SCOPE NEWSLETTER

European Sustainable Phosphorus Platform

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European Sustainable Phosphorus Platform

In partnership / supported by: IWA the international water association, EurEau, CIWEM Chartered Institution of Water and Environmental Management, ECSM 5th, LIÈGE université

ESPP waste water phosphorus removal workshop

On 9th October 2019, at Université de Liège, ESPP organised a workshop on phosphorus removal in sewage works. **This looked at directions for water protection policies and at operator experience and feasibility of phosphorus removal down to increasingly strict discharge limits.**

The workshop brought together sixty EU and national regulators with water companies and utilities from across Europe.

The workshop was organised in partnership with / supported by: IWA (the International Water Association), Eureau, CIWEM (Chartered Institution of Water and Environmental Management), Université de Liège and ECSM'19 (European Conference on Sludge Management).

Optimising phosphorus removal strategies

Maria Albuquerque, Veolia, presented the group's **holistic approach to water, soil, energy and nutrients** and challenges to resource recovery from wastewater.

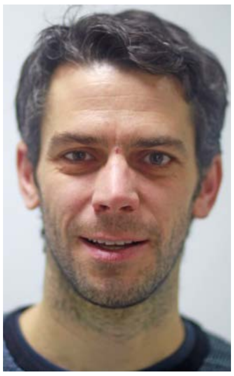
She presented the **Veolia Phosphorus Recovery Roadmap,** within the group's Ecosystemic Approach which links cities and territories, water cycle management and agriculture, with an emphasis on returning nutrients and carbon from wastewater to soils, including the current important practice of composting and agronomic valorisation of composts. Actions towards phosphorus recovery include "**Phosforce**" (working with science and research), technical implementation to develop full-scale reference installations and link to commercial business units, and an emphasis on process control systems. Veolia's actions runs through to field application of products, including field tests and quality programmes for fertilising products from wastestreams (QualiAgro with INRA France) and a Smart App for farmers to support soil carbon management.

Technologies for nutrient recovery exist and pilots have been demonstrated, but wider implementation is currently hindered by the lack of a more significant market demand for these secondary raw materials. The development of circular economy value loops on this field (nutrient recovery for recycled based fertilizers) would benefit from either specific regulatory changes, allowing costs to be passed on to customers, or economic incentives (such as monetisation of externalities). **More studies, and in particular economic and policy studies would be relevant to determine the best policy instruments**.

Veolia is today particularly working on a comprehensive approach to respond to the new German phosphorus recovery legislation, with both technology solutions and a decision process for different sewage works and sludge configurations. At the global level, **Veolia has engaged a partnership with Yara** (Nutrient Upcycling Alliance) to develop value chains for circular agriculture and to identify and implement concrete circular economy business models.

Holistic approach

Veolia is addressing **future stricter phosphorus discharge limits from waste water treatment works** (wwtps), with both technology and systems control developments. An emphasis is on **improving P-removal in existing wwtp**, for example by retrofitting of sidestream biological phosphorus removal, using RAS (return activated sludge) and specific process control (Aquavista). This can reduce phosphorus discharge and optimise metal salt (coagulant) consumption by retrofitting of existing infrastructure.



Jeroen Deurinck, Aquafin, summarised Aquafin's water board's strategic approach to phosphorus removal choices, as agreed with the Flanders regulator.

Aquafin treats wastewater for 5.5 million p.e., covering the whole of Flanders, with over 300 wwtps in operation ranging from 100 to 200 000 p.e. In 1991 around 30% of Flanders wastewater was collected and treated, reaching 87% in 2018.

A **strategic exercise is today engaged with the Flanders Environment Agency to define priorities for wastewater investments**, as a function of the ecological status of receiving water bodies and allocation of different pollution sources (wwtps, agriculture …). The regulator has then defined impact reductions for each pollution sources (this implies political choices). Aquafin is now defining the most cost effective measures to achieve the reductions required.

Priority actions depend on political objectives of the regulator, the possible load reduction relative to the receiving water body and the cost per unit of nutrient emission avoided.

