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Innovation in the European water sector

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1. Introduction

Water challenges facing us today

Water is vital for life on Earth. To safeguard sufficient quantity and quality for both humans and ecosystems, we must carefully manage this precious resource, especially in the face of new challenges created by climate change and population growth. In this Science for Environment Policy Future Brief we examine innovations within the water sector to help meet these challenges. We provide an overview of research into the best ways to recycle and re-use water, the latest water treatment technologies, and innovation within water governance itself.

The fresh water which sustains terrestrial life makes up less than 1% of the total stocks of our 'blue' planet (Grey et al., 2013). This must be carefully managed to ensure 'water security' for all. This complex concept can be broadly defined as:

"The availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies" (Grey et al., 2013).

We are currently facing a crisis of water security; globally roughly 1.2 billion people face conditions of water scarcity, defined by the UN as less than 1000 m^3 per capita per year (UN-Water & FAO, 2007). Even in Europe, a relatively water secure region, around half of the countries, representing almost 70% of the population, are in a state of water stress, coping with less than 1700 m^3 per capita per year (Bixio et al., 2006).

Water pollution also presents a substantial threat: at least half the world's population suffers from polluted water (Jones, 2009). Furthermore, overexploitation and lack of clean water is putting ecosystems under extreme strain, and in the current epoch 10000–20000 freshwater species have become extinct or are at risk (Vörösmarty et al., 2010). Researchers are only just beginning to quantify the ecosystem services provided by networks of biota, but all indications point to the far-reaching effects of such changes.

Several interacting factors are thought to be responsible for the increasing pressure on good quality water supplies (Jones, 2009). Together, population growth and climate change have the greatest effect (Allan, Xia & Pahl-Wostl, 2013). The threefold increase in the global population during the 20th century resulted in a six-fold increase in water use (Bogardi et al., 2012; Jones, 2009). This has been further exacerbated by growing urbanisation, affluence and land-use change in many watersheds, countries or river basins. Rising affluence is often accompanied by lifestyle changes which entail increased water demand, such as a greater proportion of meat in the diet (Jones, 2009).

IPCC assessments show that climate change is exaggerating the imbalance in water resources, with an increase in precipitation in high northern latitudes but reductions in other areas, such as southern Europe (Bates et al., 2008). This has led to severe droughts in some areas and flooding in others (Bogardi et al., 2012; Allan, Xia & Pahl-Wostl, 2013). Areas that rely on water supplies from snow and glacial melt are also likely to be affected, as these are predicted to decline, especially in the longer term (Bates et al., 2008; Allouche, 2011); groundwater reserves are also being rapidly depleted (Jones, 2011). Furthermore, higher water temperatures, along with extremes of drought and flooding, will likely affect water quality and impact aquatic wildlife, exacerbating the effects of pollution (Bates et al., 2008; Bogardi et al., 2012).

Climate change and population growth also interact, and the unbalanced effects of climate change are, in many areas, worsened by similarly unbalanced population growth. In fact, those areas with the highest predicted population growth, such as sub-Saharan Africa, the Middle East and parts of the Indian subcontinent, are also among the worst affected by climate change (Jones, 2009; Grey et al., 2013). Furthermore, countries that are predicted to suffer the greatest impacts on water security are also generally poorer. With less money to invest, and less technical knowledge, these countries may struggle to build the monitoring, administrative and management capacity, institutions, infrastructure and 'governance' (i.e. agreements) needed to meet their complex water security issues (Jones, 2009; Grey et al., 2013).

1.1 What is water innovation?

As we have seen above, water security involves a combination of physical, chemical, biological, social and economic factors, all acting at different scales and changing over time (Bogardi *et al.*, 2012; Grey *et al.*, 2013; Martins *et al.*, 2013; Moore *et al.*, 2014). The complexity of these challenges in a rapidly changing world means that new, locally-adapted and innovative solutions are often required. Water innovation can apply not only to new sustainable technologies but also to new partnerships extending across public administration, research and industry: new business models and new forms of water governance that are not only innovative themselves but can also stimulate and support technological innovations (Martins *et al.*, 2013; Moore *et al.*, 2014; European Water Platform, 2014). Furthermore, innovation need not be an entirely new technology or concept; novel combinations and innovative ideas for improvements on current technologies and systems, all have a part to play (EIP Water, 2014).

