BTO Verkennend Onderzoek

S E P T E D

Disruptive technologies for hybrid systems

Summary

Technological advancements are changing the way we think and provide infrastructure services. The water sector is entering a new era of water management where conventional centralised systems are making way for more One Water focused hybrid systems where water, in all its forms, is seen as valuable commodity that has to be closely monitored, digitalised, accounted for and reused. In order to create such transformations, a number of 'disruptive' technologies are expected to accelerate this transition process. This trend alert seeks to unravel which technologies will disrupt the water sector in the coming 10 to 15 years, paying attention to the regulations and policies needed for mainstreaming such technologies. A reflection will be given as to what impact these disruptive technologies and regulations might have on the water sector in The Netherlands.

Image from Watersource (2018).

S E P T E D

Trend and background

Throughout the 19th and 20th century, the urban water management system was characterised by large-scale centralised systems. The general availability of water at the time and the general lack of technologies to reliably and cost-effectively treat contaminated water shaped these centralised systems to remotely source water supplies. However, over-exploitation linked to increased economic growth and the effects of climate change on available water sources, require us to seek new (adaptive) urban water management systems that use available fresh water more efficiently (Larsen et al., 2016). These new systems are intended to be integrated, multipurpose in nature, and rely more on local water supply. They incorporate both centralised and distributed systems components, often referred to as *hybrid systems*, where operational features such as water use, energy, materials and operational labour are optimised (Wang et al., 2018). While these hybrid systems certainly do not yet represent the norm, leading cities around the world are increasingly adopting these system components.

A leading component in these new hybrid systems is the concept of 'One Water', which has previously been described in an earlier trend alert 'One water, one health' (BTO 2017.049). This concept is based on the idea that all forms of water in the urban area are linked and form a system that is best managed in an integrated fashion to provide effective urban water service (Mukheibir & Howe, 2015). This integrated urban water cycle provides resilience against extreme weather conditions, such as drought and flooding, by adopting a portfolio approach consisting of a combination of options, each one performing well over different conditions. This ensures that the combined system is resilient over a wide range of conditions. The One Water recognizes that water is more than just a service provision – it is a key component of liveable cities (Mukheibir & Howe, 2015; Voutchkov, 2019).

In response to the growing need for more hybrid systems, the water supply planning paradigm will evolve from reliance on traditional fresh water resources towards building an environmentally sustainable diversified water portfolio, such as the One Water approach (Daigger, 2019; Voutchkov, 2019). In order to create such transformations, a number of 'disruptive' technologies are expected to accelerate this transition process. A collection of essays written by four experts in the field of (urban) water management, Dr. Glenn Daiggar[1], Dr. Upmanu Lall[2], Nikolay Voutchkov[3] and Will Sarni[4], have sought to identify the key technological changes that they believe will transform the water sector. These essays are a product of a research program developed by the Inter-American Development Bank and are brought under in an overlying document called '[The Future of Water]'.

Using knowledge from these four experts, this trend alert seeks to unravel which technologies will 'disrupt' the water sector in the coming 10 to 15 years. Attention will also be paid to the regulations and policies needed for adopting such technologies. Furthermore, a reflection will be given as to what impact these disruptive technologies might have on the water sector in The Netherlands.

Disruptive technologies

In order for a technology to be disruptive, the technology needs to be I) unique and II) significantly more efficient than the existing technology it replaces (Voutchkov, 2019). In this section, the four experts bring forward several (emerging) disruptive technologies that will help to achieve One Water focused hybrid systems. These technologies are categorized into resource recovery & energy self-sufficiency, advanced oxidation, membranes and digitalisation. An overview of all disruptive technologies is given in Table 1.

[1] Professor of Engineering Practice at University of Michigan.
[2] Professor of Engineering at Columbia University.
[3] Director of the International Desalination Association.
[4] Founder and CEO at Water Foundry.

S E P T E D

Table 1: Summary of technologies that will disrupt the water sector in the coming 10 to 15 years.

