Technical University of Denmark

Urban drainage research and planning. Quo vadis?

Arnbjerg-Nielsen, Karsten; Langeveld, Jeroen; Marsalek, Jiri

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A compendium of hot topics and features from IWA Specialist Groups

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International Water Association (IWA)
Alliance House
12 Caxton Street
London SW1H 0QS
United Kingdom

Telephone: +44 207 654 5500
Fax: +44 207 654 5555
Email: water@iwahq.org

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Preface

In 2012 The International Water Association (IWA) has published the first edition of the compendium of hot topics and features from IWA Specialist Groups. The aim was to raise the profiles of the IWA Specialist Groups and their visibility, by inviting them to briefly present the current state of knowledge in their respective fields and, more important, to identify emerging topics, questions, trends and challenges. The compendium included contributions from 25 Specialist Groups.

In 2016, we are happy to publish the second edition of the compendium, with 38 free format contributions from 36 Specialist Groups and 2 Clusters presenting their visions and challenges in water science, research and management, with a diversity of approaches ranging from detailed technical and scientific aspects to more integrated approaches.

The 48 IWA Specialist Groups are the core vehicle for IWA members networking and for issue-based interactions on water related scientific, technical and management topics within IWA. Specialist Groups facilitate cooperation, networking and knowledge generation, primarily through regular conferences, meetings, working groups, task groups, newsletters and publications. They are created on a voluntary basis by IWA members and strongly supported by IWA office.

IWA Clusters facilitate and promote conversations across IWA Specialist Groups, and also with partner associations, to address cross-cutting issues, to integrate knowledge and approaches, and to provide solutions at scales which are beyond those of one single Specialist Group.

Specialist Groups and Clusters contribute to the implementation of the Strategic Plan of IWA, especially to content development, knowledge dissemination and professional development. More information is available at http://www.iwa-network.org/iwa-specialist-groups/

The work of Specialist Groups and Clusters is coordinated and supported by IWA Science and Technology, Specialist Groups Manager Dr Hong Li. Please feel free to contact her by email at hong.li@iwahq.org if you require any further information or have any questions about the content of this compendium.

We invite you to both discover the challenges, the vision and trend of the contents that IWA Specialist Groups and Clusters cover, and to bring your own contributions by joining them and participating in their stimulating activities.

Prof. Jean-Luc BERTRAND-KRAJEWSKI
University of Lyon, INSA Lyon, France
Chair of the IWA Strategic Council Sub-Committee for Specialist Groups and Clusters

Alternative Water Resources

Written by *Francisco Cubillo and Patricia Gómez* on behalf of the Cluster

Introduction

The increasing divergence between water resources and demands all over the world highlights the need for more reliable and resilient water supplies to reach an appropriate resources/demand balance.

With the changing climate, and increasing issues surrounding water, food and energy due to human population growth, urbanisation and climate change, we are increasingly facing resource scarcity, including water shortages. Traditional water resources such as surface and ground water are not sufficient anymore because of quality and quantity issues, although this varies among regions and countries.

Thus, the definition and development of diverse solutions to cope with emerging concerns in the water supply sector is essential.

Technology has been providing water solutions to every problem, contextualised with different costs, impacts and consequences. The first solutions focused on looking for additional reliable and good quality raw water resources without considering that large infrastructures were required to abstract, store and convey water to consumption points. Evolving enabling technologies led to new forms of alternative resources that were able to satisfy needs, to provide appropriate water quality for health protection and to fulfil specific requirements for water-related activities. But sometimes, costs or environmental impact made solutions unfeasible or generated social reluctance. Every context and city has a variety of options with different figures of marginal costs (economic, social and environmental) and with different reliability for the availability/demand balance. All over the world the search for affordable, acceptable and reliable solutions is still a common challenge for water supply planners.

The focus of the Alternative Water Resources (AWR) Cluster is to improve resilience and reliability of the water supply through the combination between water balance and service provision. An adequate balance looks for a fundamental aim, which is providing service by supplying the total water demanded. It is the main factor of the service, from which other conditions are considered, like hydraulic properties, water quality, continuity, customer service, etc.

This Cluster perspective highlights the need for water supply solutions for professionals to respond to the global challenges ahead and suggests the importance of analysing to diagnose, compare, decide and solve. Every analysis is done to find the best solutions. The idea and the principles of the Cluster allow a comprehensive and integrated approach, with the aim of an appropriate service, the focus on the main variables, the inclusion of security, resilience and risk principles, and an assessment framework. Alternative resources (demand or offer) are the elements to consider. Indicators and metrics to assess and compare should be identified.

Existing Cluster's knowledge

In addition to surface water and groundwater resources, many countries and utilities have promoted the acquisition and development of alternative water resources, practising reuse, desalination, greywater, artificial recharge, rain harvesting, demand management, etc.

A review of alternative options that focuses on resources and demand has been compiled and described in detail in a compendium, "*Alternative Water Resources: A Review of Concepts, Solutions and Experiences*". It also describes case studies and parameters to assess their costs and benefits.

Moreover, new technologies facilitate the adaptation of water's characteristics and its conditions to regulations and requirements for its use and consumption. Technologies need feasibility but also increased awareness. Thus, perception issues and social acceptance are certainly very important. Likewise, considerations of the requirements of potential users, appropriateness of contractual arrangements, environmental implications and technology's future effects and comparisons of costs/tariffs with conventional resources will encourage more utilities and governments to implement the smart use of new water resources and new solutions. This will be summarised in a monograph on social acceptance and preferences from citizens, customers and society (in general) about alternative resources, solutions, sharing of costs, impact on water rates and invoices.

The Cluster also includes considerations of energy reduction (recovery), increased efficiency, and decreased water consumption to reach both environmental and economic sustainability.

Therefore, the Cluster seeks water supply solutions that are not necessarily new, are new technologies, and which must be new methods of assessment and analysis to select different ways of guaranteeing an efficient and resilient water balance. The cluster scope includes the following:

- conventional and non-conventional resources;
- demand as a whole (including losses);
- planning supply systems;
- operational efficiency;
- sustainability.

Main challenges

The Alternative Water Resources Cluster is working to integrate knowledge and approaches, and define new paradigms, in order to identify new opportunities for improving water supply services. The main challenges for the Cluster in facilitating new water solutions for an adequate balance are the following:

- Updated knowledge about assessment of alternatives to the resources/demand balance. This would be based on identifying potential alternative water resources, enabling technologies and potential contributions to demand management in terms of water consumption and water losses, not only for usual operation but also for emergency scenarios. Every solution should include an assessment of costs and energy use ranges, emission levels, environmental impacts and social acceptance levels.

- Establishment of new methods, processes and indicators to analyse and compare options. The final aim is to propose a methodology for a consistent comparison of different options and solutions.

- Propose new standards and paradigms for reliability, resilience and risks in water supply systems. The standards on robustness and resilience need to be defined, measured and quantified for any city, and the main threats in water supply management such as drought, flooding rain, ageing infrastructures among others. The Cluster looks for a common approach to select criteria and methods for assessing resilience in urban systems. It will be a key contribution to the subsequent development of diverse solutions to ensure water availability and demand balance.

Conclusions and development agenda

Therefore, in practice, the general objective of this cluster is to enable a common approach to selecting the various ways to guarantee an efficient and resilient water balance. It is aimed at developing a "portfolio" of options and properly assessing their contribution to resource–demand balance and its risk. This will enable an informed comparison of the diverse options, their costs and their benefits. Consequently, a utility can make informed decisions on how much of its water portfolio should be acquired from surface supplies, groundwater, desalination, demand management, reuse, rainwater/stormwater harvesting, etc. for every planned horizon. The Cluster will also assess the components needed to create reliability and resilience in water supplies. This will enable more efficient planning of water resource portfolios in a changing and uncertain world.

The Cluster will involve members and external partners from utilities, industry and local government, as well as all other water professionals who are interested in promoting new water solutions. This includes defining what the possible solutions for the best use of water resources could be, under different conditions and in different regions:

- Increase resource use efficiency, which means integrating dimensions from the supply side, operational side (transmission) and technology side (treatment), reducing water consumption (including water loss), and decreasing energy use (closer to energy neutral or energy recovery).

- Facilitate the sharing of knowledge and information, integrate the different approaches already performed by relevant specialist groups and/or task groups, synthesise different elements and collaborate with relevant external partners and associations.

- Evolve from less efficient to more efficient water management, reaching robustness and resilience.

In this regard, the development agenda is based on the following:

- integrating knowledge and searching for improvement opportunities from the variety of perspectives that specialist groups, task groups and working groups have;

- creating platforms for bridging knowledge and people from different segments and fields;

- staging unique events and opportunities aimed at addressing key cross-cutting issues and showcasing successful stories from both a utility's standpoint and from those of the countries and regions;

- developing advocacy for funding possible projects on water research in areas requiring joint applications of research and practice;

- producing tools and publications, including a compendium of alternative water resources;

- aiding in the creation of more concrete water supply solutions by defining a set of metrics that will allow quantitative comparisons between alternative water resource options.

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Anaerobic Digestion

Written by *D. Batstone, H. Spanjers, J. Rodriguez, J. B. van Lier, E. Morgenroth, M. M. Ghangrekar, R. Saravanane, T Shimada and A J Guwy* on behalf of the Specialist Group

Anaerobic digestion is one of the most active IWA Specialist Groups, with over 1000 members, active sponsorship of three task groups or working groups, and organisation of on average, one Specialist Group conference per year. This is highlighted by our recent World Conference – AD14 in Viña del Mar, where over 750 delegates attended, and 200 papers and 441 posters were presented. The themes at the Anaerobic digestion conferences provide a very good review of major themes of interest in anaerobic digestion. Over the years, we have always observed a large number of papers focusing on specific aspects related to the themes of (1) solid waste and energy crop management; (2) biosolids and sludge management; (3) industrial wastewater. These application areas have been strongly supported by investigation into microbial ecology, mathematical modelling, chemical analysis, process innovations and novel technologies. Over the past 5 years though, we have seen several major new themes emerge. These have been driven by both market opportunities and scientific advances. The goal of this review is to further outline challenges and opportunities for wastewater treatment researchers and practitioners in these areas, as well as the specific role of anaerobic digestion technologies within these application areas.

Major emerging themes

The key topics we as a Specialist Group can identify as major developing areas are the role of anaerobic processes in waste mining and resource recovery, production of chemicals through bioprocessing and bioproduction, and integration of anaerobic digestion processes into the larger evaluation framework, including upstream and downstream -environmental- systems, and advanced wastewater treatment through emerging processes such as anaerobic membrane bioreactor systems.

Anaerobic processes for resource recovery

Anaerobic digestion is the only biochemical process that removes organic contaminants, while converting this into a useful energy carrier, methane. Recently, research has also focused on the integration of acidogenic and methanogenic processes for simultaneous production of biohydrogen and methane from wastewater treatment (Radjaram and Saravanane, 2011), or from lignocellulosic substrates in two-stage systems. Generation of both fuels would enhance the potential application towards sustainability of the process (Massanet-Nicolau *et al*., 2013). Another theme is looking into alternative forms of energy offsets, more specifically methanol. The abundance of shale gas in the USA has resulted in less favourable lifecycle costs for anaerobic digestion at municipal WWTPs. Conversion of methane to methanol is an emerging technology that will help further expand anaerobic digestion.

Over the past 2 years there have been considerable fluctuations in phosphorus and nitrogen pricing, and this has emphasised the realisation that in particular, phosphorus is a non-renewable resource, with the peak in mineral production expected to occur around 2030 (Cordell *et al.* 2009). Added to this, nitrogen is very expensive energetically to produce, and the other macronutrient potassium is becoming depleted in major agricultural zones. While fluctuations have stabilised, price is currently in the order of US$5 per kilogram phosphorus, and US$1 per kg nitrogen, and steadily rising. While manure is a classic and significant source of nitrogen and phosphorus worldwide (Cordell, Drangert *et al.* 2009), for industrial agriculture, the phosphorus market is dominated by mineral resources. This has energised research into recovery of phosphorus from waste streams, mainly as calcium and magnesium phosphates, including struvite ($MgNH_4PO_4.6H_2O$ (Le Correet al. 2009). Even in net export countries, such as Australia, (where 50% of the phosphorus in food is exported), 25% of phosphorus and nitrogen, and 100% of potassium can be recovered from waste streams (Mehta *et al*., 2016).

Anaerobic digestion has minimal impact on nutrient concentrations. This has been previously seen as a limitation, but is now emerging as a benefit, with the energy content being used in an integrated process to drive full nutrient recovery (Verstraete *et al.* 2009). This will result in changes in the modes of operation of anaerobic digestion to further enhance nutrient recovery, and the focus is likely to move beyond simply phosphorus to full recovery of nitrogen, potassium, and water by a range of novel techniques.

Nutrient recovery will also require a higher degree of operational flexibility and understanding of the underlying anaerobic process, to enable treatment of different waste streams (wastewater through agro-industrial solid wastes), as well as cater for downstream processes such as water recovery.

Bioprocessing and bioproduction

Anaerobic processes have been used for thousands of years to 'value add' to organic feedstocks by converting them to a wide range of largely fermented foods and beverages. This has also been widely used in the 20th century in industrial biotechnology to produce bulk industrial chemicals such as ethanol and organic acids, as well as high-value products, including pharmaceuticals. Over the past 15 years, we have seen two significant and genuine innovations that are dramatically changing the landscape of industrial biotechnology (Batstone and Virdis, 2014).

Until recently, biotechnology focused on the use of pure or highly enriched cultures to generate speciality products from very pure feedstocks. This has limited application of industrial biotechnology to higher value chemicals, including higher cost feedstocks that compete with the food value chain, and which often require expensive sterilisation of both the reactor and the feed. In contrast, mixed culture biotechnology (MCB) uses environmentally ubiquitous microbes to produce a mixture of chemicals (Kleerebezem and van Loosdrecht 2007). These organisms are faster, can convert more complex feedstocks, and are capable of working under different hydraulic regimes. The mixture of products needs to be directed by manipulation of concentration, temperature, pH, and redox, and there needs to be a certain degree of downstream separation. Research is now moving from a focus on systems analysis to a deeper understanding of how mixed culture fermentations (and biotechnology) is influenced by environmental conditions, and how control handles can be best manipulated. This should be combined with further research into downstream processing to develop the concept of a biorefinery that can generate multiple products from raw nonsterile feedstocks with a high degree for market driven flexibility.

Bioelectrochemical systems have been one of the major developments in the anaerobic process world over the past 10 years, with an initial focus on direct generation of electricity from anodic biological processes (Lovley 2006). The current cost of bioelectrochemical systems (approx. 100x that of conventional anaerobic systems), and relatively low performance makes them (currently) a limited proposition for electricity generation. A far more compelling application appears to be use of electrochemical systems with either pure or enriched cultures to generate specific products. These can either be done via partial oxidation at the anode to generate partly oxidised products (e.g. 1-3 propanediol from glycerol), or by reduction at the cathode (e.g. generation of CO_2 from methane) (Rabaey and Rozendal 2010). The exciting thing about this is not just the enhanced and highly efficient use of electricity. There is also the range of capabilities derived from the enormous flexibility of this technology, including the ability to set potential, electrode material and cell geometry, the ability to favour specific organisms, or planktonic versus electrode biofilms, and the ability to manipulate ion flow through the membrane.

The two issues of MCB and bioelectrosynthesis are highly complementary, as MCB is generally needed as a pretreatment process for bioelectrosynthesis, and both can operate in complementary processes within the overall biorefinery process.

Integrated systems assessment

This review has focused so far on the promise of anaerobic processes to replace existing technologies, including activated sludge wastewater treatment, mineral fertiliser production, and industrial chemical manufacturing. However, there will clearly be longer term applications for both practical integration of anaerobic digestion with larger systems, as well as its integration with larger process models. Integrated systems modelling, life cycle assessment, and integrated environmental assessment not need to include the whole water and energy cycle, and anaerobic processes are emerging as a clear segment within overall systems modelling. A clear example is emerging methods to model larger wastewater treatment plants, with adaptation and integration of biochemical models such as the IWA developed Anaerobic Digestion Model No. 1 (Batstone *et al.* 2002) into key integrated models such as the Benchmark Simulation Model (Jeppsson *et al.* 2007). The process of integrating models has been very complementary, not only providing important tools such as interface models, but demonstrating the strengths of each sub-model. As an example, the advanced pH model within the Anaerobic Digestion Model No. 1 is clearly relevant to the whole water cycle, and this has led to establishment of a new IWA Task Group on Physicochemistry Modelling (Batstone 2009), which will not only enrich modelling of aquatic chemistry, but is applicable to all topics raised in this review.

Advanced wastewater treatment

Modern high-rate technologies are successfully implemented at a large variety of industries. Granular sludge bed based systems are most commonly applied, whereas China seems to be the most rapidly growing market. Very high loading rates reaching 40 kg COD per m^3 reactor per day are feasible reducing reactor volumes to a minimum. Current applications are limited by the maximum specific conversion capacity and/or efficient separation of the produced biogas from the sludge. For more 'extreme' types of the wastewaters these limitations are more pronounced resulting in disappointing loading potentials. Examples are wastewaters characterised by high temperatures, high salinity, presence of toxic compounds, high fat, oil and grease content, high solids content, etc. Various research groups are presently focusing on the development of anaerobic membrane bioreactors (AnMBR) making use of either submerged or cross flow configurations (Liao *et al.*, 2006). The full retention of anaerobic biomass prevents specific rinsing of key organisms for specific substrate conversion, whereas the membrane assisted separation process provides a solids free effluent. The growing number of research papers has led to separate conference sessions at the Anaerobic Digestion World Congress. Working at relatively high sludge concentrations, cake layer management seems to determine membrane fluxes (Jeison and van Lier, 2007; Lin *et al.*, 2010). At present, the impact of increased shear-forces on anaerobic microbiology, physiology and biochemistry is currently being investigated (see, for example, Menniti *et al.*, 2009). With the drop in membrane prices and the relatively low required fluxes with concentrated wastewaters, AMBR systems seem to be of particular interest for those applications where successful granular sludge bed systems cannot be guaranteed.

Conclusions

Anaerobic processes have a major role in future sustainable water management, and also across all areas of human activity, including agriculture, industrial chemicals, and energy generation. There are clearly novel areas to apply the basic principles we have developed over the past 50 years of research, including MCB, and electrochemically mediated processes. In addition, new science will be needed to fully enable resource recovery and provide new downstream processing options for the biorefinery of the future. At the same time, we need to recognise that there has been an enormous amount of work done already, which is particularly applicable to other fields such as domestic wastewater treatment, including upstream sewer processes. It will be important to retain this important knowledge as we move into new and exciting applications.

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Assessment and Control of Hazardous Substances in Water

Written by *Maria Fürhacker, Christa S. McArdell, Yunho Lee, Hansruedi Siegrist, Thomas A. Ternes, Wenwei Li and Jianyong Hu* on behalf of the Specialist Group

Introduction

Micropollutants (MPs) comprise organic or inorganic substances with persistent, bio-accumulative and toxic properties, which may have adverse effects on human health or/and biota. For MPs to be considered as persistent organic pollutants (POPs) under the Stockholm Convention, organic chemical substances (carbon-based) need to possess a particular combination of physical and chemical properties such that, once released into the environment, they are persistent: remain intact for exceptionally long periods of time (many years); become widely distributed throughout the environment as a result of natural processes involving soil, water and, most notably, air; accumulate in the fatty tissue of living organisms including humans, and are found at higher concentrations at higher levels in the food chain; and are toxic to both humans and wildlife.

Micropollutants, whereas some of them are also termed as emerging contaminants, include pharmaceuticals, personal care products, steroid hormones, industrial chemicals, pesticides, hydrocarbons, solvents, detergents and many other compounds. Emerging pollutants have been recently detected in wastewater and the aquatic environment, although they might already have been present for decades. Prominent examples of emerging pollutants are pharmaceuticals, oestrogens, ingredients of personal care products, biocides, flame retardants, antioxidants, benzothiazoles, or perfluorinated compounds (Richardson and Kimura, 2016; Richardson and Ternes 2014). In addition, the speciation and fate of metals such as lead, cadmium, mercury, arsenic, antimony, radon, uranium, beryllium, platinum, palladium, and gadolinium are only partly known; for many of them, neither the concentration nor the effects are tested. Micropollutants are usually found in water at trace concentrations, ranging from a few picograms per litre to several micrograms per litre. Innovative analytical instrumentation such as hybrid mass spectrometry (MS) enables the identification and quantification of organic pollutants down to the lower nanogram per litre and nanogram per kilogram range in environmental matrices and drinking water. These low concentrations and the large variety of single substances constitute a challenge for the analytical detection, but also for the treatment and removal processes. Micropollutants are present in many products of daily use or consumption such as drugs, cosmetics, pesticides, etc., or those that are used in industry. Some micropollutants are primarily discharged by (chemical) industry as they are used for chemical synthesis or product preparation.

About 100,000 chemicals are registered in industrial countries such as those of the European Union or the USA. It can be assumed that more than 10,000 chemicals are entering sewer systems and eventually wastewater treatment plants (WWTPs). A European-wide monitoring study on the occurrence of MPs in 90 different WWTP effluents showed the presence of 131 target organic compounds in European wastewater effluents, in concentrations ranging from low nanograms to milligrams per litre. The most relevant compounds identified in the effluent water samples in terms of frequency of detection, maximum, average and median concentration levels were sucralose, acesulfame (artificial sweeteners), PFOA, PFHxA, PFHpA, PFOS (perfluoroalkyl substances), N,N′-diethyltoluamide (DEET; insect repellent), benzotriazoles (corrosion inhibitors), a wide variety of pharmaceuticals, organophosphate ester flame retardants, X-ray contrast media, pesticides, triclosan (antibacterial) and gadolinium (from magnetic resonance imaging contrast media used in hospitals). The toxicity tests applied in this study showed some toxicity. From the total number of 75 WWTP effluents analysed for oestrogenicity, 27 sample extracts showed estrogenic activity higher than the detection limit >0.5 ng/l oestrogen equivalents (EEQ). Twenty-five effluent sample extracts were screened for dioxin-like activity, of which 21 exceeded the detection limit (0.1 ng/l $TEQ_{biotest}$), but the maximal detected dioxin-like activity was only 0.4 ng/l $TEQ_{biotest}$. Finally, three out of 13 effluent samples tested on acute toxicity revealed themselves harmful for the growth of yeast and diatom organisms (JRC, 2012).

While pharmaceuticals are frequently transformed in the body and a combination of unaltered pharmaceuticals and metabolites are excreted by humans, other contaminants enter the wastewater without being metabolised. Microbial transformation products (TPs) can be formed during biological wastewater treatment, in contact with sediment and soil as well as during bank filtration. Furthermore, TPs can be formed by UV-light in surface waters and during oxidative treatment such as ozonation or disinfection with chlorine. Hence, in addition to the original MPs, the TPs formed in the environment as well as in technical processes have to be considered in a comprehensive evaluation.

Therefore, the increasing concern on the health of the aquatic environment has become a worldwide issue. Recently, researchers and government agencies have begun to classify chemicals as contaminants of emerging concern (CECs), often because of their high volume use, potential for ecotoxicity in non-target species, and the increasing number of studies that report their occurrence in the environment. CECs can be broadly defined as synthetic or naturally occurring chemicals that are not regulated or commonly monitored in the environment, but have the potential to enter the environment and cause adverse ecological or human health impacts.

The key environmental questions for the Assessment and Control of Hazardous Substances in Water Specialist Group is the protection of human and environmental health, especially in the light of increasing knowledge of new and emerging effects. These effects include many different aspects of endocrine disruptors, but also organ-specific toxicities such as liver toxicity, nephrotoxicity, neurotoxicity and immunotoxicity. In addition, we also have to cope with challenges such as non-monotonous dose–response relationships or indirect effects derived from, for example, antibiotic-resistant bacteria or changes in the gut microbiome and resulting effects.

The biggest challenge finally remains to link the complex mixture of MPs occurring in freshwater or marine systems with thousands of industrial and natural chemical compounds to environmental effects; and to evaluate and manage the resulting risk.

Advances in the area

Sources of hazardous substances such as point sources from industry or manufacture of, for example, metal, pulp and paper, chemicals, food, drugs as well as many others are increasingly investigated, and many studies show that the concentrations of single substances can be very different. However, municipal WWTPs containing consumer-related products and diffuse sources are also important discharge points. Diffuse sources are deposition, agriculture (e.g. pesticide application, groundwater recharge, sewage sludge application to land), traffic, power generation, mining, waste disposal (e.g. incineration, landfills) or could be accidental releases (e.g. spills). In general, the newly detected compounds are present in the aquatic environment at low to very low concentrations (picograms per litre to nanograms per litre); nevertheless, certain substances are contaminants of emerging concern as they show carcinogenic or mutagenic reactions or are toxic for reproduction (CMR substances) or are allergens or endocrine disruptors. Most of them do not show toxic effects in the measured concentrations of the individual compounds, but it cannot be excluded that they appreciably contribute to an overall toxicological effect of the complex mixtures present in environmental matrices. Hazardous substances may also reach groundwater by infiltration of surface water, relevant for human health.

Monitoring and analytical methods

Beside the trace analysis of organic contaminants in environmental samples, the sample preparation and clean-up is one of the key issues, as it can influence signal suppression or enhancement and method parameters such as limit of detection (LOD), limit of quantification (LOQ), linearity, accuracy, and precision. Farré et al. (2012) present recent approaches for sample preparation like monolithic (particle-free) solid-phase extraction (SPE), immuno-affinity chromatography (IAC), molecularly imprinted polymers (MIPs), restricted access materials (RAMs) or nanoparticles in SPE to resolve selectivity and sensitivity issues. The development of online SPE has allowed reductions in sample manipulation, times of analysis, sample and solvent volumes.

For monitoring of MPs in water environments, a variety of chromatographic and spectroscopic detection techniques are already available while for *in situ* monitoring sensitive, robust and affordable techniques are still highly desirable. The improvement of the analytical methods allowed to measure the majority of the polar organic MPs as well as their TPs. Modern hybrid mass spectrometry systems (e.g. FT-MS, ion trap MS, SF-MS, Q-MS, TOF-MS) allow the determination of MPs and their TPs and deliver information of mass fragments which can be used to identify the chemical structure. One possibility for confirming the chemical structure of TPs is nuclear magnetic resonance spectroscopy (NMR). Recently, hybrid triple quadrupole-linear ion trap mass spectrometer (Qq-LIT-MS) in combination with NMR was applied to elucidate the chemical structures of 27 biological TPs (bioTPs) of a couple of MPs transformed in contact with soil and sediment. The combination of MS2 and MS3 spectra using Qq-LIT-MS is essential to determine the MS fragmentation pathways crucial for structural elucidation (Richardson and Ternes, 2013). The evolution of high-resolution (HR), high accuracy mass spectrometry (MS), coupled with liquid chromatography (LC, together LC-HRMS) enables new possibilities for detecting polar organic contaminants in complex samples (Schymanski et al. 2014). With LC-HRMS not only a screening for suspected substances (based on prior information, but where no reference standard is available) can be performed, but also a non-target screening for unknown compounds.

Recently, the success of infrared spectroscopy-attenuated total reflectance (FTIR-ATR) sensors for simultaneous detection of multiple-species of MPs such as chlorinated hydrocarbons (CHCs) and monocyclic aromatic hydrocarbons (MAHs) suggests the promise of this technology (Lu et al., 2013a; 2013b).

Biomonitoring is an essential tool for rapid and cost-effective environmental monitoring. Most common bioanalytical tools are based on the use of enzymes, nucleic acids, whole cells and immunoreactions. Biochemical tests can be applied in addition to chemical monitoring and as alternatives or screening methods before animal tests are conducted. In the methodology of alternative test methods in ecotoxicology considerable advances have been made in recent years. Nevertheless, a potential still exists for the application of non-animal alternatives for aquatic and terrestrial ecotoxicity testing as four key areas of potential current and future high vertebrate usage were determined as (1) the identification of endocrine disruptors, (2) the assessment of bioaccumulation, (3) acute toxicity and (4) chronic toxicity (Burden et al., 2015). In terms of endocrine disruptors, the OECD (2012) launched the document “Guidance Document on Standardized Test Guidelines for Evaluating Chemicals for Endocrine Disruption”. The document compiles a large set of methods and the key questions addressed concern likely mechanisms of endocrine action and any resulting apical effects that can be attributed to such action. The key advice for each assay is given in the form of a table which lists a series of scenarios for combinations of different assay results and varying backgrounds of existing data, and provides advice on interpretation and further testing that may be considered in each scenario. As the field of endocrine disruption is still developing, the document will be subjected to periodic revisions. Guidance is provided on assays and the endpoints for endocrine modalities (oestrogen/androgen/thyroid/steroidogenesis (EATS) modalities).

Treatment methods

Investigations into treatment methods focusing on the elimination of micropollutants from point sources, such as municipal or industrial wastewaters, aiming to improve surface water quality, have been intensively conducted around the world in recent decades. These investigations have resulted in a shortlist of technologies with potential for application:

- Biological processes have been studied to identify the possibilities of increasing the elimination of micropollutants. Generally, the hydrophobic substances (about two-thirds of the regulated substances) are sorbed onto sludge, resulting into a significant load reduction, but also to a transfer of pollution to sludge. As a consequence, especially in some cases of significant industrial load contribution to the plant, this may impair sludge end routes (agricultural application). At the moment there is no treatment technology able to reduce significantly the micropollutant content in the sludge line, except thermal destruction at high temperature (incineration). Owing to hydrophilic properties and the persistent nature of pharmaceuticals and personal care products (PPCPs) and endocrine-disrupting chemicals (EDCs) in wastewater and/or surface waters, the removal of PPCPs and EDCs is much more difficult than other organic compounds typically present in wastewater. Thus, many EDCs and PPCPs were not removed efficiently by conventional WWTPs (Ternes 1998) as established wastewater treatment units are not well designed to treat such compounds (Kolpin et al., 2002). Sludge age and nitrifying capacity are the critical parameters to enhance removal efficiencies. Recently, it has been noted that membrane bioreactors (MBR) could offer some advantages over conventional activated sludge (CAS) in eliminating certain PPCPs and EDCs. However, MBR systems are still not effective for removing a broad group of recalcitrant compounds (e.g. carbamazepine, diclofenac, clofibric acid, 17α-ethinyloestradiol (EE2), etc.). Furthermore, MBR systems often require high energy consumption in operational process. For further enhancement, advanced treatment is therefore necessary.

- Oxidation technologies, well known from drinking water treatment, have shown great potential for removing micropollutants in wastewater treatment. Treatments with ozone, or UV combined with hydrogen peroxide, are most promising, which can achieve significant eliminations of a broad range of micropollutants based on the reaction with ozone and OH radicals. Other oxidants/disinfectants such as chlorine, chlorine dioxide, ferrate, and permanganate are effective only for selected micropollutants containing electron-rich moieties. In addition, chlorine may present a higher risk due to the production of harmful chlorinated by-products. Among the oxidation processes, ozonation has been most extensively tested as an enhanced wastewater treatment technology for micropollutant elimination from laboratory to full-scale. Depending on the wastewater composition and on the applied ozone dose, transformation products can be produced during wastewater ozonation such as assimilable organic carbon (AOC), aldehydes, nitrosamines, and bromate etc., therefore requiring careful consideration. A biological treatment by, for example, sand filtration after ozonation is highly recommended for the removal of AOC or nitrosamines, and especially if a further removal of phosphorus and suspended solids should be achieved.

- Adsorption to activated carbon is also efficient with a range of targeted compounds slightly different from oxidation technologies. However, the micropollutants are transferred onto the activated carbon which needs to be disposed of properly. In case of granular activated carbon, a thermal reactivation is possible.

- Filtration with tight membranes as used in reverse osmosis and nanofiltration can remove micropollutants very efficiently, while producing a brine that contains highly concentrated waste. The associated high energy needed makes these technologies much costlier than the previous ones; therefore they are only interesting for locations with limited water flows, high water stress and where energy constraints are not problematic.

In recent years, the full-scale implementation of the most cost-effective technologies, being ozone treatment or sorption onto activated carbon, has been achieved. Several plants with powdered or granular activated carbon applications are in operation, and ozonation of wastewater is implemented in full scale (e.g. in Germany and Switzerland). Appropriate operating conditions (dosing and control strategies) have been established. Switzerland has taken a leading role, as the Swiss Water Protection Act has been in force since January 2016, demanding an upgrade of wastewater treatment to eliminate micropollutants by 80% in about 100 out of 700 WWTPs within the next 20 years, treating about 50–60% of the Swiss wastewater released to sensitive surface waters. The increase in costs for wastewater treatment due to this law has been estimated at 130 million US$ per year, which is equal to about 10–15% of the current costs of wastewater treatment (15 US$ per capita per year). Of the required investment, 75% will be financed by a federal fund, fed by a fee of 10 US$ per year for each Swiss inhabitant. The energy consumption is expected to increase by 5–30% in a WWTP, and nationally by 0.1% (Eggen et al. 2014). To assist with the decision for the choice of technology, Schindler Wildhaber et al. (2015) have recently proposed a modular laboratory decision tool to test the feasibility of ozonation as an option for advanced wastewater treatment. In these modules, the assessment of four parameters is proposed: the matrix effects on ozone stability, the efficiency of micropollutant removal, the formation of oxidation by-product (bromate and *N*-nitrosodimethylamine) and bioassays to measure specific and unspecific toxicity of the treated wastewater. If criteria are not fulfilled, the marginally more expensive treatment with activated carbon may be the better choice. In upcoming years, further experience will be gained with practical issues relating to dosing strategies, best application of powdered activated carbon directly to sludge or in filters, contact time for treatment with granular activated carbon and the combination of more than one treatment.

In addition, a high effluent water quality is also required for water reuse, particularly for contaminants of emerging concern, such as EDCs and PPCPs. Since conventional wastewater treatment processes, as currently in practice, are not sufficiently effective for eliminating EDCs and PPCPs (Li and Yu, 2015a), many of these micro-pollutants are being discharged into surface waters. Therefore, emerging organic contaminants such as PPCPs and EDCs become a significant barrier to widespread acceptance of water reuse.

Other methods for degrading efficiently PPCPs and EDCs in wastewater/water use white-red fungi and their oxidative enzymes (i.e. laccase (Lac), manganese peroxidase (MnP), lignin peroxidase (LiP)) as biocatalysts (Lawler, 2015). Although these fungal oxidative enzymes have been known to be able to break down polysaccharides, celluloses and hemicelluloses as well as lignin (a natural aromatic polymer) or phenolic compounds (Singh Arora, and Kumar Sharma 2009, Ramos et al., 2004; Pointing 2001), there is still research needed on the degradation of non-phenolic EOCs, i.e. PPCPs and EDCs in wastewater and water by laccase. In addition, electrochemical stimulation has recently emerged as an effective and "green" means to enhance *in situ* bioremediation performance; it takes advantage of the selectivity and sustainable nature unique to microbial metabolism and the environmental benignity and excellent controllability of electrochemistry (Li and Yu, 2015a, 2015b).

New regulations

Water quality standards are usually derived based on a risk assessment approach. To identify substances hazardous to humans and the environment, substances with and without threshold, for example cancerogenic, mutagenic and substances toxic for reproduction, are distinguished (WHO 2011; ECHA 2016). For some substances there are already sufficient significant ecotoxicological data to set environmental quality standards, especially for water data sets; however, sediment data or biota standards are rare.

In different legal regulations, monitoring and management strategies are already set for well-known contaminants such as heavy metals, pesticides or polycyclic aromatic hydrocarbons. These regulations are either on national, international (e.g. WFD, 2000) or global (e.g. Stockholm Convention, 2001) levels.

Recently the POPs recognised in the Stockholm Convention of the UNEP, which was adopted on 22 May 2001 and entered into force on 17 May 2004, were extended. The Convention actually recognises 23 POPs: 12 initial, 9 were added in 2009, endosulfan was added in 2011 and hexabromocyclododecane in 2013 (http://chm.pops.int/Home/tabid/2121/Default.aspx). All signatory states need to develop a National Implementation Plan (NIP). The secretariat of the Convention is in Geneva, Switzerland. It provides guidelines and training materials, which can be found on their website. The Conference of the Parties (COP) was established pursuant to Article 19 of the Convention. It is the governing body of the Stockholm Convention and reviews and evaluates its implementation. It considers and adopts, as required, amendments to the Convention and its annexes, for example to list new chemicals brought forward by the Persistent Organic Pollutants Review Committee.

In addition, the Directive on Environmental Quality Standards (Directive 2008/105/EC) (EQSD), also known as the Priority Substances Directive of the WFD of the European Union, which set environmental quality standards (EQS) for substances in surface waters (river, lake, transitional and coastal) and confirmed their designation as priority or priority hazardous substances, was revised in 2012. For European water bodies, a good chemical status is reached when it complies with the EQS for all the priority substances and other pollutants listed in Annex I of the EQSD. The revised (second) list of priority substances Directive 2013/39/EU also includes provisions to improve the functioning of the legislation. The main features of the proposal are as follows:

- 12 additional priority substances, 6 of them designated as priority hazardous substances;
- stricter EQS for four existing priority substances and slightly revised EQS for three others;
- the designation of two existing priority substances as priority hazardous substances;
- the introduction of biota standards for several substances;
- provisions to improve the efficiency of monitoring and the clarity of reporting with regard to certain substances behaving as ubiquitous persistent, bioaccumulative and toxic (PBT) substances;
- a provision for a watch-list mechanism designed to allow targeted EU-wide monitoring of substances of possible concern to support the prioritisation process in future reviews of the priority substances list.

Both lists have international reporting and minimisation/phase out requirements and are under rolling revision. Pharmaceuticals such as diclofenac, ethinyloestradiol and oestradiol were in the proposed list, but were removed from the final list and are not subject to regulation yet. But these substances are added to the watch list and should be monitored within the European Union. Also within REACH (Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals), the information on chemicals is continuously improved and substances can be restricted in their use. The first step in the authorisation process is to identify those substances that may have serious effects on human health or the environment and, therefore, the risks resulting from their use must be properly controlled and the substances progressively replaced when possible. If a substance is identified as a Substance of Very High Concern (SVHC), the substance is added to the Candidate List, which includes candidate substances for possible inclusion in the Authorisation List (Annex XIV). The inclusion of a substance in the Candidate List creates legal obligations to companies manufacturing, importing or using such substances, whether on their own, in preparations or in articles (http://echa.europa.eu/regulations/reach/authorisation/the-candidate-list).

Scientific challenges and future research

Chemical approach

The chemical detection of new compounds, metabolites and transformation products in surface water, groundwater and drinking water needs special high-end equipment and interpretation skills. Nevertheless, it will be necessary to screen out important samples for thorough investigation. Therefore, semi-quantitative screening tests will be needed for a first evaluation of the samples. Non-target analysis helps to identify unknown sources and compounds (Ruff et al. 2015; Schlüsener et al. 2016). At the same time, there is a growing demand for high-throughput analysis because of a growing number of samples. Nowadays emphasis is directed towards achievement of maximum chromatographic resolution in a drastically reduced time; modern approaches comprise liquid chromatography at ultra-high pressures (UHPLC), the use of monolith columns, the use of fused core columns, and high-temperature liquid chromatography (HTLC) (Ferre et al., 2012).

In vitro approach (biotests)

In addition to chemical analysis, bioanalytical tools offer a complementary option for the rapid analysis of emerging pollutants and will be available online and at site analysis and continuous analysis. Besides the questions of whether detected concentrations will affect human or environmental health and how these components will react in complex mixtures, the whole complex discussion on toxicokinetics and toxicodynamics is in the focus especially when *in vitro* test systems are used.

In vivo approach

One of the biggest challenges for the near future will be the effect assessment and risk evaluation for human health and the aquatic environment for the thousands of synthetic and natural trace contaminants that may be present in water at low to very low concentrations (picograms per litre to nanograms per litre), especially under consideration of the animal testing ban and the 3Rs (replacement, reduction, refinement). Advancing the 3Rs in ecotoxicology will address not only ethical concerns, but also the legislative demands to find alternative non-animal methods, and share data wherever possible.

Risk communication

Risk communication is a new requirement to get the general public involved in strategic but also legal decisions in scientific projects. It should bridge the gap between the technical experts and the public and is a requirement for involving the general public in risk management. Previously, risk communicators have been interpreters, clarifiers and simplifiers of technical jargon. Now, the goal is informing, building trust and credibility, and establishing a two-way, interactive and long-term process, where the public and risk communicators are engaged in a dialog. Clear and effective information and communication with the public and fellow EU governments is an essential part of crisis response. It can help to exchange best practice on health risks/crisis communication and provide recommendations for preventing diseases or share information in the early stages and coordinate common strategies and messages to the public during a crisis.

Conclusions

The Assessment and Control of Hazardous Substances in Water Specialist Group has currently and will also in future have important tasks to work on. The tremendous amount of the various micropollutants and their transformation products that cause emerging concern as they potentially show carcinogenic or mutagenic reactions, or are toxic for reproduction (CMR substances) or are allergens or endocrine disruptors, need advanced monitoring strategies in terms of chemical but also effect-based monitoring and efficient treatment. To tackle these issues, interdisciplinary cooperations are necessary with other IWA specialist groups, and with other international scientific and administrative bodies. In addition, the involvement of the general public and the discussion and acceptance of risk will be one of the future challenges.

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Benchmarking and performance assessment

Written by *Enrique Cabrera Jr, Filip Bertzbach and Scott Haskins* on behalf of the Specialist Group

Introduction

The Benchmarking and Performance Assessment Specialist Group focuses on performance assessment, performance improvement and benchmarking techniques applied to water and wastewater services.

Much of the standardised knowledge on performance assessment and benchmarking in water services has been developed within IWA in the past 20 years and, while collecting and receiving inputs from a wide international base, the IWA frameworks on the topic are widely perceived as the reference for the sector.

The IWA frameworks for performance indicators and benchmarking describe the basic set of principles necessary to successfully assess and improve performance using these techniques. Additionally, they provide comprehensive repositories of pre-defined indicators with clear and univocal definitions. Many projects around the world use these indicators or others derived from the original definitions.

Performance assessment and improvement are cross-cutting tools, and their use is often complementary to other purposes (e.g. asset management, water loss management, wastewater treatment plant process improvement, etc.). As a result, the application of these tools in specific domains also requires competent knowledge of the processes to be assessed and improved. Local and regional contexts may differ, but benchmarking attempts to normalise or standardise frameworks, scoring and processes. This allows for better comparisons, networking and relevance. Consortium processes can add value through exchanges of leading practice and performance

Performance assessment is a cornerstone of regulatory schemes. In such cases, the establishment of a performance assessment system becomes a central part of the activity, although it should follow the same principles described in the IWA framework.

Terminology

From the IWA manuals of best practice on performance indicators and benchmarking:

Data elements: A basic datum from the system that can either be measured from the field or is easily obtainable. Depending on their nature and role within the system, data elements can be considered variables, context information or simply explanatory factors.

Variables: A variable is a data element from the system that can be combined into processing rules in order to define the performance indicators. The complete variable consists of a value and a confidence grade that indicates the quality of the data.

Performance indicators: Measures of the efficiency and effectiveness of the delivery of the services that result from the combination of several variables. The information provided by a performance indicator is the result of a comparison (to a target value, previous values of the same indicator, or values of the same indicator from a peer).

Context information: Context information are data elements that provide information on the inherent characteristics and account for differences between systems.

Explanatory factors: An explanatory factor is any element of the system of performance indicators that can be used to explain PI values, i.e., the level of performance at the analysis stage. This includes PI, variables, context information and other data elements not playing an active role before the analysis stage.

Performance assessment: Use of performance indicators to determine the current status and the evolution of the performance of a water or wastewater service.

Comparative performance assessment: Use of performance indicators to determine the relative performance of a water or wastewater service with respect to some peers (formerly referred to as metric benchmarking).

Performance improvement: Second phase of the benchmarking process in which best practices are identified and adapted to improve performance in a water or wastewater service.

Benchmarking: Tool for performance improvement through systematic search and adaptation of leading practices.

Existing Specialist Group knowledge

The basic principles for performance assessment and benchmarking have been established for a considerable time and included in the corresponding IWA manuals of best practice. These manuals provide frameworks that can be adapted for most situations and as a matter of fact, have been referenced in the ISO 24510, 24511 and 24512 standards.

In addition to the use of traditional performance indicators, new initiatives like AquaRating are giving a new incentive to summarise best practices in the sector and include them in a systematic assessment, which has not be done in such detail and for the whole sector on an international level before. These best practice elements (which have been used in the past by some regulators and other projects) provide an alternative that does not require actual measurements or calculations, but simply answering simple yes/no questions. The combination of metrics and practices provides a more comprehensive “system” to evaluate outcomes and means of achieving them.

The current state of the art on performance indicators has been included in the 3rd edition of the “Performance Indicators for Water Supply Services” Manual of Best Practice, which will be released in 2016. This new edition provides minor corrections to the definitions of a few indicators and updates the framework, especially for the treatment of data quality (confidence grades). Additionally, the manual provides updated links to the other manuals in the series (especially the benchmarking for water services in 2011).

General trends and challenges

Performance assessment and benchmarking applied to the water industry started as a recognised topic 20 years ago (following the establishment of Ofwat in England and Wales in 1989, an American Water Works Association Research Foundation (AWWARF) report was issued in 1996, and the International Association on Water Quality (IAWQ) Task Group on performance indicators was set up in 1997). Today the topic is at a mature stage, where the focus lies on the correct application of the basic principles and the use of the techniques for new purposes.

The two greatest challenges faced by projects and systems worldwide are the correct treatment and assessment of data quality and the realisation of performance improvement. Despite being a part of the IWA framework since 2000, very few projects around the world include data quality assessment as a part of their performance assessment systems. The new edition of the manual focuses on presenting a new way to include data quality, aiming to make its implementation easier. In any case, there is still ample room for developments on how to account for poor/good data quality when calculating performance indicators.

In line with data quality recording, the verification of the information remains another area with needs for additional work. Once limited to the work of regulators, data auditing is also part of the new AquaRating standard. Ensuring that the collected data are accurate and reliable is a costly endeavour, and developments on how to ensure that consistent data are provided at reasonable costs (for instance through statistical sampling) are on the research agenda.

The apparition of new performance indices and new assessment elements (like the good practices included in AquaRating or in Projects in United States or South Africa (see WRC 2014, Wensley et al 2011)) have also placed the spotlight on the need for better interpretation mechanisms once all indicators (and other data elements) are collected. There is the need to further compare the analyses obtained with statistical/mathematical methods imported from other sectors (such as DEA and Stochastic Frontier Analysis) and less sophisticated methods. Additionally, with the development of several indices simplifying the assessment, improvement and communication of performance, a comparison of those methods and their results to the more sophisticated alternatives is due.

Finally, the validity, impact and usefulness of new systems like AquaRating remain to be tested and seen. Technical work will be needed to assess the systems themselves, but also to develop the use of these new tools to improve the management and the performance of water services.

Conclusions

Performance assessment and benchmarking are well-established tools in the water industry. The need for performance improvement, transparency, accountability and regulatory frameworks for water services has generalised the use of performance indicators in water services around the world.

The basic principles of performance assessment and benchmarking have now long been established. However, as more experience is gathered from existing projects and new goals are set, the actual application and deployment of those principles needs to receive the focus of the industry.

However, performance assessment systems still need to take into account data quality, as the decisions based on the results obtained from those systems require a fair and proper assessment. The collection of proper confidence grades for all data and the development of techniques to include this information at the interpretation stage remain key challenges in this area. Additionally, more emphasis should be placed on actual work with data instead of “pure assessment”. The experience of industry-based benchmarking shows that ownership of the methodology by the management of utilities, and transparency of the results for participants, ensure data quality by motivated participants. Data will naturally improve if they are intensively used, discussed in workshops by peers, and if they support management practices.

Additionally, the impossibility of measuring more complex concepts with indicators has given way to new tools for assessment, focused not so much on quantitative aspects but on the qualitative issues of management and the implemented practices. The results from applying these concepts and how well they complement traditional performance assessment systems will be a matter of discussion in the coming years.

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Biofilms in the Water Environment: Trends and Challenges

Written by *Joshua P. Boltz and Eberhard Morgenroth* on behalf of the IWA Specialist Group on Biofilms

Context

The mission of the Biofilms Specialist Group is to provide a forum for the exchange of scientific and technical information among researchers and practitioners involved in the field of biofilms that occur in the water environment. The scope of the Biofilms Specialist Group includes biofilms in engineered and natural aquatic systems, and biological, chemical, and physical processes relevant to biofilms. The Biofilms Specialist Group Management Committee organizes specialised biofilm conferences, conference sessions, workshops, and related courses. More information about the Biofilms Specialist Group can be found at the external website http://www.iwa-biofilm.org/.

Introduction

Biofilms are complex biostructures which appear on all surfaces that are regularly in contact with water. By definition, a biofilm may consist of prokaryotic cells and other microorganisms such as yeasts, fungi, and protozoa that secrete a mucilaginous protective coating in which they are encased (i.e. extracellular polymeric substances (EPS)). Biofilms can form on solid or liquid surfaces as well as on soft tissue in living organisms. Biofilms are typically highly resilient constructs that resist conventional methods of disinfection. Biofilm formation is an ancient and integral component of the prokaryotic life cycle, and is a key factor for survival in diverse environments. Biofilms are structurally complex, dynamic systems with attributes of both primordial multicellular organisms and multifaceted ecosystems. The formation of biofilms represents a protected mode of bacterial growth that allows cells to survive in hostile environments and disperse to colonize new niches (Hall-Stoodley *et al.* 2004).

The presence of biofilms may have a negative impact on the performance of various systems. For example, biofouling of ship hulls and membrane surfaces reduces performance and efficiency resulting in marked financial costs. Pathogenic biofilms have also proved detrimental to human health. Biofilm infections, such as pneumonia in cystic fibrosis patients, chronic wounds, chronic otitis media, and implant- and catheter-associated infections, affect millions of people in the developed world each year and many deaths occur as a consequence (Bjarnsholt 2013). Foodborne diseases – often caused by biofilm forming pathogens – are a public health concern throughout the world (Srey *et al.* 2013). The development of multispecies biofilms on teeth (i.e. dental plaque) and their associated bacterial pathogenesis can lead to gum disease and tooth decay (Kolenbrander *et al.* 2010). Biofilms may also be undesired in the open water environment. For example, algal mat formation on water bodies is a component of the eutrophication process. Finally, biofilms that develop on the interior walls of pipes that comprise a potable water distribution system can lead to additional chlorine demand, coliform growth, pipe corrosion, poor water taste, and foul odour (Hallam *et al.* 2001).

On the other hand, biofilms, can be controlled and used beneficially for the treatment of water (defined herein as potable water, municipal and industrial wastewater, fresh/brackish/salt water bodies, groundwater) as well as in biological resource recovery from water streams. The investigation of biofilms in the water environment can, generally, be classified as one of three major areas: biofilm ecology, biofilm reactor technology and design, and biofilm modelling. Biofilm ecology is defined here as the study of components and processes that take place in the biofilm. Biofilm reactor technology and design encapsulates the development, design, operation, and optimisation of bioreactors that target controlled biofilm utilisation. Biofilm modelling is the development and application of various computational approaches to simulate, predict, or synthesize the processes occurring in biofilms and biofilm reactors.

The term biofilm *sensu strictu* refers to the microbes and associated deposits on a surface embedded in the matrix of EPS. The broader term, biofilm system, includes other components affecting the biofilm, and usually consists of (at least): the substratum (on which the biofilm forms) and the bulk phase (which flows over the biofilm). This paper will provide a state-of-the-art review of key research and practical events related to these areas of biofilm study.

State-of-the-art

For the purpose of this document, biofilms are described in context of the Biofilms Specialist Group as a state-of-the-art review that focuses on research and practice-related trends in biofilm-related biology, biofilm reactors, and models of particular relevance to challenges and opportunities regarding biofilms and biofilm systems.

Biofilm biology: methods to ecology

The biology of biofilms includes a diverse array of topics. The current focus of biofilm biology is dedicated to applying state-of-the-art approaches to evaluate biofilm ecology in relation to structure and function, including the identification of factors that drive biofilm formation and dispersal.

The symphonic application of biological methods is essential to the understanding of microbial films biology. Currently, the often combined use of quantitative polymerase chain reaction (qPCR), fluorescence *in situ* hybridisation

(FISH), advanced two-dimensional microscopy, and micro-scale chemical sensors has allowed biofilm researchers to create a better vision of biofilm make-up – including both the cellular matter and their excretions – than ever before. This insight has proved valuable to the advancement of understanding biofilm structure and function. The polymerase chain reaction technique has presented researchers with a simple, sensitive, and rapid technique for amplifying nucleic acid. The technique was invented by Kary B. Mullis and co-workers (Mullis *et al.* 1986) who were awarded the 1993 Nobel Prize in Chemistry as a result of this development. The qPCR method has been used to further our understanding of biofilm structure and function, and the roles that biofilms play in a bioreactor (Kim *et al.* 2009). Applying qPCR combined with micro-dissection has allowed one to quantify the stratification of functional guilds in biofilms (Terada *et al.* 2010). FISH is a technique that is based on hybridising a fluorescently labelled DNA probe to (typically for bacterial investigations) complementary sequences present in the bacterium's 16S rRNA. By proper choice of the DNA probes – phylogenetically distinct groups of bacteria can be simultaneously visualised. When properly applied to biofilms – and in combination with the right microscopic method and detection method (often multi-channel CLSM) the technique allows one to identify the spatial organisation and relative location of different bacterial groups (Okabe *et al.* 1999; Vlaeminck *et al.* 2010). Confocal laser scanning microscopy (CLSM), transmission electron microscopy (TEM), and soft X-ray scanning transmission X-ray microscopy (STXM) have been used to map the distribution of macromolecular sub-components (e.g. polysaccharides, proteins, lipids, and nucleic acids) of biofilm cells and its EPS matrix (Lawrence *et al.* 2003). More recently, optical coherence tomography (OCT) has been applied to visualize the mesoscale structure of biofilms (Wagner *et al.* 2010), and confocal Raman spectroscopy has provided a tool for studying (the chemical heterogeneities of) biofilms in situ (Sandt *et al.* 2007).

Microbial ecology is a major component of biofilm studies because of the desire to control biofilm development, biochemical transformation processes, and dispersion. Davies *et al.* (1998) suggested that a cell-to-cell signal is involved in the development of *Pseudomonas aeruginosa* biofilms. The researchers findings implied involvement of an intercellular signal molecule in the growth of *P. aeruginosa* biofilms which suggests possible targets to control biofilm growth, for example, on catheters, in cystic fibrosis, and in other environments where problematic *P. aeruginosa* biofilms persist. Shrout *et al.* (2006) documented the impact of quorum sensing and swarming motility on *P. aeruginosa* biofilm formation as being nutritionally conditional. Nitric oxide (NO) is an important messenger molecule in a biological system that transmits signals inside an organism. Signal transmission by a gas that is produced by one cell penetrates through membranes and regulates the function of another cell. This discovery presented an entirely new principle for signaling in biological systems. The discoverers of NO as a signal molecule were awarded the 1998 Nobel Prize in Physiology or Medicine (Zetterström 2009). Various NO donors of clinical and industrial significance have been demonstrated viable for dispersal in single- and multi-species biofilms (Barraud *et al.* 2009).

Research on biofilm reactors has been the source of an interesting new metabolic pathway. An anaerobic ammonium oxidation (anammox) process was discovered in a pilot-scale denitrifying fluidised bed biofilm reactor. From this system, a highly enriched microbial community was obtained, dominated by a single deep-branching planctomycete, *Candidatus* Brocadia anammoxidans (Jetten *et al.* 2001). Since that time, the utilisation of anammox microorganisms in biofilm reactors has proved popular, cost effective and efficient.

The continued development of knowledge about phototrophic biofilms has elucidated their utility for nutrient removal from wastewater, heavy metal accumulation and water detoxification, oil degradation, agriculture, aquaculture, and sulfide removal from contaminated waste streams (Roeselers *et al.* 2008).

In biofilms, microorganisms live in a self-produced gelatinous matrix of EPS. These EPS consist primarily of polysaccharides, proteins, nucleic acids and lipids. In addition, the EPS provides biofilms with mechanical stability, mediates bacterial adhesion to surfaces, and serves as the three-dimensional polymer network that interconnects and transiently immobilizes bacterial cells inside a biofilm. Furthermore, EPS are capable of entrapping, or bioflocculating, biodegradable and non-biodegradable particulates in the polymeric matrix (Boltz and LaMotta 2007). Conceptually, the functions, properties and constituents of the EPS matrix are known, but the kinetics of EPS production, the rate they deteriorate materials, their contribution to metabolic kinetics and biochemical transformation rates owing to a biofilm are poorly defined. Thus, biofilm models explicitly describing EPS (Laspidou and Rittmann 2004) (e.g. Alpkvist *et al.* 2006) are scarce and lack the measurement (i.e. quantification) of fundamental mechanical properties; hence, unlocking the "dark matter" of biofilms remains a challenge to researchers (Flemming and Wingender 2010). EPS play a valuable role in biofilms resulting not only in the entrapment of particulates, but the conversion of non-readily biodegradable substrate into a readily biodegradable state, the agglomeration of metals such as selenium (Gonzalez-Gil 2016), and are essential to the granulation process.

The uptake and biochemical transformation of microconstituents (including pharmaceuticals) which persist in municipal wastewaters and have been proved to degrade during municipal wastewater treatment (Jelic *et al.* 2011) is a significant challenge to biofilm researchers and treatment system designers. Kim *et al.* (2009) compared the removal efficiencies of microconstituents classified as trace organic chemicals (including endocrine disrupting compounds (EDCs) and estrogenic activity). Results suggest that the system with a biofilm compartment out-performed the suspended growth control process. The results suggest that bioreactors having a biofilm compartment, such as integrated fixed-film activated sludge (IFAS) systems, may be beneficial for enhancing the removal of estrogens and at least some trace organics. Furthermore, the researchers found that there is evidence for removal by heterotrophic biodegradation rather than by sorption or removal by nitrifiers, which proves significant given the apparent correlation of converting ammonia-nitrogen and specific EDCs, while the biochemical transformation of other EDC types fail to correlate with nitrification. Torresi *et al.* (2016) suggest that biofilm thickness influences the biodiversity of nitrifying biofilms grown in moving bed biofilm reactors (MBBRs), and that this parameter influences a biofilms capacity for micropollutant removal. The biochemistry and microbiology of micropollutant transformation – in context of biofilms

– is under active investigation, and the identification of the responsible organisms, the role of different functional guilds, the contribution of co- versus primary metabolisms, and the significant of biofilm redox conditions are all under examination.

Reactors

Biofilms can be controlled, and the harnessing of biofilms provides the basis for their utilisation for water treatment via biofilm reactor. However, the presence of biofilms may also be undesirable in a biological water treatment system, and can cause operational difficulties that increase the expense of treatment.

Biofilm reactors: the beneficial use of biofilms

Biofilm reactors represent the primary vessel for harnessing the usefulness of biofilms for the treatment of water(s). In these bioreactors biofilms serve as a mechanism for the biological transformation of nutrients that are regarded as environmental pollutants (e.g. $CBOD_5$, N, and P). Several types of biofilm reactors have been utilised for water treatment but currently much focus is on the following types of reactors: MBBRs and IFAS processes, membrane-supported biofilm reactors (MBfRs), and granular processes.

MBBRs and IFAS processes are mature technologies that continue to evolve. State-of-the-art MBBRs and IFAS processes use submerged free-moving biofilm carriers, and can be used for carbon oxidation, nitrification, denitrification, and deammonification (Rusten *et al.* 2006; McQuarrie and Boltz 2011). Globally, there are more than 1,200 full-scale, operating MBBRs having a capacity of 200 population equivalents (p.e.) or greater. MBBRs having a capacity less than 200 p.e. are numbered more than 7,000, globally. More than 100 MBBRs exist for nitrification in aquaculture. It is estimated that there is an equal distribution of MBBRs among industrial and municipal WWT facilities designed to treat waste streams for p.e. greater than 200. The geographic distribution of these installations are estimated as:

- facilities greater than 200 p.e. – 40% in Europe, 30% in North America, 20% in continental Asia and the South Pacific (not including India), and 10% in Africa;

- facilities less than 200 p.e. (including onsite facilities) – 80% in Europe, 10% in North America, and 10% in continental Asia and the South Pacific (not including India).

A MBBR-based process at the Lillehammer wastewater treatment plant (WWTP), Lillehammer, Norway, for the treatment of municipal wastewater has been described by Rusten *et al.* (1995) and an example IFAS installation has been documented at the Fields Point WWTF, Rhode Island, USA. The MBBR is an effective platform for simultaneous partial nitritation and deammonification. The ANITA™Mox process is a commercially available system to treat side-stream Nitrogen-rich effluent using the MBBR or IFAS configuration (Veuillet *et al.* 2014). Full-scale ANITA™Mox systems exist in Europe (8) and the USA (3). A full-scale ANITA(TM)Mox systems exists at the Sjolunda WWTP, Malmo, Sweden (Christensson *et al.* 2013).

Granular biomass development and utilisation in a sequencing batch reactor (SBR) has proved an effective and highly promising environmental biotechnology for the treatment of contaminated water streams. Aerobic granules can be formed and maintained in sequencing batch reactors (de Kreuk *et al.* 2007). The potential for stable aerobic granule formation was reported by Beun *et al.* (1999). Since then, more than 25 wastewater treatment plants are operating or under construction that will utilize the aerobic granular biomass processes on 4 continents including Europe (5 in the Netherlands), South America, Africa, and Australia. All of these WWTPs plants are designed for biological nutrient removal from municipal wastewaters. The largest capacity constructed to date is 517,000 p.e. (with an average daily flow of 55,000 m^3/day in Rio de Janeiro, Brazil). A commercially available aerobic granular sludge system that has been used for successful biological nutrient removal in screened/degritted wastewater or primary effluent is named NEREDA™. A full-scale NEREDA™ process is located at the Garmerwolde WWTP, Netherlands (Pronk *et al.* 2015). The NEREDA™ process maintains a constant liquid/biomass volume. The filling, settling, and decanting steps occur simultaneously during approximately 25 – 33% of the operational period. The remainder of operation is reserved for aeration (i.e. reaction period). Approximately 10–15 minutes is required to achieve reactor quiescence. These typical operational parameters, along with conducive influent wastewater characteristics, result in effluent waters having TN < 5 mg/L and TP < 1 mg/L. These simple bioreactors are, essentially, an empty tank with fine-bubble aeration and an influent wastewater distribution system along the tank bottom. The treated effluent flows over an effluent weir situated along the top of the tank. The bioreactor has no mixers, but does have an effluent pipe and a sludge wasting pipe (which is situated near the top of the settling sludge bed to promote wasting of more slowly settling sludge). Another approach to benefit from granular biomass is to use a cyclone or screens for the selective retention of granular biomass. Granules have also been used for simultaneous partial nitritation and deammonification of high ammonia-nitrogen concentration waste streams from digested sludge dewatering units in the process named DEMON™ (Wett 2007). A full-scale DEMON™ process exists at the Strass WWTP, Strass, Germany.

Another biofilm reactor type that exhibits great potential is the membrane biofilm reactor (MBfR). The diversity of this process is a formidable strength. In these systems gas-delivery to the liquid phase happens by means of a membrane (tubular, hollow-fiber, or flat) on which the biofilm directly grows. Biofilms grow on the outer surface of the membranes, and the electron donor and electron acceptor is subject to counter-diffusion from the bulk-of the liquid and from the membrane lumen. Two systems have been promoted: the hydrogen-based MBfR (Rittmann 2006), which delivers hydrogen as electron donor to a biofilm, and the oxygen/air-based MBfR (Syron and Casey 2008) which delivers oxygen as electron acceptor to the biofilm. The latter is also known as the membrane aerated biofilm reactor (Martin and Nerenberg 2012). Hydrogen-based MBfRs have been demonstrated viable for the biochemical transformation of nitrate, nitrite, perchlorate, promate, selenate/selenite, arsenate, and chromate to name only some. As the MBfR allows for a higher control of electron donor/acceptor delivery, biofilms with defined or strong redox stratification can be developed for simultaneous oxic/anoxic process such as nitritation/anammox (Pellicer-Nacher 2010). Commercially available MBfRs exist. The MABR may be procured in North America as the ZeeLung™ process (Côte *et al.* 2014), and in Ireland as the OxyMem™ process. These process are well suited for combined carbon oxidation and nitrification, nitrification, denitrification, partial nitritation and deammonification. A single unit demonstrating the ZeeLung™ system exists treating approximately 2,300 p.e. for tertiary nitrification at the O'Brien Water Reclamation Plant, Chicago, Illinois. At least 9 full-scale OxyMem™ processes exist, collectively, treating a ranging of flows and meeting a diverse array of treatment objectives throughout Japan, Sweden, Spain, United Kingdom, Ireland, and Brazil.

The continuous enhancement and implementation of new water quality regulations, and the discovery of new processes has made mature biofilm reactor types relevant to current trends and challenges that face this community. For example, the US Environmental Protection Agency (EPA) has enacted a primary drinking water standard that requires selenium concentrations to be less than 0.05 mg/L. This regulation has impacted agriculture, mining, power (coal and oil) industries, to name a few. The use of expensive reagents and the production of hazardous residues makes the use of physicochemical treatment impractical. As a result, the biological transformation of selenate and selenite to elemental selenium is preferred. Biofilm reactors capable of operating under anaerobic conditions are required. Hence, particulate biofilm reactors, as described by Nicolella *et al.* (2000), are of renewed interest. Similarly, processes such as SANI (Wang *et al.* 2009) and DEAMOX (Kalyuzhnyi *et al.* 2006) have made use of biofilm reactors such as deep-bed filters and UASBs.