1.2 Policies on water and innovation in Europe

The water-security challenges faced by Europe broadly mimic the global issues described above. A complex interplay of climatic and demographic change, along with developments in land use, economic activities, industry, agriculture, tourism and urban environments combine to cause multiple negative impacts on water resources (European Commission, 2012a). For instance, the IPCC predicts that the number of people living under water stress in Europe will rise from 28 million to 44 million by the 2070s (Alcamo et al., 2007). Nutrient pollution, leading to eutrophication, is already a widespread problem which occurs in about 30% of water bodies in 17 Member States (European Commission, 2012b).

The Water Framework Directive (WFD), which was adopted in 2000, aimed to address all water challenges faced in the EU, including both water quality and quantity (European Commission, 2012a). Its comprehensive coverage extended beyond water distribution and treatment and encouraged integrated water resource management across different spatial scales with the participation of a range of stakeholders (European Parliament, 2000; Cook & Bakker, 2012).

In order to deal with the lessons learned from the first decade of WFD implementation, the Blueprint to Safeguard Europe's Water Resources was adopted in 2012, which aims to improve water policy implementation and ensure integration with other sectors. For example, to make real progress towards water security – encompassing both quantity and quality for humans as well as ecosystems – water policy objectives need to be integrated into those of the Common Agriculture Policy as well as the renewable energy, transport and disaster management sectors (European Commission, 2012a).

Achieving the aims and objectives of the WFD and the Blueprint to Safeguard Europe's Water Resources will require innovation and forward-thinking. To drive this innovation, and to "build an economy that is cleaner, greener and more efficient" the European Innovation Partnership (EIP) Water was launched in 2012 (European Water Platform, 2014).

EIP Water aims to "stimulate creative and innovative solutions that contribute significantly to tackling water challenges at the European and global level, while stimulating sustainable economic growth and job creation"(European Commission, 2012a). It intends to foster collaboration in the water sector across the public and private sector, non-governmental organisations and the general public (http://www.eip-water.eu/about/basics).

The Strategic Implementation Plan for EIP Water identifies five thematic priority areas: (1) water re-use and recycling; (2) water and wastewater treatment, including recovery of resources; (3) the water-energy nexus; (4) flood and drought risk management and (5) ecosystem services. Cross-cutting priority areas include: water governance; decision support systems and monitoring and financing (European Commission, 2012a).

In this Science for Environment Policy Future Brief we provide a summary of the latest research on water innovation, with a focus on technological innovations and system adaptations that have potential to be effective on a large scale. Because knowledge and technology in the sector may be excellent, but are often fragmented, there is also an emphasis on innovative governance solutions and the crucial step of disseminating and implementing advances. We begin by examining new technologies (Section 2), focusing on those related to water and wastewater treatment, the recovery of resources and the re-use and recycling of water, paying particular attention to ecosystem services solutions. We then explore innovations within water governance (Section 3), which will provide the essential framework to foster innovations in technology, and approaches to 'mainstreaming' good water practices (Section 4). These emphases are designed to align with aspects of the EIP's Strategic Implementation Plan.

2. Innovations in technologies

2.1 How is wastewater treated and how can the systems be improved?

In Europe, most wastewater treatment follows the same initial path. As a first step, wastewater is left to settle in sedimentation tanks and the sludge at the bottom is then removed. After this, the water is treated by a biological process. Bacteria feed on the dissolved organic matter, and once they have removed this, the surplus bacteria themselves are removed (Bixio *et al.*, 2006).

After these initial stages – which comprise the minimum required for discharge into surface waters – more stringent biological treatments can be used to tackle removal of nutrients such as nitrogen and phosphorus, if the wastewater is to be discharged into a sensitive area. Further treatment stages may include pathogen treatment for discharges into bathing or shellfish waters.

Membrane filtration has been developed and installed in the last decade, providing new and compact designs for wastewater treatment plants. These membranes range in pore size from microfiltration to ultrafiltration and nanofiltration and can be specialised to rid the water of pathogens, toxic metals, salinity or selectively allow nutrients through, depending on the pore size (Judd & Jefferson, 2003). There is now wide variety of membrane-based techniques which have undergone lab testing, including ion selectors, nanosponges and various sorbents –such as eggshells (Baláž, 2014), although many require considerable further testing, development and standardisation to be of wider scale use. Reverse osmosis and electrodialysis also use membrane technology, but the wastewater is forced through the membrane, and chemical reactions between the membrane and components of the wastewater are able to selectively remove specific components (Norton-Brandão, Scherrenberg & van Lier, 2013).

Other water treatments include sodium hypochlorite, ozone and UV: all highly effective in removing pathogens (Norton-Brandão, Scherrenberg & van Lier, 2013). An emerging problem in fresh waters waters is the increasing levels of micro-pollutants such as antibiotics and hormonal drugs such as contraceptives. These chemicals have been shown to have serious effects on wildlife, and currently most wastewater treatment plants have not been designed to remove them (Osachoff *et al.* 2014, Hernando *et al.* 2006).