Category	Disruptive technology
Resource recovery & energy self-sufficiency	Source separation Struvite precipitation Anammox (Anaerobic) membrane bioreactor Thermal hydrolysis Aerobic granulation
Advanced oxidation and UV	Electro-Fenton UV-LED irradiation
Membranes	Nano-structured membranes Forward osmosis Membrane distillation Electrochemical desalination Capacitive deionization Aquaporin membranes
Digitalisation	Smart sensors Digital twins Smart data analytics Blockchain Satellite monitoring Remote sensing Drones

Resource recovery and energy self-sufficiency
Traditionally, wastewater treatment plants (WWTP) were seen as purely a necessary means to protect the environment. Recently, however, WWTP are also increasingly viewed upon as a 'water resource recovery plant' where energy and organics in the wastewater are turned into valuable resources such as energy, fertilizers and purified water. Daigger and Voutchkov state several disruptive technologies for the recovery of resources.

Source separation is seen as a fundamental starting point for resource recovery. In source separation individual streams of wastewater are collected and conveyed to be treated separately. Separate collection of grey water (relatively uncontaminated) results in waste water that requires far less treatment than the combined used waste stream. Separating yellow water (urine), which contains 60% of phosphorus and 80% of nitrogen in municipal wastewater, will simplify the treatment of the remaining used water and allows increased capture of the nutrients. Furthermore, separating black water (faeces), which contains most of the organic matter, makes biogas production more efficient. According to Daigger, source separation is increasingly incorporated into new constructions. Separate grey water systems have for example been installed in China and California.

Struvite precipitation can be applied at local or centralised scales to recover phosphorus for fertilizer application, particularly from waste streams containing urine (yellow water). Technologies such as crystallization reactors help precipitate the phosphorus contained in the sludge into struvite. In addition to the recovery of valuable nutrient, the removal of phosphorus reduces operational costs because it significantly reduces the scaling problems caused by struvite on downstream piping systems. According to Daigger and Voutchkov, the number of installations to recover phosphorus by struvite precipitation is increasing rapidly. A number of WWTP's in Europe (e.g. Amsterdam) are already implementing phosphorus recovery installations.

Anaerobic treatment systems can be utilized to remove biodegradable organics with minimal energy input and generate biogas. Anaerobic Ammonium Oxidation *(Anammox)* for example, has great potential for the removal of ammonia nitrogen in wastewater. The responsible bacteria transform ammonium and nitrogen dioxide into nitrogen gas and water. This saves costs as less energy is needed for aeration and no organic carbon sources (e.g. methanol or recirculated sludge) are required. In 2007, the first large-scale Anammox reactor was built in Rotterdam. Voutchkov suggests that this disruptive technology will become a mainstream wastewater process in many WWTPs by the year 2030. Furthermore *(anaerobic) membrane bioreactor*, a wastewater treatment process which combines membranes with biological processes such as anaerobic digestion, have the potential to become mainstream in wastewater treatment due to their efficiency and compact design. In general, anaerobic treatment is already widely used for industrial treatment practices and in stabilizing organic sludge from WWTP's. Daigger and Voutchkov suggest that the interest in anaerobic treatment for direct treatment of used water and biogas generation will continue to grow. *Thermal hydrolysis*[4] is also increasingly being used to pre-treat organic material prior to anaerobic treatment. This increases the biogas yield and reduces anaerobic treatment system size.

Also aerobic treatment processes are touted to disrupt the wastewater treatment system. *Aerobic granulation* for example, is seen as a promising alternative technology to conventional activated sludge treatment systems. Aerobic granules are a type of sludge that can self-immobilize flocs and microorganisms into well-defined shapes and compact build up. This characteristic translates into a smaller WWTP plant due to the high settling velocity of the granules. The aerobic granular sludge process is also more energy-efficient as the process has a higher aeration efficiency. Voutchkov believes that aerobic granulation will be a standard for industrial and municipal wastewater treatment in the near future. Several consultancy companies, particularly Royal HaskoningDHV (Nereda), have implemented large-scale aerobic granulation treatment plants in several countries around the world (e.g. Utrecht).

