THE EUROPEAN TEST FACILITY NETWORK FOR WATER INNOVATION

# European Drinking Water Sector Foresighting Report

Prepared for the Water Test Network

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# 1. Introduction

This European Drinking Water Sector Foresighting report sets out ideas, challenges and influences impacting on the drinking water sector in Europe. Our aim for this report is to set out ways in which transforming the drinking water sector can be approached, exploited and improved upon by SMEs with cutting edge technologies and knowledge. This report provides an overview of the drinking water industry that will hopefully help guide, inspire and feed technologies and methodologies the drinking water industry requires to achieve the standards set by European and International law.

If you have a technology and would like to make use of the Innovation support Vouchers offered by the Water Test Network, please head over to the North-West Europe Water Test Network to find out more.

# 2. Political Factors

The drinking water industry across North-West Europe (NWE) has been driven by the introduction of both the EU Water Framework Directive (EUWFD) (European Commission, 2000) and the updated Drinking Water Directive (DWD) (European Commission, 2020) that provide a framework for the regulation of water legislation across the EU community. The EUWFD has shown the water industry that improved catchment management practice is a key element for the delivery of potable water supplies to meet an ever-increasing demand from both commercial & private users. The EUWFD then cascades this need for a 'prevention led approach' into the DWD and suggests compliance to regulations should be focused on pollution source control, for the objective of reducing the investments required for drinking water treatment.

The DWD defines the need for a risk-based approach to drinking water treatment within the water industry and provides clarification that all of the NWE region population have a right to access clean drinking water maintaining the commitment to Goal 6 of the sustainable development goals set by the United Nations 2030 Agenda for Sustainable Development (UN, 2015). The DWD states that all the content within it has to be transposed into EU member countries legislative frameworks within 2 years. For non-members such as the UK now that the Brexit process has concluded, it is envisaged that the legislation will be fully adopted within the UK, however, some provisions within the DWD may not be included in national legislation in the longer term (Hendry, 2018). The adopted legislation will align with European legislation, although differences will be apparent when compared to English and Welsh regulations e.g. the approvals process for water technology (Scottish Parliament, 2021). The individual countries that form the UK have their own appointed water quality regulator such as the Drinking Water Quality Regulator (DWQR) within Scotland which sets the parameters for water quality assessment to be followed by Scottish Water with prescribed limits for microbiological, chemical and visual characteristics of the drinking water (DWQR, 2020). The DWQR in Scotland will enforce this risk approach to drinking water by ensuring that Scottish Water complies with the framework defined in BS EN 15975-parts 1-2011 and 2-2013, (Security of drinking water supply. Guidelines for risk and crisis management) by 2023.

The NWE region drinking water supply is a well-established and regulated distribution system due to the impact of individual countries water resource management measures (including allocation systems, groundwater management, environmental impact assessment and demand management among others) that are already in place. However, as environmental regulations become more stringent across the water industry, water distribution companies are investigating water treatment technologies that can reduce their environmental footprint. This is just one example of the drivers for drinking water innovation and associated investments required across the NWE region, with the other key drivers summarised in Fig 1 below.


*Figure 1 Drivers for Drinking Water Technology Innovation*

The need for technology advancement within the drinking water industry is apparent, the move to adopting new technologies can present several problems. For example, current drinking water assessment methodologies with all the checks and balances present, where water quality is monitored, relies on experienced staff undertaking the sampling and physio-chemical assessment which in turn has a cost implication. Emerging drinking water treatment innovations that may reduce this cost come up against a legislative barrier, where they have no legal definition, with the trial and test of emerging technologies relying on established testing parameters within the water industry. The water companies have to seek out technology providers that can retrofit new technology to existing infrastructure and utilise existing testing methods to ensure drinking water standards are met. Examples of other barriers to innovation within the NWE drinking water industry are highlighted in Table 1 overleaf.

