Report ESPP workshop Pharmaceuticals in sewage biosolids

The evidence base on impacts of organic contaminants in sewage sludge used in agriculture

Malmö, 27 November 2016

Seventy scientists, regulators and water industry experts met at the workshop on organic contaminants and pharmaceuticals in sewage biosolids used on crops, organised in Malmö, Sweden, by the European Sustainable Phosphorus Platform (ESPP) and the Danish, Swedish and Norwegian waste associations (DAKOFA, Avfall Norge, Afvall Sverige).

All speakers' slides are available on the ESPP website *www.phosphorusplatform.eu/downloads* on the Nordic Phosphorus Conference website *https://dakofa.com/conference/conference/*

The conference was opened by Anders Finnson, Svenskt Vatten (Swedish water & wastewater association). He explained that the water industry's mission is to ensure health, safety and environmental quality in the two cycles, water cycle (sewage works purified discharge water, returning to the aquatic environment) and the sludge cycle (sewage biosolids containing nutrients and organic material used on farmland) and presented the REVAQ sludge quality certification scheme (see below).

Chris Thornton, ESPP, workshop moderator, outlined the meeting objectives. Currently, around 40% of Europe's sewage biosolids are spread to fields, so returning to farmland some 115 000 tonnes P/year. This provides low-cost nutrients for farmers, or an income when sludge sale price is negative. In addition to phosphorus, nitrogen organic carbon and trace elements are also returned to farmland. However, the continuing use of sewage biosolids on farmland faces questions from consumers, from the food industry and retailers, and from regulators, because of concerns about contaminants and their possible uptake by crops.

ESPP proposed as workshop objectives to bring together information on the status of data, science and current research, and to discuss possible joint actions or input to R&D policies.

Heavy metal contaminants in sewage biosolids are identified, well understood, relatively easy to monitor, and can (for most them) be successfully reduced at source (see REVAQ below). Pathogens can be addressed by specific sanitisation processes, and are significantly reduced in composting or anaerobic digestion operated under appropriate conditions. Organic contaminants are much more difficult to address. Problematic consumer chemicals can be addressed by phase-out or use limitations, through REACH, the EU Chemical Regulation or through voluntary industry action (perfluoroalkyl substances (e.g. PFOS), polychlorinated naphthalenes and polydimethylsiloxanes were identified as priorities by Clarke & Smith 2012). Pharmaceuticals, however, are much more difficult to reduce at source.

Status of knowledge on pharmaceuticals in biosolids

Andrii Butkovskyi, Wageningen University, The Netherlands, summarised his group's work on pharmaceuticals and organic consumer chemicals fate in source separated sanitation systems. These systems are shown to not really separate pharmaceuticals: (analgesics and anti-inflammatories, such as paracetomol, are also found in "grey water", that is non toilet, kitchen and bath water) and household products (triclosan, galaxolide) are found in toilet wastewater. Information is lacking concerning sorption of different pharmaceuticals to biosolids in sewage. Only a minority of pharmaceuticals tend to be significantly transferred to sludge in anaerobic (UASB) sewage treatment (many remain mostly dissolved in discharge water), but personal care and household products are largely found in biosolids.

Biological sewage treatment systems, which are designed for BOD (available organic carbon) removal are not optimal for removing pharmaceuticals and household chemical biocides. On the other hand, composting shows to be effective in achieving >90% reduction for some organic household chemical biocides (e.g. triclosan triclorocarban).

Damià Barceló Cullerés, ICRA Catalan Institute for Water Research / CSIC Spain, presented conclusions of 2 years of monitoring of over 200 chemicals in 15 sewage works in Spain. Concentrations of contaminants from small industries were observed to have decreased. However, a range of consumer organic chemicals, pesticides (in particular from urban use) and pharmaceutical substances (including illicit drugs, with increased levels at weekends), as well as their metabolites, are found. Partitioning of these compounds between water and sludge has been studied. A number of pesticides are identified as adsorbing to sludge (e.g. chlorpyriphos). As above, the perfluorinated chemical PFOS

(released from Teflon coatings) is identified as a problem, being found in both the water and sludge fractions. PFOS is considered an endocrine disruptor and is now on the Water Framework Directive "priority substances" list, requiring monitoring.

