Report No.435

epa Research

Industrial Water 4.0 – A Framework for Catchment-based Digitally Integrated Industrial Water Stewardship

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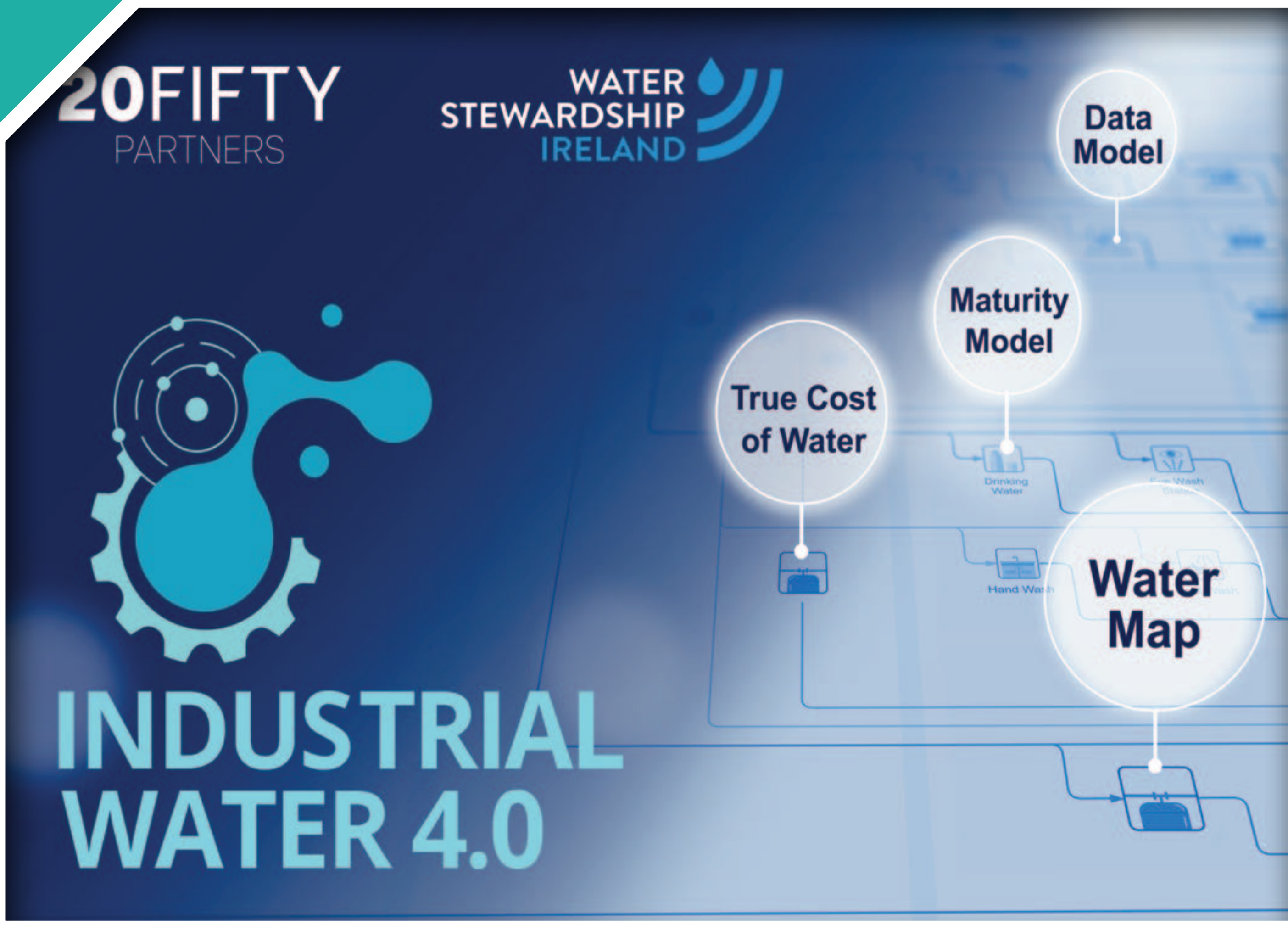

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Rialtas na hÉireann
Government of Ireland

Environmental Protection Agency

The EPA is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

The work of the EPA can be divided into three main areas:

Regulation: Implementing regulation and environmental compliance systems to deliver good environmental outcomes and target those who don't comply.

Knowledge: Providing high quality, targeted and timely environmental data, information and assessment to inform decision making.

Advocacy: Working with others to advocate for a clean, productive and well protected environment and for sustainable environmental practices.

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- Support National, EU and UN Climate Science and Policy development activities.

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- Assess the impact of proposed plans and programmes on the Irish environment.

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- Collaborate with national and EU environmental research activity.

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- Promote environmental awareness including supporting behaviours for resource efficiency and climate transition;
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- Work with international and national agencies, regional and local authorities, non-governmental organisations, representative bodies and government departments to deliver environmental and radiological protection, research coordination and science-based decision making.

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The EPA is managed by a full time Board, consisting of a Director General and five Directors. The work is carried out across five Offices:

1. Office of Environmental Sustainability
2. Office of Environmental Enforcement
3. Office of Evidence and Assessment
4. Office of Radiation Protection and Environmental Monitoring
5. Office of Communications and Corporate Services

The EPA is assisted by advisory committees who meet regularly to discuss issues of concern and provide advice to the Board.

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Identifying pressures

Industrial activity is intrinsically linked to the accessibility and availability of water. The increasing global demand for industrial water, alongside an ageing water infrastructure and the impacts of climate change on the frequency and severity of extreme weather events, poses a significant risk management challenge for organisations aiming to decouple the growth of production capacity from unsustainable consumption.

Water-related risks are consistently ranked among the top global environmental and societal risks, and businesses are increasingly experiencing significant associated financial impacts. Industry must adapt its current water management practices to reflect the changing conditions and provide both effective and efficient solutions to global and local challenges to secure the futures of their organisations.

This project was developed to advance research relating to the concept of Industrial Water 4.0, which combines the digitalisation of industrial production with water management to support a more holistic and sustainable approach to industrial water lifecycle management.

Informing policy

TThe vital role of water in supporting national climate action and broader sustainability strategies is undervalued. The findings from this research highlight that proactive water resource management can contribute to meeting national greenhouse gas and pollution emission reduction targets and mitigate the threat of climate change to water security.

Water sector targets relating to climate action and circularity policy objectives, as outlined in the proposed revision to the Urban Waste Water Treatment Directive and the proposed Corporate Sustainability Reporting Directive's reporting disclosure requirements for water, signal to national policymakers a more holistic approach at the EU level. More emphasis should be given to water in key policy areas such as climate mitigation, circularity and emerging technology supply routes. At the same time, better guidance and tools are required for industrial sites and national water service providers to engage with and address these top-down policy signals proactively.

Digitalisation action plans may increasingly be integrated into national policymaking relating to water and sustainability issues, to accelerate the uptake of digital solutions and technologies and unlock further resource efficiency and competitiveness gains.

Developing solutions

This report presents a framework for industrial water users to adopt Industrial Water 4.0. The framework was developed in collaboration with industrial sites across Europe in response to the lack of detailed guidance and decision support tools for accelerating organisations' transitions towards digitally enabled industrial water stewardship.

The framework is underpinned by a collection of integrated tools providing industrial sites with guidance to ensure water supply resilience, water resource efficiency, cost savings and water process integration with production through enabling digitalisation technologies and solutions.

The report provides insights from stakeholders across the industrial water lifecycle on the challenges, megatrends and opportunities facing industrial sites playing a proactive role in the transition towards digitally integrated industrial water stewardship. It includes recommendations for improving industrial water catchment data collection and a roadmap for decarbonising the industrial water sector. A key recommendation is to establish a national talent development programme for the application of Industry 4.0 to water stewardship and broader enterprise sustainability practices. Allied to this is the need for greater emphasis on water in national climate action and sustainability policies.

EPA RESEARCH PROGRAMME 2021–2030

Industrial Water 4.0 – A Framework for Catchment-based Digitally Integrated Industrial Water Stewardship

(2019-W-LS-21)

EPA Research Report

Prepared for the Environmental Protection Agency

by

20FIFTYPartners

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ACKNOWLEDGEMENTS

This report is published as part of the EPA Research Programme 2021–2030. The EPA Research Programme is a Government of Ireland initiative funded by the Department of the Environment, Climate and Communications. It is administered by the Environmental Protection Agency, which has the statutory function of co-ordinating and promoting environmental research.

The authors would like to acknowledge the members of the project steering committee, namely Shane Colgan, Orla Harrington, Alice Wemaere, Andrea Rubini, Paul Butler, Lisa Shiels (Project Manager) and Dorothy Stewart (Project Manager).

This report is based on research carried out/data from January 2020 to June 2022. More recent data may have become available since the research was completed.

The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

EPA RESEARCH PROGRAMME 2021–2030
Published by the Environmental Protection Agency, Ireland

ISBN: 978-1-80009-107-8 July 2023

Price: Free Online version

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Contents

List of Figures

List of Tables

List of Boxes

Executive Summary

Water is one of the most important resources on Earth. Recent events have highlighted the global and local water-related impacts on humanity resulting from a changing climate. It is becoming more apparent each year that water is the prism through which we are seeing the strongest impact of a warming globe.

The impacts are wide-reaching, and communities everywhere are facing challenges in managing the complexities associated with water management. Industrial activity in particular is intrinsically linked to the accessibility and availability of water.

This project was developed to advance research relating to the concept of Industrial Water 4.0, the interface between Industry 4.0 and Water 4.0, combining digitalisation of industrial production and water management to support a more holistic and sustainable approach to industrial water lifecycle management.

This report presents the findings of a 36-month period of desk research, a process of international and national stakeholder consultation, and the development and application of a framework and associated tools at a number of industrial partner sites. It also provides recommendations for the adoption of Industrial Water 4.0 by organisations, aimed at promoting more sustainable business operations while also supporting the development of stronger catchment management activities.

Key findings from the research include the following:

- Although water risk is increasingly viewed as business risk, organisations are still slow to recognise the true value of water to both their continued business operations and their supply chains.
- Digitalisation of water management is acknowledged as an important enabler of more sustainable organisational operations, but large gaps exist between awareness and action as organisations grapple with both data and digitalisation challenges.
- Gaps exist in supporting organisations to adopt Industry 4.0 principles, methodologies and tools in industrial water management.
- The role of water in supporting climate action is not adequately addressed in government climate policy in Ireland. Although recent evidence shows a shift to more systematically coherent policymaking at the EU level in the water domain, this has yet to be translated to the national level.
- Circularity, as it applies to water, does not adequately feature in circularity policy in Ireland; as a result, it is potentially misunderstood and not prioritised by organisations.
- Compliance is still a strong driver of organisations' engagement with better sustainability practices. Going beyond compliance is still not yet a priority for many organisations.
- Organisations are unable to accurately determine the carbon footprint associated with their water lifecycle because of significant gaps in data relating to greenhouse gas emissions from Ireland's industrial water lifecycle. Furthermore, a lack of support prevents organisations from seeking to decarbonise their water lifecycle.
- The integration of water management and production data at industrial water sites across Europe is limited at present because of issues such as data availability, lack of financing for water projects, digitalisation challenges and cybersecurity concerns.
- Both ownership of and access to water-related data are not clear-cut across many industrial sites owing to the outsourcing of key water management processes to third parties. This creates information silos and in turn reduces organisations' abilities to "do more" with their water and production data.

Key project recommendations include:

- the placing of a stronger emphasis on water in national climate action and sustainability policies to drive decarbonisation and water circularity opportunities across industry;
- the development of a national roadmap for decarbonisation of the industrial water lifecycle;
- the establishment of a national dataset for industrial water use;

- the establishment of a national talent development programme for applying Industry 4.0 to water stewardship and broader enterprise sustainability practices;
- the continued development of an Industrial Water 4.0 framework to support organisations' transition to more sustainable industrial water lifecycle management.

1 Introduction

1.1 The Future of Water

Water is one of the most important resources on Earth. Industrial activity is intrinsically linked to water accessibility and availability. The “water crisis” is what the World Economic Forum calls the fourth greatest global societal risk by impact, which will heavily affect the industrial sectors (WEF, 2019). Water is an essential resource for many industries, including agriculture, the food and beverage industry, pharmaceuticals, energy (power production, drilling and refinery processes) and information and communications technology (ICT), and they are increasingly at risk from water scarcity (Morgan Stanley, 2019).

Globally, industrial water use is expected to grow dramatically by 2050, with a 400% overall increase expected across manufacturing sites alone (UNESCO, 2021). This is unsustainable, and there is an urgent need to decouple the growth of productive capacity from water consumption. But protecting national competitiveness through greater industrial water efficiency is only part of the challenge. The quality of water and the cost of its management increase the complexity of a significant global issue. Industry in its management of water is looking for ways to adapt to changing conditions and provide both effective and efficient solutions to global challenges. For example, urbanisation and climate change – two major global drivers of the water crisis – continuously increase the pressure on the scarce resource of water (Cullis *et al.*, 2019).

Increasingly, digitalisation is providing approaches, tools and resources that are ushering in a new era of industrial water management. Digitalisation is already fundamentally changing life in many areas and will continue to do so (PwC, 2018; Forbes, 2020). The COVID-19 pandemic has intensified digitalisation efforts in many business sectors (McKinsey, 2021).

Technologies offer significant potential to transform the world’s water systems by helping utilities to become more resilient, innovative and efficient, in turn helping them to create a stronger and more economical foundation for the future (IWA, 2022). The potential for enhanced water protection via digitalisation is enormous. Leakage rates in large cities are between 10% and 50%. If digital tools can help water utilities to detect water leaks and reduce these by only 10%, this would mean annual water savings of 100 million m^3 (GE, 2016).

Utilising the value of data, automation and artificial intelligence enables water utilities to expand water resources, reduce non-revenue water, extend infrastructure lifecycles, lay the foundation for financial security and more. The value chain of the water sector connects the environment and water resources to utilities, utilities to their customers and customers to their environment. New digital technologies enable water utilities and industries around the world to gain more information and efficiency from existing water infrastructure, allowing them to improve decision-making, promote water protection, build water infrastructure for the 21st century and increase the value and benefits of the global water infrastructure.

From physical infrastructure and water quality to customer service and beyond, “digital water” can be integrated into every critical point in the water cycle. For example, remote-sensing and digital twin technologies create the link between a utility and its diversified water supply. Water and wastewater companies are at the heart of a larger digital water ecosystem that encompasses their value chains and related stakeholders.

In general, each ecosystem has stakeholders from across the water and wastewater spectrum, including private and public utilities, government agencies, technology solution providers, academic institutions, consultancies, industry associations and technology accelerators.

Digital technologies have the potential to improve daily water management and create long-term resilience to natural disasters and climate change. These improvements can increase water security for industry, trade, agriculture and households, and thus have a direct impact on economic security and growth.

1.2 Project Background

Over the past decade, Ireland has developed a strong position as a leader in addressing water stewardship responses across industry. The origins of this movement can be traced back to the launch of the Large Water Users Community of Practice in 2013 with support from the EPA to improve understanding of a complex, yet often misunderstood, national challenge. Rebranded as Water Stewardship Ireland in 2021, this voluntary, industry-led network has since expanded to over 300 organisations, including many of Ireland's largest production and service facilities, national development agencies and international stakeholders. All work collaboratively to enable large water users to become a catalyst for changing water management practices along the supply chain.