Apart from treatment technologies, ecosystems can play an important and valuable role in water purification. At the most basic level, they have a vital part to play in the whole water cycle, providing regulation and purification (Kenny, Kumar & Desha, 2013). Under the right conditions, use of wetland ecosystems for wastewater treatment in particular represents a win-win situation, because as well as providing effective water treatment they can also create much needed habitat for some seriously threatened creatures, such as some species of amphibians (Hsu *et al.*, 2011).

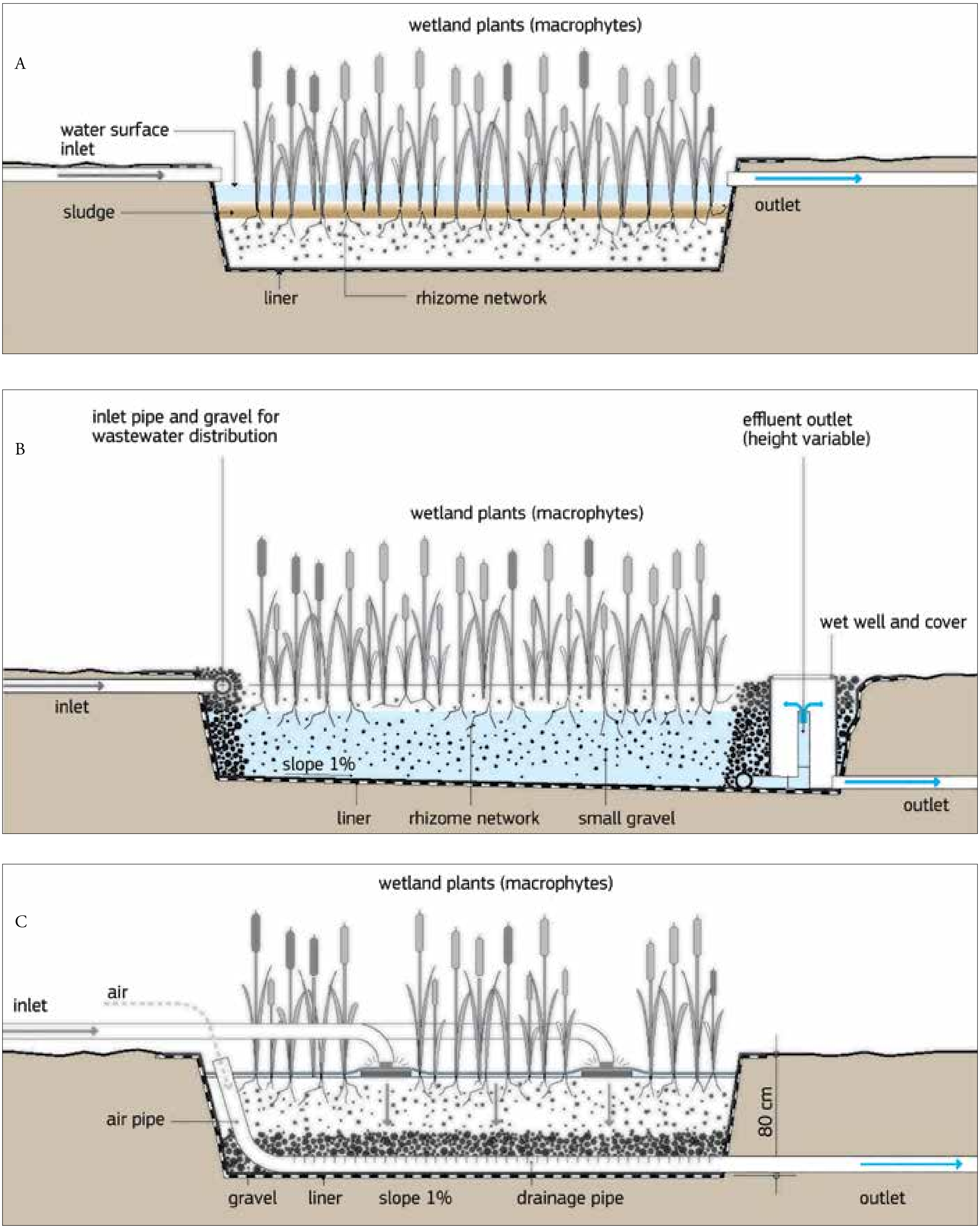

Figure 1. Panel A: Vertical flow wetland, the water is added from above and flows out in a pipe at the bottom. Panel B: Horizontal flow wetland, the water is fed into the wetland on one side and flows out on the other. Panel C: Free water surface wetland, rather than fed through the soil and gravel of the wetland, as in the first two cases, the water is allowed to flow over it, open to direct sunlight.