*Table 1 Barriers to drinking water technology innovation - adapted from EurEau (2020b)*

| Drinking water innovation | Benefits to drinking water innovation | Obstacles to drinking water innovation |
|---|---|---|
| New infrastructure within drinking water treatment plants requires planning approval and capital investment. | Showcasing emerging water treatment technologies would give any water technology company a unique selling point and a route to market. Communication with all stakeholders within a planning framework provides a wider audience to portray the benefits of adopting new water treatment technologies. | Planning approval can take long periods of time and require participation from key stakeholders such as local Government, environmental regulators and community groups. The funding options available for water innovation within the water sector may not be suitable for many companies looking to access the drinking water industry. Water supply companies are under considerable pressure to deliver a reliable, contaminant free service to all users with existing infrastructure, if new technologies are to be implemented then another source of water would have to be found in the interim to meet demand. |
| Any new drinking water treatment technology requires to be linked to a central dashboard within the existing monitoring systems of drinking water treatment plant. | Innovative methods of retrofitting new technology can be adopted and make existing control panels easier to operate and maintain. | The move to install emerging water treatment technologies requires a skilled workforce and will involve a period of downtime on any water treatment plant**.** This process can be mitigated by incorporating staff training into periods of essential maintenance. |
| The drinking water industry is highly regulated so what is gained from moving from the classical system of water treatment to new water treatment methodologies. | Emerging water treatment technologies can improve the environmental footprint of water treatment plants that are known as heavy users of electricity to supply clean drinking water. | Any new technology will have to conform to existing design regulations and the system performance will be measured against the existing water approvals process. Therefore, if not approved the technology can't be included in any drinking water treatment regime. |

The pre-existing barriers to water innovation within the drinking water industry are being tackled across the NWE region by the following agencies:

- EurEau - European Federation of National Associations of Water Services (EurEau, 2021).
- Water Europe - Member-based platform to achieve a water smart society in Europe (Water Europe, 2021).

These organisations are encouraging collaborative working on innovative drinking water projects utilising existing water testing sites, scientific & research centre input and regulatory guidance from within the water industry. At a country level using Scotland as an example – the water innovation framework is supported by agencies such as the following groups:

- Centre for expertise for waters (CREW) – Research based partnership that supports the development and implementation of water policy in Scotland (CREW, 2021).
- Centre for Sensor and Imaging systems (CENSIS) - Innovation centre that has a research theme focussed on machine learning and artificial intelligence within the drinking water sector (CENSIS, 2021)
- The Hydro Nation Water Innovation Service (HNWIS) provided assistance to Scottish SMEs within the water sector, with the Scottish Government and Scottish Enterprise investigating options for future SME support (HNWIS, 2021).

Another means of getting innovations recognized is Environmental Technology Verification (ETV – ISO 14034). ETV is designed to take the claim made by the manufactures of innovative technologies and independently verifies the performance. The body carrying out the verification is a certified inspection body (ISO 17020) to carry out ETV ISO 14034. The object of the ISO/ETV standard is to deliver benefits that increase confidence in technologies demonstrating environmental added value. As this is an ISO standard, it is recognized internationally and gives wider recognition across the globe. More information on ETV can be found at ISO 14034: Verified once, recognised everywhere | Eco-innovation Action Plan (europa.eu).

# 3. Environmental Factors

Climate change is now starting to have an impact within the water environment, with the main environmental challenges to the drinking water industry include water scarcity, stormwater events and the presence of new anthropogenic contaminants within the drinking water distribution system. A position paper published by Orgalim, Europe's Technology Industries, advocates for the sustainable use and management of water in Europe, with the expectation that on a global stage, the demand for water will be doubled by 2050 with supply expected to be reduced by 40% during the same period. Some of the options suggested by (Orgalim, 2019) for mitigating water resource issues are summarised below:

- The climate ambitions of countries would be a major factor in decision making
- To strive for zero-water leakage within water distribution networks

- The value of water has to be appreciated and a balance struck between price of supply to customers and the investment options available to technology providers
- The European region can provide the testing of resilient water treatment technologies that would address some of the global water supply issues, however, collaboration between key stakeholders and intellectual property protection will be required to achieve this.
- The use of digital technologies such as sensors or smart metering, some of which are already in service may reduce the potential for water leakage, pollutant identification and improve the environmental footprint of drinking water assets.