Finally, biofilms have recently been thoroughly investigated for their capacity to biologically generate electricity, the so-called microbial fuel cell (MFC). Liu *et al.* (2004) demonstrated that MFCs can produce electricity while biologically converting complex compounds present in municipal wastewater. There are several different means for constructing a MFC. Logan *et al.* (2006) presented means for constructing MFCs, comparing devices on an equivalent basis, and an array of related scientific principles ranging from environmental engineering to microbiology and electrochemistry. The creation of a MFC that can yield sufficient electrical output for economically viable production and utilisation eludes researchers, and is a present challenge for biofilm scientists and engineers.

Unwanted biofilms: toward control

The deleterious role of biofilms on membranes is also an area of concern to process designers and biofilm researchers. Membrane biofouling is a costly operational concern that is a feed spacer problem in spiral wound membranes (Vrouwenvelder *et al.* 2009). The role that quorum sensing plays in dispersing biofilms has led biofilm researchers to seek membrane biofouling control measures via quorum sensing (Yeon *et al.* 2009). Alternatively, Vrouwenvelder *et al.* (2011) presented a scenario for controlling spiral wound membrane biofouling by reducing flow pace, modified feed-spacer design, and an advanced cleaning strategy. Another approach to dealing with undesired biofilms that grow on membranes is to tolerate their existence, and focus on increasing hydraulic conductivity of the growing biofilms rather than trying to prevent their formation; ultimately one may benefit from the biological activity in a biofilm to improve permeate quality (Chomiak *et al.*, 2015).

Biofilm modelling

Biofilm models are essential to the study and development of both fundamental biofilm research, and the development and implementation of biofilm reactors (Morgenroth *et al.* 2000). A concensus description and comparison of biofilm models was presented by Wanner *et al.* (2006). This effort led to the widespread development and application of one-dimensional biofilm models as an engineering tool (Boltz *et al.* 2010). Nevertheless, multi-dimensional models (e.g. Picioreanu *et al.* 2004) have enhanced virtually every form of biofilm research and system development. A clear dichotomy has existed between the use of biofilm models as a research resource and the more recent use as and engineering tool. However, recently the importance of bulk-liquid hydrodynamics and system idiosyncrasies (e.g. biofilm carrier type and transport) have become an integral consideration for biofilm and biofilm reactor modelers (Kagawa *et al.* 2015; Boltz *et al.* 2016). Biofilm models have become an increasing important tool for biofilm researchers and biofilm reactor designers who are interested in the most relevant topics in environmental biotechnology including GHG Emissions (Van Hulle *et al.* 2012; Sabba *et al.* 2016), phototrophic biofilms (Wolf *et al.* 2007), and microbial fuel cells (Marcus *et al.* 2010; Picioreanu *et al.* 2007).

Trends and challenges

This paper has presented evidence of the relevance and future significance that research, development, and implementation will play in

- biofilm ecology, and elucidating the functional and mechanical role of EPS;
- greenhouse gas emissions;
- MBBR/IFAS, aerobic granular sludge, and MBfRs; and
- biofilm and biofilm reactor modelling.

Conclusions and selected areas of key research

Fundamental principles describing biofilms exist as a result of focused research, practical application, and modelling. The use of reactors for the treatment of municipal and industrial wastewaters is a common beneficial use of biofilms. Applied research exists that provides a basis for the mechanistic understanding of biofilm systems. The empirical information derived from such applied research has been used to develop design criteria for biofilm reactors and remains the basis for the design of many biofilm reactor types despite the emergence of mathematical models as reliable tools for research and practice. There is a gap between our current understanding of biofilm fundamentals and reactor-scale empirical information. Therefore, there is a clear dichotomy in the literature: micro- (biofilm) and macro- (reactor) scales. Lewandowski and Boltz (2011) highlighted this division by describing state-of-the-art basic research and practice oriented beneficial use of biofilm systems for the sanitation of water.

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Design, Operation and Economics of Large Wastewater Treatment Plants: State-of-the-Art and Upcoming Challenges

Written by *Miklos Patziger*, Hungary (secretary) on behalf of the Specialist Group on Design, Operation and Costs of Large Wastewater Plants; Chair: Norbert Jardin, Germany

Context

Large wastewater treatment plants (LWWTPs) are essential facilities not only of wastewater treatment but they have also become an integral part of the entire urban water and resoures management. Fulfilling their function strongly depends on the overall local situation: the cultural, economic and environmental background. Additionally, the wastewater treatment process is among the largest energy consumers of a municipality. Accordingly, dealing with LWWTPs includes a large scale of activities: design, operation, economics, modelling, biology, chemistry, hydrodynamics, membrane-technology, microbiology, nanotechnology, treatment and disposal of residuals, etc.

The Specialist Group on the Design, Costs and Economics of Large Wastewater Treatment Plants has been one of the main forums worldwide since 1971 for supporting exchange between experts in theory and practice. The hot topics of the Specialist Group comprise a variety of issues related to LWWTPs and are continuously evolving with the actual challenges of the field.

This report shows the state-of-the-art of the field with an emphasis on upgrading existing WWTPs, emerging challenges and new concepts.

Existing LWWTPs

The activated sludge process celebrated its 100th birthday in 2014. Since activated sludge technology-based LWWTPs have been applied, a huge number of comprehensive research programmes and innovations have been set in motion in past decades worldwide. In the past few decades, biological wastewater treatment has gone through rapid development.

Although most LWWTPs across Europe, North America, Australia and certain parts of Asia fulfil quite strict requirements and high standards for treatment efficiency and economics, there are still many challenges to be addressed.

Mechanical treatment step

The satisfactory operation of the mechanical treatment units is crucial for the safety, maintenance and effectiveness of the entire treatment process. Mechanical treatment requires a large part of the labour time of the total WWTP. Automation, increasing operational safety and minimizing maintenance expenditures are crucial for achieving cost benchmarks.

The mechanical pretreatment consists of screening or sieving, grit removal and, if advantageous, primary settling. The tendency towards finer screens helps to avoid operational and maintenance problems in subsequent treatment units.

Although in the past two decades measuring methods and process modelling, especially computational fluid mechanics, have developed rapidly, little attention has been paid to the mechanical treatment step. The design and operation principles of grit chambers and primary settling tanks need to be improved using detailed hydrodynamic investigations comprising fine-scale *in situ* measurements and computational fluid mechanics modelling.

The main function of grit chambers is to protect the biological and sludge treatment processes from coarse material (screenings) and matting, inorganic material (gravel, sand), grease and oil. The attempt to remove the largest amount of inorganic materials consisting of a wide range of particle sizes (from 0.1 up to 1–2 mm) without removing too much particulate organic content is extraordinarily challenging. This requires improved design and operation guidelines including recommendations for an optimized geometry, especially cross-sectional design and length. The key point of the operation of aerated grit channels is an appropriate air intake control for different geometries and inflow conditions (dry whether inflow, wet weather inflow, peak flows occurred by storm events).

Primary settling tanks are an integral part of the entire wastewater treatment process, sludge treatment and digester gas production. With new developments emerging in wastewater and sludge treatment over the past three decades, especially since biological nutrient removal has been required, their function and operation has become more complex.

Optimizing the removal of particulate organic matter will increase gas production in anaerobic digesters but excessive removal will deprive the biological nutrient removal process of carbon for biological nitrogen and phosphorus removal. It allows optimization of the energy generation of the plant by removing as much particulate chemical oxygen demand (COD) in the primary settling tank as possible without impairing the biological nitrogen removal. Approved design procedures and boundary-condition-driven control strategies (capacity used, scraper mechanism, sludge removal) have to be developed that can contribute to a satisfactory primary settling tank function. It is always possible to ferment a fraction of the primary sludge to produce just enough carbon for the biological nutrient removal process.

Anaerobic pretreatment of strong industrial waste water is becoming popular which may deprive the plant of essential readily biodegradable COD (rbCOD) for nitrogen and phosphorus removal. Pretreatment of industrial waste water by physical–chemical methods is sometimes beneficial to protect the biological processes. Chemicals are widely applied for precipitation of phosphorus, flocculation and to increase the efficiency of sludge dewatering. Chemically enhanced primary treatment (CEPT) is especially used in coastal cities and at LWWTPs with low temperature wastewaters. CEPT increases the effectivity of the primary treatment quite cost-effectively and it leads to a reasonably enhanced digester gas production. However, CEPT may lower the carbon to nitrogen proportion at municipal LWWTPs, decreasing the efficiency of denitrification. Therefore current development needs of CEPT cover the enhancement of the effectivity of the subsequent biological treatment (Wang *et al.* 2009).

A new challenge of mechanical treatment step is the treatment of combined sewer overflow. The steadily increasing requirements of surface water quality control, for example as formulated in the EU by the Water Framework Directive, result in increasing demands to reduce the discharge of untreated combined sewer overflow. The new role of primary treatment is thus to let a maximum of the combined sewer flow to pass at least through mechanical treatment. In this way the discharge of totally untreated sewer overflow from the sewer can be minimized. For this purpose, flexible (hydraulic capacity) mechanical steps are needed.

Biological treatment step and energy efficiency

The field of biological wastewater treatment has developed dramatically. The main driver of this enormous development was the global problem of eutrophication. While in earlier times only carbon removal was required, for approximately 30 years the enhanced removal of carbon and nutrients (nitrogen and phosphorus) has been obligatory throughout Europe and many other parts of the world. Reactor volumes, air intake demand and costs of wastewater treatment have increased considerably. This has led to several activated-sludge-based wastewater treatment technologies and reactor configurations. To support all these developments and innovations, sciences have evolved rapidly in areas such as microbiology and microbial ecology, process modelling, measurements, control and automation, membrane technology, aeration and mixing, planning and design, and process economics with an emphasis on energy considerations. Of importance is the recent emphasis on fermenting of mixed liquor or return activated sludge to assist in nitrogen and phosphorus removal which would then not require BOD in the primary effluent to enhance such removals.

A classic challenge of the activated sludge process is the problem of sludge morphology and settleability (foam and bulking). These depend on many factors. Avoiding them is still often highly complicated. Quite a new way of fighting sludge bulking and foam is nowadays based on microbiology. New approaches (Nielsen *et al.* 2010) that probably will result in a breakthrough in many aspects of activated sludge process should allow scaling from the level of individual genes/genomes up to whole communities and ecosystem-level processes. Simple strategies such as selectively surface wasting the mixed liquor and foam formers (Barnard *et al.* 2004) can lead to selection of denser sludge with lower SVI values. The recent development of granular activated sludge is remarkable in that it allows for very rapidly settling sludge while performing nitrification, denitrification and phosphorus removal in the same sequencing batch reactor system (de Kreuk *et al.* 2007).

One of the main obstacles of the activated sludge process is its high energy demand. Activated sludge plants are often among the highest energy consumers of a municipality even though the per capita consumption of a well-designed biological nutrient removal plant can be around 30 kWh per annum. Improving the energy consumption of LWWTPs is one of the most popular research fields of the Specialist Group. This is based on two main points: on one hand producing as high a rate of digester gas as possible (if possible in an enhanced way by co-digestion of sludge from smaller WWTPs and other co-substrates), on the other hand by decreasing the energy demand of the plant. It is already possible to reduce external energy supply under special circumstances (e.g. special process configurations, co-digestion to produce more biogas) to zero or even to produce more electrical energy than consumed by the plant. Nevertheless, such plants still have to be connected to an electrical grid to satisfy peak electrical energy demand. Surplus electric energy from the plant can be fed back to the grid. But it is important to remark that energy optimization should not negatively affect treatment efficiency because water quality conservation is more important for sustainable development than the possible reduction in energy demand. This argument is strongly supported by economic considerations as the fixed costs for wastewater infrastructure are dominant (Svardal and Kroiss 2011).

However, the past 20 years have been marked by the effort of WWTP operators to improve the energy balance of the plant with an attempt to achieve at least a neutral energy balance or even an energy-positive plant. Although this attempt has been successful in some cases, it was, however, always related to the technology of secondary treatment, i.e. the technology of biological COD, BOD and nitrogen removal and/or biological/chemical phosphorus removal. Once the plants are obliged to reduce pollution further below common standards, for instance for wastewater reuse, the additional operations of tertiary or even quaternary treatment must be added. These operations are always energy demanding and therefore we cannot count on energy surplus in wastewater recycling plants or in plants with the removal of pharmaceuticals, hormones and similar residual organic compounds.

Secondary settling tanks are integral part of the biological treatment unit, and usually the last step of municipal wastewater treatment. Performance and behaviour of secondary settling tanks have intensively been investigated in the last decades. Ekama *et al.* (1997) show the questions arising and a series of ongoing research programmes of the 1980s and early 1990s. Since then several comprehensive hydrodynamic investigations has led to a breakthrough in many aspects of SS. Especially the principles of the inlet geometry design – which considerably influence secondary settling tank efficiency – have been improved. Focusing on the dynamic behaviour and operation of secondary settling tanks, a wide range of sludge return strategies have been analysed (Patziger *et al.* 2012).

The new edition of the German design guideline 'DWA A 131' (DWA 2015) already includes the most important design and operation-related improvements and gives detailed recommendations on an appropriate design and operation of secondary settling tanks. However, an up to date IWA publication summarizing the full range of new findings and the state of the art in theory and practice is still lacking.

In the past, membrane technology (membrane bioreactor (MBR)) has become quite widely applied at LWWTPs. The advantages of MBRs are their reduced space demand compared with activated sludge systems equipped with secondary settling tanks, and their efficiency in producing a highly clarified effluent. Consequently MBRs can be applied at LWWTPs with limited space conditions and/or extraordinary high requirements for treated wastewater quality. The negatives of MBRs are their high operation costs due to their high energy demand and fouling. However, considerable efforts are made to overcome these problems. Moreover, new generation membranes tend to incorporate nanomaterials such as zeolites, carbon nanotubes, silver nanoparticles and others to improve properties and performance (Aim *et al.* 2012).

The challenge of energy recovery and producing a safe end product when disposing of sludge has led to interest in several options for increasing sludge degradability such as thermal hydrolysis. Recent studies have shown that digesters are breeding grounds for bacteria with resistance to antibiotics, so the effect of sterilizing the sludge would result in a useful product. The resulting increased sludge degradation leads to return streams with very high nitrogen contents, which could increase the energy consumption. The development of short-cut denitrification processes like Anammox can address this increase in nitrogen at low energy cost and with no need for additional carbon.

New challenges, new concepts

Recent global challenges like rapid population growth, climate change, water availability and water quality problems in many countries, further increasing energy costs, also strongly influence concepts in wastewater treatment and induce new innovations and developments.

The global population is increasing rapidly. For the near future a dramatic population growth is forecast. The current urban population will nearly double until 2070 and 2100. Consequently freshwater availability in urban areas is decreasing continuously. Climate change causes an additional decrease of availability of water in many regions. At the same time, increasing food production leads to increasing water demand. These problems are connected with a scarcity of natural sources for agriculture (Kroiss 2015). Therefore in many regions suffering from these problems, new concepts, new solutions and a new way of integrated water recourse management are needed.

Nowadays LWWTPs no longer solely focus on wastewater treatment. Many are already complex resource recovery facilities. In addition to water recovery, resource recovery targets the use of all resources in wastewater, such as nutrients, soil enhancer, biogas, heat and chemicals. Integrated water reuse/energy concepts are evolving and energy footprint becomes increasingly important (Kroiss 2015):

- The reuse of treated wastewater both in a 'potable' and in a 'non-potable' and/or in a 'direct' (for example Singapore) and an 'indirect' way (for example Ruhrverband, Germany).
- The control of nutrient loads and 'loss' of valuable wastewater compounds for agriculture (especially phosphorus).
- The linking of these innovations with an improved rainwater management, transfer of freshwater from one river basin to another, seawater desalination, which is the only additional source of water beyond precipitation.
- Combating the effects of micro-pollutants on the environment becomes increasingly relevant with reuse and recycling of wastewater.

Conclusions

Most of the existing LWWTPs are based on the activated sludge process. They already fulfil high standards for treatment efficiency and economics. Their development in recent decades has been enormous. However, there are still many upcoming challenges.

Current tasks at existing LWWTPs usually focus on the further enhancement of treatment and energy efficiency in a combined way.

The mechanical treatment step, especially grit chambers and primary settling tanks, is an essential part of the entire wastewater treatment process for removal and energy efficiency. The design and operation principles need further developments based on the results of state-of-the-art hydrodynamic research.

The biological treatment – research and practice – has developed dramatically in the past 20 years. The main challenges in the field are decreasing the energy demand of the biological steps (air blowers, mixers, pumps), as well as fighting settling problems of activated sludge (bulking and foam). Also, the treatment of wastewaters with low temperature and carbon deficiency needs further innovation. Ongoing research in microbiology can result in a breakthrough in many aspects.

In several countries suffering from insufficient water availability and/or wastewater treatment, new approaches are needed. In these regions wastewater treatment has to be integrated into the whole system of water and resource management. Currently huge investments are made in innovation in water resource recovery and water reuse. These comprise potable and non-potable water reuse, recovery of valuable wastewater compounds, especially nutrients (nitrogen and phosphorus), improved rainwater management, seawater desalination and combating the effects of micro-pollutants.

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Design, Operation and Maintenance of Drinking Water Treatment Plants

Written by *Zdravka Do Quang* on behalf of the Specialist Group

Contributors: *Kenneth M Persson (Sweden), Rui Sancho (Portugal)*

Introduction

The Specialist Group on the Design, Operation and Maintenance of Drinking Water Treatment Plants was created in 1996 to support exchange between experts in theory and practice. The hot topics of the Specialist Group comprise a variety of issues and are continuously evolving with the actual challenges of the field. Over the past 10 years the core issues on which the Specialist Group has focused its concerns and areas of activity have mainly related to tackle water quality compliance:

- health risk related to emerging parameters (chemical and microbiological) on drinking water treatment plants;
- natural organic matter (NOM) removal;
- control of disinfection by-product formation;
- advanced treatment processes for new micro-pollutants removal;
- plant retrofit and upgrade, maintenance procedures;
- optimization of CAPEX and OPEX for water treatment plants;
- operational feedback from case studies.

Specialist Group priorities

- Anticipate the water quality regulations evolution and continue the implementation of Water Safety Plans (WSPs) for adapting the water treatment plants' existing infrastructure and operational practices to ensure compliance with the future requirements.
- Enhance networking and exchange of practices and experience on operational issues for those involved in the design and operation of drinking water treatment plants and contribute to better understand the operational needs in terms of professional training and help troubleshooting and solving operational problems.

General trends and new challenges

Today the key enabling technology that will bring transformation in this field is definitely the trend to digitalization and the smart plant approach. It offers new opportunities for optimization of the plant operation and enhancement of plant management (chemicals dosing, workforce management, energy optimization). Big data and the numerical technological revolution (connected objects, Internet of things, sensors, and IT smart platforms) will impact and transform the way we will operate our plants.

Therefore we have observed the need to include some other important issues in our water future, such as the following:

- plant asset management;
- smart operation tools development and implementation of best practices;
- power consumption and energy management;
- life cycle analysis;
- securing produced and distributed water by online measurement of quality and control with micro-sensors (including direct potable reuse).

Recommendations on future hot topics and research development agenda

One of the key topics in respect to water treatment plant operations reliability is the WSPs and ISO22000 certification. These have been successfully applied in different countries and have provided benefits. Their implementation should continue to be promoted among the operators of drinking water treatment plants. These benefits include an improved confidence of clients and health agencies, a better control of hazards, and a better control of operations. For WSP to be effective and accepted, specific performance metrics or indicators have been defined and standard methodologies have been developed to successfully implement them. There is a need to share a common approach for implementation of WSP and exchange on the relevance of the selected operational indicators and metrics in the different countries and sites.

Another important issue is associated with climate change, including an increase in extreme events (drought, rains, flooding) resulting in water resource quality degradation (increased microbial and chemical pollution, eutrophication, etc.) which present challenges for water suppliers. These extreme events will have an impact on WSP evolution since the WSP-led improvements can strengthen system resilience, leading to sustained confidence in the production of drinking water during these changing times. The challenge is the merging of the WSPs and the Watershed Management Programs, which is implicit for an extreme event but also to assess the long-term impact of climate change on plant operation issues. For example, climate change has a significant impact on the increase of NOM level in the water resources. This affects directly the higher cost of chemicals and advanced water treatment processes in order to comply with pressure from public health authorities to reduce disinfection by-products and chlorine levels. Therefore NOM in drinking water will grow in importance during the coming years, the main areas of research being the following:

- new ways for NOM characterization, measurement and on-line monitoring;
- innovative ways of NOM advanced treatment and reduction;
- impact of residual NOM for disinfection by-product formation and water bio-stability control (biofilm regrowth);
- understanding the mechanisms by which NOM contribute to the mobilization and transport of synthetic materials: reactivity, analysis, treatment, and importance of the spread of persistent organic pollutants.

Last but not least, another hot topic concerns the implementation of the latest advances in online water quality monitoring. The development of a new generation of sensors such as the multi-parameter probes on one side and the increasing operators needs on the other have created opportunities for demonstrating the potential benefits of these innovations. Different suppliers have developed products in response to the market requirements, the main challenges and expectations being:

- improvement of quality of service by ensuring traceability of the relevant water quality indicators;
- enabling of detection of events resulting in a change in water quality and impacting both the health of the consumers and the distribution pipes;
- reduction of non-compliance risks and optimization of treatment processes;
- enhancing security for sensitive areas and buildings in cities.

Plant operators need to better share information on the benefits from these innovative tools by exchanging operational experience and lessons learned from practical application of the technology in field case studies and to assess the perspectives of future developments for this technology.

Diffuse Pollution and Eutrophication: State-of-the-Art and Global Challenges

Written by *Mi-Hyun Park, Brian D'Arcy, Ralph Heath, Leehyung Kim, Ray Earle, Zorica Todorovic, Rob Davis–Colley, Markus Venhor and Fiona Napier* on behalf of the IWA Diffuse Pollution and Eutrophication Specialist Group

Introduction

Diffuse (i.e. non-point source) pollution is caused when pollutants from a range of dispersed urban/rural land use activities contaminate waterways. Diffuse pollution arises in a catchment from many different sources, making it difficult to identify and control. An important characteristic of diffuse pollution is that it mainly results from rainfall runoff, particularly during storm events. As water flows over land it mobilises pollutants and transports them into rivers, lakes, estuaries, and groundwater, via multiple routes. Common sources of pollution include agriculture, runoff from road surfaces, urban developments, construction sites, forestry, parks and gardens and atmospheric deposition.

Diffuse pollution by its nature is complex to manage, being closely linked to land use, climate, flow conditions and soil properties. As point source pollution has been increasingly regulated and controlled globally over the past 40 years, diffuse pollution of water is now recognised as a major impediment to meeting objectives for water quality, aquatic ecosystems and related biodiversity. Managing diffuse pollution sources in a sustainable way is a key success factor in maintaining high water quality and preventing eutrophication, and therefore, the engagement of science, governance, economics and stakeholder is key in achieving this. Climate change, increasing food production and new emerging pollutants are continuing challenges to mitigating the impact of diffuse pollution on surface water quality.

This brief paper aims to give a broad overview of current diffuse pollution issues, and some insight into future direction of travel and challenges in the field.

Diffuse pollution sources

Urban diffuse pollution is a complex mixture of pollutants from multiple sources (Lundy & Wade, 2013). Main contaminants in urban runoff include particulate matters, heavy metals, hydrocarbons, pesticides, and faecal coliforms, and advancing analytical techniques continue to identify a range of widespread emerging pollutants, e.g. pesticide breakdown products, caffeine, nicotine etc. The types and loading of these pollutants are linked to urban land uses in the watershed (e.g. roads, commercial, residential, and industrial areas). Road runoff is an important component of urban diffuse pollution (Thorpe and Harrison, 2008). In the US, nationwide data evaluation results showed the highest concentration of metals from highway runoff (Lee et al., 2007). In semi-arid regions, first flush of highway runoff was reported to discharge approximately 40% of particulate loads (Li et al., 2006), 30-35% of heavy metal loads (Lau et al., 2009) and 90% of the toxicity primarily associated with copper and zinc (Kayhanian et al., 2008). Industrial land use can also greatly impact on pollutant loadings due to the misconnection of wastewater drainage piped system and misuse of stormwater drainage system (Lundy & Wade, 2013). Many activities associated with industrial estates carry a risk of diffuse pollution (careless handling and storage of oil and chemicals, cleaning activities, car washing, deicing and other spreading, unauthorised effluent discharges), or leakage from the contaminated soil (Todorovic, 2008).

Rural sources of diffuse pollution include land cultivation, fertiliser and pesticide use, livestock grazing, slurry storage and use, forestry operations and septic inputs. Agricultural runoff remains one of the leading diffuse pollution. The annual costs of dealing with the impacts of agricultural pollutants such as nutrients, pesticides, sediments and faecal coliforms across OECD countries is estimated at billions of dollars (OECD, 2012). Nutrients such as nitrogen (N) and phosphorus (P) in agricultural runoff can cause eutrophication in receiving water, often resulting in hypoxia and harmful algal blooms, and can also negatively impact drinking water supplies. Sediment is a natural component of freshwater ecosystems, but in excess can smother habitat and transport pollutants, affecting not only freshwater but also coastal and marine habitat. Agrochemicals such as pesticides, veterinary pharmaceuticals, hormones and growth agents are of increasing concern, threatening ecosystem and human health.

Managing diffuse pollution

It is well recognised that urbanisation inevitably impacts on the environment, affecting air, soil, temperature, heat energy balance, water cycle, water quality, and quantity. To reduce diffuse pollution arising from urbanisation, paradigm has been a shift from 'conventional' to 'low impact' development (LID). The concept of LID is to maintain hydrological condition of a site close to the natural setting for pre-development, reducing the impact of impervious surfaces on the runoff quality and quantity.

The LID approach has shown great potential for mitigating the impact of urban development (Ahiablame *et al.*, 2012), variously referred to in different countries as best management practices (BMP), low impact urban design and development (LIUDD), sustainable drainage systems (SUDS), and Water Sensitive Urban Design (WSUD) in Ahiablame *et al.* (2012). Urban diffuse pollution may be controlled by a series of practices as a single practice may not be enough to control the mixture of contaminants nor be universally applicable to all regions (Novotny, 2008). The approach can be structural or non-structural and fall into the following categories (Novotny, 2003): (1) pollution prevention (e.g. banning lead from gasoline, reduced use of de-icers; education of the public; adoption of site disturbance prevention ordinances and programs; implementation of programs minimising inflow into storm sewers); (2) source control to keep pollutants from contacting with stormwater runoff (e.g. surface protection of construction sites, street sweeping); (3) hydrological modifications to minimise runoff formation (e.g. porous pavement, infiltration trenches and ponds, rain barrel and green roofs); (4) reduction of runoff in the conveyance systems (e.g. swales, grassed channels and filters, raingardens, retention basins); (5) end of pipe controls (e.g. wetlands, surface/underground storage and treatment of combined sewer overflows)'.

Green infrastructure and eco-cities are the new phase of the urban diffuse pollution reduction. Green infrastructure is a network providing the components for solving urban and climatic challenges by building with nature. Main components include stormwater management, climate adaptation, less heat stress, more biodiversity, food production, better air quality, sustainable energy production, clean water, and healthy soils. Synergies between surface water management and GI have the potential to save costs and bring multiple benefits (USEPA, 2013) and yet there remain some issues for its appropriate application, and more design considerations need to be studied

The predicted growth and intensification of agricultural production over the next 10 years has the potential further deteriorate regional water systems (OECD, 2012). To reduce the pressure of agricultural runoff on water systems, improvements in agricultural runoff management and policies are required. Policy making for agricultural diffuse pollution can be more challenging than point source control, and regulation needs to cover a range of pollutants, activities and receptors. OECD (2012) offers policy recommendations toward sustainable water management from agricultural runoff: 'use a mix of policy instruments (economic incentives, regulations and information) rather than a single policy instrument (e.g. a pollution tax); enforce compliance with existing water quality regulations and standards; remove perverse support inagriculture to lower pressure on water systems; take into account the polluter-pays principle to reduce agricultural water pollution; set realistic water quality targets and standards; improve the spatial targeting of policies to areas where water pollution is most acute; assess the cost effectiveness of different policy options to address water quality in agriculture; take a holistic approach to agricultural pollution policies; establish information systems to support farmers, water managers and policy makers'.

Elements of this approach are seen in major pieces of water legislation globally, not only for managing rural environment, but also covering control of urban sources: e.g. Europe's Water Framework Directive, National Pollutant Discharge Elimination System (NPDES) Stormwater Program in the US, Nonpoint Source Management Directive and Water Circulation City Initiative in Korea, Sponge City Initiative in China, Garden Cities in UK etc.

Although currently not as widely employed as their urban equivalents, rural sustainable drainage systems (rSuDS) and rural BMPs provide opportunities to prevent, control and treat agricultural diffuse inputs, protecting receiving water quality. The potential to help mitigate extreme events, increase biodiversity and amenity value of farmland are additional benefits (EA, 2012). A few examples of such technique include BMPs regarding manure handling, constructed wetlands to capture sediment and transform nutrients, riparian buffers to capture particulate pollutants moving from upslope, tree planting to shade stream water and prevent high temperatures and benthic algae nuisances, fencing to exclude livestock disturbance of streams and their banks, etc . It is important that catchment scale management strategies are employed; a consideration of water issues across a catchment to reconcile conflicts such as the traditional drive to move water away as quickly as possible versus the potential for landscape wetting and storage.

Monitoring diffuse pollution and eutrophication

Water quality monitoring is essential for effective assessment of water quality and pollution sources. Monitoring diffuse pollution is more complex than routine monitoring of point source pollution, as it also requires monitoring intermittent wet weather events (Novotny, 2008). In addition to monitoring water chemistry, in Europe WFD assesses overall water quality status in terms of ecological status, and a range of biological indicators are also utilised to identify impact from a range of parameters (UKTAG).

In addition to familiar pollutants like nutrients, sediment etc, there is also a need for constant identification and assessment of emerging substances, posing challenges for both monitoring and analysis techniques. Compounds such as solvents in wood preservatives, foam and fire retardants, discarded recreational drugs and pharmaceuticals, phthalates leaching from weathering plastic materials, nicotine etc. (Rieckermann, 2008, Ellis, 2008), are just a few examples of an ever expanding list.

While techniques such as grab/ composite sampling of waters remain a staple of water quality monitoring programmes, recent decades have seen the development of new technologies to meet the demand for more intensive data. Recent advances in Wireless Sensor Network technologies with in-situ probes offer the ability to continuously monitor water quality in real-time. Such technologies as a part of Internet of Things (IoT) can improve water quality monitoring (Gubbi et al., 2013). Continuous turbidity in particular has the potential to act a proxy to estimating particulate contaminants such as sediment, E. coli and phosphorus.

Remote sensing, referring to aerial and satellite sensing technology, allows for monitoring water quality as well as watershed with frequent temporal scales over entire water bodies, increasing data availability (Chang *et al*., 2015). Satellite multispectral sensors developed for ocean and land monitoring (e.g. MODIS Terra and Aqua, MERIS, Landsat, SPOT, etc.) have been used for assessing inland and coastal water quality (Trescott and Park, 2013): mainly optical constituents, including turbidity, coloured dissolved organic matter, chlorophyll *a*, algal blooms, and temperature (Chang *et al*., 2015) as well as nutrients derived from their relationship with optical constituents (Su and Chou, 2015). In the USA, the Cyanobacteria Assessment Network (CyAN) project is currently being developed for an early warning system for algal blooms in freshwater systems using the series of satellite remote sensing. Advances in hyperspectral remote sensing have potential to enhance monitoring capabilities for water quality (Dube *et al*., 2015). The constellation of existing and future satellite will provide real-time, continuous monitoring of water quality to better understand the impact of diffuse pollution and eutrophication.

Recent advances in unmanned aerial vehicles (UAVs) offer real-time monitoring on demand to address the limitation of satellite/aerial remote sensing. UAVs provide low-cost data at higher spatial resolution, which is useful for small-scale waters and with limited access otherwise (Ayana, 2015). Currently UAVs with multispectral camera are used in some case studies for inland waters (Su and Chou, 2015) and future advances in sensors on board UAVs provide new potential of their applicability to water quality monitoring (Pajares, 2015). The major challenge is regulation to operate UAVs in many countries (e.g. Federal Aviation Administration authorisation in the USA).

Modelling diffuse pollution

Understanding and evaluating the processes of diffuse pollution is important and modelling provides a way to estimate diffuse pollution generation/transportation, helping to identify potential impacts, and to assess the effectiveness of BMPs (Li *et al.* 2014). Various modelling tools are available, e.g. MOdel for Urban SEwers (MOUSE), Model for Urban Stormwater Improvement Conceptualisation (MUSIC), P8 Urban Catchment Model (P8 UCM), Source Loading and Management Model (SLAMM), Stormwater Management Model (SWMM), Hydrological Simulation Program-Fortran (HSPF), Soil and Water Assessment Tool (SWAT), Source Apportionment-GIS (SAGIS), SuDS Studio etc., which use different temporal (from annual to sub-hourly) and spatial range (catchment vs. quasi-distributed) (Elliott and Trowsdale, 2007). Most of the models based on pollutant generation and treatment, such as buildup/wash-off processes, generally rely on flow modelling (Obropta and Kardos, 2007) while some models have the capability of predicting the performance of management practices (Elliott and Trowsdale, 2007).

Recent research has been shifting from stormwater pollution estimates to BMP assessment and for continuous long-term simulation (Elliott and Trowsdale, 2007; Li *et al.*, 2014). The modelling application in the past decade has also shifted: (1) target constituents from sediments/nutrients to pathogens; (2) modelling scales from local-scale to watershed-scale; (3) source areas from agricultural lands to urban lands or mixed lands' (Li *et al.* 2014).

Particularly for nutrients modelling, the MONERIS (MOdelling Nutrient Emissions in RIver Systems) model was developed in Germany and applied to Danube River and many others in Europe, Canada, Brazil and China (Kunikova, 2013). MONERIS considers both point source and diffuse source pollution discharges, integrating various administrative levels, land use, hydrological and soil data (Kunikova, 2013). This model provide a framework for assessing management alternatives to prevent eutrophication in river systems (IGB, 2010).

Trends and challenges

The paradigm of end-of-pipe treatment has shifted over recent decades to decentralised managements to prevent and mitigate diffuse pollution, and approaches mimicking natural systems and pre-development hydrology using green infrastructure are now considered and practiced in many countries worldwide, but this requires legislative and commercial frameworks to ensure a sustainable future of these systems where costs and benefits are properly identified and distributed.

At the most recent IWA International Conference on Diffuse Pollution and Eutrophication, conference presentations and publications addressed a wide range of topics including both conventional and emerging diffuse pollution issues such as new pollutants (e.g. nicotine), new research approaches (e.g. crowd sourcing), the role of citizen science, adapted agricultural economic behaviour. Common areas of concern included the following.

- Water quantity as an emerging problem in river basin management.
- How to achieve global reduction goals under current agricultural practice.
- Achieving further reduction of pollutants via urban collection and treatment systems
- Integrating modelling approaches rather than single model applications.
- The need to better understand the synergistic effect of diffuse pollutants and impact on ecosystems.
- The need to better understand future climate and land use change and associated impact on diffuse pollution.
- Better cooperation and sharing of research globally to provide a consistent, better communicated message to stakeholders and policy makers.

Changing land use is resulting in increasing diffuse pollution, with adverse impacts frequently experienced for freshwater ecosystems, potable water quality, irrigation, groundwater resources, and coastal water and habitats. Recognising this, IWA is currently planning a 'Global Impacts' report, which will consolidate existing knowledge on the problems and solutions linking land use management and water quality. To develop the content of the report, IWA specialist groups will be encouraged to invite 'impact papers' for conferences during 2016–2018.

Despite current monitoring and modelling efforts, lack of data is a key challenge. Long-term monitoring and modelling are required for a better understanding of diffuse pollution generation and transportation (McCoy *et al.*, 2015). To properly evaluate the effectiveness of green infrastructure, data prior and post implementation of BMPs are important, which are rarely available. Owing to long time lags, long-term, continuous monitoring is also required for assessing the performance of BMPs/LIDs (Rissman and Carpenter, 2015). More data are needed to characterise runoff and pollution loadings and characteritics from different land uses under different climatic conditions (Ahiablame *et al.*, 2012). Long-term monitoring of emerging contaminants in diffuse sources is needed for different hydrological and climatic settings (Ahiablame *et al.*, 2012). Enhancement of modelling techniques to simulate and evalaute BMP/LID performance is required by incorporating more types of BMPs/LIDs (Ahiablame *et al.*, 2012).

The future climate change is likely to affect the quantity and quality of water discharged from watersheds although the impact is uncertain and complex to properly simulate (Bosch *et al.*, 2014). The anticipated increased frequency and intensity of extreme precipitation events could increase diffuse pollution loads and exacerbate impacts on water systems, while more severe droughts may increase toxicities in the water owing to reduced dilution (OECD, 2012). Current modelling and simulation of climate change effects are hindcasting and the lack of data of such events projects potential high degree of uncertainties. Moreover, the uncertainties from climate change models will be translated to modelling water quality, yielding amplified magnitude of uncertainties. In addition to anticipated drought and reduced amount of available water supply, deterioration of water quality is another factor threatening water security throughout the world (McCoy, 2015). As diffuse pollution is one of the major sources of deteriorating water quality, developing a policy framework for adopting management practices to control diffuse pollution and eutrophication will help ensure water security.

The UN has replaced the Millenium Goals with the Sustainable Development Goals (SDGs)(UN, 2015) and for the very first time WATER is clearly featured as a critical item of management for sustainability achievement in the light of the global trends towards urbanisation and the challenges of supplying quality water and food for 9 billion people by 2030 under extreme variable conditions relating to global location, political security, climate change, specific arid/wet dominant factors, emerging contaminants, invasive alien species, limited phosphorous and natural resources. Improving the prevention and management of diffuse pollution has a part to play in achieving these goals.

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Disinfection

Written by *Blanca Jiménez, Chao Chen, Wenhai Chu, Andrea Turolla, John Bridgeman and Shuguang Xie*
on behalf of the Disinfection Specialist Group

Introduction

As mentioned in the first Global Technology Report of IWA in 2012, our Specialist Group of Disinfection has declared that disinfection is one of the most important steps in the treatment of water, wastewater and sludge. Now, faced with the 2030 Agenda and the Freshwater goal targets 6.1 and 6.2 regarding the safe supply for water and the need to provide sanitation for all, the importance of disinfection as a processes has been emphasized even further. We also presented some challenges for disinfection in the previous report. The first and greatest challenge for disinfection is to define the expectations of the process. The second challenge is to understand the strength and limitations of disinfection. The following paragraphs include how we assess the performance of disinfection and what standards are adequate, which viruses do we target to establish our disinfection performance targets, and how we determine an acceptable performance for disinfection.

Water professionals have been improving our knowledge and experience for disinfection. In the field of drinking water treatment, disinfection is not the same as sterilisation and has to be applied with other water purification processes to give the multi-barrier protection for water safety. The higher disinfection efficiency cannot be guaranteed until the minimisation of solids load is achieved by upstream coagulation, sedimentation and filtration. Besides the core task of pathogen (virus, bacteria, and protozoa) inactivation, more standards have been applied to the side-effect of disinfection, i.e. disinfection by-products (DBPs). In many cases, the DBP requirement is even more challenging to achieve than the requirement of microbiological safety in drinking water, wastewater, and water reuse.

During the past 5 years, many investigations have been undertaken to develop more efficient and reliable disinfection technologies in water (mostly) and wastewater to control the formation of toxic DBPs and to better understand the necessity of disinfection on not only pathogen inactivation but also to support the stability of water in the distribution system.

Development or optimisation of disinfection process

Concerning the disinfection of water and wastewater, the driver towards innovation has been historically constrained by the combination of the high degree of process consolidation and by the scarcity of strong pushes to treatment optimisation (as, for instance, the need to contain operating costs in the view of making the process sustainable or to achieve stringent goals for complying with regulatory standards). In particular, the disinfection of water and wastewater based on the dosage of chlorine-based chemicals has been extensively applied in full-scale facilities from the beginning of the 20th century, being a process characterised by great effectiveness and low technological complexity. Such factors essentially resulted in the absence of strong market and regulations promoting the development of innovative disinfectants and methodologies. However, in recent years there have been several emerging factors that are promoting new research and development activities in academia and water industry: (1) the growing awareness of some environmental and sanitary issues, such as the generation of harmful DBPs; (2) the availability of new technologies and methods for process monitoring and operation, addressing both the compliance with more stringent standards and energetic and cost savings; (3) the introduction of regulations based on different parameters or on the restriction of existing thresholds.

As for innovative disinfectants, in the search for a progressive replacement of chlorine and considering ozone, UV radiation and micro/ultrafiltration as established technologies, the only significant ongoing innovation at the large scale is represented by the use of peroxides for the disinfection of wastewater, whose market is growing rapidly in many industrialised countries. Given that peracetic acid is by far the most promising disinfectant belonging to this group of compounds (Antonelli *et al.*, 2013), the main concern about its use is related to the toxicity of the residual in the environment (Antonelli *et al.*, 2009), requiring further investigations. On the other hand, several articles have been published on the use of performic acid in recent years, including Gehr *et al.* (2009) and Karpova *et al.* (2013), although awareness of this compound is still scarce as well as its application. Otherwise, the disinfecting action of many alternative compounds on water, wastewater, and even in sludge has been reported, including silver (Aguilar *et al.*, 2007; Silvestry-Rodriguez *et al.*, 2007), also in combination with hydrogen peroxide (Orta *et al.*, 2008; Shuval *et al.*, 2009) or in nanostructured forms (Li *et al.*, 2008), although none of these showed the potential for development at full scale. However, these technologies are interesting for some niche applications, such as the control of biofilms in distribution networks in case of silver-based materials or the abatements of resistant pathogens (e.g., *Legionella*) in small-scale water circuits in particular situations, such as hospitals. In addition to this, relevant research efforts are addressed towards advanced disinfection processes and combined processes, such as photocatalysis on TiO_2 (McCullagh *et al.*, 2007), O_3/UV (Jung *et al.*, 2008), and peracetic acid/UV (Koivunen and Heinonen-Tanski, 2005), eventually promoted by solar radiation (Malato *et al.*, 2009). These technologies are particularly interesting in view of meeting stringent requirements on bacterial inactivation, of exploiting the benefits of the various processes, possibly resulting in a synergistic overall effect, and of developing sustainable technologies applicable in developing countries.

Regarding innovative methodologies for disinfection for liquid matrices, recent advancements are essentially divided between two main groups in relation to their function: (1) measurement and monitoring and (2) modelling and control. For the former, the ultimate objective is the development of reliable and low-cost instruments for the local determination of process parameters, such as UV fluence, and residual disinfectant or DBPs, which could be applied as online real-time remote sensors. Then, as for modelling and control, advanced simulation tools, such as computational fluid dynamics (Wols, 2011), or soft-computing techniques, such as artificial neural networks (Kulkarni and Chellam, 2010), were successfully applied to the modelling of disinfection processes, even in case of variable input or using a non-deterministic approach (Santoro *et al.*, 2015). It is worth mentioning that the two groups are mutually influencial, since the development of accurate and sophisticated systems in one group is essential for the progresses in the other. A further emerging trend is the assessment of the sustainability of disinfection based on risk assessment, with respect to the microbiological quality of water (Mok *et al.*, 2014) and the presence of disinfection by-products (Wang *et al.*, 2007). In detail, the objective is the development of methodologies for estimating the overall risk related to the process, especially in the view of wastewater reclamation and indirect reuse (Lazarova *et al.*, 2013).

Sludge disinfection

For solid matrices (i.e. excreta or sludge), disinfection processes are commonly confounded with stabilisation ones, which have the aim of reducing mass sludge, notably the organic matter content, rather than ensuring the safety of the material to be disposed of from the perspective of its potential to disseminate diseases. The need to revalorise sludge and excreta, the increasing lack of space in which to dispose of them, and the need to recover materials such as nitrogen or phosphorus, appeal for new ways to treat the sludge. In this regard, the progress made by research is much slower than that made for treating water and wastewater. This is unfortunate, because to effectively implement the Sustainable Development Goal (SDG) target related to sanitation in developing countries there will need to be accessible and reliable methods to inactivate the high content of pathogens found in the sludge produced in low-income regions. In fact, this is one of the targets of the 'reinventing the toilet' programme from the Gates Foundation (http://www.gatesfoundation.org/What-We-Do/Global-Development/Reinvent-the-Toilet-Challenge). This sanitation challenge in developing countries is different to the one in developed countries, as sludge and excreta closely reflecting local health conditions have a very high content of a wider variety of pathogens, thus demanding different processes for disinfection (Jimenez *et al.*, 2002, 2007). Some examples of novel disinfectants used to inactivate pathogens in sludge are silver, acetic acid, and peracetic acid (Barrios *et al.*, 2001, 2004, Díaz Avelar *et al.*, 2004, Aguilar *et al.*, 2006, Pecson *et al.*, 2007). Also, improvements to conventional processes such as those using lime have been implemented to take advantage of the disinfection effect that ammonia has on helminth eggs (Mendez *et al.*, 2004).

Water quality in distribution systems

Drinking water disinfection issues include not only pathogen elimination but also bio-stability and corrosion control in the distribution system as well as DBP formation. Recent progress in the past 5 years is summarised below.

Bio-stability

The biggest challenge for microbiological safety of drinking water may lie not in the water treatment plants but in the drinking water distribution system (DWDS) because of microbial regrowth over a long retention time. Microbial regrowth is mainly influenced by the residual disinfectant concentration and the carbon substrate (as determined by assimilable organic carbon (AOC) or biodegradable dissolved organic carbon (BDOC)), while temperature, flow, and phosphate concentration have been also regarded as limiting factors in some studies (Szabo and Minamyer, 2014; Wang *et al.*, 2012). Generally, if there is a high level of nutrients but insufficient disinfectant, the water cannot be regarded as bio-stable. Van der Kooij proposed a threshold of AOC < 10 μg/L for bio-stability in the absence of disinfectant (1984). This level is challenging to achieve because it requires a clean source water as well as advanced water treatment process. However, the high treatment cost makes it very difficult to duplicate beyond Western Europe. The US water industries prefer to control bacterial regrowth by maintaining a high level of residual disinfectant with an AOC level of 50–100 μg/L (Lechevallier *et al.*, 1996). In some cities of China, the combined AOC level of <100μg/L and higher residual chlorine of 0.3 mg/L are thought to control bacterial regrowth in DWDS (Lu *et al.*, 2005).

The linkages between bacterial regrowth, disinfectant concentration, and nutrient concentration is an area of significant interest. However, the complexity of bacterial species, behaviour, heterogeneous niches, and interactions make it hard to gain a robust understanding of the principal interactions. Srinivasan and Harrington (2007) developed a method to describe the bio-stability by combining the Monod equation and Chick–Watson law for inactivation. This model abandons the traditional way of establishing a relationship between bacteria and the limiting factors. It just shows the cutting edge curve to make the inactivation rate over the bacterial regrowth. Lu *et al.* (2012) applied this method to assess drinking water bio-stability in one sub-tropical city in southern China.

Besides the general index of heterotrophic plate counts (HPC) or adenosine triphosphate (ATP) analysis for bacterial counting in DWDS, flow cytometry and molecular biological tools have been applied to identify microbial community abundance and structure (Lautenschlager *et al.*, 2013; Aggarwal *et al.*, 2015). Unattended loose deposits in distribution systems are regarded as very important niches for bacteria to survive. Moreover, owing to their mobility, the associated bacteria reach taps easily (Liu *et al.*, 2014). The particle-associated bacteria can lead to a considerable underestimation of biomass and have a greater mobility than pipe-wall biofilm bacteria. Therefore, particle-associated bacteria present a greater risk, given the higher probability that they can reach customers' taps and be ingested (Liu *et al.*, 2016).

Among the whole family of microorganisms, some opportunistic pathogens present high resistance to disinfectants and bring a significant threat to drinking water safety, such as mycobacteria and *Legionella*. Such bacterial populations in drinking water exhibit different resistance to disinfectants, and the disinfection process employed. For example, mycobacteria are more resistant to chloramines than to free chlorine or chlorine dioxide, whereas *Legionella* is more abundant in chlorinated DWDS (Chen *et al.*, 2012). Free-living amoeba in DWDS can act as a shelter for pathogens (Delafont *et al.*, 2014; Lu *et al.*, 2016). Some nitrifying bacteria are not pathogens themselves but can contribute to chloramine depletion and leave the DWDS unprotected from pathogens (Maestre *et al.*, 2013).

Chemical stability

Water that displays large variability with particular chemical indices is defined as chemically unstable water; this includes changes in turbidity, colour, and the release of iron or lead from pipes. Disinfection plays an important role in controlling chemical stability.

In the USA, China, and many other countries, iron is the most dominant pipe material in DWDS. The chemical stability problem mainly manifests itself as coloured water due to iron release from pipe corrosion and scale breaking. Generally, iron scale has a multi-layer structure: the outer is a thin, concrete, and shell-like layer composed of ferric chemicals and magnetite; the inner is a thick, loose, and porous layer formed by ferrous chemicals. However, the morphological and physicochemical characteristics of iron corrosion scales formed under different water source histories are different (Yang *et al.*, 2012). The formation and dissolution of scale, and the resultant iron release, are controlled by electrochemistry reactions. Coloured water events are found to occur sporadically in China owing to the long-distance transportation of water (Zhang *et al.*, 2014). Changes in the levels of sulfate and chloride were observed to affect iron release and, to a lesser extent, the retention of representative inorganic contaminants (arsenic, cadmium, copper, chromium, lead, nickel, vanadium, uranium and zinc); however, the effects of natural organic matter were more pronounced (Peng *et al.*, 2013). Thus, the careful blending of different source waters, the increase of pH or alkalinity, and addition of orthophosphate were investigated and applied to address these events (Zhang *et al.*, 2014). Moreover, the introduction of desalinated water will also increase the possibility of coloured water due to the sharp rise in the Larson ratio of chloride concentration to alkalinity (Mi *et al.*, 2016). Some bacteria are associated with scale dissolution and iron release (Wu *et al.*, 2014; Yang *et al.*, 2014).

In the eastern regions of the USA and some European countries, lead pipes were widely adopted in the late 19th and early 20th centuries (Lytle and Shock, 2005; Kim *et al.*, 2011). Now, residents there experience lead release, especially when chloramination is applied to replace free chlorination for the control of trihalomethanes and haloacetic acids. Water chemistry and the composition of pipe scale are two key factors influencing lead release from pipe scale (Xie and Giammar, 2011). A weak disinfectant will lower the redox potential of pipe system and the stable lead oxide (PbO_2) will be reduced to soluble and toxic lead ion (Guo *et al.*, 2014; Zhang and Lin, 2013).

In summary, drinking water disinfection cannot simply be regarded as pathogen inactivation nor be limited to water treatment plants. Sufficient residual disinfectant is also very important for maintaining chemical stability to control iron or lead release in distribution systems. Water quality issues in the distribution system are complex and important.

DBPs

After the recognition of chloroform as a probable carcinogen and by-product produced after chlorine disinfection of natural waters in the 1970s (Rook, 1974), balancing the risk of communicable disease transmission spread by waterborne microorganisms against the risk of toxicity from exposure to DBPs has become a significant issue in water quality control. The ensuing 40 years of effort from water professionals have allowed us to improve our understanding of the significance and health risks of some DBPs including trihalomethanes, haloacetic acids, and others, leading to the promulgation of regulations and guidelines and the follow-up development of technological solutions for their control. The nature and quantity of DBPs formed depends on the type of disinfectant, dose, and the type of organic matter or other constituents present in the water (McGuire *et al.*, 2014). Consequently, common practices for by-product control fall into three categories: (1) modification of disinfection practices to suppress DBP formation, including the use of alternative disinfectants such as chloramines, UV, ozone, and chlorine dioxide; (2) reduction of precursors by processes such as enhanced coagulation–sedimentation, granular activated carbon (GAC) adsorption, membrane and chemical oxidation (e.g., advanced oxidation processes [AOPs]) before disinfection; and (3) further DBP removal after formation by membrane, GAC, chemical oxidation and reduction. Nevertheless, new knowledge pertaining to the toxicity, formation, and control of DBPs is continuously being revealed.

Several emerging DBPs have been recognised for their significance in drinking and wastewater treatment, including nitrogenous DBPs (e.g. *N*-nitrosamines (NAs), haloacetonitriles (HANs), haloamides (HAms), and halonitromethanes (HNMs)), and carbonaceous DBPs (e.g. haloketones (HKs), haloaldehydes (HAs), halobenzoquinones, and halopyrroles).

N-nitrosamines have received much attention in the drinking water industry in recent years in many industrialised nations because of their high carcinogenicity, frequent occurrence in disinfected drinking waters and wastewaters, and their potential regulation (Krasner *et al.*, 2013). Nine alkyl *N*-nitrosamines, namely *N*-nitrosodimethyamine (NDMA), *N*-nitrosomethylethylamine (NMEA), *N*-nitrosodiethylamine (NDEA), *N*-nitrosodi-n-propylamine (NDPA), *N*-nitrosodi-n-butylamine (NDBA), *N*-nitrosodiphenylamine (NDPhA), *N*-nitrosopyrrolidine (NPYR), *N*-nitrosopiperidine (NPIP), and *N*-nitrosomorpholine (NMOR), have been studied (Krasner *et al.*, 2013). Some have been identified as DBPs formed during chloramination (Choi and Valentine, 2002; Schreiber and Mitch, 2006) or the reaction of ozone with dimethylamine or certain anthropogenic chemicals (Andrzejewski and Nawrocki, 2007; Schmidt *et al.* 2008). Recently, tobacco-specific *N*-nitrosamines were also found in some chloraminated waters and identified as emerging DBPs (Wu *et al.*, 2014).

N-nitrosamine regulations and guidelines in drinking water throughout different parts of the world have been advanced as a result of their perceived toxicology and occurrence at levels of health concern. Most of the North American studies have found that NDMA formation is more associated with chloramination than with chlorination (Krasner *et al.*, 2013). The database for Unregulated Contaminant Monitoring Rule 2 showed that systems in the USA with high plant effluent NDMA (>50 ng/L) typically use chloramines as the primary rather than secondary disinfectant (Russell *et al.*, 2012), reflecting the potential for precursor deactivation by strong pre-oxidants. NDMA formed as a result of chlorination may be attributable to high source water ammonia concentrations, as chlorination of ammonia-containing waters may result in chloramine formation (Krasner *et al.*, 2013).

The basic strategies to control nitrosamine formation in drinking water include the removal and/or destruction of nitrosamine precursors and/or optimisation of the chloramination conditions (Liao *et al.*, 2014) as performance of conventional processes in controlling nitrosamines is poor (Krasner *et al.*, 2012; Wang *et al.*, 2013). Meanwhile, NDMAFP will increase greatly when the polymer polyDADMAC is used. Free chorine, especially at high chlorine exposure, could destroy and/or transform NDMA precursors, but will form halogenated DBPs as a trade-off (Shah *et al.*, 2012). Ozonation has been shown to destroy/transform secondary or tertiary amines and NDMA precursors (Lee and von Gunten, 2010; Shah *et al.*, 2012; Krasner *et al.*, 2012). Powdered and granular activated carbon (PAC and GAC) have been shown to remove wastewater-derived NDMA precursors better than bulk dissolved organic carbon (DOC) (Hanigan *et al.*, 2012; Liao *et al.*, 2014, 2015a). The general structure of nitrosamine precursors, i.e. a positively charged dialkylamine group and the non-polar moiety, explains the mechanism of nitrosamine precursor removal by these processes (Chen *et al.*, 2014; Liao *et al.*, 2015b).

Other emerging halogenated nitrogenous DBPs include haloacetamides, halonitromethanes, and halonitriles, many of which have been found to be more genotoxic and cytotoxic than the regulated DBPs (Plewa *et al.* 2008; Richardson *et al.* 2007).

Haloacetamides are the most cytotoxic of all DBP classes measured to date, and they are the second-most genotoxic DBP class, very close behind the halonitriles (Plewa and Wagner, 2015; Richardson and Postigo, 2015). Five haloacetamides, chloroacetamide (CAcAm), dichloroacetamide (DCAcAm), trichloroacetamide (TCAcAm), bromoacetamide (BAcAm), and dibromoacetamide (DBAcAm), were first quantified in the US Nationwide Occurrence Study (Krasner *et al.*, 2006). Some brominated haloacetamides, including bromochloroacetamide (BCAcAm), bromodichloroacetamide (BDCAcAm), dibromochloroacetamide (DBCAcAm), and an iodinated HAcAm bromoiodoacetamide (BIAcAm), were subsequently identified in drinking water (Richardson *et al.*, 2008; Pressman *et al.*, 2010; Plewa *et al.* 2008). Later, all 13 haloacetamides were quantified, in which tribromoacetamide and chloroiodoacetamide was first identified and quantified in drinking water (Chu *et al.*, 2012; Richardson and Ternes, 2014). Haloacetamides can form by the hydrolysis of the corresponding haloacetonitriles (Glezer *et al.*, 1999; Reckhow *et al.*, 2006), and further research has also shown that they can be formed by an independent pathway (Huang *et al.*, 2012). Amino acids are an important class of haloacetamide precursor (Chu *et al.*, 2010; Bond, *et al.*, 2012), and combined amino acids probably play a more important role in the formation of haloacetamides (Shah and Mitch, 2012). New research also found that aromatic organics and antibiotics may contribute the formation of haloacetamides in chlorinated and/or chloraminated drinking water (Chuang *et al.*, 2015; Chu *et al.*, 2016; Le Roux *et al.*, 2016). Halonitromethanes are also at least 10 times more cytotoxic than trihalomethanes (Plewa *et al.*, 2004). Nine chlorinated and brominated halonitromethanes have been identified (Choi and Richardson, 2005; Shah and Mitch, 2012). Halonitromethanes are substantially increased in formation with the use of pre-ozonation before post-chlorination or chloramination (Krasner *et al.*, 2006). Nitrite may also play a role in the formation of the nitro group in these DBPs (Choi and Richardson, 2005). Hydrophilic natural organic matter is the more important haloacetamide and halonitromethane precursor than hydrophobic natural organic matter (Chu *et al.*, 2010; Hu *et al.*, 2010), which explains the potential of traditional and advanced treatment technologies for removing the precursors of haloamides and halonitromethanes (Bond *et al.*, 2012; Chu *et al.*, 2015).

Iodinated DBPs, which are formed in significantly higher concentrations in chloraminated drinking water (Krasner *et al.* 2006; Ding and Zhang, 2009; Jones *et al.*, 2011; Yang and Zhang, 2013; Ye *et al.*, 2013; Richardson and Postigo, 2015), are more toxic than the brominated and chlorinated analogues (Richardson *et al.* 2007; Plewa and Wagner, 2015). Attention is also being paid to discover new DBPs (e.g. halobenzoquinones and halopyrroles) from different disinfection means and in different water matrices including disinfected potable water, wastewater effluents, and swimming pool water (Qin *et al.*, 2010; Zhao *et al.*, 2012; Wang *et al.*, 2013; Richardson *et al.*, 2003; Yang and Zhang, 2014). The discovery of these emerging DBPs with higher health risks suggests the need to investigate their formation and control, although their concentrations in waters are much lower than those of the regulated DBPs.

Although there are more than 700 polar and non-polar DBPs reported in the literature, little is known about their concentration levels after disinfection, and their health impacts. Alternatives, including assessing total organic halogens, overall toxicity, and precursor availability in finished waters, are being considered. Efforts are also being made to understand the ecological impacts of DBPs in receiving waters and, for potable and swimming pool waters, the significance of exposure to some DBPs through inhalation and dermal contact.

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Efficient Urban Water Management

Written by *Stuart White and Mary Ann Dickinson* on behalf of the Specialist Group

Introduction

The mission of the Efficient Urban Water Management Specialist Group is to encourage the interchange of knowledge, research, best practices and programs regarding efficient management and use of water in urban zones. A specific area of interest is exploring and promoting new solutions for urban drinking water supply and sanitation systems that improve the efficiency of water use and the efficiency of the operation of urban water and sanitation. The topics that are covered by the Specialist Group include end use water efficiency; customer demand management; drought management; level of service; network asset management; water losses management; performance assessment; environment impacts; economics; social preferences and involvement; water resource planning; and program design, are all integrated under the Efficient Specialist Group umbrella.

Devoted to promoting practical solutions for utilities, the Specialist Group also seeks to involve broad stakeholder interests and knowledge. The main forum for the Specialist Group is the biennial Efficient Conference, which has been successfully held every two years since 2001. The next Efficient conference will be in March 2017 in Tel Aviv.

The Specialist Group has also actively participated in developing and publishing information resources for water efficiency and demand management, including the 'International Demand Management Framework' (Turner *et al.* 2006) and the IWA book 'Preparing Urban Water Use Efficiency Plans' (Maddaus *et al.* 2013).

Existing Specialist Group knowledge

The Specialist Group and its members have an interest in the science, technology, policy and practice associated with water efficiency and demand management. The state of the knowledge in this field is very large; however, some aspects are described under the following headings.

Water efficiency and conservation

The work of this Specialist Group in particular focuses on the potential reduction in water demand as a result of improvements in water efficiency in all sectors of urban water use and the conservation of water through changed practices and behaviour of consumers.

The improvement in water efficiency can occur in a number of ways but the key concept of importance is defining the conservation potential. The conservation potential refers to the difference between the actual efficiency of water using equipment and appliances, and the potential efficiency of water using best commercially available appliances and fixtures. In many cases, the water that can be saved through installing the most water efficient available technology is significant; 50–75% reduction is possible in the case of many toilets, shower-heads, washing machines and cooling tower controllers, just to provide a few examples.

Achieving this can be done through a range of instruments including regulation of the efficiency of new appliances, such as the US Energy Policy Act of 1992, or in Australia the water efficiency labelling and standards scheme. Voluntary approaches have been applied in Europe such as the European Water Label and Eco-Label and the WaterSense labeling program in the US. Secondly, it is possible to regulate the efficiency of new building, new installations and new developments through the use of building codes or development consent conditions (e.g. BREEAM, LEED, NABERS, etc.). Thirdly, it is possible to encourage or financially support the retrofit of more efficient equipment through rebates, incentives, loans or mandatory disclosure of water efficiency of buildings. Finally, changes in practice or behaviour can be encouraged through communication and education programs and through pricing incentives and regulation of water using practices. In the past 20 years there has been a large expansion of available options for improving the efficiency of water use and improving water using practices. However, in some countries the evaluation of these and strategic implementation hasn't been sufficient to result in large-scale application (as can be seen in a review[1] of UK water efficiency projects).

Landscape water efficiency

In many countries the largest proportion of water use is outdoors and this is either in the form of residential lawns and gardens or playing fields or irrigation of open space by municipalities and so on. This is obviously highly dependent on existing climate, landscaping type and soil type. In recent years there have been great advances in the available technology for improving the efficiency of landscape water use through improved irrigation systems, selection of plant species, soil treatment, and automation and computerisation of irrigation including the use of soil and moisture sensors. Despite this, there are many opportunities for improving landscape water efficiency that remain in most cities and countries.

This water use category also adds to peak demand both on a daily and on a seasonal basis and therefore can create additional cost on the water supply system. In many cities there is strong interest in recycled water or second quality water from groundwater sources as a means of supplying water for irrigation, and

[1] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/308019/pb14117-water-conservation-action-by-government.pdf

this has led to the use of the so-called third pipe or dual reticulation systems where a separate network is provided to irrigate outdoor areas including municipal scale use of recycled water for median strips, playing field, parks and gardens, as well as residential areas. This can help support the green infrastructure that reduces the urban heat island that has increased health implications during times of drought. Better designing of stormwater management infrastructure can reduce the impacts of flooding and improve water quality while providing more reliable supplies of water to this green infrastructure. This leads to potential conflicts between policies around water restrictions, xeriscaping, and turf replacement programmes with broader water management objectives. The difference may be between reactive requirements in the height of the drought and managing landscape water use efficiency proactively.

Regulations and policies for water

In addition to appliance regulation and the regulation of new buildings and houses as discussed above, regulation and policies for water efficiency can include the regulation of urban water utilities to encourage and support the efficient use of water and a reduction in overall extraction from the water supply system. This can include regulatory arrangements which decouple the profitability of water utilities from the increase in water sales and alternatively provide incentives for reducing water use while increasing the level of service. Sometimes this has involved targets for water consumption on a per capita basis or targets for the increased use of recycled water as well as long-term caps on extractions of water from the environment including environmental flow requirements for rivers and other waterways.

Additionally, changes to how water companies approach infrastructure investment can improve sustainability. An example is the move from operational and capital expenditure to total expenditure (TOTEX) in the UK, which has reduced a traditional bias towards capital investment rather than operational investment such as water efficiency measures. Many countries operate similar price controls and rate setting approaches and it is important that these evolve to recognised the move away from the bias towards large supply infrastructure such as dams and desalination.

Rates and pricing for efficient water management

There are several options for improving rates and pricing to encourage water efficiency. The first important principle of water pricing is that the prices that are charged should reflect the costs of service, and that should include the environmental and social cost associated with all the aspects of the water cycle including the impact on the environment, the long-term and life cycle cost of replacement of assets, and incorporating shadow prices for externalities such as greenhouse gas emissions and the need for environmental flows.

Secondly there is often strong encouragement from the point of view of improving water efficiency for conservation tariffs which increase the per unit costs as consumption increases, often with a base level of water being provided at a lower cost to ensure social equity. The importance of ensuring that pricing structures are equitable, or that there are compensatory redistributive and protection mechanisms for less well-off consumers, is an important principle of water pricing. This is particularly the case in the transition to metered consumption. This has resulted in political issues in countries such as Ireland and Scotland; however, examples from England suggest rolling out water efficiency measures and social tariffs at the same time can lessen these effects.

An additional, although relatively little used method of water pricing, is to put in place a drought or scarcity surcharge at times when the water supply system is constrained by drought. Again, we stress the importance of ensuring that equity is maintained and that there be adequate support given for those who may be adversely affected and unable to pay. This can be easily achieved by providing mechanisms for improving the water efficiency of those customers who face significant increases in water bills but may face barriers to investment in new water efficient equipment and fixtures. Therefore, these kinds of programmes are often best undertaken in combination with education, communication and economic incentives for improving water efficiency.