Constructed and natural wetlands have been used for wastewater treatment for several decades now, and have been shown to be effective in removing nutrients, pathogens and even persistent toxic metals from the water (Kivaisi, 2001). However, there are innovations even in this relatively well-established area.

For example, Ávila *et al.* (2013) explored an integrated system using three different consecutive designs of constructed wetlands: vertical flow, horizontal flow and, finally, free water surface (see Figure 1).

Monitoring a pilot project using all three methods to treat combined rainfall run-off and sewage for a Spanish community of 2500 people, Ávila *et al.* (2013) found that the vertical flow wetland was able to remove organic matter and nitrogen and the horizontal flow and free water surface wetlands provided essential purification and disinfection of the water. This approach is especially innovative, because constructed wetlands are normally used to treat either stormwater run-off or sewage, but not both. The experimental project was monitored for 1.5 years, and demonstrated that it was able to provide good performance under both dry and wet weather conditions (including a storm). This combined treatment achieved a water quality suitable, not for drinking, but for recharging of aquifers by percolation through the ground, irrigation of forests and other green areas not accessible to the public.

Heavily polluted wastewater can also be treated using wetlands. Vázquez *et al.* (2013) used a vertical flow constructed wetland to treat the highly concentrated liquor that drains from swine farm slurry. This proved highly effective, reducing suspended solids and nitrogen concentrations by at least 93%. For example, nitrate levels fell from 178 mg NO_3-N/L to 10 mg NO_3-N/L. Dean *et al.* (2013) examined a natural wetland receiving water from a copper mine, and showed that the water's acidity and levels of toxic metals were significantly reduced once it had passed through the wetland. For example, as a result of capture by soil and plants, iron levels in the water were reduced by 45%.

Harnessing natural processes for water treatment can even extend to groundwater. Nissim, Voicu & Labrecque (2014) describe a Canadian trial in which contaminated groundwater was pumped to the surface to irrigate an area planted with willow (*Salix miyabeana*). Over the course of two years the willow plantation was able to treat 5200 cubic metres of water per hectare, achieving a reduction in ammonia pollution of at least 95%.

Technological innovations in wastewater treatments have already made major contributions to improvements in the sustainability of water systems, and more is set to come. Some innovation is driven by the development of new products, such as specialised membranes, but much of it comes in the form of novel combinations of older technologies, or careful planning and analysis of exactly what the most efficient treatment will be, depending on how the water is going to be re-used.

2.2 Wastewater as a resource

Wastewater contains important resources, such as phosphorus and nitrogen, which could, if recovered, be re-used. Integrated and innovative wastewater treatment plants of the future will be able to recover these resources as part of the treatment process, increasing resource efficiency as well as generating clean water (Guest *et al.*, 2009).

One method of capturing and reusing nutrients from wastewater is simply to use the 'biosolids', such as the sludge that is removed, for fertiliser. In order to ensure that there are no dangers to human health, biosolids need to be treated before agricultural application by heat-drying (Epstein, 2003). This practice reduces the need for chemical fertilisers, which require significant amounts of energy and resources to produce, and is used across the US and Europe, although use is very low in some EU countries, over concerns that toxic metals can remain in the fertiliser (Iranpour, *et al.* 2004).

A highly efficient way of recovering nutrient resources from domestic wastewater is via urine separation. Urine contains 70-80% of the nitrogen and 50% of the phosphorus in domestic wastewater, and separating it at source and then recovering nutrients could make it one of the most effective and energy efficient methods of resource recycling (Mo & Zhang, 2013). However, this practice requires large-scale investment in new infrastructure and as yet innovations such as toilets that separate urine and faeces have only been trialled at pilot scales (see e.g. Rossi, Lienert & Larsen, 2009) and at temporary events. Moreover, proper instructions for the use of these systems are a pre-condition for this solution.

The use of aquatic plants in this area is also showing promising developments. Plants or algae absorb the nutrients from the water and can then themselves be harvested for fertilisers or animal feeds, as long as levels of toxic metals do not become a problem. For example, Verma & Suthar (2014) were able to show that duckweed (*Lemna gibba*) purified urban wastewater while at the same time providing plant material high in protein and carbohydrate that could be used in animal feed. Although not yet widely applied, these nature-based treatments could be seen as true innovations as they integrate water purification with resource recycling, while at the same time keeping costs and energy use to a minimum (Mo & Zhang, 2013).