In the first instance, water scarcity as a result of a reduction in rainfall is increasing the need to reduce, recycle and reuse to maintain water resources and maintain water quality. The Intergovernmental Panel on Climate Change (IPCC) suggested in its report of 2008 that the Northern and Central regions of Europe would be affected by seasonal variation of water volumes coming into water catchments and this combined with higher surface temperatures during the summer months could lead to water scarcity (Bates, 2008). Further research undertaken by the World Economic Forum (WEF), suggested that water deficits within key economic regions such as Europe, are more likely to occur as a result of extreme weather events such as drought (World Economic Forum, 2019). The drinking water industry needs to have mitigation strategies in place for such climate change induced events. This which became more apparent after the 2018 heatwave that has put pressure on water resources across the NWE region of Europe (European Drought Centre, 2019). Some of the potential mitigation strategies include understanding water catchments in greater detail, the increased usage of seasonal forecasts for rainfall accumulation and greater collaboration between catchment managers on a local and national level.
In contrast to water scarcity, the impact of stormwater events after a period of sustained heavy rainfall can overload the raw water inlet of local water treatment plants across the NWE region. This spike in water inlet volumes brings potential contaminants such as suspended solids, dissolved nutrients and trace chemical compounds into the raw inlet water of drinking water treatment plants. Table 2 overleaf highlights the potential factors that may influence the effectiveness of any innovative water treatment technology.

*Table 2 Factors influencing the effectiveness of drinking water technologies after stormwater events*

| Influencing Factor | Impact on drinking water treatment |
|---|---|
| Suspended solids | Increased suspended solids requires more flocculant to be added, greater filtration of solids and increased dosing of disinfection products to maintain water quality to consumers. Many of the complaints about drinking water quality are focused on the appearance, smell and taste so drinking water regulators instruct water companies to address this issue. |
| Dissolved nutrients | Many water catchments have cultivated agricultural land within them with the application of synthetic nutrients being common practice. During stormwater events the suspended & dissolved solids can adhere nutrient particles to their surface and carry this downstream. The accumulation of nutrients such as phosphate combined with sunlight can result in algal blooms that not only block the filter but can release toxins that affect water quality (Wuijts et al., 2021). This can also be the case for humic acids released from land with a high proportion of peat. |
| Disinfection byproducts | During stormwater events, the disinfection process can be affected by the volume of water that is passing through the water treatment works (WTW). Therefore, water companies require to monitor treated water quality and make sure the disinfection process is effective and producing water safe for consumption. Variation in this process can lead to disinfection byproducts that are potentially hazardous to health (Gilca et al., 2020). |
| Excess water | During extended rainfall events typical of summer storms the excess water is captured by the drainage system and then the nearest WWTW for treatment. If the volume of stormwater exceeds the WWTW capacity then a combined sewer overflow can be used and pollute surrounding surface water that could be used as a source of drinking water. |

The issues highlighted in Table 2 are common to drinking water supplies on a global scale, not just for the NWE region. Across the European region, the scale of the drinking water treatment processes required to mitigate the effects of stormwater events can vary. This depends on factors such as catchment area, topography, existing infrastructure and the population that the drinking water treatment plant serves. Technological improvements can be implemented on existing treatment plants; however, these are bound by constraints such as:

- The length of the time that any treatment technology is in service (~ 15-25 years).
- The capital cost to retrofit water treatment technologies.
- The local regulatory environment, which is different across EU regions (O'Callaghan et al., 2020).

The impact of other emerging issues for drinking water treatment are summarised in Section 6 which links the technological challenges at present and the potential for innovative water treatment technologies to be assessed on a wider scale.

# 4. Economic Factors

The key to sustainable economic development within the global environment is the supply of a robust natural water supply. The move towards innovative treatment technologies combined with elements of water recovery are becoming increasingly important as we move towards a global circular economy; businesses need to be looking for the most efficient and economical way of maintaining supply without damaging their business models. Energy costs and scarce resources should be reasons to promote water efficiency and provide opportunities for water treatment within a circular economy. Some of the key economic issues for the water industry are summarised in Table 3 below:

*Table 3 Key economic issues for the drinking water industry*

| Key issue | Economic impact to the drinking water industry |
|---|---|
| Cost to household | The maintenance of existing drinking water supply networks requires to be balanced with the need to foster innovation within the drinking industry so that the impact of improved drinking water quality regulations, improved environmental regulation and climate change can be mitigated. To achieve this objective the drinking water industry should make provision for clear and concise information to be presented to consumers especially if the volumetric price of drinking water is to be increased. |
| Leakage in water supply networks | The drinking water industry has made extensive efforts to reduce the amount of water lost from their supply networks on a daily basis. Using Scotland as an example, over the last 16 years, Scottish Water has reduced leakage from 1104 Ml/d to 463 Ml/d (58% decrease) which has reduced the cost of water treatment and disruptive costs when the water supply is lost. This has been achieved with utilising innovative technologies to locate and diagnose faults within their networks. |
| Climate change resilience | The economic impact of climate change on drinking water networks is focused by two factors, the scarcity of water to supply existing networks and stormwater events. The impact of these two factors leads to increased operating costs within the drinking water industry and would lead to issues with them remaining competitive therefore the increased cost is passed onto the customer. |
| Population growth | The growth in the population combined with the added pressures of climate change will provide significant cost pressures on current and future water treatment facilities. Drinking water supply utilities require to factor in these changes in existing/proposed WTW facilities or the demand may well outstrip supply in the future. An example of this is when a population takes summer holidays in areas where the drinking water infrastructure does not have sufficient capacity to cope |

| | |
|---|---|
| | with demand spikes during the summer months where rainfall is usually at its lowest. |
| Net Zero objectives | Net Zero targets that have been set by governments in the NWE region will impact on the drinking water sector. Using Scotland's approach to the matter where the focus on reducing the carbon impact of drinking water (Currently 0.1 $gCO_2$equivalents/Litre (Scottish Water, 2020a) progressing by ensuring that electricity supplied to water treatment facilities is from green power generation coming on-line and developing on site renewables to reduce the need for grid electricity (Scottish Water, 2020b). Future work to meet the 2040 target include reducing the number of carbon heavy fuels used on sites and when repairing facilities or developing new infrastructure, low carbon construction methods should be considered in any options appraisal. |
| Natural Organic Matter (NOM) impact | The variability of NOM within a water source can prove a challenge for drinking water treatment plants due to the fact it can cause taste, odour and colour issues which can deter the end user. To mitigate this impact, one method is to treat drinking water with coagulant and flocculants to bring down the NOM load down to within specified limits. This approach is one selected by most water treatment facilities, however it may not suit all locations with a combination of NOM mitigation methods such as carbon filter absorption or biofiltration (Liu et al., 2020) among the other options for drinking water treatment. |

The factors that are discussed in Table 3 require the drinking water industry to provide employment so that innovation strategies or technologies can mitigate against their impacts. Using the Scottish water sector for example, provides 16,600 jobs to the Scottish Economy with only a small proportion (1072 FTE) actually involved in R & D and innovative technologies (Optimat, 2019). This figure is a statement of the R & D water innovation sector as a whole, whereas the number of employed people directly at drinking water innovation level would be much smaller. If this scenario is replicated across the NWE region then the growth of the drinking water innovation sector will be restricted over the long term with little mitigation of the issues discussed in Table 3.

The economic challenges to innovation facing the NWE region drinking water industry requires a long-term strategy that incorporates the following:

- Funding support for SMEs could come in the form of grants, loans or capital investment from Government sponsored innovation schemes that would encourage SMEs to invest time and money establishing new drinking water treatment technologies.
- Provide a framework for SMEs to access staff training packages to upskill so that innovative drinking water technologies can either be retrofitted to existing water treatment facilities or provide skills and insight that can feed into the design stage of new infrastructure.
- Build upon existing water technology testing programmes and facilities to inform asset planners within the water industry that emerging technologies can conform to existing design regulations and be examined in detail to provide standardised testing methodologies.

# 5. Social Factors

By 2025, the demands of a growing population, increased urbanisation and climate change are among the 3 greatest threats facing the planet according to the World Economic Forum (World Economic Forum, 2019). This in turn will lead to water supply issues across the globe, whilst the NWE region is unlikely to suffer regular major droughts, there is an expectation that higher annual temperatures, increased winter season rainfall and summer season rainfall associated with stormwater events will bring concerns to the water supply industry.

The UN states that access to clean drinking water is a requirement of citizens within developed and developing countries by 2030 (UN, 2015). The majority of the water distribution networks that feed the water consumption of settlements are not visible to the average person, however, some people will challenge the drinking water sector by highlighting concerns about the following:

- The quality of water at the point of consumption
- The environmental impacts of water treatment plants in their community
- The general aesthetics of drinking water treatment infrastructure

Agriculture is quoted as using 69% of global freshwater resources, however, the impact of increased food production across the globe is placing pressure on water supplies and this is likely to undergo growth over time (UNESCO, 2021).

