



View of Recife. Foto: Juliana Costa

*Twenty-six young scientists, mainly from Germany and Brazil, participated in the workshop “How do we want to live tomorrow?” and identified four central research topics: a) integrated watershed management in urban regions, b) sustainable sanitation and rain-water management, c) micropollutants and d) information flow and people’s involvement.*

# How do we want to live tomorrow?

Perspectives on water management in urban regions

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## Foreword

The sustainable use of water resources in urban regions is essential in order to ensure a livable environment for future generations. Stakeholders from politics, science, industry and society deal with these challenges of water management all over the world. In this context, a central question is “How do we want to live tomorrow?” The German National Academy of Sciences Leopoldina, the Brazilian Academy of Sciences (ABC) and the Centre for Water and Environmental Research at the University of Duisburg-Essen (ZWU) organized the workshop “Perspectives on Water Management in Urban Regions” from

4th to 7th October 2016 in Essen, Germany, in order to discuss which research topics and questions are relevant for the future water management in urban regions. This workshop continued the series “Water in Urban Regions”, initiated by the Leopoldina and the ABC in 2014 in São Carlos, Brazil (Anthonj et al., 2014).

The organizing institutions invited young scientists to the workshop, since they are the ones who will shape the future of research in urban water management. Twenty-six young scientists, mainly from Germany and Brazil, participated in the workshop and identified four central research topics: a) integrated watershed management in urban regions, b) sustainable sanitation

and rainwater management, c) micropollutants and d) information flow and people's involvement. Considering the motto of the workshop "How do we want to live tomorrow?", the young scientists formulated research questions within these four topics, which – from their perspective – are relevant for the future of urban water management. They are convinced that extensive research in the identified areas generates important know-how for the stakeholders involved. The young scientists' aim is a contribution to the development of more viable, sustainable and humane cities in the future.

The present science policy report reflects exclusively the views of the young scientists participating in the workshop. A list of authors is available in the appendix.

We, as the organizing science institutions, would like to thank particularly Professor José Tundisi (member of ABC, São Carlos), Professor Peter Fritz (member of Leopoldina, Leipzig) and Professor Klement Tockner (member of Leopoldina, Berlin) as well as Professor Bernd Sures, Professor André Niemann and Professor Daniel Hering (all ZWU) for coordinating and supporting the event.

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## Executive summary

More than half of the human population currently lives in urban areas and according to the United Nations, cities will be the living space of an additional 2.5 billion people by the year 2050 (UN, 2015b). The proportion and speed of this urban growth increase the pressure on water resources, and is often seen negatively. However, this challenge can also be a chance to substantially improve the quality of life in urban areas, if we consider how we want to live tomorrow and actively shape our future. As a group of interdisciplinary young scientists authoring the current science policy report, we agreed that we want to live in cities where sustainable, integrated watershed management guarantees public health and environmental safety. This requires sanitation and rainwater management, solutions for dealing with contaminants, such as micropollutants, as well as information flows and public involvement in water management.

Integrated watershed management as part of urban planning takes into account interdisciplinary relationships and connects different sectors, for example city administration, health providers and water managers. It also ensures access to sustainable, adaptable, effective and resilient rain and wastewater management, which

includes the specific needs of vulnerable groups. Such a rain and wastewater management considers water reuse as a possibility to increase the available water supply. A growing number and increasing concentration of micropollutants in the aquatic environment are a health risk. It is important to understand their fate and effects and to develop appropriate management strategies. In such decision-making processes, all aspects of water management should be included and local stakeholders involved. Moreover, comprehensive and optimized information flows improve the understanding of water-related problems and must be used to help communities to set priorities, take action and assume responsibilities. Education, capacity building and community engagement are particularly important for creating ownership, identification with water resources and environmental consciousness.

Further research is needed in these areas to better understand challenges and chances of water management in growing urban areas and to develop scientifically based solutions. This scientific knowledge will build the basis for policy-making and implementation of actions in urban water management. In this way, we believe a better and more desirable urban environment can be achieved for future generations.

## Integrated watershed management for urban areas

Urban areas cannot be seen as closed systems. As cities are part of the catchment-scale water cycle, they compete with other land uses, such as agriculture or mining, for their shared water resources. This conflict of use includes aspects of water quantity as well as quality. Consequently, urban water management issues should be faced as a whole. Smart management schemes should consider urban areas as an integrated part of watershed management, which has the potential to increase cities' resilience to intensified natural disturbances caused by climate change, such as floods and droughts (Birkmann et al., 2016).