Facilitated by 20FIFTYPartners, a Limerick-based firm recognised internationally for its contribution to corporate water stewardship standards' development and technical deployment, Water Stewardship Ireland has been at the forefront of a number of leading initiatives. These initiatives include the development of a national roadmap for water stewardship leadership in industry and agriculture in Ireland (Stockil *et al.*, 2018) and of the globally recognised Certified Water Stewardship (CWS) programme. The latter has to date trained over 600 organisations across Ireland in water stewardship activities by helping participants to obtain an externally accredited certification for their sites' water management efforts. Collectively, accredited sites now account for 30% of Ireland's water use.

This project is a result of the work of 20FIFTYPartners and the Water Stewardship Ireland community. It arose from the EPA Research Office introducing members of this community to relevant European programmes and stakeholders, including the parties involved in previous EU-funded research programmes such as E4Water3 and a leading European research institute, DECHEMA (Deutsche Gesellschaft für chemisches Apparatewesen – German Society for Chemical Engineering and Biotechnology).

Roland Berger (2014) determined that, along with Germany, Ireland is a front runner to take advantage of Industry 4.0 (I4.0) opportunities, including the nascent Industrial Water 4.0 (IW4.0) component (Figure 1.1). The front runners are characterised by a large industrial base and modern, forward-looking business conditions and technologies. On this basis,

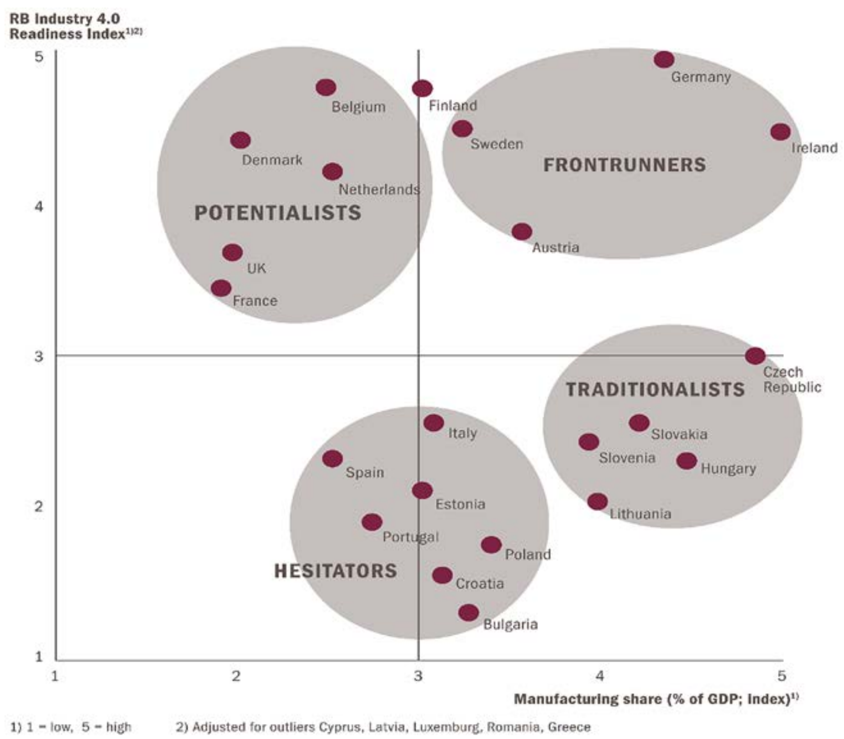

Figure 1.1. The Roland Berger (RB) I4.0 Readiness Index. Source: Roland Berger (2014); see https://www.rolandberger.com/publications/publication_pdf/roland_berger_tab_industry_4_0_20140403.pdf.

Ireland and Germany are well positioned to take an international leadership role in IW4.0. This position is complemented by the rapid growth in recent years of Ireland's reputation for adopting and advancing water stewardship practices and standards.

1.2.1 Industrial Water 4.0

The ever-increasing proliferation of digitalisation across society has given rise to what many are calling the "fourth generation" industrial revolution (Box 1.1).

> **Box 1.1. Industry 4.0**
>
> "The **Fourth Industrial Revolution** or **I4.0** is a seamless collaboration of diverse advanced technologies of autonomous processes to produce connected products and provide services through real-time information transparency" (Mubarak and Petraite, 2020). "This way, products and means of production get networked and can 'communicate', enabling new ways of production, value creation, and real-time optimisation" (i-SCOOP, 2021).

This is rooted in domains such as "big data", "Internet of Things" (IoT) and "cyber–physical systems". Across Europe and beyond, governments and wider stakeholder groups are actively developing policies and support environments to protect and/or enhance their national competitiveness in this new environment.

Although digitalisation in industrial production and the process industry is progressing rapidly both nationally and internationally, digitalisation in the water industry has not yet reached a similar level.

To counteract this, the German Water Partnership has defined the term "Water 4.0" and understands it as the linking together of sensors, computer models and real-time control combined with the heavy use of intelligent networks and the Internet. The evolution of "Water 4.0" is illustrated in Figure 1.2.

DECHEMA has advanced research into digitally integrated industrial water management by developing the IW4.0 concept, as described in Box 1.2 and shown in Figure 1.3.

The aim of IW4.0 is to help decouple water consumption and economic growth. However, this

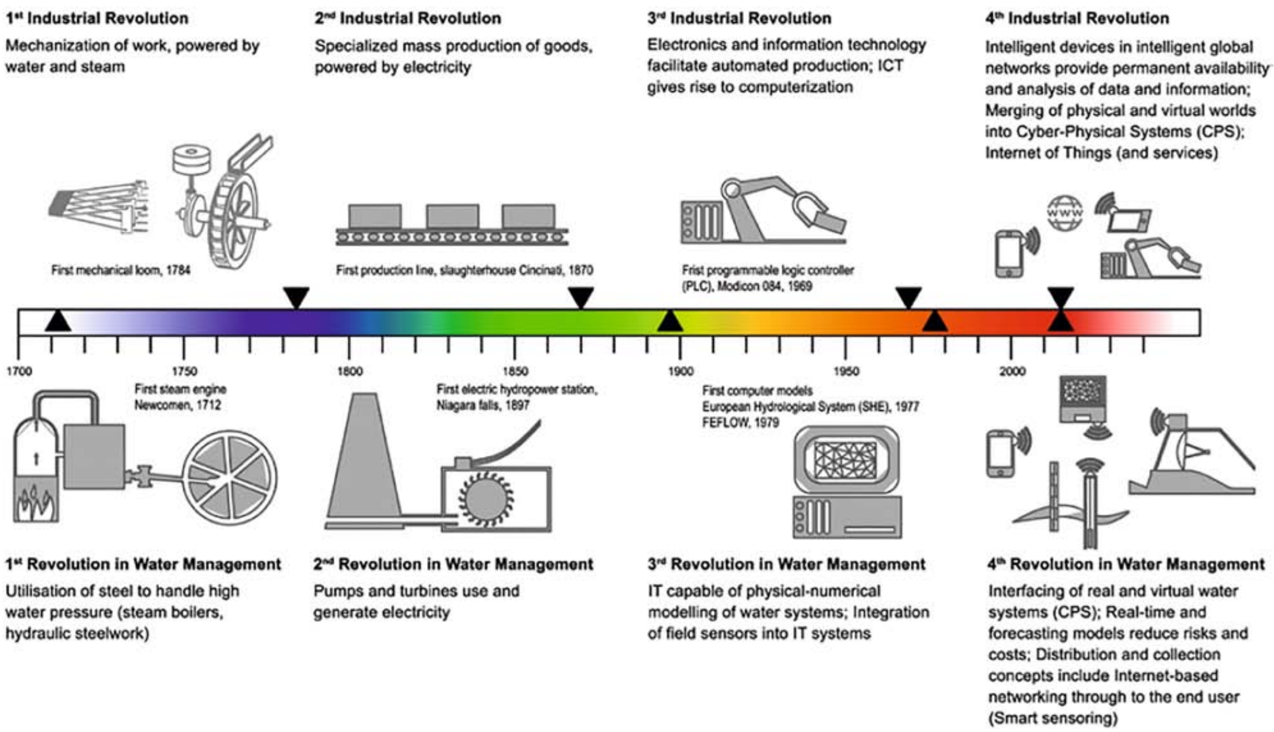

Figure 1.2. Evolution of Water 4.0. Source: German Water Partnership (2018); see https://germanwaterpartnership.de/wp-content/uploads/2018/02/gwp_water_40_2019.pdf.

Box 1.2. Industrial Water 4.0

IW4.0 is the interface between the digitisation of industrial production and the digitisation of water management. It incorporates the concepts of Water 4.0 and I4.0, with the aim of connecting water resources and industrial water use. From an integrated industrial water management perspective, the Industrial Water 4.0 approach comprises digitisation in industrial water management, linking this with industrial production, and connecting industrial water management with municipal (waste)water management and water resource management. The increased integration of sensor technology, ICT and simulation will create opportunities to better perceive complexity and interconnectedness, early warning and decision-making processes at industrial sites (Becker *et al*., 2019).

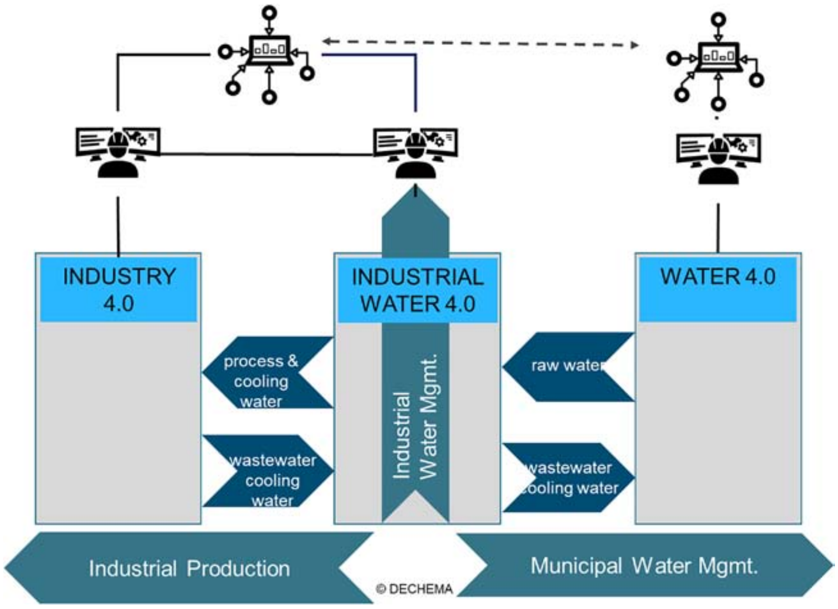

Figure 1.3. The integration of Industrial Water 4.0 (Industriewasser 4.0) in industrial production and municipal/water resource management (Becker *et al*., 2019).

poses key economic, environmental and societal challenges, including the following:

- **Exploitation and contamination of freshwater**: a major challenge for industry and society today is to effectively address the unsustainable exploitation and contamination of freshwater resources. The annual quantity of water used by industry is growing rapidly, and this places untenable pressure on water supplies both in Ireland and elsewhere.
- **Poor water efficiency**: to meet the needs of present and future generations, industrial production systems need to become more sustainable. Many industries use more water than their production processes require because they continue to use inefficient technologies and fail to adopt the best water stewardship systems and standards.
- **Lack of financing for water projects**: generally, resource efficiency and waste reduction require little additional motivation if there is a clear link to greater profit margins. However, in relation to water projects, it is generally recognised that the return on investment is seldom clear to many businesses because of the perceived low cost of water, uncertain outcomes and competing site priorities. As a result, many water improvement projects never get off the ground.
- **Lack of availability of appropriate tools for industrial water management**: water is a complex resource, with quality, quantity, cost and context-specific dimensions to be considered.

Traditionally, industrial sites have attempted to reapply tools and standards originally developed for managing other resources such as energy to water management, with limited effect. There is still considerable work to be done in developing appropriate water stewardship tools for industrial sites, and these tools can be developed only through collaboration and collective action.
- **Horizontal integration of water stewardship along the water supply chain**: water stewardship by its very nature requires streamlined interfaces both within industrial sites and more generally between municipal supply, industry users and environmental regulators. In particular, better integration of data sources and information flows is needed across the water lifecycle in the context of the Water Framework Directive (WFD) and river basin management plans. The achievement of such integration presents significant data management and organisational challenges.
- **Vertical integration of water management at the site level**: industrial water management also presents significant vertical integration challenges at industrial and municipal water sites in ensuring that meter- and sensor-level devices are connected with communication gateways to control higher-level management systems. Addressing issues around the introduction of open data protocols, the integration of legacy systems, vendor and procurement management and data modelling is paramount and requires significant investment and effort.

A great challenge for the future will be transferring I4.0 expertise and technologies to industrial water management and to water resources and municipal water management. This transfer is the main building block of the IW4.0 project

1.3 Research Objectives

Building on the IW4.0 concept developed by DECHEMA, this project attempts to address industrial water digitalisation challenges and opportunities, as well as extensively engage industrial sites in digitally enabling water stewardship implementation, to identify possible pathways to mainstream proactive water management at industrial sites.

As a result, the overarching objectives of this research are to:

- develop a framework for digitalisation of industrial water management and water stewardship and support;
- more tightly integrate industrial water management with the digitalisation of industrial production;
- identify and address barriers to, challenges in and opportunities for tying in industrial water management with digitalised municipal water management (supply and wastewater treatment, including water resource management at the catchment level).

1.4 Research Approach

The methodology adopted by this research project involved bringing theory and practice together to identify the adoption potential of I4.0 tools, technologies and practices in the industrial water lifecycle and collaborating with industry to develop a framework of tools and guidance to support organisations on their journeys towards better water stewardship.

This process involved desk-based research, engagement with project partner sites to pilot and validate developed approaches, and engagement with the broader industrial water community through (1) Water Stewardship Ireland Community of Practice quarterly events and (2) outreach activities, including semi-structured interviews with experts across the industrial water sector from Ireland, Germany, Belgium and the Netherlands. The experts were employees of multinational pharmaceutical, chemical, food and beverage, and semiconductor manufacturing companies charged with both operational and corporate responsibility for industrial water management.

The methodological steps of this research project (which are aligned with the report structure) were as follows:

- carry out desk-based research of national and international emerging trends and research in the areas of industrial water management and Water 4.0 – digitisation of industrial water (Chapter 2);

- conduct EU and national water policy reviews and consultations with industry stakeholders to understand and validate key global drivers of the next evolution of industrial water management (Chapter 2);
- develop a framework and guidance to support industry in grappling with emerging megatrends through tools including (1) a digitally enabled water stewardship maturity model, (2) a standardised methodology for water lifecycle mapping, (3) a standard data model for quality and quality and (4) a methodology for establishing the true cost of water (Chapter 3);
- make recommendations based on the findings of the project (Chapter 4).

2 The Emergence of Industrial Water 4.0

This chapter provides a summary literature review of Industrial Water 4.0, beginning by identifying key global, national and local industrial water management risks and then highlighting the role of water stewardship in responding to these risks, examining the opportunities for digitalising industrial water management to support better water stewardship and finally outlining the opportunities and challenges that relate to adopting IW4.0. A more detailed literature review is presented in Appendix 5.

2.1 Water Risk is Business Risk

> If climate change is a shark, water is its teeth. (WWF, 2016)

Water-related risks are consistently ranked among the top global environmental and societal risks (WEF, 2020), and businesses are increasingly experiencing significant associated financial impacts (CDSB, 2021). Currently, 17% of the global population reside and 10% of gross domestic product (GDP) is generated in water-stressed regions; these figures are projected to increase to 51% and 46%, respectively, by 2050 (WWF, 2020). Several factors are expected to affect water availability and quality in the coming decades, with competition for water exacerbated by various natural and anthropogenic factors such as changing demographics, industrial and agricultural activities, pollution and climate change (CDP, 2021; CDSB, 2021).