Advanced oxidation processes and UV

Water reuse for potable purposes is also gaining popularity in several developing countries. One key challenge with this idea is that man-made micropollutants, such as pharmaceuticals, personal care products and nano-materials, also need to be removed from the wastewater, which conventional WWTP technologies do not easily or completely achieve. Removal of such micropollutants is typically done by advanced oxidation technologies which use a combination of oxidants such as ozone (O3) or hydrogen peroxide (H2O2) and UV to produce high reactive oxygen species for the removal of organic and inorganic compounds. Due to the fact that man-made micropollutants in wastewater are likely to increase in the near future, both Daigger and Voutchkov suggest that advanced oxidation processes will be increasingly applied in advanced water treatment and water reuse applications.

One such emerging advanced oxidation technology is called *Electro-Fenton*, which was developed by the Centre for Water Research at the National University of Singapore (NUS). The treatment process utilizes hydroxyl radicals to oxidize hazardous contaminants that are not easily degraded in conventional water and wastewater treatment plants. The technology produces virtually no sludge, has an easy plug-and-play set-up and uses electricity instead of chemicals. It is expected that the Electro-Fenton technology will be up-scaled in the near future due to these positive characteristics.

Furthermore, UV is also widely used for disinfecting effluent from WWTP and drinking water facilities. The conventional UV systems, however, typically use fluorescent lamps that contain mercury and are susceptible to breakage. *UV-LED irradiation* generate UV-irradiation with significantly less energy than conventional UV installations. Another advantage of UV-LED irradiation systems is that it can be turned on for instant operation. Conventional UV systems typically require a warm-up period before achieving full UV-radiation. Voutchkov expects that UV-LED irradiation systems will evolve into very competitive and yield significant life cycle costs in the next 5 to 10 years.

Membranes

Advances in membrane technology have driven down the energy (and cost) needed for membrane treatment. This steady trend, coupled with increasing costs of conventional water treatment and water reuse systems

[4] Thermal hydrolysis is not an anaerobic treatment technology, but it is critical pre-treatment step to enhance anaerobic digestion and biogas yield.

(due to more stringent regulatory requirements), are expected to further accelerate the attractiveness of membrane treatment. Voutchkov, who is a specialist in desalination, foresees that the world-wide municipal water supply in urban coastal regions will grow from 10 to 25% by the year 2030. Disruptive membrane technologies mentioned by Voutchkov, with high cost-reduction potential, are discussed below.

Nano-structured membranes have the potential to cause a leap in membrane treatment cost because they can produce more fresh water from the same membrane surface area than current conventional reverse osmosis (RO)-membranes on the market. This is because nanostructured membranes have a higher permeability with the same levels of salt (or other contaminant) rejection. These advantages reduce the physical size and construction of membrane desalination plants.

Forward osmosis holds potential to reduce energy use for salt separation. In forward osmosis, a solution with osmotic pressure higher than that of the (salinity) source water is used to separate fresh water from the source water through a membrane. The process significantly reduces the energy needed to drive the water through the membrane. Forward osmosis has until now largely been applied for the treatment of wastewaters from the oil and gas industry and high salinity brines. However, with such energy reduction potential, it is expected that forward osmosis could also be commercially applied for other purposes.

Another membrane technology that could disrupt the water sector are further advancements in *membrane distillation*. In membrane distillation water vapour is transported between a hot saline stream and a cool fresh water stream, separated by a hydrophobic membrane. A small temperature difference between the two streams drives the transport of the water vapour. This process is known to deliver very high water recovery levels (as compared to RO-membranes) and lower energy use (as compared with conventional thermal evaporation technologies). Membrane distillation has the potential to become a mainstream in desalination, industrial water reuse and brine treatment.

Electrochemical desalination is a disruptive technology that is able to desalinate seawater to drinking water quality using a low amount of energy. The treatment process involves a combination of ultrafiltration, electro-dialysis and continuous electro-deionization. High pressure is not required which reduces the overall costs of the treatment. Furthermore, the electrochemical desalination process is more efficient by nature because it separates and moves a smaller mass of material (ions and salts) through low pressure membranes. It is expected that this technology can reduce costs (for drinking water purposes) by 15-20% by the year 2030.