For domestic wastewater, key challenges identified are improving household connections, addressing storm and rainwaters and optimising wwtp performance. **Investments at wwtps generally show to be effective and efficient**.

Defining priorities which are cost effective

Regarding phosphorus discharges, three measures are identified as cost-effective:

- **increasing biological treatment (secondary) capacity** to 6x dry weather flow, so reducing impacts of rainfall events
- **online analysis and control of coagulant dosing** for low level simultaneous chemical P-removal, leading to a general increase in coagulant consumption
- **tertiary sand filtration** with iron and carbon dosing

Aquafin considers that these measures will generally enable to achieve discharge of around 0.3 mgP/l [see below], that is reduce by around half Aquafin's current total phosphorus discharges, and also reduce nitrogen to around 3 mgN/l.

As an example, the Houthalen-Oost wwtp, 9 000 p.e., discharges into a natural park Natura 2000 area and the wwtp outflow is higher than the receiving river flow. **Optimisation of chemical P-removal using online P analysis and a control algorithm, is today achieving 0.5 mgP/l discharge with an objective of 0.3 mgP/l** [yearly average total phosphorus target value], with a metal:P ratio of around 3.

Flexible permits and catchment/load permitting

Lydia O'Shea, Wessex Water, UK, outlined the cost challenges of phosphorus removal in small sewage works, and presented the catchment permitting approach implemented with the UK regulator.

For a typical 2 000 p.e. wwtp operating secondary (biological) treatment, inflow phosphorus of c. 8 mgP/l might be reduced to 5 mgP/l discharge. Adding phosphorus removal to achieve 1 mgP/l, with dosing at one or two points (inflow, outflow), would cost around 1 – 1.3 million UK£. To achieve 0.25 mgP/l [annual average] would require an additional tertiary treatment process, taking the cost to 3.5 – 3.84 million UK£ investment, that is **around UK£ 2 000 per inhabitant**. This does not take into account additional operating costs (coagulant costs, maintenance, increased sewage sludge).

To optimise cost-effectiveness, **catchment permitting has been implemented in the Bristol – Avon river catchment, covering 66 wwtps, as a full scale implemented "trial"**. Each of the wwtp's operating permits has been updated, and a single operating techniques document has been developed covering the whole catchment. The total phosphorus load must be reduced from 138 tP/year [annual load*] in 2019 to 93 tP/y in 2019 (in fact 80 tP/y has been achieved). Each wwtp has an annual average maximum P discharge permit, but also a flexible "stretch target", which together enable the catchment load reduction target to be achieved. There is flexibility in the approach, where one wwtp might exceed the stretch target this can be compensated by another wwtp in the catchment that is overperforming.

** annual load is calculated on the basis of 24 composite (24h) samples per year x flow volume.*

This catchment permitting trial has demonstrated clear benefits:

- **25 million UK£ investment saving** (avoiding capital expenditure on P-removal processes at some wwtps)
- this cost saving enables justification of phosphorus reduction as **"cost beneficial" under the Water Framework Directive** articles 10 and 11
- **phosphorus load reduction achieved to date is** better than target
- updating of permits, and of the **data reporting** and management system, collation of data on phosphorus emissions,
- because this is a full-scale, real catchment trial, implemented in regulation, it is **replicable to other catchments**

Work is currently underway to verify local impacts on rivers downstream of wwtps where stretch targets have been exceeded.

Discussion is also underway to **extend the catchment permitting to cooperation with farmers**, whereby the water company would pay farmers to reduce phosphorus emissions (e.g. in-drain phosphorus traps, buffer strips …) which can be much more cost effective than P-removal in small wwtps.

National wastewater nutrient policies

Daniel Klein, EGLV (Emschergenossenschaft & Lippeverband) water boards, Germany, summarised developments and expectations for P-removal requirements in Germany.