Temperature rises due to climate change are projected to significantly intensify the global hydrological cycle, resulting in more powerful storms, increased flooding and drought conditions (IPCC, 2022).

2.1.1 Operational impacts

Table 2.1 lists some examples of the disruption to industrial activity resulting from extreme hydrological events in 2022.

2.1.2 Financial impacts

Between 1980 and 2020, total economic losses from weather- and climate-related events among the European Environment Agency's 32 member countries, that is, the 27 EU Member States plus Iceland, Lichtenstein, Norway, Switzerland and Türkiye, was between €450 billion and €520 billion. This is forecast to increase in the coming decades as a result of climate change and the associated impacts on the hydrological cycle (EEA, 2022a). In response to these challenges, the EU has introduced a new Climate Adaptation Strategy (EC, 2021a). This aims to gather better data on current and projected climate-related risks and losses from meteorological events (e.g. storms), hydrological events (e.g. floods) and climatological events (e.g. heatwaves, cold waves, droughts), which will inform holistic responses to climate change adaptation.

According to a study carried out as part of the Joint Research Centre (JRC) PESETA project, exposing the global economy to global warming of 3°C would result in an annual welfare loss of at least €175 billion (1.38% of GDP). Under a 2°C global warming scenario, the loss would be €83 billion/year (0.65% of GDP), while restricting warming to 1.5°C would reduce the loss to €42 billion/year (0.33% of GDP) (Szewczyk *et al*., 2020). From an Irish and UK perspective, the study suggests that the main economic losses will be associated with coastal flooding, river flooding and drought, with losses to GDP of almost 0.5% under a 3°C warming scenario.

2.1.3 Water risk assessment for industrial sites

Water risk assessments at industrial sites have traditionally been carried out in response to health and safety concerns (e.g. slips, trips and falls due to water spills, legionella prevention and control), operational concerns (e.g. the impact of water equipment failure on production output) and environmental concerns such as limiting effluent concentrations in accordance with water quality regulations.

Such a narrow perspective on assessing water risks at the site level is no longer adequate (WWF, 2020). Industrial sites will need to consider their operational and supply chain vulnerabilities to water stress and extreme precipitation events, vulnerabilities that will

Table 2.1. Impacts of global extreme hydroclimatic events on industrial activity in 2022

Country	Impact	Sources
China	Record heatwave and high temperatures led to drought conditions and consequently the shutdown of industrial organisations to conserve water for the residential population; reduced hydropower capacity; and lower crop yields. The heatwave was followed by heavy, intense rainfall from a typhoon, causing flash flooding in certain regions	CMA, 2022; WMO, 2022
France	Worst drought on record, which resulted in reduced agricultural yields affecting production. Moreover, temperature limits of water discharged from a nuclear powerplant were increased to avoid powerplant shutdown as a result of low water levels and the associated high temperature of waterbodies	Météo France, 2022; Reuters, 2022a
Germany	Summer heatwave led to record high temperatures and drought, resulting in disruption to cargo shipping on the Rhine due to low water levels	DWD, 2022; Reuters, 2022b
Ireland	Heatwave and drought conditions led to increased demand for water resources and low reservoir levels, which in turn led to residential and business water conservation notices being issued	Irish Water, 2022; The Water Forum, 2022
Norway	Hydropower reservoirs ran low because of low rainfall and needed to be regenerated in summer, leading to a halt in electricity exports to the EU	*New York Times*, 2022
Pakistan	Heatwave temperatures affected agricultural yields and were followed by heavier than usual monsoon rains, resulting in over 1000 fatalities and the shutdown of industrial activity in affected areas	FT, 2022; WMO, 2022;
USA	Exceptional drought conditions in western and central USA led to record low water reservoir levels, with impacts on energy production, through reduced hydroelectricity production and biofuel feedstock, and on manufacturing output as a result of lower yields of crops such as cotton, soybeans and flax	NOAA, 2022

be exacerbated by climate change, the tightening of environmental regulations to limit cumulative impacts on water quality from increasing population and industrial activity, and increasing demands for environmental, social and governance (ESG) reporting by stakeholders and investors (WRI, 2019; WWF, 2020).

Risks faced by companies may be categorised as physical (e.g. scarcity, flooding, quality), regulatory (enabling environment, management instruments, institutions, governance) or reputational (media scrutiny, biodiversity importance, investor demands) (WWF, 2020).

The physical risks associated with water management at industrial sites have received the most attention (WWF, 2020) because of their direct impact on site operations and their relevance to future environmental reporting regulations such as the upcoming Corporate Sustainability Reporting Directive (CSRD) (EU, 2022a) and influential environmental reporting initiatives from organisations such as the Task Force on Climate-related Financial Disclosure (FSB, 2022) and the Science Based Targets Initiative (SBTi, 2022). However, the complexity of water risk resilience planning means that it is important to account for the broader reputational and regulatory landscape risks in individual countries and regions that may limit the implementation of risk reduction measures (WWF, 2020).

2.1.4 Policies relevant to industrial water management

EU policy response

Two of the European Commission's six priorities for 2019–2024 (EU, 2019a), "A European Green Deal" and "A Europe fit for the digital age", are directly relevant to Industrial Water 4.0 management through their promotion of a carbon-neutral and resource-efficient economy enabled by a new generation of technologies. Both priorities inform "A New Industrial Strategy for Europe" (EC, 2020a), which aims for the EU to lead the twin green and digital transitions that will transform the EU into a fairer, more prosperous society with a modern, resource-efficient and competitive economy with no net emissions of greenhouse gases (GHGs) by mid-century. The Eighth Environment Action Programme (8th EAP), building on the European Green Deal, sets out priority objectives for 2030 and the conditions needed to achieve these (EU, 2022b). The 8th EAP aims to speed up the transition to a climate-neutral, resource-efficient economy, recognising that human wellbeing and prosperity depend on healthy ecosystems.

Table A5.2 in Appendix 5 outlines EU policy and legislation that support the achievement of the European Commission's priorities and industrial strategy with relevance to water.

National policy response

Without appropriate action to mitigate water risks, water quality is projected to decline because of factors such as increased population, increased commercial/industrial activity, flooding events mobilising pollutants and lower river water levels due to water stress during summer months limiting the dilution of wastewater concentrations (Irish Water, 2021a).

Figure A5.8 and Table A5.3 in Appendix 5 highlight the national plans and strategies in Ireland that offer insights to inform the proactive management of water at industrial sites.

2.2 Industrial Water Stewardship

2.2.1 Corporate-led water stewardship

Water stewardship has received significant attention in recent years, both globally and in Ireland, as businesses and communities respond to the increasing challenges and risks surrounding the shared responsibility of water resource management.

> **Water stewardship** is defined as using water in a way that is socially equitable, environmentally sustainable and economically beneficial. This is achieved through a stakeholder inclusive process that involves site and catchment based actions. (UNIDO, 2022)

The term "water stewardship" has various meanings depending on the specific context. However, it is generally understood to encompass an approach that promotes water users taking responsibility for their own influence on a shared resource and working together to manage it sustainably (Water Footprint Network, 2021). This reflects the systems thinking perspective, namely that the challenges and risks associated with water resource management cannot be solved by individuals but can be addressed only through coordinated, collective action (GIZ, 2019). The successful implementation of water stewardship allows enterprises to engage with local stakeholders and understand the water-related challenges and opportunities they face, facilitating the development and integration of strategies to address social, environmental and economic concerns across the entire water lifecycle (Stockil *et al*., 2018).

Corporate-led water stewardship initiatives have been motivated by various drivers, such as improved resource efficiency, environmental protection concerns, and ESG reporting and transparency requirements, which are increasingly demanded by enterprise shareholders, societal stakeholders and consumers. Because the scope of the proposed CSRD (EU, 2022a) is being expanded to include all large companies and all companies listed on regulated markets (except listed microenterprises), it is envisioned that water stewardship frameworks and external accreditation will help businesses to meet their ESG reporting obligations (EU, 2022a).

2.2.2 Nationally led water stewardship

Water stewardship to date has predominantly taken a bottom-up approach, with enterprises and local societal stakeholders leading implementation efforts. However, it is increasingly being promoted by national bodies and agencies to meet national resource efficiency and environmental protection objectives, while also contributing to meeting the broader Sustainable Development Goals (SDGs) of the United Nations. This section presents three examples from across Europe of national water stewardship initiatives for enterprises.

Ireland

In response to the gap in national support for water stewardship, the CWS programme, developed by 20FIFTYPartners in partnership with Water Stewardship Ireland and the Lean & Green Skillnet, was established in 2019 and has been promoted by Irish Water (the national water service provider; now known as Uisce Éireann) to engage organisations across Ireland in water stewardship activities (Water Stewardship Ireland, 2021). It achieves this by supporting participants to commit to a water stewardship action plan; sites receive an externally accredited certification for their efforts (Irish Water, 2021b). The programme supports business customers with training on lowering water consumption and reducing operational costs, while also protecting the environment (Water Stewardship Ireland, 2021). As at 2022, over 600 organisations had participated in the programme, collectively accounting for over 30% of Ireland's water use. The successful implementation of over 1400 conservation projects has been attributed to the CWS programme. The programme's success has led to interest from the UK and other European countries regarding potential replication by national water service providers, tailored to different national contexts such as industrial sector characteristics and regional water stress conditions.

Finland

As part of its commitment to the United Nations Agenda for Sustainable Development, Finland's Water Stewardship Commitment challenges companies to assess water risks in their value chains and engage in collective action to develop sustainable water use and governance (Ministry for Foreign Affairs of Finland, 2020). It links directly to national SDG implementation and engages the public sector, academia and non-governmental organisations. The commitment was founded by Finnish research institutes, ministries and WWF (World Wide Fund for Nature) Finland in 2017 and has gained signatories from major Finnish companies and key water-using sectors. The aim of the commitment is to make Finnish companies the most responsible water stewards in the world by 2030.

Germany

The International Water Stewardship Programme (IWaSP) is implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit on behalf of the German Federal Ministry for Economic Cooperation and Development and the UK Department for International Development. It supports business, government and civil society to partner with each other and develop joint solutions to water-related risks through engagement of over 70 global companies. At the programme's end in March 2019, IWaSP and its partners had enabled water security for 2,722,179 direct beneficiaries and 10,134,960 indirect beneficiaries, with a focus on water-stressed regions in developing economies (IWaSP, 2019). Building on IWaSP's success, the Natural Resources Stewardship Programme was developed, enabling private–public–civil society partnerships to manage the natural resources (scope expanded beyond water) needed for sustainable growth and better livelihoods (NatuReS, 2020). This highlights the potential for water stewardship programmes to act as an introduction and catalyst to accelerate broader natural resource stewardship programmes.

2.3 Digitalisation as an Enabler of Better Industrial Water Stewardship

While industrial water stewardship is gaining significant traction globally, another aspect of management that has received attention is the prospect of enabling digitalisation across the industrial water lifecycle. Various terms are used to refer to this water digitalisation, such as "Smart Water", "Water 4.0" and "IoT for Water". The main benefit of digitalisation in the industrial water sector is having more manageable water processes as a result of digital technologies, which improves resource efficiency by optimising processes and equipment while limiting pollution events through greater oversight of operations and associated early warning systems.

Digitalisation of the water sector through technologies such as artificial intelligence (AI), digital twins, digital data spaces, disruptive technologies and instrumentation and circular economy digital water innovations can result in significant environmental, operational and economic benefits.

Digital water solutions reduce the environmental impact of water operations via

a) reductions in energy demand for water supply and sanitation services;

b) better control of emissions from wastewater treatment plants;

c) enhanced capabilities for real-time, in situ water quality monitoring; and

d) increased water use efficiency across sectors and reduced leakages.

Digitalisation is a critical tool in advancing global water security and protecting the planet's water resources sustainably. Overall, digital technologies provide a wide array of possibilities for achieving the zero pollution ambition in the water sector. (EC, 2021b)

Over a 6-year period (2014–2019), the EU funded 255 water-related projects under Horizon 2020 with around 1 billion euros. In recent years, digital aspects have increasingly been included in the research agenda with the aim of accomplishing the scientific goals described in Table A5.4 in Appendix 5.

Water Europe has identified how digitalisation of the water management sector can support regional objectives to deliver a resilient and green economy (Water Europe, 2021). Water Europe's recommendations for the digitalisation of the water sector include:

- adopting a common data platform for data valorisation and information sharing;
- supporting smart quantitative water management and water conservation through monitoring;
- supporting the upskilling of the workforce to diffuse digital culture in the water sector;
- optimising drinking and wastewater plants to reduce operating expenditure (OpEx) and capital expenditure (CapEx);
- improving transparency and data sharing in the sector and with the public to promote multidisciplinary cooperation.

2.4 Adoption of Industry 4.0 in Industrial Water Management

2.4.1 Objectives of Industry 4.0

I4.0 describes a continued trend towards automation and data exchange in manufacturing technologies and processes. This can include capabilities such as cyber–physical systems, cloud computing, artificial intelligence, Industrial Internet of Things (IIoT), robotics and augmented/virtual reality, and it offers benefits to enterprises through cost efficiencies, operational agility and democratising data (IMR, 2022).

Ireland's Industry 4.0 Strategy 2020–2025 (DBEI, 2019) outlines I4.0 as a key output of Future Jobs Ireland, the government's new economic pathway aimed at ensuring that Ireland is well placed to prosper in a rapidly changing global economy. Examples of how international I4.0 trends and drivers may impact on Irish manufacturing sites are shown in Figure 2.1.

2.4.2 Challenges in implementing Industry 4.0

While digitalisation offers many possibilities for improving water management for responsible water stewardship, several challenges limit the uptake of digital solutions among industrial sites and water service providers. The ICT4Water EU cluster has developed two roadmaps and an associated action plan. The intention is to define and deploy a group of actions for the development of digital water services in the single market. These will address digital water issues relating to services, data management, interoperability, intelligence, cybersecurity and standardisation, including synergies between the proposed solutions and other related sectors (e.g. circular economy, water reuse, transport, energy, agriculture and smart cities), while also considering social aspects (e.g. operators, consumers, legal issues, water value awareness) (EC, 2018).

Other key I4.0 challenges and risks include defining an I4.0 strategy, rethinking the organisation and processes to maximise outcomes, understanding the business case, conducting successful pilots, making the organisation realise that action is needed, considering change management, company culture and acceptance, and interconnecting departments and talent (i-SCOOP, 2020).

2.5 Themes from the Review of Industrial Water 4.0 Literature

2.5.1 Growing awareness that organisations need to assess their water-related risks as part of long-term resilience planning

Based on a review of the industrial water management and water stewardship literature, organisations

Process Industries	
Pharmaceuticals and Chemicals	**Pharmaceuticals** • Personalised healthcare is driving a shift towards more targeted products. • Information-based medicine and innovative monitoring and delivery mechanisms are being developed. • Flexible batch-manufacturing processes and patient data capture and analysis are becoming key enablers. **Chemicals** • Digitalisation is enabling the streamlining of complex processes and operations. • Value-added data services around chemical products are being developed (e.g. apps for providing technical recommendations to clients).
Food and Drinks	• directly with farmers and food manufacturers. Farmers and food producers are thus becoming retailers. • Product customisation is being enabled through the ability to adapt nutrient content to particular categories of customers.