Another innovation able to integrate treatment and resource recovery is that of bioelectrochemical systems (Zhang & Angelidaki, 2014; Rozendal *et al.*, 2008). Initially, research into these types of systems was dominated by microbial fuel cell (MFC) systems. In these systems specialised microbes break down the organic matter in the wastewater and, in doing so, release electrons, creating an electric current which could be used as a power supply (Science for Environment Policy, 2013b).

Further work in this field has led to the development of microbial electrolysis cells (MECs). In this case, with a small input of electricity, microbes are used to recover valuable resources from wastewater (Science for Environment Policy, 2013b). Research so far has focused on the production of hydrogen and methane gas from wastewater using MECs; however, studies have shown that other valuable chemicals, including ethanol, formic acid, hydrogen peroxide and acetate, can also be produced (Zhang & Angelidaki, 2014).

Toxic metals, dangerous pollutants in wastewater but valuable resources once recovered, can also be removed using these systems. Luo *et al.* (2014) showed that at the laboratory scale an MEC used to treat acid mine drainage was able to recover copper and nickel from the wastewater, as well as produce enough hydrogen gas to offset the amount of energy needed to drive the system.

So far, these systems have been trialled almost entirely in laboratories, although an EIP Water Action Group (MEET-ME4WATER) has been set up to address the problem of scaling these technologies up, and bringing them to market (see Box 1). Cusick *et al.* (2011) report on the only pilot-scale trial to date, an MEC used to treat wastewater from a winery. The MEC was able to reduce organic matter by 62% and the hydrogen produced offset the amount of energy needed.

Box 1

The MEET-ME4WATER (Meeting Microbial Electrochemistry for water) Action Group focuses on overcoming barriers to scaling up microbial electrochemical technologies in order to bring them to market more quickly. The Action Group will focus on two lines of work:

1. Microbial electrochemical technologies (MET) applied to urban and industrial wastewater treatment (and desalinated water production) at zero energy and sludge production/disposal cost.
2. MET applied to recovery and synthesis of added value products (i.e. compounds from urine, caustic soda, hydrogen) from wastewater at zero energy and sludge production/disposal cost.

See: http://www.eip-water.eu/working-groups/meet-me4water-meeting-microbial-electrochemistry-water-ag110

A further development in this field comes, as with many innovative ideas, in the form of a new combination. Sun *et al.* (2009) demonstrated that MFCs could be used to provide the electricity needed to drive MEC systems. In this way an integrated MFC-MEC system could be both effective and energy efficient.

2.3 Re-use and recycling of wastewater

Knowledge of the exact destination and use of wastewater can be a key factor in improving sustainability. In some cases, wastewater may be re-used without requiring treatment and in others treatment can be fine-tuned to improve the efficiency of the process and allow the water to be recycled.

Recycled wastewater can be made available for use in diverse areas such as agricultural irrigation, industrial processes, toilet flushing, and replenishing groundwater reserves (Mo & Zhang, 2013). Globally, more than 70% of water withdrawal is for agricultural irrigation (Bogardi *et al.*, 2012), therefore improving sustainability in this area is vital. Importantly, recycling of water for this purpose can be combined with re-use of nutrient resources without the need for costly recovery processes (Norton-Brandão, Scherrenberg & van Lier, 2013). Wastewater typically contains both nitrogen and phosphorus as well as small amounts of other elements essential to plant growth, such as iron, manganese and zinc, amongst others (Chen *et al.*, 2013). If these are allowed to remain in the water used for irrigation then the need for fertiliser, as well as expensive further water treatment or nutrient recovery processes, is reduced (Chen *et al.*, 2013).

The ideal levels or combinations of nutrients in the treated water will vary with crop and soil type, as well as the irrigation system and land drainage. However, this should not present barriers, as nutrient composition can be controlled by careful design of the treatment process. Furthermore, defining guidelines for water reclamation based on agricultural requirements could have both economic and environmental benefits (Norton-Brandão, Scherrenberg & van Lier, 2013).

Use of water in industry is also an important issue; in total, industrial processes account for around 16% of global water withdrawals. To promote sustainable use of water in industry, the project AquaFit4Use (see: http://www.aquafit4use.eu/), partly funded under the EU's 7th Framework Programme, focused on industrial water recycling using innovative, cross-sectoral approaches in the four industries with the highest water demands in Europe: paper, chemical, food and textile.