The impact of compounds such as pharmaceuticals becoming more prevalent in drinking water supplies is largely unknown to the general populations unless this impact is reported in local and national press. Therefore, the building of stakeholder partnerships within regional communities is especially important to raise awareness and allow people to understand the impact.

Public awareness is also increasing with a greater understanding of the impact of microplastics within the water environment. Campaigns by local, national and international bodies have placed microplastics at the top of the agenda and this development has received much greater engagement than other key issues for the drinking water industry such as pharmaceuticals or agricultural issues as mentioned above. The drinking water industry does disseminate information promptly when a supply issue occurs, but a challenge still exists to inform and engage consumers when new issues come to light before they become critical to drinking water infrastructure such as deliberate contamination or a terrorist attack restricting water supply.

# 6. Technological Factors

Cost effective ways of upgrading or making improvements to existing water treatments and new technologies that are simple but extremely effective, are in demand. An aging infrastructure means an increased demand for new technologies – but they need to complement and fit within the footprint of current facilities.

New technological advancements for the drinking water industry need to be efficient in energy consumption, show upgrades to existing technology and if possible be of modular design thus adding value to current technologies or literally compact and cost effective.

These factors combined are essential for the development of innovative water treatment technologies, however, the issues that are highlighted in Figure 2 below are becoming a challenge for the drinking water sector across the NWE to deal with effectively whilst still maintaining distribution volumes and quality assessed drinking water.

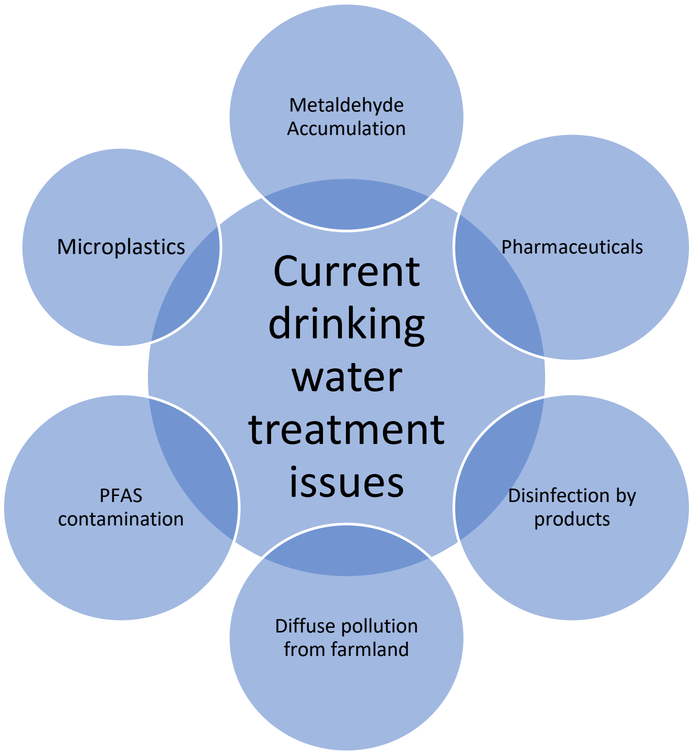


*Figure 2 Current challenges for drinking water treatment in Europe*

These key issues are summarised in more detail below:

**Accumulating pharmaceuticals:**

The impact of pharmaceuticals on the water industry has been widely studied with many compounds isolated from wastewater, groundwater and in some cases drinking water (Kim et al., 2020). Approaches for the removal of these compounds have focused on using advanced oxidation protocols (AOPs) (Taoufik et al., 2021) or reusing activated carbon that has been recovered from an existing drinking water treatment process (Luján-Facundo et al., 2019). The potential of these compounds to contaminate drinking water supplies is limited, but it is still an area of concern for drinking water supply companies.