Product Manufacturers	
Medical Devices	• MedTech products are moving towards end-to-end solutions for better care at lower prices, including connected health and drug delivery through data capture. • Personalised healthcare and customisation of medical products are being developed including combination products and diagnostics.
Computer and Electronics	• The Computer and Electronics Sector is becoming a key enabling sector for Industry 4.0, providing intermediate goods to other industrial sectors and making their products and services knowledge intensive.
Engineering	• Digitally enabled flexible batch-manufacturing processes will be required to address increased product customisation trends.

Figure 2.1. Example of international I4.0 trends and drivers in key Irish manufacturing sub-sectors. Source: DBEI (2019).

increasingly view ensuring continued access to high-quality water as a material risk for business. In particular, the operational and financial impacts of water shortages globally have been magnified by recent extreme climatic events, as highlighted in section 2.1.1. In addition, based on the increased attention that Irish Water is paying these risks in its planning decisions, it is possible that industrial sites will increasingly need to account for these risks in site resilience planning and, as a result, will require guidance on developing the appropriate assessment frameworks.

Key water management risks for organisations both globally and in Ireland as identified from the literature review include:

- water stress resulting from over-abstraction of freshwater resources because of increasing population and economic activities;
- waterbodies not being able to assimilate pollutant loads because of increasing population and economic activity, resulting in associated residential, industrial and agricultural emissions to water;
- contaminants of emerging concern (e.g. pharmaceuticals, food additives and microplastics) not being regulated or managed effectively, posing potential threats to public health and the environment;
- underinvestment in ageing water infrastructure affecting flood prevention and the continuity of water supply, with recurring infrastructure failures undergoing maintenance rather than future-proof systems being developed with adequate investment.

2.5.2 Lack of alignment of water and climate policies in Ireland

Based on the review of high-level policies at the EU and Irish national levels, reducing water pollution, reducing water consumption and climate adaptation have been identified as priorities in policy and legislation with relevance to industrial water management. More holistic water policymaking at the EU and national levels will require more emphasis to be given to water in policy areas such as climate mitigation, circularity and emerging technology supply routes, while simultaneously providing better guidance and tools for industrial sites to engage with and address these top-down policy signals proactively.

Recent evidence of a shift towards more systematically coherent EU-level policymaking in the water domain can be seen in the proposed update to the Urban Waste Water Treatment Directive. This highlights the importance of wastewater treatment in achieving EU-wide carbon neutrality and circularity objectives, while also setting more stringent pollution emission limits and expanding pollutant monitoring with relevance to human and environmental health.

Water is not a pillar of Ireland's Climate Action Plan 2021 (DECC, 2021a), with references limited to the sectoral adaptation plans, while the Waste Action Plan for a Circular Economy 2020–2025 (DCCAE, 2020) identifies water management as an area for research prioritisation, with a focus on the waste and circular economy challenges. The Waste Action Plan also highlights the food, water and nutrients value chain as one of seven key product value chains that should be prioritised. Unlike the EU, Ireland has yet to develop action plans and strategies relating to the hydrogen economy, bioeconomy, built environment, forestry and soil.

2.5.3 Integration of water and digital policy increasing at EU level but more action needed

Digitalisation policy considerations are receiving significant attention because of the potential enabling role that digital technologies may play in the transitions towards a "smart water" society (European Commission, Water Europe, ICT4Water cluster). Digitalisation action plans may increasingly be integrated into national policymaking relating to water and sustainability to accelerate the uptake of digital solutions and technologies and unlock further resource-efficiency gains.

The need for such action plans is highlighted in the literature, as there is significant potential for digitalisation in the water sector. However, the water domain is relatively immature in the standardisation of ICT solutions for business processes and the related implementation in the legislative framework (EC, 2018). This lack of maturity was identified as being due to the fragmentation of the sector, the absence of a holistic vision and a lack of technology integration and standardisation (EC, 2018). ICT4Water has also published reports on the business models of digital solutions (EC, 2021c) and the need for digital water in a green Europe (EC, 2021d), and is currently working on an updated digital action plan, which is due to be finalised by the end of the first quarter of 2023 (ICT4Water, 2022).

The main challenge in adapting industrial production for the fourth industrial revolution is that it will require existing structures to be broken up. There is widespread talk of disruption to existing markets at their base. In a survey initiated by DECHEMA on the IW4.0 framework and the EU Water Mining project (Carter *et al.*, 2022), the challenges concerning the establishment of a business case for I4.0 can be summarised as follows:

- Initial investment and new business approaches: many challenges remain in estimating and evaluating initial investments. The initial costs of digitising industrial processes are still high and not in proportion to the benefits. Closing this gap will require new, breakthrough business concepts.
- Higher complexity: standardising and increasing the availability of open protocol and software solutions is a continuous process. Although industrial networks are collaborating intensively on the standardisation of communication protocols, I4.0 architectures, cybersecurity and vendor-independent interoperability, the technologies are not yet ready for deployment.
- Breaking up silo mindsets: digitalising internal and external processes poses a major challenge in terms of the use and release of internal information. Overcoming this mentality requires in-depth change management, capability development and transparent vertical communication.

2.5.4 To overcome digitalisation obstacles to supporting IW4.0 adoption, people must be at the centre of the change

I4.0 is not just about technologies. It looks at the impact of industry on and the role of society and workers (e.g. collaboration between human and machine as with collaborative robots).

The key difference between the third and fourth industrial revolutions is that I4.0 also integrates people into the manufacturing process (Sanghavi *et al*., 2019). Reducing the idea of I4.0 to new technologies only repeats the error of previous system changes. People, technology and organisations must be carefully coordinated if the step from traditional production to a connected factory is to succeed.

Only in this way can the promises of digitalisation, such as flexibility, innovation and better overall results, be realised. Furthermore, merging the three elements of people, organisations and technology inevitably leads to better economic and innovation capabilities (Korge, 2019). The link between technology and organisations is a clear prerequisite for connecting existing processes. Only then can the implemented (solution-oriented) technology be aligned with the (corporate) goals. Consequently, the new IT infrastructure can provide valuable data for monitoring and improving operations, processes and services. In contrast to previous industrial revolutions, I4.0 is defined as agile, modular and open for new business opportunities. However, to benefit from the opportunities associated with the adoption of I4.0, industries undergoing transformation will need to both upskill and reskill their workforces.

2.5.5 Lack of support available to enable Industrial Water 4.0 adoption

While international guidance is available on the main steps in the water stewardship journey, such as the WWF's water stewardship steps (WWF, 2013) and the CEO Water Mandate's six commitment areas (UN Global Compact, 2019), country-specific guidance is lacking. To overcome this obstacle to the widespread adoption of water stewardship principles and practices, the literature review suggests that the gap should be filled with the provision of simple national guidance documentation and programmes to support organisations with limited resources in their stewardship journeys and enable reputable accreditation for their efforts.

While the water risk tools highlighted in section A5.6 in Appendix 5 are useful for identifying general hotspots for water stress, flooding, quality, etc., and how these risks may change over time at the national and regional levels, these tools and approaches are limited in informing risk resilience planning at individual industrial sites because of the level of detail this requires.

Overcoming this limitation will require sophisticated decision support tools that capture local constraints and high-resolution spatial information of projected physical risks. Furthermore, this literature review has identified a gap in how digital enabling technologies can accelerate the transition towards responsible water management at industrial sites in Ireland. However, several guidance documents for the water sector generally, and relevant EU-level projects such as the ICT4Water cluster, may be drawn on to inform specific guidance nationally.

Based on the gaps identified in the provision of guidance across water risk and the digitalisation of water management, detailed frameworks and tools are clearly needed to guide industrial sites in their transitions to digitally enabled water stewardship.

2.6 Summary

Building on the IW4.0 concept developed by DECHEMA (outlined in Chapter 1), this chapter has sought to identify the emerging themes and challenges that organisations face in engaging with IW4.0. Addressing recent trends in Water 4.0 and water stewardship both globally and in Ireland, this chapter has provided crucial input into the development of a framework for IW4.0.

In Chapter 3, the results of this work are presented, focusing on developing a framework in response to the identified gaps in the provision of support for the adoption of IW4.0, a methodology outlining how the framework was developed and an analysis of the lessons learned from the application of the developed framework at industrial partner sites.

3 A Framework for Industrial Water 4.0

3.1 Purpose

The focus of this project, as outlined in the research objectives, was on developing a framework for IW4.0 to guide organisations that want to adopt a more digital approach to water management and stewardship in their sites and across their catchments.

Based on the insights described in Chapters 1 and 2 of this report, it was identified that industrial organisations require detailed guidance and associated decision support tools to accelerate this transition.

As a result, a number of resources and tools have been developed, tested and refined in this project to help industrial organisations to assess their current water management practices and provide them with step-by-step guidance to help them proactively accelerate their transition to water resource stewardship at catchment level.

Considered collectively, these tools form an integrated framework for IW4.0 stewardship practices that supports industrial sites in ensuring water resource supply resilience, water resource efficiency and cost savings, water process integration with production, and wastewater treatment and associated environmental pollution prevention based on enabling digitalisation technologies and solutions. An overview of the framework is shown in Figure 3.1, which identifies each of the tools developed.

Each component tool of the framework is described below, along with high-level guidance and case studies associated with each tool's application. For each tool the intended purpose, application (including case studies) and associated lessons from industrial sites are described.

There is currently a wide range of information sources that industrial sites can use. However, individual sites may find it daunting to locate and evaluate these data to generate meaningful, actionable insights.

The framework developed in this project equips sites with the tools they need to assess their site's maturity in relation to international best practice in industrial water stewardship, map their industrial water lifecycle in a standardised fashion, estimate the true cost of water and undertake future state scenario planning.

This chapter outlines the framework, provides guidance and signposts case studies showing how industrial sites can make use of publicly available resources, and describes the frameworks/tools developed as part of this research project, to inform digitally enabled water stewardship. It also provides an overview of the purpose of each framework component and analyses the key lessons learned from the application of each component at industrial sites.

3.2 Methodology

The proposed suite of tools was trialled at the three industrial partner sites and subsequently refined using iterative feedback from over 30 additional industrial sites to ensure that the tools would be applicable to the broadest industrial audience possible. These tools provide industrial sites with guidance on identifying next steps on the journey towards proactive industrial water stewardship and the enabling role of digitalisation technologies and solutions for addressing water resource supply resilience, water resource conservation and efficiency/circularity, effective wastewater treatment and associated environmental pollution prevention measures.

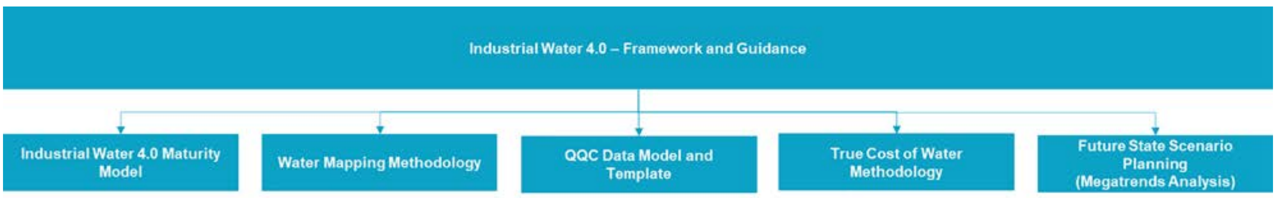

Figure 3.1. Overview of IW4.0 framework and associated tool components.

3.3 Lessons from the Application of Industrial Water 4.0 Framework Tools

This section highlights the main outputs from the development and application of the IW4.0 component tools.

3.3.1 Industrial Water 4.0 maturity model

Purpose

A gap was identified from the review of the academic and grey water stewardship literature and associated industrial water standards in relation to the enabling role that digital and virtual systems may play in accelerating the overarching objectives of the water stewardship agenda (see sections 2.4 and 2.5), which include improved water efficiency and water quality and associated environmental and social impacts. Currently, no maturity model exists that focuses explicitly on industrial water stewardship. However, a number of existing water standards and digitalisation and I4.0 maturity models could be used to inform the development of such a model.

Following a detailed examination of water stewardship standards, water digitalisation maturity models and general I4.0 policy documents, this study proposed developing a maturity model to guide industrial water users in their transition to improved water stewardship. This transition would involve harnessing digitally enabling technology capabilities such as real-time monitoring and control systems, vertical and horizontal data integration, and emulation and simulation applications to optimise operational process management and mitigate associated direct and indirect environmental impacts.

The methodological steps taken to develop the maturity model were as follows:

- The problem was defined and existing documentation and maturity models were reviewed to identify relevant dimensions, criteria, indicators and sub-indicators.
- The initial formulation of the maturity model was based on this literature review and steering committee feedback.
- A questionnaire was developed for expert feedback on the proposed maturity model.
- Interviews were carried out with industry experts and feedback gathered.
- The final version of the digitally enabled industrial water stewardship maturity model was developed (Figure 3.2).

The proposed model has undergone a number of iterations, including modifications based on input from 20 experts across 16 organisations in the industrial (water) sector from Ireland, Germany, Belgium and the Netherlands. These experts were senior management staff of multinational pharmaceutical, chemical, food and beverage, and semiconductor

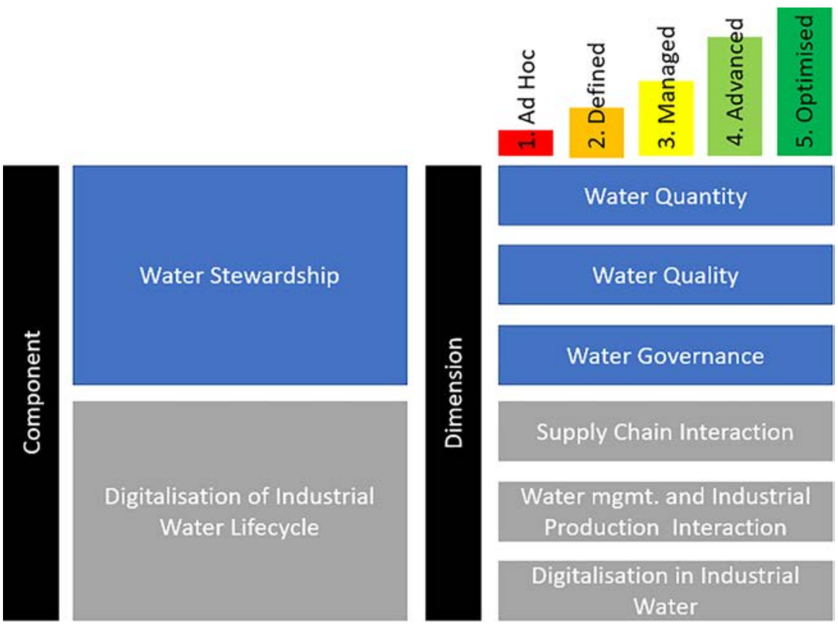

Figure 3.2. Digitally enabled industrial water stewardship maturity model components and dimensions.

manufacturing companies charged with both operational and corporate responsibility for industrial water management.

Application

This maturity model is primarily targeted at large industrial water users in the pharmaceutical, chemical, steel, food and beverage, and semiconductor manufacturing sectors, as they provided expert input into its development. However, the broad scope of indicator coverage means that the tool is relevant to almost every industrial organisation regardless of size or sector. To have the greatest impact in terms of implementing guidance from the tool, buy-in from the highest level of the participating organisation (preferably board level) is key. For carrying out the assessment and associated data collection, the following roles are deemed suitable:

- sustainability managers/officers;
- water managers/officers;
- energy managers with responsibility for water;
- environmental managers/officers.