In the textile industry, water is used for many processes such as dyeing, bleaching, printing and washing, and demand is high. In the dye process alone, for example, 100 litres of water are needed for a single kilogram of fabric (Vajnhandl & Valh, 2014). It is also difficult to implement improvements to wastewater treatment in this industry, as many textile companies in the EU are small to medium sized enterprises. This slows development of on-site treatments as it requires large investment with long payback times (Vajnhandl & Valh, 2014).

Under the AquaFit4Use project a number of textile companies carried out detailed analyses of their water-related processes. Based on these, as well as laboratory and pilot-scale studies using novel technologies and ideas, a new approach was developed. This included three steps: (1) detailed analysis identifying processes where low quality water can be re-used, and those which require the water to be more thoroughly treated before recycling; (2) separation of wastewater streams, based on pollution levels, to improve efficiency and avoid costly treatments if they are not needed; (3) development of on-site, small-scale treatment processes using the most effective combination of different treatments (Vajnhandl & Valh, 2014).

On-site wastewater treatment for industry allows for development of a decentralised system using the most efficient processes to produce water that is 'fit for purpose', while at the same time taking the pressure off centralised mixed treatment plants. This approach again emphasises the importance of identifying exactly where the treated water will be re-used and what quality is needed, and then tailoring treatment processes to those findings. In this way, innovative solutions, specifically designed for the types of wastewater and re-use, can be found.

3. Innovations in water policy and governance

Technological innovations are vital to achieving true sustainability of our water supply. However, the complex nature of water security, which incorporates a vast array of socio-economic and environmental factors, at scales from local to global, also requires innovative water governance: the human systems that affect the use, development and management of water resources (Bogardi *et al.*, 2012; Rouillard *et al.*, 2013).

A key concept in this area is adaptive water governance, which has arisen from the idea of adaptive management (Rouillard *et al.*, 2013). In its simplest form, adaptive management can be described as: "*learning more about something from managing that something*" (Allan, Xia & Pahl-Wostl, 2013). This can mean careful monitoring of how events unfold to allow for reflection and learning, followed by possible revision or re-designing of policy. In the next stage, these new developments can be implemented, allowing the policy framework to respond flexibly, improving all the time (Allan, Xia & Pahl-Wostl, 2013). Computer modelling can aid this process, by allowing 'what-if' testing of networks and operating rules without recourse to expensive testing in the real world. Such decision-support systems (DSSs) can also save time and resources. Using careful monitoring of and reflection on the information collected from different sources, robust decision making can be achieved, even in the face of uncertainties.

The idea of adaptive governance is not 'new' as such, but there are surprisingly few examples of it being fully implemented (Allan, Xia & Pahl-Wostl, 2013; Bixio *et al.*, 2006). The Water Framework Directive does allow for this approach, with Member States free to use several iterative cycles for policy implementation. However, in many cases, systematic methods to incorporate new knowledge incrementally, and hence deal with uncertainty and complexity, are lacking (Allan, Xia & Pahl-Wostl, 2013).

As well as the importance of monitoring and subsequent adaptation, many researchers stress the need for an integrated, multi-disciplinary, multi-sector approach to innovative water governance, which also includes participation from a range of stakeholders (Moore *et al.*, 2014; Bogardi *et al.*, 2012; Cook & Bakker, 2012; Martins *et al.*, 2013; Rouillard *et al.*, 2013). These forms of collaboration can lead to highly effective networks which enhance learning and knowledge exchange (Moore *et al.*, 2014; Ludwig *et al.*, 2011; Martins *et al.*, 2013).

Conducting a systematic review of research into innovation in water policy, Moore *et al.* (2014) identified pivotal aspects of innovative water governance. These included some discussed above, such as an adaptive and integrated approach allowing for reflection and learning, as well as the need for effective networks and collaboration. In addition to these, the researchers also highlighted political reform (see Box 2), policy entrepreneurship and the establishment of 'safe' spaces for policy experiments.

Box 2

Decentralisation in rain water drainage and harvesting

Decentralisation – the use of smaller, more local services rather than a central plant – has been suggested as a valuable shift, at least under some circumstances, towards a sustainable water supply; improving efficiency of treatment and allowing local adaptation to a changing world (Libralato, Ghirardini & Avezzù, 2012; Partzsch, 2009; Kenny, Kumar & Desha, 2013).

In several countries, rainwater treatment is centralised, using 'combined drainage networks': a system that sees rainwater transported long distances, mixed with sewage for dilution purposes and treated with costly processes before it is pumped into the sea. Furthermore, such combined, centralised treatment plants can struggle to cope with variation in rainfall. In extreme cases, these can overflow and cause pollution in streets, rivers and coastal areas: a factor set to become more extreme as climate change progresses.