Prof Barceló noted that Arizona State University, USA, manages the *NSSR* (National Sewage Sludge Repository) and the Human Health Observatory (HHO), two archives and shared resources including sewage sludge and biosolids from over 200 cities in the U.S. and around the world, accompanied by meta data on contaminant concentrations and wastewater treatment plant information. Collaborative use of these resources is invited. He also noted that *Halden 2015*, a meta-analysis of 143 000 publications on contaminants of emerging concern in the environment (in general, not in sewage in particular), showed regulation of identified pollutants to be slow, with 14 years passing on average before action is taken. International sharing of knowledge and data on organic contaminants in sewage biosolids could help forward understanding and speed up the process of improving the safety and value of biosolids.

Natural robustness of soil

Jakob Magid, University of Copenhagen, presented data on heavy metals, soil biology, antibiotic resistance, pathogens, genetic contamination and nutrients, resulting from 'accelerated' application of sewage biosolids, manure and urban waste compost on the CRUCIAL farm test site near Copenhagen. The project has been running since 2003 with application at both normal as well as artificially high levels, the latter today equivalent to 130-210 years normal application. Results show a doubling of soil carbon, and a concomitant improvement of soil physical properties (e.g. increase in water retention and decrease in bulk density). Soil concentrations of copper and zinc increase, and the higher zinc can increase the crop value (micro-nutrient) but accumulation in soil must be limited.

The results show that soil microbial activity increases in proportion to applications, but that soil bacterial functions and soil bacterial diversity are not impacted. Antibiotic resistance of soil bacteria (pseudomonads) results from application of these materials, but this is largely reduced after 3 weeks and is no longer detectable after 6 weeks. Dr Magid concludes that the soil bacterial system is highly resilient and that organic contaminants in sewage sludge or other organic material, as applied, do not seem to pose problems.

The CRUCIAL study sites offer potential for specific study of impacts of pharmaceuticals and organic contaminants, and collaboration with interested research groups is invited.

Hannah Rigby, Imperial College London presented work with the UK Food Standards Agency on the potential for transfer and uptake of organic contaminants to food from the use of biosolids and other recycled wastes as nutrient sources in agriculture. The Food Standards Agency is supportive of use of sewage biosolids and other recycled wastes in agriculture, but wants an evidence base to demonstrate the safety of this practice.

She presented 'worst case scenario' testing where dairy cows were fed, under controlled experimental conditions, sewage biosolids, compost-like-output (the organic fraction from mechanical biological treatment of MSW = municipal solid waste), meat and bone meal ash, poultry litter ash and paper sludge ash, mixed into their feed (at up to 5% dry matter). Crop trials were also conducted. A range of priority organic contaminants were tested in the wastes and in the milk and crops. Preliminary results showed a significant increase in milk of dioxins (PCDD/F) compared to control cows for sewage biosolids fed to cattle at 5% dry matter intake to simulate ingestion of contaminated foliage by cattle. This is an unrealistic 'worst case' in that use of such materials on grassland should normally avoid risk of direct ingestion of biosolids by cattle, and even in this case, the dioxin levels in milk remained below one third of EU limits. Tests on arable fields showed no detectable uptake of ortho PCBs, ortho PBBs, PBDEs or PAHs into grain.

This work concludes that there is a minimal risk to the food chain from agriculture use of these secondary nutrients materials, but work is ongoing to complete chemical analysis of milk and crop samples for the range of priority organic contaminants found in the waste materials.

Does sludge treatment remove pharmaceuticals?