Present-day water planning schemes in urban areas often do not link the impact and demand of different sectors, such as agriculture, industry or public services. Additionally, they often neglect challenges resulting from population growth and the linked increase in the demand for water, housing, energy and transportation (Bahri, 2012). In contrast, integrated watershed management includes all sectors in water-related management decisions. It is adaptable to the specific local and regional needs, because water demand and water-related problems are defined by local and regional conditions, such as climate, water availability, and ecological and socio-economical water quality and quantity needs. Integrated watershed management comprises internal components as well as external factors. Internal factors are man-made

structures such as legislations, institutional frameworks, sectors and stakeholders, and different scientific disciplines, while external factors are human requirements (consumptive and non-consumptive uses and contamination) and natural physiographic characteristics. Two external factors – groundwater and ecosystem services – are highlighted here and exemplify the need for an integrated watershed management.

### Long-term responses from impacts on groundwater

Many cities are located in dry regions (e.g. Middle East, North Africa, Central Asia, Southwest USA, and Northeastern Brazil), where surface water resources are not reliable in their temporal availability. Moreover, many cities show heavily polluted surface water bodies (e.g. Dakar, Mumbai, and São Paulo). Consequently, more and more cities rely on groundwater to meet the freshwater demand. Groundwater is usually considered a safe resource as (i) it is protected by an unsaturated zone from direct contamination, and (ii) it is less affected by droughts due to average residence times of several years. However, cities' groundwater reserves are increasingly deteriorated by various anthropogenic actions, mostly related to unplanned urban expansion and economic growth. Generally, we can distinguish between two types of man-made impact. The first one is overuse, i.e. excessive groundwater withdrawal, which results in groundwater levels dropping, land subsidence, and salt-water intrusion or upconing, especially in coastal areas. Overuse usually happens in cities that share their underground water bodies (aquifers) with irrigated agricultural land – a conflict of use that recently became very prominent in California (Skelton, 2015). Moreover, cities experience a decrease in the natural recharge of their groundwater resources due to a high degree of ground sealing. The second negative anthropogenic impact is pollution, which results (i) from rainwater collecting contaminants at the ground surface, (ii) percolation through contaminant materials, such as solid waste disposals and (iii) leaking, or simply not existing, sewage systems (Foster and Tyso, 2015). The sustainable availability of safe freshwater also depends on interactions with surface water bodies. Surface waters can pollute groundwater and vice-versa. Some rivers keep their natural flow exclusively through the recharge from aquifers, and therefore the reduction of overexploitation and pollution is essential for the maintenance of the natural ecosystem of these rivers. In order to solve the problems related to the quality and quantity of cities' groundwater reserves, legal frameworks for long-term scales are needed. Furthermore, water allocation concepts must integrate all sectors of water use in order to preserve safe freshwater resources for the future.



(1) Phoenix Lake in Dortmund, Germany. The lake is an example of urban integrated watershed management, where the area, a former industrial plant, was revitalized featuring a lake for flood retention, recreational and commercial areas, as well as housing. Source: Rupert Oberhäuser/Emschergenossenschaft

### Future Research Questions:

1. How can sufficient freshwater supply from groundwater reserves be guaranteed, while managing this resource in a sustainable manner?
2. To what extent can we improve the recovery of groundwater reserves with technologies like managed aquifer recharge (MAR) using, for example, treated wastewater?
3. How can we couple the understanding of surface and sub-surface processes to develop better mechanisms to avoid contamination of groundwater from surface water and vice-versa?

### Ecosystem services

Ecosystem services are the direct or indirect benefits people derive from ecosystems, which result in security, basic material for a good life, health, good social relations, and freedom of choice and action (MEA, 2005). Some of these ecosystem services are, however, increasingly threatened by unsustainable use and environmental degradation: a fact that is especially true for ecosystem services related to freshwater environments. This has been acknowledged by multiple directives that ask for the protection of ecosystem services, e.g. Aichi Biodiversity Targets (Convention on Biological Diversity, 2010), UN Sustainable Development Goals (UN, 2015a). Furthermore, the economic dimension of ecosystem services is of increasing interest and relevance (Hansjürgens et al., 2016). Hence, there is a clear need for ecosystem services to be integrated into local and regional planning (Martinez-Harms et al., 2015) to ensure their protection, with the long-term goal of safeguarding human well-being and also biodiversity.

Multi-functional management measures create areas that provide multiple ecosystem services to the local population. Restoring buffer strips along channelized river sections within urban areas, for example, provides new, enlarged “riparian” spaces that can be used for recreational purposes, such as walking, swimming or barbecuing. They also ensure better protection from flooding and create new habitats for aquatic and terrestrial organisms. Further, establishing more of such multi-purpose areas, with the potential to increase a system’s resilience, could be a way forward to avoid critical tipping points. These tipping points are known to occur due to complex feedback mechanisms or interactions between two or more forces that lead to large, rapid and potentially irreversible changes with significant backlashes for human well-being (Leadley et al., 2010).