Decentralisation in this case can have multiple benefits. Not only does it reduce the costs and energy needed for transportation and intense treatments, the rainwater can often be harvested and used on-site for non-drinking purposes such as flushing toilets, or for various industrial processes.

In her review of the situation in Germany, Partzsch (2009) identified three 'smart' policy instruments which can support decentralised rainwater technologies: investment grants for decentralised technologies, water extraction fees and separate fees for water use and for effluent production. Together, these instruments motivated those most likely to block a shift to decentralisation (e.g. companies involved in central supply), as well as those already in favour of green technologies. Other countries have also made moves towards decentralisation in this area. In 2002 Belgium passed a national law making the installation of rainwater harvesting systems mandatory for all new construction, and in 2007, France announced tax credits for rainwater harvesting systems, but these were retracted in 2014.

However, Partzsch (2009) also found barriers to decentralisation. For example, in Germany all households and businesses are obliged to connect to the central system, giving little incentive for them to look towards innovative, decentralised approaches.

Box 3

Action Group:

CITY BLUEPRINTS - Improving Implementation Capacities of Cities and Regions

City Blueprints aims to establish a network of European cities to share best practices on Urban Water Cycle Services. Innovation in water governance may enable and accelerate the application of state-of-the-art technology. In addition, the Action Group will drive bringing innovative models of water governance, aligned with technical innovations, to the market.

See: http://www.eip-water.eu/working-groups/city-blueprints-improving-implementation-capacities-cities-and-regions-ag041

Innovative governance is not only required for good water management; it is also needed to stimulate innovation itself. The European Innovation Partnership on Water's online marketplace is an example of this. It aims to foster the strong collaborations and effective networks needed by providing a 'match-making' tool that gives stakeholders from every aspect of the water sector the opportunity to share ideas and make useful contacts (see Box 3 for an Action Group which aims to develop innovative water governance). These voluntary, multi-stakeholder groups aim to develop, scale up, and take innovative technologies to market, as well as initiating and promoting collaborative processes for change (http://www.eip-water.eu/working-groups/action-groups).

4. From water innovation to 'mainstreaming': what are the challenges in spreading good practice?

Even when the latest scientific evidence has allowed good policies to be drafted, and technologies are developed and made available, these practices can fail to achieve their potential.

Divergent interests, multi-level governance structures and risk aversion in public administration can all pose challenges to the effective implementation of policies and technologies. A high-level policy such as the Water Framework Directive can be inconsistently implemented. For example, Member States can have different levels of sector integration and interpret policies – and the language used – in a variety of ways They might also prefer to 'fit' existing country-level institutions to new policy requirements rather than create new, specially designed organisations (Liefferink et al., 2011) which, while not inconsistent with the WFD, might lead to inconsistent implementation, even within the same watershed.

Even if national water management becomes further decentralised to River Basin Authorities (RBAs, which aim to develop a holistic and evidence-based understanding of local interests, problems and solutions), it does not necessarily follow that the mechanisms to deliver innovative, effective management practices are also in place. Southern et al. (2011) suggest some innovative approaches to improving the functioning of such authorities, including developing national resource databases and policy mechanisms that transcend property and institutional boundaries. The importance of capacity building, such as improving GIS tools and scientific literacy, and engagement with grassroots organisations and key individuals in the local area was also highlighted. They advocate a move towards incentive- and voluntary-based measures, and away from 'over-regulation', penalties or prosecution, to encourage cross-boundary working.

Such approaches help develop contiguous water management to spread innovative water policies and technologies. However, in some countries – such as the UK – there can be land tenure issues that favour individual landowners over larger-scale water stewardship (Southern et al., 2011). Examining the management of a common pool resource, McKean and Ostrom (1995) highlight key lessons: the boundaries of a resource and the criteria for membership of the group must be clear; users should have the right to modify the rules of use over time; infractions should be monitored and punished, and institutions for managing large resources should be layered, with considerable authority devolved to small components. Systems such as these, which require managing a common resource for long-term benefit, used to be widespread in Europe before being legislated out of existence or eliminated through land transfer to individuals. Resurrection of these systems, after long disuse, may represent an adaptive approach to water governance in Europe, even if it is not exactly innovative. There is also some evidence that a 'neutral' or independent organisation, acting as a facilitator, can play a positive role in enabling participatory water management (Rouillard et al. 2014) and that clear conflict mediation processes are beneficial in multi-stakeholder processes.