Drought and climate change

The increased awareness of the impact of long-term climate change, in particular on water security, with more frequent and extreme droughts means that there is a greater level of attention being paid to different planning methods for increasing the resilience of our water supply systems. This includes in some cases quantifying the benefits of water efficiency and providing insurance against increased frequency and severity of droughts as well as improving the water supply demand balance over the longer term.

Some planning involves the consideration of 'drought proofing' water supply systems which usually has high capital and energy costs associated with it. Drought response strategies will become increasingly important as we see the impact of drought spreading across the globe including recent examples in Australia, California, São Paulo and in the Philippines (see, for example, a recent report[2] on the California drought). This is driving a range of new decision making approaches for water resources planning including real options analysis and robust decision making that move towards best value rather than least cost planning.

The water energy nexus

There has been a considerable amount of work on the links between the water and energy utility sectors. Much of this focus has been on the energy intensity of water production, transport, treatment and use (See in particular the work of the Pacific Institute, the Alliance for Water Efficiency, and the Institute for Sustainable Futures on the water-energy nexus). This has become more significant as some cities have expanded and have tapped into close and easily available water supplies and have moved further away or to more expensive and energy intensive water supply systems e.g. inter-catchment transfers, desalination, and wastewater recycling. The increase in standards and expectations regarding sewerage treatment and wastewater recycling as well as water treatment standards have all increased the energy intensity of the overall urban water supply and sanitation system. The International Water Association's Water and

[2] http://www.allianceforwaterefficiency.org/AWE-Australia-Drought-Report.aspx
[3] http://www.iwa-network.org/WaCCliM/

Wastewater Companies for Climate Mitigation (WaCCliM[3]) project has developed tools and a database of measures to help utilities reduce carbon emissions. This is being trialled in Mexico, Peru, Thailand and Jordan and will be developed further into an IWA Water–Energy–Carbon framework for utilities worldwide.

Beyond the utility level, national governments put forward their approaches and targets for reducing carbon emissions in COP21. An initial analysis[4] of this showed major gaps in representation of the water sector. Countries such as Azerbaijan through the European Commission funded the ClimaEast project which recognised water sector emissions from water supply and irrigated agriculture as an area to target (see 2014 workshop outputs[5]).

In addition, there is now increased awareness of the energy costs associated with heating water both for domestic purposes and for process heat in industry. This constitutes the largest proportion of the embedded energy in water in many cases. This accounts for 5% of UK carbon emissions or 8% in Australia[6] and needs to be addressed in conjunction with energy efficiency on heating and cooling homes to meet targets set in COP21. As a result of this increasing awareness attention is being paid to the water energy nexus, particularly in relation to the linkages between energy efficiency and water efficiency programs which can provide a 'double dividend' through reducing greenhouse gas emissions at the same time as reducing water use, as well as a recognition that there are higher avoided costs associated with the electricity and energy industry which can help improve the economic case for water efficiency programs themselves. Examples of joining up and partnership approaches for water and energy include guidance[7] developed for social housing in Wales and including water efficiency measures in energy retrofit schemes and regulations. Tools such as the household water and energy calculator[8] developed in the UK have also been successfully implemented in behaviour change projects.

Non-revenue water

Non-revenue water refers to water that is lost from the water supply system because of leaks, bursts, under-registration of meters, or theft and includes water which is not accounted for in the normal metering and pricing system.

The International Water Association, through the Water Loss Specialist Group, which itself grew out of the Efficient Urban Water Management Specialist Group, has developed a robust accounting method which classifies and enables quantification and comparison of the various categories of non-revenue water. In particular, it allows the development of numerous performance indicators such as the Infrastructure Leakage Index, by which different water supply systems can be compared. The particularly useful aspect of this framework is that it moves away from comparing water supply systems on the basis of percentage water losses which can be quite misleading, given the differences in underlying demand. The framework also provides the clarity that is required between real losses which are physical losses from the water supply system compared to apparent losses which are a result of the other sources of non-revenue water.

It has also been clear that the issue of pressure management must be considered at the same time as non-revenue water to reduce the actual losses from the system both from ongoing losses but also from mains breaks. There have been considerable advances in this field in the past 10 years. There are many different referenced works on this issue (e.g. Lambert 2002).

Public involvement in water efficiency

There are two aspects to the involvement of the community in water efficiency. Firstly, there is the importance of engagement of members of the public in the implementation of water efficiency programs, whether this be retro-fitting programs, support for regulations on the efficiency for water-using appliances, or improvement of water using practices by consumers through behavioural change programs. Another aspect of this is service innovations either through retail competition (water companies compete to provide smart metering and water efficiency) or through innovation where water companies partner with communities on green infrastructure/ water reuse. A post outlines this on the blog[9] of the Alliance for Water Efficiency Financing Sustainable Water. Add website to make it Financing Sustainable Water website.

The second example of the importance of community engagement in water efficiency relates to determining community preferences in relation to the strategies and options which are developed for water efficiency, and assessing the appropriate level of service for sustainability of water supplies. Many of the decisions relating to these questions involve trade-offs and are not straight-forward technical or economic questions, and therefore it is highly appropriate to use techniques which strongly engage citizens in the choices that are often being made on their behalf and using funds which are provided by water customers. Examples of the approaches that can be used are described in several references (see, for example, Gastil and Levine 2005) and some organisations[10] involved in this field.

Efficiency in wastewater networks and treatment

Wastewater treatment is a significant component of the capital cost of the urban water supply and sewerage system. It has a much higher capital cost than water supply in many cases. Also the environment implications of poor levels of wastewater treatment are often quite significant, and there is continual community pressure to improve sewerage and stormwater treatment including to improve bathing, water

[4] http://aaronbh2o.blogspot.com.au/2015/12/cop21-intended-nationally-determined.html
[5] http://www.climaeast.eu/events/1725
[6] http://www.urbanwateralliance.org.au/publications/UWSRA-tr100.pdf
[7] http://www.energysavingtrust.org.uk/organisations/sites/default/files/Guidance%20on%20water%20and%20associated%20energy%20efficiency.pdf
[8] http://www.energysavingtrust.org.uk/domestic/water-energy-calculator
[9] http://www.financingsustainablewater.org/blog/competition-water-sector-financing-fourth-generation-water-infrastructure
[10] http://www.deliberative-democracy.net/

quality, freshwater quality and remove nutrients which can be the source of eutrophication and blue green algae. Therefore the Efficient specialist group has had an active interest in improving the efficiency of wastewater treatment to improve the overall performance of urban water systems; this includes both the conveyance i.e. transport as well as the treatment systems and of course the increased interest in productive reuse of wastewater and stormwater.

Water efficiency in low and middle income countries

There are a range of quite different issues which apply in considering the role of water efficiency in low- and middle-income countries (LAMIC) relative to cities in high income cities. Firstly, in many cases, there are a number of households which do not have any or the whole suite of appliances and fixtures. This means that the cities and towns in LAMIC countries will be on a very steep growth curve in per capita water use as development increases and as more households and businesses are connected to the water supply system and accumulate appliances and fixtures for water use. In many LAMIC cities, the water use of those appliances and fixtures is not optimal and in fact the efficiency is less than those in high income countries, which means they will experience a rapid growth in water use for the next decades before it reduces as it has in most high income cities. Similarly, many of these cities do not have extensive sewer networks and where such networks exist there is not adequate treatment. Therefore the water and sewerage systems are both extensively bound together in terms of future development.

Finally, it is often the case that LAMIC countries have relatively high rates of non-revenue water including real losses from the water supply system. The combination of these factors means that the approaches that need to be taken will differ from high income countries, but also that there is an even greater potential for improving the efficiency of water use and for reducing future capital and operating expenditure and environmental impact at a lower cost. It is therefore important that the planning and development process, including the financing through multilateral finance organisations and national governments, takes these issues into account and recognises the importance of the demand side of the water system and the potential of the water efficiency and 'getting it right first time'.

General trends and challenges

There are several areas which are emerging in the urban water industry that are of interest to the efficient specialist group, and it is hoped that the specialist group can play a role within IWA in terms of exploring these areas. These include the following areas of interest.

Water–energy–food nexus

As indicated above there is strong awareness of the importance between the linkages of water and energy; this occurs in both directions, in the energy intensity of the water sector but also the water intensity of the electricity generation and other parts of the energy sector.

This is likely to become much more important with the increased focus on long-term climate change and support and interest for mitigating greenhouse gas emissions. In addition, there is also recognition of the connections with the food sector both in terms of energy requirements of food growing and food production as well as the water requirements from the point of view of irrigation but also the possibility of mitigating the impact of water and energy use through changes in the food sector. This includes improved efficiency of food production as well as global analysis and consideration of global dietary changes. Irrigated agriculture and urban water use are often considered as competing and therefore in some areas this has caused a land use and resource conflict particularly as cities grow and as the world becomes more urbanised, and as the requirements for food increase this resource and land-use conflict is only likely to increase. There is also a strong interest in and opportunities for urban agriculture and pressures on peri urban areas for food.[11] New innovations in point of use monitoring and feedback for behaviour change (i.e. showering) are being trialled in the UK and Spain through the DAIAD project.[12]

Another nexus aspect is bioenergy impacts on water as well as food systems. It is expected that the IWA Efficient specialist group will continue to explore this area, and to integrate with the effort that may be made at the IWA level. It is certainly of increasing interest to IWA to be involved in global issues including the sustainable development goals and the climate change targets which have recently been negotiated.

Smart metering and utilities: improved demand forecasting

Improving demand forecasting for urban water relies upon a detailed knowledge of the factors that influence demand. The use of smart meters, with greater resolution of water demand data, and data from numerous end use studies (measuring the demand from individual water uses) have enabled an improved picture of current demand. When these results are coupled with predictions of future changes in water using equipment and practices, and urban land use and sector growth, this can allow improved forecasts of future demand. The trend to smart metering, including electronic meters, remote reading, will continue, possibly in combination with joint metering of energy and water. Current research is also focusing on how these data can be used from a customer perspective to help change behaviour and reduce demand for water (example from Anglian Water[13]).

Efficiencies in water loss management

Water loss management, including pressure management, has now become a core part of water supply system asset management and operations in many cities and towns. The field is also rapidly advancing, through new technology and improved methods of diagnosis and prioritising repairs. Additionally, consideration of the sources and scale of background leakage and plumbing losses is important. A recent study[14] from the UK identified that around 4.1% of toilets leak and this needs to be considered from a water efficiency and leakage perspective.

11 http://www.sydneyfoodfutures.net/
12 www.daiad.eu
13 http://www.wwt-smartnetworks.net/wp-content/uploads/sites/106/2016/03/Paul-Glass.pdf
14 http://www.watefnetwork.co.uk/files/default/resources/Water_Event_2_December/Workshopdeckfordiseminati.pdf

Innovative planning with alternative water resources

It is now widely recognised within the water industry, and the IWA, that the historical approach of developing water infrastructure has not been optimal in ensuring economic, social or environmental outcomes. There is interest in integrating the historically separate parts of the urban water system: water supply; wastewater collection and treatment; and urban stormwater management. This includes wastewater treatment and reuse, stormwater or rainwater capture and reuse and improved water efficiency. It can involve challenging the economy of scale associated with water and wastewater networks, including in-building, or precinct wastewater reuse schemes. Water quality fit-for-purpose and stormwater reuse integrated in the landscape, as well as capture and reuse of nutrients are all part of this strategic approach. There are environmental, and even cost advantages that can be realised with such methods.

This is outlined in Chapter 10[15] of the 2015 World Water Week Report. There are many names being used for these approaches from One Water to Water Sensitive Cities but the practical aspects of integrating the broad range of planning and operations across the water cycle is the next step to truly integrating water management. This also recognised the need to consider efficient urban water management within the broader context of resilience and functioning of cities including links with transport, energy and other infrastructure needs. The International Water Association is developing a Charter on Urban Waters that will address these issues and will be launched at the 2016 World Water Congress in Brisbane.

Research and development agenda

The Specialist Group has a number of projects that it is pursuing, including the following:

- Promoting the use of integrated resource planning and demand management, including developing best practice water efficiency programs across the IWA membership and through the biannual conferences and the World Water Congress.

- Developing performance indicators for water efficiency, in collaboration with the Benchmarking and Performance Indicators Specialist Group.

- A study of the sources and scale of background leakage, and plumbing losses within buildings. This is a joint initiative with the Water Loss Specialist Group.

- Strategic assessment of international water efficiency actions. Initially, this will be limited to urban water management and domestic/ non-domestic water efficiency or conservation programmes.

- Water Use Efficiency in Energy and Agriculture. This initiative will examine the role of water efficiency in the water-energy-food nexus and determine the research and needed policy actions.

We are also actively involved in wider International Water Association projects and activities, including:

- Water and Wastewater Companies for Climate Change Mitigation (WaCCliM);

- developing a charter on urban waters;

- joint work with the Communications and Public Engagement Specialist Group (workshop at IWA World Water Congress in Brisbane).

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[15] http://www.iwa-network.org/downloads/1440582594-Chapter%2010.pdf

Forest Industry

Written by *Michael Paice and Gladys Vidal*, July 2016

Introduction

The Forest Industry Specialist Group addresses environmental issues within the forest industry, particularly in the pulp and paper industry and the emerging biorefinery industries. We organise symposia and workshops, and promote dissemination of relevant scientific and technical information to IWA members. Symposia are usually held in countries with major pulp and paper manufacturing industries, most recently on a triennial basis in the USA, Brazil, Canada, and Chile. Some important issues for the industry include optimising water use and effluent treatment technologies, receiving water effects, and the challenges of wastewater treatment for new biorefinery technologies.

Overview of the industry

The predominant technologies for conversion of wood into pulp and paper products are the kraft process for chemical pulps used in printing and writing papers, tissue, towel, and packaging, and mechanical pulping (TMP, CTMP) for newsprint, magazine and increasingly as a kraft pulp replacement in certain market sectors. Both kraft and mechanical pulping processes produce effluents that require treatment before discharge to receiving water. Most countries regulate the discharge of biochemical oxygen demand (BOD), chemical oxygen demand (COD), and suspended solids. Some countries also regulate for effluent acute toxicity (e.g. Canada) and effluent conductivity and colour (e.g. Chile). Aerobic effluent treatment processes predominate with activated sludge, aerated lagoons, and biofilm activated sludge being commonly employed. Anaerobic processes are less common, although more are recently being installed for biomethane production.

Globally, the industry has experienced a rapid expansion in South America and Asia in recent years, with a stable or declining market in North America and Europe. Demand for newsprint and printing and writing papers has decreased, while markets for tissue, disposable towel, dissolving and fluff pulps, and packaging have expanded. Some of the increased market demand has been met by increased rates of fibre recycling. Furthermore, large hardwood kraft mills have been built in South America and Asia, mainly using fast growing Eucalyptus from plantations. Recently there have been some announcements of bioproduct mills in Scandinavia, producing softwood kraft and a variety of byproducts including electrical power, lignin, biofuels, etc. In an integrated forest products industry, forest management, harvesting, and lumber and other wood products manufacturing are important parts of the picture, but these operations tend to discharge less water and therefore have less influence on the receiving water environment.

Challenges and recent trends for effluent treatment and energy efficiency

In Canada

The Environment Canada Environmental Effects Monitoring program has been assessing pulp and paper receiving waters for more than 20 years now. Initially enrichment and endocrine disrupting effects were discovered downstream of some mills. Better understanding of the causes of these effects and implementation of solutions has resulted in a much improved effluent quality, and it is generally concluded that the current regulatory framework is now providing effective protection of receiving waters.

Energy savings inside the mill as a result of improved heat conservation and co-gen projects can result in lower effluent flows, and effluents with more concentrated organics and salts. This can present a challenge for compliance with acute toxicity testing which requires exposure of trout and Daphnia to undiluted effluents. Nutrient discharges are an issue in some locations. However, many kraft mills are now able to operate their aerobic treatment plants without addition of supplemental nitrogen and phosphorus. Phosphorus and nitrogen are present in some mill streams from wood sources, and, in aerated lagoons, nitrogen fixation can be a significant source of nutrient nitrogen.

Several mechanical pulping mills which have low water usage and a highly concentrated (BOD) effluent have now installed anaerobic treatment as a source of biomethane for use within the mill. This offloads the existing aerobic biotreatment plant, which becomes essentially a polishing stage for achieving the required discharge effluent quality. The combined anaerobic aerobic treatments generate less secondary sludge, which is otherwise a significant disposal issue for activated sludge operations. Combined sludge is dewatered and either incinerated, landfilled, or land spread. Other approaches to sludge handling and use are the subject of ongoing research.

Pulp and paper companies are looking for diversification in their product portfolios to replace the declining demand in the traditional paper grades. In Canada, there is an increased focus on power generation, and some manufacturing of new forest-based materials such as cellulose nanocrystals (CNC), cellulose filaments (CF), and kraft lignins. The handling of effluents from these new manufacturing processes is also being addressed.

In Chile

The Chilean kraft pulp industry is under pressure from local governments, and more broadly from the climate change agenda and environmental non-governmental organisations, to minimise their environmental impact. To improve exports and profitability and minimise environmental effects, the industry is working more on applied research with partners in the research centres and universities. Owing to water scarcity in the south of Chile, the industry is working with partners to develop knowledge of watersheds (geography, water levels in ground water, etc.). Flow monitoring stations are being used to better predict surface and ground water availability.

Monitoring programs have been developed in Chile for effluent discharge based on mill locations (discharge to rivers or the ocean). Organic matter (BOD or COD) are the main regulated parameters, while some mills are required to remove colour by tertiary treatment. Nutrients and chronic toxicity effects such as endocrine disruption are not currently regulated, but have been monitored in receiving waters. Depending on receiving water studies such as degree of biodiversity, some mills have been required to improve their wastewater treatment performance. Most wastewater designs are activated sludge, aerated lagoons or moving bed biofilm reactors (MBBRs).

Solid wastes are a big issue for the industry; the goal is to find alternative uses for solids other than landfill. Sludge stabilisation and conditioning, for example by composting, can provide a useful fertiliser product for plant growth (landspreading), subject to environmental and health regulations. Other solids such as dregs and grits are being used as inorganic amendments for soils.

Odour control is another important topic. Chile now has regulations for total reduced sulfur (TRS) including H_2S emissions in different unit operations of the kraft mill. Existing mills that do not have TRS collection systems must install them by 2017, while new mills must have collection and monitoring systems.

Research Agenda

Some recent topics for environmental research in the Forest Industry include the following:

1) Minimising nutrient N and P discharge to receiving waters. It has been found that supplemental nutrients can be lowered for both aerated lagoons and activated sludge.
2) Optimising the microbiology of activated sludge. Newer techniques such as fluoresence *in situ* hybridisation (FISH) are increasing our understanding of causes of upsets and variable floc structure.
3) New methods of handling primary and secondary sludge, including better drying techniques, digestion, and hydrothermal liquefaction for conversion to biofuels.
4) New anaerobic treatment designs. The upflow anaerobic sludge blanket (UASB) and the internal circulation reactor (IC) have proved difficult to operate owing to loss of granules. Lower rate designs may be more appropriate for pulp and paper effluents.
5) Reuse of kraft mill bleaching filtrates after treatment by various technologies.
6) Aerobic granular sludge bioreactors for improved effluent treatment.
7) Alternative use of biosolids, dregs, and grits in agriculture or other industries.
8) Use of advanced oxidation processes (AOP) such as the Fenton process for tertiary effluent treatments.
9) Use of membranes for internal recirculation of water in processes and/or recovery of valuable products.
10) Use of constructed wetlands after an activated sludge treatment.

Conclusions

Pulp and paper mills use significant quantities of fresh water and must employ large effluent treatment plants to comply with receiving water regulations. Effluent biotreatment is an essential component of the manufacturing process and therefore require continuous monitoring and improvement to allow mills to compete in today's global economy. Changes in manufacturing technologies and new production targets have resulted in more concentrated and more diversified effluents which are challenging researchers to provide innovative solutions. From a broader perspective, considering the forest resource from plantation through harvesting to manufacturing, we need to develop water life cycle concepts that include water quality and security, as well as environmental footprint.

Groundwater

Updated[1] *by Shafick Adams* on behalf of the Groundwater Restoration and Management Specialist Group

TERMINOLOGY

Adaptive management. An iterative process of optimal decision making in the face of uncertainty, with an aim to reducing uncertainty over time via system monitoring.

Aquifer. A geological formation which has sufficient storativity and permeability to hold and transmit appreciable quantities of water.

Hydrogeology. The scientific study of the occurrence, distribution, and effects of groundwater, and of its hydraulic and chemical interaction with geological materials.

Introduction

Most liquid freshwater available on Earth is stored in aquifers; groundwater therefore dominates, by volume. It is estimated that groundwater is a primary source of drinking water for as many as two billion people and drives a significant part of the world's irrigated agriculture (Morris *et al*. 2003; Kemper 2004). Many countries (e.g. Denmark) and cities (e.g. Dhaka and Mexico City) are dependent on groundwater as a supply source. Groundwater is broadly defined as, water stored in geological formations below the Earth's surface. In hydrogeological terms, however, the top of the saturated zone is called the water table, and the water below the water table is called groundwater. Under natural conditions, groundwater moves by gravity flow through rock and soil zones until it seeps into a streambed, lake, or ocean, or discharges as a spring' (*Encyclopedic Dictionary of Hydrogeology*, Poehls and Smith 2009). Subsurface hydrology is mainly concerned with the quantity and flow of groundwater and other fluids, chemical interactions between the fluids and the rocks through which they pass, and the transport of solutes and energy through geological porous media (RNAAS 2005). Hydrogeology includes the following:

- groundwater hydrology;
- contaminant hydrology;
- unsaturated zone hydrology.

Droughts and increased demands have triggered the search for alternative water supply options. This has led to an increase in the exploitation of groundwater supplies, especially in semi-arid and arid regions, often with little understanding and management of the consequences (e.g. saltwater intrusion, mining of groundwater and impacts on linked systems). In some places poor land-use planning threatens the quality of the groundwater; where groundwater becomes contaminated, this increases the cost of treatment necessary before its use in water supply. In many areas of the world, groundwater still receives very little protection within water laws and is often considered to be only linked to the land above the aquifer being exploited (i.e. considered as private water). Yet groundwater remains the principal, in places the only, option for water supply across a large proportion of the world and is hence of pre-eminent importance. Billions of people rely on this underinvested resource compared to surface water systems. Groundwater should be managed within an integrated framework that takes into account the impacts on and by linked systems and the effects of land-use planning. It should be noted that groundwater systems are more complex and thus inherently more difficult to manage than surface water. The perceptions of the public and policy-makers or their lack of awareness of groundwater, as well as the generally poor understanding of its behaviour and occurrence, represent important causes of emerging problems (Burke and Moench 2000; Quevauviller 2007). This paper will highlight some of the challenges and trends within the discipline of subsurface hydrology.

Perspectives on subsurface hydrology

Over the past number of decades, hydrogeology has evolved from a science of how to find and exploit groundwater into the integrated management of this finite and interconnected resource as well as emphasis on the quality of the water. This can be seen by the progression of laws and regulations governing groundwater use and pro-

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tection being developed across the world. Advances in subsurface hydrology include, among others:

- Estimation techniques for hydraulic properties
- Groundwater-surface water interactions
- Mapping and modelling of large-scale aquifer systems
- The nature and variability of groundwater recharge
- Vulnerability assessments
- Techniques for enhancing recharge, storage and recovery
- Transboundary aquifer management
- The behaviour and fate of contaminants in groundwater
- Groundwater- or aquifer-dependent ecosystems
- Fractured and heterogeneous aquifer behaviour
- Improved monitoring techniques (including remote sensing)
- Improved integrated modelling systems
- Unsaturated zone linkages
- Subsurface groundwater storage and management
- Economic valuation of groundwater resources
- Importance of groundwater in providing goods and services to communities

Challenges and trends

Environmental stress is driven by the growth in population and urbanisation and the resulting energy, transport and development trends at country and global levels (World Bank 2010). The 2015 and 2016 global risk register of the World Economic Forum lists 'water crises' as the top global risk. The 2016 register has as the top impact 'failure of climate-change mitigation and adaptation'. Groundwater resources are also intricately weaved within the emerging environmental issues (see UNEP's 21 issues for the 21st century, UNEP, 2012). High-level challenges, that are not necessarily unique to groundwater, include:

- Global change (e.g. climate change and variability)
- (Ground)water pollution and depletion
- Rapid urbanisation with increasing supply demands and higher pollutant loads
- Coupling of the various reservoir fluxes in time and space
- Governance of water and related resources
- Emerging contaminants
- Data collection (monitoring) and data availability (management) including Big Data management
- Uncertainty quantification (e.g. model and parameter uncertainties)
- Poor land-use planning
- Scale and heterogeneity
- Capacity development
- Complete description of complex systems
- Operation and Maintenance of water schemes
- Groundwater valuation and financing

Challenges related to groundwater management are numerous and overlapping. Giordano (2009) and Morris *et al*. (2003) give a more detailed global assessment of the issues and solutions facing groundwater. Groundwater is often poorly understood because of its hidden nature and assessments often rely on indirect measurements and long-term investigations and investments to determine fully the behaviour of complex aquifer systems. The problem is often short-term investigations and investments; long-term data sets are very rare. The invisibility of the resource may be complicating the management thereof. However, groundwater cannot be considered a mysterious phenomenon or resource anymore; it can be described using established scientific laws (Narasimhan 2009). Standard groundwater management approaches depend on the presence of basic data and on institutional capacities (FAO 2003). Data, and the collection and management thereof, remain a major area of concern. Remotely sensed information is used routinely for characterisation and extrapolation but cannot be seen as a substitute for ground-based programmes or detailed fieldwork.

The integrated water resource management (IWRM) approach, which combines consideration of surface water and groundwater, should strengthen frameworks for water governance to foster good decision making in response to changing needs and situations (Cap-Net 2010) and provide mechanisms for the adaptive and holistic management of the water cycle over time. However, different funding approaches are followed in managing the surface and groundwater resources owing to the inherent difficulty with quantifying the economic value of groundwater resources and the general lack of appreciation of groundwater as a resource.

Changing patterns of precipitation and evapotranspiration will inevitably alter groundwater flow patterns through changes in recharge-discharge relationships (Narasimhan 2009). Groundwater systems are affected by climate change in a variety and complexity of ways, depending on whether an area becomes wetter or drier. It is possible that an increase in rainfall will not lead to increased recharge if the annual distribution of rainfall also changes; and vice-versa, decline in rainfall could see an increase in recharge if intensity and seasonality change. Groundwater availability is less sensitive to annual and inter-annual rainfall fluctuations (i.e. climate variability) than surface water (Giordano 2009). However, the overall impact of climate change on groundwater and surface water resources is expected to be negative over the long term. However, groundwater resources, if managed correctly, are generally more resilient to climate variability and change and often used as a buffer resource between droughts. The role that groundwater can play in mitigating climate change threats is also significant (Foster *et al*. 2010b). Adaptation strategies will rely on investment in better and more accessible information, stronger and cooperating institutions, and natural and man-made infrastructure to store, transport and treat water (Sadoff and Muller 2009).

Future research trends mainly deal with reducing uncertainty and risk and are intimately linked with the challenges faced. The dearth of information on most aquifer systems often results in poor management plans. This is often linked to over-exploitation but can also lead to the underuse of groundwater resources. The trend is towards adaptive management strategies and this pragmatic approach is now recognised as an alternative solution for systems where we have an incomplete understanding of the behaviour of a system (Gleeson *et al*. 2011; Holman and Trawick 2010; Brodie *et al*. 2007; Seward *et al*. 2006). However, it is also evident from the literature that adaptive management can be understood from a variety of perspectives and is often perceived as yet another catch phrase (Allan and Curtis 2005). The adaptive or learning-by-doing approach is a flexible management framework that allows for changing conditions of the (ground)water and institutional systems. To ensure the success of the approach existing institutional and cultural constraints will have to be mapped and changed to effectively transition into an adaptive management approach. The continuous monitoring of these systems remains crucial for the provision of background data and information to evaluate and validate adaptive management approaches. For planned high-risk activities the adaptive management or monitoring approach must be preceded by detailed studies and a good grasp of how the system behaves; adaptive management is about urgency and reducing uncertainty and risk over time. Clean-up of a contaminated system is extremely difficult and costly. In the absence of local information and protocols, international best practices should be adapted to local conditions (Adams 2009).

The remainder of this paper gives broad overview of the main issues that have been identified to be the focus of the Groundwater Restoration and Management Specialist Group for the next few years.

Urban groundwater management

Half of the world's population reside in cities and, within two decades, nearly 60% of the world's population will be urban dwellers. Groundwater is generally more significant for urban water supply in developing cities and towns than is commonly appreciated and is also often the 'invisible link' between various facets of the urban infrastructure. Groundwater as a conjunctive use resource will have to be increased and treated to a standard that is fit for purpose owing to the increased incidences of pollution. Groundwater is a fundamental component of the urban water cycle and there is always need for it to be integrated when making decisions on urban infrastructure planning and investment. In most developing cities the installation of mains sewerage systems and wastewater treatment facilities lags considerably behind population growth meanwhile shallow groundwater can become contaminated from inadequate *in situ* sanitation. Groundwater's role in designing and developing water sensitive cities and settlements are receiving considerable attention and should be strengthened.

Groundwater contamination and restoration

Throughout the world, aquifers capable of providing water of high quality for potable use are threatened by organic and inorganic contamination emanating from human activities. Worldwide, numerous examples can be cited of water supply aquifers rendered unusable without treatment owing to releases of contaminants from various agricultural, industrial, commercial and other sources. Contamination of aquifers presents major technical, regulatory and management challenges. Treatment of contaminated groundwater is also complex owing to the type and concentrations of contaminants that may result from these releases. The extent of anthropogenic contamination of groundwater aquifers worldwide is not known. Restoration of aquifers requires innovative approaches and technological solutions. These approaches ranges from the very costly long-term above surface solutions to in-situ techniques that requires long-term monitoring. Management of large urban groundwater basins becomes particularly challenging in the context of past, continuing and future contamination of aquifers from residual contamination that remains persistent at detectable levels. Some of these issues have been summarised in a recent IWA publication on this topic (Kavanaugh and Krecic 2008; Dimkić *et al.* 2008).

Interactions between different water bodies

Groundwater is often still managed and legislated separately from surface water resources – the trend worldwide is to manage the two as integrated systems, which nevertheless behave differently in time and space and must be studied separately at the fundamental level. The Cap-Net (2010) report notes that: 'Traditional institutional separation of surface water from groundwater has created fundamental communication barriers that now extend from technical expertise to policy developers, operational managers and water users. These barriers impede the understanding of the processes [i.e. recharge and discharge mechanisms] and consequences of groundwater-surface water interactions [on linked ecosystems]'.

Integrated water resource management and the increasing impact of groundwater abstractions on linked surface water bodies call for an improved understanding and quantitative description of the interactions between the different components of the hydrological cycle (atmosphere, surface and subsurface). Data collection and monitoring has been neglected and is often not resourced with a view to collect long-term spatio-temporal scale data. The main challenge is the issue of scale, especially temporal scales, as surface water responses are generally faster than those of groundwater. Various approaches and methods have been developed to study the interactions at different temporal and spatial scales—usually involving modelling approaches. Exchanges between reservoirs are often invisible and the fluxes measured indirectly. Quantification of the fluxes is extremely difficult and fraught with uncertainty. Data collection, monitoring infrastructure and guardianship have been neglected and is often not resourced with a view to collect long-term spatio-temporal scale data. Development and uptake of new monitoring and data acquisition techniques should be a priority that is only made more important at a time of climate change and increasing demands. Because of the differences in approaches for surface water and groundwater the incompatibility of data sets and conceptual understanding complicates groundwater-surface water assessments. Modellers are continuously developing tools to integrate the various reservoirs at different scales using various, often manipulated, data sources obtained from direct and indirect measurements.

Groundwater governance and policy

Technological interventions and scientific understanding are well established and the characterisation and assessments of these systems can be performed at a very high confidence level. However, the sustainability of installed schemes ultimately depends on how we operate and manage these schemes or interventions. Again, the need for adequate long-term data and large-scale investments in assessments are required for the efficient management of these systems. The science to policy link is often to blame for the proper uptake of robust management systems and tools. A system is needed where stakeholders at all levels contribute to the sustainable utilisation of the resource. Groundwater governance gaps are usually highlighted during periods of extreme events, development of unconventional gas resources and agricultural overexploitation, as examples. A global groundwater governance project recently assessed global groundwater governance and the policy neglect of this valuable resource. This global study defines groundwater governance as 'an overarching framework and set of guiding principles that determines and enables the sustainable management of groundwater resources and the use of aquifers'. The lack of adequate governance – i.e. overarching enabling frameworks and guiding principles – hinders the achievement of groundwater resources management goals such as resource sustainability, water security, economic development, equitable access to benefits from water and conservation of ecosystems.' (see www.groundwatergovernance.org). Linked to the issue of governance is the inadequate financial models associated with developing groundwater schemes. Most institutions do well in establishing capital expenditure projects with minimal operational expenditure costs. Groundwater schemes usually require a lower level of capital expenditure but a higher long-term operational expenditure plan. This is often cited for the failure of groundwater schemes. Governance is a crosscutting issue within the water sector but also needs strengthening across the energy, agricultural and mining sectors to ensure sustainability.

Conclusions

Efficient management of groundwater relies on the effectiveness of applicable legislation and institutional arrangements as well as good understanding of the behaviour of the aquifer or well-field being managed (i.e. quality and quantity) (Dimkić and Milovanović 2008). Groundwater management has developed into an interdisciplinary science and is not just the purview of the hydrogeologist. The discipline-specific approach to solving specific research questions is important but on its own it cannot address current environmental problems. A coordinated approach that links various disciplines is important. Catchment management can only be effective if landuse management is linked to water resource management. It is thus good to see that water research is becoming more multidisciplinary in nature (see Kamalski 2010; Foster *et al* 2010a). However, there seem to be very few management tools that are able to coordinate such activities at the local scale. Research on a country and global level often takes place in parallel and is uncoordinated. Managing groundwater over multigenerational timescales will require monitoring and management that is integrated, adaptive, inclusive and local (Gleeson *et al*. 2011). The challenge to all stakeholders is how we translate our ever-growing scientific knowledge into improved management of all resources and bringing about change in human behaviour. The specialist group will also look at how it can mend the 'broken bridges' between science and policy.

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Health-related Water Microbiology

Written by *Gary Toranzos, Marion Savill, Hiroyuki Katayama, Gertjan Medema, and Rosina Girones* on behalf of the Specialist Group

Introduction

The Health-Related Water Microbiology Subgroup has been involved in all aspects of public health where water has the role as a vector/reservoir of pathogens. Members of this specialist SG include microbiologists, microbial ecologists, public health professionals, environmental engineers, virologists, bacteriologists and parasitologists. Our aim is to understand how pathogens can be transmitted via water and which barriers are effective in stopping the transmission. Having such a diverse group of experts has shown to be our greatest strength. As a result of this, the group has been involved in discussions on emerging threats such as Ebola virus. Although Ebola is usually transmitted by contact with bodily fluids from infected subjects, it also has been shown to be excreted in the faeces by infected patients. To this end, we organized a workshop during our last semi-annual meeting in Lisbon, Portugal, to discuss all the details in regards to how Ebola-containing faeces should be handled both in Africa as well as Europe, the USA and other countries. The workshop was very successful and showed how such a diverse group of experts can readily come up with viable alternatives when faced with such a dangerous pathogen.

Our group has also been one of the first water groups to discuss Extreme Events, such as earthquakes, floods, tsunamis, etc., vis-à-vis dangers to public health. We have held workshops on this topic and many of our members are very active in this important area of research. The varying lack of preparedness by local and government agencies, as well as a disconnection of the public with these types of events has pushed our group to discuss this at every one of our meetings, where we have members who have been through these extreme events give an account of what was done, by whom, what was successful, what should not be done again and how we can plan for future events. This work is currently being planned to be put in writing in conjunction with the other groups who held Extreme Event Workshops.

The science is going well, and there are lots of papers being presented at our semi-annual meeting. However, there are still barriers that need to be taken into consideration. The fact that research is expensive, limits developing countries from doing so, and more and more molecular methods are being used. This is also a barrier to research. Our group has been very involved in overcoming this barrier by giving travel grants to those promising students from developing countries to come to our meetings. This has been highly successful, and hopefully as we get recurrent funds, we will be able to impact more and more students.

Our final goal is to work more with the IWA Cluster, Programme and mentoring initiatives, all of important to assisting water and our group as a whole, members individually and growing young scientists.

General trends and challenges

Microbial risk assessment

For several years the group has been involved in the discussion of microbial risk assessment (MRA) as a tool of integrated and regulatory science and a possible alternative to epidemiological studies which are expensive, time consuming and impossible to deal with in terms of site-specificity. MRA is being applied all over the world and our members have been actively promoting, teaching and using MRA to determine risk to public health as a result of using waters for drinking, irrigation of food crops as well as primary, secondary and tertiary recreational contact.

New emerging pathogens and NGS techniques

Apart of the classical recognized pathogenic bacteria, viruses and parasites that continue to challenge our waters, new emerging pathogens are increasingly recognized. A very exciting new avenue is the use of metagenomics for the characterization of microorganisms in water have been published (see, for example, Cantalupo *et al*. 2011; Ju et al 2015; Keeli *et al.* 2015) showing a wide diversity of microbial contaminants. There is great potential for metagenomics to be a very important and promising methodology. Although metagenomics presents a unique opportunity to get information on the content of all species simultaneously present in a sample, direct detection of nucleic acids using New Generation Sequencing (NGS) techniques is still not as sensitive as e.g. PCR. Therefore the development and validation of sensitive approaches using NGS techniques for analysing potentially contaminated water will be of great value in order to determine if they can be used as rapid and reliable tools for the quick identification of the most significant microorganisms associated with public health risks and understand their environmental behaviour and transport. In addition to enable correct interpretation of the huge amounts of data generated by deep sequencing, there is a need for accurate and fast bioinformatics algorithms.

New indicators of faecal contamination/risk/treatment

The quality of water used for drinking, irrigation, aquaculture, food processing or recreational purposes has a significant impact on public health on a global scale. Faecal pollution is a primary health concern in the environment, in water and in food. The development of new indicators of faecal contamination/risk/treatment, etc., is also a topic that is being discussed in our group. The use of viruses that cause asymptomatic infections in humans as indicators of faecal contamination is coming up, as is the concept of Microbial Source Tracking; this term is being used to determine the source of contamination, and is being fine-tuned by many of our members. The most significant viral indicators proposed are human viruses, bacteriophages and plant viruses. Human DNA viruses – adenoviruses and polyomaviruses – associated with persistent infections are used as the most specific viral human indicator parameters currently quantified by molecular methods.

Contamination Sources and Microbial Source Tracking

Detailed knowledge about the contamination sources is needed for efficient and cost-effective management strategies to minimise faecal contamination in watersheds and foods, evaluation of the effectiveness of best management practices, and system and risk assessment as part of the water and food safety plans recommended by the World Health Organization (US EPA 2005; WHO 2004). There are increasingly large numbers of methods to identify the possible sources of faecal pollution, among these, a great number are based on published Bacteroidales assays (Boehm *et al.* 2013) and others involve bacteriophages and viruses (Bofill-Mas *et al.* 2013). Human adenoviruses (HAdV) and polyomaviruses are the most commonly used human viral faecal indicators and human Microbial Source Tracking (MST) markers, as they are excreted by a high percentage of the human population and are highly prevalent all over the world in different environmental water matrices (Rusiñol *et al.* 2014; McQuaig *et al.* 2012). There are also non-human viral faecal indicators that can be used to trace bovine-, ovine-, porcine-, and avian-specific faecal pollution. Bovine (BPyV) and ovine polyomaviruses (OPyV) have a wide dissemination among livestock, although they do not produce clinically severe diseases. A recent review by Bofill-Mas and co-workers summarized human and nonhuman viral quantitative tools applied by the science community in different countries and diverse water matrices, and underlined the high host specificity and high sensitivities of these viral tools (Bofill-Mas *et al.* 2013). Environmental samples are characterized as complex matrixes and the different variables regarding microbial survival and host specificity have a significant impact on the efficacy of all MST approaches. Furthermore, the choice of MST methods and approaches is largely dependent on the objectives of the study, considering that the ultimate MST goal is the identification of faecal microbial contamination and its sources in the environment, water and food.

Antibiotic resistance in water

In May 2015, the World Health Assembly of the WHO approved the Global Action Plan on combatting Antimicrobial Resistance (AMR). Antimicrobial-resistant bacteria and their antimicrobial resistance genes are common in water and wastewater. Therefore, understanding and addressing the role of water, sanitation and hygiene (WASH) in combatting antimicrobial resistance is a critical element of the Global Action Plan. Antimicrobial-resistant bacteria and their antimicrobial resistance genes are common and widespread contaminants in water and faecal wastes. Current WHO guidelines for drinking-water, recreational water and safe use of wastewater contain no information on antibiotics and other antimicrobial agents, their metabolites, antimicrobial-resistant bacteria or their AMR genes. For risk assessment and risk management strategies to be developed and implemented there is need for a foundation of evidence to underpin recommended actions. Our group organized a workshop with WHO at our Lisbon conference to develop a research agenda for WASH aspects of AMR. Important research elements are to understand the fate and transfer of AMR genes in the water environment.

Conclusions and research or development agenda

A growing area of importance internationally is the concept of "One Water" where water as a whole is assessed and not the individual silos of water e.g. drinking water, wastewater, grey water etc. This concept is becoming increasingly important with climate change occurring impacting on water scarcity. From the international perspective, the transition to the Sustainable Development Goals (SDG) and the content of SDG6 reflect that the world is nearer a true One Water concept. Our group focusing on the health aspects adds a new dimension to this so that we have "One Water One Health". This concept is starting to be addressed at different symposia and is one we in HRWM will be focusing on in the future. We have the microbiological skill sets required to address this. By working with the IWA Clusters and Programmes and incorporating all skills we plan to develop the "One Water One Health" theme.

Future perspectives for technical and scientific developments are related to the production of more quantitative information on the pathogens in water, standardization, multiplex assays and very important also developing sensitive protocols for applying NGS techniques facilitating the automation of the processes. Also building interactive data base for mass sequencing studies available for non-specialized end-users is a remaining challenge.

There are always challenges to our efforts, and the greatest challenge has been our inability to have a task force that can be ready to act whenever there is a problem with public health. Although this is the job of governments and the international community, our group has the necessary expertise to work on an advisory level. We have not had a strong answer to this yet, but this is being discussed with members of the WHO, PAHO, USEPA, and other international and national agencies.

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Hydroinformatics[1]

Background

Water and environment issues, exacerbated by climate change and global population issues, have become a major challenge for human economies and their governments. They necessitate increasingly complex approaches at international level. The essential aim of environmental management is to avoid, if possible, or at least to minimise, the risks of crises in water supply and wastewater treatment for populations, in water scarcity for irrigation, in the management of the consequences of floods, and so forth. The traditional vision of a 'water domain' founded on a separation of problems and cycles (small/large) on the one hand and 'professions' (drinking water, sewage and evacuation, hydrology, fluvial, maritime, groundwater) on the other, seems to gradually fade away, opening up possibilities for unifying/integrating various approaches and visions.

Over recent decades, society has become much more aware of the threatened sustainability of 'the second economy', which we commonly call the 'natural environment'. Most built infrastructures are considered as interferences in the environment and their impacts must be correspondingly minimised and, if possible, made controllable. This trend has been supported in recent times by the long-term discussions on climate change. The water world, especially, has become much more sensitive to and aware of these issues. There is a new awareness of the notion of 'environmental footprints' in society.

Awareness and sensitivity in society, which is becoming more open, transparent and communicative, have been increased by modern developments in information and communication technologies (ICT). The Internet is accessible nearly everywhere at any time providing web-services for communication, information and sharing of documents, pictures, music and videos. Because of ease of access to a variety of information and views, citizens in a post-modern society (commonly associated with what the European Union Lisbon agenda likes to call an 'information society') have become more curious and active, and even proactive about upcoming changes and the consequences of these for their futures, and even for their lives. Politically-oriented developments within society that are, ostensibly at least, directed towards more educated and more engaged citizens, have led to more individuals and public interest groups wanting to understand what is happening within their environments: what is being planned on a local or global political level and why this should be good and beneficial to them. Groups want to be heard and to participate in the decision-making processes: they want to be involved in matters about which they care and communicate. However, it is essential that they clearly understand, which are the *objective constraints* related to physical laws or political/economic reasons and whether whatever is done or desired *is subject* to these constraints. The technical means for communication and information necessary to meet these ends are at hand. ICTs have dramatically changed whole economies and societies, system components are becoming smaller and increasingly network-orientated and mobile and the flexibility of software is opening new dimensions. 'Information-sharing' and 'cooperation' between citizens and stakeholders, consultants, authorities and lawmakers have become a central and feasible issue of the day.

Professional engineering and businesses are unthinkable today without the evolution of the Internet and mobile devices, which represent the dominant infrastructure of ICT. Networking-embedded systems and networking services are offering new perspectives in nearly all fields from engineering to households; they are pushing developments in all areas, representing an enormous business market, which will also reflect mentally on developments in society.

In view of these changes in society and technology, all of what is called 'water sector' activities (including all activities and aspects of use, management, legislation and directives, protection and political decisions concerning water) is being completely transformed and modified. These transformations are founded on three pillars:

(i) Dealing with water problems on different scales of structures and integration in the face of foreseen scarcity, generalised pollution, climate change and the growth of mega-cities.
(ii) Change in the composition of decision making bodies: instead of technical experts only, a whole new entity composed of stakeholders including the general population, elected bodies, NGOs, the media, is now evolving.
(iii) Penetration of all activities, structures, behaviour and reflexes of the whole water industry and indeed of all concerned groups and individuals by ICT, the Internet and mobile communication networks.

It is in this context that the *definition of hydroinformatics* as the collection (including data surveys, etc.), creation (including modelling), interpretation (including integration of various domains inputs), communication (including projection of the results and impacts towards large public) and management (including aiding decision makers) of information concerning water sector activities should be used. Indeed, to become an accepted player in these fields, hydroinformatics has to change its mentality and views; it has to implement techniques and methods from ICT and information science to collaborate intensively with other disciplines, and not only at a technical level. Only in this way can relevant aspects of socio-economics, law and regulations, culture and traditions, workflow, psychology, information policies and media be integrated into 'system' approaches. Such systems will change the working lives of engineers, their educational objectives, create job opportunities and influence societies; they will support decision making in collaboration with the public, showing

[1] Developed largely on the basis of the chapter 'Hydroinformatics Vision 2011' in 'Advances in Hydroinformatics': Editors: Philippe Gourbesville, Jean Cunge, Guy Caignaert; ISBN: 978-981-4451-41-3 (Print) 978-981-4451-42-0 (Online)

the benefits and risks to involved citizens and stakeholders and help generate consensus.

Hydroinformatics takes and will take advantage of the general progress of ICT (hard and soft), as all human activities do. Clearly, the increase of CPU power (massive parallel computing, cloud computing, etc.) extends the possibilities of our numerical models, and of three-dimensional displays; clearly Web 2.x opens access to our information to millions of new users; and the new products in the fields of micro-sensors, alternative power supply, wireless telecommunications, revolutionise the whole domain of real-time monitoring, big data and, consequently real-time management. But the evolution of hydroinformatics is finally driven, not by these techno-progresses, but by the growing awareness that, even if modelling is historically the centre of hydroinformatics, it should be connected and interwoven with all the various aspects of businesses in the areas of water-environment. Viewed like that, hydroinformatics is the template for a business process approach of all projects as well as implementation of management systems within water sector.[2]

Hydroinformatics today looks at the creative solutions to the challenges coming about with the move of society towards open information, to the globalisation of business-markets and to networking in the internet. The potential and options of modern ICT will be implemented everywhere within the water sector. The IAHR/IWA hydroinformatics community, involving academics, researchers and practitioners, participates proactively in finding these creative solutions by offering and using its past experience, to develop a new approach to water sector activities, collaborating in the implementation, application, communication, and information management matters, jointly with all stakeholders.

Hydroinformatics in the context of its main areas of interest and activities

Informatics and information in the water sector

'Hydroinformatics' includes all information technologies, methods, models, processes and systems applied in the 'water-sector' and water-issues-related neighbouring fields. Information is understood in an abstract sense; it may be about physics, environment, economy, social issues, organisation, law, regulations and more. Models and processes concern physics, business, workflow, communication, management and more again. Thus, hydroinformatics applies, generates, models, manages, transforms, condenses and archives information concerning the 'water-sector'.

Traditionally hydroinformatics has been focused on the numerical simulation of physical processes in so-called 'models'. This limitation is too narrow. The term model has to be widened to any kind of *information to be modelled* in the water sector. As information combines data, methods, syntax and semantics; any simulation model is just a piece of information in the same manner as an engineering report, a digital elevation model (DEM), a water level monitoring application, an operational plan of a treatment plant or a workflow map.

Activities in the water sector are oriented towards building, managing and operating water-related infrastructure and utilities as well as towards observation/understanding/management of hydro environment for providing water, for improving its quality, for managing its quantity and for protecting against damages in view of sustainability and climate change. The activities are embedded in the objectives of a sustainable socio-economic development of society and communication processes between citizens, stakeholders, companies and politicians.

We are at a time when the influence of modelling is growing rapidly. Models of complex physical and human behaviour are coming into routine use. Ordinary, everyday devices contain inbuilt processors running embedded models. We barely notice the insidious spread of models into our lives. The hydroinformatics community should be leading the way by embracing and promoting the many and varied uses of models in water and environmental management and engineering.

Besides techniques and methods directed towards the description and functioning of systems, models remain the core technological elements of hydroinformatics, but they have to be understood, in a wider sense than has traditionally been the case. Traditionally they have described the physics of flow and transport and its interaction with other aspects such as the growth and decay of species, habitats and populations, and then in terms of quality and quantity. These models interact with further models about socio-economic developments of regions, generating a nonlinearly interacting system of models of whatever is supposed to constitute 'the real world'.

Projects, infrastructure and the business of organisational units have to be managed and coordinated. Strategies for workflow and for running processes of technical, business, financial and communication systems have to be designed for in-house, public, and political environments. The transformation and interfacing of information from various fields have to be modelled by descriptions and methods, which support their implementation in digital form. To create tools and methods allowing all water sector stakeholders to conceive and interweave (if not normalise) integrated and coherent Information Systems is no doubt the future.

Models of physical and organisational processes might be seen just as generators of information providing raw data from diverse application fields. In 'hydroinformatics', this information has to be cultivated for the pragmatic reason for which it has been produced. It has to be processed and adapted to the needs and objectives of the water sector. It is important to remember the diverse nature of interacting simulation models in physics, environments, societies, economies and organisations.

Models, however, are not the only aspects to consider: information, be it raw from observation or from simulation, has to be transformed in such a way as to be communicated in a transparent manner to professionals, politicians and citizens for decision making and consensual understanding. Moreover, 'models' are not necessarily in the form of software; they may also be intellectual concepts, which, if

[2] A **business process** or **business method** is a collection of related, structured activities or tasks that produce a specific service or product (serve a particular goal) for a particular customer or customers. Business Processes can be modeled through a large number of methods and techniques.

they concern the water sector and if they ask for informatics to be forwarded, must be put into action or disseminated within the hydroinformatics field.

The scope of activity or movement in hydroinformatics, embraces the full range of what is commonly called *business models*[3] from public open-source developments through to private commercial developments, without bias towards any particular business model.

Some examples of the subjects that hydroinformatics already relates to and interacts with, and is likely to develop tremendously are the following:

(1) Major role played by GIS as system structuring all information, as pivotal point of integrated information systems. Note that GIS as a specific tool fades away, becomes a part of other bases, like ORACLE Spatial.
(2) Real-time problems: sensors, SCADA, real-time databases, related telecommunication systems.
(3) Tools of operational management (work management systems), of the maintenance and of asset management.

Whenever water related problems, or, more widely, environmental questions are concerned, there is *continuity* in the background of all of the activities that follow. Typically in most situations there is an initial 'problem' stemming from engineering needs, from political or investment projects, etc. Then one tries to find 'solutions' that are nothing else but elements leading to or aiding the decisions. This logical chain from 'generating fact' to the solution-decision goes across a number of 'businesses' or 'stakeholders' and must be repeatable at any time. Therefore, it is obviously highly desirable to maintain strong consistency in concepts, data, and information along this chain. This is not necessarily the case but it is a major point for hydroinformatics because it is its 'natural role' to ensure such consistency, mainly by conservation of uniqueness of data and information. When one considers the chain beginning with projects conceived by, say, administrators or politicians and continuing through design, impact studies, decision to implement, construction and operation there is a need for guidelines ensuring the consistency. Hydroinformatics can supply means and ways to elaborate such guidelines for various types of activities related to the water sector.

Research and Science

The sustainable development of the water sector comes down, in implementation and practice, to engineering tasks and thus 'hydroinformatics' must be seen as an engineering discipline. In this sense, 'hydroinformatics' has its own research objectives, which aim at the foundation and promotion of the water sector in all its aspects.

In short, research in the hydroinformatics field might be summarised, albeit very unconventionally, in the terms: 'information and its model building'. This may be understood in the sense of structuring information about physical and organisational processes. New techniques have to be developed, new methods designed, the range of validity and performance investigated and models interfaced by a standardisation of procedures and data. Innovative concepts about geometrical representation and information-defined objects using by modern ICT must be investigated, with virtual communication and collaboration processes considered with *emphasis on non-engineering clients*, such as partners, as well as processes for education and promoting understanding in decision-making. Integrated processes reflected in hydroinformatics tools, which are sufficiently interconnected, may open new requests and needs for further applied research, basically in the bottle necks of existing technologies (such as new features in graphical tools, much faster computational engines, wireless nets and mobility, etc.).

Education and lifelong learning

Hydroinformatics aims to provide training for people who are 'information managers and advisors' in the necessary skills for their work. These people are not 'managing' people or organisations: they managing information within complex areas of the water sector and to that end they must be knowledgeable in this specialist subject. They must be knowledgeable enough to understand the constraints, difficulties, limitations and possibilities of these domains in order to be able to coordinate the information coming from each such domain and to organise feedbacks and interactions that will be beneficial to the further development of both.

These people must have a sufficient knowledge about water and environmental processes to run and validate the corresponding models. They must understand the processes that are mapped in the related models; they must be able to condense and interface information; they must be able to organise workflow and information processes; they must be able to manage documentation and presentation; they must be able to make information transparent to advise decision makers and communicate with the public.

Social skills in collaborating with people of different professional and cultural backgrounds are needed. To optimise this whole, they must be able to make information and findings flow in interactive ways from one domain to another so that the knowledge, the progress, the innovations and the applications in a domain can be improved thanks to information coming from other domains.

This profile demands knowledge about the physics of water in hydraulics, hydrology and the environment, about mathematics and computational methods, about information modelling and communication as well as about the supportive means of ICT. Complementary to these are methods of geometrical modelling, presentation, documentation and a spectrum of selected topics from computing and social science, economics and psychology, the latter supporting the skills necessary for a multicultural interdisciplinary collaboration in an international, sometimes virtual, environment. Those concerned should have a basic grounding in civil engineering because of its central role in project implementation but also in water/environmental legislation and in geography and cartography. The educational training

[3] A business model describes the rationale of how an organisation creates, delivers, and captures *value*—economic, social, or other forms of value. The process of business model design is part of business strategy. In theory and practice the term 'business model' is used for a broad range of informal and formal descriptions to represent core aspects of a business, including purpose, offerings, strategies, infrastructure, organisational structures, trading practices, and operational processes and policies. Hence, it gives a complete picture of an organisation from high-level perspective.

should be 'hands on' with models of all kinds. The process of taking responsibilities should be inculcated through training by internships in companies. The outcome of such curricula should be an engineer who can support consensual views and actions of decision makers and users, on the one hand, and executive professionals and engineers, on the other hand, with respect to science, engineering and social environments. The engineer should be able to maintain this qualification throughout his career through ongoing training periods.

This will lead to an intense demand for engineers, managers and, above all, leaders in public services and in the private sector educated in hydroinformatics to address a rapidly changing society.

Universities, research and professions

Universities are changing in modern times with the transition towards an 'information society', under the 'Bologna Declaration'[4] and as mass education institutions. They are reacting to their new role by introducing new profiles and grades of professionalism. In Europe the 'Bachelor degree' is seen as a first professional degree qualification while the 'Master' has become the second degree that may or may not be sought by the future professionals, whether working in practice or research-oriented. The 'Doctoral thesis' is a degree awarded at the end of a system of taught courses and a research project that in many cases is trivial or formal; in most cases, it has nothing in common with the requirements of new contribution to the field as used to be the case up until the middle of the second part of the 20th century. This requires universities to react correspondingly in terms of numbers and qualifications, and it requires a clear profile and definition of 'hydroinformatics education'. At present, the profile is rather vague and differs from place to place. Therefore, owing to the international character of hydroinformatics and to guarantee the integrity of the profession as much as possible, some professional benchmarks are needed. Universities in the short term (10–15 years) should 'standardise' their ideas about the nature of an objective and professional 'hydroinformatics' profile. Without this, the profession cannot interact or provide feedback to the university and the university cannot satisfy the needs of the profession. Today most people think that 'hydroinformatics = modelling and/or GIS and/or programming', and that is clearly not sufficient.

Standards cannot be imposed formally: they have to be developed by academia in collaboration with the profession and those in practice. If there is a known curriculum framework and if the water sector professions recognise in practice the minimum content of this curriculum, such as is necessary to be called a 'hydroinformatics diploma', then the profile of the 'hydroinformatician' will need to be clearly defined and founded. Note that, following the Bologna agreement, the fundamental rethinking about a doctoral degree opens the way to better specification of hydroinformatics curricula in the sense that it gives 3 years more for specialised studies replacing original research required for a doctoral degree.

Currently the link between the research and practice is weak and the time necessary to transfer the R&D results towards practice is shockingly long if one compares it to the ICT sector. To improve the situation it is necessary to open the existing hydroinformatics community to, or more importantly create a larger hydroinformatics community inclusive of, ICT professionals, engineering consultants who do the bulk of water-related engineering as well as to water systems management companies and institutions (specifically urban water utilities).

Hydroinformatics: quo vadis? What can we do?

In our present initiative, we are concerned about two things in particular. The first is objective: whatever we may wish for, whatever we may do, what is going to happen within the next 10–15 years; the other is subjective: what we would like, what we can do, what we shall try to do during this period.

What is going to happen?

It seems clear today that the entire water sector will be dominated by ICT and Internet-like technologies. This may lead in the more or less distant future to the unification and possibly the standardisation of the management of information within areas of water industry. Things will converge towards the concept of 'smart water networking' including, of course, projects and the implementation of work in coastal areas and river basins, for food and agriculture, for industrial use, energy production and biogas, for drinking and wastewater processing. Nevertheless, it is very likely that the driving force in this will be urban water management the management of utilities. This is because the population's needs today are greatest in this area, because most of the human population will be grouped in the mega-cities. Now technology in this area lags far behind the sophistication of ICT tools used in other branches of the water sector (e.g. numerical modelling) and, hence, the gradient of implemented innovative applications will be the steepest. It is apparent that all other sectors will join in the run and the driving forces will come from the ICT industry, not from hydraulic research, because the former produces industrially applicable**,** often off-the-shelf systems and devices that may modify the systemic approach while the latter can only produce embeddable tools like fourth-generation modelling software. Because of the importance of water, these developments will very quickly penetrate the realm of decision-making, i.e. politics, financing of investments, social sciences, information and communication with citizens, etc. On the other side of the spectrum they will most likely completely modify the current (traditional) way of working through consultancy and the relationship between the applications/industry (including consultancy and contractors) and university research in the field of hydraulics, hydrology and water management:

- It is *very* likely that today's market for modelling software will decline and possibly fade away. It may well be replaced by 'modelling software and expertise as a service'. All recent developments of 'software as a service', 'infrastructure as a service', 'development as a service' that so far have been limited to the area of computer and informatics applications will no doubt flow over into the water sector

[4] In full, joint declaration of the European Ministers of Education convened in Bologna on 19 June 1999, http://www.cepes.ro/services/inf_sources/on_line/bologna.pdf

within the next couple of years. Already most of applications we use on our laptops are stored somewhere in the cyberspace, and 'cloud computing' will help it.

- This will lead to pressure from 'modelling software and expertise' business on the water-oriented research to go beyond today's limitations in mathematical theory, computational hydraulics and computational fluid dynamics. The same will happen in physics, for example sedimentation theories. This will also lead to pressures on university education and curricula. Indeed, such enormous, revolutionary changes will ask for different *technical leadership* within the structures of water sector industry, i.e. for different generations of engineers. Given a minimal 5 year cycle of engineering education, and given the delay necessary for education institutions to adapt themselves (at least another 5–10 years), there will be an enormous push, coming from the needs of industry, towards university degree and postgraduate specialisation in specific courses and institutions.
- Networking-embedded systems and networking services are offering new perspectives in nearly all fields of technological infrastructure from the engineering industry to households; they are pushing developments in all areas representing an enormous business market. This also holds for the field of Hydroinformatics. Integrated intelligent electronic nets of all components and services must be designed and operated for the generation, management, distribution and billing of fresh and waste water in cities, on the level of water-basins, for the management of floods and droughts beyond regional levels. In addition, the interlinking of water systems with other areas such as power generation, cooling and intermediate storage of energy under ever changing conditions has to be considered. Only using such technologies can meet the challenges set by global warming and climate change possibly in the future.

As an example of what would happen whatever we do, consider one of currently predominant business models: the sale or granting of in-perpetuity (generally 20–25 year) licences to use software packages. We can clearly see the demand for pay-by-use software and technology advances now support this business model in a reasonable way. Nevertheless, we are already on the way towards software as a service becoming a regular business model for hydroinformatics.

What would we like or what can we do?

Hydroinformatics can try to accompany the movement, to accelerate it as much as possible, to make some parts of it more coherent, and lead our colleagues and partners towards integrating these changes. Incidentally, this means, of course, stretching our networks beyond IWA and IAHR, trying, however, to keep intellectual leadership in order not to lose the experience and knowledge gained during past 30 years of existence of our 'IWA–IAHR hydroinformatics community'.

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Institutional Governance and Regulation

Water Resources Management and Climate Change

Written by Slava Dineva and Jennifer McKay on behalf of the Specialist Group

Introduction

Climate change is a substantial challenge of our generation, and work related to this important issue affects every person on Earth.

This global-scale study provides a big picture overview of issues about climate change and water resources management, discusses new research and insights, addresses particular concern and implications, promotes advances on institutional governance and regulation that play a major role in identification of corresponding solutions across the water sector.

Many water managers now recognise that climate change is a significant issue that must be incorporated in integrated water resources planning and decision-making.

Terminology

Water governance is about the way the management of water resources is guided and organised. Alongside encouraging the application of appropriate technical solutions, it comprises the organisational, legal, financial and political aspects that guide and organise the interactions among, and collective actions taken by, all actors involved in the management of water resources. The concept of 'governance' is widely used both in practice and in policy science literature, with a great variety of meanings.

Climate is the weather pattern we expect over the period of a month, a season, a decade, or a century. More technically, climate is defined as the weather conditions resulting from the mean, or average, state of the atmosphere–ocean–land system, or average weather conditions.

From a human perspective, climate change is the departure from the expected average weather (temperature and precipitation) for a given place and time of year. In contrast with extreme events, climate change is the long-term shift in the expected or average weather. Climate change reflects significant shifts in the mean state of the atmosphere–ocean–land system that results in shifts in the atmosphere and ocean circulation patterns, which in turn impacts regional weather.

Climate change: present state

Many climate-related changes are already being observed globally, including changes in: air and water temperatures; sea level; freshwater supply; frequency and/or severity of intense hurricanes and heavy downpours, loss of sea ice; etc. These changes are likely to increase and threaten to profoundly impact the physical and biological environment, economic prosperity, and human health. Climate change influences events across timescales from months to a season (e.g. floods and droughts), year-to-year variability, and longer-term changes over centuries (e.g. sea level rise, elevated global temperatures and attendant changes in precipitation). While we must learn to adapt across all of these timescales, this is especially challenging because we are adapting to a 'moving target' (Karl, 2009).

The rate of temperature increase is a key element related to the severity of climate change impacts. NASA (National Aeronautics and Space Administration) and NOAA (National Oceanic and Atmospheric Administration, US Department of Commerce) analyses reveal record-shattering global warm temperatures in 2015. It was the warmest year since modern record-keeping began in 1880, according to a new analysis (Figure 1; Brown *et al.*, 2016). The record-breaking year continues a long-term warming trend: 15 of the 16 warmest years on record have now occurred since 2001. Globally-averaged temperatures in 2015 shattered the previous mark set in 2014 by 0.23 °F (0.13 °C). Only once before, in 1998, has the new record been greater than the old record by this much. The planet's average surface temperature has risen about 1.8 °F (1.0 °C) since the late-19th century, a change largely driven by increased carbon dioxide and other human-made emissions into the atmosphere. Most of the warming occurred in the past 35 years, with 15 of the 16 warmest years on record occurring

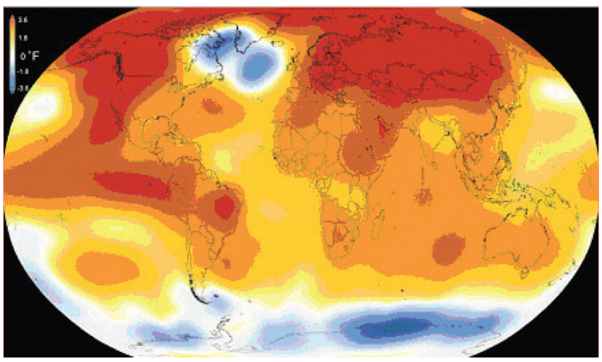

Figure 1. Earth's warming, 2015. Orange colours represent temperatures that are warmer than the 1951–1980 baseline average, and blues represent temperatures cooler than the baseline. Source: NASA Goddard Space Flight Center's Scientific Visualization Studio (Brown *et al.*, 2016).

since 2001. Last year was the first time the global average temperatures were 1 °C or more above the 1880–1899 average.