Anita Rye Ottosen, Rambøll engineering Denmark, presented data on the fate of pharmaceuticals and personal care chemicals in composting of biosolids. Studies have been carried out by Aarhus University with two Denmark composting companies (KomTek Miljø And Odense Nord Miljøcenter) and Rambøll, in outdoor "mile" composting systems, as widely used in Denmark. This followed a literature study in 2009 which suggested that data was insufficient on fate of organic contaminants in composting.

Studies in real composting (of a mixture of sewage biosolids, garden green waste and straw) looked at 20 organic contaminants, showing variable levels of degradation of household chemicals such as triclosan, musks, DEHP plasticiser, anti-inflammatory drugs (30 – 50% degradation), antibiotics (>85%) but zero degradation of female sex hormones. The degradation took place principally in the first few days of composting.

Conclusions are that organic contaminants are (mostly) significantly reduced in composting, but that further work is needed to identify which substances are degraded and under what conditions.

Jörgen Magnér, IVL Sweden, presented studies of the fate of pharmaceuticals in different sewage sludge hygienisation processes and in soils. Degradation of pharmaceuticals in anaerobic digestion (38°C, 55°C), pasteurisation, advanced oxidation (AOP), ammonia treatment and thermal hydrolysis was tested using sewage sludge spiked with 13 different pharmaceuticals (at 1 µg/kg). Although results were complex, the highest level of degradation was mostly noted in anaerobic digestion. Female hormones were however not degraded except with thermal hydrolysis. In further tests hydrothermal carbonisation showed to reduce total pharmaceuticals levels to around one third at 200°C/2h or to one tenth at 220°C/4h.

Dr Magnér also presented tests using lysimeters at Petersborg Farm, Skåne. Of 23 pharmaceuticals analysed, 15 were detected in sewage sludge, but only 4 were detected in soil after 35 years of sludge application and only one (caffeine) in water coming out of the bottom of the lysimeter. Acidic pharmaceuticals seem to move through soil more than others.

Conclusions are that sewage sludge application to farmland is an insignificant source of pharmaceuticals to the environment compared to sewage works discharge water, and that pharmaceuticals in sewage sludge are mostly retained in the surface soil and biodegraded there.

Kai Bester, Aarhus University, Denmark, summarised studies of pharmaceuticals in sewage sludge from four different Danish sewage works (wwtps) and fate in different sludge treatment processes. Results suggest that transfer of pharmaceuticals to sewage sludge can be estimated by the substance's partition coefficient (if $>10^4$, then 90% will go to sludge rather than being discharged in water), but that degradation is very difficult to predict. Some pharmaceuticals were not degraded in any of the four wwtps studied, others were degraded rapidly in some of the wwtps but not in others. No relation to biosolids properties or sludge retention time could be identified.

Further studies shows that ozonation removes some, but not all pharmaceuticals, but with a high energy cost. Composting shows different degradation performance for different pharmaceutical substances, with significant differences according to composting temperature. Biofilm reactors (fixed sand or moving bed, both anaerobic and aerobic) are effective in degrading a range of pharmaceuticals (21 out of 26 tested pharmaceuticals degraded >20% after 20 hours residence time), including recalcitrant molecules such as beta-blockers and X-ray contrast media. Further work is needed to reduced residence time and optimise the biological conditions.

Dr. Bester concludes that activated sludge degrades some pharmaceuticals, and that this can be today partly predicted for different substances. Different sludge treatments, on the other hand, have varying impacts on pharmaceutical degradation, information is lacking and degradation of different substances in different sludge treatment systems is not predictable. Overall, sludge post-treatments can remove significant amounts of pharmaceuticals, but cannot guarantee removal of all pharmaceuticals, and further work is needed into the identity and levels of metabolites generated in these degradation processes.

Marilyne Soubrand and Magali Casellas, Limoges University France, indicated that 60% of pharmaceutical substances tested entering sewage works are detected in sludges and confirmed that today there is little data available on pharmaceutical removal in sludge treatment, particularly because this is very variable for different sludge treatment processes and different pharmaceutical molecules.