It should be noted that, as the maturity model is cross-sectoral and takes a "one-size-fits-all" approach, it outlines the typical steps that industrial organisations must take to achieve maturity in each dimension. However, in practice, some organisations may skip or ignore indicators or criteria that are not relevant to their specific context (e.g. regularity requirements, water stress). Future sector-specific maturity models for industrial water management could be built on the foundation of the current model to provide tailored guidance and data collection requirements for individual industrial sectors.

The high-level guidance shown in Table 3.1 can be used by industrial organisations to gauge in a simple way their maturity, from level 1 (ad hoc) to level 5 (integrated), in relation to digitally enabled water stewardship at their sites, and explains the general next steps required on the journey towards sustainable water management. The high-level description of each level corresponds with the criteria, indicators and associated evidence that industrial organisations are expected to collect and disclose to demonstrate their maturity level and the type of action required to progress towards water stewardship best practice.

Lessons learned

Initial findings from the application of the maturity model across 20 industrial sites in multiple countries highlight the various stages of both stewardship and digitalisation maturity across sites and the importance that sites give to sectoral benchmark comparison and best practice guidance in driving implementation of digitalisation for industrial water stewardship at their organisations.

Based on semi-structured interviews with 20 experts across 16 organisations in Ireland, Belgium, the Netherlands and Germany, findings from experts on the application of the maturity model relating to the maturity of current industrial water management practices at their sites were as follows:

- Operational managers, production managers and utilities managers were identified as having the greatest responsibility for and impact on water management. However, they are also responsible for energy and production management, which can often lead to water management receiving less attention.
- The subscription to water standards at industrial sites was low.
- Carbon reduction targets are more mature, in terms of reporting, than water targets.
- A payback time of 1.5 to 5 years is company policy for project approval among the majority of those surveyed. This is a challenge for water projects, as their payback times typically exceed this range.
- Companies accepted that accounting for the true cost of water (energy, chemicals, etc. nexus) would decrease the payback time of water projects, but there is currently a lack of awareness of and formalised methods for such calculations.
- Digital integration with municipal service suppliers is limited. However, there are several examples of industrial sites sharing water indicator data with industrial/chemical park water and wastewater providers (Germany and the Netherlands).
- The sharing of information by industrial sites with water service companies, relating to parameters such as predicted water demand, wastewater loads, and temperature and quality of wastewater, was identified as valuable for optimum management of water services by the water service provider in terms of resource efficiency and circularity.

Table 3.1. Industrial Water 4.0 maturity model: high-level dimension descriptions

Dimension	Ad hoc/initial	Defined	Managed	Advanced	Optimised
Water quantity	No importance given to water beyond cost, with water KPI metrics not reported or considerable data gaps from site(s)	All water sources and uses are mapped, risks understood, costs quantified, stakeholders, etc.	All water sources and uses are actively monitored and reported with continuous improvement processes in place	Water use is optimized with respect to other on-site resources and with production, and proactive response to foreseeable regulations	Water use across supply chains, catchments, etc. are managed as a shared resource
Water quality	No consideration given to improving water quality beyond regulatory compliance	All water sources and discharges are characterised in terms of water quality, risks understood, costs quantified, relevant stakeholders identified, etc.	All water sources and discharge quality parameters are monitored and reported with continuous improvement processes in place (beyond regulatory compliance)	Water quality monitoring and management for pollutants of emerging concern and potentially more stringent regulation limits	Water quality across supply chains, catchments, etc. are managed collectively
Water governance	No water resources policy and management plan in place at organisation	A water resources policy and management plan is under development, considering company-specific water source and discharge risks, costs and stakeholders	A water resources policy and management plan is in place which addresses issues of competences, etc.	Water-related decisions are made based on full sight of impacts and interplays across the site	Water-related decisions are made based on full sight of impacts and interplays across the water lifecycle and raw materials lifecycle
Supply chain interaction (water supply chain and wider suppliers)	Interaction with local water utility or service provider only for reasons of payment. The data exchange is mainly analogue or via mail, document	On-site resource management available. Resource management strategy completed. Stakeholder dialogue for fully integrated data management with local water utility or service provider	Automized data exchange with local water utility and environmental data (site and catchment) are available in real time	Optimization of water and resource management and production adapts dynamically on resource availability	Data exchange across organizational boundaries optimizes resource planning and production. Plant compliance, stewardship and authorizations can be realized in real time
Water management and industrial production	No or ad hoc data connection with production and resource management. The production is stable but for major changes and maintenance it needs to shut down	Water and resources are automatically mapped and monitored. Relevant KPI and KEI provide first real-time insights into the production	The digitization at site level is completed. All assets are connected and all production sites are transparent. Water and resources are automatically analysed. First control bots for self-optimization reduce risks and failure	Site and production are agile on fluctuating water and resource availability. Production is full automized. The interaction between water, resources and production is continuously analysed and self-optimized	Production can be considered as smart. The integration of new services is fast. Production adapts automatically on water and resource availability

Table 3.1. Continued

Dimension	Ad hoc/initial	Defined	Managed	Advanced	Optimised
Digitization in industrial water	No or single monitoring of resource paths and consumption. Plant operation is mainly ensured because of long-term experience of the staff	Assessment and evaluation of all available and connected assets. Strategies for sustainable water and resource strategy are developed and included in business and investment strategies	Relevant KPI and sustainability KEI are integrated into site production monitoring. All site data are accessible and plant, process and resource optimization takes place	Data management on water and resource streams across all units improves their use by automatically adjusting and optimizing them on the real-time demands	Water management is fully integrated into the production ecosystem considering the environmental conditions within the catchment and other stakeholders

KEI, key experience indicator; KPI, key performance indicator.

- Several sites said that services provided by third-party organisations were often overpriced, and they planned to implement similar monitoring regimes utilising in-house skills. Conversely, several organisations said that specialised third-party services companies were most competent to manage water because of sectoral expertise, which ensures regulatory compliance for the industrial end user.

The three main challenges to improving industrial water stewardship identified based on stakeholder consultations were as follows:

1. The most common challenge that participant sites reported was the high upfront cost of water projects, with company payback time limitations a significant obstacle to project approval.
2. The second most common challenge was a lack of awareness from top-down management of the importance of water stewardship and digitalisation for industrial water management. However, it was noted that there has been recent progress in this regard, particularly since the COVID-19 pandemic, due to the global shift by companies towards reporting more ESG information and the automation of production facilities to enable them to operate with limited numbers of staff on-site. Evidence of increased top-down buy-in for improved industrial water management is seen through organisations seeking accreditation for water stewardship standards and setting up dedicated task forces to deal with increased customer requirements for industrial water guidance and consulting.
3. The third most common challenge was a lack of risk assessment for operations and supply chains. The identification of key operational risk parameters was a challenge because of the varied types of production from site to site, while access to data from suppliers (beyond monetary spending) was particularly challenging for multinational organisations with globally complex supply chains.

3.3.2 A standardised methodology for water lifecycle mapping

Purpose

Mapping an industrial water system and providing a visualisation of the map produced gives organisations an easy-to-understand format for multiple stakeholders to use, including water managers, senior management, general employees and existing or prospective clients. It enables industry to establish the current state of industrial water management on-site (i.e. water flows, water types, water metering coverage, water balance/footprints, data flows and technologies).

As part of this project, a more standardised approach to industrial water mapping was developed and piloted at three industrial partner sites. A standardised approach not only enables a better understanding of the current state of water lifecycles at different sites but also provides a guide to the potential future state of water stewardship activities when greater adoption of I4.0 technologies is incorporated in industry.

The main advantage of the water mapping standard developed during this research is its adaptability to different industrial site characteristics and priorities.

Application

A standardised mapping template (Figure 3.3) was developed that divides the water system into distinct service types, based on water service types identified in the US EPA Lean & Water Toolkit (US EPA, 2011) and further refined by the authors in association with the project's industry partner sites over a 3-year period. The template follows the flow of water through the site, with water supply entering on the left and the subsequent flow of water to the right towards the final sink. It details the five stages of the water lifecycle, namely:

1. supply and distribution (e.g. abstraction, mains water, alternative supply sources such as harvested rainwater);
2. pre-treatment (e.g. demineralisation, reverse osmosis);
3. end users (e.g. heating/cooling for production, cleaning, ingredient in final product, domestic applications);
4. post treatment (e.g. wastewater treatment);
5. sink (e.g. public sewer, waterbody, tanker).

The template is filled in with the various water processes, showing water flows from left to right across the industrial site from supply and distribution through to the final sink. It is worth noting that a number of sites may have different configurations based on their specific production type (e.g. food and beverage, pharmaceutical) and that the template can be adapted to sites' specific needs (e.g. deleting or adding service types and sub-processes).

The application of a detailed site water map (Figure 3.4) developed using the proposed template is described in Box 3.1.

Lessons learned

Findings from applying a water mapping methodology and tool at industrial sites indicate the importance of using water mapping, not just for its role in helping organisations to understand the water lifecycle but because it provides a platform for subsequent data collection and analysis.

Lessons learned from the application of the mapping tool at industrial sites include the following:

- Water mapping is the first step towards gaining a detailed understanding of the industrial water lifecycle. It enables sites to understand their entire water lifecycle from supply to sink, including the key water types used on-site.
- The mapping tool can be used to gain an understanding of a site's water mass balance. This will help to identify areas of significant water use and problem areas, including water that is unaccounted for and uncontrolled losses.
- A diagnostic mapping tool can identify operational management optimisation opportunities through the identification of water leaks, water process equipment efficiencies, and the potential for reusing water and other resources such as energy and biosolids.

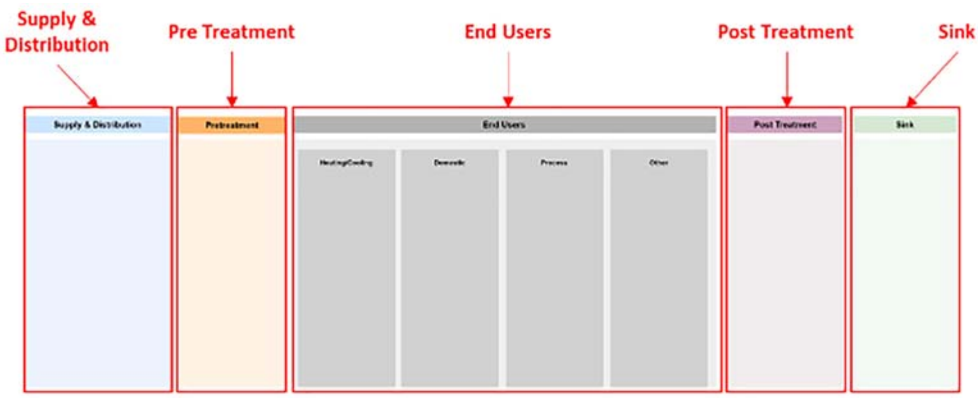

Figure 3.3. Site water mapping template.

Box 3.1. Case study: application of water mapping template by partner organisation

The creation of a site water map enabled one partner organisation to comprehensively understand water flows across its complex pharmaceutical site. The site has over 70 end users for water, while there are 11 different water types within the site's water lifecycle. The map has enabled the organisation to identify significant water users and high-risk areas and understand its site metering coverage. Analysis of certain water types has also enabled it to identify opportunities to reduce and reuse water on-site.

Furthermore, the site has used the map as a tool for communicating with various stakeholders, encouraging behavioural change among employees, presenting business cases for water-related projects to senior managers and demonstrating water management competence to third-party auditors.

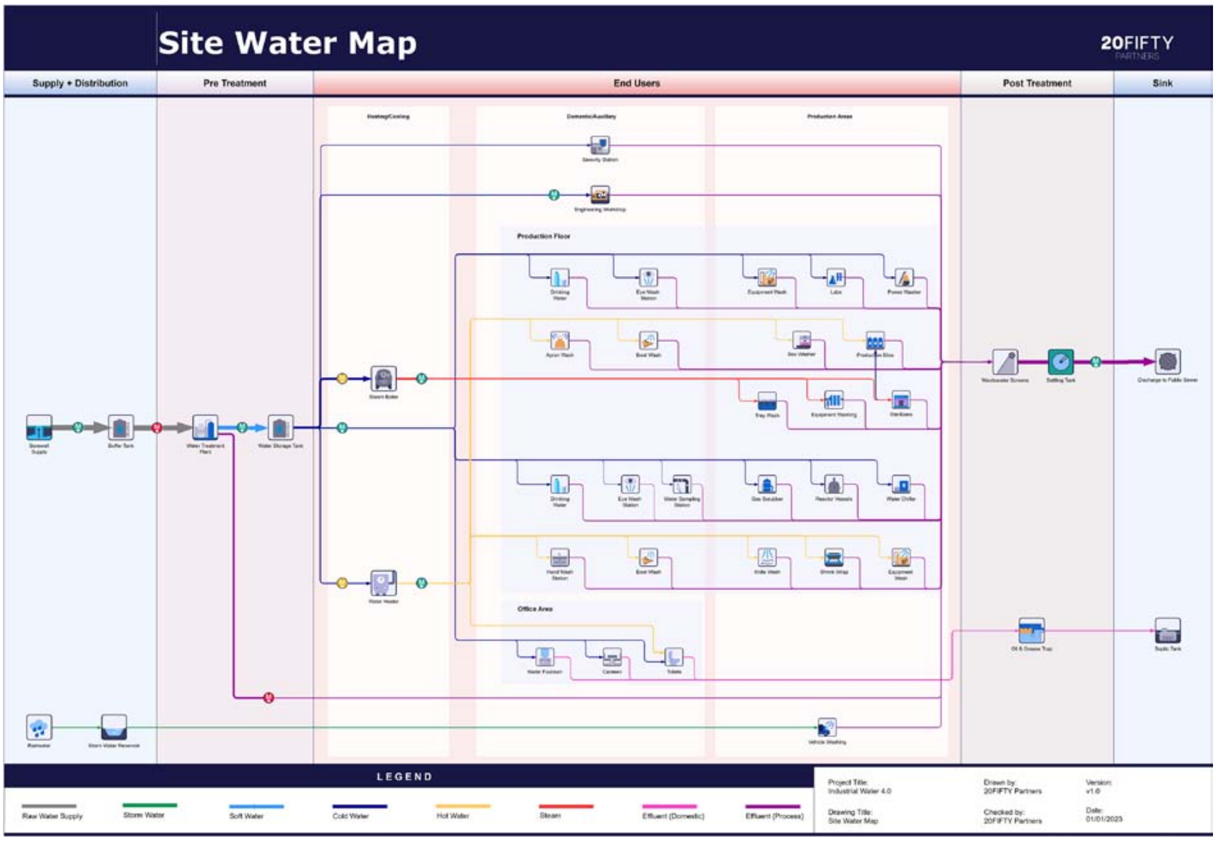

Figure 3.4. Example of a detailed site water map.

- It can inform emergency responses to water equipment/process failures (e.g. what downstream processes will be affected and if a process may need to be shut down or can be bypassed).
- It can be used as a communications tool to demonstrate clearly to stakeholders such as parent organisation management, customers, regulators and water stewardship auditors that the site is managing its water in a proactive manner.
- It can be used to demonstrate evidence of water management that meets water stewardship standard criteria to third-party auditors.
- It can inform calculations of the true cost of water, to justify water projects based on potential cost savings.
- It can improve understanding of the flow of key water types and how they support the identification of key quality-related input and output parameters across significant water users.
- It can support action plan development for responsible industrial water management.
- A water map can be used as a platform, playing an important role in identifying the key quantity data available across the entire lifecycle, a key input into the quantity, quality and cost (QQC) model.