Anomalies more accurately describe climate variability over larger areas than absolute temperatures do, and they give a frame of reference that allows more meaningful comparisons between locations and more accurate calculations of temperature trends.

The 2015 temperatures continue a long-term warming trend (Figure 2).

Scientific understanding of global warming is increasing. Scientists are more than 95% certain that global warming is mostly being caused by increasing concentrations of greenhouse gases (GHGs) and other human (anthropogenic) activities (America's Climate Choices, 2010; IPCC, 2014). During the 21st century the global surface temperature is likely to rise a further 0.3–1.7 °C (0.5–3.1 °F) for lowest emissions scenarios using stringent mitigation and 2.6–4.8 °C (4.7–8.6 °F) for highest.

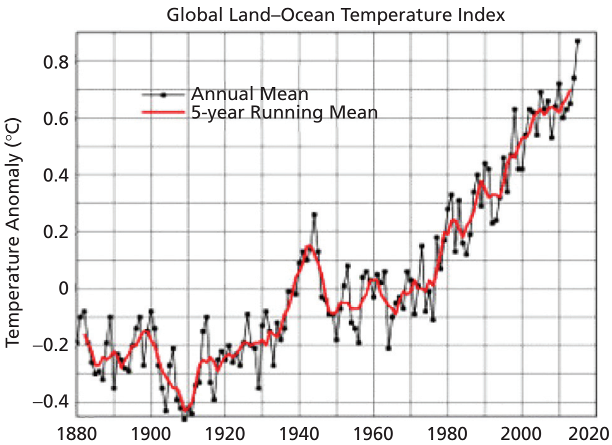

Figure 2. Global mean surface temperature change from 1880 to 2015, relative to the 1951–1980 mean. The black line is the annual mean and the red line is the 5-year running mean. Source: NASA GISS (2016).

Future climate change and associated impacts will differ from region to region around the globe. Anticipated effects include warming global temperature, rising sea levels, changing precipitation, and expansion of deserts in the subtropics. Warming is expected to be greater over land than over the oceans and greatest in the Arctic, with the continuing retreat of glaciers, permafrost and sea ice. Other likely changes include more frequent extreme weather events including heat waves, droughts, heavy rainfall with floods and heavy snowfall; ocean acidification; and species extinctions due to shifting temperature regimes. Effects significant to humans include the threat to food security from decreasing crop yields and the abandonment of populated areas due to rising sea levels. Land ecosystems are also changing in response to a warmer world.

Carbon dioxide is the largest human-produced driver of our changing climate. Figure 3 shows global average carbon dioxide concentrations. Carbon dioxide emitted into the atmosphere by human activities influences the amount of the Sun's energy trapped by Earth's atmosphere (Cole, 2015). Atmospheric carbon dioxide levels recently surpassed a concentration of 400 parts per million (ppm)—higher than at any time in at least 400,000 years. Levels of the heat-trapping gas methane now exceed pre-industrial amounts by about 2.5 times. Human-made carbon dioxide continues to increase above levels not seen in hundreds of thousands of years (Buis et al., 2015): currently, about half of the carbon dioxide released from the burning of fossil fuels is not absorbed by vegetation and the oceans and remains in the atmosphere.

Sea level rise is a natural consequence of the warming of our planet. When water heats up, it expands. So when the ocean warms, sea level rises. And when ice on land melts and water runs into the ocean, sea level rises. For thousands of years, sea level has remained relatively stable and human communities have settled along the planet's coastlines. But now Earth's seas are rising. Globally, sea level has risen about eight inches since the beginning of the 20th century and more than two inches in the past 20 years alone. All signs suggest that this rise is accelerating.

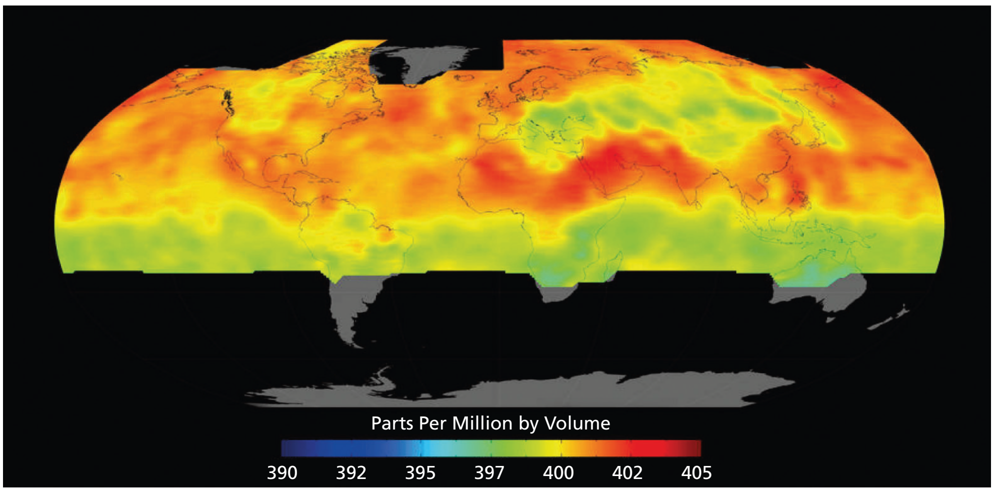

Figure 3. Global average carbon dioxide concentrations as seen by NASA's Orbiting Carbon Observatory-2 mission, 1–15 June 2015. OCO-2 measures carbon dioxide from the top of Earth's atmosphere to its surface. Higher carbon dioxide concentrations are in red, with lower concentrations in yellows and greens. Source: NASA/JPL-Caltech (Buis, 2015).

Governance: present state

The newest effort by the global community to stem the anthropogenic effect on the world's weather regime is the Paris Agreement (2015). The Paris Agreement falls within the framework of the United Nations Framework Convention on Climate Change (UNFCCC) governing GHG emission measures from 2020. The agreement was negotiated during the 21st Conference of the Parties of the UNFCCC in Paris and adopted by consensus on 12 December 2015, but has not entered into force (opened for signature for one year on 22 April 2016). This ambitious and balanced plan was a historic turning point in the goal of reducing global warming.

Countries' past and future contributions to the accumulation of GHGs in the atmosphere are different, and countries also face varying challenges and circumstances and have different capacities to address mitigation and adaptation. Mitigation and adaptation raise issues of equity, justice and fairness. Many of those most vulnerable to climate change have contributed and contribute little to GHG emissions (IPCC, 2014). Comprehensive strategies in response to climate change that are consistent with sustainable development take into account the co-benefits, adverse side effects and risks that may arise from both adaptation and mitigation options. The design of climate policy is influenced by how organisations perceive risks and uncertainties and take them into account.

Water resources management: present state

Climatic factors such as temperature, rainfall, snowfall and so on have a significant impact on water resources management. The current resolution of many climate models, which provide information about continental scale changes in extremes of temperature, drought, rainfall, and changes in sea level and arctic ice extent, is already adequate to address important policy issues. For others, particularly those at regional scales relevant to their constituents, policymakers have to request regional climate models with resolutions of 50 km and finer to be most useful for informing additional water policy decisions.

Energy usage is closely linked to seasonal temperatures so that demand for sources of energy such as natural gas, oil and electricity increases during abnormally hot summers and extremely cold winters.

Countries experience water stress and water-related disasters that will grow worse due to climate change without better policy decisions.

Certain activities could contribute and strengthen ability to withstand challenges such as economic hardships, population growth, development, and significant droughts through appropriate programmes, policies, and investments that strengthening adaptive capacity.

Land ownership is found to be a principal characteristic that helps the community cope with challenges and adapt to change (Perveen, 2012). Public awareness concerning the importance of knowledge increases. Maintenance and strengthening of the institutions and internal mechanisms is most valuable. This essentially highlights the crucial role that local organisations supporting the communities must provide to be effective. Two stressors perceived with greatest vulnerability to communities are droughts and economic downturn.

Effective decision-making to limit climate change and its effect on the water resources can be informed by a wide range of analytical approaches for evaluating expected risks and benefits, recognising the importance of governance, equity, value judgments, economic assessments and diverse perceptions and responses to risk and uncertainty.

As competition between water users and water use sectors increases, the potential for conflicts between stakeholders over a variety of water quantity and quality issues will increase. This is especially true as governing institutions and hence priorities at the international scale are different from the intra-national scales. About water-related conflicts globally, for example, cooperation is more prevalent than conflict in international river basins (Wolf *et al.*, 2003). The Trans-boundary Freshwater Dispute Database (TFDD) addresses the water resource management issues and concerns at the international level and investigates hydro-political interactions at several scales.

At all scales, cooperative events outnumber conflictive events (Perveen, 2012). This goes against the conventional belief that conflict is the norm when it comes to freshwater interactions. At all scales of analysis a large proportion of events are low intensity, and mainly verbal interactions. However, a higher proportion of verbal actions are conflictive intranationally and cooperative at the international scale. Water quality events are more frequent at the intranational scale than the international scale (Perveen, 2012).

Swyngedouw (2004) suggests that there is an urgent need to consider democratic modes of water governance on a variety of inter-related geographical scales. This is particularly acute in regions with strongly competing water demands (e.g. urban versus rural demand regarding scarce water).

Water scarcity is one of the most pressing global issues today. Water scarcity affects more than 40% of the global population and is projected to rise (World Bank, 2016). Over 1.7 billion people are currently living in river basins where water use exceeds recharge. Floods and other water-related disasters account for 70% of all deaths related to natural disasters. All of this is happening in a context where the crucial agenda of access to services is still an unfinished agenda. Despite impressive gains over the past several decades, today 2.4 billion people lack access to basic sanitation services. About 700 million people lack access to safe drinking water. More than 80% of wastewater resulting from human activities is discharged into rivers or sea without any pollution removal. Accelerated actions are needed in many countries so that water to be more accessible and safe to all, and to achieve government objectives to meet water treatment and discharge standards for industries and municipalities.

Water management is weakest in the poorest countries. It is predicted they face the greatest negative impacts of climate change in the future (Dineva and McKay, 2012). Therefore, investment in national water resources, management capacity, institutions and infrastructure should be a priority.

There is now an recognition that bottom-up and inclusive decision-making is key to effective water policies. A number of legal frameworks have triggered major evolutions in water policy; however, their implementation has faced difficulties, for example the European Union (EU) Water Framework Directive and the UN Millennium Development Goals (MDGs). The application of the concept of Integrated Water Resources Management (IWRM) has brought uneven results within and across countries, and requires frameworks that consider the short-, medium- and long-term in a consistent and sustainable way. The Sustainable Development Goals (SDGs) will form the global agenda for ensuring the safe, reliable, equitable and efficient supply and service delivery of water and sanitation, and will challenge water sector to innovate and evolve.

Addressing climate change across water sector raises such complex issues as policy development, regulatory compliance, and implementation strategies. There is an acute need for widespread and specialised knowledge to address such issues, and for tools and opportunities to enable the involvement of wide range of international participants: policymakers, development practitioners, corporate sector, researchers, graduates, and mid-level professionals.

Climate change will make water quantity more unpredictable. In a warmer world, water stress will increase. The roughly 1 billion people living in monsoonal basins and the 500 million people living in deltas are especially vulnerable. Poorer countries, which contributed least to the problem, will be most affected.

Climate change is a major driver for increasing pressure on water resources, which will possibly aggravate the effects of other water stressors and alter the reliability of current water management systems and infrastructure. As a result, many areas that today suffer from aridity will probably experience increasing water scarcity (Bates *et al.*, 2008), like the Mediterranean, Central and Southern Africa, Europe and Central and Southern America. Some areas of Southern and Central Asia will probably experience an increase in the overall runoff, although this will generally occur during the wet season and thus may provoke flood episodes (Huntington, 2006) without providing water during dry seasons.

For adaptation, institutions have to design its activities through the following options:

- Economic options: financial incentives; insurance; payments for ecosystem services; pricing water to encourage universal provision and careful use; disaster contingency funds; public-private partnerships.
- Laws and regulations: land zoning laws; building standards and practices; water regulations and agreements; laws to support disaster risk reduction; laws to encourage insurance purchasing; defined property rights and land tenure security; protected areas; patent pools and technology transfer.
- National and government policies and programmes that support research and development, innovations: national and regional adaptation plans including mainstreaming; sub-national and local adaptation plans; economic diversification; urban upgrading programmes; municipal water management programmes; disaster planning and preparedness; integrated water resource management; integrated coastal zone management; ecosystem-based management; community-based adaptation.
- Strengthened water resources management: by underpinning evidence-based knowledge for planning and decision-making to maximise development opportunities and minimise climate risks.
- Strengthened water resources development: by supporting investments that improve resilience to climate variability and change, enhance food and energy security, and enable countries to follow a lower carbon growth path.

General trends and challenges

Climate change is the major, overriding issue of our time, causing crises in economy, health and safety, food production, security, and other dimensions, and its impact is only expected to grow.

Preparing for climate change: adaptation programmes and policies

This is especially challenging because we are adapting to a 'moving target'. Climate will continually change, moving at a relatively rapid rate, outside the range to which society has adapted in the past. Because of this uncertainty, adaptation plans will need to be robust, flexible, and able to evolve over time.

There are two courses to respond to climate-related impacts (Karl, 2009): (1) mitigation, meaning options for reducing heat-trapping emissions such as carbon dioxide, methane, nitrous oxide, and halocarbons; and (2) adaptation, meaning changes made to better respond to present or future climatic and other environmental conditions, thereby reducing harm or taking advantage of opportunity. Most mitigation strategies concentrate on reducing GHG emissions through energy efficiency and the adoption and development of zero- or low-carbon technologies. Both mitigation and adaptation are essential for a comprehensive climate change response strategy. Supporting proactive climate adaptation plans and programmes will enhance the resilience of the natural resources in the face of changing climate conditions. Adaptation plans will probably span time scales from months to years to decades, and spatial scales from local to state, to regional, and to national. Adaptation plans will need to be periodically evaluated and adjusted in the light of new scientific findings and changing conditions.

Creating a drought early warning system

Inter-agency effort is designed to serve as an early warning system for drought and drought-related risks, enabling response to periods of short-term and sustained drought. The role of governing institutions is to develop leadership and to implement an integrated drought monitoring and forecasting system at federal, state, and local levels as well as to communicate to local communities by providing accurate, timely, and integrated information to help mitigate drought-related impacts.

Developing water and climate adaptation plans for river basins

The water and climate adaptation plans that have to be developed for river basins as result of studies undertaken by researchers and experts are intended to help to bridge climate change predictions for river basins that will be affected by changing climate trends and the decision makers. The purpose is to assist stakeholders and decision makers in assessing and planning for the risks generated by climate change impacts on water resources; to provide a basis for future plans and studies of adaptation to climate change impacts in the river basins; and to stimulate cooperation and debate across the basins towards additional and more detailed studies on climate change impacts at regional and basin scales. River basins are projected to experience increases in water use by the public water supply, industry, energy, and agricultural and irrigation sectors. It is widely expected that new hydropower plants will be constructed in the near future, making energy (primarily through hydropower) the most important water use in river basins.

Improving climate information and services for the future

Climate change affect the function and operation of existing water infrastructure – including hydropower, structural flood defences, drainage, and irrigation systems – as well as water management practices. Programs related to services and information to improve management of climate sensitive sectors such as water resources through observations, analyses, decision support tools, and user interaction has to be developed. New information tools and planning processes are attempting to overcome the barriers at local, regional, and national levels in both developing and developed countries. Development of assessments and adaptation strategies from international to local levels, and collaboration with stakeholders on enhancing their capacity to use climate information and related decision-support resources should be promoted. Informed decision-making requires continued development of integrated data products and decision support tools in response to the needs of climate sensitive sectors. An effective response to changing climate conditions will require an integrated, flexible, and responsive government-wide approach.

Need for cooperative responses, including international cooperation, to effectively mitigate GHG emissions and address other climate change and water issues

Climate change has the characteristics of a collective action problem at the global scale, because most GHGs accumulate over time and mix globally, and emissions by any agent (e.g., individual, community, company, country) affect other agents (IPCC, 2014). Effective mitigation will not be achieved if individual agents advance their own interests independently. Cooperative responses, including international cooperation that incorporate specific policy decisions related to curbing the growth of atmospheric greenhouse gases, are therefore required to effectively mitigate GHG emissions and address other climate and water issues. The effectiveness of adaptation can be enhanced through complementary actions across levels, including international cooperation. Outcomes seen as equitable can lead to more effective cooperation.

Clean energy (e.g. solar) and energy efficiency may offer an opportunity to improve sustainable management of water resources.

Conclusions

This global-scale study not only emphasises how crucial the climate and water issue is, but it is also a key point that should make governing institutions and policy makers stand up and take notice: now is the time to act on climate and water issues.

Institutions and agencies should be at the forefront of scientific understanding in this area, bringing together advanced measurement technologies, cutting-edge research, monitoring vital signs, developing new ways to observe and study interconnected natural systems with long-term data records and tools to better see how the state is changing, as well as sharing this knowledge with the global community, working with other institutions around the world that contribute to protecting the water resources, and promoting it to be filtered to the local level. Research and management will require close collaboration with experts in related fields. Significant efforts are needed in ensuring collective action to scale up governance responses to climate-related water challenges. Managers of water institutions, policy planners and decision-makers across the water sector have to support programmes to plan for and adapt to climate change, sound water management regulatory frameworks, and mitigation and adaptation strategies that address complex climate-sensitive issues. Water governance is a call for change and for transdisciplinary leadership in the way we manage water both in developed and in developing countries.

Research and development agenda

Working on water and climate change issues across borders

This is a key topic to be worked on by the Specialist Group to strengthen water governance to fit current and future water challenges.

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Instrumentation, Control and Automation in the Global water industry

Written by *Oliver Grievson, Juan A. Baeza, Ken Thompson, Pernille Ingildsen, Gustaf Olsson and Eveline Volcke*, on behalf of the Instrumentation, Control and Automation Specialist Group

Introduction

Instrumentation, Control and Automation (ICA) has been a focus of the International Water Association (and its predecessor the International Association on Water Quality) since the 1970s. ICA provides the monitoring and control tools needed to meet the current demands in both potable water and wastewater industries to monitor and control unit processes, plant behaviour or large systems involving networks, plants and receiving waters.

ICA has been long established in electrical engineering and in the (chemical) process industry. It is more than Information Technology (IT) or Information and Communications Technology (ICT), but comprises all of the following aspects:

- To **understand process dynamics**, how it is influenced by disturbances and identifying potential control handles. This will govern the need for instrumentation, where to locate the sensors and what to manipulate.
- The development and follow-up of adequate **sensors and instrumentation** (including transmitters and actuators) for process monitoring and control.
- **Data handling, telemetry and communication**: the generation and recording of data from the measurement point to the end user, through communication systems and/or data collection.
- **Data and information management**. Data processing: screening, filtering, noise reduction etc. to obtain a sufficient data quality, that once analysed can be transformed into meaningful information, knowledge, and insight.
- **Process control and automation**: the use of information generated from data to automatically control unit processes, parts of the network or treatment works or the entire system as a whole. Controller design and tuning.
- The conversion of data into information for **decision-making**, for example to assist operators in the day to day operation of the water industry.
- **Edge Processing**: using advanced embedded industrial computer technology to process data at the facility, provide local control, and enable real time asset management and increase proactive maintenance.
- Dynamic system **modelling and simulation** in view of design and control.

When successful, ICA is a hidden technology that is increasingly ubiquitous to all of the industry's customers, whether industrial or domestic. Although the technology is mostly hidden, it provides a whole new level of water utilities floating on top of and interfacing the physical structures.

The ultimate aims of ICA are not only to keep the industry's assets running and to meet the product requirements, for example in terms of effluent quality, but also to do so in an efficient and effective way, balancing investment and operational costs, robustness, quality and care for the environment in an optimal operation using the right technology.

Over the past 40 years or more the International Water Association and its speciality in ICA has been a key driver for the knowledge of the industry to date. With the Internet of Things (IoT) technology and data explosion, the challenge is greater than ever before.

Existing Knowledge and Practices in the Global water industry

The experience within the Global water industry in terms of ICA is extensive and multifaceted. There are various levels of development in ICA between and within countries and the existing ICA knowledge and practices in the water industry are quite variable.

Existing knowledge and practices in wastewater

The primary concern in the **wastewater collection network**, namely the sewer system and associated pumping stations, has so far been on monitoring and controlling the flow of wastewater, through flow and level sensors and switches. Pumping stations are typically controlled based on the level in the wet well. While this type of instrumentation potentially holds a lot of information, data are mostly not collected centrally. More could be gained through a structured approach, coordinated actions and further data analysis using for example dynamic models. '**Smart Wastewater Networks**' have been developed ranging from monitoring of just flows solely for a monitoring basis to fully model based controlled networks. The most notable of these in recent times is the wastewater collection network in Cincinnati's Metropolitan Sewer District, although Smart Networks have been developed in cities such as Barcelona, Copenhagen, Paris and Lisbon among others.

The development of **Smart Wastewater networks** started from monitoring of reactive triggers creating warnings and simple operational changes, which is common in most pumping stations (think of a high wet well), to the really smart systems with a fast forecast model that is continually optimising the network. The tools available for implementing smart wastewater systems are rapidly expanding, including recent advancements in real time flow based pump sequencing to optimise energy use based on system flows.

Modelling and simulation can play an important role for process understanding, data analysis and in the development of operating strategies. They have, for instance, been applied to predict influent flow rates and demonstrated their usefulness in assessing and controlling greenhouse gas formation and emission.

ICA tools are better developed in **wastewater treatment plants (WWTPs)**, although the ICA level present is very much dependent upon the size and the complexity of the treatment works as well as local policy. Small treatment works may have simple flow measurement only with no control systems at all whereas complex works may have full supervisory control and data acquisition (SCADA)-based instrumentation and control systems with the occasional treatment works having some element of advanced process control.

Instrumentation ranges from simple flow monitoring using level-based or electromagnetic flow measurement, simple in-line monitoring of chemical parameters as pH or conductivity in the influent or final effluent for compliance purposes, to complex process parameters such as online analysers for nutrients as ammonium or phosphate in the reactors, and multiparametric equipment based on spectral fingerprints.

Automation devices such as automatic control valves and variable speed drives for pumps and blowers are common on larger plants and generally provide good controllability of treatment works for its optimisation.

Control systems are common place depending upon the size of the WWTPs and have become more accessible for operators. Standard feedback control loops on activated sludge plants include control of variables such as sludge age, dissolved oxygen, nitrate in anoxic reactors, ammonium in aerobic reactors or phosphate in the effluent, by manipulating different operational parameters. While single-loop controllers have become commercially available products for the control of individual unit processes, more advanced control systems based upon combination of different control loops or by multi-variable controllers have been developed and tested by simulation, although there is a lack of full-scale implementations. These advanced control systems could take information from different variables and manipulate other variables to control the process to the best possible state. These developments are evaluated and optimised using modelling and benchmarking principles to obtain the minimum cost of operation with the required performance. New advanced controllers using industrial computers are providing high-end local processing capabilities for the price of traditional programmable logic controller (PLCs) and remote telemetry units (RTUs), creating new applications for improving system efficiencies and reducing reactive maintenance.

Drinking water treatment

As for **drinking water treatment**, many of the implementations in the wastewater treatment industry were adopted in terms of control and automation of both small and larger treatment plants. Major differences involve the need for all plants independent of their size to have at least minimum control of process parameters (turbidity, pH, total organic carbon/dissolved organic carbon (TOC/DOC), conductivity, ammonia and chlorine) at the inlet and outlet of the plant. Bacteriological parameters such as coliform and *Escherichia coli* total counts are also important but are not measurable in real time or online and hence the plants are monitored by surrogate measurements. The level of automation also differs in this field of application: proportional–integral–derivative (PID) controllers, SCADA systems, data collection and process control modelling are applied in some but not in other plants.

In the **water distribution networks**, ‘smart network’ technologies have been widely researched but not widely implemented so far, mainly due to implementation costs. The US Environmental Protection Agency has invested over US$60 million in developing advanced techniques for real time understanding of water quality anomalies. The average non-revenue water for utilities world-wide is around 30%, which impacts available water resources and energy costs for water delivery. There is significant work underway to incorporate emerging smart technologies to reduce NRW for utilities.

In industries other than water and wastewater treatment as such, the use of control and automation is widely implemented and non-potable water recycling has been increasingly gaining popularity. Introduction of water-saving devices and real-time control of corrosion and scaling have been developed in larger scale. In agriculture, even though it is considered to be the sector with the largest consumption of water, the implementation of systems such as water meters with advanced characteristics such as remote control and communication has not been widely extended.

Hence, monitoring the full water cycle is a current challenge, even though smart technology and data analytics exist today. It would include monitoring the state of water reservoirs (surface water and ground water) as well as the state of water recipients (rivers, streams, lakes, the sea). Although this is an emerging area, some interesting applications such as the Ganges river monitoring network are being implemented.

General trends and Challenges

Within the water industry, there is currently a desire to move to an integrated water system bringing together the potable side of the business, the customer and the wastewater side of the business all the way back to the receiving environment: that is, including the full water circle, water from nature and back again. This integrated system should have full focus on smart capabilities that rapidly collect and analyse data into information and knowledge to provide future insight. The industry is not there yet but progress has been made. A cultural change in water utilities, so that it is well understood that the intelligence part of the utility is not a ‘nice feature’ but the brain of the system, should receive much more attention than it does currently. The changing workforce with the retirement of the ‘baby boomers’ will be an opportunity to speed up adoption of smart technology and will be expected to be used by the next-generation workforce. There are common challenges that this approach brings as well as opportunities.

General challenges

1. Security
2. Telemetry and communication
3. Instrumentation specification and installation
4. Skills and training

Security

The issue of cyber security is ever-growing within the water industry with technological developments such as the IoT and the Industrial Internet of Things (IIoT) and its integration with plant control systems. There have been incidents within the water industry where PLCs and SCADA systems have been connected to the internet and remote use of control systems has created a risk to the quality of the product and physical damage to treatment plant assets. Add complexities such as WiFi, Bluetooth, GSM/GPRS, 5G communications and the complexity of IT and ICT, and security becomes a big issue within the water industry. It has become a sub-speciality that must be incorporated into every element of the industry especially within ICA.

Cyber security in the water industry needs to be paramount and it is well developed through international organisations that are designed to educate and assist with security issues. However, the water industry will always be a target and ICA in particular. It will be a strategic decision in the water industry across the globe to decide what is connected, what should be separated control areas and what the impact of this will be operationally.

With current estimates of 50 billion connected devices in the world by 2020 (CISCO), the industry understands that the number of devices that are connected to the internet in the future is going to increase; this is one great concern in terms of the correct management of the networks. For potable water this issue is of particularl importance, since the health of billions of people can be at stake.

Customer data privacy and protection should also be considered as a security matter and treated appropriately.

Telemetry and Communication

Within the water industry at the current time are a wide range of communication protocols that challenge the industry to have a variety of choices for the instrumentation that is produced. The protocols available range from a traditional 4–20 mA analogue loop, to HART, Profibus, Fieldbus, Ethernet, GSM, Radio, DNP3 and WITS (to name a few). This requires utilities to integrate and normalise disparate data streams using different communication protocols for all of their instruments, which causes the following issues:

(1) Interoperability problems;
(2) Smart system design challenges;
(3) Increased overall costs to the global industry.

This is a complex issue and is dependent on each project and utility, but it is desirable that in the future most systems should become compatible to avoid information losses among instruments to take profit of all of the 'intelligence' that can be gathered by an instrument. This is unlikely to occur in the near future because of the lack of technology providers' willingness to migrate from their proprietary mesh systems. The interim approach is to develop a unique set of application programming interface (APIs) that allow disparate systems to be merged into a common platform where the data streams can be normalised and analysed for spatial relationships.

One additional aspect of the increased communication capabilities is the possibility of centralising all the information in a single control room. It is possible to connect several small plants to the same control room where expert process engineers can help the local operators when more advanced problems appear. This structure solves the typical limitation of availability of sufficiently skilled staff. The work that has been done in Canada's First Nations Water 60 community water systems is an excellent example of this.

Instrumentation specification and installation

One challenge around instrumentation itself is that the installation of instruments should be thought of as part of engineering projects. This would result in better selection of the instrumentation, improved installation in very representative points, lower costs, and a move forward into good operation of the instrumentation asset. The operation of the system, whether it is a treatment works or a network, is only as good as the data that is being collected, which has a major effect on ICA in general.

Moreover, the problem is actually larger than only the installation of instrumentation. A smart system should be flexible, with several operational variables that can be regulated. If there is no flexibility designed, the instrumentation will not make much difference to the optimisation of the system. Rather, it is relegated to become 'monitoring for alarms', which greatly minimises its value.

Another need in instrumentation is the development of international specifications to avoid intensive site trialling by instrument purchasers. The lack of specifications causes additional costs to the vendor, which are eventually passed on to the water industry as a whole. Also, the water industry needs to accept that water and wastewater systems are more alike than not. Acceptance of this basic premise will lead to a higher level of confidence in data from other trials and less need to conduct local trials.

Skills and training

There is a global shortage of engineers and engineering technicians; this has long been seen in the water industry as a whole. Most of the projects do not often include the participation of ICA engineers, which leads to inefficient choice of sensors and instruments and can be detrimental to the correct functioning of the systems or unnecessarily increase costs between the project phase and the implementation. As ICA is a specialist area within the water industry that is seldom understood correctly, there is a great risk to both the design and operation of the discipline within the water industry. When developing and implementing a smart system, there will be a need to have data scientists and data engineers as part of the team. These positions are in high demand as utilities and consulting companies increase staffing for the IoT revolution.

Specific training about dynamics and control for water industry staff would provide better capabilities in solving the typical problems that appear in these processes. Additional benefits can be reaped when this training is combined with modelling, so that the control of the systems becomes clearly smart. Finally, another topic of interest for training is the formulation of optimisation problems and the application of mathematical methods for minimisation, which are useful for model calibration and for selection and optimisation of control strategies.

Challenges in wastewater

There are challenges that are specific to the wastewater industry as the analytical challenges and gaps still present in instrumentation technology or the development of control wastewater networks in what has been termed active system control (as an alternative to real-time control).

Instrumentation

The challenge of instrumentation is being driven by regulatory needs, especially within Europe. In particular, these issues surround biochemical oxygen demand (BOD), phosphorus and dangerous substances, specifically metals and emerging concerns of medical residuals, pesticides, microplastics, nanoparticles, microbiology and hormone substances.

For BOD the accuracy of the method is being challenged as the quality standards are now under 10 mg/L, meaning water companies need to operate at approximately 5 mg/L. This is challenging the accuracy of the laboratory method and its operational usefulness. However, BOD is hardly ever used as a measurement for control purposes. It is used for checking the water quality, since it takes 5–7 days to obtain the value. Rather, the specific oxygen uptake rate is used for control purposes. Alternatives such as the measurement of tryptophan as a surrogate have been proposed but require more development. Measurement of chemical oxygen demand (COD) also poses some challenges, because of regulations on associated chemicals. There are also advanced instruments using spectroscopy that can measure BOD and COD at very low levels in near real-time.

The measurement of phosphorus has always been a challenge for the water industry, especially as it is normally regulated as total phosphorus and monitored in its soluble reactive form. Like BOD, the quality standards are decreasing, with 0.1 mg/L phosphorus being proposed in certain areas of the globe. This is a challenge for current online measurement techniques.

The online measurement of dangerous chemicals, including metals and organic compounds as micropollutants or emerging contaminants, is a particular challenge to the wastewater industry. There are current technologies that can measure metals but their cost limits their application to all but the largest treatment works where there is an actual or perceived risk. However, the lack of a treatment process step means that the development of these technologies is a low priority.

Adopting a more biology-based approach to automation is needed, such as the development of a common database of microbiology in several steps of the treatment process. This will enable users to act depending upon the information of the database (an example of this is the Global Wastewater and Water Microbiome database). The detection of excessive growth of some indicator microorganisms would denote operational problems that could be automatically corrected by modifying operational conditions of the plant. There is advanced work being done in developing advanced sensors for biological measurements from the medical industry that should be leveraged by the water industry.

Wastewater Network and System-wide control

The development of network control within the water industry has been ongoing since the first attempts in Cleveland, USA, in the 1970s. This area has developed hugely, to the most advanced systems that are using modelling to control the network in countries such as Denmark.

The challenges in controlling the wastewater networks are numerous but need to include the following:

- inputs from rainfall;
- the development of network models that are suited for network control;
- development of network based instrumentation and its correct placing and a measurement of the uncertainty of these monitoring methods;
- development of the control strategies that integrate the wastewater network to the wastewater treatment systems and develop the strategies that enable the best and most efficient treatment for the wider environment;
- use of advanced monitoring technology to define when the combined flow is clean enough to divert into the water sources to avoid overwhelming the downstream wastewater treatment plant and impacting the treatment efficiency.

Challenges and trends in Potable Water

The main challenge for the potable water industry has been **microbiological detection and control**. The need for faster and automated detection and control has been researched, and some systems have been improved and developed, such as online flow cytometry. While for pathogenic bacteria some improvements have been observed, the same cannot be said for viruses and fungi, which constitutes a big future challenge. Biosensors and bioassays are being developed and applied as well, with the main goal of integrating the biological treatment and management of drinking water into an overall more complex, but at the same time more sustainable and safer overall, approach. Trihalomethane monitoring and control constitutes a good example of this.

The **interconnection between sensors** to provide failure information (for example using conductivity sensors to detect failures in pH sensors) or the use of real-time data validation tools are areas that will be widely applicable as we move forward to greater automatisation of systems and as more data become available for handling and management by the industry.

The use of **water networks** is expected to increase, and these systems can help to gain clarity between leakage, non-revenue water and chargeable consumption. Also, it will be possible to establish consumption patterns and use predictive analytics to regulate supply. An increase in metering capabilities and the advancement of advanced metering infrastructure (AMI) technology provide several new data streams for customer leak detection, backflow events and meter tampering, which will improve the understanding of overall system operations and reduce the cost to consumers.

The use of **systems with increased capabilities and communications** (IoT) is beginning to replace common networked systems. This can generate more possibilities for programming and data management, which can lead to more efficient water use and reduced infrastructure costs. Also, the increase in available information will allow easier automatic detection of failures in systems and speed up maintenance or repair.

At the same time, even though the expected changes in the industry are meant to increase safety to consumers, and reduce water losses and the costs associated with it, there are still major problems to address: a huge increase in the data and information available can lead to confusion and mistakes if not well handled; more qualified personal might be needed in case problems arise; utilities can be dependent of certain types of supplier (according to the communication protocols they use, intellectual property); longer-lasting batteries might be needed to decrease the maintenance costs of systems; and internet safety. These are all problems that are being addressed, and solutions for many have already been developed and are being tested in large applications.

Development Areas

The main process-independent development areas of ICA throughout the water cycle can be summarised in the following points:

1. **Standardisation of the communication protocols** moving away from the traditional 4–20 mA analogue loops to a potential future in the Ethernet applicable across the water network. This will allow greater information on instrumentation state to be monitored.
2. **Data management:** as the amount of data increases, so will the need to convert the data into usable information, knowledge and future insight. This includes both corporate data for water companies and customers, and how both interact together.
3. **Automated Model-Based Control** of water and wastewater systems including distribution, collection and treatment.
4. **Sensor development in key areas** such as the need for improved microbiological sensing and network-based quality monitoring in potable water and on the wastewater side flow and level measurement in sewer environments.

Marine Outfall Systems: Current Trends, Research and Challenges

Written by *D. A. Botelho, B. Miller, P. Roberts, O. Obessi, M. Mohammadian, M. Wood, D. D. Shao, J. Bradley, R. Morelissen, and A. W. K. Law* on behalf of the Specialist Group of Marine Outfall Systems

Introduction

Marine outfall systems have long been used for the discharge of industrial and domestic effluent as a means of increasing its dilution in, and improving the assimilative capacity of, the receiving environment. It is recognised that the fundamental frameworks for design and construction of marine outfalls are well established. The following summary of this framework has been applied successfully on many outfalls over many decades and is expected to remain in practice for quite some time.

Acceptable concentrations of all constituents must be determined and agreed with the community and regulators. These concentrations and associated mass loads are based upon the short term and long term impacts to humans and the ecosystem. The acceptable zone of impact (often referred to as the regulated mixing zone) must also be agreed. Acceptable physical impacts such as jet-based entrainment, shear, bed scour and density stratification must also be agreed and regulated.

The characteristics of the wastewater stream must be established. These include the volume, duration and variation of flow and the variation in concentration of each of the constituents.

The potential mixing capacity in the receiving water environment must be understood. The variability in water depths, currents, stratification and winds is necessary to provide an understanding of potential dispersion and mixing.

The location and design of the outfall diffuser must be a compromise between costs, construction methods, required near field dilutions and the subsequent fate and dilution of the far field plume. Diffusers can vary from a simple ‘end-of-pipe’ through to long outfalls maximising flux-based exchange or high-energy outfalls maximising jet-based entrainment.

The outfall must be maintained to ensure marine growth or physical damage does not reduce the performance. The receiving waters and ecosystem must be monitored to ensure that the outfall is performing as originally planned.

Being a relatively mature field of engineering and science, the ongoing research and changing trends are focused on improving techniques to reduce uncertainties at each of the stages. These trends include better understanding of acceptable ecological impacts; better field and process measurement techniques; better writing of regulations and legislation; better and more cost effective construction and maintenance; better communication and engagement with community and stakeholders, and better prediction of near and far field dilutions for complex diffusers. However, as regulatory requirements change and new technologies come to light, design of outfalls will necessarily require further thinking to work within a sustainability paradigm.

Below we present brief descriptions of the specific terminology adopted in the area of marine outfall systems, some current trends in research and practice recently presented at the International Symposium on Outfall Systems (hereafter ISOS) in Ottawa, Canada (May 2016) and topics selected by the Specialist Group that require closer attention for research and development in the near future.

Terminology

Figure 1 illustrates some of the outfall terminology described in this section. Technical terms adopted throughout this report are presented below for ease of reference.

Outfall or outfall systems—a piece of engineering structures designed to convey industrial and/or domestic effluent into ambient waters as a means of reducing the impact of (treated or untreated) anthropogenic waste to acceptable levels to the receiving environment.

Zone of impact or the regulated mixing zone—a finite and well-established area surrounding an outfall that is agreed with regulators and stakeholders where water quality constituent concentrations can be exceeded over locally accepted and prescribed values for natural waters.

Jet entrainment—incorporation of ambient water into the released effluent stream leading to increased mixing with ambient waters.

Jet shear—the velocity gradient in the interface of the released effluent stream and the ambient water.

Bed scour—erosion of the seabed associated with the location and operation of the outfall system. It may occur from direct impingement of, or increased bottom shear stress caused by the released effluent stream or from interaction between the outfall structure with the local ambient currents and wave action.

Density stratification—vertical density gradient in the ambient waters generally induced by temperature, salinity, suspended, or dissolved solids.

Near field — the region adjacent to the outfall where the initial jet momentum flux, buoyancy flux and outfall geometry

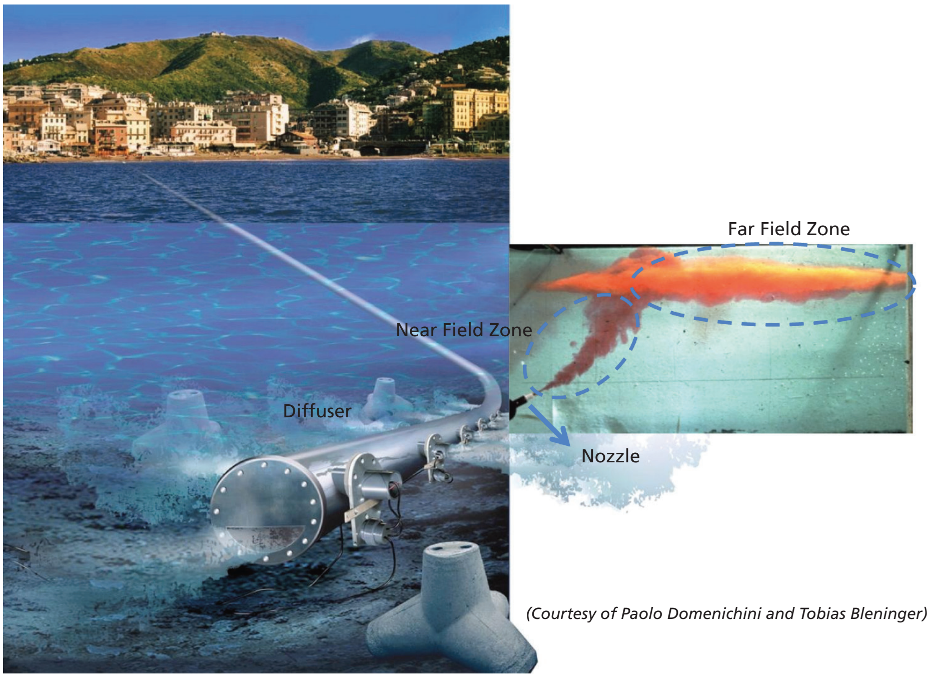

Figure 1. Some common terms about submarine outfalls adopted in the text.

dominate the dynamics of the released effluent trajectory and mixing with the receiving waters.

Far field - the region of the receiving water where the trajectory and dilution of the released effluent stream are dominated by a combination of buoyant spreading and ambient diffusion.

Plume—the released effluent stream characterised by its momentum flux and buoyancy fluxes.

Diffuser or manifold—generally the final section of the outfall system that includes one or more ports delivering the effluent stream to the receiving environment.

Nozzle or port—a component of the outfall system of reduced cross section with the intent of maximising the initial jet momentum flux and associated mixing with the receiving ambient water.

Current trends and practice

This section presents the current trends in research and practice adopted in the design, operation, and regulations of marine outfall systems. The aspects presented herein summarise the works presented in the International Symposium on Outfall Systems (ISOS 2016) held between 10 and 13 May 2016 in Ottawa, Canada. The Symposium received 89 delegates from around the world where 69 papers were presented. Being the premiere conference on marine outfall systems sponsored by both IWA and IAHR, the outcomes of ISOS 2016 truly represented the state of the art on research and practice in the field.

Table 1. Topics of papers presented at ISOS 2016 shows topics covered by the papers presented at ISOS 2016. It is quite clear that numerical modelling (both near and far field modelling) are being widely used in both research and applied engineering of outfall systems. Laboratory studies are still extensively used for research but are not being broadly adopted for modelling real cases. Between systems of interest, sewage effluent discharge was the most referenced; however, much interest in dense discharges (i.e. desalination) was also noticeable. Field characterisation studies were not widely presented at ISOS 2016, however a keynote presentation by Phil Roberts showed the application of different field measurement techniques for effective outfall design. These techniques included a combination of thermistor and conductivity chains for ambient velocity characterisation with acoustic Doppler current profilers for the description of the ambient velocity field. Roberts' presentation was used to challenge the often-loose definition of dilution-based regulatory mixing zones, which have not kept pace with technological advancements, which nowadays allow more meaningful analysis of outfall impacts in the environment.

Despite much interest in the physical aspects of outfall systems, little was presented at ISOS 2016 with reference to ecological implications of construction and operation of outfalls, and whether such effects should be formally included in regulations and guidelines for outfall designs. More specifically, the ISOS 2016 discussion panel session raised the need for improved understanding of the effects of larval fish mortality associated with entrainment into outfall jets. Additionally, it was noted that the effects of emerging contaminants in the environment (i.e. endocrine disruptors), particularly in association with sewage discharges from outfalls, have not been systematically addressed. Research on the interaction of outfalls with its surrounding ecology will require integration between different disciplines (e.g. biology, ecology, biochemistry, physics, and engineering) for further development. Other future challenges discussed by the expert panel are presented in the following section.

Future challenges

Despite being a mature field of science and engineering, there are clearly some challenges ahead for improvement in design considerations, establishment of regulatory guidelines and better understanding of the physical and biological

Table 1. Topics of papers presented at ISOS 2016

Topic	Number of papers on the topic(papers can cover one or more topics)
Far field Modelling	21
Sewage Discharge	15
Near field Modelling	13
Near field CFD Modelling	11
Near field Laboratory Experiments	11
Desalination Discharge	10
Water Quality Modelling	8
field Experiments	5
Intake and Outfalls Design	5
Discharges in Rivers	4

Other themes (fewer than three papers on each topic): Oil Spill Modelling, Bubble Plumes, Field Characterisation and Monitoring, Hydrothermal Systems Modelling, Industrial Discharges, Near and Farfield Model Integration, Turbulence Measurements, Construction and Installation Methods, Decision Support Systems, Multiple Discharge Analysis, Stormwater Discharges, Data Analysis Techniques, Discharges Under Ice Cover, Internal Diffuser Hydraulics, Nozzle Characteristics, Pollutant Effects on Biota.

interactions between the outfall-released effluent stream and the receiving environment. While it is recognised they are not exhaustive, some of the more pressing challenges are summarised below.

Physical processes

Although the fundamental physical aspects of the dynamics of outfall discharges are reasonably well established, opportunity exists to improve the understanding of the discharge dynamics under a range of environmental conditions. Such an understanding would allow improved outfalls design by optimising their performance with respect to the environments in which they operate and better integration of outfalls on a sustainability basis.

Both laboratory and numerical modelling techniques have been widely used for progression of our current knowledge on outfall systems, and it is not surprising they will still be important avenues of research in the future. Over the past decade, laboratory techniques were developed to unravel flow and mixing characteristics in the laboratory, including three-dimensional laser induced fluorescence (3DLIF) and three dimensional light attenuation (3DLA) methods introduced by Tian and Roberts (2003) and Nokes (2008). These techniques enabled the study of mixing processes with good accuracy and integrity for relatively simple discharge conditions, including jets and plumes in deep ambient water, and other more complicated conditions like discharge from multiport diffusers in shallow and flowing ambient water. Flow behaviour near solid boundaries and under unstable conditions still present complex flow phenomena that require further understanding. Recent research undertaken for inclined discharge of dense flow in shallow water (Jiang *et al.*, 2014; Abessi and Roberts, 2015) revealed that the flow is physically three-dimensional and particularly complex near the boundaries, which elucidation with further development of three-dimensional experiments will be required in the future. This is of particular importance for understanding the impacts of discharges on benthic communities within the mixing zones of the outfalls.

Experimental conditions have also been mostly limited to discharges in stationary environments and single port diffusers. It is expected that the sophisticated techniques and apparatus for three-diemsional mapping will be used for researching flow interactions arising from the discharge of multi-port diffusers and multiple co-located outfalls. Discharges in non-stationary and unsteady environments have not been fully explored in the laboratory yet. Future laboratory research in this area is expected considering environmental conditions are seldom stationary and regulations quite often prescribe analysis of mixing conditions over different time scales.

Given its flexibility, compared with laboratory experiments, numerical modelling techniques will also play a crucial role in the advancement of our understanding of physical processes over the next decade. Hydrodynamic and transport models will form the basis for both research and applied studies, particularly considering realistic, local scale, environmental forcing, and the multitude of configurations that can be adopted for multiport diffusers.

Despite advances on both simplified and three-dimensional modelling approaches, there are still some modelling issues that require further research that have not been fully explored. In particular, it is expected that development of more advanced algorithms for dealing with mixing mechanisms will be directly applicable to outfall systems. Of these mechanisms, mixing associated with double diffusion processes (e.g. by both salinity and temperature differences), turbulent mixing in stratified zones, mixing of jets and plumes under crossflows, and mixing under the combined effects of wind, wave and tides are important processes that should receive increased effort in future research. Recently, large eddy simulation (LES) approaches have become possible for outfall systems and it is expected that this approach will lead to better understanding of mixing phenomena. Nonetheless, further research will be required to create more robust LES software such that mainstream practitioners can use this method for their outfall design.

Furthermore, as the computing power is increasing, improved techniques will be required to enhance simulation accuracies. This in turn has led to further questions about coupling various models at different spatio-temporal scales, a trend that has just started being developed over the last decade. It is expected that improved coupling algorithms will be used for integrating near and far field models, particularly the adoption of coupled computational fluid dynamics (CFD) and geophysical fluid dynamics (GFD) models. More specifically, two-way coupling techniques need to be developed such that interactions from both smaller to larger scales as well as from large to small scales can be accurately represented.

Discharges under ice cover

While most efforts have been devised for ice-free environments, little attention has been given to the operation of outfalls in cold regions, where the ambient water in the rivers, lakes or seas can freeze during wintertime. When the partly or fully frozen ambient water receives large volume of typically much warmer effluent, the buoyancy of the discharge forces the plume to rise and considerably lose heat as it reaches the underside of the ice cover. The buoyancy loss associated with the heat exchange with the ice cover is a process that is not accounted for in most existing near and far field models. The discontinuity in heat transfer that occurs at the ice-water boundary poses further challenges to numerical models. Recently, an ad hoc ice module that accounts for the thermodynamics was integrated into a hydrodynamic model to simulate ice-covered discharge scenarios (de Graaff *et al.*, 2015).

Remote-sensing imagery has been used to observe ice formation and melting over the receiving water body, and to relate the transient ice cover to weather conditions and the rate of waste heat discharged from a power plant (Garrett *et al.*, 2010). The ice and snow cover on the receiving waters impedes their ability to recover from oxygen depletion caused by wastewater discharges. Winter conditions also leave the receiving waters at their lowest level and flow rate of the year, which limits the assimilative capacity available for the wastewater. Contrastingly, particularly when the discharge occurs in ice-covered rivers, warm effluent can produce an open-water lead downstream of an outfall throughout the winter, providing oxygen input through surface aeration (Lima Neto *et al.*, 2007). The presence of an open-water lead, on the other hand, can alter flow distribution and cause potential bed scour and bank erosion. Further studies on the extent and frequency of lead formation as well as its impacts on the fluvial processes and ecological aspects are warranted.

Management of the effects of multiple outfalls

Rapid and large-scale industrialisation of coastal areas is an on-going challenge for both the environment and the design of efficient marine outfalls. National planning strategies (in Gulf Cooperation Council (GCC) countries, for example) often identify coastal regions in which multiple industries can be developed. Examples include so-called free zones and industrial cities, and may involve the construction of ports, factories, refineries, power/desalination facilities, wastewater treatment plants, etc. Such zoning optimises land use, but can lead to the release of multiple marine discharges within a few square kilometres of coastal waters. This raises issues for the environment, regulation, modelling and engineering.

High pollutant loads in a relatively small marine area can cause significant local ecological stress, and multiple pollutants can act synergistically on flora and fauna. If the coastal waters are relatively poorly flushed, then pollutants may accumulate locally. For example, multiple thermal outfalls can cause significant seawater warming, effectively raising the ambient temperature over a region. In extreme situations, mixing zones around individual outfalls may overlap, resulting in large areas where target concentrations are exceeded. This can complicate regulatory decisions where effluent environmental regulations are prescribed in terms of 'excess' concentrations at the edge of defined mixing zones. Localised pollutant build-up can also reduce the efficiency of outfall designs, by limiting the availability of non-effected ambient seawater for mixing.

These problems are often exacerbated by a lack of reliable information sharing between neighbouring facilities. Data on discharge constituents and release rates are often not available and so it can be difficult to plan, locate and optimise new outfalls. This scarcity of information by indicates that environmental impact assessments and, or engineering studies for each outfall are effectively and often done in isolation.

Several measures can help to address these issues. Common outfalls are sometimes used to discharge combined wastewater from industrial zones. This can confine high pollutant concentrations to a specific area, which may have been identified as low risk ecologically or as a region of potential rapid mixing and dilution. Examples include outfalls at the Sohar Industrial area in Oman, and the Ras Laffan Industrial City in Qatar. Combined outfalls can also be used to merge 'complimentary' wastewater discharges. For example, thermal discharges from refineries and power stations can be combined with cold discharges from liquefied natural gas (LNG) regasification plants, or small volume discharges of highly concentrated effluent (e.g. partly treated wastewater) can be combined with large volumes of cooling water. This has been successfully applied at some sites in GCC countries (e.g. Bahrain) where no other methods of treatment are currently in place.

Perhaps most importantly, regional planning studies are vital to successfully managing the effects of multiple outfalls. Computational modelling studies can be done to determine optimum outfall locations, and discharges can then be coordinated appropriately, accounting for in-combination effects. Construction and operation management plans must be supported by open information sharing between industries and operators in a region, which might be coordinated by the site owner, overseen by the environmental regulator.

In contrast to the inclusion of several outfalls in a single specified industrial zone, such as in GCC countries, other governments are pushing for amalgamation of several discharges in freshwaters into a single discharge location to the marine environment. The New Zealand regulatory environment relating to the management of freshwater is currently undergoing change resulting in improving the way fresh water is managed. This change stems from further realisation that freshwater is New Zealand's greatest natural and economic asset and that the pressures from fresh water resources are becoming increasingly evident in a number of ways. The New Zealand Government's long-term vision for fresh water includes amongst other criteria that freshwater quality is maintained or improved and that outstanding lakes, rivers and wetlands are protected. More stringent limits on nutrient levels along with other contaminants are being established to ensure ecosystem health and protection of human health for recreational requirements are met. These changes are likely to result in an increased reliance on the discharge of treated wastewater to the marine environment through estuary, harbour and offshore outfalls.

With most of New Zealand's 4.4 million people living at or near the coast, the environmental acceptance and cost efficiency of the many appropriately sited and operated outfalls has led to a high level of understanding of the environmental impacts associated with such discharges. The increased pressure on fresh water and more stringent regulatory regime is further supporting the increasing use of marine outfall systems. For example, a number of inland communities that are within cost effective conveyancing distance of ocean outfalls have or are ceasing treated wastewater (domestic sewage and industrial wastewater) discharges to fresh water and conveying their treated wastewater to existing coastal community ocean outfalls. Other new or upgraded marine outfall systems are planned as a result of this trend.

Sustainable outfalls

Resulting from increasing water flow rates in the associated processes, outfalls tend to become larger with the increasing demand in power and water use. Furthermore, the environmental awareness is increasing in governments and communities worldwide, thus fostering the demand for compensation projects to offset the impact of the outfall discharges. In addition to government demands, the power and water markets are focusing on making systems more energy efficient. Furthermore, desalination and water reclamation are gaining momentum worldwide owing to water stresses and water security, and owing to the significant reduction in membrane filtration cost over the last few decades. The discharge of brine from these processes through submerged outfalls remains of concern in terms of its impacts on the receiving water. Over the past two decades, the design practice for a submerged desalination outfall is being established to minimise these impacts. Future technological development in desalination, which can alter the effluent characteristics, can, however, lead to further changes in outfall configuration and design practice, as described below.

The design and construction of outfalls traditionally aim at minimising the impacts of the outfall on its environment. While this is a key aspect of a well-designed outfall, options exist to transform the 'problem' of the outfall into an 'opportunity'. By taking into consideration the natural environment in which the outfall is placed and the system it is part of from the start of the outfall design, opportunities can be identified for the environment and system. These trends provide interesting opportunities to combine the minimizing of outfall impacts with opportunities for innovative and sustainable designs of outfall systems, such as the following:

- creating opportunities for nature (e.g. habitats) with the intake and outfall system;
- using the natural processes and system in the project area to optimise the functioning of the intake and outfall system;
- combining the design with other functions or operations in the project area.

This requires a different design approach that starts from a thorough understanding of the natural system, desired function of the envisaged infrastructure and the vested interest of stakeholders. This is contrary to the traditional approach, which starts from a design concept focusing on the primary function (Vriend *et al.*, 2015). The benefits of this design approach for an intake and outfall system could include the following:

- creation of added value for both the developer and stakeholders, which may result in shorter permitting procedures and more societal support for the project;
- potential for cost saving on a life-cycle basis (e.g. by sharing the investment costs with stakeholders that also have interest in this development, or by using existing facilities or natural processes);
- potential for creating new habitats, which may replace some other mitigating measures, etc.

In the sea water desalination industry, greater water recovery is being sought after that can reduce brine volumes to be managed. Besides conventional reverse osmosis (RO), other processes including membrane distillation (MD) are being investigated to recover additional water from brine; and pressure retarded osmosis (PRO) and reverse electrodialysis (RED) are being investigated to add to the brine energy recovery. Both PRO and RED change the characteristics of the brine stream (being more diluted with lower density but higher volume flux), and their addition would change the design of an existing brine outfall, if implemented.

In terms of water reclamation from wastewater effluent, experience shows that the reclamation processes can be added to original standard wastewater treatment plant designs by including additional reactor units. At the same time, submerged outfalls designed for the original scenarios and capacities would frequently be unable to function adequately given required working capacity changes may not be easily implemented if not conceptually anticipated from project inception. Thus, a more 'dynamic' or 'adaptive' design that is workable with a wider range of discharge flow rate and effluent characteristics will be desirable for the future.

When opportunities such as these are considered, mutually beneficial situations can be created for developer and stakeholders, which may result in shorter permitting procedures, potential cost savings, and creation of new habitats.

Conclusions

While being a mature field of science and engineering, research and applications of outfall systems have benefited from advancements on experimental techniques, computational power increase and numerical algorithm developments. Outfall systems have also benefited from the increased understanding of marine science and in some cases the better understanding by governments, regulators, key stakeholders and community at large. On the other hand, regulatory pressures in conjunction with the need for more sustainable use of outfalls dictate better understanding of mixing mechanisms such that outfall performance can be maximised for the environments in which they are located and in such a way that their design can evolve with the requirements of new water and energy market technologies. As a result, the IWA Specialist Group on Marine Outfall Systems proposes the following topics for focus in research and development over the coming years:

- Development of improved understanding of mixing phenomena for stratified conditions and boundary effects for outfall discharges, as well as further understanding of mixing under unsteady environmental conditions. Such understanding should be achieved by means of both laboratory and numerical modelling experiments and will allow better integration of outfalls within a sustainable design concept.
- Development of improved understanding of the cumulative effects of several outfalls within a same location to form the basis of science-based guidelines and site-specific, ecologically-relevant environmental criteria with regards to the establishment of industrial estates. This will require the identification of 'outfall hot-spots' and medium-to-long term monitoring of their performance and water quality and ecology of surrounding waters. In this case, regional numerical modelling should also form an integral part for the development of guidelines, assisting in exploring different sets of outfall arrangements.
- Establishment of a new paradigm for outfall design that is adaptive to future technological changes in treatment technology, maximising water reclamation and energy efficiency, and monitoring and understanding of the impacts of the discharge on the receiving marine environment.

Furthermore, instead of only focussing on minimising environmental impacts, to create opportunities with a sustainable outfall design to improve other coastal functions (e.g. improving flushing or coastal protection) or the receiving environment (e.g. creation of local healthy habitats). Creation of this new paradigm should be accompanied of close liaison with governments and regulatory agencies for insertion of this new paradigm within their coastal zone management framework.

- Preparation of improved education and communication strategies over outfall systems with governments, regulators, key stakeholders and communities at large in that order to promote further understanding and in some geographies acceptance of such systems.
- Improvement of the understanding and rationales for the assessment of the interaction and balance between outfall discharge locations and the associated degree of the treatment of wastewater before discharge.

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Membrane Technology

Written by *Val S. Frenkel, Xia Huang, Kuo-Lun Tung and Franz Frechen* on behalf of the Membrane Technology Specialist Group

Introduction

In recent years, membrane technologies have started to play a vital role in solving water scarcity on the planet, which is in close association with global climate change. The major reasons are that membranes allow not only effective separation of various contaminants from water sources to achieve the required quality, but also exploration of water resources from non-traditional sources such as wastewater and seawater for direct or indirect portable reuse.

The objective of the Membrane Technology Specialist Group (MTSG) is to educate professionals and public around the globe without barriers about membrane technologies and to promote and exchange knowledge on membrane technology. Special attention is paid to the young professionals who will increasingly encounter membrane technologies in their professional life. The group consists of a vast spectrum of active members (scientists, researchers, engineers, membrane industry professionals and end-users.) in academic, industrial and public sectors. The group has grown to be one of the largest Specialist Groups within IWA.

Existing MTSG knowledge

Membrane market

Membrane technologies have infiltrated every corner of water and wastewater treatment such as municipal and industrial water, advanced wastewater treatment and reuse, sea and brackish water desalination (Frenkel 2010). The major reasons are the unique features of membranes in providing complete treatment and solving the water shortage problems that are in close association with global climate change. This has helped in accelerating the growing rate of membrane market (Frenkel and Lee 2011).

Membrane market: current situation

During the past 10 years, the annual growth rate of reverse osmosis (RO) desalination, microfiltration (MF)/ultrafiltration (UF) membranes for drinking water treatment, and membrane bioreactors (MBRs) for wastewater treatment and reuse has been 17, 20 and 15% respectively. The reasons for this have been the similar capital, operation and maintenance costs as that of conventional treatment processes, a smaller footprint, fewer chemical requirements and much better pollutant removals. The energy requirement has been relatively high, although this is reducing with the rapid advance in R&D activities in this field.

The membrane market was strong in 2010 while it was quite different between market sectors and particular places, regions and countries around the globe. In general in 2010 the strongest membrane markets were sea water desalination by reverse osmosis (SWRO) and MBR technologies. A similar trend can be expected in 2011–2016, as shown in the Table 1.

The growth rate of the SWRO market has been driven by the needs of the recent water supplies in places that are in the reasonable proximity to the ocean. Recent SWRO plants are large, with a capacity of 100,000 m^3/day or more. For example, the largest operating membrane desalination plant in the USA was the Tampa Bay SWRO, with a capacity of 25,000 m^3/day. In 2015 the Carslbad SWRO plant with a capacity of 50,000 m^3/day started to produce desalinated water in California. The largest SWRO plant in the world was the Magta plant in Algeria, with a capacity of 500,000 m^3/day (Kurihara 2011), while in 2013 the Soreq SWRO desalination plant in Israel with a capacity of 624,000 m^3/day started operation.

Table 1. Forecast on membrane market (billions US$) for 2011–2016 (Kwok *et al.* 2010)

Market sectors using membranes	2011	2016
Desalination pretreatment	0.05	0.13
Membrane bioreactors	0.53	0.90
Drinking water	0.17	0.33
Tertiary wastewater treatment	0.16	0.39
Industrial applications	0.16	0.30
Subtotal MF/UF membranes	**1.07**	**2.05**
RO/NF (nanofiltration) Industrial applications	0.33	0.51
RO/NF Desalination	0.42	0.67
Subtotal NF/RO membranes	**0.75**	**1.18**
Total MF/UF/NF/RO membranes	**1.81**	**3.25**

The membrane market in 2011 was forecasted to be US$1.8 billion, but it is estimated to increase to US$ 3.25 billion over the next 5 years (about 80% growth) and reaching US$ 3.44 billion by ear 2018, taking into account only the MF/UF/NF/RO membranes. However, it is worth noting that the estimation of membrane market has great fluctuation depending on the data sources. For example, global world market of membranes for water and wastewater treatment in 2011 was also evaluated at about 4 billion dollars (http://www.oecdrccseoul.org/article/global-membrane-market-for-water-and-wastewater-treatment). In addition, MBR world market in 2011 was also estimated at about US$380 million (http://bccresearch.blogspot.com/2011/07/global-membrane-bioreactors-mbr-market.html).

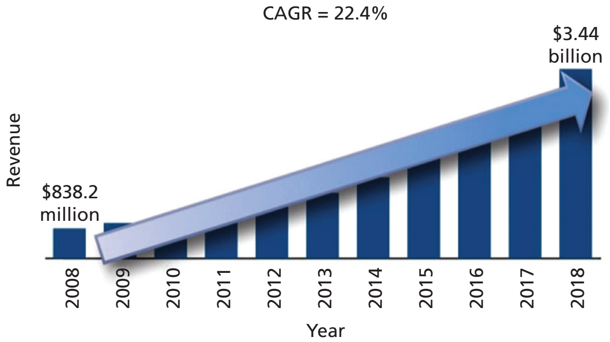

Figure 1. Global MBR market: treatment volume and revenue forecast (global), 2008–2018. Source: *Water & Wastewater International.*

The MBR market has been driven by needs for recycled water, upgrading of ageing facilities with challenged acquisition of the additional land and by the need for additional water by the industrial sector. In Europe, GE Water Technologies-Zenon (hollow-fibre) and Kubota (flat-sheet) have supplied most membrane equipment for the large MBR plants. However, new companies with novel concepts of membrane module design are slowly penetrating into municipal and industrial MBR markets. Therefore fierce competition in the MBR membrane and equipment market supply can be expected in the coming years and exponential growth of the MBR market as a result (Lesjean *et al.* 2011).

There is important growth in MBR plant sizes around the world, as shown in Table 2. More than 40 largest MBRs commissioned have a peak daily flow of more than 100,000 m^3/day. Especially the engineering application of MBR in China has attained tremendous development recently. The total treatment capacity reached 7.5×10^6 m^3/d by 2015 (Xiao et al., 2014).

Membrane market: current challenges

In general, much current R&D on membrane technologies is related to analysis and control of membrane fouling, which is a chronic trouble for the operation of all membrane types. The reason is that the reduction of the relatively high energy demand to operate membrane plants still remains one of the key considerations for membrane processes over conventional treatment technologies, and the higher energy consumption is in close association with membrane fouling. In the coming years, similarly to the previous years, many efforts will be dedicated to managing membrane fouling and reducing operational energy.

Disposal of membrane concentrate associated with high pressure membranes, NF and RO operation is another challenge of membrane processes, especially if high pressure NF and/or RO membrane systems are used for salty and high concentrated industrial effluents and wastewater reuse. Recently, many studies on membrane distillation/crystallisation, forward osmosis and pressure-retarded osmosis have started to address the disposal of membrane concentrate.