They presented data from the *SIPIBEL* project, studying the fate of pharmaceuticals in the Bellecombe (Haute Savoie, France) sewage works (activated sludge process) which treats a mixture of hospital and municipal wastewater, with sewage sludge treated by either liming or mesophilic (c. 37°C) anaerobic digestion. Lachassagne et al. 2015 presents data from this site for 11 pharmaceuticals, showing the pharmaceuticals were generally removed in anaerobic digestion, but not in liming, but possible degradation metabolites were not assessed. For some of the pharmaceuticals, sludge treatment modifies the solid/liquid partitioning.

They further presented studies of pharmaceutical behaviour in soils. Soil column tests, with application of sewage biosolids, showed very low or non detectable concentrations of pharmaceuticals in leachate water coming out of the bottom of the soil columns. Tests showed that did not show toxicity of this leachate.

These studies are part of ongoing work in France to better understand the behaviour and possible significance of organic contaminants in sewage sludges, including the ESCo MAFOR report (see SCOPE Newsletter *109*) and the IMOPOLDYN project (funded by ADEME France - interactions micro-pollutants / organic matrices in fertiliser materials of waste origin: influence on the dynamics of micro-pollutants during land-spreading. Results suggest that pharmaceuticals behaviour is not related to the 'composition' of sludge (e.g. lipid content) but to interactions between molecular properties (in particular, different functional chemical groups, such as hydroxides, metal ions, cationic/anionic groups) of the pharmaceutical molecule and of sewage sludge flocs.

New treatment options, such as sludge pre-treatment upstream of anaerobic digestion (e.g. by ozonation) can both reduce pharmaceuticals and increase biogas production.

Poster presentations

Marissa de Boer, SUSPHOS, presented studies of uptake of pharmaceuticals (spiked into urine) to different recycled fertiliser products, which were then used to grow tomatoes. The lowest pharmaceutical uptake was in struvite. Uptake to tomatoes was very low: 750 kg dry weight tomatoes would have to be consumed daily to reach the ADI limit (1% of the therapeutic dose, in the worst case).

Meritxell Gros, Catalan Institute for Water Research, presented the occurrence of 40 multiple-class antibiotics and veterinary pharmaceuticals in field trials, fertilized with dairy cattle manure and pig slurry at a rate of 170 kg N/ha per year. Soil sampling was performed prior to fertilization and two and seven months after fertilization, at soil depths up to 120 cm. In cattle manure amended fields only three substances were detected at low µg/kg levels, while in pig slurry amended fields up to eight pharmaceuticals were identified at concentrations from ten to hundred µg/kg. Most of the pharmaceuticals detected were identified at all soil depths, indicating the liability of these substances to leach to groundwater bodies and deteriorate the quality of aquifers.

Håkan Jönsson, Swedish Agricultural University, Uppsala (SLU), presented the collaborative work group "Upstream work for sustainable recycling" started by VA-kluster Mälardalen. This is an open work group on upstream knowledge synthesis and research projects to address pharmaceuticals and consumer chemicals inputs to sewage, biosolids, soil and crops. Possible questions include modifying prescription/prescription free drug choices, actions in health institutions, treatment by enzymes in sewage, impacts of composting and digestion.

Trine Eggen, Norwegian Scientific Committee for Food Safety (VKM) Panel on Animal Feed, presented a risk assessment of contaminants in sewage sludge applied on Norwegian soils in 2009 using a tier-approach for prioritising pharmaceuticals. Her poster identifies 12 areas where knowledge necessary to support such risk assessments is currently lacking. She suggests that antimicrobial resistance should be an issue in future risk evaluations of sewage sludge. *http://www.vkm.no/dav/2ae7f1b4e3.pdf*

Zulin Zhang, James Hutton Institute, Scotland, presented results of a field trial where municipal sewage sludge, manure (mainly cattle) and compost (food wastes) and then soil analysed for a number of organic contaminants (industrial chemicals, combustion pollutants) and for ARGs (antibiotic resistant genes). Concentrations of the organic contaminants (e.g. DEHP) were higher in sludge > compost > manure and resulted in correspondingly higher levels in soils. Multiple applications of organic fertilizers resulted in higher ARGs in comparison to inorganic fertilizer although ARG abundance in soil showed to decrease over time.