#### Future Research Questions:

1. Can ecosystem services (e.g. groundwater recharge, mass stabilization and erosion control, maintenance of water cycles, regulation of local and regional climate, etc.) that are lost due to the degradation of riparian vegetation be compensated upstream or downstream in a river catchment?
2. Can multi-purpose management measures help to reduce trade-offs between biodiversity conservation and the delivery of ecosystem services (e.g. water for sanitation) in urban areas? Can they help avoid tipping points?

#### Decision support systems and models

From the global perspective, urban areas experience an ongoing rapid growth and structural changes which increase the pressure on water resources. In order to preserve these resources for the future and to foster cities’ resilience, urban water management schemes must be integrated into the watershed context and should be adaptable to specific local needs and challenges. To support such a flexible water management, tools, such as decision support systems (DSS), should be adaptable to specific situations and challenges as well. Hence, one general management tool does not work for all urban areas. Instead, bottom-up development schemes for specific DSS are needed.

Today, many decision support tools incorporate computer models, which shape decision-making processes. They are used to understand and visualize complex systems, calculate water budgets, and simulate scenarios. Models are always based on data, which has to be generated by monitoring (e.g. measuring water flows, surveys among stakeholders). As models are simplified repre-

sentations of real world processes, they always include a certain degree of uncertainty. These uncertainties result from insufficient data, but also from a lack of appropriate model concepts. Especially in complex environments such as urban areas, present-day models are not able to encompass all relevant links between water-related processes, including the different sectors and disciplines. There is a need to bridge gaps between different model types (e.g. natural processes versus socio-economic responses) and to find smart solutions to link them. Additionally, in order to make these new and more complex management processes successful, it is vital to make them transparent and to increase people’s awareness and support for water-related issues (see chapter Information Flow and People’s Involvement).

#### Future Research Questions:

1. What new model concepts are there that link all relevant water-related processes?
2. How can different water demands be measured and considered in defining water withdrawal limits and how can easily applicable models for this task be developed?
3. Which basic components of a DSS are common to all situations and which components are specific to the local question and therefore need to be flexible?

#### Sustainable sanitation and rainwater management

Sustainable sanitation systems are vital to human health and to the quality of aquatic ecosystems. They are characterized by being economically viable, socially acceptable, and technically and institutionally appropriate systems for the collection, transport and treatment of human excreta. They should ideally also protect the environment and natural resources. In many parts of the world, urban growth is often unplanned and uncontrolled, which results in gaps of the provision of sanitary facilities and threatens sanitary safety. Moreover, in urban areas, space for implementing sustainable sanitation systems is usually limited. Additionally, extreme rain events, which are predicted to occur more frequently in some regions owing to climate change, can cause overflows and contamination of aquatic ecosystems, while during droughts increasing concentrations of contaminants may occur (Wu et al., 2016). The augmented discharge of known and emergent contaminants can furthermore result in yet unknown effects on human health and aquatic ecosystems (see chapter on Micro-pollutants). From our perspective, the following research

areas and questions are relevant for the future development of sustainable sanitation and rainwater management in urban regions:

### Access to sanitary system

Uncontrolled, fast-growing (peripheral/periurban) areas of cities often lack sanitary infrastructure, posing a specific threat to the urban water cycle and to human health. In these areas, water bodies become means for wastewater disposal and thus a hygienic risk (Fletcher et al., 2013). Inefficient or poorly managed decentralized technologies like septic tanks or pit latrines cause diffuse pollution (Bahri, 2012). Hence, the connection of households to the urban sewer systems is usually perceived as a prerequisite for the prevention of sanitary and environmental problems. However, maintenance of the sanitary system from collection to transport, treatment, reuse and disposal has to be guaranteed. If the connection of emerging peripheral areas to the system can be realized by means of planning and construction, this would be a solution. In areas where connection to the sanitary infra-



(2) Cesspit used for wastewater disposal in a poor community situated at the southern region of Parelheiros District (Municipality of São Paulo). It is not unusual to find cesspits dug up to the water table, bringing pollution to groundwater that will be exploited by nearby dug wells.

Source: Alexandra Suhogusoff

structure is challenging or even not possible, decentral solutions may be the answer. In this case, new approaches must be developed in order to collect and treat all liquid emissions. Moreover, suitable and sustainable sanitary solutions that are demand-driven, adapted to local requirements and elaborated with the participation of all stakeholders, taking into account the specific needs of vulnerable groups, have to be identified and implemented (Lüthi et al., 2012). In this context, engineering innovations, such as phytotechnologies (Zalewski and Wagner-Lotkowska, 2004), should always go along with capacity building (e.g. ISOE, 2016) and it is of crucial importance that the local population accompanies and influences the development and adaptation of technologies (see also chapter on Information Flow and People's Involvement).