Membrane market: current drivers

There are also many factors influencing membrane market. These are decreasing investment and operational costs, new and more stringent legislations on effluent discharges, local water scarcity, increasing confidence in membrane technologies, compact footprint of membrane plants compared with other technologies, and high efficiency of salt removals, which will accelerate penetration of membrane technology to several market areas in the near future. Latest needs by Oil and Gas industry when exploring fracking technologies for oil and gas exploration triggered significant interest in membrane technologies and development of the treatment processes based on already available membrane applications and requiring new membrane technology based processes.

Membrane standardisation

The high pressure membranes such as RO and NF became commodities items well standardised across the industry and the most common high pressure element sized 8 inches × 40 inches (200 mm × 1,000 mm) can be found in any RO/NF facility around the world. As RO/NF facilities becoming larger in size the high diameter RO sized 16 inches (400 mm) diameter or 18¼ inches (450 mm) found their place in the design of the new desalination plants.

Low-pressure membranes are still not standardised across the industry and this situation complicates the development of the MF/UF projects including MBR. More time is required to develop and procure MF/UF projects than is otherwise possible, resulting in more costly projects. However, there are numerous signs of the standardisation of low-pressure membranes with MF/UF as membrane manufacturers are following up the after-sale market offering membrane replacement to the operational MF/UF and MBR facilities (Frenkel 2010).As part of the Amedeus European research project, a report about MBR standardisation including recommendations has been published (De Wilde *et al.* 2007, www.mbr-network.eu)

Enhancing membrane performance with nanomaterials

Next-generation membranes are being developed that incorporate nanomaterials, such as zeolites, carbon nanotubes, silver nanoparticles and others to improve membrane properties and performance. These membranes have higher fluxes, resist breakage to a much greater extent, and/or exhibit reduced biofouling. Membrane processes based on even more advanced nanoscale control of membrane architecture may ultimately allow for multi-functional membranes that not only separate water from contaminants, but also actively clean themselves and check for damage, detect contaminants, or combine detection, reaction and separation.

Several nanomaterials are used for the formation of organic–inorganic porous composite membranes such as Al_2O_3, TiO_2, SiO_2, nAg (silver nanoparticles), CNT (carbon nanotube), chitosan and others. These nanomaterials improve membrane properties, such as (1) increased skin layer thickness, (2) higher surface porosity of the skin, (3) suppressed macrovoid formation, and (4) higher permeability of the membrane (Taurozzi *et al.* 2008).

The very efficient transport of water through CNT membranes seems promising for energy reduction in seawater desalination. However, the road to useful industrial

Table 2. The largest MBR plants worldwide*

Installations	Location	Technology Provider	(Expected) date of commissioning	PDF (MLD)	ADF (MLD)
Henriksdal, Sweden	nr Stockholm, Sweden	GEWPT	2016-2019	864	536
Seine Aval	Acheres, France	GEWPT	2016	357	224
Canton WWTP	Ohio, USA	Ovivo USA/ Kubota	2015-2017	333	159
Water Affairs Integrative EPC	Xingyi, Guizhou, China	OW		307	
Euclid, OH, USA	Ohio, USA	GEWPT	2018	250	83
9th and 10th WWTP	Kunming, Yunnan, China	OW	2013	250	
Shunyi	Beijing, China	GEWPT	2016	234	180
Macau	Macau Special Administrative Region, China	GEWPT	2017	210	210
Wuhan Sanjintang WWTP	Hubei Province, China	OW	2015	200	
Jilin WWTP (Phase 1, upgrade)	Jilin Province, China	OW	2015	200	
Caotan WWTP PPP project	Xian, Shaanxi, China	OW		200	
Brussels Sud	Brussels, Belgium	GEWPT	2017	190	86
Macau	China	GEWPT	2014	189	137
Riverside	California, USA	GEWPT	2014	186	124
Brightwater	Washington, USA	GEWPT	2011	175	122
Visalia	California, USA	GEWPT	2014	171	85
Qinghe WRP (Phase 2)	Beijing, China	OW	2011	150	
Nanjing East City WWTP (Phase 3)	Jiangsu Province, China	OW	2014	150	
Yantai TaoziWan WWTP (Phase 2)	Shandong Province, China	OW	2014	150	
Jilin WWPT (Phase 2)	Jilin Province, China	OW	2014	150	
Qinghe	China	OW/MRC	2011	150	150
Changsha 2nd WWTP	Hunan Province, China	OW	2014	140	
North Las Vegas	Nevada, USA	GEWPT	2011	136	97
Ballenger McKinney ENR WWTP	Maryland, USA	GEWPT	2013	135	58
Assago	Milan, Italy	GEWPT	2016	125	55
Daxing Huangcun WRP	Beijing, China	OW	2012	120	
Jinyang WWTP (Phase 1)	Shanxi Province, China	OW	2015	120	
Cox Creek WRF	Maryland, USA	GEWPT	2015	116	58
Yellow River	Georgia, USA	GEWPT	2011	114	71
Shiyan Shendinghe	China	OW/MRC	2009	110	110
Aquaviva	Cannes, France	GEWPT	2013	108	60
Urumqi Ganquanpu WRP	Xinjiang Uygur Autonomous Region, China	OW	2014	105	
Busan City	Korea	GEWPT	2012	102	102
Wenyuhe River Water Treatment (Phase 2)	Beijing, China	OW-MRC	2010	100	
Hebei Zhengdi WWTP	Hubei Province, China	OW	2014	100	
ZhuHai Qianshan WWTP	Guangdong Province, China	OW	2016	100	
Guangzhou	China	Memstar	2010	100	
Wenyuhe	Beijing, China	OW/Asahi Kasei	2007	100	100
Beijiao WWTP renovation project	Ordos, Inner Mongolia	OW		100	
Xianlin WWTP PPP project	Nanjing, Jiangsu, China	OW		100	
Beijiao WWTP	Ordos, Inner Mongolia	OW		100	
Zhengding new district WWTP	Zhengding, Hebei, China	OW		100	
Chengxiang WWTP Phase I	Haiyan,Zhejiang, China	OW		100	
Chengxiang WWTP Phase I	Haiyan,Zhejiang, China	OW			

*Last updated February 2016. PDF: Peak daily flow, Megalitres per day. ADF: Average daily flow, Megalitres per day. GEWPT: GE Water and Process Technologies. OW: (Beijing) Origin Water. MRC: Mitsubishi Rayon Corporation.

applications of CNT membranes may be yet a long and arduous one owing to the selectivity and cost requirements (Verweij 2007). Maximous *et al*. (2009) prepared PES ultrafiltration membrane with entrapping Al_2O_3 nanoparticles and used this membrane at the activated sludge filtration. Al_2O_3 nanoparticles decreased the adhesion or the adsorption of the EPS on the membrane surface and increased the filtration performance of membrane.

In particular, incorporation of quorum quenching nanomaterials makes the membranes 'reactive' instead of a simple physical barrier. Kim *et al*. (2011) prepared an acylase-immobilised nanofiltration membrane with quorum quenching activity. This membrane prohibited biofouling, namely the formation of mature biofilm on the membrane surface owing to the reduced secretion of EPS.

Overall, these nanomaterials could contribute to the development of specific membranes in many desired ways. One challenge in the future will be to use these developments to tailor membranes for processes that rely on driving forces other than pressure, such as forward osmosis or membrane distillation.

Forward osmosis (FO) and membrane distillation (MD)

In the context of climate change, the environmental and energy issues become essential and must be taken into account in the design of membrane systems and in their mode of operation, so that membrane processes remain or become competitive. The relatively high energy demand to operate conventional pressure driven membrane processes (NF, RO) still remains a challenge to be managed. As alternatives to reverse osmosis (RO), membrane distillation (MD) and forward osmosis (FO) are being considered for low-energy seawater desalination and wastewater reuse

Forward osmosis (FO)

FO, a novel low-energy and natural process, has been developed in the past few years as an alternative membrane technology for desalination. Many studies on the use of FO for industrial and domestic applications can be found in literature. During the past decade, FO has been studied in wastewater treatment, seawater desalination, the food industry for stream concentration, for fracking and produced water volume minimisation as well as for purifying water in emergency situations. New and high performance FO membranes are being researched (Chou *et al*. 2010; Wang *et al*. 2010).

In September 2008, Modern Water (Guildford, UK) built the world's first FO+RO desalination plant in Gibraltar on the Mediterranean Sea. This local plant successfully completed testing procedures of the product water and, since May 2009, water has been supplied to the local community. A year later, in September 2009, a larger desalination plant was commissioned in the Sultanate of Oman at Al Khaluf. This new plant shares pre-treatment facilities with an existing RO desalination plant, providing a good opportunity to compare both technologies. Results were better than expectations, especially on resistance to fouling and product water quality. Moreover, despite the very bad quality of the source seawater, the FO membranes as a pre-treatment to RO have not been cleaned or replaced over the year of operation. In contrast, when not using FO as a pre-treatment the RO membranes from the other desalination plant had to be cleaned every two to four weeks and had been replaced over the 1-year operation time. This clearly demonstrates the low fouling propensity of the FO process compared with the other pre-treatment technologies to RO membrane process.

Other key advantages of the FO desalination process are (1) the energy consumption is lower by more than 30% compared with conventional pre-treatment to RO, (2) chlorine tolerance and compatibility with a variety of biocides with FO membranes, (3) inherently low product boron levels, and (4) higher availability than conventional RO plant owing to low fouling and simple cleaning when required.

The success of the FO process at the industrial level depends on how to prepare an efficient FO membrane having minimal internal and external concentration polarisations as well as how to separate salt free water effectively from the draw solution (Ng *et al*. 2006).

Membrane distillation (MD)

MD uses hydrophobic porous membranes as supports for a liquid/vapour interface and the vapour is transported in the membrane pores by diffusion. Indeed MD is particularly interesting because the principle itself of the transfer and selectivity of these membranes does not depend on the osmotic pressure of the solution as for the RO or the FO.

Recent work has shown the use of the MD process for the over-concentration of brines up to very high salt concentrations and thus for improving the recovery of RO plants (Méricq *et al*. 2010), for the crystallisation of salts for their valorisation (Ji 2010). Another interesting application is when coupling the MD process with solar energies (Méricq *et al*. 2011; Guillén-Burrieza *et al*. 2011) or the recovery of heat, which can make MD become a sustainable process. The work in progress on this topic throughout the world relates to the design and development of new membrane modules (Winter *et al*. 2011) and integrated systems, and on the characterisation and long-term control of membrane fouling and its properties (Krivorot *et al*. 2011). Some platforms with long-term testing of the MD system coupled with solar energy or waste heat recovery are under operation in many countries such as the Netherlands, Spain, Tunisia and Singapore.

Conclusions and outlook

Membrane fouling and energy consumption when operating membrane processes are still important challenges that need to be optimised and improved using innovative tools and technologies, as well as best operational practices. Nevertheless, for a wide range of applications in several areas, membrane treatment is becoming a competitive and economically viable option.

The main factors influencing the rapid growth of membrane technology are the following:

(1) multiple global challenges such as energy/resource shortage, climate change and rapid population growth; (2) improvement in membrane materials and modules; and (3) operational stability such as better antifouling, integrity testing of membrane processes.

The key drawbacks of membrane technologies are high energy consumption and relatively high cost. In addition, questions still remain about the durability and lifespan of the membranes: the 20-year lifespan claimed by manufacturers in continuous MBRs has yet to be proved through operational experience.

Owing to its aforementioned intrinsic properties, membrane technology will be the centre of one of the core technologies for us to face multiple challenges in the future. Membrane technology will provide great help to meet five of the fifteen Global Challenges (TMP 2011) for Humanity, namely sustainable development and climate change, water scarcity and water quality, balance population and resources, health issues and reduction of diseases and immune microbes, renewable energy and energy conversion.

One of the manufacturers of FO membranes in the US, the California based company Porifera confirmed similar results when comparing FO to UF as a pre-treatment to RO to desalinate water. FO demonstrated lower fouling comparing to UF pre-treatment. When using FO as a pre-treatment to desalinate water there are many opportunities to use different draw solutions other than Sodium Chloride to keep process running and optimise it.

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Metals and Related Substances in Drinking Water

Written by *Matt Bower, Margherita Ferrante, Colin Hayes, Tiina Leiviskä, and Jun Ma* on behalf of the Specialist Group

Introduction

Some metals, in trace amounts, can be essential to life, whereas others are highly toxic. The Specialist Group aims to improve awareness and understanding of the issues connected with metals in drinking water.

Contamination of drinking water by metals and metalloids can occur throughout drinking water systems, from 'source to tap' owing to industrial effluents, natural sources, water treatment chemicals, water mains and domestic pipework systems. Effects of metal contamination can range from aesthetic, such as discolouration and adverse taste and odour, to significant health impacts for those consuming the water.

Existing Specialist Group knowledge

The metals and metalloids most commonly associated with drinking water are listed in Table 1 together with the World Health Organization (WHO) guidelines, European Union (EU) and US standards that apply, their main significance and the principal control options.

Table 1. Metals and metalloids in drinking water

Metal or metalloid	WHO Guideline (µg L^{-1})	EU standard (µg L^{-1})	US standard (µg L^{-1})	Health	Aesthetic	Mineral balance	Control
Aluminium	100–200	200	50–200		✓		Source treatment and process control
Antimony	20	5	6	✓			Source treatment (rare)
Arsenic	10†	10	10	✓			Source treatment (common)
Barium	700*	—	2000	✓			Source treatment (rare)
Boron	2400	1000	—	✓			Source treatment (rare)
Cadmium	3	5	5	✓			Source protection (industry)
Calcium	—	—	—			✓	Source and point-of-use treatment
Chromium	50†	50	100	✓			Source protection (industry)
Copper	2000	2000	1300	✓	✓		Restrict use and corrosion control
Iron	—	200	300		✓		Source treatment and pipe rehabilitation
Lead	10†	10	15	✓			Pipe removal and corrosion control
Magnesium	—	—	—			✓	Source and point-of-use treatment
Manganese	(400)‡	50	50	(✓)	✓		Source treatment
Mercury	6	1	2	✓			Source protection (industry)
Molybdenum	—	—	—	✓			Source treatment (rare)
Nickel	70	20	—	✓			Restrict use and corrosion control
Selenium	40†	10	—	✓			Source treatment (rare)
Sodium	—	200,000	—	✓			Source treatment or blending
Uranium	30†	—	30	✓			Source treatment (rare)
Zinc	—	—	—		✓		Restrict use and corrosion control

*Likelihood of imminent revision upwards to 1.3 mg L^{-1}.
†Provisional value.
‡Health-based value, not GV. Health significance under review.

Sources of metals contamination

The combination of quality risks facing a particular water supply is unique to that supply, and may vary with time. Some types of supply are especially vulnerable to particular contamination. A Drinking Water Safety Plan approach is advocated for identifying and managing risks. Common ways in which metals may enter water supplies are listed below:

Source

- Naturally occurring contamination arising from local geology and catchment conditions.
- Changing circumstances in the catchment mobilising metallic elements .
- Man-made contamination of the natural environment.

Treatment

- Addition and inadequate removal of metal ions used in water treatment process.
- Use of inappropriate materials in contact with water during the treatment process.
- Contamination of water treatment chemicals.

Distribution

- Corrosion of pipeline materials .
- Use of inappropriate pipeline or storage materials.
- Ingress of contaminants.

Internal plumbing systems

- Corrosion of plumbing materials and fittings (potentially exacerbated by inadequate conditioning of the water).
- Use of inappropriate plumbing materials.

General trends and challenges

Particular issues relating to metals and metalloids in drinking water are highlighted in the summaries that follow:

Chromium

Chromium is usually classified as a heavy metal with some metallic properties. Chromium may exist in the environment as either anionic or cationic species, depending on its valence state. Recent studies have linked chromium VI in drinking water to gastro-intestinal cancer in experimental animals and indicated that public exposure to chromium VI in general may be higher than previously thought. Based on a study by the US National Toxicology Program (NTP), it was showed that oral exposure to chromium VI was carcinogenic in experimental animals. It is carcinogenic to humans by inhalation but there is evidence that the dose response by the oral route is non-linear. Hexavalent chromium (VI) compounds are widely used in industry, while trivalent chromium (III) is used as a nutritional supplement. Cr(VI) is considered to be more toxic and carcinogenic than its trivalent form which is much less bioavailable. Chromium could be introduced into water by both natural and anthropogenic activities such as dissolution of minerals, manufacturing and mining, tanneries, electroplating and paints.

A range of techniques have been employed to remove heavy metal ions or anions, including chemical precipitation, ion exchange, solvent extraction, adsorption, membrane filtration and electrochemical technologies:

(1) Capacitive deionisation (CDI) has been studied as a low-cost and easy-to-operate process for heavy metal removal and water purification CDI is an electrosorption process that uses a low electrical field (0.6–2.0 V DC) to remove ions from solution by adsorbing them onto the electric double layer (EDL) of two porous electrodes.
(2) Liquid membranes include bulk liquid (BLM), emulsion liquid (ELM) and supported liquid membranes (SLM). Among the different liquid membranes types, the SLMs have been widely used for the separation of the toxic compounds. BLMs are not economically scalable to industrial applications, while the more practical SLMs tend to lose solvent to the water phases and their lack of stability which may embarrasses the applications.
(3) Activated carbons have been widely used for the adsorption of Cr(VI) in terms of their wide availability, developed physical and chemical properties. The micropores in activated carbons could physically adsorb Cr(VI) from water via the Van de Waals force.
(4) Microscale granular metallic iron (zero valent iron, mZVI) has been widely used as a reducing agent for the remediation of a variety of contaminants in permeable reactive barriers. However, the cost of this method is considered high and the process duration can be at least 15 years. Meanwhile, nanoscale zero valent iron can be directly injected as a slurry in the sub-surface for the remediation of a variety of contaminants such as azo-dyes, chlorinated solvents, chlorinated pesticides, inorganic anions and transition metals. Iron nanoparticles have been injected in at least 26 sites worldwide for the remediation of a variety of organic and inorganic contaminants. However, such treatments are handicapped by high treatment cost.
(5) Fe-doped nanosheet mixed metal oxides were developed with high efficiency removal of chromium from water, which may be potentially used in water treatment plants due to its low cost and convenient operation.

Arsenic

Arsenic (As) is a metalloid widely distributed in the environment because of many geological and hydrogeological processes. In addition, it is widely used in various fields such as electronics, agriculture, wood preservation, metallurgy, and medicine.

Groundwater arsenic contamination occurs worldwide. It has caused particular problems in South Asia, especially in Bangladesh and West Bengal, that depend extensively on tube wells for rural water supply.

It is known that inorganic As species, i.e. As(III) and As(V) are more toxic than organic species such as arsenobetaine, arsenocholine, and other organic compounds found in food. Inorganic arsenic (iAs), along with fluoride, is considered to be of major public health concern from exposure through drinking water, which represents the main source of exposure for human populations.

Numerous epidemiological studies show strong evidence of causal association between As exposure through drinking water at concentrations above 100 µg L^{-1} and skin and internal cancer, particularly cancers of the urinary bladder, lung, and kidney in adults in addition to non-carcinogenic effects including dermal lesions, hypo- and hyper-pigmentation, keratosis; peripheral vascular disease; cardiovascular diseases; type 2 diabetes; adverse pregnancy outcomes; respiratory diseases and adverse immune response. Considering the toxicity of arsenic, the WHO and the US Environmental Protection Agency have set the maximum acceptable level of arsenic in drinking water at 10 µg L^{-1}.

Several conventional technologies for arsenic removal from water, which include oxidation, adsorption, coagulation–flocculation, and membrane techniques, are applied. Often these processes are not cost-effective for effluent containing high concentrations of arsenic and generate large amount of sludge. Furthermore, most of these treatments have been reported to be less efficient for the removal of arsenite (As(III)) than arsenate (As(V)). Accordingly, conventional techniques, as well as new experimental ones, generally focus on treatment technologies on arsenate removal by using a two-step approach consisting of an initial oxidation from arsenite to arsenate followed by a technique for the removal of arsenate.

Interest in natural flocculants has increased recently because they are potentially less toxic, more environmentally friendly and biodegradable, and, in some instances, less expensive and more abundant than synthetic flocculants.

Electrocoagulation process with aluminium as sacrificial anodes in a continuous filter press reactor have been tested, after arsenite was oxidised to arsenate by addition of 1 mg L^{-1} hypochlorite. This experimental technique produces small amounts of sludge, but possible interferences of other ions by electrocoagulation have not yet been published.

Among common technologies, the adsorption method is widely used for the merits of low cost and easy operation. New insights derived from an emerging class of adsorbents, such as nanomaterials made of carbon, titanium, iron, ceria, or zirconium, which have high reactivity and high specificity. Nevertheless, due to their high surface energies, they tend to aggregate in aqueous media, which results in a drastic decrease in surface area and therefore in a reduced capacity and selectivity, reducing the process lifetime and potential for real life application. A promising new adsorbent material for arsenate removal is the novel class of metal organic frameworks (MOFs), which possess high surface areas, tuneable pore sizes and shape, high thermal stability, and a relatively simple synthesis.

The experiments in progress on new low cost and easy operations, with lower environmental impact than conventional ones, should be encouraged and supported economically. Owing to the different scenarios of arsenic groundwater contamination, future research efforts should focus on meeting the arsenic drinking water standard, field testing, developing post-treatment processes, and evaluating the stability of arsenic-laden wastes.

Vanadium

Vanadium is released into the environment mainly by the combustion of oil and coal, but also from natural sources such as volcanic emissions. At the moment, vanadium is on the US Environmental Protection Agency Drinking Water Contaminant Candidate List for consideration as a regulated chemical in drinking water due to its possible carcinogenicity. Owing to the concern about vanadium toxicity in humans, vanadium speciation and removal from water have been investigated extensively. Several techniques can remove vanadium from water such as ion exchange, coagulation-flocculation and nanofiltration. In addition, vanadium has a strong affinity towards iron materials and that also controls vanadium mobility in natural water systems. Besides vanadium removal from water, vanadium recovery should also be considered at the same time. Vanadium and its compounds have multiple applications in industry, moreover, the EU has been highly dependent on vanadium import.

Use of iron/manganese nano-particles for heavy metal removal

Unlike groundwater, which often contains arsenic, manganese or iron; surface drinking water resources seldom suffer heavy metal pollution in isolation. However, there are some pollution accidents, like mine tailings leaks, leading to a sudden rise in one or more heavy metals to a very high concentration in drinking water resources. Here we need simple methods, which are highly effective, for heavy metal removal and are suitable for both large municipal-scale systems and small supply systems.

Manganese oxides have been widely used to adsorb heavy metals in water. Compared with pre-formed manganese oxides, manganese oxides formed *in situ*, usually prepared simply by oxidising $MnSO_4$ with $KMnO_4$, have higher surface areas and higher adsorptive potential for the heavy metals in water. This process offers many advantages such as low space and energy requirements; simple plant design; is easy in maintenance, operation and handling; and low capital and operational costs. Moreover, using Fe(II) as the reductant, we can prepare Fe–Mn binary (hydro)oxides, which can remove anionic heavy metal from water with a high efficiency, such as arsenic, lead and cadmium from water.

Lead

Since the early 1970s, standards for lead in drinking water have tightened considerably as health effects become clearer, particularly impacts on learning and IQ of children. The WHO, in its booklet in 2010 on Childhood Lead Poisoning has drawn attention to the following:

- recent research that indicates that lead is associated with neuro-behavioural damage at blood levels of 5 µg dL^{-1} and even lower, and that there appears to be no threshold level below which lead causes no injury to the developing human brain;
- an increase in blood lead level from less than 1 to 10 µg dL^{-1} has been associated with an IQ loss of 6 points and further IQ losses of between 2.5 and 5 have been associated with an increase in blood level over the range 10 to 20 µg dL^{-1}.

Most lead in drinking water comes from the lead pipes that were used to connect a home to the water main in the street and are still in service. In Europe, it seems possible that up to 25% of homes still have lead pipes, putting one in four children at risk as a worst case in some areas. In the USA and Canada, it is estimated that about 3% of homes have lead pipes. Consequently, lead concentrations can vary significantly between water outlets in buildings and over time depending on water residence times in pipework. In some circumstances, lead leaching from alloy fittings containing high levels of lead and leaded solder also causes problems– this source is becoming increasingly significant in some parts of the world.

One obvious solution is to take out all the lead pipes but there are problems, including (1) high cost, (2) disruption, (3) split owner-ship, and (4) the refusal of consumers to cooperate. Just taking out the lead pipes owned by the water company does not solve the problem and can even make matters worse in the short term with increased lead concentrations caused by physical disturbance of the pipework. Recognising the possible extent of problems, there is a need for water companies to operate corrosion control in their supply systems. Optimal plumbosolvency control will likely entail pH elevation (to between 8 and 9) and/or the dosing of a corrosion inhibitor, the most effective being orthophosphate at typical doses of 0.5 to 1.5 mg L^{-1} (as P). In the UK, 95% of water supplies are dosed with orthophosphate, at an optimum concentration, and over 99% of random daytime samples now comply with the WHO guideline value of 10 μg L^{-1}. Where lead concentrations have been stabilised it is important not to make changes to the supply that can destabilise lead resulting in significant increases in lead concentrations–recent cases in the USA have demonstrated this.

The human health and the importance of minerals and mineral balance in drinking water

Although the subject of some debate, it is likely that the mineral composition of drinking water can affect health, both positively and negatively. The hardness of water is a measure of the content of divalent metals, especially Ca^{2+} and Mg^{2+}. Waters from granite or some kinds of sandstone are referred to as being 'soft', while especially limestone causes 'hard' waters, rich in these minerals. Substantial concentrations of micronutrients, appearing at μg L^{-1} concentrations, such as Mo (for proper liver function), Se (antioxidant), V (in many enzymes), and Cr (proper energy production) are also generally present in hard water (Rosborg *et al.* 2003). An older American ecological epidemiological study stated that the death rates due to high blood pressure and arteriosclerosis were higher in cities where the drinking water had low concentrations of Ca, Mg, Na, K, HCO_3, SO_4 and Ba, as well as of Cl, Si, Li, Sr and V, but often higher concentrations of Cu (Schroeder 1966). Costi *et al.* (1999) concluded that a regular lifelong daily intake of drinking water with highly bioavailable Ca may be of importance for maintaining the Ca balance and improving the spinal bone mass. Ca rich mineral water supplementation for one year showed an increase of the bone mass density in postmenopausal women (Cepollaro *et al.* 1996). Several studies have clearly indicated that Ca and Mg in drinking water are protective against premature death from cardiovascular diseases (Rubenowitz *et al.* 1999; Rylander *et al.* 1991; Sakamoto *et al.* 1997; WHO 2006) as well as from cerebrovascular diseases (Sakamoto *et al.* 1997; Yang 1998a). Yang *et al.* (1999a, b) also found that hard water protected from some forms of cancer, and even low birth weight (Yang *et al.* 2002), and Jacqmin *et al.* (1994) concluded a protective action against cognitive impairment in elderly.

Conclusion

The summaries above highlight several topics relating to metals in drinking water, both as problems and as a source of vital trace nutrients. On the one hand, many of the issues are the same as they were 10 years ago – lead pipes and fittings are still common in older properties and arsenic remains a problem in some groundwaters. However, progress is being made – new and exciting developments are being made in the treatment of metals in water, especially in the fields of nanotechnologies and novel adsorbents. For many metals, this needs to be considered alongside improved control at source as part of a coherent source to tap approach. The monitoring of metals also needs to improve in order to properly understand the problem and identify a solution. This is especially true of small water supplies and those in developing countries.

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Microbial Ecology and Water Engineering

Written by *Tom P. Curtis, David R. Johnson and Adrian Oehmen* on behalf of the Specialist Group

Introduction

The International Water Association can help the International Water Industry confidently face the unprecedented global challenges of providing and protecting water in the face of urbanisation, climate change and population growth. Microorganisms and microbial ecology, present powerful and prominent opportunities in meeting that goal.

The Water Sector is already the world leader in the application of microbes for engineering, primarily in water and wastewater treatment. Empirically developed biological technologies in a rich variety of formats are the mainstay of wastewater treatment. The role of microbial communities in drinking water treatment and distribution is perhaps less widely recognised, but no less important. Indeed, microbes impinge on almost every aspect of the water cycle, from the well-known, as in biological wastewater treatment, to the arcane, as in the formation of raindrops. Microbes are even thought to precipitate precipitation.

Although – or perhaps because – we are leaders in the application of microbial ecology in engineering, we recognise that we are still at the earliest stages of the development of this branch of engineering. The application of microbial ecology is undergoing a period of rapid technical and theoretical change with developments that are at the absolute frontier of scientific knowledge. The Microbial Ecology and Water Engineering (MEWE) community is not a passive consumer of science, but we are actively pushing at that frontier, uncovering deep and universal truths that gain recognition beyond the industry.

Our fundamental goal is to develop and apply this very challenging area of science for the benefit of all. This requires a three-pronged approach.

Firstly, we must put the power of the new biology in the hands and minds of practitioners today. This is both difficult and important. We already have the tools and concepts required to make more efficient use of our water infrastructure now. Our predecessor was the Activated Sludge Population Dynamics WG (pre-cursor of MEWE), which made an excellent contribution, using simple protocols based around light microscopy to help advise operators. We need to emulate them by finding comparatively simple, and accessible, ways to manage microbial communities in wastewater and water treatment technologies. This requires a thoughtful and effective partnership between academics and industry.

Secondly, we must deepen our predictive understanding of the microbial ecology of the systems at our disposal not simply for the pleasure and pride of publication, but to advance the rate of innovation. Innovation is key to meeting those global challenges and at present innovation is slow! Arguably, innovation is too slow to meet the rapidly shifting challenges of the developing world.

Thirdly, we must take that new predictive knowledge and find new applications in the water cycle – be it corrosion prevention, groundwater treatment or initiating rainfall. There are no intrinsic limits to the areas where we can apply the power of microbial ecology to the needs of water engineering.

These are ambitious goals; truly fulfilling these ambitions means putting the task of applying microbial ecology to the challenge of sustainable water in the same intellectual bracket as the war on cancer or the work of CERN (European Organisation for Nuclear Research). Our task is no less important and should demand no less intellectual rigour or commitment.

Existing Specialist Group knowledge

In the MEWE Specialist Group, among one of the key aspects related to our current knowledge deals with the application of microbial methods dedicated to the detection and quantification of different groups/sub-groups of microorganisms in water or wastewater treatment systems. The evolution in the application of these techniques has changed rapidly as a function of the ever-advancing technology. Several sequencing techniques are available for fingerprinting diverse microbial communities, such as those present in activated sludge systems, where one of the most commonly applied at present is high-throughput amplicon sequencing. These methods are useful for determining the number of reads corresponding to a given genetic sequence, which is related to the proportion of a microbial population within a community. Other methods include microscopy-based visualisation techniques such as fluorescence *in situ* hybridisation (FISH), which allows quantification of the biovolume of cells binding to a fluorescent probe. While more time consuming and laborious than high-throughput methods, it can avoid certain issues such as the biases associated with DNA extraction and polymerase chain reaction (PCR) amplification.

Linking the abundance of particular organisms with their metabolic functions and activity is usually just as important as quantifying the number of organisms themselves. The application of, for example, 'meta-omics' to the microbial communities underpinning water/wastewater treatment plants is rapidly expanding. Meta-omics refers to techniques that attempt to describe the complete (or nearly complete) set of species, genes, transcripts or proteins present within a microbial community of interest. Meta-omics has conventionally been applied for one of two reasons. First, they are used to obtain a description of a WWTP microbial community. This includes identifying species that correlate with particular functions (i.e. who's there and what are they doing), which species, genes, or gene products tend to occur together (i.e., co-occurrence profiles), and which species, genes or gene products are common or unique across a set of WWTP communities. Second, meta-omics are used to explore how changes in operational parameters, environmental conditions, or performance metrics correlate with changes in the composition of species, genes, or gene products. Other methods that link the community structure and function include quantitative real-time polymerase chain reaction (qPCR), which can be used to determine the abundance of functional genes (or gene transcripts) of interest (e.g. for ammonia oxidation, or polyphosphate formation), and microautoradiography or RAMAN spectroscopy linked with FISH (MAR-FISH, RAMAN-FISH), which aim to identify substrate uptake or other relevant functions with the specific groups of organisms.

With our ever-increasing knowledge regarding the abundance and activity of organisms relevant in water/wastewater treatment processes has come a more in-depth understanding of how these processes work. In-depth knowledge of the microbially-driven processes occurring in water systems is of key importance in order to better control them. Predicting the performance of these highly dynamic systems that can suffer frequent disturbances is very challenging. This knowledge can lead to direct benefits in how these systems are operated, for purposes of increasing removal efficiency or improving cost-effectiveness, and can be incorporated into new and more advanced process models. Optimising nitrogen and phosphorus removal efficiency in wastewater treatment plants (WWTPs), for example, simultaneously reduces the need for supplemental addition of carbon sources and chemical precipitants and reduces oxygen demand, thereby lowering operational costs. Microbial ecology is playing an important role in this context since increasing our knowledge on the identity and metabolism of the microbial communities responsible for biological nutrient removal aid the development of novel processes, optimises existing processes and enhances mathematical models. There are several examples of discoveries leading to such advances, and which provide opportunities to upend conventional systems and technology. First is the discovery of the anaerobic ammonium oxidation (anammox) process, which relied on the identification of a novel group of bacteria that mediates ammonium and nitrite removal from wastewater without the need for aeration. Second is information on the metabolic pathways of nitrifiers and denitrifiers, and new insights to the roles of those microbial groups in regulating, for example, nitrous oxide emissions. Finally is the progress achieved in understanding competition between different microbial groups, such as the polyphosphate accumulating organisms (PAOs) and glycogen accumulating organisms (GAOs), to optimise enhanced biological phosphorus removal (EBPR) processes.

Translation of the current knowledge of the MEWE specialist group towards industrial application for process design or optimisation is an important component of the group's work, where we are only starting to scratch the surface of the potential impact that can be realised with the new knowledge being generated through microbial ecology. Realising this objective involves strong interaction with professionals across the other IWA specialist groups. This is a high priority for MEWE. One of MEWE's key roles in the IWA is to expand upon the limits of our current knowledge and understanding of the key microbial processes taking place in water and wastewater, both in engineered (e.g. treatment plants) and also natural environments. Our members possess a diverse array of backgrounds and experiences to meet the challenges associated with assessing the wide range of processes relevant to the water sector. We have a deep fundamental knowledge of microorganisms and their biochemical processes that is continuously expanding. Putting this knowledge to use to improve the quality of our water is the ultimate goal. We believe that this goal can be best achieved by close interaction with water professionals worldwide in order to achieve technological solutions that meet our current and future needs.

General trends and challenges

The global challenges for the MEWE Specialist Group are challenges for the whole of the global water industry: we need to make the best use of our existing water infrastructure and develop wholly new technologies fit for the low energy, low carbon urban future we face in the 21st century.

The MEWE Specialist Group has a particular role in transmitting the astonishing rate of development in contemporary microbial ecology to the water industry in a form that the industry can use and apply. There is a substantial lag between science and application at present. This reflects the relatively conservative nature of the water industry, where careers, technologies and legislation have been built around 20th and even 19th Century concepts and technologies. However, the excitement and wonder of new science is often at the expense of the technical accessibility and predictability that practitioners need.

Nevertheless, those practitioners and water utilities taking up the new tools are finding that they can reduce costs and gain beneficial operational insights. For example, flow cytometry is being explored and adopted for drinking water quality monitoring. Flow cytometers are expensive, but quickly provide easy-to-interpret results and the cost per sample is very low. It is likely that nucleic acids-based technologies will be adopted if they can be deployed just as simply, even if the capital costs are relatively high. Once deployed, this could give water utilities tools to monitor and manage the biological resources in water and wastewater treatment. This is desirable in itself and will ready the industry to reap the benefits of more fundamental studies on the microbial ecology of water engineering.

In the coming decade a slow-down in the dizzying pace of development of the methodological toolbox is likely to emphasise the need to develop knowledge, and not to just generate data. There will be a growing realisation that all engineered biological systems are subject to a set of universal rules. These rules will be applied in a concrete framework that will create design and management guidelines that can be used to develop new capabilities. The construction of the framework will require a cultural change within MEWE, with a greater emphasis on generating validated quantitative theories that may require, for example, the routine use of the high performance computing.
This synthesis of cheap and rapid methods with a usable predictive framework will generate many "hot topics" as the community gains new abilities and confidence and these may well include:

- o de-skilling of new technology;
- o generic models for design;
- o low-energy wastewater treatment and resource recovery;
- o new technologies for water treatment and distribution;
- o micropollutants and antimicrobial resistance;
- o genomics meeting public health;

Conclusions

The microbial ecology and water engineering specialist group possesses a deep understanding of the microorganisms present in the water cycle and how these organisms function, with the ability to apply a wide array of advanced tools for monitoring and assessing their activity, and know-how regarding the implications that this information can have on water and wastewater systems. MEWE is placing a high priority on increasing our application-driven focus in order to meet the challenges being faced within the water sector. Further consensus-building would be beneficial in order to come to an agreement regarding the best approaches and methodologies in applying microbial ecology tools for each intended purpose. Strong communication and dissemination is needed with water professionals from other areas in order to highlight why deeper knowledge regarding microbial populations and their activity is beneficial towards water or wastewater treatment plant operation. Increased training regarding the available state-of-the-art tools may also help to demystify the techniques and reveal the benefits that they bring to the table. Also, additional efforts focused on practical case studies quantifying the improvements in cost-effectiveness would aid in achieving more widespread application. Overall, the MEWE specialist group is committed towards achieving innovative advances in the water sector that result in lower treatment costs and improved water quality, and welcomes others to join us in this exciting endeavour and have a positive impact on water sustainability across the globe.

Modelling and Integrated Assessment (MIA)

Written by *Ingmar Nopens, Julien Laurent, Kris Villez, Lluis Corominas, Peter Bach, Lorenzo Benedetti, Manfred Kleidorfer, Lina Belia, Marie-Noëlle Pons, Ulf Jeppsson, Xu Wang, Xavier Flores-Alsina, Jose Porro, Albert Guisasola, Domenico Santoro, Ignasi Rodriguez-Roda, Andy Shaw, Paloma Grau and Elena Torfs*

Introduction

The objective of the Specialist Group is to address and promote various aspects of modelling, simulation as well as the formal methods of applying systems analysis to managing and improving the quality of the aquatic environment. This includes the development and application of mathematical models and modelling tools such as optimization algorithms, time-series analysis and forecasting, computational procedures for decision analysis and support, uncertainty analysis, design of experiments, meta-modelling, etc. The Specialist Group hereby stimulates transfer of knowledge between academia and industry and between different areas and disciplines within the water cycle, but also promotes tackling of complex challenges in a multidisciplinary fashion. In this regard, the group acts as the glue and maintains a forum for discussing inter-disciplinary issues within IWA to augment the different elements of problem-solving with those having for example engineering, economic, social, institutional (legal, governance) and cultural dimensions. Therefore, the Group is also directed at developing and promoting the application of systematic procedures of Integrated Assessment. It has two conference series under its wings, i.e. Watermatex (every 4 years) and WWTmod (every 2 years).

Existing Specialist Group knowledge

The MIA Specialist group has been and still is strongly committed to the organisation of several Task Groups and Working Groups. As a result, considerable Specialist Group knowledge is summarised and compiled in Scientific and Technical Reports (STR), which are typically the end product of a Task Group. STRs are available on Respirometry, River Water Quality Model No. 1, Guidelines for ASM Modelling, Benchmarking of Control Strategies, Uncertainty in Wastewater Treatment Design and Operation, Minimizing Wastewater Utility Greenhouse Gas Footprints, Physico-chemical Framework.

General trends and challenges

Spinout from WWTmod2014

In the wake of WWTmod2014, Nopens *et al.* (2014) presented recent trends that should maximise the benefits of activated sludge modelling, being one of the items of the SG. Key themes that were discussed included:

- The resource recovery paradigm

The rapid paradigm shift from being a wastewater treatment industry to becoming a water resource recovery industry has clear implications for WWT modelling. In line with the vision of turning wastewater treatment plants (WWTPs) into ‘factories’, not only different water quality ‘factories’ for reuse (e.g. water fit-for-use by means of traditional treatment followed by a custom train of membrane filtration steps) can be envisioned but also other resource factories such as energy (biogas production through anaerobic digestion), nutrients (such as struvite, ammonium-nitrate, and ammonium-sulphate fertilisers) and other products such as plastics (PHA production through reformed anaerobic digestion). For this reason, the generation of maximum product quantity ensuring quality, represents a new key objective.

A unit process that has not received sufficient attention in the last four decades in terms of modelling is the primary settler, as well as primary treatment in general. The models that are currently used are mostly based on empirical equations mimicking measured removal efficiencies only relying on e.g. a flow-dependency to describe diurnal or wet weather variability. However, they do not really model the underlying particle separation mechanisms. Developments at both the experimental and modelling levels are on the way (e.g. Bachis *et al.*, 2015).

- Balancing of model complexity

Over the last few decades, the biokinetic submodel (ASM) has received the most attention in WWTP modelling. In that respect, maximum growth rates and parameters relating to microbial substrate affinity are often adapted without proper justification during model calibration. It seems that these ‘lumped’ kinetic terms can be used improperly to cure most remaining deviations of model predictions from measurements. This leads to mere fitting exercises, resulting in large uncertainty in parameter estimation and significantly reducing the predictive power of the model. The fundamental underlying reason for this is the fact that WWTP sub-models have become imbalanced, that is, some processes are described in great detail (with even unjustified over-parametrization of certain biokinetic sub-models) whereas others remain too simplistic. This leads to the misuse of degrees of freedom available in the more complex sub-models to compensate for defects in the simplified sub-models. Most models for primary and secondary settling, mixing, and aeration are good examples of these simplified sub-models. It should be realised that the models used for these processes stem from the early days of WWTP modelling and have not been reconsidered since. Nowadays, new tools are available, such as Computational Fluid Dynamics (CFD) and methods for characterising settling, which could help to better understand how these processes work, especially in presence of coupled effects.

Model balancing is also something to keep in mind when developing models to better describe technologies or subprocesses for resource recovery. Models for these unit processes can be developed in isolation, to engineer a quality product through thorough process knowledge (in other engineering fields this is called 'Quality by Design' or QbD). However, these models need to be embedded in integrated models of the entire treatment plant, to better capture the overall picture and investigate how good a solution is when accounting for different performance criteria. Therefore, the objective of the model to be developed should always be clearly defined up front, as stipulated by the Good Modelling Practice guidelines (Rieger *et al.*, 2012). Different objectives usually need different models, both in terms of complexity and accuracy. However, the overall balance of an integrated model is an often-overlooked issue that deserves much more attention than it is currently receiving. Methods for checking model (im)balances using uncertainty analysis should be developed in the near future to address this in a systematic and objective way.

- Source separation and decentralisation
Decisions on source separation and decentralisation of treatment have a large impact on overall wastewater system behaviour and have already led to a lot of debate. However, this should be viewed within a larger framework, keeping in mind that WWTPs are gradually reforming into resource recovery plants. Verifying economic viability and optimisation of such systems will also require dedicated models, as the human brain is simply not capable of accounting for all of the interactions and constraints involved, let alone the dynamics of such systems. To achieve this, the evolution of model development described should take place over the next couple of years, ensuring that new developments and insights are taken into account when developing the models.

- Using models and innovative evaluation tools
The application of wastewater treatment models has partly moved from being research tools helping to increase the understanding of these complex systems to standard engineering tools. This change in use requires a shift of effort from model building to developing tools to (1) assist in preparing simulation data; (2) facilitate running simulations; (3) analysing results; and (4) reporting and report exporting.

- Integrated tools
Whereas the focus in engineering practice during the last few decades has been on developing simulators to run process models, new developments focus on integrating different tools into platforms to design, optimise and operate more areas of the urban water cycle. One direction of development is integrated urban water system modelling, which includes water resource recovery facilities (formerly wastewater treatment plants), the catchment, the sewer system, and the receiving water body. Another emphasis has been on including other connected fields such as pipe design and equipment selection into the same platform. Control system design has been a major driver for the simulator and model developments, but the classic focus has been on high-level process control, neglecting low-level controls and automation (Gernaey *et al.*, 2014). Here, a clear interaction with the Specialist Group on ICA is required.

- Incorporating uncertainty analysis
In recent years, the use of models as aids in the design and operation of treatment plants has been steadily increasing. In design, mathematical models implemented in simulation software are the first and often the only design method engineers employ. They are used instead of – or in combination with – conventional heuristic guidelines (with safety factors). In operation, mathematical models are increasingly used for optimisation.
In contrast to design guidelines, where uncertainty and variability are accounted for through the use of safety and peaking factors, process models normally do not incorporate risk evaluation procedures. Therefore, when using simulators to predict energy requirements, resource recovery potential, effluent quality and environmental risks for a plant with a 30-year design horizon, it is unclear how uncertainties linked to climate change, for example, will translate to appropriate design flexibility to meet all the criteria outlined above (Belia and Johnson, 2013).

Trends from our Task Groups and Working Groups

Several trends and challenges can be retrieved from the different Task Groups and Working Groups that are currently active within the MIA SG:

Task Group on Modelling of greenhouse gas emissions from wastewater treatment plants

Trends and challenges for modelling GHG emissions from wastewater systems can be summarised as follows:

- In recent years more and more water utilities have been generating inventories of their greenhouse gas emissions based on standard protocols, such as that of IPCC. However, in these protocols methodologies for estimating methane emissions from collection systems and nitrous oxide emissions from WWTPs are lacking.
- Research has been focusing on developing mathematical and qualitative models describing the various pathways for nitrous oxide production to assess current nitrous oxide emissions from WWTPs and identify mitigation strategies. There are now several validated models that can be used, representing different nitrification and denitrification pathways.
- A methodology for selecting mathematical models for nitrous oxide emissions has been developed.
- Research has focused on further developing methane models for sewers to predict methane emissions from gravity sewers and now a commercial model for predicting methane production/emissions from both gravity and pressure sewers exists.
- Research has focused on developing mathematical models for methane oxidation to better predict methane emissions from WWTP aeration tanks.
- There are very few water utilities that use models to get a more realistic picture of their methane and nitrous oxide emissions and attempting to mitigate them.

- Methods and equipment/sensors for measuring nitrous oxide and methane in WWTPs and sewers have improved.

Remaining challenges include the following:

- Getting water utilities to overcome the perception that methane and nitrous oxide emissions from sewers and WWTPs are too complex to address, when they can actually be measured fairly easily, modelled and mitigated in different ways.
- Most water utilities are not required to accurately assess their methane and nitrous oxide emissions and reduce them; therefore, they have little incentive to do so other than voluntary environmental stewardship and sustainable practices.
- Implementing and calibrating mathematical models for both methane and nitrous oxide still requires a high level of modelling expertise.
- Commercial products that include models with certain limitations can be misapplied by users with no expertise in methane and nitrous oxide modelling.

An STR is currently being written on this specific topic and should be out later this year.

Task Group on Generalized Physicochemical Framework

Conventional biological process models, such as the activated sludge model (ASM) family, typically lack a detailed description of physico-chemistry in biological wastewater treatment processes. Even though these models have been adequate so far for improved understanding, design and control, this is no longer true for many resource recovery processes. Cost-effective design and operation of such systems require detailed descriptions of the involved physico-chemical processes. Examples currently under study include struvite precipitation (Kazadi-Mbamba *et al.*, 2015a, b) and the biological nitrification of urine (Fumasoli *et al.*, 2015; Masic *et al.*, 2016b).

pH is one of the most important process variables strongly affecting stoichiometry and kinetics of biological/chemical processes occurring in WWTPs (Batstone *et al.*, 2012). For this reason, future modelling needs, such as plant-wide phosphorus (P) removal and its potential recovery as a fertilizer, high strength wastewater nitrification/denitrification, high salinity anaerobic digestion and biological phosphorus removal will require proper pH estimation since some of the kinetic expressions are acid-base dependent. The potential interactions of P with other compounds (Ca, Mg, Fe) and the complex chemistry (trivalence gives a strong non-ideal behaviour) require the consideration of non-ideal-conditions (ion strength, ion activity, ion pairing) to correctly describe multiple mineral precipitation dynamics (Lizzaralde *et al.*, 2015; Solon *et al.*, 2015; Kazadi-Mbamba *et al.*, 2015a, b). We still lack basic information on the concentration range of the various ions in wastewater and on how the concentrations vary with time (i.e. wastewater catchment activities, sewer corrosion, etc.).

Task Group on Design and Operations Uncertainty (DOUT)

There is a need for scientific methods that assess the probability of compliance, quantify key sources of uncertainty and evaluate how risk, benefits, and costs are distributed among stakeholders such as consultants, contractors, operators, and owners. The Design and Operational Uncertainty Task Group (DOUT) (Belia *et al.*, 2015) in conjunction with several other efforts under the DOUT umbrella is working on methods that incorporate explicit uncertainty evaluations in simulation-assisted design and operation. The group's Scientific and Technical Report is under way with publication expected in 2017.

Working Group on Computational Fluid Dynamics

CFD is a rapidly emerging field, with application to almost all unit processes. However, except for UV-initiated disinfection and advanced oxidation processes (Lyn and Blatchley *et al.*, 2005; Santoro *et al.*, 2010), CFD is hardly used in a widespread or routine way as a design, risk management, or troubleshooting tool. This offers clear opportunities to further develop the value of CFD in wastewater process evaluation. A limitation is that there are currently few CFD modelling experts within the environmental sector. To address this, the IWA Working Group on CFD & Wastewater recently published recommendations for Good Modelling Practice when applying CFD to WWT unit processes (Wicklein *et al.*, 2015). Scientific challenges concerning the use of CFD in WWT could be identified:

- Development of improved yet computationally-efficient models for use in plant-wide modelling (compartmental models for activated sludge tanks, one-dimensional models for settling tanks) using knowledge gained from CFD simulations (Laurent *et al.*, 2014).
- Coupling to activated sludge biochemical kinetics models.
- Incorporation of density-coupled solids transport in suspended growth reactor CFD models.
- Improved description of rheology, especially for digester models.

Working Group for Life Cycle Assessment of Water and Wastewater Treatment

LCA will play an important role by evaluating new technologies and processes for water and wastewater treatment in terms of overall environmental sustainability. LCA can help in identifying solutions with low environmental impacts and to identify trade-offs from one area of environmental concern to another. ISO standards (ISO, 1997; 2006a; 2006b) provide guidelines for conducting LCA studies. However, there are no specific guidelines for LCA in the field of wastewater treatment. The seminal work of the Working Group for Life Cycle Assessment of Water and Wastewater Treatment was the publication of a literature review on LCA studies applied to wastewater treatment (Corominas *et al.*, 2013). The analysis of the papers showed that within the constraints of the ISO standards, there is large variability in the detailed execution of different studies. The need for stricter adherence to ISO methodological standards to ensure quality and transparency was made clear and emerging challenges for LCA applications in wastewater treatment were identified:

- Adaptation of impact assessment methods to include emerging pollutants (e.g. organic micropollutants, nanoparticles or pathogens).

- Development of more regional impact assessment factors.
- Improvement of data quality.
- Reduction of uncertainty in LCA data and impact assessment.

Current work of the Working Group is directed towards writing a report that collects recommendations for Good LCA Modelling Practice applied to wastewater treatment processes.

Working Group on Integrated Urban Water Management

Integrated modelling approaches in urban water management have evolved significantly over the last decade as evidenced by several major reviews on the topic (Bach *et al.*, 2014; Benedetti *et al.*, 2013; Lerer *et al.*, 2015) and special issues in Water Science & Technology (Sitzenfrei *et al.*, 2014) and Urban Water Journal (Schütze and Muschalla, 2013). Benefits of integrated approaches have been demonstrated in a large number of urban drainage studies and, more recently, its engineering application has been recognised by the scientific community (Pikaar *et al.*, 2014; Rauch and Kleidorfer, 2014).

Current trends are shifting towards more holistic and interdisciplinary approaches and the linking of models beyond the urban water sector to include economics, human behaviour, and urban development (Bach *et al.*, 2014). Involvement of stakeholders throughout the modelling process is becoming increasingly viable and effective for investigating sustainable water management options (Voinov and Bousquet, 2010; Voinov *et al.*, 2016). Model complexity is increasing and the advancements of computational hardware and open source platforms for model integration are supporting the development of new tools. In the urban drainage field, better guidance and understanding of real-time-control have advanced integrated urban wastewater modelling (Benedetti *et al.*, 2013). Data requirements and availability, however, remain a major challenge for calibrating and validating integrated models (Bach *et al.*, 2014; Langeveld *et al.*, 2013a). To guide the advancement of the modelling science, the Working Group on Modelling Integrated Urban Water Systems (MIUWS) was established in 2013 to promote the exchange of ideas and to create a network of experts in the field.

Adoption of models in practice remains slow. In 2015, the Working Group conducted two industry and research workshops on understanding the status of adoption of integrated models in practice. These workshops, held at the 9th IWA Symposium on Systems Analysis and Integrated Assessment (Watermatex 2015, Gold Coast, Australia) and the 10th International Urban Drainage Modelling Conference (Mont-Sainte-Anne, Canada) sought insights from researchers and practitioners. Some major findings indicated that practitioners are embracing the benefits of integrated modelling approaches as witnessed in a Dutch case study that was a centrepiece of discussions (Langeveld *et al.*, 2013b). Communication of the modelling and its tangible benefits, however, needed urgent improvement. Understanding how models can be used for better decision-making and policy regulation were seen as challenging tasks for future research. The emergence of new data sources and open data standards could lead to innovation in the field.

Looking at these developments it is clear that integrated urban water management will continue to broaden its scope of the urban environment, which is supported by the MIUWS Working Group. While there are opportunities to improve sustainability and resource efficiency in building and operating our systems, these new modelling approaches will continuously frame new research questions on model linking, data management, model calibration, and consideration of uncertainties.

Other trends in the scope of MIA

- AB systems
  The AB-process was originally developed as a means to separate COD removal from nitrogen removal. In modern applications the main goal is more often to recover additional energy from the incoming municipal wastewater. The process consists of two main stages: the A-stage, where COD-rich material is redirected from the wastewater to energy-recuperation processes and the B-stage, where the emphasis is on the compliance with effluent regulations (i.e. mainly nitrogen removal).

  At the moment high rate activated sludge (HRAS) systems, being the most popular A-stage technology, are operated at a safe SRT to meet discharge limits. However, this decreases the energy recovery potential. Modelling can help in gaining more knowledge in the mechanisms and operational strategies playing a role in this process. With respect to the A-stage, Nogaj *et al.* (2015) include colloidal material and slowly biodegradable soluble material in their ASM-based model. Smitshuijzen *et al.* (2016), on the other hand, use a simpler approach to describe the performance of highly-loaded aerobic COD removal reactors. Another common problem in the operation of AB-systems is the poor settling behaviour of the sludge coming from the A-stage. Current research focuses on the link between biology, hydrodynamics and the sludge settling and flocculation properties. B-stage modelling mainly comes back to the models describing nitrogen removal and possibly nitrous oxide emissions. These models are already quite established and are now used to design control strategies (Al Omari *et al.*, 2015).

- Numerical techniques
  Several researchers are focused on the development and implementation of efficient simulation techniques. These relate mainly to increasing the efficiency of available simulation software and is most often focused on getting the best of Ordinary Differential Equations (ODEs) (steady state solution, stiff systems, continuous/discrete/hybrid problems e.g. SBR) (Rosen *et al.*, 2006), solving multi-dimensional sets of implicit algebraic equations (for physico-chemical modelling (Flores-Alsina *et al.*, 2015)), handle partial differential equation systems and translation to ODEs (e.g. biofilms, settling (Boltz *et al.*, 2011; Bürger *et al.*, 2012)), and systems with heterogeneous properties (e.g. computational fluid dynamics). The increasing use of local/global uncertainty/sensitivity analysis during modelling studies will require the use of new tools to accelerate the process (parallel/cloud computing) and guarantee convergence (Vanrolleghem *et al.*, 2015). In addition, methods to automate and speed up protocols for model identification are being developed and include model reformulation techniques, transparent black-box modelling (Masic *et al.*, 2016a), deterministic optimiza-

tion schemes and systematic decoupling of model identification steps (Masic *et al.*, 2016b).

- Design of experiments: response surface methodology and symbolic regression
  The need for understanding both the direct effects and side-effects of various processes (within the urban water and wastewater system as well as in other process related industries) at different spatial-temporal scales, and often under dynamic conditions, has suggested the development of advanced unit process models (or sub-models) able to describe the complex bio-chemical and physical phenomena occurring. These sub-models, in which relevant processes are mechanistically described and integrated, are required to be computationally efficient while maintaining an adequate level of accuracy. To achieve this objective, meta-modelling techniques able to generate 'a model of a model' are sometimes used. In other words, as a model is a theoretical representation of various phenomena in the real world, a meta-model is yet another abstraction containing properties of the model itself. The starting point for building accurate meta-models is to conduct experiments according to efficient experimental design. This is also driven by the need for collecting accurate data with limited resources available, i.e. budget and time. From an engineering perspective, efficient experimental design would allow not only to generate meta-models but also to: (i) reduce time to develop new products; (ii) improve performance of existing processes; (iii) improve product reliability and robustness; and, (iv) evaluate and optimise design alternatives. Once the experiments are designed and completed, various meta-modelling techniques can be used to develop mathematical relationships able to describe the observed data. Among those, the use of response surface methodologies and symbolic regression techniques are increasingly gaining popularity in the scientific community.

  The use of response surface methodology (RSM) was introduced by Box and Wilson (1951). The main idea of RSM is to use a sequence of statistically-designed experiments to obtain an optimal surface that represents the response of the investigated process to a variation of an input variable. As acknowledged by the authors, this model is only a polynomial approximation of the actual response surface of the system, but it is used because it is easy to estimate and apply, even when little is known about the process. Since then, numerous alternative RSMs have been introduced with various degree of success, including those based on radial basis functions, neural networks, stochastic processes, etc.

Symbolic regression is a type of regression analysis that searches the space of mathematical expressions to find the model that best fits a given dataset, both in terms of accuracy and simplicity (Schmidt and Lipson, 2009). No particular model is provided as a starting point to the algorithm. Instead, initial expressions are formed by randomly combining mathematical building blocks such as mathematical operators, analytic functions, constants, and state variables. New equations can then be formulated by recombining previous equations using genetic programming and can be subsequently tested on a validation database to determine their robustness against extrapolation and overfitting.

Research and Development Agenda

- Data management
  Modern simulators will easily create gigabytes of data and this can overwhelm users. Special tools are required to firstly deal with the sheer volume of data created, then encapsulate knowledge to help users analyse all of the data generated by the simulator, and lastly, to evaluate the results based on multiple criteria (i.e. big data). More attention should be given to how the human brain processes information. Based on this, new tools should be developed to improve the conversion of data into information, leading to a better basis for decision making.

- Closer interactions with other SGs to further strengthen the 'integrated' aspect of the Specialist Group need to be established. This both goes for application fields (e.g. drinking water and process water technology) as well as methodological aspects. A potential way would be to setup joint Task Groups on specific topics. Concrete examples are the potential launch of Task Groups on 'Modelling of water disinfection' and 'Modelling of membrane processes'.

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Nutrient Removal and Recovery: Trends and Challenges

Written by *Pusker Regmi, Susanne Lackner, Siegfried Vlaeminck, Jacek Makinia and Sudhir Murthy*

Introduction

The beginnings of biological nutrient removal (BNR) from wastewater date back to early 1960s with major breakthroughs and developments for combining both nitrogen and phosphorus removal in 1970s in South Africa. Harmful algal blooms, hypoxic conditions, and loss of submerged aquatic vegetation (SAV) are the results of the accelerated growth of algae and phytoplankton due to higher concentrations of nutrients. Eutrophication poses risks to public health, resulting from direct exposure to waterborne toxins and/or consumption of shellfish contaminated with algal toxins. To combat harmful effects of eutrophication due to excessive loading of nitrogen and phosphorus in the aquatic environment, BNR has emerged as the preferred method worldwide for nitrogen especially. The early and late 1980s saw BNR expand to North America followed by Western Europe for its inherent benefits compared with other physical and chemical means of nutrient removal methods. Over the last decade, BNR has rapidly spread to many parts of developing countries in Asia, South America, and Africa as the most economical and effective method of managing nutrients from wastewater (Steffen, et. Al., 2015).

Nutrient limits

Technology based nutrient limits are now prevalent or being promulgated in Europe and Asia including more recently in large population centres of China and India. In North America, water quality based limits prevail, with phosphorus limits being mainly applied to fresh water systems, and nitrogen limits applied to estuarine systems and a combination of a few locations that transition between both systems. The typical design requirements for total nitrogen is 10 mg/L, regardless of the strength of wastewater and of the carbon/nitrogen ratio. More stringent nitrogen limits are applied to sensitive estuarine systems, with limits as low as 3–4 mg N/L for total nitrogen. Ammonia requirements are more variable and are as low as 1 mg N/L or not specified in many cases. Total phosphorus limits are usually between 1–2 mg P/L with much more stringent limits of 0.1–0.2 mg P/L being applied to sensitive water bodies, and as low as 0.05 mg P/L limits applied for very sensitive lakes and rivers in North America.

Current and future approaches for nutrient removal

Nutrient removal systems have successfully been operated in many parts of the world for decades to protect receiving waters against eutrophication. However, those systems have been focused on treating wastewater and disposing of the residuals for complying with effluent standards using extremely conservative design methodologies (typically not designed optimally, thus using more resources, such as electricity and chemicals). This regulatory compliance-based paradigm began to shift in recent years towards intensification of treatment and minimisation of resource consumption. As the nutrient removal in traditional BNR processes is closely entangled with organic carbon, the shift in optimising carbon and energy balances profoundly affects nutrient management. The future wastewater treatment facilities may become more environmentally sustainable through (1) maximising removal efficiencies, (2) optimising designs, while (3) conserving significant material and energy resources. Intensified low energy demanding technologies for retaining biomass in bioreactors are brought forward (granular sludge, biofilm carriers, and hybrid systems). The promising paradigm-shifting include also shortcut nitrogen removal processes, i.e. the nitrite shunt process (nitritation/denitritation) and deammonification (partial nitritation/anammox), first with applications on sludge reject water (sidestream) but with a strong intention to move towards implementation on the waterline (mainstream).

Nutrient recovery

Recovery and reuse of nutrients from wastewater has attracted increased focus over the past decade. Such a circular (closed-loop recovery and reuse) approach also requires plugging the recovered products into the phosphorus and nitrogen fertiliser market. Nutrient management in alternative streams from source separated urine, food waste, agriculture and aquaculture also deserves more attention. Especially the recovery of phosphorus as limited resource has been investigated and technical solutions for P recovery are available.

Nutrient management

Nutrient removal and nutrient recovery should not necessarily be considered as alternatives or competitors, both can complement each other in rendering a treatment scheme as resource efficient and low impact as possible. Integrated nutrient management in those facilities should take into consideration economic indicators and overall environmental impacts, such as greenhouse gas (especially nitrous oxide) emissions and carbon footprints; development and application of sustainability metrics, energy efficiency, use of recovered products and chemical usage.

General trends and challenges

Challenges

The main challenges for nutrient removal and recovery efforts are the following:

(1) cost of technologies;
(2) sustainability in the context of meeting low effluent standards;
(3) desired complexity of the process and availability of skilled labour force;
(4) greenhouse gas emissions from wastewater nutrient removal facilities;
(5) impact of climate change on eutrophication and water use patterns;
(6) public awareness and acceptance of nutrient recovery from wastewater as viable means of nutrient recycling.

New trends: opportunities in response to the challenges

In the context of rapid urbanisation and population growth, the wastewater sector is faced with increasingly stringent regulations in order to protect receiving water quality or promote reuse. The very low nutrient discharge limits, intended to protect water quality, often require treatment technologies that are very stringent, but are able to support ecosystems services that can create wealth and well-being for served populations. Technological advancements in wastewater treatment often follow changes in regulatory requirements that demand increased efficiency and reduced capital or operating costs. When a conventional wastewater treatment plant is required to comply with effluent nutrient standards, opportunities can be assessed for managing both capital and operating costs. Typically, the plant footprint is increased with the addition of aeration tanks and other tank capacity.A corresponding increase in electricity consumption is required for increased aeration, pumping, and mixing. In addition, larger quantities of chemicals for supplemental carbon and alkalinity may need to be provided. Raw wastewater contains energy in the form of indigenous organic carbon which is more than the energy needed for its treatment. However, conventional systems are woefully inefficient in using the carbon already inherent in the wastewater. In fact, a large portion of influent carbon is mineralised aerobically at the expense of aeration energy, and external carbon has to be added to achieve sufficient levels of treatment. In some parts of the world (especially China), anaerobic mineralisation of carbon upstream of wastewater treatment plants results in a lower amount of carbon available for nutrient removal. Furthermore, the added complexity with nutrient removal increases the qualifications required for plant operators.

Opportunities

Removal technologies

- Intensification of treatment processes and compact footprints (immersed and biofilm membranes, granular sludge, biofilm carriers, biomass separation technologies using magnets, ballast, screens and cyclones, hybrid systems).
- Short-cut nitrogen removal processes (including deammonification, denitrifying and anaerobic methane oxidation (DAMO) and nitrite shunt).
- Low and ultralow N and P thresholds to achieve stricter effluent standards and the implication for treatment/ reuse .
- Energy neutrality and process control approaches for nutrient removal.

Recovery technologies

- Phosphorus recovery from wastewater (sidestream or mainstream processes), ashes (from sludge incineration), or source separated schemes (black water, yellow water, etc.).
- Nitrogen recovery from sidestream process or alternative streams (black water, yellow water, etc.).
- Nutrient reuse by the fertiliser market and the farmers.
- Organic recovery as a by-product of nutrient removal.

Carbon footprint considerations

- Greenhouse gas emissions.
- Mitigation from nutrient removal to nutrient recovery processes.

Intensification of treatment processes

As the demands for intensification of treatment increases, technologies with more compact footprints are being developed that create niches for selection of specialized organisms for either nitrogen or phosphorus removal. These niches are created either (1) in biofilm or granular processes, (2) by uncoupling the solids retention time of the different organisms in the suspended, biofilm or granular systems, and/or (3) by improving settling rates through natural granulation approaches or with ballasts.