Current German federal P-removal requirements reflect the Urban Waste Water Treatment Directive, at 2 mgP/l [see below *] for wwtps between 10 000 and 100 000 p.e. and 1 mgP/l for larger wwtps. However, some federal states (Land) already have limits of 1 or 1.5 mgP/l for wwtps < 10 000 p.e. or limits of 0.3 mgP/l for larger wwtps, for example. Also, **operators can receive financial bonuses if they voluntarily accept lower limits**.

Achievable levels of P-removal

Emschergenossenschaft & Lippeverband (EGLV) cover a total of 3.8 million population and more than 4 000 km^2 in the Lippe and Emscher river catchments in the Ruhr area. EGLV is currently achieving concentrations of around 0.4 – 0.7 mgP/l, using "standard" secondary treatment technology of biological P-removal in combination with simultaneous chemical P-precipitation (coagulant dosing). EGLV considers that **discharge limits of around 0.5 mgP/l can be reliably achieved with these standard technologies in most wwtps, but that to achieve 0.2 or 0.3 mgP/l** (average/mean values; see [*]), **upgrading of wwtp to add tertiary treatment (flocculation, filtration) is needed**.

** NOTE: The discharge limits defined in the EU Urban Waste Water Treatment Directive 1991/271 are "monitoring" limits ; in contrast to "annual average limits" as currently discussed in some cases.*

Directive 1991/271 specifies in Annex I how many monitoring samples must be taken during the year for different sizes of wwtps, and how many samples are allowed to fail the specified discharge limits (as a function of the number of samples taken).

Over the whole of Germany, point sources today still represent around one third of phosphorus emissions, but with variations from 20% to nearly 100% for different catchments. The **German Environment Agency (UBA) has indicated that discharge limits from wwtps will have to be notably reduced to achieve EU Water Framework Directive objectives** for "Good" quality status of 0.045 – 0.15 mgP/l in river water (annual average).

The **definition of discharge consents** is critical. In some case, numbers currently discussed refer to "mean" limits, which are less demanding (but therefore, usually lower) than "monitoring" limits (see note below).

Dr. Klein notes that tightening P discharge limits will increase the phosphorus content in sewage sludge and in sewage sludge incineration ash, which will be advantageous under the new German P-recovery legislation.

Jóannes Jørgen Gaard, Denmark Ministry of Environment and Food, outlined how Denmark is addressing phosphorus challenges. **Nutrient levels in 95% of Denmark's surface waters are above Water Framework Directive "good" quality status levels, but only 35% of the emissions of Phosphorus are from point sources** (mainly wwtps).

Most phosphorus emissions are from agriculture. For wwtps, the main problem is storm overflows (CSOs). In order to improve performance and cost-effectiveness, the national tendency is towards fewer but bigger wwtps.

Sewage phosphorus is included in the national Waste Plan, which specifies that at least 80% of sewage P is expected to be recovered for recycling or reused with biosolids in agriculture. This target is expected to be maintained in the new 2020-2026 Waste Plan. Agricultural phosphorus and other sources are not addressed.

Financial tools to drive P-removal

Landfill tax is deducted from wwtp operators' funding cap, so they benefit by reducing landfilling. Copenhagen (Biophos) is currently planning to 'mine' separately landfilled sewage sludge incineration ash, to recover phosphorus, and so benefit from landfill tax reimbursement. In the past, a tax on CO_2 emissions from incinerators led to sewage sludge being exported to Germany (this tax was abandoned in 2009).

Operators pay tax (deducted from funding cap) according to **wwtp discharges, currently 22€/kg for phosphorus, 4 €/kg for nitrogen and 2 €/kg for organic carbon**. Thus although the average wwtp discharge permit for phosphorus is 1.5 mgP/l [annual average], the real average is 0.45 mgP/l (or 0.35 mgP/l if the average is calculated proportionate to flows).

The Denmark "resource" tax on phosphorus emissions from wwtps was introduced in 1993, and resulted in a 62% reduction in P emissions, and then a 50% increase in the tax levels in 2014 resulted in a further 20% reduction. Whereas revision of wwtp operating permits is complex (need to respect BAT), taxation is faster and simpler to implement.

For the future, Denmark considers that **EU water policy revision should better include the objective of resource recovery**, including energy, phosphorus and nitrogen.