### Future Research Questions:

1. How can we ensure universal access to sanitation, using urban planning and capacity building?
2. How can we enhance sanitation systems that are adequate and equitable, embedding them into a holistic strategy, which includes water, sanitation and hygiene issues (WASH)?
3. How can legal frameworks and economic incentives be developed in context of good governance to improve urban sanitary infrastructure and use?

### Wastewater management

In urban areas, wastewater treatment has traditionally relied on centralized treatment systems. However, Wastewater Treatment Plants (WWTPs) and sewer systems may become quickly overloaded and inefficient owing to fast urbanization. Additionally, the potential of wastewater to be a resource, from which heat, fertilizers, metals and other substances can be extracted and reused, has often been neglected. Furthermore, in periurban areas that are less densely occupied, connection to the centralized system may be an expensive alternative. Thus, the optimal solution may be based on semi-decentralized systems, which are a combination of a central WWTP and additional small, decentralized units. This may also create opportunities for recycling wastewater in the context of 'zero emission' and 'zero waste' urban environments (e.g. zero emission regional planning, described in Varga & Kuehr, 2007 or eco-cities portrayed in Joss et al., 2011). In these cases, monitoring and control are relevant issues. Regardless of the selected wastewater treatment system (centralized, decentralized or semi-decentralized), professional expertise and practi-

cal skill as well as monitoring of all activities are essential for its success. Optimizing cost-effectiveness, building even more sustainable systems (e.g. long-lasting new materials) and improving WWTP's efficiency (including pathogen elimination) are also important issues related to sanitation in urban areas. Financial sustainability and economic aspects, such as the potential for new jobs and creating business opportunities, should not be neglected.

#### Future Research Questions:

1. Are there alternative strategies for optimizing effectiveness of wastewater treatment in urban and periurban areas (centralized/semi-decentralized/decentralized)?
2. Are there new long-lasting, corrosion-resistant materials for adaptable sewer systems?

#### Rainwater management

Diffuse pollution, resulting from contaminated runoff water, is still a problem facing developed and developing countries. Research challenges are how to deal with (i) increasing pollutant loads (especially suspended solids and related contaminants) in runoff that reaches aquatic ecosystems and (ii) new emerging contaminants (Fletcher et al., 2013). Aiming at decreasing runoff quantity and improving runoff water quality, several techniques such as rain gardens and constructed wetlands have already been applied around the world under different frameworks. Since the effectiveness varies from site to site and depends on the covered urban area, it is necessary to spread and adapt them to achieve significant results. Further research is also necessary to improve techniques aiming to prevent pollution emission and thus to reduce runoff pollution before it reaches water bodies (e.g. reducing phosphorus in detergents and sulphur concentration in fuels). In general, techniques are not yet well established owing, for example, to a lack of standardized protocols for monitoring and variability in catchment characteristics. Furthermore, these techniques rely mostly on bioretention and infiltration and must be improved for implementation in areas with special characteristics, such as high slopes and high water tables. More research is needed to improve the efficiency of these solutions and to investigate better ways to combine and locate them.

#### Future Research Question:

1. How can we reduce runoff quantity and improve runoff water quality discharged into aquatic environments in order to prevent sanitary and environmental problems?

#### Water reuse

Water reuse is an environmental-friendly and a low-cost opportunity to increase the available supply of water (Nasiri et al., 2013), for example using greywater (wastewater without fecal contamination) for watering gardens, toilet flushing, or washing clothes. In this context, implementing water reuse in cities can generate sustainable water supply solutions, improve water supply resilience and help reaching the 'zero emission' goal, i.e. a system within which all discharges are recycled and no pollutants are discharged. Therefore, it is necessary to include options for water reuse in urban planning, apply innovative policies for building adapted infrastructure and develop specific regulatory provisions, including economic incentive schemes (Wilcox et al., 2016). Acceptance of these systems and participation of stakeholders, especially of the local population, are crucial (see also chapter on Information Flow and People's Involvement). Different treatments are necessary according to the reuse source and also for the different uses that this resource will have. Such reuse sources can be greywater or blackwater, the latter meaning wastewater containing human waste. Therefore, new and efficient treatment technologies must be developed in order to fit the needs of the stakeholders (Tortajada, 2006). Furthermore, laws regarding quality parameters have to be established and enforced for each specific use (direct potable uses, indirect potable uses, non-potable uses such as irrigation of urban agriculture and industrial uses) and controlled properly, in order to protect public health and avoid environmental impacts (UNEP/GEC, 2005). It is necessary to develop adapted, low-cost and effective infrastructure systems to distribute the reused water. In most cases, buildings have to be retrofitted. Besides infrastructure, educating planners and practitioners (capacity building) is of crucial importance in order to ensure the proper functioning of the systems (UNEP/GEC, 2005).

