of **zeolite concentrations in European sewage plant influent** varying from 10 mg/l (Hopping 1978) to 60 mg/l in hard water areas of Germany (Fischer *et al.* 1978).

======== Increased sludge filtration times ========

Sludge filtration time was on average 40% longer with zeolite addition. This is thought to be the result of negative effects on flow structure, either by complexing metal ions or because of the amporphousness of zeolite. Longer contact times (24h) or higher zeolite concentrations (up to 3g/l) caused even longer filtration times (5 – 9 x longer).

======== Increased sludge solids ========

Zeolite also caused an **increase in sludge solids: a 25 – 30% increase in mixed liquor suspended solids**, although this did result in improved sludge settling. Fischer *et al.* (1978) had previously reported increases in sludge suspended solids of up to 33%. Unlike Fischer *et al.*, however, the authors found no improvement in treatment efficiencies of COD, P and N as a result of zeolite addition.

Zeolite addition caused a **significant increase in sludge aluminium content**, from 5 mg/l (mixed liquor suspended solids) to 10 – 13 mg/g. This increase is not as high as would be expected given the 15% (approx.) aluminium content of zeolite. This difference was not expected by the authors.

"Effects of detergent zeolite in a nitrogen removal activated sludge process", Water Science Technology vol. 38 n° 2, 1998.

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