European water and nutrients policies

Trudy Higgins, European Commission DG Environment, summarised the current status of the ongoing Fitness Check of EU water policies, in particular the Water Framework Directive 2000/60, and of the evaluation of the Urban Waste Water Treatment Directive 1991/271 (UWWT). Official conclusions are expected to be published early 2020.

The evaluation shows that deterioration of water quality has been halted, but that **only 40% of surface water bodies are in "good" quality status**.

Urban wastewater is reported to be a significant pressure in 12% of water bodies, compared to 25% for agriculture.

Key challenges identified are:

- **agriculture**
- **hydromorphology** (canalisation of rivers, draining of wetlands …)
- **persistent industrial/consumer chemicals** (such as PCBs and PFOS = Teflon derivatives)
- **new pollutants** (pharmaceuticals, microplastics, …)
- impacts of **climate change**
- integrating **circular economy** (resource recovery) and energy savings
- appropriate **water pricing**, to cover costs

Important actions already engaged by the European Commission are the **Strategic Approach to Pharmaceuticals in the Environment** (see ESPP eNews n°33), the proposed new Regulation on **water reuse** (see ESPP eNews n°23) and the proposed revision of the **Drinking Water** Directive.

Compliance with the Urban Waste Water Treatment Directive is still insufficient (distance to target statistics), with 91% wwtp compliance for tertiary treatment in the EU15 but only 66% in the EU13 (accession states). Amongst others, relevant areas identified as possibly requiring further action include better consistency of designation of eutrophication Sensitive Areas , improving management of storm overflows (CSOs) and treatment of wastewater from scattered dwellings (septic tanks, etc.)

Investment requirements to achieve wastewater treatment compliance are very considerable in a number of countries (e.g. Bulgaria, Italy, Poland, Romania, Spain …) as well as investment needs to renew and maintain infrastructure. Funding is also needed to support and implement innovation. Work is underway with OECD looking at investment needs in wastewater and at financing sources (not yet published).

Action against pollutants at source is a priority. For example, the Pharmaceuticals Strategy targets reducing unnecessary use of pharmaceuticals.

Reducing pollutants at source

Claire McCamphil, European Commission DG Research & Innovation, summarised conclusions from Horizon 2020 projects on nutrient recycling and outlined **future perspectives** for nutrient management in Horizon Europe.

She underlined that the **Water Framework Directive does set demanding obligations** to achieve nutrient conditions consistent with "Good" Status objectives, and that four years after the deadline (2015) for compliance with this directive, action at MS level is clearly not sufficient to achieve EU environmental targets.

She notes that addressing both point and diffuse sources of nutrients is necessary. **Agriculture should be a key target area for action**, as well as waste water collection and treatment.

Nutrient load reductions for both sectors need to be incorporated into water body standards and into permitting programmes and agricultural measures. There is still considerable delay on this, despite the fact that the measures, technologies, etc. exist.

A major difficulty appears to be in **attributing the cost of the measures** equitably. This must be confronted to move forward. Nutrients are but one pressure for which solutions are needed. One way in approaching this was explained, where a water company in the UK (Southwest Water) in its upstream thinking project http://www.upstreamthinking.org/ showed that **reducing agricultural nutrient losses through catchment management measures could be sixty-four times more cost effective than further investments in wwtp P-removal**. Other UK water companies have also devised such schemes https://www.ofwat.gov.uk/wp-content/uploads/2015/11/prs_inf_catchment.pdf. But it is to be noted that underpinning such schemes there must be a clear enforcement of existing binding measures on farmers to meet e.g. the Nitrates Directive and P control for diffuse sources established under article 11 of the WFD.