3.3.3 Data audit tool for industrial water risk

Purpose

On-site water systems are highly complex and evolve over time. As one drills down into each major process, the complexity increases and the need to access the following becomes evident if water-related risks are to be identified and controlled:

- quantity data (e.g. from building management systems, flow meters, supervisory control and data acquisition systems, programmable logic controllers);
- quality data (e.g. from laboratory systems, inline monitors, third-party reports);
- cost data (e.g. from financial systems, maintenance systems, energy systems).

For example, in a cooling tower scenario, one cannot simply optimise water quantity or water use without due regard to quality parameters, such as microbial growth, or indeed costs, such as those for maintenance or chemical treatment.

From a data analytics perspective, further complexity is added by the need to incorporate the additional dimensions of location and time into the data models. Therefore, every measurement point in the water lifecycle of the plant has QQC parameters that must be tracked and analysed over time and more importantly in the context of their precise location in the major water processes of the site (Figure 3.5).

Without looking at these dimensions in a holistic manner, risks and optimisation opportunities cannot be fully understood.

Of critical importance to the transition to the increased digitalisation of water management and stewardship at industrial sites will be data availability and the associated evaluation of the quality/representativeness

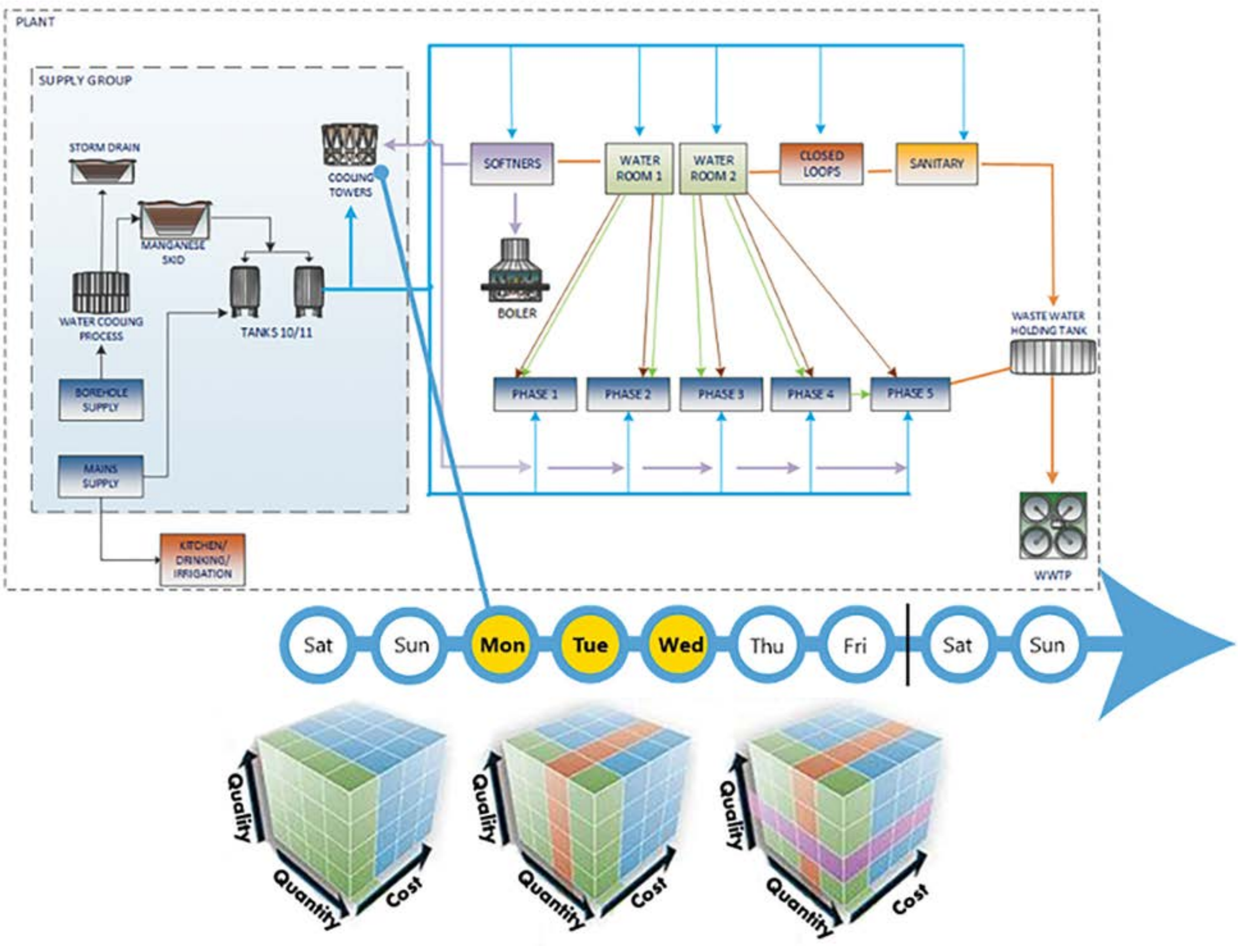

Figure 3.5. QQC model.

of these data to inform site-specific, broader catchment and supply chain action plans.

Data availability is often identified as a barrier to proactive water management at industrial sites, with good quality and timely data a prerequisite for the data analytics and predictive tools offered by IW4.0 technologies in the water domain. Data relating to water at industrial sites primarily include data on water quantity (e.g. water consumption, wastewater discharge volumes) and water quality (e.g. total suspended solids, biological oxygen demand (BOD), nutrient and pollutant concentration), with different data requirements for different sites based on their production type.

To overcome vertical and horizontal data integration challenges and ultimately control risks related to the QQC of water inside and outside site boundaries, first the quality of current data across the water lifecycle must be assessed. This is a key input into the development of a generic data model for IW4.0 and a crucial input into the assessment of risk across significant water users.

The research team have published a risk assessment methodology (Trubetskaya *et al*., 2021a), as shown in Figure 3.6. This can be used as a tool for qualitative and quantitative risk assessment and for decision support at industrial sites. A key finding from using this methodology has been the importance of having a strong data model to inform better risk assessment and management.

Risk assessment generally is an iterative process with the following steps:

- an initial identification of the roots of the risk;
- an analysis of these roots and of the consequences of the risk being realised in the industrial and public water sectors;
- a consideration of their combined risk outcome by evaluating the magnitude of the risk;
- some judgement of the acceptability of the risk;
- a decision on how to act, either in risk mitigation or in demonstrating that the risk is low and the residual risk is being acceptably managed.

The risk assessment process is represented by the continuous control loop that is an iteration of data collection, analysis and decision-making. The risk assessment process suggests actions that can effectively manage the risk followed by any additional mitigating analysis or action. Because the process is iterative, it can be repeated an unlimited number of times to mitigate risks. Risk assessment alone does not reduce risk. It informs the decision-making and associated actions needed to manage risk. Management action related to risk mitigation assumes that the responsibility has been passed to the risk owner, who is accountable for the actions and their completion, so that the risk is mitigated accordingly.

This section outlines the development of a generic template that industrial sites may apply to identify water data availability and quality. It can be tailored to suit sites' specific characteristics and priorities

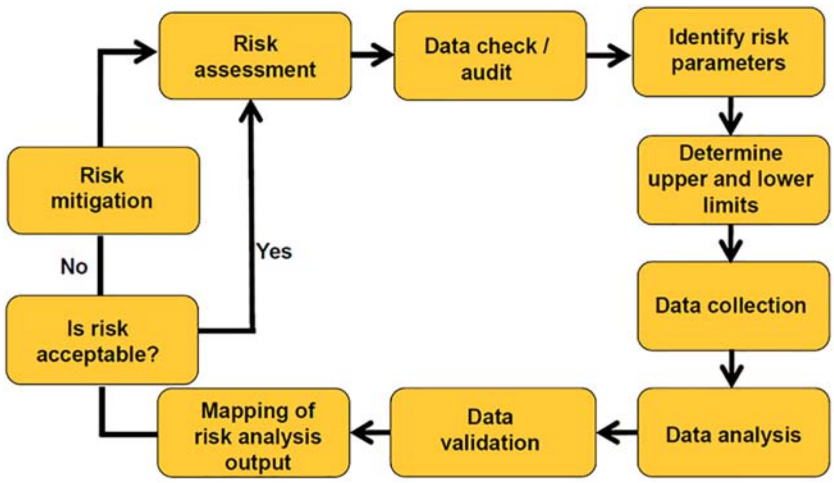

Figure 3.6. Flow chart of risk flow assessment methodology. Source: reproduced from Trubetskaya *et al.* (2021a); licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

to support risk assessment across significant water users. The methodology applied to develop this data model involved the following:

- a comprehensive literature review to identify the key quality input and output risk monitoring parameters across the significant water users identified;
- the development of a data model for standardising the approach to data availability and quality assessment;
- the validation of the data model at industrial sites.

Application

This section summarises the key process steps used to apply the data audit tool.

- Step 1 – Identify key quality input and output risk monitoring parameters across the significant water users identified. As noted in section 3.2, water lifecycle mapping offers a platform for data collection, with the potential to assess data quality on significant water users by source, pre-treatment, end user, post treatment and sink. The research team used the site lifecycle maps developed in section 3.3.2 as a starting point with each partner to define key significant water users on-site and then to identify the key input and output parameters associated with each user.
- Step 2 – Undertake a data audit plan based on a standardised approach to auditing the availability and accessibility of data across each significant water user identified.
- Step 3 – Undertake a data audit assessment to determine the quality of the key data associated with each parameter using best practice criteria for I4.0 data quality assessment.
- Step 4 – Perform a risk assessment post data audit. Following the completion of the water data audit across the three sites, the project team trialled the risk assessment methodology with two significant water users at the partner sites – cooling towers and wastewater treatment plants – using the risk assessment process described above.

Lessons learned

Findings from project participants based on the development and application of a generic water data quality audit tool, a proof-of-concept risk tool for cooling towers, and an academic publication outlining a wastewater-related risk assessment methodology at industrial sites are outlined below:

- **Data quality audit tool:**
  - Participants realise the importance of having access to good-quality data for insightful decision-making relating to water. Good-quality data are a prerequisite for implementing I4.0 solutions such as digital twins and artificial intelligence.
  - Based on the application and validation of the data quality audit template at the three partner sites, it was possible to assess the level of data accessibility, quality (i.e. completeness and validation) and automation controls for significant water users by selecting the input and output quality parameters of most relevance to the site. The scoping questions also enabled the sites to measure against their own benchmarks regarding water data availability and quality.
  - Each of the three sites had different water data management maturity levels. The differences were primarily related to the manufacturing sectors that the sites belong to and the degree of regulatory compliance required in their environments.
  - Perhaps the most notable finding from the application of this tool across the three sites was regarding data accessibility, particularly where third-party service providers were involved in supporting water operations. Issues relating to ownership of and access to data emerged from the findings, with the potential for limited access to create information silos being a major concern for the organisations.
- **Risk assessment methodology and tool for wastewater treatment:**
  - The research team published an approach to assessing wastewater risks for the industrial sector (Trubetskaya *et al.*, 2021a). This paper identified that the potential wastewater-related risks that could hamper the operation of an entire manufacturing facility are currently inadequately defined and under-researched.
  - This study involved a review of the academic and grey literature for parameters of significance to industrial wastewater treatment

and regulatory compliance, and the validation of literature findings through experimental data collection to quantify the impact of significant process parameters on critical process outputs. From a business perspective, managing and minimising risks will be possible when the number of impact parameters is small and the relationships between different parameters are clearly understood.

3.3.4 A standardised methodology for calculating the true cost of water

Purpose

Because of the low direct costs of water, various true cost of water assessments have been developed to help organisations better understand the often-hidden costs associated with industrial water management, such as energy, chemical and materials inputs for water processes (Malhotra *et al*., 2021). The true cost provides a valuable insight into the operation of industrial sites, a means for internal and external benchmarking and internal cost control, and the necessary data to financially justify any modifications required (Walsh *et al*., 2017). Moreover, the data generated from calculations of the true cost of water may be used in the calculation of a water footprint or a lifecycle cost (Walsh *et al*., 2016). While the complexity of the tools available ranges from spreadsheets to web-based platforms, the first step in determining the true cost of water is accurate water accounting (Malhotra *et al*., 2021).

The methodology developed for calculating the true cost of water using the proposed tool is outlined in Figure 3.7, which shows the data collection requirements for industrial sites and the outputs generated, such as a financial summary, by process. Highlighting the indirect financial cost associated with treating and processing water at industrial sites allows a holistic understanding of the cumulative cost and for the true cost of water to be assessed and justified in a coherent, standardised fashion. The insights generated by applying this methodology will allow site water managers to better justify projects by accounting for the indirect costs of water rather than considering the direct cost of water alone, which often leads to projects being deemed financially prohibitive because of unsatisfactory payback times.

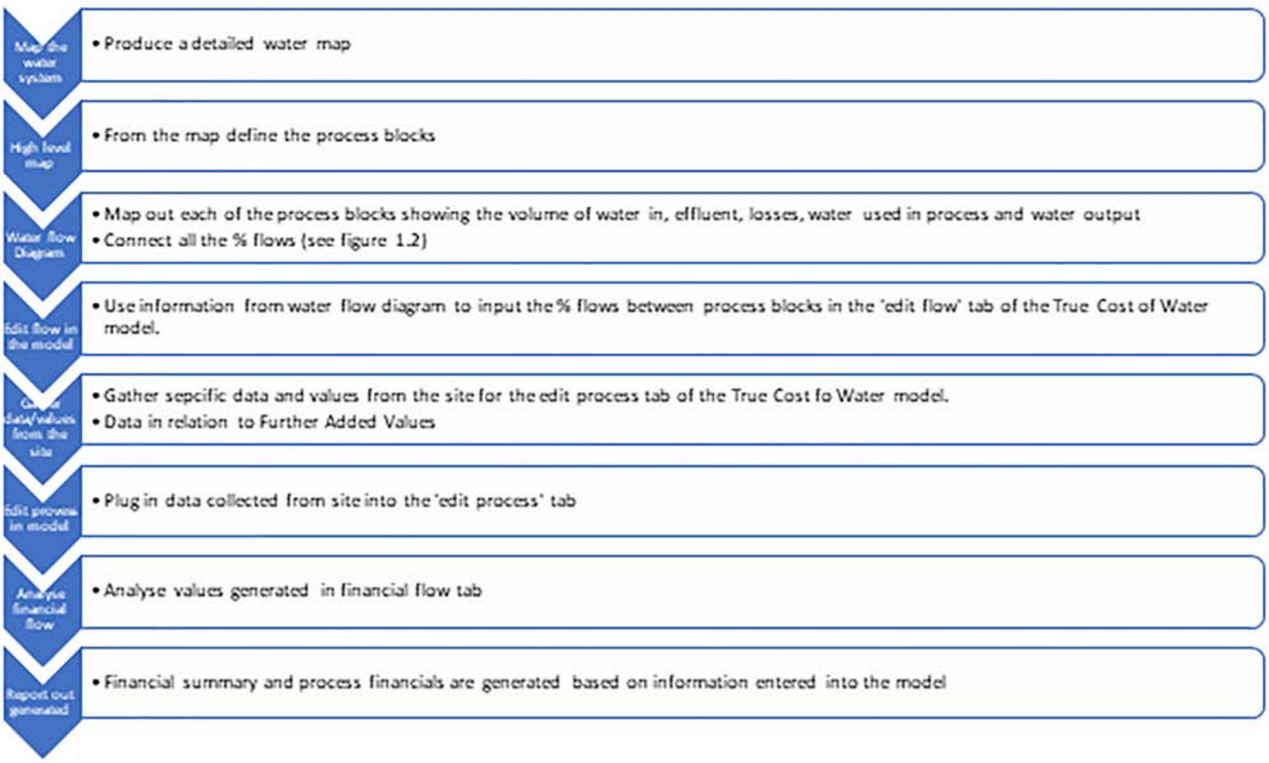

Figure 3.7. Methodology for calculating the true cost of water.

Application

The novel aspect of the proposed model is that it has been developed to aid industrial sites in calculating the true cost of water at points of use (i.e. it is a process-based approach) rather than on a simple whole-site basis, providing greater insight into how costs can be reduced. This model evaluates the water balance of the system accounting for water intake, effluent, water losses, water used by the process and water output. It details where value is added and costs are incurred. The model provides a snapshot analysis of water use and the true value at points of use to assist in developing more sustainable practices that could lead to a reduction in water consumption. Water scarcity is a global issue, and this model helps facilities to understand their water use, the true costs of their water use and potential areas for water savings. The tool also can also determine carbon emissions associated with each cost step to identify potential carbon savings.

Lessons learned

Access to representative data is essential for realistic calculations of the true cost of water. Lessons learned from the application of the tool at industrial sites include the following:

- A good understanding of the location of major indirect water costs in the industrial water system can inform business case development for efficient processes and equipment through optimisation, reconfiguration or replacement.
- As water is the primary energy carrier for heating and cooling at industrial sites, the tool has the potential to identify opportunities for using waste heat and for cost savings.
- The current tool could be further expanded to include a decarbonisation layer, which would involve using emission factors to convert energy and material/chemical data into associated carbon emissions, which could inform decarbonisation measures associated with water management.

Box 3.2. Case study: application of water map to analyse true cost of water at partner site

Mapping the water lifecycle was an important element in the development of the methodology for analysing the true cost of water at one of the partner sites. By identifying significant water users, water types used on-site and key inputs into each, the site used the water map to identify the true cost of water on-site.

This map can enable the site to identify optimisation projects in process areas of known high consumption and high cost. By establishing the true cost of water in key process areas, the site can create a business case based on a return-on-investment/payback period that is significantly more attractive than a business case based on projected incoming and outgoing costs alone.

3.3.5 Supporting future state scenario planning: global megatrends

Purpose

The purpose of this tool is to give industrial sites a way of identifying the main industrial water and regulatory trends (collectively referred to as megatrends) that they may face in the coming years. A review of both the literature and stakeholder consultations has identified a gap in resilience planning across water management in industry, due to departmental silos and data availability issues, that is leaving organisations ill-equipped to deal with emerging global trends.

The development of this tool entailed reviewing national and EU policies and general industrial trends to identify the upcoming megatrends with most relevance to industrial water stewardship and providing industrial sites with a template to outline the relevance of these trends to their specific sites. This will allow sites to prioritise addressing the megatrends that will significantly affect their operations and develop action plans and strategies for successful business resilience.

Based on the research team's national and EU-level policy analysis, engagement with Water Europe's Industry Working Group, the EPA project steering committee and project partner sites, and a review of the academic and grey literature, five global megatrends were identified as likely to be most relevant to the transition to sustainable industrial water management. These megatrends are (1) climate adaptation and water supply risk, (2) zero pollution, (3) decarbonisation, (4) circular economy and (5) emerging technologies and supply routes.

Based on the findings, the other tools in the IW4.0 framework were adapted to support organisations in strengthening their on-site water management to mitigate the potential impacts of each megatrend.

Application

A methodology was developed to help industrial sites develop their current understanding of each of these megatrends and how it specifically relates to their sites both now and in the future.

To test the effectiveness of the approach, a pilot of the proposed megatrend exercise was carried out with the three project partner sites (Table A2.1) prior to engagement with wider industrial organisations. A template was devised to identify the key drivers, challenges and opportunities related to analysing the potential impact of the megatrends on organisations' water management at their sites, on their business models and in their catchments.

The project team then held an industry-wide workshop at the Water Stewardship Ireland Community of Practice Meeting on 12 May 2022. The workshop involved presenting the preliminary research findings from the IW4.0 project and discussing the collective challenges and opportunities facing industrial water management in Ireland. The future state scenario planning (megatrend analysis) template was presented to 16 Community of Practice members, followed by the distribution of a worksheet asking participants for written feedback on the potential impact of each megatrend on their site. Responses were received from participants across a diverse range of sectors – the food and beverage, pharmaceutical and life sciences, healthcare and transport sectors – and national agencies. A summary of participant responses about each megatrend is shown in Table A2.2. Participants were also asked to rank the megatrends in terms of perceived importance to their industrial sites. The order was as follows:

1. climate adaptation and water supply risk;
2. zero pollution;
3. decarbonisation;
4. circular economy;
5. emerging technologies and new supply routes.

Notably, the two most important megatrends to industrial sites, namely climate adaptation and water supply risk and zero pollution, reflect the top-down policy emphasis that each of these megatrends receives at the EU level and national level in Ireland.

Lessons learned

Views of workshop participants from industrial sites about each megatrend's relevance to their sites are outlined below and summarised in Table A2.2.

Appendix 2 summarises the key findings from the stakeholder consultations with industrial partner sites and the workshop with Water Stewardship Ireland Community of Practice members on the drivers, challenges and opportunities across the five megatrends identified.

3.4 Themes from the Application of the Industrial Water 4.0 Framework

This section presents the main findings from consultations on and the application of the IW4.0 framework. These are based on consultations with experts from across Europe, an analysis of the industrial engagement insights generated using the IW4.0 framework and the application of each of the framework component tools by the three partner industrial sites.

3.4.1 Limited appreciation of the true value of water at corporate level

A recurring theme across the stakeholder consultations was the lack of emphasis placed on the value of water by organisations at senior management level, with a lack of awareness from top-down management of the importance of water stewardship and digitalisation for proactive industrial water management.

This is seen most acutely in the funding challenge facing participant sites in gaining approval for water optimisation projects. The high upfront cost of water projects slows large-scale deployment of water-focused projects, with company payback time limitations for asset procurement a significant obstacle. Payback time limits for projects are typically 1.5 to 5 years among most of the participating organisations. This is a challenge for water projects, which typically exceed this range. Companies accepted that mapping their water and accounting for the true cost of water (energy, chemicals nexus) would improve the payback time of water projects, but there is currently a lack of awareness of and formalised methods for such calculations.

Recently, progress has been made in recognising the true value of water due to the global shift by companies towards more reporting of ESG information. Moreover, the COVID-19 pandemic has accelerated the transition towards automating production facilities to enable these to operate with limited staff on-site. Based on the increasing number of companies that will be required to report non-financial data in the upcoming CSRD, more organisations will be required to report on water quantity and quality parameters beyond solely large water users.

Evidence of increased top-down buy-in to improved industrial water management is seen through organisations seeking accreditation for water stewardship standards and setting up new dedicated task forces to deal with increased customer requirements for industrial water guidance and consulting. To aid industrial sites in this regard, there is a need to raise awareness among enterprises of the true value of water to business and to support the roll-out of water stewardship competency development programmes and initiatives for employee upskilling and site verification schemes.

3.4.2 Limited national support for organisations to commence decarbonisation of the industrial water lifecycle

Recently, a more holistic approach to the resource management of the industrial water lifecycle and its impact on carbon and energy has received significant attention. This has led to an emerging research field, referred to as the energy–water–carbon (EWC) nexus, the aim of which is to understand the complexities and possible synergies involved in taking an integrated approach to the management of resources and to provide guidance to accelerate the transition to a low-carbon society.

Currently, significant data gaps exist in relation to GHG emissions for the industrial water lifecycle in Ireland, and, during stakeholder consultations, industrial sites cited the need for national sectoral benchmarks and emission factors.

Moreover, publicly available data are limited on industrial site water processes and associated carbon emissions throughout Europe, primarily because these data are commercially sensitive. Currently, there is no detailed roadmap for the decarbonisation of the Irish industrial sector beyond the high-level targets of the Climate Action Plan 2021 (DECC, 2021a).

A review of national industrial decarbonisation strategies throughout Europe found that almost all focus exclusively on eliminating emissions associated with site operational energy requirements by decarbonising energy sources and improving energy use efficiency. Limited attention is given to how improved site water management and stewardship could reduce on-site, upstream and downstream GHG emissions. However, a number of national industrial decarbonisation strategies have highlighted the potential role of improved water management in the transition to a low-carbon society. The UK Industrial Decarbonisation Strategy (DBEIS, 2021b) details actions needed to decarbonise the industrial sector and refers to the contributions of improved water efficiency to energy and emission reductions. The relevance of water to decarbonisation has also been highlighted for the paper and board industry in the Netherlands (TNO, 2021).

Given the significant role that water plays in industrial site production processes, energy systems and associated GHG emissions, it is envisioned that the EWC nexus will receive greater attention in future industrial decarbonisation strategies (Trubetskaya *et al*., 2021b). By linking proactive water management to meeting decarbonisation/net-zero priorities at industrial sites, water projects become more important strategically.

Water utility sector decarbonisation roadmaps across Europe

Lessons for the decarbonisation of industrial water management can be learned from international climate mitigation roadmaps for water utilities in the UK (Water UK, 2020) and in Denmark (Danish EPA, 2021) and other Scandinavian countries (Larsen *et al*., 2022). These outline the decarbonisation potential of renewable energy sources for electricity and thermal energy requirements, improving operational efficiency through operation optimisation and upgrading old infrastructure, resource recovery, and carbon sequestration and offsetting. Rani *et al*. (2022) propose pathways for a net-zero-carbon water sector through energy-extracting wastewater technologies and identify four key strategies to achieve energy efficiency in the water sector, namely (1) improving process energy efficiency; (2) maximising on-site renewable capacities and biogas upgrading; (3) harvesting energy from treated effluent; and (4) providing a new paradigm for decentralised water-energy supply units. The European Commission's 2022 proposal for updating the Urban Waste Water Treatment Directive aims to make the wastewater sector energy neutral and move it towards climate neutrality (i.e. reduce GHG emissions by 62.5% compared with 1990) by reducing energy use, using the larger surfaces of some wastewater treatments plants to produce solar or wind energy, encouraging water reuse and using sludge to produce biogas, which can replace natural gas (EC, 2022a).

Lessons learned on emissions accounting and emission factors in the water sector (US EPA, 2010; Danish EPA, 2021; UKWIR, 2022a) and case studies on the deployment of decarbonisation technology in the Irish industrial water sector are outlined in Appendix 3.

National policymakers will need to be cognisant of the relationships between climate action and other policy areas at the EU and national levels to identify potential synergies and challenges. For example, the EU Zero Pollution Action Plan outlines a number of high-level targets that may require more stringent wastewater emission limits at water service, industrial and energy facilities. These typically require more energy-intensive processes and/or additional chemical and material inputs, which in turn result in greater direct and indirect GHG emissions. Understanding these trade-offs will allow for more coherent national polices to help meet climate action targets.

3.4.3 Digitalisation of industrial water management and integration with production at a nascent stage

Aligned with observations made by the EU ICT4Water cluster, this research project has identified that industrial water end user process digitalisation and integration with production technology is currently implemented at only a low level throughout Europe. However, several experimentation and demonstration projects offer potential pathways to mainstream deployment. Among the sites involved in this research, any water process digitalisation and integration with production data that has occurred has often been only at site level. Data exchange with parent organisations (enterprise resource planning systems, manufacturing execution systems, etc.) is often limited because of cybersecurity concerns surrounding commercially sensitive information, but also because many sites avoid sharing information if there is no legal requirement to do so, as it requires additional resources for limited or no perceived added value. Access to data from third-party service providers responsible for water processes on-site was also limited, with issues surrounding data ownership and sharing.

3.4.4 Third-party ownership of data non water quantity and quality can lead to information silos

Perhaps the most notable finding from applying the data audit tool across the three project partner sites was regarding data accessibility, particularly where third-party service providers were involved in supporting water operations. Issues of data ownership and access emerged as significant, with limited access to data resulting in information silos among industrial sites and their service providers.

A finding from interviews with stakeholders on the application of the maturity model was that several sites found services provided by such third-party organisations often to be overpriced and they plan to implement similar monitoring regimes using in-house skills within their organisation. Conversely, a number of organisations said that specialised third-party companies were most competent to manage water because their sectoral expertise ensures regulatory compliance for the industrial end user.

3.4.5 Digitally integrated water catchment opportunities for industrial water

Findings from consultations with industrial sites across Europe indicated that the identification of key water risk parameters is a challenge for specific sites because of the various types of production water and wastewater profiles and different local catchment characteristics (e.g. hydrology, climate, weather events, population, built environment, industrial intensity, conservation areas). Moreover, access to supply chain data from business suppliers, beyond monetary spending, is particularly challenging for multinational organisations with globally complex supply chains.

Data exchange interfaces between industrial sites (e.g. in industrial estates) and more generally between municipal supply/treatment, industry end users and environmental regulators offer the potential to generate high-resolution digital twins of water systems for improved operational management insights, maintenance planning, emergency response preparedness and capital planning. Based on interviews with industrial site participants, digital integration between water service providers and industrial sites is more mature in Germany and the Netherlands than in Ireland, with real-time monitoring of customer water consumption and the quality of wastewater emitted from industrial sites representing a crude digital twin of water distribution and treatment for a group of industrial sites. However, a lack of data integration was observed between industrial site water management systems and industrial production systems, which limits the optimal treatment and circularity of water on behalf of the industrial water service provider. The sharing of information by industrial sites with water service companies relating to parameters such as predicted water demand, wastewater loads, temperature and the quality of wastewater was identified as valuable for optimum water service management in terms of resource efficiency and circularity.

While tools are freely available for identifying general water risk hotspots for water stress, flooding and quality, as is associated guidance on how these risks may change over time at the national and regional levels, anecdotal evidence from stakeholders suggests that these tools are limited in terms of informing risk resilience planning at individual industrial sites because of the lack of detail available at the sites.

3.4.6 Going beyond compliance to address shared water challenges

Engagement with industrial sites as part of this project shows that they view water stewardship standards as paramount in demonstrating their sustainable water management efforts. However, the standards are often viewed as overly complex and time, labour and data intensive, particularly for organisations new to water stewardship.

This is evident in the relatively low adoption levels of these standards among industrial sites. Among the stakeholders consulted with multiple sites globally, there was a reluctance to commit to multi-site certification because of the perceived limited value of achieving certification because of the high cost of certifying several sites coupled with the complexity of data collection and sectoral benchmarking on a site-by-site basis.

Despite this, most stakeholders interviewed noted the importance of engaging in better water governance and more proactive water stewardship in their catchments. This was observed particularly among sites with a broad global reach in numerous instances of supporting other global sites and suppliers and customers in developing countries to ensure good water governance.

One stakeholder noted that one of their client plants in India is not allowed to release any wastewater from its site and instead must incinerate it all to comply with water regulations, which offers no incentive for water efficiency and quality improvement. Another stakeholder mentioned a policy at its plants in water-scarce areas, where the company has set a target to be net-water positive by 2025 and to replenish more than 100% of the water they extract in water-stressed regions by filling local aquifers.