Barriers to the diffusion of innovation include the widespread reluctance of water utilities to trial new technologies (EIP Water, 2014). This is partly because of their heavy investment in existing, long-lasting technologies, with maintenance or renovation of this equipment claiming a large portion of current budgets (Krozer et al., 2010; EIP Water, 2014). Other barriers include a high cost of installing new technologies, a particular problem for small or medium enterprises (SMEs) considering development of closed-loop industrial treatments. For example, as discussed above, uptake of on-site treatment and re-use of water has been particularly slow in the textile industry, largely because many European textile businesses are SMEs (Vajnhandl & Valh, 2014).

Furthermore, there are currently no EU-wide standards for the re-use of water (EIP Water, 2014). As a result, different Member States have different specifications and any company marketing a new technology may find the costs of certifying it for multiple countries to be prohibitive (EIP Water, 2014). In some countries, consumers are required to pay for connection to the mains system in any case, so incentives to test a new technology are lacking.

The fragmented nature of small water utilities and SMEs can also slow the diffusion of innovation. As a solution to this problem, the EIP Water task force has recommended that networks between purchasers be established (EIP Water, 2014). In this way groups can exchange information on best practices and will be able to make larger orders, possibly reducing the cost but also making it a more viable proposition for suppliers.

Effective water pricing can stimulate uptake of new innovations if it reflects true financial, environmental and resource costs (Hrovatin & Bailey, 2002). Separate charges for water use and effluent, in particular, can drive industry towards increased efficiency, investment in water treatment innovation and closing of local water cycles, for example treatment and recycling of water on a single industrial site (Partzsch, 2009). However, many pricing policies still suffer from the difficulties of defining and restricting a user group, and of equitable utilisation in a manner that does not harm the environment, thus any pricing must be backed up by clear and appropriate regulation.

The concept of a water 'footprint' can also provide a useful tool to help drive innovation. Originally developed for entire countries, water footprint was calculated as domestic water use as well as the 'virtual' water imports which encompasses the water used to grow imported food, for example (Hoekstra & Hung, 2002). However, this concept has now been expanded to quantify water use for regions, companies and even individual products, considering production and supply chains as a whole (Boulay et al., 2013). The Water Footprint Network provides a free tool for governments, companies or any interested party to calculate their footprint, providing an easily understandable statistic that can help improve efficiency and highlight areas where water consumption could be reduced.

Trial of innovations can also be supported through grants. For example, 'Preparatory Action on development of prevention activities to halt desertification in Europe' (European Commission, 2013), supplied grants for multi-disciplinary pilot initiatives aimed at testing specially designed technologies or techniques, while also disseminating best practices to improve water savings. As well as providing important information for further improvements and ways of reducing cost, grants can also be used to combat risk aversion. For example, approaches in the Netherlands have been used which provide financial support to cover any unexpected additional costs or adaptations that might arise (EIP Water, 2014).

5. Conclusions

When it comes to water, it is obvious innovation matters: there is tremendous potential to meet the urgent need for change with new combinations of new and old technologies, and by improving recycling and re-use systems. However, it is clear that innovation should not be confined to technological measures alone, and finding the best technology does not pose the most significant challenge, although resources need to be made available at a local scale to determine those which are most appropriate.

The main issues lie in the co-ordination and decision making between interest groups, and in the gap between the development of innovative technologies, and their roll-out on a scale that will improve water use. Grants, financial incentives and pricing strategies can all help. However, experiments with economic instruments should not obscure the fact that management of large bodies of water needs strong collaboration between many parties on multiple layers. This is where catalysts for change like the EIP Water could provide vital support for coordination.

Good long-term planning will mean greater integration and coherence with other environmental objectives, for example, supporting wildlife habitats, or nutrient and mineral recovery for agricultural efficiency. Decentralisation of water treatment and harvesting could have significant benefits to improve efficiency and adaptive capacity, and to set the conditions for greater local responsibility and accountability for water resources.

Inevitably, this will take hard work, long-term effort and public support, so short-term and competitive mechanisms should not be the overarching focus. The development of guidelines for conflict mediation and participatory planning may also help local, national and catchment-level organisations to make practical steps to achieve good water management.

The research collated for this brief – and the scale of the challenge – imply that 'innovation' needs to permeate every aspect of the water sector, from supply chains and processing to management and dispersal of new technologies. Crucially, new advances will need to allow for local planners, users and suppliers to make locally determined changes, based on good information from detailed enquiry, to their own water systems and technologies. If sufficiently enabled and supported to innovate, monitor and improve their own processes incrementally, it might then be possible to maintain a high set of environmental, social and health standards that treat water as a shared but limited resource.

6. References

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