Horizon 2020 priorities were water innovation and circular economy. **Challenges identified** from projects funded include:

- making the **link between nutrient removal and nutrient recycling**
- **complexity of regulation** (e.g. End-of-Waste)
- **public acceptance** of recycled nutrient products, related to real or perceived risks
- product quality **certification**
- need for **benchmarking** of large scale, operational nutrient recovery installations
- how to make resource recovery economic? How to design effective and feasible **economic instruments and incentives**

Horizon Europe will open new opportunities. The Missions on "**Soil Health and Food**" and on "**Healthy Oceans, Seas and Inland Waters**" are likely to be relevant for addressing nutrient issues. The proposed "**Circular Bio-Based Europe**" Partnership is expected to develop actions on nutrients from biomass and from waste. The European Green Deal, the landmark policy of the new Commission (to be adopted within the first 100 days of the new Commission being in place), will set a future approach to climate and environment priorities Actions to address nutrient cycles could be addressed within the following initiatives: zero pollution, farm to fork, climate, biodiversity.

Horizon Europe must respond to the future priorities of the incoming Commission – and with that in mind, thinking is engaged on how to reduce the losses of N and P to levels that allow for living within safe **Planetary Boundaries.**

Research is envisaged on:

- how to apply this concept to **regional or river basin level**
- the development of **nutrient budgets** (building on work under the UNECE)
- targeting nutrient reduction loads at regional level
- the development of **circular economies for nutrients**
- the **market mechanisms** or other levers that are missing to facilitate the transition to living with safe nutrient limits.

While primary research is envisaged, a focus would be on regional demonstration to show that closing nutrient cycles is possible and on an integrated approach to meet environmental obligations for water, air, biodiversity and climate.

Achieving low wwtp phosphorus discharges

Peter Vale, Severn Trent Water, UK, representing **UKWIR** (UK Water Industry Research, joint organisation of the UK water companies), presented conclusions and consequences of the **CIP2 trials, testing 20 different phosphorus removal technologies full scale in sewage works** (see ESPP eNews n°26).

The UK water industry has invested around 2 billion UK£ in phosphorus removal over the last two decades, so reducing wwtp P emissions by 60%. Despite this, phosphorus remains the main (non morphological) cause of water quality failure in the UK. In the Water Industry National Environmental Programme (WINEP) many more smaller wwtps will need to implement P-removal, and for those with P-removal already in place (mainly > 10 000 p.e.) discharge consents lower than 1 mgP/l [*] will be required. Modelling suggests that for significant stretches of river 0.1 mgP/l would be necessary. This Plan also underlined that **diffuse sources (agriculture, septic tanks) are a major problem** and must be addressed.

**: UK phosphorus sewage works discharge limits are currently assessed as "annual average", that is the mean of samples taken over the year must not exceed the limit. The number of samples required per year varies from 4 (< 10 000 p.e.) to 24 (> 50 000 p.e.).*

Test results of technologies in real wwtp operation

The CIP2 tests were launched to establish what lower discharge limit levels were really achievable in wwtp operation, and at what financial, energy and chemical costs. Results of CIP2 testing of different technologies (**Mecana pile cloth filter, BioMag, DynaSand, FilterClear**) are presented in ESPP eNews n°26.

Overall, the operating experience with different technologies in the field in sewage works showed that 90% phosphorus removal is reliably achieved, and that **0.5 mgP/l can be achieved in many wwtps by optimising existing infrastructure** operation. However, the CIP2 trials also showed that consistently achieving 0.1 mgP/l is very difficult. This level was sometimes achieved at some sewage works, but not at other times, or not at a different sewage works with the same technology.

Consequently the UK regulator (Environment Agency) has defined a **"Technically Acceptable Limit" of 0.25 mgP/l** for the horizon 2025. Lower limits may be considered after that.

Photos above: Severn Trent Water. Top: CoMag (Finham wwtp). Middle: Nereda. Below: Filter Clear (Codsall wwtp).

Investment costs

Under the current investment period (Asset Management Plan AMP6, 2015-2020) **Severn Trent is already upgrading over 10% of its 1000 wwtps to achieve 0.5 mgP/l (around 40 wwtps) or lower limits (down to 0.22 mgP/l).**

New technologies being installed include (see photos):

- **FilterClear** (4 wwtps, of which Codsall already commissioned and achieving 0.5 mgP/l);
- **Nereda** granulated sludge biological P-removal (3 wwtps, some additional chemical P removal may be needed);
- **CoMag** (magnetite settling, Finham underway, objective 0.22 mgP/l);
- **Mecana** (pile cloth rotating disk filters, 15 wwtps already operating, 15 more planned, in particular smaller wwtps).