Capacitive deionization has the potential to recover high amounts of fresh water and reduce the physical size and capital costs of desalination plants. The technology uses ion transport from saline water to electrodes of high ion retention capacity. The transport is driven by a small voltage gradient where ion exchange membranes separate the ions from the water. The energy cost of treated water in capacitive deionization correspondents with the amount of removed salt (rather than with volume of treated water). This makes capacitive deionization particularly cost-effective for the treatment of low salinity applications, such as brackish water.

Lastly *aquaporin membranes,* may offer the ultimate breakthrough for low-energy desalination. Similar to nano-structured membranes, aquaporin membranes combine the ability to have high permeability with high salt rejection at the same time. Through low-energy enzymatic reactions, aquaporins (coated on the membrane) selectively conduct water molecules in and out of the cell, while preventing the passage of ions and other solutes. Although current experiments have been small-scale, it is expected that aquaporin membranes will be scaled-up to yield high-reward benefits by the year 2030.

Digitalisation
Another key future trend is the digitalisation of the water sector. Digital technologies provide management

S E P T E D

solutions that help minimize water losses in the distribution system, maximize operational efficiency and asset utilization. Furthermore, digital technologies are likely to help in the transition towards One Water focused hybrid systems by providing real-time access to water quantity and quality data for consumers, technology provides and regulators. Voutchkov suggests that by 2025 80% of utilities in large cities of developed countries are expected to have water supply systems incorporating digital water features. Moreover Sarni believes that by 2030 digital water technologies will be as incorporated into society as in the energy and transportation sectors (e.g. Uber). Several disruptive digital technologies mentioned by Voutchkov and Sarni will be discussed below.

Advanced metering infrastructure, systems that gather, process and analyse real time data of water use in a given area, are likely to become mainstream in the water sector. *Smart sensors* can be used to identify, quantify and ultimately eliminate leakages within a water distribution system (e.g. Optiqua and Aquadvanced).

Several utilities are also using sensor data to construct a digital replica of a physical entity. This so called *digital twin,* allows lessons to be learned within a virtual environment, which can be applied in the physical world – ultimately transforming asset management and operation. An earlier trend alert (BTO 2019.034) describes the impact that digital twins could potentially have on the water sector.

Smart data analytics, such as Cloud to Street, can help make sense of the vast amount of (big) data generated from smart sensors and other monitoring technologies. This will further help optimise asset management of utilities. In terms of storing data, *blockchain* applications are likely to offer utilities and consumers opportunities to collectively keep records of water quantity and quality data. Blockchains, which are already at work in making transparent supply chains, could be translated into the water sector for catchment to tap water quality mapping.

Smart sensors, coupled with smart data analytics, also have the potential to facilitate the use of off-grid and localized solutions for water and wastewater treatment, along with strategies to build hybrid One Water systems. Real time monitoring with smart sensors allows infrastructure technologies to become independent and more directly connected to the needs of the customer. Citizens could be mobilized with low-cost smart sensors to measure household water quality (e.g. Dropcountr and Rachio). With smart sensors, and other advanced metering technologies, becoming smaller, cheaper and more readily available, it is likely that water utilities (and citizens) will be adopting these technologies on a wider scale in (their) water distribution systems.

Besides advanced metering infrastructure, *satellite monitoring* and *remote sensing* are also likely to become mainstream to monitor leaks or contamination in water distribution systems and (river) catchment areas. Several companies, such as Utilis and Satelytics, are already offering such technologies. Another aerial monitoring method that is likely to become mainstream in the water sector is the deployment of *drones.* These can also be used to assess real-time conditions as a preventative measure.

Disruptions in the system

Technology-wise, the water sector seems to be ready to shift from traditional centralised water management systems to One Water focused hybrid systems. All four experts agree, however, that technology cannot by itself bring radical change, let alone ‘disrupt’ pre-existing infrastructure. Several changes in the (governance) system will simultaneously need to take place in order to encourage adoption and mainstream disruptive technologies. The authors also share insight into what they believe will be disruptive regulations and financing mechanisms in the foreseeable future for the water sector.