Workshop conclusions

- **Incineration** of sewage sludge can be an appropriate solution depending on local conditions (e.g. contaminated sludge, lack of agricultural space for spreading …) but is **lower down the recycling hierarchy** (energy "recovery" not recycling). Even if phosphorus is recovered from ash (to produce fertiliser or for industry applications), organic carbon, nitrogen, potassium, sulphur and micro-nutrients are lost.

- Concerns about sludge contaminants must be taken seriously and addressed both by **developing data and information to support risk assessments**, and by taking **upstream actions** wherever possible to reduce contamination of sewage sludge. For industrial chemicals and consumer chemicals, this is possible by actions targeting users and households (reduce discharge to sewers), but for pharmaceuticals it is much more difficult.

- Public exposure risk to organic contaminants via sewage sludge should be put into **context of exposure from other routes** (both the same and other organic contaminants via direct contact and in household dust, air, water). However, this does not absolve the need to address sewage sludge use in agriculture in order to inform farmers, the food industry, consumers and decision makers.

- Veterinary pharmaceuticals and hormones are also present at significant levels in **manures**, and this should also be addressed, both by reductions at source where possible, and by monitoring and treatment where manure nutrients are recycled.

- There still a **need for more data** regarding fate of organic contaminants, including pharmaceuticals in sewage sludge. There is more data on heavy metals, and more data on organic contaminants in water (sewage works discharge, rivers, drinking water) than in biosolids. The question is multi-faceted: contaminants in biosolids, fate in sewage treatment and in sludge treatment processes, in soils, in crops, both short and medium term presence and impacts.

- **Pharmaceuticals and other organic chemicals in sewage sludge are varied and complex**, and cannot be considered as a single issue. Of the wide number of molecules, new pharmaceuticals and chemicals, breakdown products, which to monitor? Further data and understanding is needed to try to identify different families of substances which have similar behaviour, but without over-simplifying.

- **Pharmaceuticals and hormones** are important challenges, because of the inherent obstacles to upstream reductions, both in sewage sludge and in animal manures.

- More immediately however, **industrial and household chemicals** require monitoring and action, in particular:
  - PFOS (perfluorooctane sulfonate) and other perfluorinated chemicals, e.g. from Teflon
  - triclosan and triclocarban
  - brominated flame retardants and substitute chemicals
  - dioxins
  - PAH (poly aromatic hydrocarbons).

- **Composting** is generally effective for removing many, but not all pharmaceuticals. Female hormones however are largely not degraded.

- **Removal of organic contaminants in sewage treatment systems** is very variable and difficult to predict, depending on contaminant molecule chemistry, sludge properties, dewatering and treatment conditions.

- **Anaerobic digestion** can break down some pharmaceuticals, but further work is needed to better understand how to improve this, including looking at sludge disintegration upstream of digesters (e.g. Cambi, Haarslev, Biothely). Further work is needed on degradation metabolites to verify if these pose issues.

- There is potential to develop **new sludge treatment process chains** in order to improve pharmaceuticals removal, e.g. treatments upstream of anaerobic digestion, or modification of conditions in digesters and in the sewage works biological treatment cycles.

- Female **hormones** are often not degraded in sludge treatment, but this may be not of environmental or health significance. Manures either spread or going directly to soils from animals in the field often contains significant levels of such hormones.

- **Antibiotic resistance** is a globally important health issue, and should be better studied for sewage biosolids application. Knowledge shows that soils can naturally adapt, because soil organisms naturally release antibiotics, so that antibiotic resistance appearing after sludge application seems to be only temporary.

- Several studies confirm that **movement of organic contaminants to groundwater** is very low from sewage sludge land application. This is unsurprising, as the contaminants found in sludges are those which tend to partition to solids, and not to water.

- Data is needed to develop **robust risk assessments** of agricultural use of sewage biosolids, and also of manures, taking into account fate of and possible impacts of pharmaceuticals in sewage treatment processes, sludge treatment, in soil and possibly in crops and for grazing livestock. This cannot be feasibly done for the large number of pharmaceutical molecules and other organic contaminants, so screening is needed to identify priority substances.

Research needs and knowledge gaps

The Norwegian Food Safety Authority indicated that the 2009 VKM food safety report (Eriksen et al. 2009) assessed heavy metals and organic contaminants pharmaceuticals in sewage sludge used on farmland, concluding that use was safe if guidelines are respected. A risk assessment was also carried out for antibacterial-resistant bacteria and resistance genes in soil following application of sludge by evaluating the likeliness of development of resistance based on the drug residues in the STP water, in the dry sludge and in soil. A mandate has recently been made by the Norwegian Food Safety Authority to engage update of this report, including the issue of antibiotic resistance.

The Swedish EPA also concluded in 2005 (Österås et al. 2015): *"The results indicate that levels in soil after long term sludge additions do not pose a risk to the soil ecosystem or humans. These findings are in line with earlier findings".*

It was also noted that EU R&D funding has a JPI (Joint Programming Initiative) on Antimicrobial Resistance *http://www.jpiamr.eu/* It could be proposed to include sewage-born pharmaceuticals in this work.

Areas identified as priorities for further research:

- **Data, and communications summaries of data,** to justify the contribution of sewage biosolids use in agriculture to nutrient recycling and to soil carbon, in particular as regards the Paris Climate Change commitment to increase soil carbon by 4/1000 (CO_2 fixation).

- **Antibiotic resistance in soil microbes** after sewage sludge application. Is it possibly transmissible to health-relevant microbes? Is it consistently transient (natural soil adaptation) or is it a potential lasting issue of concern?

- Understanding of how **different molecular properties of organic contaminants and pharmaceuticals** (partitioning coefficients, chemical functional groups) fate in different sewage works processes (impacts of retention times, microbacterial species …), sludge treatment processes, sludge dewatering, in different sludges, in soils. An initial 'wish list' could be defined of data linking different molecular properties to behaviour.

- **Fate of pharmaceuticals in anaerobic digestion** of sewage sludges, including breakdown metabolites, as a function of digester operating conditions.

- **Adaptation of sewage works or sewage sludge treatment process chains**, or new treatment systems, to improve removal of organic contaminants.

- **Risk assessment models** for organic contaminants in land application of sewage biosolids, and also of manures, after different treatments, based on contaminant molecule characteristics, sludge treatment processes and parameters.

Recommendations for action

The following actions were proposed to take forward the objectives identified above:

- Establish a simple **data base of key relevant papers and reports, concerning organic contaminants in sewage sludges and their possible transfer to soil and crops.** A first list of papers as proposed by workshop participants, is included below. This is open to input to update.

- Propose **collaboration at a global level** with similar work in other continents, e.g. US the *NSSR* (National Sewage Sludge Repository) and the Human Health Observatory (HHO) see above.

- Develop a **document presenting the advantages of sewage biosolids recycling to agriculture**: circular economy and jobs, farmers' income, nutrient recycling, organic carbon – soils and climate change (4/1000), safety and environmental aspects, with recognition that other solutions for sludge management are appropriate according to local situations. ESPP or joint document? For decision makers.

- **Input to definition of R&D programme**s (EU Horizon 2020, other EU programmes, national R&D funding …) proposing relevant work on organic contaminants in sewage solids (see research priorities above), in particular data to support **risk assessments**:
  - workshop participants to identify and communicate consultations and opportunities for making such inputs
  - develop a joint document outlining R&D needs and priorities.

- **Identify R&D needs relevant to EU and national policies:**
  - EU Sludge Directive (86/278/EEC) and national sludge spreading regulations and plans
  - EU and national circular economy policies
  - End-of-Waste and fertiliser regulations.

- **Joint projects:** workshop participants may develop joint projects (R&D, water industry). ESPP is not an R&D brokerage operator, but can circulate proposals or partner search offers.

Workshop on pharmaceuticals and organic chemicals in sewage biosolids: questions for recycling,Malmö (near Copenhagen) 27th October 2016, organised by ESPP in cooperation with the Nordic Phosphorus Conference (DAKOFA, Avfall Norge, Afvall Sverige). Speaker slides are available at https://dakofa.com/conference/conference/programme/ *(click on the speaker's name in the programme)*

Papers and reports identified by workshop participants

Andersen et al. "Fate of pharmaceuticals and personal care products (PCPs) by composting of biosolids" Proceedings Sardinia 2009, Twelfth International Waste Management and Landfill Symposium https://www.tuhh.de/iue/iwwg/publications/conference-proceedings/sardinia-2009.html

Clarke & Smith "Review of 'emerging' organic contaminants in biosolids and assessment of international research priorities for the agricultural use of biosolids", Environment International 37 (2011) 226–247
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.652.7711&rep=rep1&type=pdf

Butkovskyi et al. "Fate of pharmaceuticals in full-scale source separated sanitation system", Water Research, 85, 384-392, 2015 http://dx.doi.org/10.1016/j.watres.2015.08.045

Butkovskyi et al., "Mitigation of micropollutants for black water application in agriculture via composting of anaerobic sludge", J. Hazardous Materials, 303, 41-47, 2016 http://dx.doi.org/10.1016/j.jhazmat.2015.10.016

Smith "Organic contaminants in sewage sludge (biosolids) and their significance for agricultural recycling", Philosophical Transactions of the Royal Society A-Mathematical Physical and Engineering Sciences 367, 4005-4041, 2009 http://dx.doi.org/10.1098/rsta.2009.0154

Halden "Epistemology of contaminants of emerging concern and literature meta-analysis", J. Hazardous Materials 282 (2015) 2-9 http://dx.doi.org/10.1016/j.jhazmat.2014.08.074

Hörsing & Ledin, SVU (Svenskt Vatten Utveckling) 2016-08 "Identifiering av fokusämnen för slam – organiska miljögifter" (identification of priority organic contaminants in sludge) http://www.svensktvatten.se/contentassets/41ce07e942c24bbfad6a612525da572e/svu-rapport_2016-08.pdf

Hörsinget et al. al., SVU 2014-12 "Organiska miljögifter i sockerbetor och blast odlade på mark gödslad med kommunalt avloppsslam" (risk assessment for organic contaminants when sewage sludge after mesophilic anaerobic digestion is applied to fields) http://www.svensktvatten.se/globalassets/avlopp-och-miljo/uppstromsarbete-och-kretslopp/revaq-certifiering/svu-rapport-2014-organiska-miljogifter-i-sockerbetor-och-blast---slamgodsling.pdf

Jelic, et al. "Occurrence, partition and removal of pharmaceuticals in sewage water and sludge during wastewater treatment", Water research 2011, 45 (3), 1165-1176 http://dx.doi.org/10.1016/j.watres.2010.11.010

Gorga, et al. "Determination of PBDEs, HBB, PBEB, DBDPE, HBCD, TBBPA and related compounds in sewage sludge from Catalonia (Spain)", Science of the Total Environment 2013, 444, 51-59 http://dx.doi.org/10.1016/j.scitotenv.2012.11.066

Mastroianni, et al. "Illicit and abused drugs in sewage sludge: Method optimization and occurrence", Journal of Chromatography A 2013, 1322, 29-37 http://dx.doi.org/10.1016/j.chroma.2013.10.078

Gorga,et al. "Analysis of endocrine disrupters and related compounds in sediments and sewage sludge using on-line turbulent flow chromatography-liquid chromatography-tandem mass spectrometry", Journal of Chromatography A 2014, 1352, 29-37 http://dx.doi.org/10.1016/j.chroma.2014.05.028

Campo et al. "Distribution and fate of perfluoroalkyl substances in Mediterranean Spanish sewage treatment plants", Science of the Total Environment 2014, 472, 912-922 http://dx.doi.org/10.1016/j.scitotenv.2013.11.056

Campo et al. "Occurrence and removal efficiency of pesticides in sewage treatment plants of four Mediterranean River Basins", Journal of hazardous materials 2013, 263, 146-157 http://dx.doi.org/10.1016/j.scitotenv.2013.11.056

Levén et al., JTI 2016 , ISSN-1401-4955 "Pharmaceuticals in blackwater and fecal sludge – Treatments and risks" http://www.jti.se/uploads/jti/R-54%20LL%20m.fl.pdf

Magnér et al., IVL B2264 September 2016 "Fate of pharmaceutical residues - in sewage treatment and on farmland fertilized with sludge" http://www.ivl.se/download/18.29aef808155c0d7f05054e/1473086619449/B2264.pdf

Malmborg, SVU 2014-21 "Reduktion av läkemedelsrester och andra organiska föroreningar vid hygienisering av avloppsslam"(assessment of reduction of pharmaceutical and other organic contaminants in sewage sludge under seven different sludge treatments) http://vav.griffel.net/filer/SVU-rapport_2014-21.pdf

Malmborg & Magnér, J. Env Management 153 (2015) 1-10 "Pharmaceutical residues in sewage sludge: Effect of sanitization and anaerobic digestion" http://dx.doi.org/10.1016/j.jenvman.2015.01.041

Österås et al., WSP 10196232, 2015 "Screening of organic pollutants in sewage sludge amended arable soils", report for Sweden EPA http://www.svensktvatten.se/globalassets/avlopp-och-miljo/uppstromsarbete-och-kretslopp/revaq-certifiering/naturvardsverket-rapport-screening-of-organic-pollutants-in-sewage-sludge-amended-arable-soils_151124-2.pdf

Rigby et al. "Organic contaminant content and physico-chemical characteristics of waste materials recycled in agriculture" Agriculture 5(4), 1289-132, 2015 http://dx.doi.org/10.3390/agriculture5041289

Eriksen et al. / VKM (Norwegian Scientific Committee for Food Safety) "Risk assessment of contaminants in sewage sludge applied on Norwegian soils", 20th August 2009 http://www.vkm.no/dav/2ae7f1b4e3.pdf

Smith "Organic contaminants in sewage sludge (biosolids) and their significance for agricultural recycling" Philosophical Transactions of the Royal Society A – Mathematical Physical and Engineering Sciences, vol 367, 4005-4041 http://dx.doi.org/10.1098/rsta.2009.0154

Venkatesan, et al. "United States National Sewage Sludge Repository at Arizona State University – A New Resource and Research Tool for Environmental Scientists, Engineers, and Epidemiologists", Environ. Sci. Pollut. Res. Int. 22(3):1577-1586 http://dx.doi.org/10.1007/s11356-014-2961-1

Zhang et al. "A study on temporal trends and estimates of fate of Bisphenol A in agricultural soils after sewage sludge amendment", Science of the Total Environment 515/516:1-11, 2015 http://dx.doi.org/10.1016/j.scitotenv.2015.01.053

Rhind et al. "Short- and long-term temporal changes in soil concentrations of selected endocrine disrupting compounds (EDCs) following single or multiple applications of sewage sludge to pastures" Environmental Pollution 181: 262-270, 2013 http://dx.doi.org/10.1016/j.envpol.2013.06.011