In the next investment cycle (AMP7, 2020-2025) Severn Trent will be investing some 350 million UK£ (**nearly UK£ 45 per person for its customers**), with upgrade of a further 15% of its wwtps.

Pia Ryrfors, VEAS Norway (presented in her absence by Bengt Hansen), presented the **VEAS wwtp, Norway's largest wwtp** with c. 750 000 p.e., discharging into the eutrophication sensitive Oslofjörd. The plant has been operating chemical P-removal since its commissioning in 1982.

The plant is underground, and is operated with a **very short retention time of 3 hours**. All inflow water is treated, even stormwaters, but with different levels of bypass. Nitrogen is recovered from anaerobic digester gas ammonia stripping, and is recycled as an ammonium product (4 500 t/y) by Yara. The sewage sludge after anaerobic digestion and dewatering goes to agriculture (16 000 tDS/y after limiting). **Lime is added to improve dewatering and improves the agronomic value for farmers**.

Achieving low P discharges to protect Nordic waters

Two stage pre-precipitation with iron and then aluminium coagulants maximises organic material removal upstream of the secondary treatment (two stage nitrification – denitrification clay particle biological filters) reduces organic load and alkalinity consumption for nitrogen removal and increases methane production (organic matter goes in primary sludge to digestion). A molar ratio metal:phosphorus results in around 90% total P removal (<90% if stormwater is included) and a discharge phosphorus level of 0.25 mgP/l (or 0.3 including stormwater).

Laura Rossi, Helsinki Region Environmental Services Authority (HSY), presented actions engaged to reduce phosphorus discharges from Helsinki's wwtps.

Helsinki region's **wastewater phosphorus emissions to the Baltic were reduced from around 400 to 23 tP/y from 1970 to today**, despite an increasing population (today 1.1 million people), by implementing chemical P-removal, re-organising sewage treatment to two centralised wwtps, and then implementing biological nitrogen removal which also improves P-removal.

The region's two wwtps, Viikinmaki (1.1 million p.e., underground, photo above) and Suemenoja (310 000 p.e.) are today permitted to 0.3 and 0.35 mgP/l [three-month average] and in fact **achieve 0.16 and 0.23 mgP/l**. Iron is dosed both before primary sedimentation and in the secondary aeration zone. Viikinmäki wwtp operates tertiary nitrogen removal with a post-filter. This needs phosphorus intake to feed the biological process, which limits how low P-removal can be taken.

Financial incentives for employees

The wwtps are operated to over-achieve on P-removal (below permit consent) because Helsinki municipality is committed to reducing nutrient inputs according to the Baltic Sea Action Plan. In addition, the employees of HSY receive annual bonus payments if the goals are met. These goals are significantly more stringent for nitrogen and phosphorus discharge loads than the environmental permits.

Different operational improvements have been made to further reduce phosphorus emissions. These include:

- direct precipitation (coagulant plus polymer) of (possible) **stormwater** bypass prior to primary settling
- improved **wet weather modelling of the influent water using on-line weather radar information**, enabling to reduce storm by-pass situations by emptying holding tanks (no by-pass has been required since 2012)
-

In addition, different pilot scale tests have been made to reduce the phosphorus concentrations even further in the future. These include:

- effluent tertiary polishing with chemical coagulant dosing and **Hydrotech disc filters** (after testing, full scale implementation is now under installation at the new Blominmäki wwtp).
- bypass water treatment by precipitation and **Dynadisc disc** filters

Chemical P-removal: key to low P discharges

Leon Korving, WETSUS, presented an overview of iron and phosphorus chemistry in wastewater phosphorus removal.

Iron salts are today much the most widely used approach to ensure phosphorus removal in Europe and worldwide: iron and/or aluminium salts are used for "chemical P-removal".