**Disinfection by-products:**

Traditional water treatment relies on the dosing of antibacterial compounds such as chlorine or chlorine dioxide or hydrogen peroxide to water that has passed through the initial filtration stage and most of the suspended solids have been removed by the addition of coagulants and flocculants. Depending on water volumes that are flowing into a water treatment plant, the chlorine dosing is kept to the minimum quantity that satisfies the regulatory authorities and does not cause the final customer to complain over taste/odour issues. The main issue with these compounds is that they occur in low concentrations and are not removed by existing water treatment technologies. To remove them using innovative treatment technologies may not be appropriate since the presence of the precursors is essential for effective drinking water disinfection (Gilca et al., 2020).

**Diffuse pollution:**

Excessive nutrient loading within drinking water catchments from agricultural land is a common issue across the European region with the suggestion posed by the European Environment Agency that 38% of surface water catchments and 35% of groundwater bodies could be impacted by diffuse pollution (European Environmental Agency, 2018). Member countries have introduced nutrient management methods at a local level such as general binding rules, defining nitrate vulnerable zones (NVZs) and encouraging a move away from synthetic fertilisers. The UK for example, has developed the PAS 100/110 specifications for treated organic wastes to be sold as product to reduce synthetic fertiliser usage, alternative fertiliser application rate to land and therefore mitigate diffuse pollution (BSI, 2014). Diffuse pollution incidents can also occur with the application of nutrients or pesticides too late in the growing season resulting in peaks of contaminants within drinking water catchments since the nutrients will not be taken up by the fully mature crops.

**Metaldehyde accumulation:**

The active compound in commonly utilised molluscicides is known as metaldehyde and has been found to run off easily from farmland and accumulate within drinking water catchments (Castle et al., 2017). The water industry has identified this compound as a threat to contaminant free drinking water, since it is very effective at reducing slug damage within crops but due to its mobile nature will require either a ban on land application or technology advancements to avoid breaching drinking water limits (Water UK, 2019). Metaldehyde treatment could involve the incorporation of an acclimated sand bioreactor (Rolph et al., 2020) to reduce the levels in drinking water to below the 0.1 $\mu g\ L^{-1}$ specified within the DWD. However, this approach requires to be validated at a commercial scale and would require extensive capital investment at WTW.

**Microplastics:**

The role of microplastics within the drinking water sector is not well understood at this point in time since a Water Treatment Works (WTW) is first line in the barrier to any potential contamination sources to a drinking water supply. Most of the research that has been focused on WWTP and even in this case there is no standard methodologies of sample collection, identification and classification of potential contaminants (Barchiesi et al., 2021). The risks to human health from microplastics in drinking water according to a report published by the WHO are defined as function of hazard and exposure within the water environment and are linked to the following hazards:

- The individual microplastic particles which will vary in shape and size
- The presence of chemicals that are either released from the plastic or are absorbed onto the microplastic from the environment
- The formation of biofilms on the surface of the microplastics.

The chemical and microbial toxicity arising from microplastics is thought to be low, however there are currently a limited number of studies undertaken in this area. More research is required into the potential risks to human health in this area. A study undertaken by the UK Water Industry Research sought to inform the sampling and detection methodology for the presence of microplastics in drinking water. The samples that were analysed in the study were sourced from 8 WTWs across the UK and included a range of water inlet types such as river abstraction, upland reservoir and groundwater. The results from the study found that microplastics found in drinking water were below the level of detection in most cases, with one exception when water was directly abstracted from a river source. The risk potential however, in this case was mitigated further by the effectiveness of the WTW removing microplastic at close to 99.99% removal (UKWIR, 2019). Therefore, it can be summarised, whilst microplastics are present in drinking water from all sources but current WTW remove almost all of the microplastics that are present. However, studies have been limited in scope and focused on common polymers that are found in the environment.

**PFAS contamination of drinking water:**

Per and polyfluoroalkyl (PFAS) compounds are a group of man-made common chemicals that can accumulate either within the environment or within humans. These compounds have many applications within the domestic, commercial and industrial uses as summarised below:

- Many domestic items such as frying pans benefit from the non-stick finish provided by these compounds
- Textiles and outdoor equipment which require waterproofing
- Dishwasher rinse aid
- The presence of PFAS is commonly noted as an active ingredient in fire-fighting foam
- The recycling of newsprint and other papers can also be a source of PFAS

The drinking water sector has an elevated level of concern with these compounds due to the fact that they are very persistent in nature and do not seem to undergo any microbial degradation within the outdoor environment (EurEau, 2020a). Conventional drinking water treatment methodologies provide some removal of PFAS from raw water. However, this is dependent on the functional group of the individual PFAS compound (Kim et al., 2020) and may not reduce the toxicity of these compounds. Therefore, the regulation of PFAS at a local, national and international level becomes a key issue alongside the careful management of any runoff into drainage systems as a result of petroleum fires from automobile accidents, firefighter training centres or usage on airfields either for training purposes or aircraft fires. The careful management of PFAS compounds can reduce potential contamination in the environment, however any filter or membrane used to capture becomes a special waste and therefore appropriate disposal routes should be investigated to avoid the additional costs associated with disposal.