#### Future Research Questions:

1. How can we make sure water reuse is included in urban planning (new infrastructure, retrofitting)?
2. How can we elaborate legal frameworks (quality parameters) and what are the incentives for water reuse, taking into account human health security and public acceptance?
3. How can we improve the economic and technical efficiency of wastewater treatment, considering the suitability for water reuse and resources recovery?

All these propositions for the implementation of sustainable sanitation in urban areas rely on adequate surveillance and good governance within urban regions. In this context, and as pointed out in the last section of this paper, Information Flow and People's Involvement, the participation of stakeholders, especially the local people affected, is one cornerstone for designing and implementing successful sanitation strategies, thus increasing acceptance and ownership. Building local capacities is another part of these processes and creates (economic) perspectives. Finally, to ensure the positive impact of improved sanitation measures on human health in urban areas, communication between the health and water sectors needs to be improved, e.g. to prevent outbreaks of waterborne diseases. These issues have to be tackled with urgency in order to accompany the fast growth of urban areas.

### Micropollutants

Micropollutants are substances which cause deleterious effects on organisms' health or water uses at trace concentrations (Luo et al. 2014). Some examples of problematic micropollutants are pharmaceuticals, metals, pesticides and polycyclic aromatic hydrocarbons (PAH; class of substances that originate mostly from combustion of organic matter and that are cancerogenic or might be endocrine disruptors) (European Parliament, 2008). Micropollutants have relevant impacts on freshwater systems and many urban water bodies. These contaminants enter the water bodies by various human activities and they are often not removed by conventional wastewater treatment (Luo et al. 2014). Pharmaceuticals may remain active after passing through the human body and wastewater treatment plants, with consequences for various aquatic organisms. For example, estrogenically active compounds can impact the reproduction of aquatic wildlife (Schug et al., 2016), or the excessive use of antibiotics by the human population and in farming contributes to the development of multiresistant bacteria strains (e.g. Furtula et al., 2010, Hölzel et al., 2010).

Guidelines for water management are available for some individual pollutants (see below, section Management Tools and Solutions). Nevertheless, a much larger number of contaminants is released into the environment compared to what is legally regulated. Such pollutants occur mostly as complex mixtures that have synergistic, additive and antagonistic effects on human health and on the environment. Recent reports suggest that mixtures of pharmaceuticals show greater effects compared to the individual compounds, especially after chronic exposure (Petrie et al., 2015). Additionally, organic compounds undergo chemical and biological degradation, which generates a diversity of metabolites that are often unknown and may be toxic as well (Machado et al., 2017).

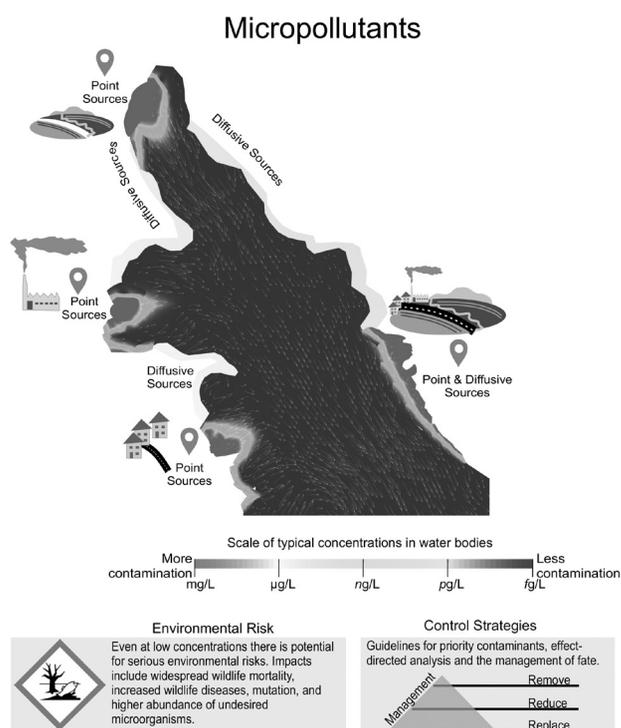
Given the current scientific knowledge, it remains a relevant challenge to identify the individual compounds as well as to predict the impacts of contaminant mixtures on urban waters. Therefore, it is crucial to conduct future research on the above mentioned issues, focusing on the major challenges, management tools and solutions.