In some countries in Europe nearly all phosphorus removal is by chemical P-removal (e.g. UK, Sweden). Even in the Netherlands, which has around half biological P-removal (EBPR), nearly all sewage sludge incineration ash has an iron:phosphorus molar ratio of 0.6.

Iron is also naturally present in both soils and wastewaters. It is an essential (micro)nutrient for both crops and for human health. Iron is also added to drinking water in many regions, both in purification (removal of organics) and to prevent plumbsolvency (lead from old piping or from solders). Iron in wwtp influent is 2 – 10 mgFe/l.

Iron salts ("coagulants") ensure several functions in wwtps. They chemically react with soluble phosphorus (precipitation of insoluble iron phosphate), by adsorption of soluble phosphorus onto iron compounds (oxides, hydroxides) and also by coagulation of both iron – phosphorus complexes and organic particles, so facilitating their removal (sedimentation, filtration …). Iron coagulants also bind sulphur (so limiting H_2S odour problems) and improve sludge dewatering.

Innovation in iron – phosphorus chemistry

Discussion has been ongoing for many years, and is unresolved, about how iron used for P-removal impacts crop availability of phosphorus in sewage sludge products (biosolids). Some experts say that the phosphorus is rendered non plant available, others say it is accessible to crops, and others say that the spreading of such biosolids can reduce soil phosphorus losses to surface waters. The iron and aluminium contents of sewage sludge incineration ash also impact processes for phosphorus recovery using acids to extract P from the ash.

Innovative pilot tests are underway by WETSUS at Breda wwtp, The Netherlands, looking at forms of iron phosphate in digestate. **Anaerobic conditions in digesters can result in up to 80% of the phosphorus being present as Vivianite (paramagnetic iron(II) phosphate),** which offers potential for magnetic separation and P-recovery. The chemical reactions in sewage sludge are comparable to release and binding of accumulated phosphorus from lake sediments under anaerobic conditions.

In a different direction, work is underway on using iron oxide sands in **phosphorus traps in agricultural drainage ditches**, with projects including coating the drains themselves with iron sand compounds (rather than installing trap infrastructures) or moving to an iron-based medium which can be regenerated to enable P-recovery as well as removal.

Patricia Aubeuf-Prieur, Kemira, presented operating experience from Olomouc wwtp (260 000 p.e.), Czech Republic, showing how systems control of chemical P-removal (KemConnect) can reduce phosphorus discharges, ensure more reliable discharge consent compliance and optimise coagulant consumption.

Czech regulations today fix phosphorus discharge limits at 1 – 3 mgP_{total}/l average (with maxima of 3 – 8 mgP_{total}/l), depending on wwtp capacity, but **0.75 mgP_{total}/l average in eutrophication Sensitive Areas** (as defined by the Urban Waste Water Treatment Directive 1991/271).

In 2004 the discharge limit for Olomouc was reduced from 3 to 1 mgP_{total}/l average, resulting in an increase in iron coagulant (ferric chloride) consumption from 650 to 850 t/y. **Lower P discharge consents generally result in significantly increased coagulant use.**

Combining technology with know-how

In 2017, development of an **operation algorithm for coagulant dosing** enabled a reduction to 750 t/y. This algorithm automatically adjusts coagulant dosing at two points in the wwtp (secondary treatment, clarifier) to flow and to phosphorus measurements at inflow, within the sewage works and in discharge.

In 2019 (ongoing) the **KemConnect P Optimiser system** was installed, with to date a significant further **reduction in ferric coagulant consumption** (approximately half, but this may be partly due to lower flows because of low rainfall over recent months). The system provides easily accessible data and distant monitoring for operators.

Conclusions are that chemical P-removal coagulant dosage should be responsive to phosphorus levels and flows, which are highly variable in many wwtps, in order to ensure discharge limits are respected and avoid over-compliance, so optimising coagulant consumption. Rainfall significantly impacts phosphorus removal, e.g. at Olomouc by-passing of secondary treatment, and **impacts of climate change are already visible and are impacting phosphorus discharges**.