Short-cut nitrogen removal

The successful implementation of shortcut nitrogen removal processes can revolutionise and significantly improve the ways in which biological nutrient removal is achieved at wastewater treatment facilities, making them much more efficient and sustainable. Shortcut nitrogen removal represents a paradigm shift for the water industry, offering the opportunity for sustainable wastewater treatment, and the opportunity for the wastewater industry to be energy neutral or even net energy positive with dramatic reductions in treatment costs, which has widespread economic, environmental, and societal benefits. Some examples are listed below:

(1) The nitrite-shunt process which skips the nitrate step of biological nitrification-denitrification offering significant savings in aeration and carbon usage for nitrogen removal. This process, often referred to as the nitritation/denitritation process, can use 40% less carbon and 25% less oxygen.
(2) The use of recently discovered biological pathway of anaerobic ammonia oxidation (anammox) offers one approach to shortcut the conventional nitrification-denitrification processes. The benefits of anammox include as much as 2/3rd less oxygen and 90% less carbon requirements for nitrogen removal which translates into energy and carbon efficient nitrogen removal at a reduced cost.
(3) Researchers have also been exploring the use of anammox with DAMO. DAMO offers a carbon-efficient

pathway for nitrogen removal which allows carbon recovery for energy generation. A portion of biogas (methane), which is generated by anaerobic digestion of captured carbon for energy generation, can be used to fuel denitrification in DAMO process with a significant reduction in sludge production. The fact that small amount of nitrate is produced in the anammox process as a by-product and nitrate is removed by DAMO process with reduced carbon input opens a strong synergistic potential for a combined application.

(4) Finally, elements of nitrite-shunt can be coupled with the anammox process based on variable carbon/nitrogen ratios available.

Anammox-based technologies are already proven for high nitrogen strength wastewater typically found in the sidestreams after anaerobic digestion. The applications of similar technologies to treat wastewater in the mainstream are now being demonstrated worldwide.

Low and ultralow nitrogen and phosphorus thresholds

New approaches for treating nitrogen and phosphorus to low and ultralow levels are being developed. The nitrogen and phosphorus removal approaches often use fermentation or supplemental carbon in suspended or biofilm processes. The throughput rates for these processes and new types of supplemental carbon sources continue to be investigated. Ultra-low phosphorus removal is more recently being investigated using technology combinations of clarification, filtration and membrane treatment. Many new types of clarifiers, filters and membranes are now being used in parallel or series to achieve very low phosphorus limits of 0.05 mg P/L or less.

Energy neutrality and new process control approaches

Energy associated with aeration alone to facilitate biological treatment accounts for approximately 60% of the total energy consumption. The conundrum of traditional biological treatment is that electrical energy is used to destroy chemical energy, breaking down organic compounds in wastewater instead of harnessing them for energy generation or use as a carbon source for nitrogen removal.

It is now well-known that the chemical energy available in wastewater is more than the amount required for treatment, which means that wastewater treatment plants have great potential for being energy neutral or generate surplus energy to supply back into the grid. The latter could potentially transform the plants into energy producers rather than consumers. Traditional nitrogen removal involves nitrification where oxygen is supplied to convert ammonia to nitrate mediated by a group of bacteria commonly known as nitrifiers. Further, nitrate is converted to nitrogen gas by heterotrophic denitrifying bacteria using biodegradable organic carbon in oxygen-limited conditions. The major shortcoming of biological nitrification-denitrification is that a significant fraction of influent carbon gets oxidised to carbon dioxide during nitrification with no energy generation potential. Therefore, there is greater need of innovative technologies that allow the capture of wastewater carbon for energy generation and nitrogen removal with reduced carbon input. A positive by-product of such an approach would be the reduction in aeration and volumetric requirements for nitrogen removal, since there is no need to accommodate carbon removal. Consequently, the challenge to perform adequate nitrogen removal at reduced carbon amounts is a topic of great interest and research around the world.

The cornerstone of shortcut nitrogen removal technologies lies on recent advances in control strategies enabled by advanced sensors and automation. In fact, advanced aeration control strategies such as ammonia-based aeration control (ABAC) and ammonia and NOx based control have revealed benefits of carbon-efficient nitrogen removal with significant reduction in over-aeration (i.e., savings in aeration energy demand) which is a major improvement over the conventional dissolved oxygen control. In addition, these advanced aeration control strategies can be optimised for nitrite-shunt which offers additional savings in carbon and energy requirements for nitrogen removal and open opportunities for integration of even more efficient anammox pathways.

Recovery technologies

Phosphorus recovery

There has been a growing interest in the new category of processes that extract nutrients (nitrogen and phosphorus), with market value, from wastewater treatment streams. Traditionally, the primary focus of wastewater treatment has been on removing the nutrients to prevent ill-effects of nutrient pollution on stressed water bodies around the world. However, the concept of nutrient recovery as opposed to removal of the nutrients form wastewater is still waiting wide-spread adoption.

Technologies for removal and recovery of phosphorus from wastewater have advanced considerably in recent years. Phosphorus is a non-renewable resource and is mined at just a limited number of locations worldwide, primarily China, Morocco, the United States and Western Sahara. To show the need, it is estimated for the EU alone, roughly 975,000 tons of phosphate fertilisers has to be imported to sustain harvests and supply of crops.

Municipal wastewaters have long been thought to act as sources for phosphorus as they act as mineral deposits and the recovery has increasingly been recognised as being part of a more sustainable wastewater treatment process.

Most of the phosphorus entering a wastewater treatment plant ends up in the sludge. There are three principle routes for closing the phosphorus cycle by recovery from wastewater.

(1) Application of biosolids to land or development of products from biosolids

Traditionally, phosphorus from wastewater stream is recovered and reused by application of the sewage sludge directly to arable land. This practice continues with many new approaches for creating organic products in the fertiliser sector or for soil amendments. However, in recent years, legislation in parts of Europe and northeastern United States have limited the direct use of sewage sludge for land-spreading due to high urban densities, increasing concerns over pollutants in the sludge, and because of availability of other organic sources (such as manure).

(2) Recovery of phosphorus as struvite

Recovery of phosphorus is possible in the form of struvite crystals or magnesium ammonium phosphate (MAP) through crystallisation from the aqueous sludge phase. The phosphorus can be recovered either before or after to the sludge dewatering unit. Crystallisation of struvite directly from the sludge after digestion offers the additional benefit of improved sludge dewatering and plants can even benefit from savings in operational costs for sludge handling.

(3) Recovery of phosphorus from sewage sludge ashes

The third route is the recovery of phosphorus from the ashes of incinerated sludge. The thermal treatment process destroys all pathogens and organic pollutants and the resulting ash contains the highest concentrate of phosphorus compared to any other waste stream during municipal wastewater treatment. However, the ash also contains heavy metals that are not degraded in the incineration process and might restrict the use in agriculture. Treatment to separate the nutrients from the pollutants is therefore often necessary.

Nitrogen recovery from sidestream process

There are a limited number of facilities around the world where ammonia-nitrogen is stripped and recovered. The stripping conditions are typically improved by increasing the pH or temperature of the sidestream centrate or filtrate. The stripped ammonia is then recovered using an acid source. Typically, recovering ammonia from the sidestream process has not been cost-effective (due to stripping, recovery and transportation costs) and therefore, there are only a few facilities practicing this concept.

Nutrient recovery and reuse in the fertiliser market

There is a variety of phosphorus recovery technologies on the market now and it is generally believed that enhanced biological phosphorus removal (EBPR) (with the application of the sludge on land) and struvite crystallisation are the safest and most favourable options.

The uncertainties with the market price for phosphorus on the one side and the lack of information on product quality and consumer demands for products from recovered phosphorus on the other side require further investigations. Also the development of new technologies that address factors like ease of technology implementation and scale of operational benefits will be necessary.

Organic recovery as a by-product of nutrient removal: There are efforts underway to develop concomitant approaches for organics recovery associated with granulation and/or EBPR. Different types of organic polymers can be extracted as by-products.

Carbon footprint

Greenhouse gas emissions and mitigation

Nitrous oxide is a potent greenhouse gas with global warming potential of 310 (or 310 times more powerful than carbon dioxide). In the past decade, efforts to understand the magnitude and mechanisms for the production of nitrous oxide from the BNR processes have resulted some preliminary understanding of this complex process. Microbial nitrogen transformation pathways in a BNR system are hard to decipher with several key bacterial groups competing for the same substrates and leveraging multiple synergies. Research and modelling is underway to understand the mechanisms for production and emission of nitrous oxide from autotrophic nitrifiers and heterotrophic denitrifiers aided by advances in modelling and molecular tools capable of isolating microbial group with high degree of resolution. An IWA task group for this topic is developing a consensus on parameters associated with greenhouse gas production from these organisms and a scientific and technical report is a projected end-product.

Summary

Nutrient removal and recovery activities are accelerating in many regions of the world. There is greater interest in nutrient recovery, and to develop more energy and chemical efficient approaches for nutrient removal. There is also an increase in interest for treatment intensification. All of these drivers are resulting in exciting new research and applications.

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Particle Separation

Written by *Katsuki Kimura, Arjen van Nieuwenhuijzen, Harsha Ratnaweera and Martin Jekel* on behalf of the Specialist Group

Introduction

Particle separation is necessary both in water and wastewater treatment, and also occurs in natural aquatic situations. Characterisation of particles and an understanding of particle transport and transformation processes is indispensable for better control of particle separation processes.

Particle Separation is one of the oldest Specialist Groups of IWA. The Particle Separation SG was initiated before IAWQ and IWSA merged. Topics of concern within this SG have been extended from conventional particle separation processes (e.g., coagulation–flocculation/sedimentation/flotation/filtration) to newly emerging processes such as membrane processes and fine/micro sieving processes. Particle removal nowadays is not only essential to proper water and wastewater treatment, but also determines the possibilities for optimization of energy efficiency of processes and for energy and nutrient recovery from wastewater and sludge treatment. The definition of 'particles' has become wider with the progress of analytical techniques, especially in the sub-micron range. Additionally, the presence of nano-sized particles raises many concerns related to particle separation processes These important topics have been intensively discussed in previous specialised Particle Separation conferences. The most recent Particle Separation conference was held from 22 to 24 June 2016, in Oslo, Norway, following the one held in 2014 in Sapporo, Japan.

Control of emerging engineered nano-sized particles (nanoparticles)

The presence of engineered nano-sized particles (nanoparticles, generally defined as particles with at least one dimension <100 nm) has been recognised in both natural and engineered aquatic environments, and has raised many concerns. Although potential effects of nanoparticles on human health and environments are not fully understood, they are likely to be present in water supplies. Removal of nanoparticles in water/wastewater treatment processes has not been fully assessed. Understanding and control of the behaviour of nanoparticles are therefore necessary. Engineered nanoparticles include carbon nanotubes, composite catalysts, metal oxides and many others. Upon release of the nanoparticles into the environment, they are likely to interact with aquatic surfaces and biological species as well as to aggregate, depending on the interplay between electrostatic and van der Waals interactions (Thess *et al.*, 1996). It was reported that carbon nanotubes were relatively stable at solution pH and electrolyte conditions typical of aquatic environments (Saleh *et al.*, 2008), which would make removal by conventional coagulation/sedimentation difficult. It was shown that metal-oxide nanoparticles could be removed through coagulation but that the removal efficiency varied significantly and was dependent on the type of nanoparticles, coagulant type, and other aqueous conditions such as pH, NOM concentration and suspended solid concentrations (Sun *et al.*, 2013). Silver nanoparticles have been used in a variety of consumer products such as medicines, clothing and cosmetics. Release of silver nanoparticles into sewer systems might make wastewater treatment plants major point sources of pollution by silver. According to a field study of German wastewater treatment plants by Li *et al.* (2013), wastewater treatment plants are not potential point sources for silver nanoparticles in the aquatic environment: conventional mechanical and biological treatment in sequence was found to be effective for control of silver nanoparticles. Sun *et al.* (2013) demonstrated that silver nanoparticles can be effectively removed by conventional techniques (coagulation/sedimentation) under well-optimised conditions. Membrane processes have a significant potential for control of nanoparticles. Removal of engineered nanoparticles by membranes and membrane fouling caused by them are of great interest. Wu *et al.* (2014) investigated membrane fouling caused by nanoparticles by using fluorescent quantum dots. Plasmid DNA, which has been widely utilised in molecular biology, may be also regarded as engineered nanoparticles and might pose serious concerns as it can lead to genetically new viruses and bacteria (Lorenz and Wackernagel, 1994). Control of plasmid DNA would be very difficult: it was reported that double-stranded plasmid DNA with a 350 nm hydrodynamic diameter penetrates through membrane pores as narrow as 10 nm under pressure (Arkhangelsky *et al.*, 2011).

Optimisation of conventional processes as pretreatments for the following membrane processes

Application of low-pressure membranes (microfiltration (MF) and ultrafiltration (UF)) to potable water production has drawn much attention as they can significantly improve the safety of drinking water by efficiently rejecting pathogens such as *Cryptosporidium*. However, membrane fouling, which causes deterioration in membrane permeability, increases both the initial and operational costs of membrane processes and still hinders the benefits gained from the technology. Mitigation of membrane fouling is necessary for widespread use of membrane processes in drinking water production. To do so, identification of agents that cause membrane fouling and optimisation of pretreatment processes are important.

In recent studies, biopolymers, a fraction of NOM, have been shown to be key agents in evolution of membrane fouling (Kimura *et al.*, 2004; Yamamura *et al.*, 2007; Hallé *et al.*, 2009; Peldszus *et al.*, 2012; Kimura *et al.*, 2014). On the other side, coagulation is a major option as pretreatment before membrane processes (Howe and Clark, 2006). Therefore, identification of coagulation conditions for efficient biopolymer removal is important. The efficiency of pre-coagulation for reducing fouling is not only dependent on the type of coagulant and its dose but also on the operational conditions, especially on pH (Kabsch-Korbutowicz, 2006). Kimura and Ando (2016) demonstrated that an extremely high dose of a coagulant is necessary to maximize biopolymer removal. Integration of coagulation with other options (e.g., activated carbon adsorption) should be investigated to reduce the dose of a coagulant, leading to efficient control of membrane fouling in subsequent MF/UF. A research group at the University of Waterloo has intensively investigated biofiltration as a pretreatment for UF and shown that it is effective in removing both particles and biopolymers (Hallé *et al*., 2009; Peldszus *et al*., 2012). Schulz *et al.* (2016) reported that biologically operated ion-exchange filters were observed to offer several beneficial synergies for control of membrane fouling.

Recent developments in membrane technology are focusing on development and application of ceramic membranes. In contrast to many polymer membranes, ceramic membranes have extremely high chemical and physical stability, long working life and similar separation characteristics. Ceramic materials are generally very stable chemically, thermally and mechanically, and in addition are frequently bio inert. They are therefore ideal materials for many applications in oil and gas, chemical and pharmaceutical industries or in direct applications for municipal water and wastewater processing. Direct membrane filtration of raw sewage by ceramic ultrafiltration and nano filtration membranes is under trial investigations at several places (Kramer, 2015).

Image analysis related to particles separation processes

Digital image analysis (DIA) is a powerful tool for many water and wastewater applications. It is employed to study and characterize complex size, shape and features of particles (Chakraborti *et al*. 2003) as well as to understand and model the aggregation, breakage and regrowth mechanisms (Jarvis *et al.* 2005). In the past decades DIA has often been used in activated sludge processing (Mesquita *et al.* 2011), settling velocity measurements of aggregates (Vahedi & Gorczyca 2014), membrane fouling (Mendret *et al.* 2007), natural organic matter removal (Xiao *et al.* 2011) and coagulation/flocculation processes (Yu 2014). Usually, the image processing techniques consist of the following steps: image acquisition by digital camera or microscope, image preprocessing (colour/contrast adjustment, background subtraction), objects (particles) detection on the image, calculation of geometrical parameters of each particle (size, area, perimeter, fractal dimension). Then these geometrical characteristics are taken for further analysis.

A research team at the Norwegian University of Life Sciences has been running the image analysis tests related to coagulation/flocculation process and dosage control for several years now. First, the tests were conducted in the laboratory scale – jar-tests with complex solution model wastewater, images acquired by high resolution SLR camera. The particle aggregation during slow mixing period of coagulation was observed non-intrusively and the flocs' geometrical parameters were calculated, including fractal dimension, using DIA (Sivchenko *et al.* 2013). Analyses were continued with the different model wastewater types (hard and soft) and different concentrations of contaminants. Strong relations between inlet water qualities, coagulant dosages, images of flocs and resulting water efficiencies were found. Several texture analysis techniques were tested in order to quantify flocs' images considering the texture of the whole image, not each particle separately. Such techniques will considerably simplify the image analysis procedure of future coagulant control system. Variables obtained by texture analysis methods were proven to predict the coagulant dosages up to 96%, without revealing any other information to a multivariate model (Sivchenko *et al.* 2014). Thus, images of flocs are highly correlated to coagulant dosages and could be used for process optimisation.

Currently, the research continues in one of the Norwegian wastewater treatment plants. The tests have moved from laboratory scale to full-scale tests. A fully automated system with real time remote control and surveillance functions is required. A prototype is under construction which will receive and analyse images to optimise the coagulant dosage prediction. Texture image analysis methods give an opportunity to employ cheap and fully controllable cameras, which is a strong advantage of this research.

Advanced particle removal for energy recovery

Dissolved air flotation (DAF) and fine or micro sieving can be applied to achieve advanced suspended solids removal from wastewater. Sieves and DAF can be used in wastewater treatment plants to replace the pre-sedimentation tanks or may be implemented in front of biological treatment units to decrease the solids load on the activated sludge process and to improve particle separation for bio-energy production (via digestion). The DAF-process is approximately 10 to 20 times more space efficient than sedimentation (STOWA, 2014). New generation sieves are equally applicable. Demonstration research at large scale and full scale trials at municipal wastewater treatment plants showed that DAF and sieves can achieve much higher TSS-removal than conventional pre-sedimentation tanks, thus producing more biodegradable sludge fit for biogas production. Owing to advanced removal of particle-related COD and phosphate and the partial removal of ammonia (because of stripping effects), the low loaded biological activated sludge process was performing excellently, although the relatively low BOD/N-ratios reduced denitrification efficiencies.

The dry solids content of the separated flotate sludge exceeded conventional primary sludge, and DAF and/or sieves could be applied on a much smaller footprint than a sedimentation tank. Sieves and DAF seems to be robust technologies with a relatively fast return of investment when applied and operated correctly, especially if energy recovery is targeted.

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Pretreatment of Industrial Wastewaters

Prepared by *Santino Eugénio Di Berardino, Ioannis Alexiou, and Mitch Laginestra* on behalf of IWA Specialist Group on Pretreatment of Industrial Wastewaters

Introduction

Industrial wastewater is a global issue and covers a wide range of industries and (by their nature) contaminants. Ranging from the food and beverage industries (representing organic wastes) through to the petrochemical, pharmaceutical, mining and electroplating industries, a significant variety of contaminants exist, which in some areas are discharged illegally to either sewer or environment, resulting in several significant issues (environmental damage, biodiversity deterioration, uptake into the food chain, etc.).

A key focus in many developed countries is the appropriate and sustainable treatment of industrial wastes to enable safe discharge to sewerage systems or the environment. As a general rule, the locality of industries dictates, to a large extent, the discharge of generated wastewaters. Many large industries are located in metropolitan or outer urban areas, and most of these will generally discharge to an available sewer, which transfers the waste to a municipal wastewater treatment plant. However, there are a large number of facilities that are located in regional and rural areas (dependent on resources used for the industry). These will include mine sites, but may also include wineries, abattoirs and similar facilities, which rely on food production. In these cases, it is more common that wastewater is treated on-site and discharged to the environment. There are also several centralised industrial treatment facilities that have a small sewer catchment dedicated to the industrial discharge (common in Southeast Asia) or rely on tanker transport (common in the Middle East).

Industrial wastewater is typically characterised by a wide range of contaminants which, if released inappropriately to the environment, will impact on water resources and amenities. In the past 30 years, evidence of industrial contamination has prompted for calls on tighter regulations of these systems, and wastewater has become a key target for control by regulatory authorities. Coupled with this, in some areas, where drought or water resources are scarce, the wastewater is regarded as resource, and treatment and reuse of the effluent is advocated. There is a significant amount of research associated with control of industrial wastewaters. Much has also been undertaken on anaerobic treatment of high organic wastewaters to biogas, and waste to energy. This represents a major driving force in development and take-up of pre-treatment of industrial wastes, where economic gain may be realised in treatment of wastewater, through resultant energy generation.

Some aspects of industrial wastewater pretreatment programmes (technical, administrative, fiscal) include the impact of industrial discharges on municipal treatment works and transfer systems; characterisation and categorisation of industrial wastewaters; end of pipe treatment technologies and in-plant water efficiency control, planning, development, management and troubleshooting of industrial wastewater treatment facilities; recycling, material recovery and waste minimisation; waste to energy and treatment and disposal of toxic sludge. Consequently, a robust approach in pretreatment of wastewater systems from an environmental and economic base, targets generation of useful by-products:

- energy generation;
- effluent re-use;
- residuals management.

Current issues

Industrial wastewater is typically characterised by a wide range of contaminants which, if released inappropriately to the environment, will impact on local and potentially regional resources (surface water, groundwater and land). This, in turn, can adversely affect natural amenities and human habitation (drinking water, crop growth, food chain, etc.). Consequently, the appropriate collection, treatment and disposal of contaminants of concern is paramount to ensure sustainable industrial operations and management.

Some of the contamination issues include the following:

- organic overloading of surface waters, leading to loss of amenity;
- loss of nutrients and eutrophication in surface water;
- emission of greenhouse gas as part of inadequate/storage and treatment of high strength organic wastes;
- impacting of beneficial re-use on municipal biosolids (through addition of toxic materials);
- mine acid drainage,
- arsenic groundwater contamination;
- land contamination.

Around the world, there are numerous cases of industrial-scale contamination and losses of environmental and social amenities from pollution (mine sites in South America, South Pacific, Africa, Eastern Europe, etc.; industrial pollution and contamination of potable drinking water supplies in Africa, the Americas, Asia).

Cost-effective treatment is also a major issue, with many industrial operators not interested in treating wastewater unless there is a rapid payback or unless the core business is impacted, with environmental concerns often last on the agenda. It is fair to say that most operators adopt economic principles which drive the process of wastewater management and implementation.

Legal, policy and management systems affecting industrial innovations

Two very important pieces of global legislation were approved by the United Nations in 2015 which have a tremendous implication on industrial, manufacturing and commercial activities especially in relation to environmental legislation. The United Nations approved the new set of Sustainable Development Goals (SDGs) for 2030, in New York in September 2015, with a wide range of issues and targets influencing global consumption and production patterns as well as the use of natural and mineral resources in parallel with specific socio-economic targets. Following the SDGs approval another major piece of legislation was delivered by the United Nations COP in Paris with the Climate Change agreement which aims to tackle also energy production and direct/indirect efficiencies in global industrial, manufacturing and commercial sectors.

Indeed as part of the future trends within IWA industrial specialists groups should be the projection for specific and general measures that industries should follow to make the necessary transition to the new models of energy and resource efficiencies as approved by the United Nations in 2015. Transition patterns to the new or innovative models of production should be monitored and reported within and from IWA's Specialist Groups relevant to these sectors.

Revising policies and legislation nationally and globally will be making the movement of goods and services linked with the supply chains of various industrial sectors a bit more resilient and sustainable beyond the typical methods of the past decades that addressed linear production and growth models on strict financial measures and reviews.

As a typical research and development study in many environmental institutes and think tanks in the European Union, case studies analyse various industries for the following:

- potential innovations that would bring them into 'smarter systems' (often following big data and 'the internet of things' for resource and energy needs);
- a wide range of improvements in industrial management systems primarily focusing on efficiencies with monitoring and control tools, i.e. clean-tech productions;
- and the use of applied CSR (Corporate Social Responsibility) reporting schemes which more often end up acting as a planning guide on what kind of technical and/or soft measures industries will need to improve efficiencies and minimise waste/wastewater streams over several years to achieve SDGs linked with their industrial sectors.

Risk analysis in industrial production has matured from a prevention scheme (legally binding) to a business evaluation model from the start of the investment, with alternatives for clean technology sought from an early design to avoid any possible contaminants and leaks that could be considered as detrimental to the business model and the brand projected by the owners of the facilities. This new way of thinking of industrial production also affects any supply chains linked with a specific product with an objective of improving whole-life assessments.

Additionally the use and establishment of eco-parks internationally that aim to attract greener investments and to enable improved regional and national production and manufacturing is also a subject of constant review; following conceptual developments on material flows versus cost accounting (MFCA, etc.), addressing areas of the evolving circular economy and investigating further case studies on industrial ecology themes.

In particular the opportunities on innovations with nanomaterials, the use of graphene as an evolutionary material with the potential to replace many aspects of controlling and capturing contaminants, and endless improvements in catalysts produced would provide a blueprint of how new and modernised industries will have to be pre-defined for their own environmental management risks to be tackled, but also to achieve potential improvements in the environmental management of current industries.

Existing knowledge and treatment of wastewater

As a general rule, the locality of the industry will dictate the discharge of the generated wastewater. The availability of the sewer typically results in preferential discharge to it, with subsequent dilution with domestic wastewater and treatment affected by the municipal WWTP. There are also industries located in regional and rural areas (dependent on resources used for the industry), which typically are licensed to treat on-site with local disposal (usually more stringent license criteria). Consequently,

Table 1 Contaminants and treatment of industrial wastewaters

Industry	Typical contaminants	Typical treatment
Dairy	Organics, fats [BOD 3,000 mg/L]	DAF, biological (aerobic)
Meat/poultry	Organics, fats, blood, manure [BOD 2 - 5,000 mg/L]	DAF, biological (anaerobic/aerobic)
Vegetable/fruit	Dissolved organics, sugars [BOD (2,000 mg/L)]	neutralisation, biological (aerobic)
Bakery	Organics [BOD 3,200 mg/L]	Biological (aerobic)
Iron/steel	Phenols, SS, ammonia, cyanide [BOD 500 mg/L]	Coagulation (biological)
Galvanising industry	Heavy metals	Chemical precipitation, filtration
Petrochemicals	Phenols, oils [BOD 750 mg/L]	Separation, chemical oxidation, bio
Pulp/paper	SS, organics [BOD 4,000 mg/L]	Separation, biological
Textiles	SS, Organics, metals [BOD 6,000 mg/L]	Coagulation, biological, membrane, ozonation
Plastics/resins	Organics, phenol, oils [BOD 2,500 mg/L]	Separation, chem. oxidation, biological treatment
Beverage	Organics, sugars [BOD 2,000 mg/L]	Biological (high rate anaerobic, aerobic)

the treatment of industrial waste is very site specific and several treatment units are appropriate for these, which are dictated by the type of contaminants and the required water quality criteria.

Generally, there are numerous technologies for treatment: dissolved air flotation (DAF), anaerobic digestion, aerobic oxidation, chemical oxidation. Most of the processes have been developed from the wastewater and water treatment fields. However, specialised technologies have also been developed, particularly to deal with some of the more noxious contaminants of concern.

Some examples of treatment trains for varying industries in developed countries are as summarised in Table 1.

It can be seen that DAF, biological treatment and chemical coagulation are common processes. It should, however, be acknowledged, that contaminant take-up in the sludge of the treatment system will require specialist management, and the more noxious contaminants will require chemical fixing and disposal at a secure landfill.

General trends and challenges

As noted above, the key priority for pretreatment of industrial wastewaters is demonstration of control of contaminants and enabling sustainable facility operations and efficient management of resources, to achieve industrial and manufacturing objectives within a circular economy model.

In Europe there is considered to be a renewed environmental conscience creating a shift in industrial production, use of resources and energy (use of energy efficient technologies and the introduction of renewable energy resources including solar, biomass, wind and hydropower). Legislation and economic incentives have been introduced to encourage adoption of ecologically friendly design such as extended producer responsibility (EPR) legislation. (Alexiou, 2014). Up to 1980, end of pipe pollution reduction was typically adopted, after which there was a strong focus on legislation. In 2000, cleaner technologies emerged, and since 2010 the advent of sustainable production has now largely been adopted in Europe (Di Bernadino, 2014).

Anaerobic digestion, bioethanol production, membranes and tri-generation are some of the most promising technologies allowing the recovery of by products and simultaneous production of heat, cooling and power with technical, economic and environmental benefits (Alexiou, 2014). However, there are numerous other technologies currently being researched and implemented, including the following:

- low-energy DAF systems (smaller, more efficient, bubble size, without chemicals) (Menkvled, 2014) to enhance performance and operating costs;
- biochemical injection materials (including reactants, catalysts, adsorbents) and Nano-membranes for dealing with pesticides (Keller, 2014);
- chemical oxidation processes (which included Fenton, pyrite catalysed by hydrogen dioxide, sodium hypochlorite and ferrate oxidation) of pulp/paper industrial wastewater (Zhang, 2014);
- use of adsorption materials for removal of a wide range of contaminants (including colour from textiles, heavy metals, radioactive materials (Huang *et al.*, 2014);
- alternative coagulants and aggregation in removal of particulates (Licsko, 2014).

There is also considered to be an increasing adoption of effluent reclamation from pretreatment of industrial wastewaters. Furthermore there are several installations in Australia and elsewhere that have adopted advanced treatment (at the end of the biological system) to enable reclamation for hosing down and washing (but separated from the production of foodstuffs).

Conclusions and research or development agenda

In summary, while industrial pretreatment covers a wide array of industries, the solutions are very site specific. General trends include research and development in the following areas:

- anaerobic digestion and generation of energy for high strength wastes;
- cost-effective aerobic treatment for wastewaters less than 2,000 mg/L BOD;
- membrane treatment for entrapment of contaminants;
- ion exchange and adsorption process for metal contaminants;
- water efficiency and advanced treatment methods to achieve water reclamation/re-use.

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Public and Customer Communications

Written by *Sandra Hall, Abby Crisostomo, Declan Hearne, Patricia Bakir and Kari Elisabeth Fagernæs* on behalf of the Specialist Group

Introduction

In all aspects of the water industry, success requires active engagement of audiences. Independent of the sector, effective communication can make a real difference. It can encourage positive behaviour change, increase support for investment and enhance local communities and the environment.

While integrating communication and engagement into the wider community and utility water management is something that will always be an area to improve upon, pressures on the industry – from climate change to political unrest to ageing workforce and infrastructure – highlight the need to consider how to further encourage good communication.

Whether through enhancing the capacity of the water industry by building knowledgeable advocates and understandable experts; appropriately incorporating new and digital technologies to expand and improve services; or, making the way for systemic change by encouraging different behaviours and social norms, it is clear that public and customer communications and engagement is a quickly changing and critical component of a functional and sustainable water industry.

Communication to drive growth and change

There are real opportunities for 'good' communications to deliver better outcomes for our industry. In all parts of the water industry, communications, marketing, consumer behaviour, and partnerships have become very important to the future. Parts of the industry have embraced new engagement methods and communication tools, but there are lessons to be learned and best practice to be determined.

With such a breadth of professionals, expertise and view of the field the knowledge capacity of our water professionals is a grand challenge. To ensure that the industry remains engaged and effective with our stakeholders we need to address the shortages in the industry's education and knowledge transfer. The public and customer communications specialist aims to raise the capacity of the industry by:

- providing an opportunity to share learnings and best practice;
- arming professionals with the tools and resources available, or explore the tools that need to be developed; and
- inspiring and encouraging collaboration across the industry and across sectors.

We are moving beyond a pure focus on consumer-driven, one-sided marketing and communication in the industry and exploring how we are becoming an engaging industry, working in partnership to drive growth and change. Our view of communications and marketing in the industry has changed and we now expand our profession to include:

- building customer and stakeholder relationships;
- cross segment partnerships;
- research synthesis and adoption;
- education and professional development;
- water literacy and language used; and
- social transformations - community attitudes and behavioural change.

Embracing new tools

Digital engagement technologies, such as information and communications technologies (ICT) and social media are increasingly enabling improved interaction between the organisations that manage and provide water and the water users, resulting in improved services, consistent revenue streams, water efficiency through behaviour change and better engaged stakeholders. However, the myriad number of new technologies available to connect and engage with water users and the public can be downright daunting for both the provider and the user.

Key themes of research include the following:

- ICT use for data collection;
- ICT use for bill payment and revenue collection;
- ICT use for water efficiency and behaviour change;
- Social media use for building trust;
- Social media use for crisis management;
- Social media use for participatory engagement;
- Choosing the right digital tool for the job;
- Case studies and other resources.

ICT can improve interaction between those who manage water and those who use it, even in places lacking consistent internet access. But with the vast array of tools available – from social media to apps and SMS to smart meters and more – water professionals need help navigating the options.

A Twitter campaign to map and respond to water leaks may be a useful tool for one community; while another community may need remote sensors that provide information to users to manage their own water use; and yet another in a rural area might gain the most from an SMS platform that allows people to understand and monitor water availability.

Societal behavior change

Behaviour change has become a buzz term, with many organisations recognising the need to go beyond traditional forms of communication if issues related to demand management and water security are to be addressed. However approaches to adoption of behaviour change measures are fragmented and lack integration in the overall design and management of service delivery. Water crises associated with climate change have driven a number of high profile integrated interventions where consideration of behaviour change was delivered in a systematic manner.

California and San Pablo are still in the grips of water shortage and approaches to behaviour change have been major components in the overall responses. In 2011, Brisbane was similarly gripped by a water crisis and installed a suite of behaviour change measures that targeted household water usage to decrease to less than 140 litres per household—half the historical norm. The targets were met and remained at approximately 160 litres per household even after the drought had long since abated.

But do we need to wait for crisis to start integrated behaviour change campaigns? Projects on water and energy efficiency behaviour change in the UK and Western Australia have observed that in-home programs achieved the best results. Practical frameworks, such as the behaviour change wheel (BCW) (Michie *et al*., 2011), provide a systematic way of identifying relevant intervention functions and policy categories based on what is understood about the target behaviour. Interventions and policies to change behaviour can be usefully characterised by means of a BCW comprising: a 'behaviour system' at the hub, encircled by intervention functions and then by policy categories.

Public and customer communications professionals

Public and customer communications professionals share communication methods, techniques and tools that build customer satisfaction and trust, improve utility performance and establish sustainable water management practices. They aim to raise the profile of communications and engagement as a key strategy in providing water and wastewater services. Public and customer communications professionals are 'specialised generalists' and they work in different types of water organisations. They are the following:

- communication and marketing professionals from Water and Waste service providers;
- communication and marketing professionals from other segments;
- water educators;
- social scientists;
- research adoption professionals; or
- partnership/relationship managers.

They have a university education in technical or other disciplines, often including communications or journalism. Their strength is to follow relevant occurrences and trends in society and use this information to influence organisations, activities and services. They know how to inform and communicate proactively with different types of interest groups (management, employees, customers, suppliers, owners, financers, society, etc.) using their capacity to adapt language and messages to the needs of each group. Globally, we are looking to these professionals to help drive change and provide us with the tools and knowledge to tackle the wicked problems of the industry.

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Resource Recovery from Water

Willy Verstraete, Peter Cornel, Ilje Pikaar and Hong Li

Introduction

Driven by environmental, economic, and ecological benefits, the importance of water conservation, source separation, energy efficiency, and resource recovery from water and wastewater systems are becoming more globally recognised. Indeed, some resources present in 'used water' deserve to be recovered and recycled. Its reasonability depends on various boundary conditions. Some of the resources (including water itself, energy and phosphorus) have already become of interest in the context of climate change and sustainability and their recovery is, to some extent, being implemented in practice. Yet overall, the core of urban wastewater management relies on dissipation/ mitigation/removal rather than recovery. As such, the feeling still persists that making the things which are present in used water 'dissipate', i.e. disappear as much as possible in the safest, most robust and economic way possible. This is particularly the case for waters contaminated with faecal matter (e.g. sewage), which have been subject to a long history of cultural 'disgust' perpetuated by sanitation practices that treat wastewater as a hazard that must be separated from the population.

Water utilities and their consultants are becoming increasingly aware of the need to implement resource recovery. Their main motives are to *reduce costs* by recovering materials, reduce energy usage with the goal of becoming *carbon neutral*, mitigate *risks* (for instance from the occurrence of precipitates, for example phosphates; the emission of odours, such as hydrogen sulfide; emission of greenhouse gases, such as methane or nitrous oxide; the discharge of metals into the environment; the increase in salinity; and economic risks from increasing labour costs), protect valuable natural resources like groundwater reservoirs and natural phosphate deposits, and more broadly to establish or support a utility image that is environmentally friendly for *reputation management*. In recent years the industry sector has become increasingly supportive of the concept of resource recovery because it aligns with the broader vision to rebrand wastewater treatment plants as water resource recovery facilities.

From a technological viewpoint, we can produce reclaimed water and can recover resources including calcite, energy, nitrogen, phosphorus, and elemental sulfur from 'used water'. But resource recovery alone is inadequate. Besides the fact that resources recovery must be technically and economically feasible and undoubtedly legally allowed, as well as available in sufficient amounts at 'fit for purpose' quality, a key pillar for the success of resource recovery is the social acceptance of recovered resources and, in particular, *acceptance by customers/end-users of the recovered products*.

Nevertheless, as we are entering an era of circular economy (firmly anchored in various ambitious national, European, and global initiatives and guideline documents) that is aware of the need for integrated sustainability, it is important for the International Water Association (IWA) to demonstrate its commitment to all aspects of resource recovery. The creation of a specific Cluster overarching all specialist groups in the IWA is demonstrative of this willingness to act and this integration is believed to be key to create change. The focus of the Cluster is to deal with four main objectives:

1. To *promote resource recovery* from water and wastewater, for example, by identifying existing examples and exploring their potential for extending to other places, raising awareness and social acceptance, outlining possible routes for resource recovery, assessing constraints, and ensuring successful marketing strategies.
2. To accompany and promote awareness among utilities and operators of WWTPs on their way from 'disposal companies' to producers of valuable products.
3. To network on innovations of resource recovery through *conferences, meetings, working groups,* publications, etc.
4. To promote links with *complementary organisations*, especially outside the field of water, to find proper ways to build value chains where waste is converted to resources in a well-managed and beneficial way.

The Resource Recovery Cluster has produced the *State-of-The-Art Compendium* and was the main author to the 7th World Water Forum white paper of the Resource Recovery chapter. Details on the state-of-the-art of resource recovery from water can refer to these two documents.

Existing knowledge and current challenges

Recovering resources is in itself nothing new. Ample research and techniques are out there already in terms of resource recovery from water (energy, water, nutrients, and other materials). However, major developments have recently been achieved in practices and techniques with the potential to recover water, energy, and a wide array of value-added components. There is an entire spectrum of resources to recover.

As the first focus and at the top of the agenda, *water reuse and reclamation* has advanced. Reusing water enhances the potential for conserving existing freshwater resources, and could be a more reliable source than pumped surface and groundwater in some areas, as it is less sensitive to drought conditions and increased demand. The fit-for-purpose approach is often considered when practising water reuse, which includes using reclaimed water for potable water reuse, non-potable water reuse (e.g. irrigation, industrial water use, etc.) based on the quality of the reclaimed water. Challenges remaining with the water reuse includes, the embedded energy, competitive cost, and public acceptance due to the 'yuck factor' and cultural issues, etc.

Although water reuse is on the top of the agenda, the hottest topic relating to resource recovery is energy efficiency in water and wastewater systems. Energy-related matters within the water and wastewater systems include both energy production and recovery, and most of the energy forms generated or recovered are reused to feed into the treatment system and in turn increase energy efficiency and occasionally become an energy-positive system. But even more important as the overall energy balance, might become a demand driven production of power and heat, a challenge especially in combination with renewable energy production. As the price of fossil fuel drops, one of the biggest challenges for energy recovery is to compete with conventional energy sources. Professionals have to adjust infrastructure and institutions to handle biogas or heat. It takes public resources and political will to kick-start markets.

There are multiple nutrients that can be recovered from used water treatment plants with phosphorus (P) and nitrogen (N) as the most commonly recovered nutrients. Nutrient recovery was partly triggered by the success of using mineral fertiliser for food production which also stimulated discussions of food security and utilising reused water for irrigation. The time has also come to re-use the nitrogen by directly upgrading it at the site of recovery to a valuable feed or food. Although technically possible, nutrients from sludge and waste streams in general are removed rather than recovered, and in addition, nutrients are rarely of either uniform quality or large quantity. There can be positive or negative consequences of using sludge as fertiliser, as variable levels of mercury and other heavy metals accumulate over time, and risk excess nutrient loads trickling into streams. High start-up and running costs of new recovery plants mean the end products cannot compete well at market: it is still generally cheaper to mine nutrients than recover them.

Valuable components such as sulphur, cellulose, metals, and also biochemical generated organics (bioplastics, for instance) have the potential to gain importance as the societal acceptance of the cyclic economy gains more traction.

To be successful, recovering resources from water-based waste streams must be both beneficial for the environment, economically attractive, and socially accepted (triple bottom line principle). A proper reflection on design of products and processes, market prospects, appropriate public policies and regulations, and institutional arrangements are fundamental for accelerating resource recovery, and are currently lacking. Importantly, there must be a readiness to accept usage of the recovered materials and to recognise their true value. A set of milestones has been defined to develop a comprehensive and holistic approach to resource recovery. To achieve proper resource recovery, *value chain sectors* – that until now hardly collaborated – need to start interacting and exchanging information. This requires a strong knowledge sharing and collaboration. In addition, recovered resources need to enter a chain process of valorisation and to optimally achieve this, close interaction with other actuators in the recovery such as the people dealing with side-streams in the feed and food industry and in the solid waste management is of crucial importance.

Key focuses on resource recovery from water

At present, the world economy is quite unsteady, and in many respects not in favour of the circular economy. Most of us have to constantly adapt our endpoints in terms of what and how we should recover resources. Nevertheless, there is one very clear argument to pursue the issue of resource recovery from water: it *clearly fits in the context of abatement of climate change* and is in line with *sustainable development* ensuring we meet the needs of the present without compromising the ability of future generations. Recovery of resources thereby represents a driver in order to achieve a more sustainable planet.

The major tasks that the IWA should address, by means of its Cluster on resource recovery from water, are as follows:

- Provide a *sound science and technology basis* for resource recovery from water: create awareness about the fact that a variety of options for recovery of resources from water and used water are possible, and deserve support for scientific exploration and technological development.
- Encourage appropriate *policies and legal frameworks* empowering Resource recovery from water: inform various agencies and individual influencers to create the political and legal frameworks which facilitate the overall education, research and development, technological implication, and effective application of re-use of resource from water.
- Demonstrate the potential interests and benefits from *the pull side*: interact with the markets dealing with primary production, with manufacturing of commodities, and with utilities rendering services to society, with the goal of learning about their technical needs, their dynamics of scale, and the economical frameworks in which they operate.
- Stimulate discussion to establish clear-cut situations where the consumer profits from resource recovery from water, and interact with the general public to learn from the consumer to what extent he/she is favourable/ unfavourable towards issues of beneficial re-use and to further understand aspects of non-acceptance of recycled commodities. Develop *platforms of interaction and consultation* so that cases can be highlighted and the overall acceptability of re-use can be raised in the mind of the public.
- Join forces acting towards the goal of establishing a cyclic economy: establish *a broad network with other fields* serving the general public so that the water sector is in synergy with other societal movements and can contribute to the circular economy.

Ultimately, the cluster aims to influence the way recovered resources are being viewed and recognised by the public, by researchers, by investors, and by decision-makers. Promoting good practices and ways to approach and collaborate upon the topics are issues at which the cluster will take aim, along with encouraging appropriate concepts of resource recovery, whether social, economic, political, or environmental.

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Resources-oriented sanitation systems

Written by *Mariska Ronteltap and Günter Langergraber* on behalf of the Specialist Group

Context

These are good times for resource-oriented sanitation: resource recovery, saving of resources and waste recycling are booming. Particularly in wastewater, there are many elements to recover: water, nutrients and energy are apparent, but also lipids, cellulose and alginate. Despite it being obvious, recovery is not always easy to implement. Not practically, as the wastewater may be collected in a location far away from the area where nutrients, water or energy are required; transportation costs become a strong hindrance. Not socio-culturally, as bringing back nutrients into the food cycle may be considered unacceptable. And not financially, as most recycling systems require an investment upfront, which is not always available. Moreover, most resource recovery approaches bring in too little income to allow for coverage of the operation and maintenance costs. The fact that sanitation costs money, and the polluter pays principle, has not yet been fully embraced.

Still, in a world with increasing scarcity not only of economic, but also of physical and environmental resources, resource efficiency of wastewater management becomes more urgent than ever. The resources-oriented sanitation specialist group aims to identify, promote and support available technical solutions and to track their implementation potential.

The IWA Specialist Group on Resources-Oriented Sanitation

The IWA Specialist Group on Resources-Oriented Sanitation focuses on sanitation systems that aim to extend the boundaries of conventional sanitation solutions

Figure 1 Waste does not exist ('afval bestaat niet' in Dutch) – the motto of a large Dutch garbage collection company Van Gansewinkel (picture: credo, Eindhoven).

- by avoiding long-distance transport of wastewater in sewers; and
- by facilitating safe use of resources (water, nutrients, organic matter, energy)

in such a way that the use of non-renewable resources and negative environmental impacts are minimised.

For resources-oriented sanitation systems to be sustainable from more perspectives than resource-efficiency they have to comply to the protecting and promoting of human health by

- providing a clean environment and breaking the cycle of disease;
- being economically viable, socially acceptable; and
- technically as well as institutionally appropriate.

For sustainable implementation of sanitations systems, it is of utmost importance to take into account the whole system and not only single technologies.

This chapter outlines some of the trends and challenges for resources-oriented sanitation, as observed by members of the IWA Specialist Group.

Existing knowledge, experience and practice

In several textbooks and guidelines, practitioners and decision makers are advised to start planning for their sanitation system at the end of their service chain, where the so-called products are to be used. This is sometimes referred to as reversed-chain thinking, or the reversed chain approach. Examples of such products are the following:

- liquid fertiliser, for example hygienised urine or blackwater from ultra-low flush toilets;
- solid fertilisers such as struvite, hydroxyapatite;
- irrigation water;
- briquettes or pellets, serving as a source of biofuel or fertiliser;
- protein sources for use in aquaculture or agriculture.

Urine as a resource of nutrients

Urine has been in the picture as an interesting nutrient resource for quite some time. The slow-release fertiliser struvite, a concentrated solid product, can be produced relatively easily by the addition of magnesium to hydrolysed urine. This is applied frequently in places where urine is collected separately, like in festivals, airports and medical projects. After-treatment of the remaining liquid fraction is necessary to remove ammonia and organic matter; in the SaNiPhos process, nitrogen is recovered in the form

Figure 2 Urine collection tank in Arba Minch. Ethiopia (picture: Elke Müllegger, EcosSan Club, Austria).

Figure 3 Struvite reactor at Arba Minch University, Ethiopia (picture: Günter Langergraber).

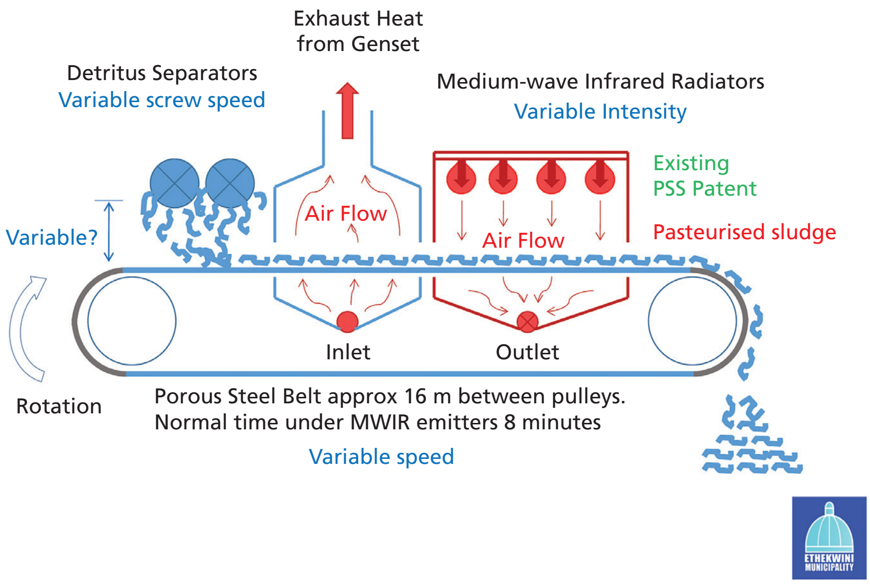

Figure 4 Schematic of the LaDePa machine (with courtesy of Dave Wilson, eThekwini Water and Sanitation).

of ammonium sulphate (www.saniphos.eu/). For decentralised systems, where regular measurement of the required amount of magnesium may not be an option, magnesium may be dosed through sacrificial electrodes (Hug and Udert, 2013). Because of its high ionic strength, urine also offers possibilities for other electronic processes, such as microbial fuel cells for energy production, also called urine-tricity (Chouler *et al.*, 2016), or electrolysis to rapidly remove ammonia and organic matter. In a spin-off project (www.vuna.ch), pre-electrolysed urine is distilled which concentrates the urine such that 97% of the water content is removed. This greatly simplifies transportation of the product.

After hygienisation, urine can be used directly as a fertiliser. Because of its content of phosphate, magnesium and potassium, it qualifies as a complete fertiliser. In Arba Minch, for example, urine-diverting dry toilets (UDDTs) have been introduced and collected urine has been demonstrated as liquid fertiliser after storage (Figure 2). Even in the early phase with only few UDDTs implemented the transport of large volumes of urine (firstly from the households to the treatment site and secondly after storage to the fields) has been considered a problem. Thus, within the CLARA project (Langergraber *et al.*, 2014) the applicability of struvite precipitation in Arba Minch has been investigated. A pilot-scale reactor has been constructed by Arba Minch University (Figure 3). Struvite has been produced and tested in field trials against artificial fertiliser. The field trials showed a similar fertilising effect of artificial fertiliser and struvite—a very convincing argument for farmers towards usage. However, struvite application has been shown currently not feasible economically compared with artificial fertiliser, mainly because artificial fertiliser is heavily subsidised in Ethiopia.

Figure 5 Prototype of the LaDePa machine in an old container (left), pasteurised faecal sludge (middle), and hygienised end product (right) (pictures: Günter Langergraber).

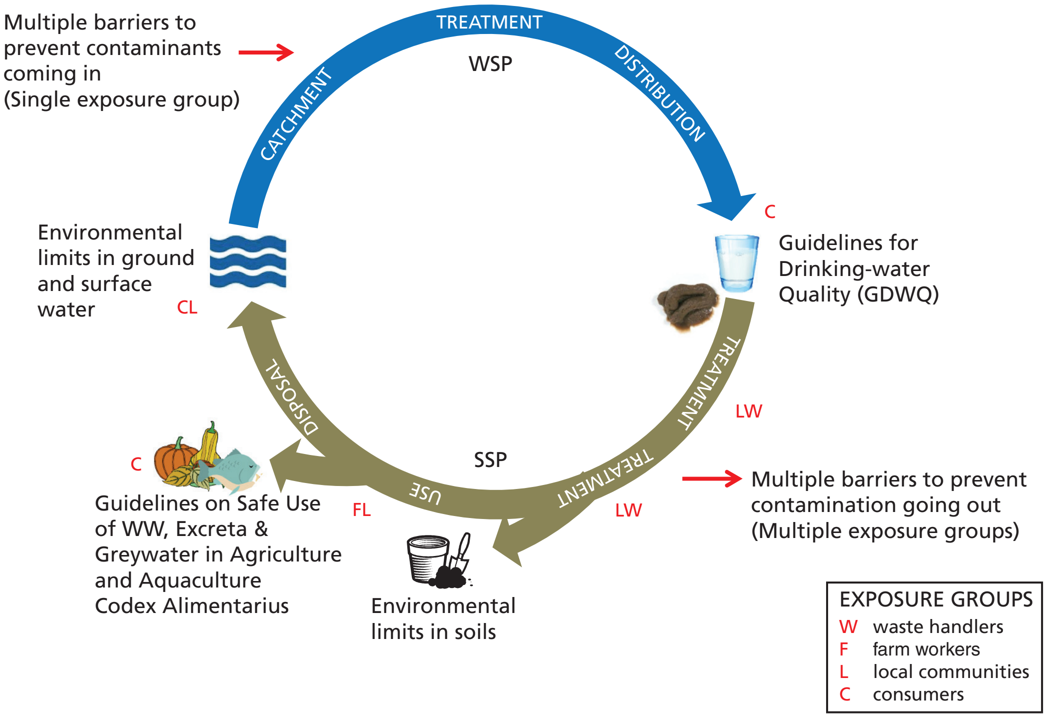

Figure 6 Closing the WSP and SSP loop highlighting especially exposed groups (with courtesy of Kate Medlicott, WHO).

Source separating the nutrient rich urine from the remaining wastewater greatly simplifies treatment and decreases the risk of eutrophication from the sanitation system. Therefore, urine is source separated in, for example, more than 100,000 households around Durban in South Africa and in more than 150,000 houses, mainly vacation houses, in Sweden.

Recovery options from faecal sludge

When human excreta are collected from onsite sanitation systems, be it septic tanks or pit systems, we speak of faecal sludge rather than wastewater or sewage. Faecal sludge needs to be collected, transported and treated in a safe manner, such that sludge handlers do not come in contact with faecal sludge, there is no leakage, and treatment products are applied only after sufficient hygienisation. Faecal sludge is high in pathogens; yet, it also contains a large amount of nutrients and organics, which makes it attractive for agricultural purposes: as a soil conditioner, for irrigation, or as fertiliser in the form of pellets. The use of faecal sludge as a soil conditioner can range from deep row entrenchment of untreated faecal sludge and surface application of hygienised faecal sludge in the form of blackwater, to bagged compost that is sold as a commercial product.

Deep row entrenchment is a form of direct use of raw faecal sludge in forestry applications. By burying sludge in deep ditches, odours are eliminated and the risk of exposure to pathogens is reduced. Trees with a high nitrogen demand are then planted on top of the buried sludge, and they can be harvested for economic purposes. Still, as with other forms of land application, thorough care needs to be taken to prevent environmental contamination (Strande *et al.*, 2014).

Surface application of hygienised blackwater (Nordin and Vinnerås, 2015) is gaining popularity in Sweden, and can grow rapidly as there are some 120 000 houses in environmentally sensitive areas with closed septic tanks for collection of blackwater. Large housing projects with vacuum toilets and production of biogas and fertiliser from blackwater are planned, for example in Sweden (Helsingborg and Stockholm), the Netherlands (Sneek), Germany (Hamburg) and Belgum (Gent).

Treatment in the form of drying, sludge stabilisation and pathogen inactivation can be done to varying extends through drying beds, (vermi- or co-)composting and pelletisation. Co-composting is very interesting because the exothermic reaction contributes strongly to the pathogen inactivation (Koné *et al.*, 2007). Yet, additional material in the form of organic matter is required, and that may not always be available.

A technique quickly gaining in popularity is thermal drying followed by pelletising; good examples are the Omniprocessor, whose development was made possible through the Reinvent the Toilet Challenge by the Bill and Melinda Gates Foundation, and the LaDePa machine from South Africa (Harrison and Wilson, 2012). LaDePa stands for latrine dehydration and pasteurisation: faecal sludge is cleaned from solid waste; then dewatered via screws which deposit pellets on a moving belt. The pellets are dried with air at 100 °C, and pathogens are inactivated by medium wave infrared radiators. Any sludge between 20% and 35% solids can be treated to an 80–90% solid product. The pellets can be sold and used as a fuel or as a soil amendment. The LaDePa fits in a shipping container, making it possible for the treatment to come to the toilets, rather than having to transport the sludge to the treatment (Figures 4 and 5).

Other promising developments include black soldier fly (*Hermetia illucens*) production, where the larvae feed on faecal sludge and are harvested for their protein content, and anaerobic digestion with enhanced pathogen inactivation methods.

Recent developments

WHO Sanitation Safety Planning

In 2015, WHO published a manual for Sanitation Safety Planning (SSP; WHO, 2015). The SSP methodology promotes and facilitates appropriate sanitation through prevention, assessment and planning from a systems perspective. Especially for for resources oriented sanitation systems in which resources should be (re)used the SSP methodology can be a useful tool for coordinating activites of stakeholders, reducing risks for exposure groups in the sanitation chain, and supporting operation and maintenance activities. Figure 6 shows a flow diagram in which the SSP methodology is linked to the WHO Water Safety Planning (WSP) methodology (WHO, 2009). Contrary to WSP, where only few stakeholders/exposure groups are involved, along the sanitation chain there are many points of exposure that must be considered and many exposure groups at potential risk.

Guideline ‘Principles for planning and implementation of new sanitation systems’ (DWA A-272, 2014)

Recently, the German DWA published a new framework for planning and implementation resources-oriented sanitation systems. The authors believe that the new DWA guideline can have big impact because:

1. it is the first guide for planning and implementation of resources-oriented sanitation systems; and
2. it has been released from DWA, an organisation that is well known in the water engineering field for their design guides and standards (e.g. for conventional technological solutions for wastewater treatment such as activated sludge plants).

Professionals consider guidelines from DWA as state-of-the-art and thus the new guideline shall help resources-oriented sanitation systems to become state-of-the-art.

The main objective of the new DWA guideline is the provision of a systemic approach for planning and implementation of resources-oriented sanitation systems (which are named ‘new sanitation systems‘ in Germany). The guideline shows the benefits of resources-oriented sanitation systems by comparing them with conventional systems in which all wastewater is collected and treated together and finally discharged. The main target groups of the guideline are persons and organisations that are involved in and responsible for planning of water infrastructure, i.e. planners, technology providers, authorities, etc.

The guideline describes principles of resources-oriented sanitation systems and specific boundary conditions under which these systems can be especially beneficial. These specific boundary conditions include (among others): new settlements, areas with demographic changes (population decline) and/or water stress (limited availability of drinking water), and existing infrastructure that need to be rehabilitated.

Incentives for using resources-oriented sanitation systems are the following:

- reusing nutrients in agriculture;
- generating energy and/or using heat from wastewater;
- eliminating specific contaminants in higher concentrated waste streams;
- fulfilling higher requirement in terms of hygiene;
- reaching higher emission standards;
- reducing drinking water intake when using service water generated from treated wastewater.

Owing to the large number of possible technological solutions, the DWA guideline does not provide detailed dimensioning for single technologies. However, it provides some fundamental data required for planning, for example the flow and concentrations of the separated waste streams.

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Sludge Management

Submitted by *Banu Örmeci* on behalf of the Sludge Management Specialist Group

Sludge treatment and management is a growing challenge for treatment plants globally. The cost of sludge treatment constitutes approximately half of the cost of wastewater treatment, and the quantities increase as new wastewater treatment facilities are built and the existing ones are upgraded to keep up with the growing population and stricter regulations that require more treatment.

In sludge, organic matter constitutes to 50–60% and the nutrient content can vary from 10% to 40% of the dry solids. The energy content of sludge solids is similar to that of coal. The benefits of agricultural use of sludge include recovery and reuse of nitrogen and phosphorus, carbon soil sequestration and limitation of greenhouse gas emissions, and increasing the organic matter and biological activity in the soil. New and novel technologies can recover these resources, remove toxic chemicals, effectively kill pathogens and achieve net-zero energy use or even net energy production at wastewater treatment plants. These new generation technologies can also achieve very high quality sludge that can safely be used for agriculture, landscaping and other beneficial uses. Returning carbon to the soil through agricultural use of sludge, rather than burning or landfilling it, can help mitigate climate change, create a positive soil carbon budget, and increase the crop yield.

Global sludge quantities continue to increase, and sludge generation in the USA and Europe is estimated to be approximately 7 million and 10 million dry tons per year (EuroStat, 2012; WEF, 2011). Generation rates vary widely between developed and developing regions in the world, but even in Europe large variations can be seen among countries. For example, Malta produces the lowest (0.5 g dry solids per population equivalent per day) and Austria the highest (97 g dry solids per population equivalent per day) sludge quantities in Europe, which can be explained by the differences in their regulations and processes used for wastewater and sludge treatment. Overall, we have seen a continuous increase in sludge generation in the past decade with the exception of Germany, which was able to reduce its sludge from 2.5 million to 2 million dry tons per year (EuroStat, 2012).

European Union (EU) Sewage Sludge Directive 86/278/EEC established the minimum criteria for the agricultural use of sludge in Europe. The directive was brought into effect in 1986, and set limit values for concentrations of heavy metals. A new directive is expected to bring more stringent requirements, particularly for pathogens and organic micropollutants in the near future. Since the Directive, many of the European countries have created their own regulations for agricultural use and have accepted more restrictive limits for heavy metals, pathogens and micropollutants. For example, Austria, Czech Republic, Denmark, France, Germany, and Sweden have now limits on organic micropollutants which include AOX, DEHP, LAS, NP/NPE, PAH, PCB, and PCDD/F (Mininni and Dentel, 2013). Countries that rely on incineration and other thermal processes for disposal (e.g. Austria, Belgium, the Netherlands, Germany) have established very low limits for heavy metal concentrations. For example, Germany's heavy metal limits are 10, 900, 800, 8, 200, 900, 2500 mg/kg of dry matter for Cd, Cr, Cu, Hg, Ni, Pb, Zn, respectively. On the other hand, Denmark, France, Finland, Italy, Luxembourg and Poland have stricter limits on some of the indicator bacteria and pathogens (e.g. *Salmonella*, *Escherichia coli*, faecal streptococci, enteroviruses, helminth eggs, enterobacteria). The large variation in heavy metal, pathogen, and micropollutant limits has resulted in very different practices for agricultural use and final disposal of sludge across Europe. Spain (65%), United Kingdom (65%) and France (50%) heavily rely on agricultural use, and Greece and Iceland exclusively use landfilling (EuroStat, 2012). However, the Landfill Directive (1999/31/EC) of 26 April 1999 states that the amount of biodegradable waste going to landfills must be reduced by 50% in 2009 and by 35% in 2016 compared with the 1995 levels. Accordingly, the Member States relying heavily on landfilling for sludge disposal have to look for and start implementing other disposal alternatives. Eventually, landfilling of sludge is expected to be abandoned in EU unless other disposal options are completely unavailable. Thermal processes coupled with heat and energy recovery are increasingly becoming the preferred choice for sludge management in Europe, and more than 90% of sludge is incinerated in the Netherlands and Switzerland. The most recent draft (2015) of the German Sludge Ordinance bans the agricultural use of sludge after a transition period of approximately 10 years and requires the recovery of phosphorus during treatment. The Ordinance also aims to send all municipal sludge to incineration after 2026. On the other hand, Sweden prefers and encourages the agricultural use of sludge and aims to recycle at least 40% of phosphorus and 10% of nitrogen through land application of sludge.

The US Environmental Protection Agency (EPA)'s 40 CFR Part 503 Rule (1993) provides requirements for the management of sludge and creates incentives for the beneficial use of sludge. Over the years, several states have made substantial changes to their land application requirements and some states, such as Texas and Florida, have effectively restricted the land application of Class B sludge. The number of land appliers in Texas has decreased by 75% in recent years and the quantity of land applied sludge has fallen by 25% (WEF, 2011). In Florida, there are new requirements for phosphorus-based nutrient management as well as pathogen removal and new restrictions on lime-stabilised sludge. Several other states are considering the adoption of similar changes. In addition, the EPA has identified nine pollutants (barium, beryllium, 4-chloroaniline, fluoranthene, manganese, nitrate, nitrite, pyrene, silver) and several other analytes and organic micropollutants that are under consideration for potential regulation in the future. Meanwhile, increasing public opposition to sludge has also led to several counties in mid-Atlantic states, California, and Georgia to consider bans on land application. Finally, the EPA recently refined the definition of solid waste to include sewage sludge and required the development of maximum achievable control threshold (MACT) standards for sewage sludge incinerators. Therefore, these incinerators are likely to be the subject of new regulations in the near future which may force some of the treatment plants to consider landfilling as a cheaper alternative.

China is estimated to generate 22–30 million tons of sludge annually in spite of the limited availability of wastewater treatment in the country (CGI, 2011). The Chinese government has earmarked US$50 billion for wastewater infrastructure projects for the next decade, which will rapidly expand the sewer network and increase the number of wastewater treatment plants. Therefore, China is expected to substantially increase the global sludge generation in the near future. In fact, in the past 5 years alone, an annual increase of 5% was reported in sludge generation. Between 2005 and 2010, the number of treatment plants tripled from 718 to 2,823, and was expected to exceed 5,200 in 2012 (CGI, 2011). Owing to the lack of a comprehensive regulatory framework for sludge treatment and management, it is not uncommon to see the direct discharge of untreated sludge into the environment in China. This is particularly a problem for industrial wastewater sludge where the concentrations of heavy metals and toxic compounds are high and can pose a threat to the environment, public health, and economy. However, things are changing rapidly. Wastewater treatment plants are now required to have sludge treatment, and the importance of resource recovery is also recognised. Currently, approximately 48% of sludge is used for agriculture, 34% is landfilled, 14% is discharged into the environment, and the remaining 4% is incinerated or used for other purposes (CGI, 2011).

Final disposal options, regulatory and policy trends, public perception, availability and feasibility of technologies, and potential for resource recovery are some of the drivers that determine the regional practices adopted for sludge treatment and management. Based on the current trends, agricultural use of sludge will likely be more challenging and expensive in the near future and there will be a shift towards exceptional quality sludge for land application with strict limits on heavy metals, emerging contaminants and pathogens. A shift towards wastewater treatment processes that generate less sludge either by employing pretreatment technologies or by switching from aerobic to anaerobic treatment processes should also be expected. Alternative wastewater treatment technologies, such as using microalgae for nitrogen and phosphorus removal, are also gaining attention for their potential to replace biological sludge with algae biomass that can be used for biofuel or biogas generation. Reducing the quantity of sludge during treatment has become a major priority due to the inability of many plants to meet the demands for agricultural use and cover the high cost of final disposal. However, sludge reduction should be limited to the amount compatible with the final outlet and the best overall energy balance.