### Improving risk assessment for micropollutants

Individual contaminants have traditionally been the basis of environmental quality standards and regulations (European Parliament, 2008; EPA, 2017). Therefore, continuous efforts to prioritize single contaminants and dangerous mixtures may form a basis for a scientifically sound, contaminant-directed management. In this context, priority micropollutants could be classified by their chemical properties (e.g. metals, polychlorinated biphenyls-PCBs), their function (usage; e.g. agrochemicals, pharmaceuticals) or public awareness (persistent organic pollutants-POPs, traditional, emerging). Such classification is useful for assessing their fate, controlling their release, and communicating problems, respectively. Notwithstanding the importance of contaminant prioritization, it is unlikely that all individual contaminants and their potential mixtures would be addressed within a time-frame suitable to management actions. The American Chemical Society reports >117 million organic and inorganic chemical compounds that have been manipulated by humans (CAS Registry, 2016). Additionally, the CAS Registry updates daily ~15,000 new compounds, with 1–2 % of them entering the market and, eventually, the environment (CAS Registry, 2016). Therefore, innovative approaches for identification and mitigation of the effects of environmental contaminants are required. In this context, a promising alternative for improving the risk assessment of micropollutants is the effect-directed analysis (EDA) (Brack, 2003). This method is receiving increased attention because it focuses on the potential biological effects of substance mixtures to identify the chemical compounds driving the toxicity (Burgess et al., 2013). Such an EDA approach often provides a cost-effective identification of problematic contaminants in complex mixtures and might support more efficient risk assessments of contaminant mixtures.

### Future Research Question:

1. How can we improve prioritization of individual micropollutants and their mixtures?
2. How can effect-directed analyses or other new technologies be enhanced to address the toxicology and impact of micropollutants?



(3) Fate and Effects of micropollutants in a hypothetical urban water body, performed by hydrodynamic modelling. The flow field, represented by white arrows, and the emissions from punctual or diffusive sources (i.e. agriculture, industry, domestic waste, roads) are shown. The lower boxes highlight potential effects of micropollutants as well as control and management strategies.

Source: own presentation

## Fate and effects

Given the large number of different micropollutants and their various potential effects on the biota, it is important to better understand their environmental behavior and interaction with organisms in order to control their deleterious consequences. The fate of contaminants is determined by the combination of many anthropogenic and natural (biotic and abiotic) variables and processes that influence the contaminant environmental behavior (source, transport, transformations, and environmental concentrations) (Machado et al., 2016). In turn, the effects of contaminants depend on the level of contamination, organism biology, organism physiology and environmental conditions (Monserrat et al., 2007). Forecasting and managing fate and effects of contaminants might be a challenging task, given the high complexity of the processes and the large number of unknown variables. Thus, there is a need for further research on the environmental behavior and potential effects of relevant environmental contaminants, their mixtures and metabolites in aquatic ecosystems.

Regarding the tools to better understand and manage fate and effects of environmental traditional and emerging micropollutants, it is crucial to invest in the collection of laboratory data on chemical properties and toxicity (EPA, 2017). Similarly, the acquisition of field data on contaminant concentrations accompanied by information on environmental health might be essential to elucidate the underlying mechanisms and the resulting impacts of micropollutants. In this sense, approaches such as biomonitors, bioindicators, biomarkers, toxicity tests and/or techniques such as effect-directed analysis (Brack, 2003) are promising tools that might help to characterize the nature and severity of effects (Monserrat et al., 2007). Likewise, the use of state-of-the-art multidisciplinary models might constitute useful tools in the field and laboratory analyses. In fact, different scenarios that consider various variables and processes (e.g. climate conditions, anthropogenic inputs) can be conveniently investigated using combinations of hydrodynamics, water quality and transport models (e.g. Matta et al., 2016), as reported in Figure 3. Coupled hydrodynamic and water quality models have been successfully used in management measures on contaminated sediments in Dutch rivers (Alonso, 2010). Similarly, the coupling of chemical-biological models has been of great use when implementing site-specific environmental quality criteria for trace metals (Paquin et al., 2003).

Last but not least, we suggest increasing efforts in order to understand and enhance the water quality biological degradation within wastewater treatment systems (and in natural environments) through an enhanced microbial activity. Concentration increases through membrane filtration might enable microorganisms to use even micropollutants as food source.

## Future Research Questions:

1. What are the fate and the effects of micropollutants (substances and mixtures) on both human and environmental health?
2. How can multidisciplinary modelling help to investigate fate and effects of micropollutants?
3. Can biological degradation be a possible solution for the degradation of micropollutants?

## Management tools and solutions

There are promising management tools and solutions related to the challenging tasks of controlling micropollutants in urban waters (surface and groundwater). Firstly, the increasing awareness of the general public, environmental authorities and stakeholders has resulted in a number of international guidelines on the

prioritization and assessment of contaminant toxic effects (European Parliament, 2008; EPA, 2017). For instance, Brazilian resolutions such as the Ordinance of the Ministry of Health (2.914/2011) determine the limits for some priority contaminants in drinking water. In terms of environmental contamination, the Brazilian resolutions 357 (CONAMA, 2005) and 396 (CONAMA, 2008) classify respectively surface water bodies and groundwater, and determine that the mixture of contaminants should not cause toxicity to wildlife, opening a legal framework for an effect-directed analysis. In a similar way, the European Commission has reported the need to establish acceptable contaminant threshold values on water sediment and biota for a more successful implementation of the Water Framework Directive (European Parliament, 2000). Guidelines for the scientifically sound establishment of the fate of priority contaminant mixtures in Europe are also available (European Commission, 2012). While there are some guidelines available, the establishment and implementation of appropriate science-based environmental quality standards remain an important topic requiring further research and policy action.

Environmental management is particularly dependent on scientific evidence and expertise; in fact, without it there would be no basis for environmental regulation. The so-called precautionary principle has emerged as an approach for environmental protection (European Parliament, 2008), providing the philosophical authority to take decisions in the face of uncertainty. Substantial evidence (WHO, 2004) supports the conclusion that contemporary environmental health risks result from complex interactions among genetic, nutritional, environmental and socioeconomic factors. The precautionary principle can be used to encourage research, innovation and transdisciplinary problem-solving dealing with complex risks (WHO, 2004).

Some of the management attempts to reduce the release of micropollutants in the environment are tackling of problematic substances or mixtures and replacing them by less toxic alternatives, or the development of strategies to reduce their release in the environment. An alternative strategy is the removal of micropollutants either directly from the input source (e.g. enforcement of enhanced treatment of hospital wastewater to remove pharmaceuticals) or in the process of municipal wastewater treatment. Several conventional methods can be applied to achieve this aim (e.g. activated charcoal treatment) (Luo et al., 2014). So far, these methods are expensive and might not be applicable in all situations. First applications of such alternative techniques already gave promising results (Ali et al., 2012). Nevertheless, cheaper and more efficient methods to remove micropollutants have to be developed; research into such processes is urgently needed.

#### Future Research Questions:

1. How can we better implement guidelines for environmental quality standards?
2. How can we reduce or replace the use of micropollutants?
3. Which are the effective technologies to remove micropollutants based on the input sources?

#### Information flow and people's involvement

Currently, communication in water science and water planning is mostly done in a top-down approach. Information about water and water management is distributed via politicians, decision-makers, scientists and managers to the people directly affected by their decisions and actions. These people frequently cannot express their water-related ideas, wishes and worries, nor can they influence the decisions that affect them. By following this one-way-approach, useful information gets lost and can no longer be fed into urban (water) planning, resulting in additional costs for the society (EAA, 2014). However, this information must be used not only to optimize urban water planning in terms of cost-efficiency, but rather to establish environmental goods as a cultural value, to guarantee acceptance for water-related measures by relevant stakeholders and creating a solid base of information on which urban water science of excellence can be developed.

Cities where the community is empowered and has a basic knowledge related to water issues will have more eyes watching out for problems, more brains developing solutions and more people talking to each other to solve the issue. With the right knowledge and support, citizens may generate data and local solutions at low or no cost for regulators and companies. Money and time are saved by good communication flows, community empowerment, iterative process improvements, and adequate use of pricing and funding instruments. The challenge is how to implement multi-directional communication structures, which enable participation of the population in an efficient, systematic, sustainable, and transparent way. In addition, scientific basis, data availability, truthfulness and unification are paramount for an information flow, enabling stakeholders to actively manage water resources and offering transparent results to the public. From our perspective, the following research areas and questions are relevant for stakeholder engagement and information flow in urban water management:

## Information flows

Information flows must be used in water-related issues to foster participatory processes. The first challenge is to identify the existing information flows, how they work and where they do not. Thus, it is possible to identify bottlenecks and lack of communication channels, taking into account the goals that need to be achieved, the scale of the issue that is being addressed, and the level of participation of all relevant stakeholders (the general public, scientists, school teachers, water supply companies, governmental agencies, lawmakers, etc.) interested in the water related issues (ICWE, 1992). The main objective is multi-directional communication, i.e. between all stakeholders, adapting the information to the cultural background of the focus group. For example, publicity events related to water issues do not just raise the awareness for potentially toxic substances and how to prevent their release to the environment, but also may induce reflection, possibly changing the behavior of the citizens. Such a status quo analysis is particularly important to set up a water information policy. It also helps to understand the interdisciplinarity of any problem-solving approach.

Communication and the creation of platforms for exchange about water resources focused on specific stakeholders can help by involving key actors in the process. Moreover, the adoption of existing or new lobby structures can be used to reach stakeholders at higher political levels. Getting all relevant stakeholders involved in the generating and use of information will improve ownership and understanding of water-related issues. This is the basis for participatory decision-making processes where stakeholders' interests – from politicians to water managers to affected people – are included.

### Future Research Questions:

1. What are the information flows related to water issues, and how do they work?
2. How do we transform one-directional information flow into a participatory, engaging process?