Regulations and financing

What are the necessary regulatory conditions for disruptive technologies to be widely adopted? In general, Voutchkov points out that the fundamental

S E P T E D

legal framework for water provision and treatment, which in most countries is regulated separately, needs to be transformed into a unified One Water Act that recognizes water as a valuable resource in all of its forms and uses. Integrated (urban) water management is more likely going to succeed, with a single unified One Water Act rather than with several fragmented Water Acts. It also reduces the administrative burden for citizens and the business sector who want to adopt certain disruptive technologies in their households and businesses.

Furthermore, Voutchkov and Lall state that new enabling regulations need to be brought into place to promote water reuse and the recovery of nutrients from wastewater. While technologies for extracting valuable nutrients such as phosphorus already exist, the regulations allowing the use of the recovered nutrients as by-products, such as fertilizers, are still under development or non-existent. Also, very stringent requirements on water reuse and nutrient recovery (based on the precautionary principle) could be a challenge and burden for adopting such practices. Currently, the European Union (EU) is developing revised fertilizer regulations, which are expected to shorten and simplify the path of the use of nutrients recovered from wastewater. According to Voutchkov, two to three more years will be needed before the regulations apply and these products are EU certified for safe use. Recently the EU also adopted a minimum quality requirements for water reuse in agriculture.

Independent from the necessary regulations to promote water reuse and nutrient recovery, Voutchkov further states that social acceptance among the public will be another key factor in determining the success of any water reuse and nutrient recovery program. The public needs to be well informed of the benefits of water reuse and nutrient recovery for long term water security and be convinced that it is safe for usage. The private sector will also likely play an important role in adopting water reuse and nutrient recovery. Lall believes that the private sector will modify current water systems in use by installing off-grid provision and treatment systems. Many private water companies across the world are already offering services to design and implement for decentralised water and wastewater systems.

Lall also believes that new forms of public-private partnerships will be responsible for a radical transition in the way environmental regulation is financed and implemented. According to Lall the current 'passive' form of environmental regulation (resource allocation and environmental permitting) will make way for more adaptive and participatory investment and regulation, driven by environmental goals with both short and long term objectives. Central to this new form of regulation will likely be new public-private partnerships which are financed by so called 'Green Bonds'. These Green Bonds are designated bonds intended to encourage sustainability by financing environmental projects. Active monitoring techniques are required to verify that the environmental investment objectives are met. There is growing interest among NGO's (and other private organisations) and governments in using these instruments. Since a lot of stakeholders would be needed to be involved in such collaborations, Lall believes it will take time before Green Bonds will be become disruptive. However, enabled by disruptive monitoring techniques (see section digitalisation) and the continuing pressure on licence to operate for major global companies (competition for water), Green Bonds are bound to become disruptive in the water sector.

Another disruptive financial arrangement that Lall foresees are emerging creative financial instruments to address climate change risks (such as flood and drought risks). Currently, many insurance companies base their insurance contracts (that require financial loss verification) on a point estimate of a 100-year event. Such estimates generate significant uncertainty and cause potential for mispricing risk in the near and long term. In order to counter this, Lall thinks that the use of parametric financial instruments, such as index insurances and catastrophe bonds, could be an attractive alternative to traditional insurance contracts. In such insurance forms, a parametic index is formulated

S E P T E D

based on the event of concern. If such an index is triggered, the financial instrument pays off without the need for actual loss verification. The premium is priced based on the probability of the event occurring. The transaction costs are thus consequently lower, with improved pricing. Parametric financial instruments have already been established in several parts of the world. In Peru for example, central banks were insured from floods through a parametric index linked to El Nino occurrences. Lall believes that such creative financial instruments will disrupt water/climate risk management in the (near) future.

Scale

What would the optimal scale level be to promote and adopt technological changes? Some of the disruptive technologies aligned with the concept of One Water are local and intended for the decentralised scale. The authors agree, however, that most of the disruptive technologies still need pilots to assess the best scale of implementation and network designs. Most of the best practises so far are found on city-level. The Public Utilities Board (PUB) in Singapore for example, operates a holistic smart water grid with sensors and analytic tools to provide a real-time monitoring and decision support system. On the other hand, in China, 16 flood-prone urban areas are holistically being designed to function as 'sponge cities' where at least 70% of rainwater will be absorbed or reused by 2020.