Therefore, the emerging contaminants to the drinking water supply discussed above will prove a challenge for the NWE region drinking water sector to mitigate the effects over the coming years. Since treatment for individual compounds is likely to be too costly for water companies to invest in, the focus will be placed on consumer usage and greater regulation which will require enforcement through statutory instruments and the associated financial penalties for breaching discharge consents.

# 7. Opportunities for drinking water treatment technology

## *1. Ceramic Filters*

The drinking water sector has traditionally used filtration as a method to provide a barrier to suspended particles within the treatment process, since the pore size of these filters determines the effectiveness of contaminant removal. These membranes have a pore size that can achieve microfiltration, ultrafiltration and nanofiltration (Li et al., 2020) with the currently available options of either a polymeric or ceramic material composition. Polymer-based filtration is common within WTW due to the low cost of production and the ease of installation. Polymer-based membranes can have a shortened time in service due to dissolved compounds that attack the construction material, they foul easily reducing the filtration capacity and the membranes are hydrophobic in nature, resulting in membrane fouling that cannot be removed with subsequent back washes (Giwa et al., 2019). Alternatives to polymeric membranes have included ceramic membranes that can be composed from alumina or silicate (He et al., 2019), with have the advantage of being thermally stable and resistant to chemical attack giving them a potentially long lifespan in service. Additionally, ceramic membranes may reduce the environmental impact of the current model of water treatment (filtration, coagulation, oxidation and disinfection) by eliminating the need for a sedimentation stage within the water treatment process and therefore lessen the need to input the same volume of disinfection chemicals to reach the prescribed water quality standards compared to polymeric membranes (Asif and Zhang, 2021). However, the decision to specify polymeric or ceramic membranes within a drinking water treatment system should take into account factors such as cost, potential lifespan and site-specific suitability. In some rural areas for example, increased NOMs or dissolved metals can damage installed ceramic filter membranes, with the only option to have a robust pre-treatment system that protects the ceramic filter when in service (G. Galjaard, 2015). Water process designers require to strike a balance between effective water treatment to set standards, site specific factors and the final cost of any installed membrane technology.

## 2. *Ultraviolet LEDs (UV-LEDs)*

UV-LEDs have emerged as a potentially viable option for water disinfection within WTW since they do not have the same environmental, energy and safety issues during the installation, service life and decommissioning phases compared to conventional mercury-based UV treatment systems. It has been established during funded research trials that UV-LEDs perform well when challenged with inactivating *Cryptosporidium* and other potentially pathogenic bacteria such as *Legionella* or *Salmonella* (Li et al., 2019).

The effectiveness of UV-LEDs to undertake water disinfection is also highlighted by a study undertaken by Typhon Treatment Systems[1] Ltd in partnership with Cranfield University that states that UV-LEDS can achieve the disinfection characteristics required on a bench scale and the data received was comparable to an experiment run in parallel at a WTW. The comparison of the data allowed the development of standard methodologies and validation controls applied to water disinfection by UV-LEDs and the demonstration of the scale up required to operate this technology at operational WTWs (Jarvis et al., 2019). A Canadian based company Acuva[2] has developed a UV-LED disinfection system that is focused on flow rates through the treatment chamber of up 5 l/min so this is more likely to be applicable for off water network dwellings or small businesses that do not require high volumes of potable water. Therefore, the disinfection properties of UV-LEDs have been analysed in detail and the initial scale up has been shown to be effective within in an operational WTW. The challenge is to formulate the testing and validation methodology so that existing WTWs across water distribution networks can take advantage of this technology. Further analysis of the environmental benefits would be beneficial and also a costing analysis for water distribution providers to assess whether retrofitting to existing water infrastructure is achievable.