## Digitalization

Digitalization is a key factor for generating participation and engagement. It is already transforming our societies, particularly by changing the direction and extent of information flows. The water sector will no longer be an exception, as the potential benefits are attractive (GWP, 2016). Digital technologies are useful because they allow people to access large amounts of information, give feedback, or even generate new



(4) In a community school situated in Parelheiros District (Municipality of São Paulo), graduate students from University of São Paulo present instructions related to dug wells sanitation, cesspits ideal location, and cleaning steps for disinfection of wells, water storage tanks and drinking water.

Source: Alexandra Suhogusoff

information. Furthermore, new mechanisms of including stakeholder's perspectives and suggestions into water management have to be identified and tested. For example, a citizen might report grey water illegally flowing into a creek via a smartphone application and this report would then appear on an interactive online map. Engagement, participation and awareness of the people with regard to causes related to water resources can be fostered through the development of user-friendly technologies. They also allow for monitoring by members of the public. A recent study (Le Coz et al., 2016) showed how social media can be used to promote the collection of photos and videos to better assess river flows and to improve flood mapping after severe events. Such initiatives show how qualitative and quantitative data can be collected by the public and used in hydrology. Traditional media such as radio and TV should also not be forgotten, as they usually reach people of all ages and in isolated places.

Finally, two threats related to digital technologies have to be considered: (i) Big data companies already collect water-related data and perform commercial research on how to foster digitalization and integrate user-information (e.g. water consumption behavior). This implies a high potential for collaboration in communication processes, but also entails the risk of engaging big data companies acting for their own profits. Scientific research focusing on steering and generating information flows is necessary, so that this information is not restricted, selected or changed due to particular

interests. (ii) Digital technologies create a mass of irrelevant or even misleading data by which bottom-up communication and participation are especially affected. Therefore, guidelines and rules as well as control mechanisms need to be implemented.

#### Future Research Questions:

1. How can scientists working on water-related information flows balance the risks and benefits of collaborating with big data companies?
2. What user-friendly technologies can be used for the exchange of water information among specific target groups (e.g. school children, elderly, disabled people etc.)?

#### Self-sustained development of information flows

Information policy might change in the long run due to self-sustained development: Human relations are very effective for spreading messages, and for increasing sensibility for topics. Tools for managing communication and participatory decision-making have to be developed, taking into account an interdisciplinary approach. The participation of children and students must be further developed, because they function as multipliers. Educators must promote, test and stimulate new approaches in this area. Furthermore, citizen science can be a way to actively engage people in water-related scientific research. Activities embracing students, families and societies as a whole, such as living labs (Niitamo et



(5) Connect Stakeholders.  
Source: own presentation

al., 2006), must be incentivized to create awareness and ownership. The people's participation in information flows creates actors who are capable of receiving and producing data, increasing critical discernment. This kind of self-sustained development makes parts of the top-down communication system obsolete by a direct uptake of citizens' opinions and needs. Thus, water information policy needs to be flexible and transparent and has to adapt over time with regard to new needs and objectives. One format for such exchange could be a concept presently developed in Germany called "Reallabore" or "Real World Laboratories" (Bernet et al., 2016).

#### Future Research Questions:

1. How should water information processes adapt to self-sustained development?
2. How can human relations be used to spread water-related information?

#### Pricing and water information policy

Pricing is a less obvious and purely top-down instrument of communication. However, it is among the most powerful ones, and will always motivate bottom-up information flows. In this sense, important linkages are: (i) The level of prices, incorporating resource costs and external costs of pollution (OECD, 2009b), must raise the awareness of the "true value" of water. The "true value" informs people about the scarcity of the resource and its limited capacity to absorb pollution. (ii) The price structure can set appropriate incentives to reduce water consumption, reuse water, unseal surfaces for improved rainwater management or prohibit water pollution. For example, the latter can be achieved by a pollution-related basis of assessment, which is particularly interesting for large industrial polluters. Setting incentives must take the customers' behavior into account in order to develop comprehensive long-term strategies (e.g. investment in water-efficient technologies or in-house wastewater treatment will trigger water tariff reduction for those customers). Acceptance can be strengthened when the price structure copes with different and sometimes conflicting objectives (AWWA, 2012), such as social tariffs for vulnerable communities. The need for tariff balances can be perceived in participatory processes. Such processes also allow understanding the need for monitoring activities. (iii) Funds from pricing must guarantee the operability of water services and cover private costs, if possible (OECD, 2009b). They can also be used to fund new information flows, e.g. to educate the population about the rational use of water. There is potential for social net benefit because these information flows might significantly lower the costs for providing water services (see above, section Information Flows). Funds can also be

used to implement market-based instruments (OECD, 2013), e.g. schemes for trading abstraction rights or pollution rights, as these instruments generate valuable information flows between market participants.

## Future Research Question:

### 1. How can pricing be embedded into water information policy?

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