We have finally come to a point that sludge is seen as a renewable resource of energy, nutrients, organic carbon, and water. Resource recovery will continue to be at the centre of sludge treatment and management, with special emphasis on harvesting the energy value through anaerobic digestion and thermal processes, co-digestion of sludge with food and other organic waste to increase biogas production, phosphorus recovery, and beneficial use for agriculture. Other resource recovery opportunities include bioconversion of sludge to value added products such as biopolymers, bioplastics, biopesticides, biosurfactants, bioflocculants and enzymes, which are rapidly finding applications and new markets in the industry.

Increasing demands and costs for energy and nutrients provide a strong push for the development of new technologies that can extract resources from sludge. Phosphorus recovery through struvite is a good example where there are now several technologies with good track records that can recover struvite from sludge and cut down energy and chemical costs, minimise scaling problems, and reduce the phosphorus content of sludge and related eutrophication concerns. In addition, the importance of and necessity for new and innovative thickening and dewatering technologies should also be highlighted. After all, 95–99% of sludge is water and it is the water content that determines the size and design of downstream treatment processes as well as the feasibility of land application, incineration and landfilling.

Finally, the development of realistic and enforceable regulations adapted to local situations and accompanied by standardised methods for sludge characterisation and guidelines for good management practices are needed (Spinosa, 2015). To this end, CEN (European Committee for Standardization) in Europe has established the TC308 that aims to achieve the standardisation of methods for sludge characterisation and generation of guidelines for best management practices. More recently, ISO (International Organization for Standardization) established the Technical Committee 275 which aims the international standardisation of methods and protocols for characterising and managing sludge.

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Statistics and Economics

Focus on water pricing policies, funding issues and improving and enlarging statistical information

Written by *Ed Smeets* on behalf of the Specialist Group

Introduction

The Sustainable Development Goals (SDGs) integrate economic, social and environmental aspects and recognise their interlinkages in achieving sustainable development in all its dimensions. Sustainable water management is not only a goal itself, but also a necessary requirement to achieve all other goals. Good water governance is a precondition for water security and sustainable economic and social development. However, economic growth and human development cannot be achieved at the cost of ecosystem degradation, which would compromise the needs of current and future generations. The world needs sustainable solutions where water, ecosystems and livelihoods are secured.

Water security faces significant challenges due to environmental degradation and climate change and variability. Vulnerability to these threats depends on the resiliency of water systems and infrastructure. A major policy question today is what type of water management and policy is required to increase resiliency and reduce society's vulnerability to increasing threats.

Developing a better understanding of the economic value of water security is a priority. A major source of water management problems is the fact that water resources have a high value which has not been fully considered by all water users and explicitly accounted for in water policies, hindering development of effective strategies for solving the water crisis. Thus, without improved signalling on the true value of water (taking into account, for example, scarcity, pollution, access and users), sustainable development may not materialise and ecosystems quality may be permanently damaged.

There are contradictory calls on data and monitoring. Some say that there is too much monitoring and that it needs to be simplified, while others that there is a lack of adequate data in the water sector for decision making and transparency. Such contradictions complicate efforts to improve water management and secure funding and investment. Investors need clear, reliable data before investing in water—as they would before investing in any other sector.

Worldwide, urban cities face a range of dynamic pressures due to urbanisation, growing water scarcity, decreasing water quality, and increasing frequency of extreme events. Under this context, current models of urban water and sanitation management and infrastructure are no longer sufficient to insure adequate and sustainable water supply sanitation.

Urbanisation, coupled with rising standards of living and education is leading to a rise in expectations of rural water users. Additionally, the recognition that access to clean water and sanitation is human rights has created an important point of reference for what communities consider an acceptable level of service. These challenges require a shift in emphasis in rural water supply policies and initiatives in developing countries, away from a focus on the provision of hardware for first-time access towards an emphasis on the provision of a lasting service which sustainably provides for water provision in quantity, quality, and continuity.

The 2015 World Economic Forum identified water as one of the major financial risks for businesses and growth. A major challenge is how to engage public finance so as to attract additional funding from other sources such as micro credit, multilateral banks, private sector and non-profit donor funds. The financing gap in water has not only been about insufficient finance but also about insufficiently well packaged financing opportunities. This is due to the traditional approach where water and finance are treated independently. Conventional and new funding sources (such as climate finance, philanthropy and others), need to be explored.

Existing knowledge

In the past, several workshops and conferences were organised by our Specialist Group around the topics as mentioned in the introduction, in general or more in detail dealing with for instance specific aspects of water pricing. In addition, many presentations by members of our Specialist group took place on several World Water Congresses and articles were published in *Water Utility Management International*.

Some of the present active members of our Specialist Group have extended knowledge of water pricing and financing water infrastructures and thus have the capacity to make important contributions to the discussion of this topics. Besides that, it is worthwhile mentioning that some of them are working in countries facing water scarcity. This will facilitate case study elaboration on this topic. For instance, for seasonal tariffs, it should be easier to know, at least in these countries, to what extent they are being used and they have proved to be effective.

Moreover, since the early 1990s the Specialist Group – in particular the Working Group on Statistics – has carried out international surveys to collect data on water production, water use and water charges and on water regulation. The information is published as a leaflet at the biennial IWA World Water Congress. This means that the Specialist Group has a lot of knowledge about these kinds of data and is able to produce tables, graphs, time series about different countries and different cities.

Trends, challenges and future directions

To answer questions on the issues above, we would like to explore in the next years the following aspects:

- Analysis of the commercial part of the water business is important in understanding the water demand, the customers' behaviour and price elasticity. Furthermore, it helps understanding specific water market mechanisms. Understanding these mechanisms and their influence on water demand is important to manage and justify technical investments and R&D in the water sector. Also to compose investment programmes and to succeed in cost recovery on the long run.
- Water pricing and tariff structure are a complex and interesting matter, but also other aspects of the economical side are worth to be investigated in the near future, like customer behaviour or customer segmentation. Research domains can be broadened to marketing issues like willingness to pay in general, willingness to pay for softened water, business case concerning intelligent metering, analysis of customer related processes and so on. The Specialist Group on Statistics and Economics will analyse time series of the data, in cooperation with universities.
- The water regulation and the differences in national regulations play a major role in understanding differences in water pricing, water taxes and so on. It explains a lot, but not everything. In most cases, regulation reflects the urgency of total cost recovery in the water sector, but often regulation tries to create an equilibrium between economic, social or ecological tariff setting.
- Another challenge for this Specialist Group is to get more countries and cities involved in the new edition of the water leaflet in 2016 and 2018. A better spread of these countries around the globe would create a plus value. Also it is still an open discussion whether or not to prepare a questionnaire for the developing regions.
- The aim is to analyse in depth the different water tariffs applied worldwide and how the water infrastructure and operators are financed in order to provide the financial information needed for optimising the decisions in the investment or operational process.
- The water delivery, sanitation and wastewater treatment services are quite a (technical and economic) challenge in the most part of the world. The water price and the sewer/ wastewater treatment tariffs are the key elements in financing one of the vital services for human life. There is a great uncertainty about the costs, revenues and cash flows generated by the operation of the water services and a greater demand for solidarity and, at the same time, a reduced capacity of the public authorities to finance this solidarity. The price level shows the people's capacity to pay, the importance of this services for society and the care for the environment. The tariffs should be the financing source able to ensure the sustainability on the long term of water services. In this respect, the Specialist Group will investigate the different tariffs used across the world, starting with the active members' countries.
- Providing water is a complex and costly process. Thus, the service provider must cover the operational cost (preferable) from tariff. On the other hand, the infrastructure renewal and development are essential for long term service running. Financing the water infrastructure and the service delivery (operational expenses) are (should be) the two most important challenges for the utility's executive and decision- makers in a context of drastic reduction of available funding, even though the water sector is already underfinanced and demands huge additional investments. In analysing these aspects, the Specialist Group will look after the way of covering the operational expenses; how the investments are financed; the local/central/international involvement in financing water projects; the impact of the financial and economic crisis on water infrastructure development and water services; what financing and pricing policies should be implemented to ensure and maintain access to water services, once people are connected to the network; lessons learned from the previous tariffs policies.
- Water resources management. The natural water cycle has long been characterised by substantial variability, which plays a large role in how modern water systems are managed. Increasing competition for water across sectors increases the importance of the river basin as the appropriate unit of analysis to address the challenges facing water resources management; and modelling at this scale can provide essential information for policymakers in their resource allocation decisions.
- Water governance, regulation, and institutional frameworks. It is essential to identify good practices and develop practical tools to assist different levels of governments and other stakeholders to engage effective, fair and sustainable water policies. Which are the set of rules, practices, and processes through which water resources management decisions are taken, implemented, and monitored.
- Water statistics and data collection methods. Why is it so difficult to get good international water statistics? Water demand and supply estimation.
- Urban water supply and sanitation. How urban water and sanitation utilities are financed, which are their various water tariff structures, in which way do they insure accessibility, how to assess their performance, and how they are facing increasing vulnerabilities, among others.
- Rural water supply and sanitation. Given the adoption of access to water as a human right, it is no longer sufficient to exclusively address access, but rather focus on sustainable water supply in quantity, quality, accessibility and reliability. How can we move away from traditional rural supply approaches focused on infrastructure provision towards the supply of a reliable service that lasts indefinitely?
- Agricultural water management. How to meet ever-rising demand for food while at the same time increasing farmer incomes, reducing poverty, and protecting the environment, all from an increasingly constrained water resource

base, are the main challenges facing agricultural water management.

Participants will have the opportunity to take part in a forum to debate on these important issues, share experiences and knowledge covering the entire water cycle, ultimately influencing major policy decisions. It will convene water practitioners, policy makers, regulators, and researchers, to exchange and share their experiences and research results about all aspects of Water Economics, Statistics, and Finance.

Conclusion

Within the IWA community, the Statistics and Economics Specialist Group is the central group for elaborating economic, financial and statistical topics. Although in the past many activities in this respect were developed by the Group, there is still a lot to discuss. That is why the Specialist Group will be dealing more in detail with these topics in the coming years, mainly focusing on water pricing policies, on funding issues and improving and enlarging our statistical information.

Strategic Asset Management

Written by *R. Amaral and H. Alegre* on behalf of the Specialist Group

Introduction

Water services are fundamental to the sustaining of societal quality of life. The infrastructures responsible for the provision of such services represent a major portion of the value of municipal physical assets and are expected to be managed for current and future generations.

'Asset management' (AM) is a modern term for an old practice: managing urban infrastructure assets has been a continuous task for many thousands of years. Nevertheless, a more comprehensive and well-devised strategic approach has been evolving in the past few decades. Water utilities are increasingly being forced to adopt a long-term approach and to manage the infrastructures in an optimal way, striking a balance between performance, risk and whole of life costs.

The ISO 55000 standard defines AM as the 'coordinated activity of an organisation to realise value from assets'. The concept of AM started to be applied in the financial sector and has evolved in other areas such as engineering, currently assuming many forms and meanings. For utilities the focus is mainly on the physical assets, which are at the root of the term 'infrastructure asset management' (IAM). It requires competencies in three fundamental areas of knowledge: management (financial, economic and organisational), engineering and information. IAM needs to be planned at three distinct levels – strategic, tactical and operational – requiring each one to be perfectly aligned with the others.

IAM has significantly advanced in recent years, in particular in terms of the formal approaches and of the monitoring and decision-support tools. From a practical standpoint, very good examples of cutting-edge utility practice have emerged.

In this context, the Strategic Asset Management Specialist Group (SAM-SG) aims to do the following:

- promote and disseminate leading-edge approaches to Strategic Asset Management;
- strengthen the activity in developing regions;
- leverage the participation of the young water professionals in the group;
- consolidate an IWA vision, key principles and best practices of infrastructure asset management.

The SAM-SG has more than 600 IWA members. The main activities of the group include specialised conferences (LESAMs), co-organised conferences, workshops and seminars, keynotes, task groups, participation in R&D projects, publications in IWA journals, newsletters and training and dissemination of materials.

Existing Specialist Group knowledge

Australia and New Zealand

Australia and New Zealand are broadly known as one of the world leader schools in IAM (see, for example, Heck, 2008; Schulting and Alegre, 2007). Changes in these countries started primarily from the reform of local governments in the mid-1980s and in the first half of the 1990s. The process stimulated the reassessment of councils' infrastructures and the national governments have strongly endorsed the concept of IAM (see, for example, GAO, 2004; GWRC, 2009). In Australia, there are different drivers being used to improve AM such as legislation, regulatory licence requirements and accounting standards. In the water industry, the way was led by Sydney Water and Hunter Water after the New South Wales government passed legislation to restructure water boards as 'state-owned corporations' (Jones *et al.*, 2014). In New Zealand, the increasing requirements in terms of legislation have been the main driver for practising IAM development. The recent amendment to the Local Government Act which introduced the requirement to develop a 30-year infrastructure strategy (LGA, 2014) is noteworthy. The Office of the Auditor General has also been an important driver for AM improvements in New Zealand (IPWEA and NAMS Group, 2006). In both countries, IAM manuals were published and a range of training initiatives were carried out to assist with legislation or regulation compliance. Water utilities were to become commercially based and customer focused (see, for example, Kelly, 2005; IPWEA and NAMS Group, 2006). Utilities are required to report extensive asset management related information and are externally audited. Benchmarking projects have also been used to drive AM performance improvements. The Water Services Association of Australia (WSAA) started these projects in 2000, with the IWA co-sponsoring the programme since 2007. The WSAA's Aquamark Framework has been applied since 2004 for assessing asset management process maturity. The 2012 project involved 37 participants principally from Australia and New Zealand, but also from the USA, Canada and the Philippines. The Australian and New Zealand AM 'school' is synthesised in the International Management Manual, revised and updated periodically (current edition: IIMM, 2011), which is dedicated to different types of public infrastructure and promotes the total asset management process.

UK

In the water industry, the first comprehensive introduction of the principles of asset management was in the UK in 1989 (GWRC, 2009). At this time, water companies in England and Wales were privatised in response to the need for increased investment and with the idea of them becoming more efficient (Ofwat and Defra, 2006). In the period leading up to privatisation, it was necessary to provide investors with information about the condition of infrastructures and investment requirements associated with the process. Subsequently, the role of the water and wastewater services economic regulator (Ofwat), introduced by the UK government at the time as privatisation, has been the main driver to asset management improvement in the sector. The water companies are required to develop five-year AM plans (AMPs) proposing and justifying expenditure needs, the financing requirements and the implications for price limits and average bills. These plans are reviewed and approved by Ofwat that sets limits on the prices the water companies can charge their customers. The development of these plans is currently centred around the UK Common Framework for Capital Maintenance Planning takes into consideration the guidelines periodically published by the regulator, aiming to promote a continuous improvement process. Developed through a UK Water Industry Research (UKWIR) project, the Common Framework is founded on risk-based principles and encompasses an economic approach that allows the trade-off between capital and operational cost options to be considered. It was launched in 2002, after the House of Commons Environmental Audit published in 2000 accused the water industry of 'intellectual neglect' (Anglian Water, 2015). Since then, several UKWIR projects have added knowledge to the Common Framework. A remarkable change has been the introduction of total expenditure ('totex') in AMPs, combining both capital 'capex' and operating expenditure 'opex'.

USA

In the USA, IAM is developing, although not as fast as in the aforementioned countries. According to Jones *et al.* (2014) this is primarily due to the different structure of the water industry, which comprises many more organisations and a mix of private and municipal entities. Nevertheless, some US water utilities, such as Seattle Public Utilities, started to implement a comprehensive AM approach in the early 2000s, in line with the Australian and New Zealand 'school' (Kelly, 2005). Since 2006, the speed of uptake of IAM has been increasing, in large part due to the Strategic Asset Management Communication and Implementation research programme (known as 'the SAM Challenge'), which has created an enabling environment at both national and utility level (Graf and Blakenship, 2011). This project was sponsored by the Water Environment Research Foundation (WERF) and included the participation of the UKWIR and the Global Water Research Coalition. The SAM Challenge and other research programmes have strengthened the Sustainable Infrastructure Management Program Learning Environment (SIMPLE) as the leading reference for AM knowledge and guidance. Currently, SIMPLE provides guidance, decision support tools, practices and case studies structured to answer the so-called 'five-core question', set out in the guidance published by the US Environmental Protection Agency (USEPA, 2008), applying a ten-step method. The 2013 Water Infrastructure Asset Management study, prepared by McGraw-Hill Construction in partnership with CH2M HILL, paints a picture of the state of IAM in the water industry in the USA and Canada.

Canada

The first AM concepts and guidelines were introduced in Canada from the mid-1990s. The National Research Council (NRC) Canada has played an important role in this regard, carrying out multiple initiatives (e.g. the Infraguide and the Municipal Infrastructure Investment Planning projects). The NRC's AM recommended approach can be viewed as 'the six simple questions' (Vanier, 2000). The Walkerton (Ontario) accident, which occurred in 2000 and resulted in the deaths of seven persons owing to a drinking water system's contamination, had a profound impact on the management of water infrastructure in Canada. The Walkerton inquiry report has been the basis of new legislation and regulatory changes, following a period of increased activity and development in AM practices. In 2007, the Public Sector Accounting Board introduced new accounting standards for public infrastructure in Canada (PSAB 3150), similar to the USA's Government Accounting Standards Board Statement 34 (GASB 34). This is having a national transformational impact on the evolution and development of asset management practices in Canadian municipalities (Andres, 2012). The information provided by PSAB 3150 has triggered several important AM initiatives, such as the first national report card on the state of municipally owned water, wastewater and road infrastructure (CCA *et al.*, 2012, 2014).

European initiatives

The twin decision support systems CARE-W (Computer-Aided Rehabilitation of Water Networks) and CARE-S (Computer-Aided Rehabilitation of Sewer Networks) were developed in European Research projects. These projects were aimed at assisting water utilities to establish a rational framework for rehabilitation plans of water and wastewater networks (Sægrov, 2005; Sægrov, 2006). The projects ended respectively in 2004 and 2005, and since then a number of applications have taken place in several countries. In technical and scientific terms, Portugal (LNEC) and Norway (SINTEF) launched AWARE-P (Advanced Water Asset REhabilitation in Portugal, www.aware-p.org), following the CARE path. This initiative allowed the establishment of a sound and systematic infrastructure asset management approach, nowadays an international reference, and publishing corresponding guidance manuals and software tools. More recently, the TRUST project (www.TRUST-i.net) was developed under the 7th Framework Program of the European Union. This was a 4-year project starting in 2011 with the aim of delivering knowledge to support TRansitions to the Urban Water Services of Tomorrow, enabling communities to achieve a sustainable, low-carbon water future without compromising service quality. In the scope of IAM, apart from technologies and analytical tools, TRUST results include an objective-oriented approach to IAM, the TRUST/AWARE-P IAM approach, designed to support a continuous improvement management process. It is an outcome-oriented IAM planning for long-term sustainability, embedding key ISO 55000 requirements, as well as the IWA guidance and recommended best practice on performance assessment, benchmarking and good management. This approach is incorporated in a series of IAM best practice manuals. An e-learning course on this subject was also made available (Alegre *et al.*, 2016).

Other relevant worldwide initiatives

Many other relevant initiatives around the world could be highlighted. Here some examples are presented.

- In Portugal, the TRUST/AWARE-P IAM approach has been applied in collaborative projects (www.iniciativagpi.org) launched by the National Civil Engineering Laboratory (LNEC), in partnership with IST (Technical University of Lisbon), Addition and several water utilities.

- In France, the renowned Scientific and Technical Association for Water and the Environment (ASTEE) has recently published two guides on asset management for drinking water supply networks.
- In the Netherlands, there are several platforms (e.g. the VVZBs, the cooperation of wastewater treatment managers, AM working group) focused on IAM and a lot of congresses, courses and meetings in this regard have been held in recent years. AM policies are directed by service targets, much more than economic reasons.
- As part of the Danube Water programme, the International Association of Water Supply Companies in the Danube River Catchment Area (IAWD) has recently finished a capacity building project, over a period of 18 months, with the main goal of creating greater awareness and improving AM practices for 17 water utilities from Bosnia and Herzegovina, Montenegro, Macedonia and Serbia (www.danube-water-program.org).
- In Japan, the Ministry of Health, Labour and Welfare (MHLW) established the 'asset management guidelines for water supply utilities' in 2009, to encourage utilities to adopt AM. Many utilities have established medium- to long-term infrastructure renewal and financial plans based on these guidelines (Sawai, 2013). In 2013, the MHLW provided a Simplified support tool for AM, particularly driven for small-scale utilities.
- The Korea Water Resources Corporation (K-water), South Korea's leading water-related company, developed an asset management roadmap as a first step of a process to strengthen its asset management programme. Asset management terminologies were translated and an AM foundation appropriate for the Korean business culture was established, contributing to creating an AM path for all Korean organisations.
- In 2011, Rand Water, the largest water utility in Africa, started a paradigm shift from an engineering approach to an asset management approach (Lange and Kasan, 2013). Several initiatives were carried out, including a restructuring of the SAM division, an AM maturity assessment and the implementation of guidelines provided in PAS 55.
- The Asian Development Bank (ADB) has published a guide about water utility asset management, aiming to improve sustainability of operations and realise the full benefits of ADB loans for water supply. The guide presents an overview of asset management and includes the experience of four water utilities in Pakistan, the Philippines, Australia and Vietnam.

IAM specifications and standards: moving from PAS 55 to ISO 55000

The existence of globally accepted standards and guidelines for asset management, which provide a common language for the main concepts and terminology and establish the general principles and requirements, is seen as a major step forwards.

The Publicly Available Specification PAS 55, the British standard for the optimised management of physical assets, was first published in 2004 and was substantially revised in 2008 (PAS 55-1: 2008 and PAS 55-2:2008). It has been broadly adopted in a variety of sectors around the world, including good examples of application in the water sector. Emerging from the success of PAS 55, the International Standards for Asset Management ISO 55000 were launched in 2014. The ISO 55000 series comprises three documents and the most significant change from PAS 55 is the target scope of application; where the PAS 55 specification focused exclusively on physical assets, the ISO 55000 series is designed to apply to any asset type. Some utilities have been working on or have already acquired the certification of the ISO 55001 standard. The WSAA has recently implemented a collaborative project between 25 water utilities aiming to develop implementation guidelines for ISO 55001 applicable to the Australian water sector (Muruvan *et al.*, 2015). Sendai Wastewater Utility acquired the first certification of ISO 55001 in Japan in March, 2014 (Abe and Mizutani, 2015). Based on the Sendai experience, a user's guide for applying ISO 55001 was created and published by the Sewerage Department of the Ministry of Land, Infrastructure, Transport and Tourism of Japan. These example initiatives clearly indicate the strong interest from the water industry in ISO 55001.

General trends and challenges

The following major areas are expected to be hot topics in within the next few years.

ISO 55000 standards

The implementation of the ISO 55000 standards in the urban water sector is a great opportunity to achieve sounder AM systems and spread IAM best practices. So far, it has attracted a lot of attention and different utility or national level initiatives, as presented before, are currently underway. Taking advantage of the different experiences and perspectives and for a more effective and efficient process, joining global efforts to provide implementation guidance should be explored. The implementation of ISO 55000 standards should also contribute to address the still existing gap between strategic and operational levels alignment.

Communication on IAM

External and internal communication has been widely recognised as one of the key existing bottlenecks for a change in policies, mindsets and practices in IAM. Difficulties exist within the water utilities, both in communication between decisional levels and between departments. Major barriers also exist in communication between stakeholders, particularly utilities, political bodies and society. Despite good recent achievements in this regard (see, for example, van de Ven-Glastra *et al.*, 2015; Alegre *et al.*, 2015), communication on IAM is still a battle to be won in the coming years.

Cross between technical, financial and accounting approaches

IAM has tended to be approached based on partial views (e.g. business managers' and accountants' view, water engineers' view, policy-makers' view). This has led to the increasing level of accumulated deficit in capital maintenance and thus ageing and loss of infrastructure value. The current concession models and funding schemes do not ensure service sustainability beyond the term of the contracts. Accounting practices are also frequently preventing the application of good long-term planning. Given this situation, understanding the consequences of the current financing and accounting practices in terms of the infrastructural sustainability and addressing across the board approaches is a major future challenge. To take a step forwards, advantages and disadvantages of different solutions should be discussed with all key stakeholders: utilities, regulators, funding agencies, accountants, user's representatives, researchers, academics, policy-makers.

Service-centric asset management

Traditional IAM approaches are asset-centric, i.e. they tend to consider the individual contribution of each asset, without understanding the whole system performance. As water infrastructures are networks assets, there is a need to manage the infrastructure on the basis of ensuring service and risk levels, rather than individual components (see, for example, Reksten *et al.*, 2013). Furthermore, with water utilities increasingly focused on the customer, effective service-centric AM is essential now more than ever.

Conclusions and research or development agenda

Strategic asset management of urban water infrastructures has significantly evolved around the world in recent years and has converged to increasing international consensus.

The implementation of the ISO 55000 standards in the water sector will be a major challenge in coming years and is a great opportunity to take strategic asset management to the next level. An across-the-board view of technical, financial and accounting approaches and service-centric procedures should also be addressed in future research agenda. Bringing together utilities, academics, researchers and consultants and policy-makers and regulators should continue to be encouraged. It is up to the utilities to launch this process. It is also the role of academics, researchers and consultants to participate in it. Policy-makers and regulators should promote the necessary enabling changes and create the adequate incentives and conditions.

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Sustainability in the Water Sector

Written by *C. Davis, M.B. Beck, R. Villarroel Walker, H. Zhang, K. Loucks-Powell, A. Adedugbe, S. Kenway, and P. Goethals* on behalf of the Specialist Group

Introduction

The Sustainability in the Water Sector Specialist Group, which includes more than 1,500 members, plays several distinct roles in helping the International Water Association (IWA) achieve the goal of sustainability that is imbedded in its vision: a world in which water is wisely managed to satisfy the needs of human activities and ecosystems in an equitable and sustainable way (Lisbon Charter, 2015).

Pushing forward and broadening the frontiers of research in sustainability

Although there is a general shared understanding that sustainability in water addresses economic, social, and environmental issues over time, our analysis has become more complex as we look beyond single factors (e.g. water supply or water quality) to the interactions of multiple factors, all of which may be important but impacted differently by various actions and actors. An example of an activity of the Specialist Group in continuously expanding our knowledge from a multi-faceted perspective is IWA's journal *Sustainability of Water Quality and Ecology*, published in collaboration with Elsevier. Similarly, a report on ecosystem services and urban water infrastructure (Beck 2016), blends consideration of social, infrastructure, and financial benefits with ecosystem benefits and services. From a time perspective, that report provides not only a history of water/ wastewater infrastructure impacts on ecosystem services, but also examines the impacts of the artificial time cycles (24/7 versus seasonal) and constraints in variation of flows that are imposed by grey infrastructure. The broad scope of the research issues currently considered by the Specialist Group is indicated by the title of a workshop sponsored by the Specialist Group at the 7th World Water Forum in Korea in 2015: 'Pending Research Questions Linked to Sustainability Assessment: An Analysis Based on Integrated Perspectives from the Water-Energy-Food-Ecosystem Nexus'.

Encouraging continuing attention to broad, long-term sustainability issues

While the ideal of sustainability underlies all activities of the International Water Association, immediate technical, political, financial, and social issues are so pressing that attention can easily drift away from broader impacts on communities, economies, and ecosystems over time. This is illustrated in an editorial by Peter Goethals and Martin Volk in which they noted that even for a journal with the word sustainability in its title, 'In the first version of most papers, sustainability was not or rather vaguely mentioned' (Goethals and Volk 2016). A vital role of the Sustainability Specialist Group is to push for the broader long-term concerns associated with sustainability to be taken into account in all aspects of IWA's work.

In an organisation as large as IWA, where multiple complex technical areas co-exist, programmes can become increasingly focused on the specifics of advancing the technology, without attending to potential unanticipated consequences for communities, economics, and ecosystems. The challenge is not necessarily to have more workshops or publications that focus on sustainability, but to bring the concepts of sustainability into IWA's workshops and publications.

Identifying new areas where the concept of sustainability is important but has not yet been addressed

In 2013, the Management Board of the Sustainability in the Water Sector Specialist Group polled all members of the Group to see which topics were of most interest to them. Two new working groups added to the group's roster of activities were Workforce Sustainability and Sustainability in Industry. In the case of Workforce Sustainability, the aim has been insuring that utility workers in water and wastewater services are qualified and prepared to do quality work. The focus of research and support has been on engineers and skilled trade workers (e.g. water and wastewater treatment plant operators). In the case of Sustainability in Industry, the intent is not only to encourage policies and regulations to enforce sustainable practices, but also to provide customised guidelines and training materials that will help industry employees (e.g. in manufacturing, mining, and oil production industries) understand sustainability principles and practices (e.g. water use reduction, water reuse, and improving water quality).

Bridging the gap between research and implementation

As an organisation, IWA is clearly working to become more focused on real-world implementation. The Lisbon Charter, addressed primarily to regulators while also addressing other stakeholders, came out of the Lisbon World Water Congress, which also included a track on sustainability in industry (IWA 2015). The continued emphasis on industry in the programme planned for the World Water Congress in Melbourne in 2016 reflects a continuation of a shift toward implementation that is mirrored in the activities and concerns with focus of the Sustainability Specialist Group.

Dissemination of Information about sustainability

The Sustainability Specialist Group has, since the publication of the 2012 Compendium, used three primary approaches to dissemination of information about sustainability. One has been facilitation of workshops (e.g. a workshop on clean technologies at the World Water Congress in Lisbon in 2014 and a workshop on workforce sustainability at the Water Development Conference in Jordan in 2015). Other forms of dissemination have included publication of the journal *Sustainability of Water Quality and Ecology*, publication of papers by individual members, and publication of the Sustainability Snapshot newsletter. The first edition of the Sustainability Snapshot newsletter, published in 2015, featured articles about sustainable mining in Chile, work with industry to conserve water in Australia, and insights about technologies for nutrient recovery. Another vehicle that is available, but one that has not been fully utilised, is the Global Water Platform (www.globalwaterplatform.org), a knowledge management system developed by IWA under the guidance of the Sustainability Specialist Group.

Technological innovation for sustainability in the water sector

Members of the Sustainability Specialist Group are collaborating for the creation of a database on clean technologies under the BeCleantech initiative. This database is being hosted in the www.becleantech.org website and is supporting the generation of data-driven insights about technology trends, gaps, and synergies. The initiative considers technologies involved in the delivery of water and wastewater services for sectors such as municipal utilities, power generation, manufacturing, agriculture, and extractive industries.

Existing knowledge in sustainability

The magnitude and breadth of current knowledge in relation to sustainability is beyond being summarised succinctly in this report. However, areas of progress include the following:

1. Increased ability to measure and track key variables through systems and to look for opportunities to modify processes in beneficial ways (e.g. use of a multi-sectoral analysis to track the flows of energy, water, and nutrients through the water/wastewater systems of London, and identify alternative technologies that would allow water savings and energy/nutrient recovery (Villarroel Walker et al. 2014);
2. Recognition of the importance of workforce sustainability, so that the individuals providing water and wastewater services throughout the world will be qualified, skilled, and knowledgeable enough to handle the challenges of protecting public health and the environment, despite challenges associated with retirements, rapidly changing technologies, regulations, and social structures, and inconsistent funding (Davis 2013; Davis and Curtis 2014);
3. Increased attention to economic aspects of sustainability. Two examples are the reports on the economic value of ecosystem services (Beck 2016) and the global market and technology analysis for phosphorus and nitrogen fertilisers recovered from animal and human waste (Villarroel Walker and Beck 2014);
4. Increased willingness and ability to simultaneously analyse cases and effects in multiple dimensions of the water-energy-food-climate nexus (Beck 2011).
5. Development of tools and performance metrics for measuring the sustainability of systems (e.g. life-cycle analysis tools, mass balance approaches, integrated environment models, decision support system, and ecosystem analysis tools) (IWA 2006; Kenway *et al.* 2007); and
6. Increased understanding of the potential effects of climate change, population growth, demographic changes, energy needs, food consumption patterns, urbanisation, economic changes, and policy regulations (Goethals and Volk 2016).

Emerging issues and action plans

Many of the hottest emerging topics in the area of sustainability relate to translating abstract or complex knowledge into components that will help effect real-world change. An interesting example of the need for focus on practical implementation came from the Leaders Forum conducted after the World Development Conference. When the specialist group leaders attending the Forum (many of whom were academics) responded to the question of what technological break-through would appear to help us achieve adequate water and sanitation for low-income countries, the consensus was that no technological innovation could be expected to have that effect. Instead, they stressed the importance of *capacity-building* among the staff responsible for planning, operating, and maintaining water and wastewater facilities in those countries.

Workforce sustainability is of equal concern in more affluent countries. Water and wastewater utilities throughout the world rely on the knowledge, motivation, and skills of their staff to provide clean water and protect the environment. Many factors endanger workforce sustainability including: employee retirements and resignations; poorly managed changes in equipment, policies, and infrastructure; inadequate documentation and access to information by employees; work processes that make inefficient use of staff; and lack of collaboration among utilities and stakeholders (such as educators and international organisations) to address shared workforce challenges.

In many places, it is a challenge to find qualified candidates for mission-critical jobs, and make sure that staff have the information and motivation they need to do reliable work. This is an area where utilities, educators, and organisations who are involved in trying to support the work of utilities can learn from each other. To support information-sharing and collaboration in this area, IWA has distributed a survey to collect information from utilities across the world on best management practices in the following aspects of workforce sustainability:

- needs assessment and strategic planning;
- candidate development;
- staff preparedness (documentation, training, development, and knowledge management);
- sustainability awareness;
- optimised use of staffing available;
- staff motivation; and
- cost-effective workforce investments through collaboration.

This survey includes not only acquisition of descriptions of programmes, but collection of the actual tools used to perform the work (e.g. checklists, training materials, and examples of products produced in connection with the programmes). The product of this effort will be an online interactive Global Guidebook on Workforce Sustainability that will include links to videos, reports, presentations, and documents in a variety of languages. The product will be a book that fully utilises Information Technology to make information visually appealing, engaging, interactive, and accessible. Examples of features of the desired product are the ability to be viewed on mobile devices; access to videos of staff explaining or implementing their programmes; the ability to sort for resources in different languages and within different geographical regions; and the ability to auto-translate documents into different languages. This guidebook can be a great reference resource for international organisations and utilities. However, one aspect of the intent of the online guidebook will be to make information accessible to utility staff members who may not speak English, could not necessarily have access to the hard-copy publication, or would be unlikely to have the opportunity to attend an international conference. Online publishing would make it feasible to provide this information free to water and wastewater utilities struggling, often in difficult circumstances, to provide reliable services across the globe.

A second hot topic relates to use of *water by industry*, which accounts for 10–59% of the water use at country level (WBCSD 2005). Industrial water use is significant not only because of its quantity but because of frequent impacts on water quality and ecosystems. The purpose of the Sustainability in Industry Working Group is to create shared principles but customised and readable guidelines, case studies, and training materials to help bring industrial water practices into alignment with broad long-term sustainability objectives. Two significant barriers that currently exist to sustainable use of water by industry are the cost of improved operations (which may not seem cost-effective if the right incentives are not put in place by local and national policies) and lack of clarity about what would constitute sustainable operations and maintenance in their area of operation.

The purpose of the Specialist Group's Sustainability in Industry project is to reach effectively into industry itself by providing products that are customised by industry and understandable to the managers who make investment, maintenance, and operational decisions, as well as guidebooks and training materials that will be comprehensible to staff who handle industrial design, construction, maintenance and operations.

Concrete steps towards promoting more sustainable practices include academic research, policy formulation, and often regulatory shifts. However, a further step needs to be taken to ensure that research, policy, and regulations are expressed in terms that are known to individuals who work in industries such as manufacturing, mining, power production, and oil and gas. The action plan proposed supports these steps through the following:

- creation of a document on sustainability principles that can be applied to multiple industries and written in a language that appeals the non-academic audience;
- creation of an IWA-curated toolbox of existing tools that can be used to assess sustainability of industrial operations with regard to factors such as water demand, water quality, water transmission and storage, energy use, and transparency of reporting;
- case studies of industries which have adopted sustainable practices;
- training materials to provide guidance in more sustainable use of water and water quality; and
- distribution of reports, presentations, and training materials through industry venues (e.g. trade publications and conferences) and through online publications.

A third area of action is *providing useful and accessible information* on appropriate tools and approaches for achieving sustainability in the water sector, including industrial use of water. The Global Water Platform (GWP) offers a unique opportunity to organise this information for easy and free access online. The long-term goal of the working group is build-up on GWP and proactively take products to the industries and regulators that they are intended to serve. The BeCleantech Initiative can leverage the capabilities of the GWP and benefit from the search and navigation functions of the platform. However, the existing BeCleantech website will be continued as a separate front-end that will allow users to both view and post content.

The journal *Sustainability of Water Quality and Ecology*, which has already published six volumes during the past three years, aims to contribute to the improvement of the water management by providing new insights from a broad angle. In particular, the integration of social sciences in water management was a major gap within IWA, and the journal aims to integrate these aspects in particular. The journal attracts papers related to integrated monitoring and assessment, but also related to new policy development needs, such as communication, awareness-building and decision-making. To achieve this, during the past year, new active and committed board-members were attracted to deal with the increased flow of tasks. Last year, the journal also changed to a new editorial system (EVISE) to improve the editorial and publication flow. In this context, papers are also directly linked to an issue after acceptance, and special issues are developed as 'virtual issues' to reduce processing times of papers. The journal also aims to attract interesting reviews in the future.

Conclusion

Upcoming efforts of the Sustainability Specialist Group will include academic research, developing tools that can help utilities and industry improve their practices. There is a certain tipping point at which cumulative data on impeding disaster or failure begin to modify both perception and behaviour. Individuals and organisations realise that a change in practices is needed to protect social, environmental, and financial rewards. It is at this point that the Sustainability Specialist Group hopes to provide training material that explains why and how to move towards more sustainable practices, tools that 'fit to their hand,' and guidelines that are relevant and directly applicable to their scope of influence.

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Tastes, Odours, and Algal Toxins in Drinking Water Resources and Aquaculture

Written by *Andrea M. Dietrich, Byung-Uk Bae, August Bruchet, Gary Burlingame, Chao Chen, Ricard Devesa-Garriga, Niels O. G. Jørgensen, Djanette Khiari, Naohiro Kishida, Tsair-Fu Lin, Pinar Ömür-Özbek, Richard Stuetz, Susan Watson, Jianwei Yu, Arash Zamyadi and Lifeng Zhang* on behalf of the Specialist Group for Tastes, Odours, and Algal Toxins in Drinking Water Resources and Aquaculture

Introduction

The human senses are designed to both provide pleasure and to protect humans from their environment. Noticeable and undesirable tastes and odours in drinking water or aquaculture produced fish and shellfish can evoke a response, illicit concern, and even generate fear in consumers. Off-flavour, which is the combination of tastes and odours perceived by consumers, is another term associated with undesirable water and aquaculture products for human consumption. A concurrent concern is the occurrence of cyanotoxins in water and their potential health effects for humans, and aquatic, terrestrial, and avian animals. The drinking water and aquaculture industries recognize that providing products that have acceptable consumer satisfaction leads to consumer confidence and averts loss of trust and subsequent loss of revenue.

Existing Specialist Group knowledge: a global snapshot

This Global Snapshot of tastes, odours, and toxins in water and aquaculture was obtained by asking Specialist Group Committee members to assess the occurrence of these issues in their country or for countries of which they had direct knowledge. Tastes and odours were assessed using the major categories from the Taste-and-Odour Wheel. The results are summarized in Table 1.

Overwhelmingly, the major issue in water and aquaculture are cyanobacteria and their associated earthy/musty tastes and odours and production of cyanotoxins. Cyanobacteria plague at least six continents and inhabit warm, temperate, and cold climates. That earthy/musty odours are the dominant aesthetic issue in water agrees with previous reports that in the 21st century, earthy/musty tastes and odours exceed those of chlorinous odours which dominated in the 20th century. Chlorinous odours, both from disinfectants (chlorine, chloramines, and chlorine dioxide) and non-disinfectant sources, are still perceived by consumers and professionals worldwide to be the second most prominent aesthetic issue in drinking water.

After earthy/musty and chlorinous odours, several other categories appear that have similar occurrence across the globe. One category is marshy/swampy/septic/fecal/sulfurous odours due to a myriad of volatile organic sulfur compounds, including hydrogen sulfide, dimethyl disulfide, dimethyl trisulfide, and mercaptans, and the non-sulfur containing indole and skatole. Another prominent category is medicinal odours which can be associated with halophenols and iodomethanes. Frequently occurring odours in many countries include musty/moldy odours associated with haloaniosoles; fishy odours associated with amines or oxidation of polyunsaturated fatty acids; and hydrocarbon or sweet chemical odours associated with a myriad of industrial chemicals and sometimes chemical spill.

The most noticeable global taste issue is tastes from salt water intrusion, salinization, and increased total dissolved solids (TDS) due to drought, evaporation, and agricultural/industrial inputs.

General trends and challenges within the next 5–10 years

The trend is that the issues of tastes, odours, and algal toxins in water and aquaculture are increasing globally and will increase for the short and, probably, long term. The complex environmental, climate, human, and interdisciplinary factors that contribute to tastes, odours, and toxins in water and aquaculture mean that there are many challenges to be considered in an attempt to control increasing aesthetic and toxin issues. The experts in our Specialist Group perceive the topics below to be the major challenges in the next 5–10 years.

Challenges in Aquaculture

- Harmful/nuisance algal blooms and associated human and food web toxins, tastes, and odours
- Concentrations of tastants and odourants in fish and shellfish produced with water recirculation
- Improve monitoring of off-flavours in aquaculture products
- Methods for easy detection of off-flavours in aquaculture products.
- Simple, effective control methods of tastant and odourant producers for aquaculture industries

Table 1 Global snapshot from source to tap to human nose/mouth: major tastes, odour, cyanotoxin issues in drinking water and aquaculture in the 21st century. Note: locations of occurrence based on knowledge of Specialist Group members and not comprehensive for all countries.

Tastes Odours, and Toxins	Example aesthetic and/or health problem	Example Source	Region or Country of Occurrence		
			Fresh Water Sources	Drinking Water	Aquaculture
Algal Toxins	Cyanotoxins; microcystins; Saxitoxins; Cylindrospermopsin	Cyanobacteria	Argentina, Australia, Bangladesh, Brazil, Canada, China, Czech Republic, France, India, Israel, Japan, Kenya, Morocco, New Zealand, Norway, Portugal, Spain, South Africa, Sri Lanka, Taiwan[1], Turkey, Uruguay, Venezuela, United Kingdom, USA, Zimbabwe	Australia, Bangladesh, Brazil, Canada, China, Czech Republic, Morocco, New Zealand, Norway, Portugal, Spain, South Africa, Sri Lanka, United Kingdom, USA, Taiwan, Uruguay, Venezuela, Zimbabwe	Australia, Bangladesh Canada, India
Odours from the Taste-and-Odour Wheel					
Earthy, musty	Geosmin; 2-Methylisoborneol; Alkylmethoxypyrazines	Cyanobacteria Actinomycetes fungi	Argentina, Australia, Brazil, Canada, Chile, China, France, Japan, Korea, Philippines, Portugal, Spain, Taiwan, Uruguay, USA	Argentina, Australia, Brazil, Canada, Chile, China, France, Japan, Korea, Portugal, Singapore, Spain, Taiwan, Uruguay, USA	Australia, Bangladesh, Brazil, Canada, China, Denmark, France, Israel, Japan, Netherlands, Portugal, Scotland, Spain, Taiwan, Thailand, USA
Musty, moldy, cork	Haloanisoles	Methylation of halophenols	France, Sweden, USA	China, France, USA	
Chlorinous odours	Chlorine; Chloramines; Chlorine dioxide	Disinfection		Australia, Canada, China, France, Spain, Taiwan, USA	
Chlorinous odours	Cyclohexylamine; 3,5-Dimethyl-pyrazole; Unknown	Amino acid reaction products	China	Australia, China, France, Japan, Taiwan[1], USA	
Grassy, Hay, Woody odours	cis-3-Hexen-1-ol;; cis-3-Hexenyl acetate; β-Cyclocitral	*Microcystis* Vegetation Driftwood	Canada, China, Japan	China, Japan	Bangladesh
Marshy, Swampy, Septic, Faecal Sulfurous odours	Dimethyl disulfide; Dimethyl trisulfide; Hydrogen sulfide; Mercaptans; Indole; Skatole	Decaying vegetation; algae; and macroalgae; Methionine	Canada, China, Japan Taiwan, USA	China; USA	
Vegetable, Fruity odours	trans-2-cis-6-Nonadienal	Cucumber odour from *Synura*	Canada, China	China	
Fishy odours	Trimethylamine; trans, trans-2,4-Heptadienal	Polyunsaturated fatty acids; Amines	Canada, China, Japan, USA	China	USA
Rancid odours	Octanal; Diacetyl; Methyl butanal	Industrial chemicals			
Medicinal odours	Halophenols; Iodo-methanes; 3-fluoro-methyl-phenol	Chemicals; Disinfection by products	China, France, Japan, Spain, USA	China, Japan	
Chemical-Hydrocarbon odours	BTEX[2]; Styrene; methyl and ethyl t-butyl ethers	Gasoline; Polymeric materials	China, Japan, USA	China, Japan, USA	Bangladesh
Chemical-Sweet odours	Methyl methacrylate; 2EDD[3]; TMD[4]; Anisole	Industrial chemicals	Argentina; China, Japan, Spain	China, France, Japan	
Chemical Spills	Mixed odours	Chemicals; Petroleum	China, Japan, Taiwan, USA	China, Japan, Taiwan, USA	
Metallic Flavour	1-Octenol; unknown	Copper; Iron; Corrosion; Bacteria	Japan, USA	China, Japan, USA	
Tastes from the Taste-and-Odour Wheel					
Sweet	Sugars				
Salty	Salt water intrusion; TDS; Sodium	Water withdrawal; hydraulic fracturing	China, Japan, Spain, Taiwan, USA	China, Japan, Taiwan, USA	
Sour	Acids, H^+				
Bitter	Copper; Iron; Minerals	Corrosion, Geology	China (groundwater)	China, USA	

[1]Chinese Taiwan [2]Benzene, Toluene, Ethylbenzene, Xylenes. [3]2-Ethyl-5,5'-dimethyl-1,3-dioxane. [4]TMD: 2,5,5,-trimethyl-1,3-dioxane.

Challenges in Source and Drinking Water

- Climate change and resulting fluctuations in water quality, water quantity, and weather
- Watershed issues
  - Chemical ecology of harmful/nuisance metabolites (toxins, VOCs, etc.)
  - Eutrophication and basin development/erosion/runoff/agriculture/wetland loss
  - Invasive species (toxigenic/nuisance; warm water; halotolerant/desiccation-tolerant taxa)
- Salinization of fresh waters, both surface and ground water
- Harmful and non-harmful algal blooms
  - Increased costs of treating water
  - Harmful/nuisance algal blooms and associated human impacts
  - Cyanotoxins
    - Spread of tropical toxins in temperate areas as a result of climate change
    - Potential expanded human and animal exposure and toxicity
- Increasing occurrence of odourous episodes
  - Algal tastes and odours, including earthy, musty from cyanobacteria
  - Musty, mouldy from haloanisoles
  - Fishy odours
  - Sulphurous odours from volatile organic sulphur compounds
  - Non-algal odours from distribution system, fires, and industrial chemical inputs
- Consumer Issues
  - Perception of drinking water quality and risks
  - Communications/dialogue between consumers and water producers
  - Consumer satisfaction
- Human Sensory Factors
  - Broader and novel sensory methods/tasting panels for drinking water
  - Effects of desalination, remineralization, blending and specific ions on the taste of water
  - Update Taste-and-Odour Wheel
  - Knowledge of detection and acceptance thresholds
  - Standards/guidance based on aesthetics, perception, acceptability, and/or health
- Monitoring in Source and Drinking Water
  - On-line monitoring technology for taste and odours
  - Use of fluorescent probes as early warning tools during cyanobacterial blooms
  - New monitoring technology including biomolecular technology (qPCR, etc.)
  - On-line chemical technology (GC/MS, Orbitrap LC-MS, etc.)
- Source and Drinking Water Treatment
  - Improved algal control strategies in source waters, including
  - Alternative algaecides and ecological impacts
  - Direct and indirect water reuse
  - Cost and energy efficient desalinization
  - Applications of advanced oxidation technology
  - Small/remote drinking water treatment plants
  - Real time monitoring and treatment adjustment

Development agenda

A key transformational development in drinking water and aquaculture will be a bottom-up approach of everyone – the public, consumers, and professionals – demanding protection of water resources and the public health from impacts of climate change, chemical spills, chemical and microbial contamination, nutrient inputs, and algal blooms so as to protect the health and wellbeing of humans and ecosystems.

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Topics and Challenges on Water History

Written by *A. N. Angelakis, L. W. Mays, G. De Feo, M. Salgot, P. Laureano and R. Drusiani* on behalf of the Specialist Group on Water and Wastewater in Ancient Civilizations

Prolegomena

Study the past, before designing something for the future.
Confucius (*ca.* 551–479 BC)

Significant technological advances were achieved in the 20th century, but there were also many unresolved problems relating to management principles, such as decentralisation of processes, durability of water projects, cost effectiveness and sustainability issues such as protection from floods and droughts. In the developing world, the problems were intensified to an unprecedented degree. Intensification of unresolved problems led societies to revisit the past and reinvestigate successful past achievements. Those who attempted this retrospect, based on archaeological, historical and technical evidence, were impressed by the similarity of principles with present ones and the high level of water engineering and management practices in ancient times (Angelakis *et al*., 2005; Koutsoyuannis *et al*., 2008; Mays, 2008, 2010).

Principles and practices in water management of ancient civilisations are not as well known as other achievements (poetry, philosophy, science, politics and visual arts). A lot can be learned from ancient technologies and practices, so the Specialist Group on Water and Wastewater in Ancient Civilizations focuses on the development of water technologies through the centuries all over the world. The relevance of ancient works is examined in terms of evolution of technology, homeland security and management principles.

With the increasing worldwide awareness of the importance of water resources management in ancient civilisations, the IWA Specialist Group on Water and Wastewater in Ancient Civilizations was established in 2005 and, so far, seven IWA International and Regional Symposia and Workshop on Water and Wastewater Technologies in Ancient Civilizations have been organized in several places of the world. Within the coming three one International and one Regional Symposia and one Workshop are planned.

Ancient water and wastewater technology

Humans have spent most of their history as hunting and food-gathering beings. Only in the past 9,000 to 10,000 years have agricultural crops and animals been grown. Such revolution first took place in the hills to the north of Mesopotamia. From there the agricultural revolution spread to the Nile and Indus Valleys. During this agricultural revolution, permanent villages replaced a wandering existence. About 6,000 to 7,000 years ago, farming villages of the Near East and Middle East became cities. During the Neolithic Age (*ca.* 5700–3200 BC), the first successful efforts to control water flow (dams and irrigation systems) due to food needs were implemented in Mesopotamia and Egypt. Urban water supply and sanitation systems appeared at a later stage, in the Bronze Age (*ca.* 3200–1100 BC).

Hassan (1998) states 'the secret of Egyptian civilization was that it never lost sight of the past', because of the unpredictability of the Nile River floods and the production of grains. The ancient Egyptians depended upon the Nile not only for their livelihoods, but they also considered the Nile to be a deific force of the universe. The river annual rise and fall were related to the rise and fall of the sun.

The first actual recorded evidence of water management was the mace head of King Scorpion (*ca.* 2725–2671 BC), the last of the pre-dynastic kings, interpreted as the tool to initiate a ceremonial start to breach the first dyke to allow water to inundate the fields or the ceremonial opening of a new canal. In another part of the world, Mohenjo-Daro, a major urban centre of the Indus civilisation during the early Bronze Age, located about 400 km north of present-day Karachi, Pakistan. This city, built around 2450 BC, received water from at least 700 wells and had bathrooms in houses and sewers in streets as well as thermal baths (Jalter, 1983). The Mesopotamians were not far behind. The Sumerians, during the Bronze Age, and other ancient nations inhabiting Ancient Mesopotamia provided an enormous amount of information about themselves through cuneiform tablets. Water from the Euphrates and Tigris Rivers shaped their societies. Elaborate irrigation systems were developed requiring continuous canal maintenance and construction of waterworks. One Sumerian epic indicates that humans were created specifically to dig irrigation ditches. The Sumerian epics also referred to the effect of uncontrolled human activity on the soil and environment, being interpreted as God's curses, what we now understand as the environmental effects of intense irrigation (Mays 2008, 2010).

On the periphery of these areas (Arabia and the deserts of Iran, Pakistan and India), food production through farming and nomadic pastoralism, hunting and fishing intensified as the desert environment was used efficiently. This was the creation of oases: the most important realisation to survive in arid areas. An oasis is never a natural or casual creation: associated skills and elements use them in a new way.

It is the fruit of the union of the environmental expertise of nomadic hunter-gatherers and herdsmen with the water techniques of farmers (Laureano, 2000).

Oases depend on the hydraulic expertise and combined use of suitable animals and plants, conditions first met in the early age of metals, around the third millennium BC. In this period nomadic populations chose an agro-pastoral lifestyle and, driven by motives and pressures related to that choice, interacted, allied or established symbioses with or assimilated other groups. The technology of catchment tunnels or *qanats* allowed the spread of oases. In Iran there are *qanats* or *karez*; in Morocco there are *khettara*; and in Algeria there are *foggara*. This Persian technique has been in use for thousands of years, extending from Persia to China, up to Spain, and many other countries. *Qanats* are underground channels consisting of vertical shafts connected with a horizontal tunnel with minimum slope bringing water from a water-rich stratum. These techniques are not the result of an imposition by a central power, but expressions of the knowledge of local populations, demonstrated by their extreme variety and environmental adaptability, and by the diverse terminology used in various countries.

Other great civilisations such as the Minoans, on Crete, flourished during the Bronze Age (*ca*. 3200–1100 BC). They had wonderful water and wastewater systems, in Knossos, Malia, Phaistos or Zakros. Aqueducts, cisterns, filtering systems, sedimentation basins, rainfall-harvesting systems, terracotta pipes for water supply and sewage, and sewerage and drainage systems are described. As the Minoans developed trade relations with the Greek mainland, they influenced the Myceneans (*ca*. 1600–1100 BC). The contact of the Mycenaeans with the Minoans played a decisive role in Mycenaean culture and the dissemination of Minoan water and wastewater technologies in the central Greece and other parts of Europe. The strong bond of Minoans with Myceneans ended when the Myceneans decided to invade Crete. After a brief period of Mycenean control, the Minoan civilisation disappeared. Mycenean culture and power reached its peak around 1300 BC. Then the cultural diffusion that resulted from trade contacts with the Hittite Empire and Egypt started to deteriorate. All of these remarkable civilisations collapsed one after the other. The interesting question is whether water resource unsustainability was a significant component IN their failure (Mays *et al.* 2007).

In the later archaic (*ca*. 750–500 BC) and classical (*ca*. 500–336 BC) Greek periods, all water technologies were advanced and widespread. Their advancement of urban water technology and management is illustrated by

a b

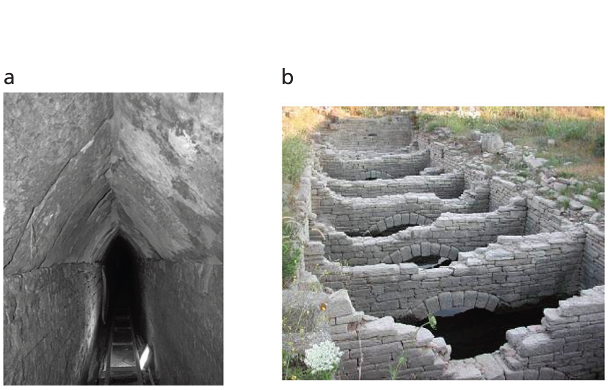

Figure 1. (a) Tunnel of Eupalinos in Samos island and (b) Rainwater harvesting cistern in Delos island.

the aqueduct of Samos (known as the tunnel of Eupalinos, Figure 1a) (Koutsoyiannis *et al.* 2008).

Large cisterns were excavated in rocky fortresses during the Classical and Hellenistic periods. Several examples show regular and well-designed shapes similar to the great rainwater cistern of the Theatre of Delos in Greece (Haut *et al*., 2015). The drained rainwater was collected to a large vaulted cistern (Figure 1b).

The Romans replaced the Greek rule in most Mediterranean locations, inherited the technologies and developed them further. The Romans substantially increased the application scale and implemented water projects in almost all of their large cities (De Feo *et al.* 2014). A few examples are the Hadrianic aqueduct in Athens and in Olympia, known as Nymphaion, which were constructed in the 2nd century AD. Nowadays, the popular but inaccurate image is that Roman aqueducts were elevated throughout their entire length on lines of arches, called arcades. Roman engineers, as their Greek predecessors, were very practical and whenever possible the aqueduct followed a steady downhill course at or below ground level (Hansen, 2006). The longest aqueduct in the Roman world was constructed in the Campania Region, in southern Italy. It is the Augustan Aqueduct Serino-Naples-Miseno, a masterpiece of engineering without spectacular features (De Feo *et al*., 2013).

These works have sometimes been useful in ensuring the health of the community even after thousands of years by their building, like in the city of Bologna (northern Italy). This city in the 19th century was affected by recurrent outbreaks of cholera caused by widespread use of shallow wells polluted by sewage. This situation was overcome by restoring a missing ancient Roman aqueduct of the Augustan age, which withdrew water of good quality from a river 20 km away (Drusiani *et al*. 2010).

On another side of the world, urban rainwater harvesting was considered a part of the water system in a city. A complete model of the urban water system of Chinese cities was first formed at the Chang'an, capital city of the Han Dynasty, at around 200 BC. This model influenced urban water system design and construction in subsequent dynasties of China until the early 19th century (Haut *et al*., 2015).

In addition, management practices were integrated, combining large-scale and small-scale systems that allowed cities to be sustained for millennia. The durability of some of the systems, as well as the support and scientific background in written documents, have enabled these technologies to be inherited by present societies despite regressions that have occurred through the centuries. For instance, the spectacular ruins of Pompeii provide a clearer understanding of a Roman urban water distribution system, with similarities to modern water distribution systems. In this sense, the ending point of a Roman aqueduct was the *castellum divisorium*, which had the double function of serving as a link between the aqueduct and the urban distribution network as well as dividing the water flow to various uses and/or areas of the city. From that *castellum*, the pipes conveyed the water to different parts of the city to the several *castellum secondarium* or *castellum privatum* (De Feo *et al*., 2014).

After the fall of the Roman Empire, when water sanitation and public health declined in Europe, historical accounts tell of incredibly unsanitary conditions: heavily polluted water, human and animal wastes in the streets, and wastewater being thrown out of windows onto people in the streets. Epidemics ravaged Europe. During the same period, Islamic cultures, on the periphery of Europe, had religiously mandated high levels of personal hygiene, along with highly developed water supplies and adequate sanitation systems, which in several cases were the same old Greek and Roman facilities, preserved along the centuries (Mays, 2008, 2010).

Ancient societies in Mesoamerica and the southwestern United States did fail, partly from the depletion of natural resources and natural climate changes, at least particularly as related to water (Mays, 2007). The period from about 150 AD to 900 AD, was the most remarkable in the development of Mesoamerica. During the Classic period, people of Mexico and the Mayan area built civilisations comparable to the advanced civilisations in other parts of the world. Those urban civilisations developed in arid highlands where irrigation (hydraulic) agriculture allowed high population densities. In the tropical lowlands, however, there was a dependence on slash-and-burn (*milpa*) agriculture, which kept the bulk of the population scattered in small hamlets. The non-urban lowland civilisation possibly resulted from responses to pressures set up by the hydraulic, urban civilisation. Teotihuacan (City of the Gods) in Mexico is the earliest example of highland urbanism (Mays, 2010).

All over the world, different water and wastewater related techniques were applied according to local conditions. For example, water supply in some Minoan settlements was dependent on springs, in others on a surface runoff or groundwater systems. Common construction mastery seems to have been applied in several places in a relatively reduced time span. It can be suggested that a group of people living in prehistoric sites were aware of the principles of water relevant technologies. This could indicate the existence of master artisans responsible for constructing and maintaining the water supply system of a community. They could also be in charge of the solution of some water-related problems and were able to provide palaces and settlements with efficient, decentralised, environmental friendly and even sophisticated water supply and wastewater systems (Angelakis *et al*., 2011).

The link between traditional knowledge and water resources sustainability

At the beginning of this new millennium, a water crisis is being experienced. How sustainable is it to live in a world where approximately 1.1 billion people lack safe drinking water, approximately 2.6 billion people lack adequate sanitation, and between 2 million and 5 million people die annually from water-related diseases. The concept of water resources sustainability is creating concern. Water resource sustainability is the ability to use water in sufficient quantity and quality from the local to the global scale to meet the needs of humans and ecosystems for the present and the future to sustain life, and to protect humans from the damage brought about by natural and human-caused disasters (Mays, 2007).

A component of water resources sustainability is the use of traditional knowledge (www.tkwb.org). The United Nations Convention to Combat Desertification (UNCCD) provided a definition: 'Traditional knowledge consists of practical (instrumental) and normative knowledge concerning the ecological, socio-economic and cultural environment. Traditional knowledge originates from people and is transmitted to people by recognizable and experienced actors. It is systematic (inter-sector and holistic), experimental (empirical and practical), handed down from generation to generation and culturally enhanced. Such a kind of knowledge supports diversity and enhances and reproduces local resources.'

How can modern day shortcomings and striving for water resource sustainability be dealt with? Possibly one way is to study the past. Traditional knowledge may play a major role in sustainability issues, especially in developing parts of the world.

Many civilisations, great centres of power and culture, were built in locations that could not support the populations that developed. Similar situations in many places around the world are appearing. Arid zones cover 41.3% of the world's land surface, corresponding to 34.7% of the planet's inhabitants (2.1 billion people). Urban growth in these areas has been largely sustained by tapping remote water resources. Under the growing pressure of global warming, these resources are becoming increasingly insufficient and are at risk of complete collapse in the medium and long term. The situation of urban centres in arid regions is therefore critical. The concentration of resources in built-up areas has worked to the detriment of outlying lands, depriving flora and fauna of the water their vital processes require and hence triggering processes of soil degradation, erosion and desertification.

It might be argued that if the ancient societies had the present day technologies, they would not have failed, but newer technologies are not the answer to the actual problems; it is necessary to rely on traditional knowledge to tackle these concerns.

What relevance does the failure or collapse of ancient civilisations have upon modern societies? Learning from the past and discovering the reasons for the success and failure of other societies seems logical. The collapse of some civilisations may have been the result of the very processes that had been responsible for their success (e.g. the Maya and Romans).

What relevance do ancient civilisations have upon modern day water resource sustainability? Better yet, what can be learnt from ancient civilisations? Diamond (2005) proposed a five-point framework for the collapse of societies: (1) damage that people inadvertently inflict on their environment; (2) climate variability; (3) hostile neighbours; (4) decreased support by friendly neighbours; and (5) society's responses to its problems. Three of these can relate to water resource sustainability.

Past, present and future cities

Urbanisation will continue to increase in the future and its impacts on the environment and especially on water and wastewater will continue to increase significantly. Production of meat, fish and dairy products consumes 2.9-fold more water, 2.5-fold more energy, 13-fold more fertiliser and 1.4-fold more pesticides than vegetables. Thus, in the near future their production will account for more than 50% of the overall water consumption.

The old water and wastewater technologies may provide valuable insights for sustainable water and wastewater engineering and management practices. Lessons to be learnt from the past could be relevant to the following: (1) design philosophy of water and wastewater projects (e.g. construction and operation period); (2) adaptation to the environment; (3) management (balancing water availability with the demand); (4) architectural aspects of the cities; (5) dietary habits; and (6) sustainability, as a design principle (Koutsoyiannis *et al.*, 2008; Mays, 2010). For example, engineers typically use a design period for structures of about 40–50 years as dictated by economic considerations. Sustainability, as a design principle, has re-entered the engineering lexicon only in the past decade. It is difficult to estimate the design principles of ancient engineers but several ancient works have been operating for very long periods. For example, wastewater and stormwater drainage systems were functioning in Minoan settlements since the Bronze Age (Angelakis *et al.* 2005). They are so advanced that they can be successfully compared to their modern counterparts.

As an adaptation strategy for coping with climate extremes, an ancient concept of rainwater harvesting is being revisited. Recently, researchers have reappraised the decentralised multi-purpose rainwater harvesting system as a useful infrastructure to mitigate water-related disasters such as flooding, sudden water break and fire events, especially in highly developed urban areas (Haut *et al.*, 2015). The Star City rainwater harvesting system in South Korea is a successful case that was designed with an intention of alleviating water-related disasters (Haut *et al.*, 2015).

Epilogue (and outlook)

Many civilisations, great centres of power and culture, could not support the populations that developed. At present, there are similar situations in many places around the world. How can the mega-water projects with the methods of traditional knowledge be balanced? Koutsoyuannis *et al.* (2008) explored the legacies and lessons on urban water management of the ancient Greeks. They summarised the lessons learned as follows.

(1) The meaning of sustainability in modern times should be re-evaluated in light of ancient public works and management practices. Developments based on sound engineering principles can have extended useful lives.
(2) Water safety is of critical importance in the sustainability of a population.
(3) In water-short areas, development of cost-effective decentralised water and wastewater management programmes is essential.
(4) Traditional knowledge could play an important role for sustainable water supply in future cities.
(5) People have always had to cope with the uncertain natural phenomena and unpredictability of the environment. These conditions shaped knowledge and adapted it locally to respond to adversity with appropriate techniques for capturing and distributing water, protecting soil, recycling and optimising energy use. These techniques constitute a great reserve of biological diversity and sustainable knowledge.