## 3. *Machine Learning & Artificial Intelligence*

Artificial intelligence (AI) methodologies have begun to be utilized within the drinking water industry to optimize water treatment processes and introduce more automation. The technology was first applied to monitoring of the deterioration of water pipes[3] [4]once they are in service, giving water companies insight into when repair or replacement is required to avoid costly service interruptions and potential contamination of drinking water supplies (Dawood et al., 2020). The deeper understanding of the water treatment process requirements brought by the introduction of AI methodologies has resulted in model data that can analyse the complex interactions between the stages of water treatment such as filtration, coagulation, oxidation and disinfection (Li et al., 2021), (Wang et al., 2021), (Huang et al., 2021). This is a complex research area which offers the potential for SMEs within the water sector to capture the knowledge generated by research groups and then exploit the market opportunities. Developing AI as a methodology for process optimization within the drinking water industry requires a selection of barriers to be overcome such as an initial skills shortage to interpret the results of any site-specific investigations,

[1] Typhon UV LED water treatment systems (typhontreatment.com)
[2] Homepage - Acuva Technologies
[3] Electro Scan, Inc. | Electro Scan Inc.
[4] Fracta AI

instruments requiring a timely response and without drift over a set time period. This can be compounded by site specific geology issues and as is the case for much of the drinking water infrastructure in the NWE region, a lack of mobile signal can make real time analysis of water treatment regimes challenging.

## 4. Other Drinking Water Treatment Technologies

The technological opportunities for SMEs to maintain and improve drinking water treatment within regulatory frameworks are not limited to ceramic filters, UV LEDs and Machine Learning. Many of the technologies that could be exploited within drinking water treatment will have to retrofitted to existing infrastructure and therefore require to be evaluated on a case-by-case basis when it comes to installation. Table 4 below outlines some of the technologies that could be developed by NWE region SMEs, (This is not an exhaustive list) including the advantages and disadvantages of installing these technologies.

*Table 4 Other drinking water treatment technologies*

| Technology | Advantages | Disadvantages |
|---|---|---|
| Biofilters (Basu et al., 2016) | Reduces the need for chemicals within the drinking water treatment process. Can limit the regrowth of bacteria within distribution systems by removing suspended and dissolved organic matter prior to disinfection. Could be a useful step in reducing membrane fouling. | Bacterial growth within the biofilter column is not well understood in cold water conditions. To overcome this, nutrient supplements that allow indigenous bacteria to grow have been evaluated. Biofilters require an assessment of incoming water quality to establish its site suitability |
| Ion Exchange (Levchuk et al., 2018, Liu et al., 2020) | Can remove charged natural organic matter (NOM) efficiently with a Magnetic Ion Exchange (MIEX) resin a likely candidate for larger scale water treatment. Can reduce the formation of disinfection byproducts (DBPs). | Creates a brine that is difficult to either reuse or dispose of because of the concentration of ions within the solution. Using nanomaterials for resin components can create a difficult to manage waste since they are effective at absorbing toxic compounds. |
| Advanced Oxidation Protocols (AOPs) (Sillanpaa et al., 2018) | This methodology can cope with the variability in NOM concentrations in water treatment plant feed waters. Can reduce the formation of disinfection byproducts (DBPs). | Unlikely to achieve full removal of NOM with the reality that smaller compounds could be formed which could be either biodegradable or on the other hand toxic. |
| Metal removal using membranes (Abdullah et al., 2019) | Differing grades of membranes can result in high efficiencies of metals removal. | Resulting wastes can be difficult to store and/or dispose of and could require special licenses increasing the operational cost. Reverse Osmosis filtration is the most |

| | | |
|---|---|---|
| | | suitable for drinking water pre-treatment, however, high operational costs could rule this technology out. |

## 8. Conclusion

This report highlights the political, environmental, economic and social issues that impact on the capability of the drinking water industry to develop innovative technologies that counteract emerging issues such as accumulating pharmaceuticals, microplastics and diffuse pollution. The report also examines the current obstacles and barriers that are present within the drinking water industry including technological issues that may inhibit innovation. The challenge remains that whilst entrepreneurial activity is occurring within this sector, constraints remain within planning systems, funding availability and the establishment of standardized testing frameworks for new technology.

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