Linking P-removal to P-recovery

Thomas Bugge, Suez, Denmark, outlined **synergies between phosphorus recycling and challenges facing wastewater operators in Denmark**:

- pressure on capacity of both wwtps and sewerage networks (urbanisation)
- energy efficiency
- increase in stormwater events (climate change)
- ongoing pressure to reduce nutrient emissions to eutrophication sensitive waters

Skanderborg wwtp (42 000 p.e.) discharges into a closed lake, for which a maximum phosphorus load of 1.38 kg/day has been fixed. Tertiary sand filters were posing a bottleneck to capacity expansion and increasingly frequent stormflow events were carrying phosphorus to the lake. A **DensaDeg XRC clarifier system is under installation** (photo below) which will use iron coagulants for flocculation, garnet filter media (dense minerals) and a hydrocyclone. A DensaDeg unit at Meru, France, operating since 1999, treating peak flows up to 2 000 m^3/h (similar capacity to Skanderborg), is achieving discharge < 0.5 mgP/l [maximum limit] and < 1 mgP/l during storm events.

This new installation in Skanderborg aims to also reduce iron dosing in the secondary treatment, so reducing secondary sludge generation, and so increasing the capacity of the biological secondary treatment.

Struvite recovery (**Phosphogreen**) has been implemented by Suez at several wwtps in Denmark: 2013 Aarhus Åby (70 000 p.e.) and 2015 Herning (150 000 p.e.), see SCOPE Newsletter n°121, and 2019 Marselisborg (220 000 p.e. operating DEMON). Benefits include reduced iron coagulant consumption and resulting reduced sewage sludge production, lower consumption of polymers for sludge dewatering, reduced electricity consumption for nitrification and related to this higher methane production, lower maintenance costs (scaling).

At **Åby**, struvite recovery from a mixture of secondary sludge (before digestion) and digested sludge enables **recovery of around 45% of total wwtp inflow phosphorus as struvite**. At Marselisborg, the recovery rate is lower but the objective is to increase this by improving the biological phosphorus removal.

Panel comments

The workshop was concluded by a panel of **Greet De Gueldre, Aquafin & EUREAU**, **Alessandro Spagni, ENEA & Italian Phosphorus Platform**, and **Marco Blazina, MM (Milan's water operator) and Aqua Publica**.

For **Eureau**, sewage sludge (biosolids) will continue to be produced, and are a valuable source of nutrients, mainly N and P, but also organic matter and energy. EurEau advocates for a medium and long term strategy for sewage biosolids, promoting recycling as much as possible, but leaving the door open to a mix of solutions. A priority in many Member States is **agricultural use of sewage biosolids**, as the environmental and economic best option, and EU should support this. Increasing demands for wwtp phosphorus removal will increase their phosphorus content of biosolids, and so agronomic value and P-recycling opportunities. Micropollutants are however a major challenge, and must be addressed by upstream source control. **Recovery of costs** of increasingly demanding nutrient removal should be linked with a market for nutrient recycling if water management is to be financially sustainable.

For **Aquapublica**, sewage sludge management is increasingly a challenge and concern, because of pressure on agricultural valorisation, despite this being the best route. More demanding phosphorus removal requirements will increase quantities of sewage sludge, with corresponding costs, accentuating the **sludge management challenge**. Reuse of treated wastewater for agricultural irrigation is also an efficient route for nutrient recycling.

In **Italy**, the main challenge seems to be **uncertainty about future regulation**. A key policy priority is to reduce phosphorus discharges, but sewage sludge management is a significant challenge. Interest in phosphorus recycling is developing.

Closing the workshop, **Jean-Christophe Ades Kemira and ESPP Board**, underlined the **importance of the regulatory framework for wastewater treatment**, because this is the main driver for environmental improvement, innovation and investment. Maintaining and implementing the demanding objectives of the Water Framework Directive should therefore be a priority for the European Commission. Low phosphorus discharges can today be reliably achieved by a combination of technology and digital monitoring and control. Future systems should aim to both remove and recover phosphorus.

The workshop venue, Université de Liège, Belgium: