Chapter 1

Editorial

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Why are we editing a book about source separation and decentralization? We live in Switzerland, an industrialized country with a highly advanced and well-functioning wastewater management system. But even in Switzerland, the central system is reaching its limits, shortcomings, which become very obvious from a global perspective. We are proud to have been able to assemble contributions from renowned authors worldwide from both research and practice. They share with us their experience and thoughts about the current wastewater system. They analyze its advantages, but also deficiencies and they have the courage to breach the paradigm that central wastewater treatment is the only possible approach in urban areas. Many of the authors of this book are pioneers in the field and have been paving the way to a more sustainable and equitable handling of wastewater. We are greatly indebted to all the authors for their contributions to this book, but even more so for their continuous research on source separation and decentralization. We hope that this book will help develop this new area into a mature field in science as well as in practice.

The 21st century is characterized by increasing resource scarcity, mainly due to rapid population growth and climate change. Accordingly, the main advantages of source separation and decentralization discussed in Part I are linked to resource management. In Chapter 2, Bruce Rittmann describes biochemical oxygen demand (BOD) in wastewater as a "misplaced resource." He discusses how energy can be recovered from wastewater and why source separation and decentralization can lead the way towards more energy-efficient wastewater handling. However, Rittmann also shows that there are limits to the importance of the wastewater sector in the general picture and presents very useful "book-keeping" tools for quantification of this importance. Additionally, he presents new

ideas to use the nutrients in decentralized wastewater systems for the growth of biomass and energy production.

Our inadequate approach to the resources captured in the wastewater system becomes especially obvious in the case of phosphorus. Phosphorus recycling was one of the early arguments for source separation of wastewater, and Dana Cordell shows that phosphorus belongs to the most important elements for humanity as it is crucial for global food security (Chapter 3). Cordell demonstrates that phosphorus scarcity cannot simply be expressed by the depletion of the phosphate rock reserves. Rather, five interrelated dimensions must be considered, namely physical, managerial, institutional, economic and geopolitical scarcity. The central importance of phosphorus recovery from excreta and other wastes for a sustainable future is of special importance for the readers of this book.

Like BOD, the nutrients phosphorus and nitrogen are also "misplaced resources." Especially in developing and fast-industrializing countries, the nutrients are desperately needed in agriculture, but at the same time they are polluting water resources worldwide. In Chapter 4, Jan Willem Erisman and Tove Larsen focus on the dramatic increase of environmental pollution due to excess nitrogen. While nitrogen shortage in some areas has severe consequences for human nutrition, the production of harmful reactive nitrogen is expected to increase dramatically because of population growth, increased protein consumption and biofuel production. Only with a better understanding how different nitrogen sources give rise to environmental effects will it be possible to develop policies that are effective in tackling these problems. As described in the chapter, source separation could be an important measure amongst other policy means.

Water scarcity as discussed by Malin Falkenmark and Jun Xia in Chapter 5 is probably the clearest example of the importance of source separation and decentralization for resource efficiency. Water sets distinct limits for population growth and human welfare, and water efficiency will help extract more welfare per drop of water. Water efficiency and especially also water recovery is greatly enhanced by separating less polluted water from toilet waste, but as discussed later in the book, the entire concept of sewer-based urban water management is challenged by water scarcity.

Our approach in this book is clearly resource-oriented. However, some substances contained in wastewater are so highly dispersed that an efficient recovery is hardly feasible. This applies especially to micropollutants, as discussed by Klaus Kümmerer in Chapter 6. Source separation in the case of micropollutants mainly aims at removing these potentially harmful substances as near to the source as possible. The "benign-by-design" principle goes a step further, to the real beginning of the pipe, the industrial production of chemicals.

In our daily life as engineers, we are confronted with physical problems concerning the functioning of the system and are asked to find the most cost-effective solutions for the requested services. However, the prevailing urban water management system is hardly set up to deal with the increasingly complex

challenges of the 21st century. Max Maurer introduces us to the undisputed advantages of the conventional centralized system and explains its success. However, Chapter 7 also helps to understand the problems of sewer-based wastewater management: high capital-intensity and extreme inflexibility. Based on in-depth analyses, Maurer identifies entry markets for on-site treatment systems with better abilities to adapt to growing demands, especially in rapidly expanding cities.

In Chapter 8, George Tchobanoglous and Harold Leverenz illustrate similar problems from a more practical point of view. Not only in fast-growing cities, but especially also in regions that have to cope with water scarcity, sewer-based wastewater management comes to its limits. In the USA, the increasing introduction of water saving devices such as low-flush toilets, conservation programs and water extraction from sewers have led to reduced wastewater flow. This has a number of negative effects including increased corrosion rates. The authors also introduce a typology of wastewater infrastructures, which is highly useful to structure discussions about decentralized technologies.

For developing countries, such problems may seem trivial. Developing countries are facing dramatic urban water management challenges, as introduced by Barbara Evans in Chapter 9. In the cities of the global South, access to basic sanitary services is low, with severe public health consequences. Although the boundary conditions are very different to those in industrialized countries, decentralized wastewater systems are becoming prevalent for similar reasons. As others, Evans also introduces tools to systematize the field, namely the advantages of "vertical" and "horizontal" unbundling of wastewater services. These tools enable us to tackle wastewater management problems efficiently, with more flexibility, and better adapted to different realities. "Vertical unbundling", for instance, allows creating different incentives along the value chain of urban sanitation, thus increasing the chance to develop a functioning system in a city.

Although there are many potential advantages of source separation and decentralization, which are extensively discussed and referenced in Part I of this book, the challenges for a paradigm change are huge (Part II). This is particularly evident for cities, where the central paradigm is deep-rooted. However, as discussed by Tove Larsen and Willi Gujer in Chapter 10, there are many chances for technology development and technology learning in various niches of the system. Depending on the socio-economic environment, these niches look different. There are many possibilities for cost-effective improvements of the present system, which may eventually lead to the development of viable alternatives to sewer-based sanitation, also in an urban environment.

Changes to the existing urban water management system inevitably invoke fears that urban hygiene could be jeopardized. Of course, this is not trivial, and the problem must be tackled with due respect. However, as Thor Axel Stenström demonstrates in Chapter 11, the risk that exposed humans are infected by pathogens is not inherently larger in decentralized wastewater systems than in

sewer-based ones. To quantify the risk, an integral assessment must include the reduction of pathogens, the transmission routes and the exposure. It is also of vital importance to follow the entire "flow" of wastewater, which originates in the household and passes through the collection and treatment part to the point of re-use or disposal. Also the downstream populations must be included.

If the end-products from decentralized wastewater systems are re-used in agriculture, the risk of contamination by pathogens must be minimized, but additionally they must reach the agricultural land efficiently and in the appropriate form. Håkan Jönsson and Björn Vinnerås provide the fundamentals to understand the agricultural perspective (Chapter 12), hereby supporting engineers in developing technologies that transform human excreta to a marketable product.

Farmers must accept fertilizers from human excreta, as well as the consumers who buy agricultural produce. In Chapter 13, Judit Lienert reviews social science studies on the acceptance of urine source separation, including the re-use of human urine in agriculture. The results are generally positive, but based on the questioning of more than 2700 users of NoMix toilets in seven European countries, the weak points of the technology also become clear. Additionally, Lienert gives some guidance on how to explore aspects of social acceptance of source-separating technologies. This illustrates how essential the involvement of social scientists becomes the closer wastewater treatment gets to the consumers.

Gustaf Olsson (Chapter 14) provides an approach based on modular build-up and standardization to increase the acceptance of source-separating technologies and make them work in practice. Similar to cars or computers, the complexity of the machinery does not mean that only specialists can use it. However, the responsibility for proper operation and the handling of failures should be delegated to professional service enterprises. Olsson suggests using remote sensing, a proven technology in other areas and simple sensors along the whole chain of "smart water grids." To allow for mass production and the economic viability of decentralized systems, we must think in terms of "plug and play" of the components.

Also from a socio-economic perspective, Bernhard Truffer, Christian Binz, Heiko Gebauer and Eckhard Störmer arrive at the conclusion that the success of source separation and decentralized technologies will depend on reliable and effective components, but even more so on integrating these into working systems (Chapter 15). These authors understand source-separating, decentralized wastewater technologies as a "systemic innovation" problem. They draw on experience from other domains to understand what it takes to develop such a field.

In Part III a wide range of technologies for the treatment of source-separated waste streams are presented. Some commercially manufactured reactors already exist, especially for greywater treatment. Many other treatment processes have been investigated in the laboratory or on a pilot scale. Nevertheless, source separation and decentralization still offer extensive research opportunities for engineers and urban planners, because the reliable operation of small reactors with concentrated source-separated waste streams poses new challenges.

Compared to conventional wastewater management, a sanitation system based on source separation and decentralization consists of many different waste streams, dispersed treatment units and involved stakeholders. This new system is more complex, but has the key advantage of allowing for wider range of technologies and business models. In Chapter 16, Elizabeth Tilley presents a conceptual approach to describe the functional groups (e.g., user interface, collection and storage) and product flows (e.g., brownwater) in any kind of sanitation system. This approach helps to identify the treatment steps and linkages that provide reliable and cost-effective sanitation. The chapter clearly shows that not only do novel technologies have to be developed, but business relationships also have to be enabled.

A thorough understanding of the composition of wastewater streams is needed to choose effective treatment reactors and identify business opportunities. On the basis of a comprehensive summary of literature data, Eran Friedler, David Butler and Yuval Alfiya (Chapter 17) discuss how socio-economic conditions and the technological development of appliances determine the composition and variability of wastewater streams. The analysis shows that treating the source-separated waste streams according to their composition allows for efficient recovery of water and nutrients. Additionally, targeted treatment improves the removal of pathogens and emerging pollutants such as personal care products.

Most pathogens are excreted via faeces. In Chapter 18, Ralf Otterpohl and Christopher Buzie present various processes to treat faecal solids. They focus on technologies with a low degree of mechanization which can be easily applied on-site in locations without infrastructures. These are mainly biological processes such as composting, but also simple chemico-physical processes such as dehydration. The authors emphasize the need for further development of the technology. Future research should focus not only on minimizing energy demand: simple operation and low maintenance are at least equally important.

Extensive experience with decentralized treatment is available for two source-separated waste streams, for faecal solids as well as for greywater. In fact, Bruce Jefferson and Paul Jeffrey (Chapter 19) argue that aerobic biological treatment of greywater is the most successful application of decentralized treatment of any source-separated wastewater. Intensive systems such as membrane bioreactors (MBRs) as well as extensive technologies such as reed beds (constructed wetlands) exhibit a similarly high performance of almost 90% BOD removal. The key challenges for greywater treatment are the high variability of the BOD load and concentration and the high fraction of xenobiotic compounds such as personal care products.

Besides organic compounds and pathogens, nitrogen is another major target for wastewater treatment. Most of the nitrogen is excreted via urine, so that nitrogen treatment technologies are mostly needed for urine or blackwater. Since nitrogen is a valuable nutrient in agriculture, the target of the treatment is recovery instead of removal if the costs are comparable to those of local fertilizers. In Chapter 20,

Kai Udert and Sarina Jenni argue that autotrophic denitrification is the most energy-efficient process for removing nitrogen from urine, but diligent process control is required to ensure stable process performance. Nitrogen can be recovered by biologically oxidizing a part or all of the ammonia in urine to nitrate. The resulting solution can be used directly as fertilizer, or a concentrated fertilizer can be produced if the water is removed, for example by distillation.

While urine contains most of the excreted nutrients, faeces have the highest chemical energy content in the form of organic substances. Gretjie Zeeman and Katarzyna Kujawa-Roeleveld (Chapter 21) discuss the use of anaerobic digestion for recovering this energy as methane gas. The most suitable waste streams for anaerobic digestion are brownwater and blackwater, due to their high faecal content. The authors show that anaerobic digestion of blackwater in an upflow anaerobic sludge blanket reactor (UASB) is a proven technology: in pilot studies nearly 90% of the chemical oxygen demand (COD) can be degraded and 60% can be recovered as methane. Further research is required to develop effective post-treatment options to remove pharmaceutical residues and hormones.

Energy recovery is also one of several applications of electrochemical processes. In Chapter 22, Kai Udert, Shelley Brown-Malker and Jürg Keller give an overview of a variety of processes which have been tested on a laboratory scale. Some of them have high potential for the treatment of source-separated waste streams. The main advantage of electrochemical processes for decentralized reactors is their direct use of electric current and voltage for process control and automation. In electrolysis, electricity is applied to remove substances such as ammonia, urea, organics and pathogens, while fuel-cell applications allow the direct conversion of chemical energy into electrical energy. The authors also discuss the use of electroactive bacteria in bioelectrochemical systems, a new technology which has lately received considerable attention.

Ammonia stripping from urine has already been tested successfully on a pilot scale by several research groups. In Chapter 23, Hansruedi Siegrist, Michele Laureni and Kai Udert present the basic principles of ammonia stripping with air and the subsequent ammonia recovery in sulfuric acid. They also discuss literature data on steam stripping and report about their own experience with passive ammonia stripping in urine-collecting systems. The ammonia stripping technology is most suitable for medium sized reactors, since corrosive chemicals or steam at high pressure and temperature are needed. An interesting combined process is struvite precipitation and ammonia stripping, which allows for the recovery of phosphorus and nitrogen as two different products.

Struvite precipitation by magnesium dosage is the most intensively researched nutrient recovery process from urine. Struvite precipitation is therefore at the core of Chapter 24, in which Işık Kabdaşlı, Olcay Tünay and Kai Udert discuss treatment processes based on the transfer of nutrients into or onto a solid phase. Again, urine and blackwater are the main substreams for this type of treatment

process, because they contain the most nutrients. Aluminium, iron or calcium can be used to precipitate the phosphate as alternatives to magnesium. Other processes that recover nutrients at or in a solid phase are adsorption, ion exchange and water removal (e.g., distillation).

In contrast to struvite precipitation reactors, which are currently tested on a pilot scale, membrane bioreactors (MBRs) are an established technology for decentralized wastewater treatment. In Chapter 25, Gregory Leslie and Zenah Bradford-Hartke report on the use of MBRs on full, pilot and laboratory scales for combined wastewater, blackwater, greywater and urine. MBRs have some ideal properties for on-site reactors: they can be compact, modular, scalable and provide consistent product quality. However, further research is needed to ensure consistent throughput capacity and to reduce their energy consumption.

Insufficient micropollutant removal is a common shortcoming of MBRs and other established technologies. Urs von Gunten (Chapter 26) discusses a wide range of chemical oxidation processes which can be used to oxidize micropollutants and remove pathogens in a post-treatment step. He argues that ozone, •OH radicals and ferrate exhibit the highest overall performance based on their reaction kinetics, oxidant stability and by-product formation. Further research is required to better understand the conditions under which chemical oxidation of micropollutants can produce toxic degradation products or unwanted by-products such as bromo-organic compounds.

Willy Verstraete, Vasileios Diamantis and Bert Bundervoet conclude the technology part of this book by presenting a concept for enhanced energy recovery from existing sewer-based sanitation systems (Chapter 27). Instead of establishing a new sanitation system based on separating the wastewater streams at the source, the authors suggest that the solids could be intercepted and concentrated in the sewer to recover as much as possible of the chemical energy of the organic solids by anaerobic digestion. Solid recovery (fractionation) can be increased by several processes such as chemically enhanced sedimentation, dissolved air flotation, bioflocculation and direct sewage filtration. The authors also present technologies to obtain high-quality effluents which can be used for irrigation or disposed of to sensitive water bodies.

Part III of this book shows that the basic idea behind source separation, that is, the efficient management of the resources contained in wastewater, can be approached with a variety of technologies and concepts depending on local socio-economic conditions and the existing infrastructure. We hope that continuous development will result in a wide range of technologies so that engineers and urban planners of the future will have more flexibility in implementing appropriate sanitation systems. Besides the development of technologies and management schemes, pioneers are needed who have the courage and the confidence to implement new concepts in pilot projects which can later serve as references. Pioneering projects and their initiators are presented in Part IV of this book.

The very early pioneers of source separation are found in Scandinavia and especially in Sweden. These actors developed the first (modern) NoMix toilet, which was a key precondition for the implementation of decentralized urine source-separating solutions also in other European countries. Björn Vinnerås and Håkan Jönsson introduce the Swedish story of source separation, which started in the early 1990s (Chapter 28). The reasons for an increased interest in urine-diverting technologies were growing environmental concerns and the ambition of the Swedish government to create closed loops. This environmental concern was reflected in the building of eco-villages, which often included on-site treatment of wastewater. Today, Sweden has around 700,000 on-site sanitation systems in a variety of settings and system configurations.

Also in Germany, diverse projects with on-site wastewater treatment have been implemented in the last two decades. In Chapter 29, Jörg Londong describes the German development of source separation. Initially, these projects were driven by universities, but relatively rapidly the field was structured via a working group within the German Association for Water, Wastewater and Waste (DWA). In a variety of German pilot projects, mainly blackwater and urine source-separating systems were tested. In the newest large-scale project in Hamburg, black and greywater are treated separately to create a fully decentralized treatment system. DWA still views the implementation of new sanitation strategies as a major task and is currently working on a German standard. Recently, the German Environmental Ministry has indicated interest in the topic, which is certainly a positive signal.

Rather similarly, but at an even greater pace, decentralized and source-separating technologies were introduced in The Netherlands. Bjartur Swart and Bert Palsma present this success story in Chapter 30. The driving force was certainly STOWA, the Dutch Foundation for Applied Water Research, which coordinates research on behalf of 26 Water Boards, the Provinces and the Ministry of Infrastructure and the Environment. Until STOWA picked up the topic of "New Sanitation" in the year 2000, source-separating technologies were of minor importance. STOWA made two crucial decisions: to take responsibility *and* to place wastewater treatment into a wider social context. Within a few years, more than half of all water boards in the Netherlands were involved in one of the 40 pilot or research projects. New Sanitation has reached a transition phase in 2011. It is now time to move from research to implementation, and several of the most promising initiatives will undergo up-scaling.

Markus Boller shows that the experience in Switzerland is rather different (Chapter 31). Switzerland took a lead in Europe by introducing a phosphate ban for textile detergents in 1986. From 1991, on-site infiltration of stormwater and separate sewer systems for all new or renovated buildings and roads were required by law. This made studies to control hazards from construction materials and traffic vehicles possible, and source control with respect to stormwater management can currently be seen as a system change in a transition phase. In

contrast, in-house installations, especially of urine source separation, have much larger consequences and are far from being accepted as state of the art technology. In Switzerland, these initiatives were strongly driven by research, with only smaller implementation projects. Markus Boller introduces the three main types: on-site wastewater treatment and re-use, separate collection and processing of urine and small-scale autarkic material and water cycles. Several of the projects were motivated by the topography in the Swiss mountains, where connection to sewers is not possible. From a technical point of view, these decentralized water schemes performed satisfactorily, but also in Switzerland, stakeholder participation and acceptance will be key to their widespread implementation.

Australia faces fundamentally different challenges than these European countries. Ted Gardner and Ashok Sharma illustrate that the primary driver for the uptake of decentralized wastewater systems in Australia is water scarcity (Chapter 32). The Australian projects are also rather different to those in Switzerland, for instance, because often the private sector has taken the lead, and not research. However, similar to Swedish holiday homes along the Baltic Sea, or cable car stations in the Swiss Alps, the original driver in Australia, which is still important today, was the provision of on-site sanitation systems in non-sewered urban and peri-urban communities. Later important drivers included sustainability aspects, which inevitably lead to the consideration of source-separating technologies.

In Chapter 33, Christoph Lüthi and Arne Panesar argue that the drivers and constraints for source-separating wastewater technologies are drastically different between industrialized and middle- or low-income countries. The solutions, however, are in principle similar to those that provide sustainable answers for the problems in industrialized countries. For different reasons, the vast majority of households in the global South will remain to be served by on-site sanitation. Often, only rudimentary pit latrines or cesspits are common. The authors understand this deplorable situation also as an opportunity to leapfrog into a fundamental system change. They demonstrate this with two interesting “case studies” with more than impressive numbers. In eThekwini Metropolitan Municipality, South Africa, more than 90,000 urine-diverting dry toilets were introduced. A program in the Shaanxi province in China by an NGO aims at introducing 27,000 source-separating sanitation systems. Overall in China, more than two million urine-diverting dry toilets have been built between 2000 and 2010. It is likely that industrialized countries will strongly profit from the experience gained in low- and middle-income countries. Possibly, we will install source-separating, decentralized wastewater technologies in the global North, which were essentially developed, tested and improved in the global South.

Finally, in Part V, we have asked two experienced scientists to give their personal opinions on a possible paradigm shift in the area of wastewater treatment. In Chapter 34, Bruce Beck discusses the historical development from his perspective and

argues for the beneficial co-existence of different wastewater paradigms. In the last chapter of this book, Peter Wilderer reflects on the nature of innovation and paradigm change. Based on decades of experience in the area of conventional urban water management and the paradigm shift discussed in this book, Wilderer encourages us to continue on the path of source separation and decentralization. As the editors of this book, we can only agree.