The use of traditional knowledge does not directly apply techniques of the past; instead, it attempts 'to understand the logic of this model of knowledge' (Laureano, 2007). Traditional knowledge allowed ancient societies to keep ecosystems in balance, performing outstanding technical, artistic, and architectural work that is universally admired. Traditional knowledge incorporates innovation in a dynamic fashion, subject to long-term testing, achieving local and environmental sustainability. Many of the old water techniques are more valuable than the more conventional ones.

The ancients for the most part lived in harmony with nature and their environment; those that did not failed. Their actions should be warnings to us: in other words, the ancients have warned us. Today we do not live in harmony with nature.

Usually 'ancient civilisations' are defined as those confined far away into the past and, therefore, dated as 'very old'. If we relate the evolution of civilisation using human life as the timescale, rather than centuries, it would be more immediate to recognise the 'ancient civilisations' as 'young' and 'modern civilisation' as 'old'. It is well known that young people have a greater risk attitude than the elderly and thus the 'first civilisations' were more genuine, spontaneous and instinctive as well as having greater risk attitudes that led them towards the construction of wonderful and fantastic works, and a better understanding the human needs and wishes. In the perspective of water and wastewater technologies, this is particularly true because water is the beginning of life, as stated by (Aristotle, *Metaphysics*, 983 b). Thus, we have to recover the ability to 'think young'—to 'think sustainable'!

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Urban Drainage Research and Planning: Quo Vadis?

Written by *Karsten Arnbjerg-Nielsen, Jeroen Langeveld, and Jiri Marsalek* on behalf of the Urban Drainage Specialist Group

Introduction

The 2011 Copenhagen cloudburst, producing 150 mm of rainfall in 2 hours, has caused, even more than the regular flooding in the UK, a transition in urban drainage planning. It took the City of Copenhagen only 4 years to pass, in December 2015, the legislation formulating the biggest investment plan ever conceived by the municipality. The plan implies the biggest redevelopment of the city for more than 200 years. The aim of the legislation is to completely retrofit the city over the next two decades, and create a resilient modern city. The backbone of this plan is climate change adaption to pluvial flooding and sea surges, but with great emphasis also on creating a great liveable city for citizens and industry. Similar plans are being conceived in other world-class cities that are also already highly ranked on the Monocles Quality of Life index, including Melbourne, Singapore, and Amsterdam. Urban drainage is the key to this transformation and the Urban Drainage Specialist Group has numerous working groups trying to frame and facilitate this process.

What do we need?

The truth is that we are not sure and hence must explore a range of solutions. During the last year, no less than three literature review studies have been published by members of the Urban Drainage Specialist Group with the aim to grasp the needs of the future by analyzing the development of urban drainage modelling and planning over the past few decades (Bach *et al.* 2014; Fletcher *et al.* 2014; Lerer *et al.* 2015). The common denominator of these studies is the fact that urban drainage is no longer a field by itself; both technology and other drivers call for trans-disciplinary work, where transition management, resilience and adaptation are key issues. This development shows strong similarities with river basin management, such as developed in the Dutch 'Room for the River' program (de Bruijn *et al.* 2015).

The Urban Drainage Specialist Group has established a number of working groups, which originally focused on traditional topics of key interest to the urban drainage community as their names suggest: Data and Models, Real-Time Control of Urban Drainage Systems, Sewer Processes and Networks, International Working Group on Urban Rainfall, Storm Water Source Control, and Urban Drainage in Cold Climates. However, new subgroups are being formed over the last decade, with names such as: Water Sensitive Urban Design, Urban Streams, and Urban Storm Water Harvesting. Each of these new groups focuses on the framing of urban drainage that goes beyond the technosphere of managing pipes, manholes, pumps, detention ponds and other typical assets in urban drainage. In fact, it now seems that good examples of the state-of-the-art inter-disciplinary research work now come from the urban drainage sector as indicated by the invited commentary in *Nature* on how to facilitate collaboration (Brown *et al.* 2015).

Key aspects of a broader framing of urban drainage planning and modelling

The need for a broader framing of urban drainage is a global trend. However, the actual needs differ, and hence there is a diversification of how urban drainage should be framed. In some areas it becomes increasingly difficult to ensure cost recovery for operation and maintenance of urban drainage, leading to deteriorating and ageing infrastructure. In other areas lack of secure water supply for urban areas facilitates questioning the current management paradigms of urban drainage; in any case technological development is a driver of change. Most regions are, however, impacted by the needs of urbanisation and urban spatial planning, climate change impacts, changes in social behaviour, and the need for higher political awareness. These topics will, therefore, be discussed briefly below.

Historically cities were small and situated wherever one could find abundant water and low risk of flooding. Low lying areas in the form of marshlands or other wet areas were simply left uninhabited and the city developed slowly around the centres. City demarcations were clear because thick walls provided good protection against the warfare technology of that era. With the development of novel forms of weapons, the city demarcations were abandoned at the end of the 19th century. Industrialisation, increasing urban populations and increased mobility have added to the process, leading to the development of (mega-)cities that cover huge areas and where it is difficult to distinguish between urban and rural areas. This has put a huge pressure on urban drainage. Short-sighted investments, in combination with high land prices, led to the development of areas that are difficult to service with urban drainage infrastructure and where the risk of flooding is very high. Most of the mega-cities, such as Tokyo, Jakarta and the urbanised area in the western part of the Netherlands, comprising Rotterdam and Amsterdam, are located in deltas, where provision of urban drainage becomes increasingly difficult, because of climate change impacts and soil subsidence.

Globally this calls for a higher integration between urban drainage and spatial planning, but economic drivers have been shown to be stronger than water safety in urban development.

Climate change impacts lead to substantial changes in the water cycle and exacerbate extremes, notably floods and droughts. It is a huge task to try to understand, predict, and quantify these changes over the relevant spatial and temporal scales. Modelling current rainfall over urban areas is already a difficult task so predicting future changes remains a huge challenge. However, good progress is being made and new paradigms are starting to unfold (Arnbjerg-Nielsen *et al.* 2013; Kendon *et al.* 2014). The problems faced by the cities are grave and demand huge investments in the upgrading of infrastructure and development of new technologies to compensate for the changes. However, at the same time the problem has a somewhat positive impact on the urban drainage community. Rather than working within a field focusing on old-fashioned infrastructure the urban drainage community is now working within a somewhat more fluid field of climate change adaptation.

Perhaps the most needed change of framing globally is the inclusion of social science. Urban drainage engineering lacks an appealing narrative. Essentially urban drainage removes problems. Once removed, there is no story, but just an annual bill to be paid. Social science helps understanding of how urban drainage can remain relevant to the general public. Implemented correctly, urban drainage technology can provide better public health, more biodiversity, more recreational value, better bathing water, better water supply security, improved equity, improved, … in short, it can create liveable cities. But without social science we do not know what to provide, nor do we know how to obtain the changes in the socio-technical paradigms that are needed to actually obtain the transition in urban water, which both the public and the professional community strive for.

The complexity of the continuously changing framing (perhaps even within a project) leads to more dynamic planning processes. Many universities still teach the paradigm of urban drainage planning as the process in which the water manager determines goals and engineers collect data and identify measures that will lead to the desired goals. Other engineers then design and construct the needed measures and operate them as anticipated. However, the change of framing means that the process is wicked and that no one solution can be identified from the beginning. Rather, the planning, implementation, and operation must be considered as concurrent processes, in which goals, means, and context are dynamic measures (Geldof and Stahre 2006). This also creates opportunities for quick wins, i.e., easy solutions that generate momentum for the overall process. At the same time, transition management is a key issue in the (re)development of urban drainage, but still in our field an under-developed research topic (Loorbach and Rotmans 2010).

In Europe, stormwater runoff has been perceived as clean until the 1980s, too polluted for direct discharge to receiving water bodies during recent decades, and now newly appreciated as a valuable resource for urban water systems, since recent research has shown that the biodiversity in urban water systems fed with stormwater is comparable to the biodiversity in rural areas (Vermonden *et al.* 2009). This example demonstrates that stormwater policies are likely to change several times during the lifetime of the infrastructure, thus requiring appropriate strategies to cope with the changing demands by the society. This is just one example of the so-called 'deep uncertainties' as discussed by Urich and Rauch (2014).

Why are we now more likely to succeed than ever before?

The needs were recognised and described already a decade ago, along with possible scenarios that are not far from the current status (Chocat *et al.* 2007). It seems that climate change as a global driver is helping facilitate the change. While mitigation of climate change is still a huge challenge, the COP21 meeting in Paris seemed to spark a bit of enthusiasm into the process. A key part of the climate change meeting was also high focus on climate change adaptation. This focus is also recognised by the general public, facilitated by observations in many places already indicating that the climate is changing in accordance with the predictions of the climate change models.

However, not only the IPCC and UNFCCC processes put higher emphasis on climate change adaptation. Over recent years it has also increasingly become clear that governments alone cannot provide the needed results. This has put higher emphasis on businesses and local governments to provide solutions and ask for novel solutions provided by industry and researchers. Utilities and cities are hence put in the spotlight and both have an interest in finding joint solutions. It does not mean that we will develop new fixed paradigms for urban drainage management; the solutions will change over time and between locations and will certainly be difficult to identify. But it also means that there is a recognised need of the key stakeholders that it is necessary to start finding the solutions. Copenhagen has made a solid business case that remains positive for a range of climatic changes (Arnbjerg-Nielsen *et al.* 2015). Other cities are well on the way to doing the same.

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Wastewater Pond Technology

Written by *Marcos von Sperling, Kara L Nelson, and Miguel Peña* on behalf of the Specialist Group

Introduction

Waste stabilisation ponds (WSP) are widely used around the world to treat biodegradable wastewaters using natural processes. The main variants of stabilisation ponds are anaerobic and facultative ponds, which aim primarily at organic matter removal, and maturation ponds, whose main target is the removal of pathogenic microorganisms. Facultative and maturation ponds rely upon the production of oxygen by algae during photosynthesis, and the utilisation of the surplus oxygen by the heterotrophic bacteria responsible for major pollutant conversion processes. There are also mechanised variants, such as aerated lagoons and high-rate algal ponds. The appropriate design for a WSP system depends on wastewater characteristics, the treatment objectives, climate, and available land area. A recent innovation in the design of anaerobic ponds is the high-rate anaerobic pond (HRAnP) concept that includes a mixing pit, biogas collection, and settling compartment. This new concept combines the best of both, high-rate and low-rate anaerobic reactors.

There are many thousands of ponds in operation worldwide. They are particularly well suited for treating wastewater from small communities, although they can be used for large cities as well (e.g. a 350-acre WSP system provides treatment for about half of the wastewater from the city of Melbourne, Australia). Developing countries with large numbers of pond systems include Brazil, Mexico, Honduras, and Uganda. Industrialised countries with large numbers of pond systems include New Zealand, the United States, Australia, Germany and France. New pond systems are expected to play a significant role in achieving Sustainable Development Goal 6.3, which requires reducing the discharge of untreated wastewater by 50% around the world.

Although ponds are simple to design, build, and operate, the hydrodynamics as well as the physical, chemical, and biological treatment processes occurring in them are incredibly complex. Much of the research conducted by members of the Specialist Group focuses on advancing the understanding of these interdependent processes. Applied research is also being conducted to understand how to ensure successful operation and maintenance (such as sludge removal and conditioning) of pond systems.

Current state of knowledge and practice

Waste stabilisation ponds are simple to design, build and operate. Their dimensioning usually uses reasonably well-known recommended organic loading rates, hydraulic retention times and first-order rate constants. Their detailed design has traditionally concentrated mainly on the configuration and positioning of inlet and outlet structures and on protection and sealing of embankments and pond bottom. Their construction is simple, comprising mainly earth movement. Routine operation is indeed trouble free, and is more related to maintenance practices than to proper operational control measures with the exception of flow measurement and control. Un-mechanised ponds do not involve electromechanical equipment and do not consume electricity. If located down gradient from the service area such that the sewer system can operate solely with gravity flow, the entire collection and treatment system can operate with no electricity.

WSP systems are particularly well suited for production of recycled water for irrigation of agricultural crops or landscapes. Removal of pathogens is essential for water reuse, and well-designed and operated WSP systems are capable of high levels of removal of pathogens and indicator organisms. Effluents from facultative ponds are usually suitable for restricted irrigation (good helminth egg removal), and effluents from a series of maturation ponds may be fit for unrestricted irrigation (irrigation of crops that are eaten uncooked or unpeeled), as these ponds are able to remove coliforms to low counts and comply with the World Health Organization guidelines. This type of reuse has the benefit of recovering not only the water but also organic matter and nutrients contained in the water; the algae in the effluent may also beneficial for soil. Irrigation with pond effluents is successfully done in several countries around the world, especially those located in arid or semi-arid regions. However, it is felt that much more could be done to expand the use of WSP systems for water reuse. New institutional arrangements as well as good risk-management regulations may be required to link treated effluent producers (sanitation companies) and farmers.

Mechanised ponds involve the addition of paddle wheels to provide mixing in raceway high-rate algal pond (HRAP) configurations, or surface aerators to provide mixing and enhance aeration. HRAP and other mechanised ponds can be used to maximise algae production for subsequent recovery of energy in the form of biogas (via anaerobic digestion of the algal biomass) or hydrocarbons that can be further refined into solid or liquid fuels. Pond systems can also be integrated with some other unit processes such as up-flow anaerobic sludge blanket reactors (UASB), constructed wetlands, and additional disinfection such as ultraviolet light (UV).

Some limitations, which are context-specific to the application of WSP systems, include: the large land requirements, high-suspended solids in the effluent, and risk of bad odours in anaerobic ponds. Each of these issues is discussed below.

Reduction of land requirements

In warm-climate regions, facultative ponds usually require between 2 and 4 m^2 per inhabitant. In temperate climates, approximately double the area is required and in cold climates (where pond systems are also used), larger land requirements are observed. If a series of maturation ponds are included in the treatment line, the total area may double. This poses a practical limitation, because in some locations a suitably large area, with sufficient gradient and good soil is not available in the vicinity of the community.

To increase ponds applicability, a reduction of land requirements is obviously welcome. The inclusion of anaerobic ponds ahead of the facultative ponds may reduce the area to around two-thirds of that needed for facultative ponds only. In some warm-climate countries, upflow anaerobic sludge blanket (UASB) reactors are replacing the anaerobic and facultative ponds, and the overall system of UASB reactors plus maturation ponds becomes smaller (but still land intensive). In this sense, the development of the HRAnP mentioned earlier has the same effect of the UASB reactor and reduces the footprint of the WSP systems down waters somewhere between 25% and 30% depending on the average water temperature.

Reduction of suspended solids in the effluent

Well operating facultative and maturation ponds rely on a good production of microalgae, which are responsible for photosynthesis. However, a large amount of these algae leave with the final effluent, and are responsible for the increase of suspended solids and particulate BOD in the wastewater discharged to water bodies. If the effluent from a pond needs to have its quality improved in terms of organic matter and suspended solids, then algae removal is a good choice.

Some of the possibilities are (1) intermittent sand filters, (2) rock filters, (3) micro-sieves, (4) ponds with floating macrophytes, (5) land application, (6) wetlands, (7) coagulation and clarification processes, (8) flotation, (9) aerated biofilters and (10) trickling filters.

Sand filtration produces an effluent with excellent quality, but tend to clog very quickly. Coarse rock filtration is not so efficient, but gives a good contribution and is much less prone to clogging (they can run for years without cleaning). Recent experiments with aerated rock filters have shown good removal of other constituents, such as coliforms. Floating macrophytes, such as duckweed, are used in several ponds in order to reduce sunlight penetration and thus decrease algal growth. These ponds give the possibility of using the high-protein content duckweed for fish ponds, but require a good strategy for their removal from the pond surface.

The inclusion of any of these processes, especially the mechanised ones, should naturally find a justification from the point of view of the needs of the receiving water body (and not only as a safeguard in terms of compliance to discharge standards), since they imply an elevation of the treatment costs and operational complexity. Wastewater treatment by ponds must remain simple, and the challenge here is to improve their effluent quality without deviating from the primary characteristic of conceptual simplicity.

Reduction of risks of malodours from anaerobic ponds

Anaerobic ponds are open anaerobic reactors, and thus may be subject to the release of malodorous gases, especially hydrogen sulphide. Substantial experience exists on how to reduce these risks, based on the implementation of ponds far away from houses, adoption of suitable organic loading rates, a good knowledge of the influent characteristics (amount of sulphate in the wastewater) and the utilisation of inlet pipes close to the pond bottom, to allow good contact between organic matter and biomass. However, because a natural treatment process is being used, there is always the risk that during a certain period something will not go on as planned, and obnoxious odours may be emanated.

Some anaerobic ponds are being covered to capture the gas and thus control their release into the atmosphere. This also creates the opportunity of biogas utilisation and carbon credits compensation. However, in many cases the anaerobic ponds are very large, and the challenge is to reliably cover a large surface area without allowing gases to escape, and still keeping simplicity as a key element. The HRAnP has a mixing chamber such that biogas collection occurs in the first quarter to third of the length, so this makes it easier to cover a smaller area and help to control bad odours.

Recent advances and hot topics

Pathogen removal mechanisms and design equations

Ponds are very important natural treatment systems for the removal of pathogenic organisms. Design equations are available to estimate the removal of helminth eggs, protozoan cysts, and faecal indicator bacteria. Current research is being conducted to develop an empirical design equation for the removal of viruses by WSP, based on performance data from many pond systems.

The main mechanism of removal for helminth eggs is sedimentation. Protozoan cysts may also be removed by sedimentation; although their settling rates are quite slow so long hydraulic retention times are required. Individual bacteria and viruses cannot be removed by sedimentation, but if they are attached to larger particles they can be removed by this mechanism. A recent review paper identified that virus attachment to solids and removal by settling is a significant knowledge gap, with conflicting reports in the literature. Current research aims at filling this knowledge gap by quantifying the fraction of different viruses associated with particles in different size ranges. It should be noted that pathogens that are removed by settling are concentrated in the sludge layer. It has been documented previously that pathogens, especially *Ascaris* eggs, can persist in pond sludge for many years. Thus, sludge that is removed from ponds (a critical maintenance activity in primary ponds) must be treated to reduce the concentration of viable pathogens.

Bacteria and viruses are mainly removed by inactivation mechanisms, especially in maturation ponds. Potential mechanisms include sunlight inactivation, predation, degradation by enzymes, and stress due to unfavourable environmental conditions. Of these three, sunlight inactivation is the best understood, and has the greatest potential to be exploited to achieve high removals in maturation ponds. Recent research provided evidence that echovirus was degraded by proteases in WSP water whereas MS2 coliphage was not. The significance of this mechanism in actual WSP systems is not yet known, but this is an exciting area for future research.

The mechanisms of sunlight inactivation are now fairly well understood because of recent research. Endogenous damage occurs when chromophores in microorganisms absorb sunlight photons leading to damage. Direct damage may occur to the chromophores (this is particularly important in viruses). Indirect damage may also occur, if the excited chromophores produce highly reactive transient species, which subsequently cause damage. Exogenous damage may occur if chromophores in the water (i.e., sensitisers) absorb light and produce reactive species that subsequently cause damage to microorganisms. Organic matter and algae are believed to be the main sources of sensitisers. Thus, organic matter has two competing effects on pathogen inactivation: it decreases inactivation by the endogenous mechanism by absorbing light, and simultaneously increases inactivation by the exogenous mechanism. Because different organisms have different susceptibility to endogenous vs. exogenous mechanisms, their relative rates of inactivation can vary depending on the water quality and specific conditions. In particular for bacteria, these mechanisms are influenced by environmental conditions in the ponds, such as dissolved oxygen, pH, and temperature. Current research is aimed at quantifying the individual and combined effects of these factors. Priorities for future research include continuing to understand the targets of damage, the susceptibility of pathogens of concern, and the influence of environmental conditions.

Models to estimate the inactivation of viruses and bacteria by sunlight in WSP have been developed, taking into account the individual mechanisms. A priority for future research is to further validate these models in full-scale ponds, with different designs and conditions. The prediction of pathogen removal efficiency involves not only the kinetic aspects of inactivation, but also the hydraulic behaviour of the ponds, which are influenced by the presence of baffles, the length-to-width ratio and the placement of inlet and outlet structures. Advancements in this field have been achieved, as discussed further below.

Understanding the mechanisms of nutrient removal

Removal of nutrients (nitrogen and phosphorus) by WSPs is highly dependent on the system design. Although simple pond systems (one to three un-mechanised ponds in series) do not typically provide much removal, specific configurations, such as maturation ponds and high-rate algal ponds are able to achieve high nitrogen removals. In the literature, classical mechanisms for N removal are reported to be: assimilation of ammonia and nitrate by algal biomass, conventional nitrification-denitrification, sedimentation of dead biomass, accumulation and decomposition on sludge layer after partial hydrolysis, as well as some degree of ammonia volatilisation. Amongst those, ammonia volatilisation due to high pH induced by photosynthesis has been frequently referred to as the main mechanism. However, recent researches are pointing out that this may not be the case. Tracer experiments with ^{15}N-stable isotopes and field measurements of actual ammonia lost by volatilisation have shown that the fraction of N removed by this mechanism may be small and have only a minor influence on the overall removal. Nitrification has been observed in some ponds and not in others – a possibility is that the presence of ammonia in the form of free ammonia (NH_3) due to high pH values may inhibit the growth of nitrifying organisms. Organisms responsible for anaerobic ammonia oxidation (Anammox) are also being investigated, using molecular biology techniques and proteomics mechanisms, in order to see if they play an important role in nitrogen removal. Anyway, nitrogen removal in shallow ponds seems to be greater than in deeper ponds.

Regarding phosphorus, a major removal mechanism could be the precipitation of the phosphates in the form of hydroxyapatite or struvite under high pH conditions. In the case of phosphorus removal, the dependence of high pH values is larger than with nitrogen: the pH should be at least 9 so that there is a significant phosphorus precipitation. Such high pH values are not consistently maintained, night and day, in most ponds, and this could be the reason why phosphorus removal efficiencies are not large in most ponds. Recent research has identified the possibility that algae can also develop a mechanism of luxury P uptake, like phosphate accumulating bacteria do in activated sludge. If this in indeed the case, and one is able to control the environmental conditions that favour this mechanism, an important possibility for phosphorus removal in ponds may be obtained.

The road is still open for more fundamental research that can deepen the understanding of mechanisms, thus allowing ponds to be more effective in nutrient removal, enhancing their applicability in situations in which the effluent needs to be discharged to sensitive water bodies or reused for an application that does not benefit from the presence of phosphorus.

Development of reliable hydraulic and kinetic mathematical models

Hydrodynamics in waste stabilisation ponds is highly dependent on the physical design (e.g. dimensions, location and type of inlet and outlets) and the climatic conditions (e.g. wind, solar radiation and temperature). Although they are often designed assuming either ideal complete-mix or plug-flow reactors hydraulics, dispersed-flow models can also be used, which better approximate the actual flow conditions. Experimental determination of the dispersion number using tracers has been done at several sites, leading to empirical equations for their simple estimation, based on physical characteristics of the pond.

Current research often employs computational fluid dynamics (CFD) models to capture the effects of short-circuiting and stratification in 2D or 3D geometries. Most recently, heat transfer models are in development., These more sophisticated approaches can be used to study the best arrangement for inlet and outlet structures and for the placement of baffles or mechanical mixing devices, aiming at increasing pollutant removal efficiencies. This better representation of the specific hydraulic behaviour of each pond is of course associated with a higher degree of complexity, but the increase in the availability and use of CFD software may result in its more systematic use by consulting companies in the design of ponds.

Traditional kinetic models for the prediction of effluent concentrations from stabilisation ponds have used first-order reactions, but recent approaches focus on the representation of biomass growth rates and the resulting uptake or release of constituents. Structures similar to the IWA Activated Sludge Model (ASM) are being developed for ponds, with the added degree of difficulty that not only bacterial growth and decay need to be modelled, but also algal biomass. At a higher level are recent models that jointly incorporate CFD and ASM models, being thus hopefully able to provide a better representation of the hydrodynamics and reaction kinetics at stabilisation ponds.

With the development of more advanced and reliable mathematical models, designers will hopefully have better tools to tailor each pond to the particular influent and site characteristics, as well as effluent quality requirements. This research is also an exciting opportunity to advance the understanding of microbial ecology in different types of wastewater systems.

Resource recovery in WSP

Significant advances are being made in recovering resources from WSP systems. Several examples have already been provided: using effluent for irrigation, the localised generation and collection of biogas in anaerobic ponds, and phosphorus recovery in algal biomass. Several groups are working on fully integrated resource recovery systems that maximise the production of algae, with subsequent recovery of energy from the algae via anaerobic digestion or production of bio-fuels. It is believed that integrated pond systems can be capable of net energy production. Several new designs are being explored for increasing algal growth rates in raceway configurations through improved mixing, recycling of algae, and feeding of CO_2. There is some evidence that feeding CO_2 into ponds can increase algal production under some conditions, whereas if the BOD is sufficient in the influent, the CO_2 produced by the heterotrophic bacteria is enough to maximise algal growth. A challenge with anaerobic digestion of algae is that the cell walls are not easy to break down. Extracting lipids from algae was found to require more energy than the gain in biogas production. Priorities for future research include optimising the overall integrated designs to recover resources with maximum efficiency. In this sense, the integration with other natural systems such as constructed wetlands and soil treatment may decrease the carbon foot-print of conventional WSP systems, but at the same time improve the energy balance of the overall system. This is a new exciting research area that may feed upon previous knowledge on agro-ecosystems for biofuels production.

Concluding remarks

The inherent simplicity of a natural wastewater treatment process is one of the first concepts that come to mind when one thinks on stabilisation ponds. For some practitioners, there may be an impression that everything that is needed is already known in this relatively old treatment process.

However, as was seen in this text, this does not mean that everything that relates to ponds is really simple: in the field of wastewater treatment, it is one of the most complex systems to understand, describe and model. From the biological point of view, the simultaneous interaction of different groups of bacteria with different algae species leads to a very complex ecological system, with mutualistic relationships between heterotrophs and autotrophs. The understanding, quantification and mathematical representation of the several different resulting biochemical processes and reactions and the growth rates of the various organisms involved are a challenge for pond's researchers. In addition, because ponds are large open reactors, their hydraulic behaviour is very much influenced by temperature, solar radiation rates, wind and placement and type of inlet and outlet structures. A reasonable representation of pond's hydrodynamics in conformity with its complex nature represents another monumental challenge.

Fortunately, with the advancement of field and laboratorial detection techniques and mathematical modelling tools, scientists are now coming somewhat closer in the understanding and representation of the mechanisms involved in ponds behaviour. The expectation is that this will assist in a better prediction of the removal efficiency of key pollutants under different environmental conditions, leading to better designs, tailored to each situation.

In closing, the future looks bright for the continued application of WSP systems to treat wastewater from small communities or any biodegradable wastewater with very favourable environmental footprints and lower capital and operation and maintenance costs compared with mechanical wastewater treatment. The future is also bright for fundamental and applied research to continue to advance our understanding of the complex processes occurring in these engineered aquatic ecosystems.

Water Security and Safety Management

Written by *Bruno Nguyen, Amit Chanan, and Ilan Juran* on behalf of Water Security and Safety Management Specialist Group

Introduction

The IWA Specialist Group on Water Security and Safety Management, 'W2SM', covers all issues related to best practice assessment, risk management, research, development and performance monitoring of emerging technology solutions for water security and safety management as well as for post-disaster recovery with regard to human-made or natural disasters.

Its scope includes water governance and preventive measures, early anomaly and/or contamination detection, smart monitoring, professional education, system vulnerability assessment, crisis management models, public communication strategies, analytical capabilities, emergency response, as well as consumer community concerns, post-disaster recovery strategies and reconstruction issues.

The purpose of the W2SM Specialist Group is to provide the water industry, utilities, consumers and the research and academic community, under the auspices of IWA, with the necessary international forum for promoting worldwide experience sharing and dissemination of advance knowledge, case studies and lessons learned, research results, recent developments in risk management and monitoring systems, field demonstrations of innovative technology solutions and emerging ideas on identified issues of water security and safety management.

The main goal of W2SM is to promote this international knowledge exchange and experience sharing forum in order to improve the emergency response capacity, accelerate the assessment of emerging technology solutions, upgrade technical capabilities for disaster impacts mitigation and recovery, and promote international cooperation of the water industry, local governance, scientific institutions and consumers' community in responding to the challenging tasks of water security and safety management.

To achieve these objectives, the W2SM scope of work includes the organisation of international conferences and dedicated workshops on a broad spectrum of issues concerning water security and safety management and publication of books/monograms at regular intervals on the identified issues. It will also work with the International Standard Organizations on the development of appropriate standards to efficiently accelerate the reliable integration of emerging technology solutions in water security and safety management practice.

Terminology

The United Nations defines *water security* as 'the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability'.

On the other hand, *water safety* relates to the possibility of ingesting or being in contact with water without incurring

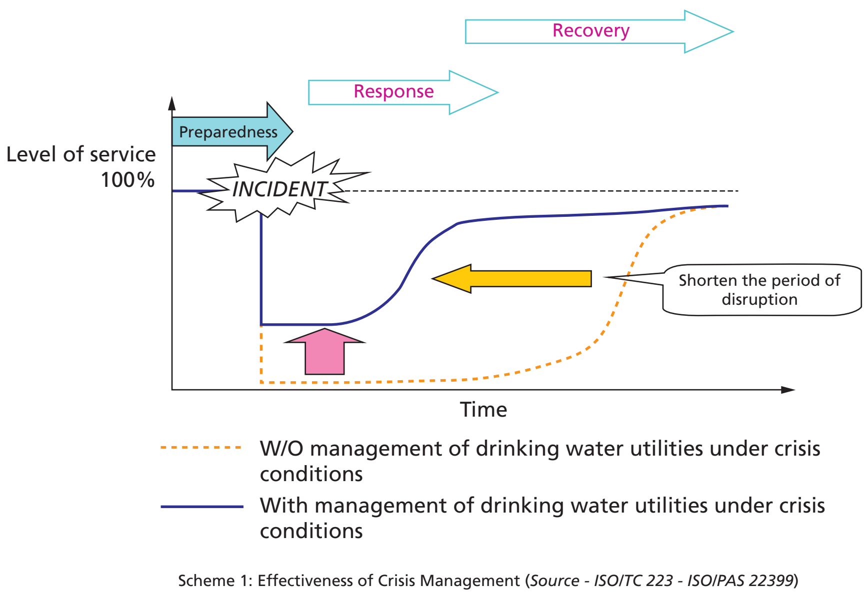

Figure 1. Resources deployed in crisis management.

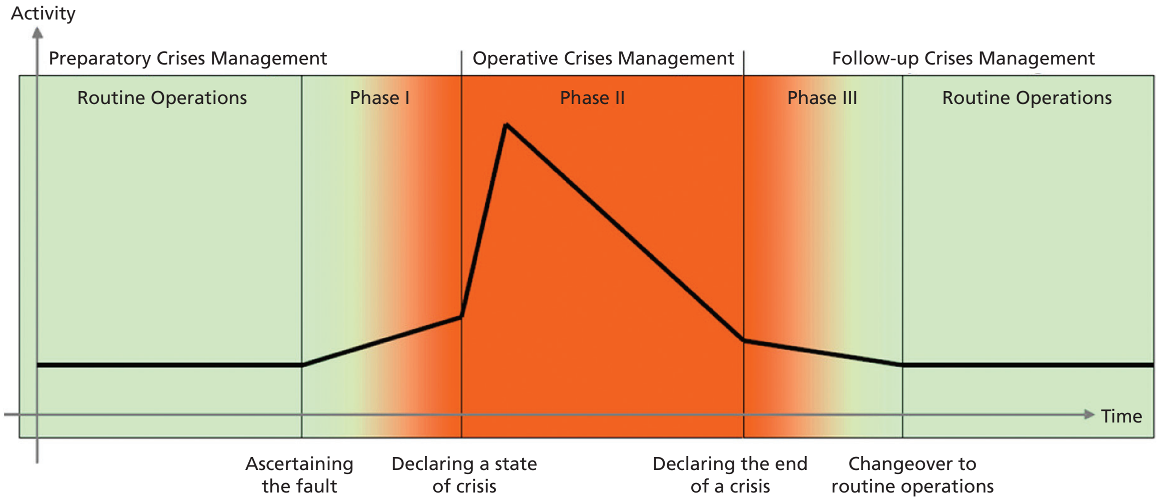

Figure 2. Resources deployed in crisis management

health risks, and therefore mostly concerns water quality and its preservation. Solutions for guaranteeing Water Safety have been developed with specific risk analysis and processes for controlling those risks: Water Safety Plan (WSP), Sanitation Safety Plans (SSP), Hazardous Analysis and Critical Control Points (HACCP), and other methodologies are now commonly used by water utilities.

The water resiliency of a given water system is built on both active security and passive security:

- Active security is principally based on the human response, know-how and adaptability; all acquired with the training of people and the implementation of accurate operational procedures.
- Passive security relates to the infrastructure resiliency and capacity to fulfil its purpose; both acquired thanks to intelligent design and realisation on the first hand, and on the second hand, with the steady maintenance of this infrastructure.

To be as best crisis resilient as possible, water utilities have to understand what characterise such situations, whose main difficulty is that they rarely occur. Several important and accepted definitions describing a crisis situation include (1) conditions for triggering a crisis; (2) level of service (Figure 1); and (3) resources deployment (Figure 2).

Existing Specialist Group knowledge

Facing unprecedented natural disasters, such as tsunamis, hurricanes, earthquakes, flooding, sea-level rise, droughts, and industrial disasters like nuclear power plant explosions, heavy pollution of rivers, and many others, the critical need for international collaboration involving state and local governments, public and private water utilities, infrastructure agencies, industry at large and the academic research community has effectively transcended geographical, institutional and cultural frontiers and has become increasingly evident.

The international dialogue is particularly timely as over the past decade a significant effort has been invested in different countries in redefining risks and security measures; improving vulnerability assessment; upgrading disaster impact mitigation capacity and recovery; implementing research and development programmes for assessing and developing innovative technology solutions, and establishing regulations for integrating such security measures in the management practices of current water systems.

The results of such efforts are currently being locally assessed to establish water security measures. International experience sharing may play a most significant role in supporting and building the necessary dialogue with national administrations and international regulatory organisations on the assessment of new regulations and the impacts of such measures on current practice.

Recent examples of incidents with debriefing and lessons learned presented at W2SM workshops include the following:

- Water supply of Tangier by tankers, Morocco, 1995
- Great Hanshin earthquake, Japan, 1995
- Ice storm, Montreal, 1998
- Power Blackout, Italy, 2004
- Hurricane Kathrina, New Orleans, 2005
- Great East Japan Earthquake, 2011
- Earthquake Haïti, 2010
- Floods in southeastern Australia, 2010
- Storm Sandy, NY, 2012

The international dialogue could also most significantly contribute to assessing current practice, developing databases on crisis management experiences, identifying priority research and development needs, and assessing emerging technology solutions.

Feedback from water operators on real case studies and lessons learned from studies of past events have significantly contributed to enrich experience and improve the expertise developed among the members of the W2SM Specialist Group; this expertise is deemed useful for enhancing preparedness and organisation of other water utilities within the IWA network.

General trends and challenges

Long before the post-disaster return to what could be called ‘normal life’, the partial restoration of a ‘tolerable situation’ for the affected people greatly depends on the availability of safety measures for drinking water and disaster public preparedness. The corporate officers in charge of water systems operation confirm that when confronted with a crisis situation, the quality and level of preparedness is the essential element differentiating an efficient response from chaos.

The origins of risks, whether direct or indirect, are numerous: natural hazards linked to the geographic situation, industrial hazards and human activities, pandemic diseases, local instability (caused by social, ethnic or religious reasons), and of course terrorist threats. But whatever the origin of these risks may be, if the resulting effects on the water service are similar, they call for almost identical counter-measures and solutions.

As there exist various cultural viewpoints within the framework of the IWA, we expect that from discussions and group work there will emerge different approaches and experience to water security and safety management. It is, for example, interesting to see in different countries or cities how boiling alerts are managed, or how a list of priority consumers is determined.

We found that there is a strong desire to create an international database on water-related or water-concerned crisis situations and to establish a record of the lessons learned, primarily, but not exclusively, from the point of view of operations. The occasions for sharing experience on incidents or crisis situations are still too few. There is a large potential for improvement of the crisis response providing that one has had the opportunity to study real case situations.

The W2SM Specialist Group has conducted a survey on what threats water utilities are considering as the most important, how their national regulation takes these risks into account, and how the utilities themselves assess their own level of preparedness.

The international disaster response and recovery strategies after natural catastrophes have been relying mainly on separate initiatives either from countries, non-governmental organisations and international companies. It is however envisioned that the international scientific community under the IWA umbrella could provide links and be used as a knowledge base and reservoir of experts ready to offer online help and advice in water issues whenever and wherever it is needed. The W2SM Specialist Group will offer its help in setting up and organising this response.

Recent developments and experience with new technologies and smart monitoring systems in the field of W2SM, their in-site demonstration testing and field performance monitoring reported by Specialist Group members will help fellow professionals to keep up to date and be abreast of current research and development initiatives and its outcome integration to improve the state of practice. Innovative risk analysis and management strategies will also be covered in this topic.

The principal topics on which the W2SM Specialist Group is focusing at the moment are:

(1) best practice assessment of effective security practices;
(2) vulnerability assessment and risk management;
(3) emergency response and public awareness;
(4) crisis management and interdependencies with critical infrastructure sectors;
(5) disaster impacts mitigation and recovery;
(6) research and development and assessment of emerging technology solutions (early warning systems for detection of water quality events, smart water monitoring and control systems, alternative water supply solutions);
(7) global perspectives of international cooperation for sustainable solutions;
(8) professional education and training;
(9) the challenge of disaster resilient community and sustainable recovery.

Conclusion

Populations in urban centres are growing, sometimes at an alarming speed, while the water resources and facilities are often becoming increasingly insufficient. At the same time, climate change issues are already putting even more pressure on developing adaptation strategies to the new and evolving context.

Emerging technology solutions may, of course, have a major impact on urban water resiliency improvements; but interaction and interdependency with other critical urban networks like energy, telecommunications or transport will have to be addressed in a global city perspective.

Governance issues will not be left aside since they are known to have an impact on the efficiency of the response and mitigation whenever a disaster has occurred.

The Specialist Group's focus and priorities for 2016 are to promote innovation, develop water security educational material, emphasising disaster preparedness and crisis management to be disseminated through technical papers in IWA specialised journals and during specialist workshops or seminars, and initiate collaboration projects with other IWA Specialist Groups, with institutional partners and with non-governmental organisations for pushing synergies, sharing experiences and enlarging visions.

Recognising the fact that being prepared can make the difference between a controlled situation and a complete disaster, the Specialist Group will encourage the analysis of lessons learned from case studies and will promote the dissemination of post-disaster reports.

Acknowledgement

We especially thank the reviewer, Ashok Hukku.

Watershed and River Basin Management

Written by *John Riddiford*, Chair of the Watershed and River Basin Management Specialist Group

Introduction

This chapter focuses on developments within the Watershed and River Basin Management Specialist Group over the past 2 years, developments in current thinking for basin management, what the key challenges are and what the suggested research agenda should be. These findings will be of use for IWA members, Specialist Group members and the broader water community.

The watershed and river basin management profession faces a range of new challenges, with freshwater resources under increasing threat around the world. Until the middle of the 20th century, watershed and river basin management challenges were predominantly local, such as water-related epidemics, oxygen depletion due to local pollution, or heat pollution effects. The complexity and scale of the challenges of water management issues has increased since the 1950s, and many aspects have reached a continental and even global scale (Somlyody, 1995).

The world has changed dramatically in several ways and the past four or five decades have brought significant changes in watershed and river basin management. The major drivers of the changes are increasing global population, which has tripled since the early 1950s and exceeded 7 billion in 2010; a significant increase in water demand, primarily for drinking water, energy and food, and the impact of dietary changes as countries develop; the rapid shift of populations from rural to urban areas (the United Nations predicts that by 2050 urban dwellers will increase from 50% to 70% of the global population or, in other words, an increase of 2.5 billion in global cities); and climate change, which influences water availability at local, regional and global scales.

Integrated water resource management

One of the effective responses to these challenges has been the theoretical and practical development of integrated water resource management. This process involves coordinating conservation, management and development of water, land and related resources across sectors within a given river basin to maximise the economic, environmental and social benefits derived from water resources in an equitable manner.

Transboundary watershed management

More challenges about how to implement integrated water resource management have arisen over the 260+ transboundary watersheds that are internationally shared, and which contribute to the economic, social and environmental wellbeing of over 70% of the world's population.

Challenges vary from continent to continent. In Africa, 905 of the continent's surface water resources come from major transboundary watercourses. Many of these rivers are governed by multilateral or bilateral agreements, but there are gaps in the agreements and cooperation within basins is uneven. The most heavily used transboundary watercourses are in Asia and treaties govern these rivers, although these are mostly bilateral in nature so basin-wide cooperation has not been developed at full scale.

In Central and South America there are examples of transboundary cooperation, but the challenge is to develop more basin-wide agreements and implement them effectively. In the countries of the European Union (EU) there is a mature and functional region-wide legal instrument covering transboundary waters (the 1992 UNECE Transboundary Watercourses Convention). The EU Water Framework Directive also applies to watersheds that cross borders of EU member states.

What is the IWA doing?

The IWA has set out, as one of its major programmes, the *Basins of the Future* programme. The programme aims to address many of the global basin challenges through developing approaches to manage the benefits and trade-offs among competing water users in a basin for a secure urban water future. Water security for good basin management requires investment in increasing efficiency, and the '5 Rs' of water management: reduce, reuse, recover, recycle and replenish/restore.

The Basins of the Future Programme focuses on cities and the competing water demands in their river basins, centred on the practical reality of managing the demands for users to secure water, food and energy. The programme is designed to build on the work of various IWA Specialist Groups and Clusters, including the IWA Watershed and River Basin Management Specialist Group and the Alternative Water Resources Cluster.

The vision of the programme is stated as follows: restoring basins and their water bodies, while mitigating climate risks (flood and droughts) for urban and industrial areas through actions at the catchment level.

The objectives of the programme are the following.

(1) Facilitate the demonstration and promotion of approaches (technologies, modelling, decision support tools, financing) which improves water quantity and quality across the water, food and energy nexus.
(2) Create and strengthen the enabling environment which supports institutions, regulations, policies and new mechanisms and opportunities for investing in catchment areas.
(3) Enable the development of climate resilience strategies from catchment to tap.
(4) Enable restoration of watersheds for economic development through industry- city-river basin cooperation which maintains and strengthens coherence between urban users and other water users in the basin.

The IWA is developing a charter to address these issues.

What is the Specialist Group for Watershed and River Basin Management doing?

The Specialist Group promotes the understanding, benefits and utilisation of integrated catchment management approaches for the beneficial and sustainable use of rivers, lakes and groundwater basins worldwide. It seeks to achieve this by sharing expertise and experience among its members and with other interested individuals and organisations, organising specialist conferences, issuing newsletters, undertaking cooperative projects and other activities of the IWA.

The Specialist Group undertakes the following activities.

- The preparation newsletters of Group activities and developments.
- The Convening of conferences and workshops. The most recent specialist conference was held in San Francisco in 2014, the next conference is programmed for the second half of 2017 in South Africa.
- The initiation of research papers and investigations.
- Collaboration with other Specialist Groups.

Some key aspects that have been recently discussed in the Specialist Group include the following issues. This is not a comprehensive list, nor is it holistic in nature, but rather provides an indication for key issues.

One of the important aspects of climate change is the increasing risk of episodic events such as drought, fire and flood, and what impact this has on water resource management. A special feature on drought and drought management from a water management perspective was published in the Watershed and River Basin Management newsletter in late 2015. Some key findings included that over every continent there are regions affected by droughts which are becoming more and more long-lasting and severe. Correspondingly there are other regions that are receiving higher rainfall rates. Governments and authorities are responding in different ways. In Australia and South Africa desalination plants have been rapidly constructed in response to severe droughts and augmenting critical water supplies, only to be mothballed when more favourable rainfall conditions prevailed. In California, which has been suffering its worst drought in the past 200 years, there is an opportunity to change the historic way in which water has been managed, and in particular groundwater. The Californian water delivery system is facing long-term structural problems. As

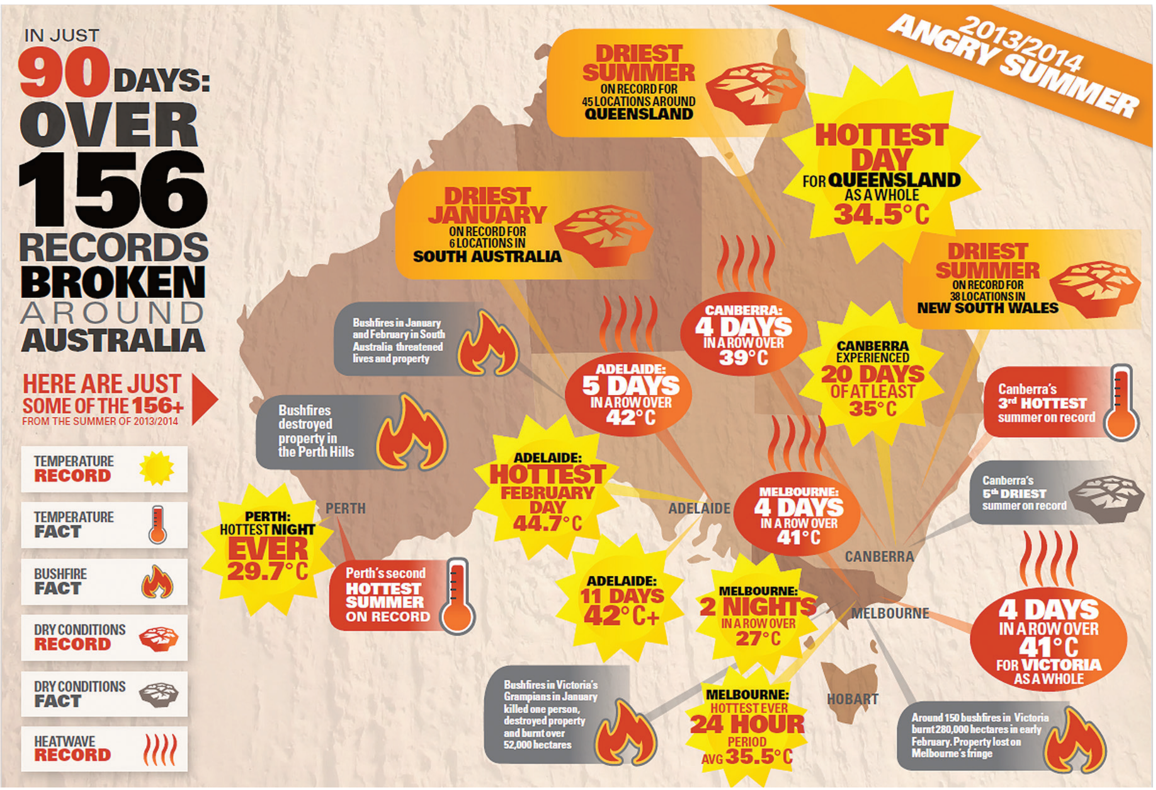

Figure 1 In Australia during the summer of 2013/14 a series of extreme events hit the nation, presenting several challenges for water authorities (BoM 2014).

mean temperatures increase, the reliability of the State's largest reservoir, its snowpack, is decreasing. The subsequent decline of the snowpack has increased the demand for new storage capacity, but the construction of large dams is politically difficult to approve and implement. There is an opportunity to change the rules governing groundwater use (Stringfellow, 2015), and hence improve groundwater banking capacity.

Conclusions and research agenda

From the 2014 San Francisco Specialist Group conference for watershed and river basin management, the following research priorities were identified. These are not exhaustive or holistic, but provide a general direction for the future research agenda.

- Identify the key challenges and management options for managers of watersheds under climate change impacts.
- Seek out different approaches for water resource management under climate change from various international and multi-jurisdictional perspectives.
- Identify the main challenges and feasible solutions for river basin management of multi-nationally shared river basins and what mechanisms would be recommended for effective transboundary watershed management.
- Identify the key research topics over the next 20 years for the IWA family in facing climate change.
- To engage with IWA's strategic partners (international agencies and organisations in the sector).
- To enable international leaders in the sector to participate in the Congress.
- To further ongoing IWA activities (including Specialist Group ventures, Task Groups, and participation in IWA Programmes).

These priorities were discussed at a basin workshop held at the IWA Water and Development Congress held in Jordan in 2015. Elements have also been taken on with the *Basins of the Future* programme.

As more reliable global climate models are developed, there is an increasing need for a deeper understanding of the impact of climate change on water resources, population growth and migration to and from river basins. Sustainable solutions are needed for climate change adaptation, to find a way to fairly share limited water resources among countries, different sectors and stakeholders including ecosystems. For this reason, the downscaling of global climate change models, which could produce reliable outputs, is a new challenge from a watershed and river basin management point of view.

The rapid growth of urbanised areas with river basins is escalating urban demand for water, as well as the need to make urban water systems more resilient to climate change. Growing competition, conflicts, shortages and the degradation of water resources make it necessary for the conventional urban water management concept to shift from an approach that attempts to manage different aspects of the urban water cycle in isolation to an integrated approach supported by all stakeholders and fitted to the larger river-basin scale (Bahri, 2012). Research is needed on what policies and strategies could facilitate more integrated urban water management into practice, how to incorporate climate change predictions in planning urban water supply and sanitation, new financial strategies, and the tools needed for decision-making in integrated urban water management.

Scientists are focusing predominantly on catchment management agencies and aspects of their institutional and organisational functions. There should be a focus on informal aspects of water resource governance and new theoretical developments, as well as from disciplines other than the natural sciences, in the fields of water resource governance and politics.

Recycling of water within and between river basins, particularly if the basin is transboundary, requires effective governing instruments—for example, methods for managing inter-catchment transfers and to address possible concerns about adverse impacts to ecology (such as invasive species) as well as water transfer infrastructure.

There is a pressing need for research to develop the science related to groundwater recharge and banking. Currently, many water districts and water suppliers are implementing groundwater banking, with mixed success. There is little or no scientific investigation of the processes involved and the approach is largely trial and error. There needs to be a concerted scientific effort to develop the fundamentals of water transport and water geochemistry (impacts on water quality) related to groundwater banking, with the objective of developing the predictive tools needed to implement it on a large scale and as a reliable storage technique.

Acknowledgements

I thank my committee members, in particular János Fehér.

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Wetland Systems for Water Pollution Control

Edited by *Günter Langergraber, Fabio Masi and Jaime Nivala* on behalf of the Specialist Group, with contributions from *Ulrich Dittmer, Nicolas Forquet, Jaume Puigagut, Roger Samso and Kela Weber*

Context

Treatment wetland/s (Figure 1) are engineered ecosystems that can be used for improving water quality, whether it relates to municipal wastewater, ground water, industrial waste streams, or diffuse pollution; and they can be implemented in urban, peri-urban, and agricultural landscapes. Wetland technologies are based on natural principles and have been shown to be one of the most efficient and cost-effective methods for improving water quality while providing benefits to the landscape. Wetland systems offer many advantages over conventional technologies, including increased local biodiversity and creation of green space within urban areas. Wetland technology is also robust and can be easily adapted to solve even the most challenging water pollution problems. Sustainability and resiliency are essential components of future planning, and wetland systems can play an important role.

The IWA Specialist Group on Wetland Systems for Water Pollution Control

The IWA Specialist Group on Wetland Systems for Water Pollution Control focuses on the following core issues:

(1) to improve the understanding of the fundamental interactions amongst water, soil, plants and bacteria inside wetland treatment systems that are used to control, transform and reduce pollution in the water cycle;
(2) to explore innovative applications and realise the full potential of wetland technology worldwide;
(3) to mainstream wetland technology within the larger field of wastewater treatment and water pollution control, and to define guidelines for proper design, implementation, and operation of such systems;
(4) to facilitate and promote research activities for the mainstreaming, continued development and advancement of treatment wetland/s technology.

Over the past decades, the members of this Specialist Group have demonstrated that wetland systems can be applied in almost any climatic condition and, in most instances, in place of conventional biological treatment technology. In fact, wetland systems often perform better in terms of environmental, social and economic considerations than other conventional technologies. Wetland systems are nowadays applied all around the world from cold to hot climates in developed and developing countries.

However, treatment wetlands (treatment wetland/s) are still often seen as 'alternative' treatment options and not as state-of-the-art technology. To overcome this, the Specialist Group started the Task Group 'Mainstreaming the Use of Treatment Wetlands' (Chair: Gabriela Dotro, Cranfield University, UK) in 2015 with the following main aims:

- to produce a textbook chapter on treatment wetland/s for use in addition to mainstream wastewater treatment textbooks (at bachelor degree level);
- to produce an updated Scientific and Technical Report on treatment wetland/s; and
- to link the activities of the Wetland Systems Specialist Group to, and find synergies with, other Specialist Groups.

General trends and challenges

Research in the field of treatment wetland/s is manifold. In this contribution, we focus and describe four main trends and challenges in research and application that were discussed during a workshop on treatment wetland/s in Lyon, France, in July 2015:

(1) wetland systems for treatment of Combined sewer overflow (CSO);
(2) microbiological processes in treatment wetland/s;
(3) numerical modelling of treatment wetland/s;
(4) application of microbial fuel cells in treatment wetland/s.

Figure 1. Wetland systems are commonly used for secondary treatment (left: vertical flow wetland in Austria; middle: horizontal flow wetland in the Czech Republic) and for tertiary treatment of domestic wastewater (right: tertiary treatment wetland near Shanghai, China). (Pictures: Günter Langergraber.)

Besides these four topics, hot research topics are using wetlands for industrial wastewater (e.g. wastewater from wineries, olive mills, etc.) and 'difficult to treat' wastewaters (e.g. high-strength wastewater and wastewater containing recalcitrant organic matter and ammonia nitrogen, like landfill leachate, or reject water from mechanical dewatering of sewage sludge). The elimination of emerging pollutants with treatment wetland/s is also widely researched as well as the use of alternative filter media (besides sand and gravel).

Wetland systems for treatment of combined sewer overflow

Pollutant discharges via combined sewer overflows are an issue of growing concern in many countries. Various studies have shown that, for many substances, combined sewer overflow pollutant loads are of a similar or even higher magnitude as the discharge from wastewater treatment plants. Furthermore, they can cause serious damage to freshwater ecosystems especially as the receiving waters are often small and therefore more sensitive to change.

Filtration in vertical flow wetlands has proved to be an effective measure in reducing pollutant loads for a wide variety of substances. Despite differences in terminology and in details of design and operation, the general layout is widely accepted. Figure 2 shows a typical design of a CSO treatment wetland/s that is commonly used in Germany. It combines a vertical-flow sand filter with a detention basin above the filter layer. Similar designs can be found in France, Italy and the USA, often in combination with ponds and tanks for sedimentation and additional retention.

In all vertical flow wetlands, particles and associated pollutants (e.g. COD, heavy metals and PAHs) are mainly retained on the filter surface. Biogenic sorption and degradation are limited to the upper part of the filter layer and the sediment that accumulates atop the sand layer. The concentration of active biomass in wetlands for combined sewer overflow treatment is extremely low compared with systems for sewage treatment. Owing to the limited biological activity, the elimination of degradable compounds is a two-step process: pollutants are retained during the filtration while elimination occurs in the following dry period when high availability of oxygen and long residence times provide ideal conditions for biological oxidation. Thus, a succession of wet and dry periods is essential for the efficacy of the treatment. There are diverging findings and recommendations about the role of the plants in purification processes and the benefits and risks of operating filters with submerged zones.

Challenges:

- In practice, the application of CSO treatment wetland/s is limited by the large area they require. Future research should therefore focus on increasing surface load to limit the required space as well as integrating wetlands in the design of urban landscapes as nature based water retention measures.
- Plants are mostly chosen based on technical considerations (e.g. robustness, mitigation of clogging risk, purification). Integrating biodiversity as a criterion for plant selection without risking the technical functioning of the filter is a major challenge.
- Vertical flow wetlands can also be applied to mitigate the effect of false connections that inevitably occur in any separate drainage system. They can treat stormwater runoff polluted by wastewater as well as overflow from sanitary sewers caused by falsely connected stormwater drains.

Microbiological processes in treatment wetland/s

It is generally understood that microbiological processes are important in treatment wetland/s. Microbial degradation/transformation of pollutants is the dominant mechanistic water treatment pathway for constituents such as organic molecules or nitrogen species. treatment wetland/s microbial communities are present in the biofilm surrounding the bed media, in the rhizosphere, or within the interstitial water. The growth of microbial communities and the associated biofilm within these areas affects treatment wetland/s hydrology, which in turn influences pollutant transport, and therefore impacts pollutant flux to different

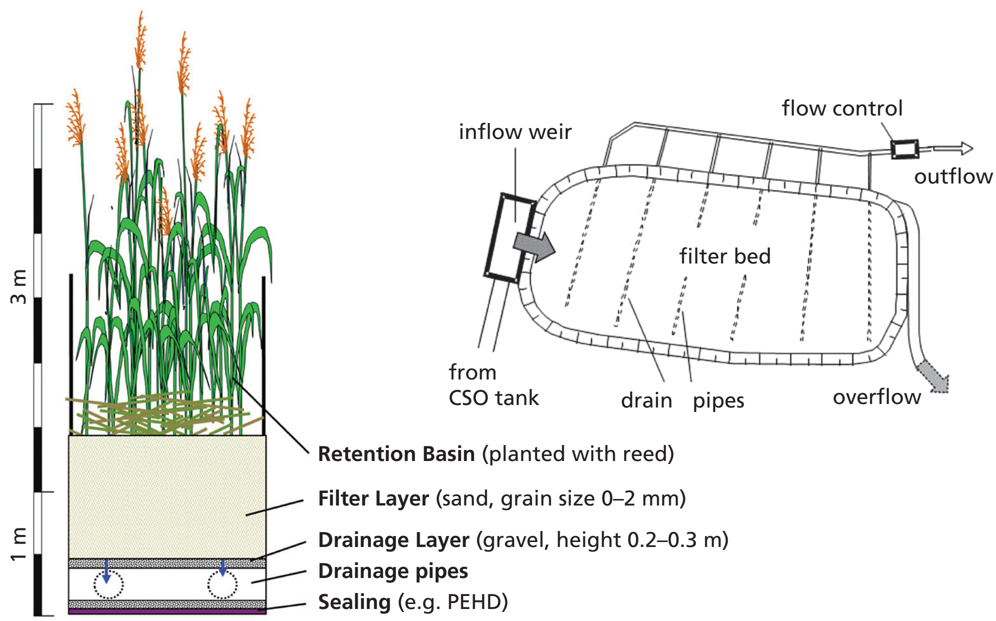

Figure 2. Cross-section (left) and schematic plan (top, right) of an exemplary CSO treatment wetland.

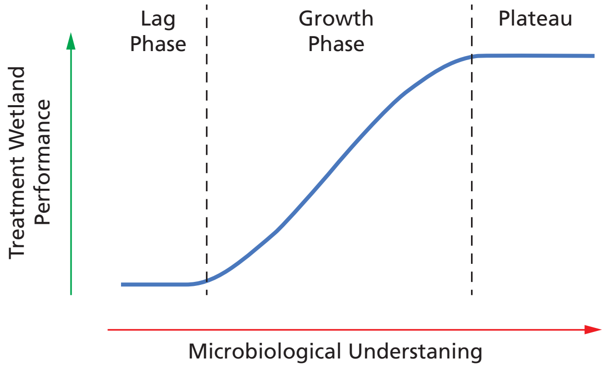

Figure 3. Overall microbiological understanding versus treatment wetland performance.

areas within the system and overall water treatment performance. The function of microbial communities within treatment wetland/s can be quite diverse owing to the diverse range of environmental regions found in treatment wetland/s. Methodologies for examining either the structure or function of environmental microbial communities are being developed across many research fields, many of which can either be directly applied or adapted for use in treatment wetland/s research. There are, however, very few treatment wetland/s research professionals with microbiological expertise pursuing method development/adaption, thus limiting the broader application of newer molecular methods or advanced function assays in applied research. This trend is, however, quickly changing as international collaborations are pursued and methodological focused studies and novel applied research studies are published. It is generally understood that a greater understanding of microbiological processes in treatment wetland/s will lead to advancements in treatment wetland/s system design, technological innovations, and eventually improved water treatment performance (Figure 3).

Understanding both spatial and temporal microbial community dynamics in different treatment wetland/s system designs is seen as a priority topic in moving treatment wetland/s research forward. The scientific understanding of what microbiological processes are important in treatment wetland/s operation is currently considered sufficient (although novel discoveries are certainly expected in the future). However, the location of different microbial functional groups, or the temporal stability the consortia responsible for those functions, has not been studied to any large degree. Spatial or temporal variability in microbial community function, structure, overall activity and population has been identified in all studies where an investigation was made. Capitalising on this understanding to take advantage of design factors is the end goal of applied microbial research in treatment wetland/s. It is expected that once a solid understanding is gained, treatment wetland/s engineers will be able to promote certain microbial functions or activity in regions where a deficit is identified, encourage faster system start-up or robustness to perturbations, and spatially control biofilm development to avoid clogging. Microbiological research in the field of treatment wetland/s is seen as important and is increasing. Continuing to include a microbiological component in applied research projects will most certainly help to improve water treatment performance of treatment wetland/s in the future.

Numerical modelling of treatment wetland/s

Numerical modelling of treatment wetland/s has gained worldwide interest during the past 15 years. For mechanistic models, coupling of Darcy-scale flow models and biokinetic models (such as CWM1 or CW2D) remains the most frequently used modelling approach and significant advances have been recently achieved. Most efforts in model development have been focused on hydrodynamics (e.g. preferential flows in gravel-based vertical flow beds), oxygen renewal, bacterial growth limitations and clogging.

The results obtained with these models have been validated with pilot-scale and full-scale systems and have been used for design purposes. However, the use of available modelling tools is time consuming, requires some competences in numerical modelling and, most importantly, their calibration remains problematic (e.g. many parameter values are directly taken from the literature on activated sludge modelling and have not yet been measured in treatment wetland/s).

Therefore, engineering-oriented models have been developed complementarily (as an example for wetlands treating combined sewer overflows). Fewer mechanisms are included and spatial description is courser. Model parameter values correspond to measurements commonly performed on wetlands like removal efficiencies. It eases their calibration but also limits their application range (inflow characteristics must be similar to those for which the parameter values have been estimated).

Developments in detailed mechanistic models in association with microbiological analysis techniques may help improve our understanding of biofilm behaviour and its influence on both treatment performance and hydrodynamics. Another upcoming challenge is to fill the gap between research-oriented models and engineering-oriented ones. The former could be employed to improve parameter estimations used in the latter. Finally, the development of engineering-oriented models may ease the spreading of modelling practice among designers and stakeholders.

Application of microbial fuel cells in treatment wetland/s

Microbial fuel cell (MFC) is a technology that generates electricity from the microbial degradation of organic and inorganic substrates. In a MFC, substrates are oxidised by specific types of bacteria (so-called exoelectrogens) that are able to transfer (directly or indirectly) the electron product of organic/inorganic oxidation to an electrode (anode). Once the electrons are transferred to the anode they flow through a conductive material and a resistor to a higher redox electron acceptor, such as oxygen, at the cathode.

The synergy between MFCs and treatment wetland/s is possible because of the presence of organic matter in treatment wetland/s owing to wastewater characteristics and its naturally generated redox gradient between the upper layer (aerobic conditions) and the deeper layers (anaerobic conditions). As a result of MFC implementation in treatment wetland/s, we would be able not only to produce small amounts of green energy (roughly ranging from 10 to 50 mW/m^2 of electrode) but also improve and monitor the overall treatment process.

MFC implemented in treatment wetland/s promotes a higher and faster degree of organic matter oxidation, which can lead to a better performance of the system or even to a higher degree of mobilisation of particulate organic matter entrapped in the filter media (clogging decrease). Furthermore, because exoelectrogens are mainly acetate-consuming bacteria, they can outcompete methane-producing bacteria, which may decrease the methane emission of constructed wetlands during wastewater treatment. Finally, the electrical signal of an MFC implemented in a treatment wetland/s is proportional to the organic matter present in the system. Therefore, it would also be a suitable bio-electrochemical tool for assessing treatment performance without any additional cost involved in the process. Overall, although still in its infancy, it represents a promising synergy between technologies that may enhance treatment performance and monitoring. The envisaged main challenges for maximising the treatment perpormance are linked to the optimisation of both operational and design criteria in treatment wetland/s and MFC cell architectures and materials.

Conclusions (and outlook)

Wetland systems, when properly designed, constructed and operated, can be applied in almost any climatic condition and in most instances, in place of conventional biological treatment technologies. Decentralised wastewater treatment, combined sewer overflow treatment, and sustainable urban, peri-urban and agricultural drainage systems are all essential approaches and tools for the future interaction of the human race with water and the environment, and wetland systems can and should play an important role. Wetland systems can also provide important ecosystem services, such as the capacity to retain nitrogen or to store sequestered carbon, buffering temperature fluctuation of the landscape, and replace the loss of green space in densely populated urban areas. Future activities on treatment wetland/s research will be driven by new applications for new wastewaters and in different local conditions. Research will focus on further technology development, optimisation and new application areas, as well as deepening the understanding of pollutant transformation and removal processes. This will be key to mainstream wetland technology and to make it be seen as an equivalent technology to technical wastewater treatment solutions.

the international water association

IWA Global Operations

address Anna van Buerenplein 48,
11th Floor
2595 DA The Hague
The Netherlands
phone + 31 703 150 792
email water@IWAhq.org

inspiring change

IWA Head Office | Alliance House, 12 Caxton Street, London SW1H 0QS, UK | Company registered in England No. 3597005 | Registered Charity (England) No. 1076690