Looking more towards the future, the authors do generally agree that water services will likely shift more towards hybrid or decentralised systems where water is locally treated and consumed at or near the point of use. Besides the causes mentioned in the introduction for this transition (page 2), the willingness of middle and higher income consumers to embrace localised solutions and the large number of companies and innovators entering this space, will bring water and wastewater systems down from the national/city level to the neighbourhood/local level. Lall refers to these systems as 'smart decentralised networks' where a local water source (rain water, surface water, ground water and/or wastewater) is used in treatment, storage and consumption at an affordable cost with high reliability in terms of quantity and quality. Many pioneering companies are currently leading the way to facilitate such networks. The Natural Systems Utilities (NSU) in New Jersey for example, has developed and operated onsite water and wastewater treatment and reuse systems in a variety of settings. In several high-rise buildings in New York City, fully automated systems were installed for onsite wastewater treatment that in turn produce near drinking water quality at a unit cost competitive with centralised wastewater systems. Also a large number of other vendors, such as Suez, Veolia and Waterfleet, offer mobile water treatment operations that bring treatment (and reuse) plants onsite.

Finally, Sarni explicitly states that disruptive digital solutions, have two challenges to overcome in order to become disruptive in the water sector: workforce capacity training and cybersecurity. According to Sarni (most) workers in the water sector are not trained in digital technology solutions. Workforce transformation will be necessary to scale the adoption of digital technologies in the water sector. Furthermore, the use of digital technologies in critical infrastructure makes it susceptible to the threat of data theft and business disruptions through 'cyber attacks'. Utilities need to (constantly) strengthen their operations with innovative cyber security solutions, such as Siga and Radiflow.

Relevance

Technological advancements have created the impetus for a broad range of innovations that will change the way we think and provide infrastructure services. The experts Daiggar, Lall, Voutchkov and Sarni have given their perspective on which disruptive technologies they believe will transform the water sector in the coming 10 to 15 years, accompanied by regulations and policies needed to adopt such technologies. What impact could these disruptive technologies and regulatory reforms have on the water sector in Netherlands? The following remarks can be made:

- The water sector in The Netherlands is already very advanced in developing and adopting the resource recovery & energy self-sufficiency disruptive technologies mentioned in Table 1. Technologies such as Annamox, Nereda (aerobic granulation) and many other resource recovery and energy-efficient technologies, such as UASB, have been developed by Dutch research institutions and applied for wastewater treatment locally and abroad. There are also new neighbourhoods being built that (could) incorporate source separation (black and grey water) into its design such as Bleijerheide, Kerkrade (Bouziotas et al., 2019) and Brandevoort, Helmond. Neighbourhoods such as Noorderhoek, Sneek already have separate black and grey water treatment systems. In terms of disruptive technologies related to resource recovery & energy self-sufficiency, the water sector in The Netherlands is setting an example for other countries to follow. The recent development to recover the biopolymer Kaumera was awarded the Dutch water innovation price 2019.

- Membrane treatment is also widely applied in the water sector in The Netherlands. Most of the drinking water companies use membrane technologies to (partly) treat water for drinking water purposes. RO, ultra- nano and microfiltration, are membrane technologies that are most common at treatment facilities at Dutch drinking water companies. Many of these forms of membrane treatment, however, still use a substantial amount of energy accompanied by a difficulty to effectively treat and dispose the brine. Disruptive technologies in membrane treatment that substantially reduce the energy demand (e.g. aquaporin membranes) and effectively treat brines (e.g. membrane distillation) could potentially be interesting for drinking water companies to reduce the energy footprint and increase the overall attractiveness of membrane treatment. In new wastewater treatment concepts, such as CoRE Water developed in the Netherlands, forward osmosis is applied to concentrated wastewater before treatment. Furthermore, as a result of climate change, new (unconventional) sources of water are likely needed to satisfy the demand of citizens[5]. One of these sources could be direct sea water desalination from the North Sea (for potable use). Desalination of sea water has not yet been applied in Netherlands on a wide-scale. However, droughts as experienced in 2018, could force drinking water companies to consider using sea water as a (secondary) source for drinking water production. De Watergroep in Belgium is currently doing a pilot for desalinating sea water for drinking water purposes. If desalinating seawater proves to be too expensive, desalinating brackish (ground)water could be an attractive alternative in the future, since this source water requires less energy to desalinate.

- The removal of man-made micropollutants from wastewater and surface water is a hot topic in the water sector in The Netherlands. Currently some conventional wastewater treatment plants at water boards do not adequately remove these pollutants (RIVM, 2017). This could be a potential health concern for drinking water companies who rely on surface water as their primary source for drinking water production. The experts mentioned earlier that disruptive technologies in advanced oxidation processes have the potential to remove hazardous micropollutants from waste- and surface water. O3 or H2O2 in combination with a high UV dosage for example, has been known to work well for the degradation of medicines and their residues[6].

[5] KWR has recently done a study on alternative sources for drinking water in the Netherlands (BTO 2019.017).

[6] KWR has done a study on the removal of polar organic micropollutants (BTO 2015.082) and pharmaceuticals from WWTP effluents (BTO 2016.064).

S E P T E D

- UV irradiation is currently used in drinking water facilities in The Netherlands to disinfect the drinking water before leaving the drinking water facilities. UV-LED irradiation could increase efficiency and reduce the overall treatment cost of UV irradiation. UV-LED irradiation also allows one to adjust the wavelength of the lights to specifically inactivate certain organisms. Research is still ongoing (at KWR) on whether UV-LED irradiation will be feasible for large-scale adoption.

- Some of the disruptive digital technologies mentioned earlier, especially smart sensors to measure water quantity and quality, could change the relationship drinking water companies have with customers. With new efforts toward sustainability and water conservation, drinking water companies are beginning to establish innovative strategies to help restructure the way people think about water use. In 2015, PWN, together with University of Bamberg, conducted a large-scale experiment to investigate how real-time feedback effected hot water consumption with the use of smart showers meters. As a result of this intervention, participants saved on average between 19% and 21% of their energy consumption in the shower (and with that also water). Drinking water companies Evides and Waterbedrijf Groningen are currently also setting up similar pilots to measure the effect of feedback smart sensor data on water consumption. Drinking water companies that embrace such advanced metering infrastructure technologies, have the potential to steer customers to adopting desirable behaviour (such as water conservation). In order for this to be a success, it is important (as was mentioned by Sarni) that drinking water companies acquire a digital workforce to keep up with the pace of digitalisation. This could involve recruiting new talent proficient in information technology and training existing employees to operate and adjust to new digital systems seamlessly. Also staff that have expertise in behavioural change could serve as added value in the context of stimulating water consumptive behaviour.

- Advanced metering infrastructure can also be deployed in water distribution systems. Recent KWR asset management research[7] concluded that several high consuming customers expressed a need for more real-time water quality monitoring in the distribution systems, e.g. at the extraction point. Deployment of advanced metering infrastructure for monitoring key parameters, such as legionella and other pathogens in the distribution system, could improve the customer service levels of drinking water companies even further.

- Lastly, it is not unthinkable that The Netherlands could one day have a unified legal framework for water provision and treatment ('One Water Act'). Even though the Drinking Water Act and Water Act are still separately enforced in the Dutch water sector, there has been a steady push for more integrated regulations in The Netherlands. The European Water Framework Directive, which integrates the many water directives at a European level, partly inspired the Dutch government to integrate various national water governance regulations on drought, flooding and pollution to facilitate integrated water management. This unified regulation is the current Water Act in Netherlands which came into effect in December 2009. Should the Drinking Water Act also be integrated into the Water Act to form a unified One Water Act? Or can we even see a further integration with other spatial planning issues in the anticipated Omgevingswet?

[7] Expected to be published in early 2020.

S E P T E D

More information

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Keywords

Disruptive technologies, One Water, hybrid system