It was observed that multinational organisations must consider local laws, regulations and socio-economic contexts when setting global goals and targets relating to water governance, as the implementation potential may be significantly affected by local water management conditions. These examples highlight the complexity of different national regulations and their impact on the ability of multinational organisations to implement water governance globally as they strive to go beyond compliance and become active water stewards.

3.5 Summary

Building on the IW4.0 concept developed by DECHEMA (outlined in Chapter 1) and reflecting on the key challenges facing industry in digitalising the management of water lifecycles, this chapter has proposed a framework to support organisations in adopting IW4.0 at their sites.

Based on the insights gained from both the literature review (Chapter 2) and the application of the IW4.0 framework (Chapter 3), Chapter 4 outlines the key recommendations identified.

4 Recommendations

In this chapter, the five key recommendations based on the project's findings are provided.

4.1 Recommendation 1: Put More Emphasis on Water in National Climate Action Policies and Research to Drive Decarbonisation and Water Circularity Opportunities Across Industry

The primary focus of water policy at EU level and national level in Ireland is preventing pollution and adapting to climate change impacts. The vital role of water in supporting national climate action and circularity strategies is often undervalued both nationally and across industry.

While mitigating the threat from climate change to water security is a key consideration, proactive water resource management can also contribute to meeting GHG emission reduction targets through decarbonising energy sources for water services and improving the efficiency of resources for treating and distributing water.

Evidence of more holistic water policymaking at the EU level – namely the proposed revision to the Urban Waste Water Treatment Directive, which sets targets relating to climate action and circularity policy objectives for the water sector (EC, 2022a), and the proposed CSRD's (EU, 2022a) business reporting disclosure requirements for water and marine resources – provides a clear signal to national policymakers that more emphasis should be given to water in policy areas such as climate mitigation, circularity and emerging technology supply routes. At the same time, better guidance and tools are needed for industrial sites and national water service providers to enable them to engage with and address these top-down policy signals proactively.

The *Whole of Government Circular Economy Strategy 2022–2023 "Living More, Using Less"* (DECC, 2021b) highlights the interconnection between the "take–make–waste" model of consumption and the enormous negative impact of this on our critical water resources nationally. This reality is often poorly understood, but it is likely that we will feel the impact of climate change and the linear economy most profoundly through water – in both our businesses and our daily lives.

The EU's Second Circular Economy Action Plan (EC, 2020b) draws attention to the need to include actions in areas with high potential for circularity and specifically identifies the area of water and nutrients as one such opportunity. We believe that this is the correct approach to take. Ireland's water sector does have significant potential to exemplify the principles of a circular economy. Areas of potential include:

- water efficiency and recycling;
- carbon emission reduction and sequestration;
- energy recovery;
- materials recovery.

However, translating this potential into reality will require significant changes nationally to policies, support programmes, water management models, technologies, regulation and infrastructure design.

Hence, we believe that unlocking the potential for addressing both decarbonisation and circularity in the water sector requires greater attention to be paid to this area in national policies, the associated support programmes and the associated stakeholder and implementation groups. It will be important for policymakers to be cognisant of the relationships between climate action, water and other national policy areas to identify potential synergies and challenges.

Understanding these trade-offs will allow for more coherent national polices and underlines the importance of understanding the EWC nexus in meeting climate action targets.

4.2 Recommendation 2: Develop a National Roadmap for Decarbonisation of the Industrial Water Lifecycle

While mitigating the threat that climate change presents to our water security should be a key consideration in national climate policy, proactive water resource management can also contribute to meeting GHG emission reduction targets through decarbonisation of energy sources for water services and resource efficiency in the treatment and distribution of water. Furthermore, there is potential for resource recovery of water, energy, biosolids and nutrients (such as phosphorus and nitrogen) and the associated upstream and downstream GHG emission savings.

Findings from the stakeholder consultations and comprehensive literature review have identified a gap in international best practice that prevents Irish organisations from meeting reporting requirements for international water stewardship standards because of the significant data gaps relating to the energy requirements of their industrial water processes and the associated emissions.

National decarbonisation and climate mitigation roadmaps for water have been developed in the UK (Water UK, 2020) and Denmark (Danish EPA, 2021). These outline the decarbonisation potential of renewable energy sources for electricity and thermal energy requirements, improving operational efficiency through optimisation and upgrading old infrastructure, resource recovery, GHG sequestration and offsetting. Furthermore, as well as including energy-related emissions (fossil fuel combustion), the Danish EPA's methodology for defining and measuring GHG emission levels includes assessing process and fugitive emissions from water and wastewater treatment plants.

Based on lessons learned from the European water sector, the authors recommend that a national roadmap for decarbonisation of the industrial water lifecycle in Ireland is developed with input from various national stakeholders.

The decarbonisation roadmap should:

- Provide a baseline of GHG emissions associated with Ireland's industrial water lifecycle through the development of an industrial sector GHG footprint tool that accounts for on-site (including fossil fuel combustion, process and fugitive) emissions, and upstream and downstream emissions associated with water processes at industrial sites.
- Identify successful case studies of industrial water decarbonisation measures (e.g. on-site renewable energy generation, energy and/or water efficiency measures and industrial symbiosis) in Ireland and internationally, and estimate the GHG emission reduction potential from sector-wide deployment of these measures in the Irish industrial water sector.
- Identify relevant national stakeholders and their supportive roles in the decarbonisation of the industrial water lifecycle (e.g. Irish Water, Sustainable Energy Authority of Ireland (SEAI), EPA, Office of Public Works (OPW), Commission for Regulation of Utilities (CRU), industry, communities, citizens).

4.3 Recommendation 3: Establish a National Dataset for Industrial Water Use

In 2022, Water Europe and CDP issued a joint declaration urging EU Member States to support the provision of consistent water information to enable organisations to tackle climate-driven water-related challenges via the Industrial Emissions Directive. This declaration noted that increasing the efficiency of our water systems can help to reduce GHG emissions by up to 10% (Water Europe, 2022).

Aligning with that declaration, the findings in this report identify a need to collate and analyse industrial water data to support the achievement of a "water-smart" society. A review of emerging policies via the literature review and extensive stakeholder consultations on the digitalisation of industrial water management have identified the strong opportunities for and benefits to industry, municipal authorities and other stakeholders (such as the EPA and Irish Water) of enhancing data collaboration to support better water stewardship.

The establishment of a national dataset for water will allow for greater oversight of industrial water management by identifying water risks to organisations, ensuring greater recognition of the true value of water, and inform future water research and development strategies. The development of an integrated national dataset for water stewardship that incorporates information from Irish Water and initiatives such as the CWS programme would provide detailed data on industrial water use in Ireland, allowing for the characterisation of water use and stewardship by large and medium industrial water users and supporting targeted interventions to support national efforts to reduce water use and conserve water.

4.4 Recommendation 4: Establish a National Talent Development Programme to Apply Industry 4.0 to Water Stewardship and Broader Enterprise Sustainability Practices

Despite Ireland's position as a leader in industrial water stewardship in Europe, to ensure continued business operations, more work is needed to promote education and raise awareness among organisations about the material risks (including operational, financial, regulatory and reputational) associated with water, to ensure that they understand both the true value of water and the business case for more proactive industrial water management. For example, the cost of inaction in regard to water risks in Europe is estimated to be five times higher than the investment needed to tackle water-related risks to industrial activities (CDP, 2021).

Stakeholder consultations outlined organisations' need for continued investment in skills and competency development to support them in transitioning to more sustainable organisations. The European Green Deal is expected to create 2.5 million additional occupations requiring specific competencies. However, the growth in green occupations is currently not equalled by a similar growth in the number of professionals with the requisite green skills (LinkedIn, 2022; Microsoft, 2022).

Ireland has identified the need to invest in upskilling its workforce to optimise opportunities and strengthen its climate change mitigation efforts. The fifth pillar of Future Jobs Ireland focuses on transitioning to a low-carbon economy (Government of Ireland, 2019a), while principle 2 of the Climate Action Plan 2021 strives to ensure that people are equipped with the right skills to participate in and benefit from the future net-zero economy (DECC, 2021a).

However, findings from this research suggest there is a gap in the delivery of skills and competency development needs across existing enterprises and that addressing this gap is vital to achieving net-zero ambitions. Of the more than 50 actions in the enterprise section of the CAP 2021, only one relates to skills development. As outlined in recommendations 1 and 2, the authors believe that focusing on developing water-related skills in organisations throughout the country can support our key climate goals. In particular, there is a need for more water researchers, practitioners and apprentices that are equipped with skill sets across areas such as water management, data collection and analysis, best practice and corporate reporting to support organisations to make their transition.

Although this research focused primarily on water, it became apparent that these skill sets are also required in areas such as waste and circularity, energy and emission management, biodiversity and broader sustainability strategy. Furthermore, a lack of coherence in sustainability standards is creating a fragmented reporting landscape and leading to global investor dissatisfaction. Recent changes in the sustainability reporting landscape, such as the upcoming CSRD, will drive the adoption of legislation for businesses across Europe that requires them to publish detailed information on sustainability data; however, uncertainties remain about the interoperability of standards (PwC, 2022). These significant alterations to a business structure will require profound changes in design, production, services, consumption and investment that will be impossible to achieve without skilled people (CEDEFOP, 2021a). All industries will see the demand for certain skill profiles increase and the demand for other skills decrease, as well as the emergence of new occupations and the need to up- or reskill people in existing environmental and non-environmental jobs (CEDEFOP, 2021b). As a result, directives such as the CSRD will present a competency-based challenge for most companies.

We believe that further support is required to complement existing initiatives and underpin a just transition for all. As well as reskilling and providing support for developing new skills, upskilling among existing businesses to address climate action needs to be a priority and requires a more specific focus on transitioning these firms. There is a clear need to understand and build the competencies of the current workforce to enable mitigation and adaptation activities. Therefore, a key priority should be focusing on identifying businesses that need support with this transition and providing that support.

4.5 Recommendation 5: Undertake Further Research into and Development of the IW4.0 Framework

The current project has developed several tools to help industrial organisations on their journey towards proactive water stewardship. Each of these tools was developed to enable organisations from any industrial sector to assess their current state and to provide prescriptive guidance on the next steps in their transition to a desirable future state of industrial water management. Although each of these tools provides generic guidance for the industrial sector, successfully implementing industrial water stewardship will require further refinement and evolution of the proposed tools as the water agenda receives more attention from industrial organisations, policymakers and academic researchers.

Through stakeholder consultations with industry experts from across Europe, it has become apparent that IW4.0 has the potential to become a pan-European framework for smarter water stewardship, combining traditional elements of water stewardship with digitalisation of the water lifecycle, enabling organisations to support the EU's ambition to become a water-smart society. The various framework components have been designed to be generic and scalable, enabling organisations across Europe to assess their current levels of maturity with regard to IW4.0 before receiving guidance and support (e.g. standardised methodology for water mapping, data quality templates, methodology for calculating the true cost of water, megatrend analysis) on how to increase their maturity level as they increasingly adopt IW4.0 practices in their organisations.

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Abbreviations

BOD	Biological oxygen demand
C3S	Copernicus ECMWF Climate Change Service
CapEx	Capital expenditure
CRU	Commission for Regulation of Utilities
CSRD	Corporate Sustainability Reporting Directive
CWS	Certified Water Stewardship
DECHEMA	Deutsche Gesellschaft für chemisches Apparatewesen (German Society for Chemical Engineering and Biotechnology)
EAP	Environment Action Programme
EPA	Environmental Protection Agency
ESG	Environmental, social and governance
EU	European Union
EWC	Energy–water–carbon
GDP	Gross domestic product
GHG	Greenhouse gas
I4.0	Industry 4.0
ICT	Information and communications technology
IIoT	Industrial Internet of Things
IoT	Internet of Things
IW4.0	Industrial Water 4.0
IWaSP	International Water Stewardship Programme
JRC	Joint Research Centre
KPI	Key performance indicator
NDP	National Development Plan 2021–2030
NPF	National Planning Framework
OpEx	Operating expenditure
OPW	Office of Public Works
QQC	Quantity, quality and cost
SDG	Sustainable Development Goal
SEAI	Sustainable Energy Authority of Ireland
UKWIR	UK Water Industry Research
WFD	Water Framework Directive
WWF	World Wide Fund for Nature

Appendix 1 Industrial Water 4.0 Maturity Model Findings

A1.1 Detailed Lessons Learned

The initial findings from applying the maturity model across 20 industrial sites in multiple countries show the various degrees of both stewardship and digitalisation maturity across sites, and the importance that industrial sites place on sectoral benchmark comparison and best practice guidance to drive implementation of industrial water stewardship digitalisation in their own organisations.

Based on semi-structured interviews with 20 experts across 16 organisations in Ireland, Belgium, the Netherlands and Germany, findings from experts on the application of the maturity model relating to the maturity of current industrial water management practices at their sites were as follows:

1. Operational managers, production managers and utilities managers were identified as the most senior people on-site and as having the greatest responsibility for and impact on water management. However, they are also responsible for energy and production management, which can often lead to water management receiving less attention.
2. The subscription to water standards at industrial sites was low, with the majority of sites following internal water standards but not seeking external accreditation as is the case with broader energy and sustainability standards (e.g. ISO 50001/14001).
3. Carbon reduction targets are more mature, in terms of reporting, than water targets, with all but one company having carbon reduction targets of some description and six companies having no corporate-level water targets.
4. A payback time of 1.5 to 5 years is company policy for project approval among the majority of the participating organisations. This is a challenge for water projects, as their payback times typically exceed this range. Moreover, companies accepted that accounting for the true cost of water (energy, chemicals, etc. nexus) would decrease the payback time of water projects, but there is currently a lack of awareness of and formalised methods for such calculations.
5. Digital integration with municipal service suppliers is limited. However, there are a number of examples of industrial sites sharing water indicator data with industrial/chemical park water and wastewater providers (Germany and the Netherlands).
6. The sharing of information by industrial sites with water service companies, relating to parameters such as predicted water demand, wastewater loads, temperature and quality of wastewater, was identified as valuable for optimum management of water services by the water service provider in terms of resource efficiency and circularity.
7. Several sites said that services provided by third-party organisations were often overpriced, and they planned to implement similar monitoring regimes using in-house skills. Conversely, a number of organisations said that specialised third-party services companies were most competent to manage water because of sectoral expertise, which ensures regulatory compliance for the industrial end user.

The three main challenges to better industrial water stewardship identified based on stakeholder consultations were as follows:

1. The most common challenge that participant sites reported was the high upfront cost of water projects, with company payback time limitations a significant obstacle to project approval.
2. The second most common challenge was a lack of awareness from top-down management of the importance of water stewardship and digitalisation for industrial water management. However, it was noted that there has been recent progress in this regard, particularity since the COVID-19 pandemic, due to the global shift by companies towards reporting ESG information and the automation of production facilities to enable them to operate with limited numbers of staff on-site. Evidence of increased top-down buy-in

to improved industrial water management is seen through organisations seeking accreditation for water stewardship standards and setting up dedicated task forces to deal with increased customer requirements for industrial water guidance and consulting.

3. The third most common challenge reported was a lack of risk assessment for operations and supply chains. The identification of key operational risk parameters was a challenge because of the varied types of production from site to site, while access to data from suppliers (beyond monetary spending) was particularly challenging for multinational organisations with globally complex supply chains.

Appendix 2 Supporting Future State Scenario Planning: Global Megatrends

A2.1 Detailed Application

A methodology was developed that helps industrial sites to identify their current understanding of each of the global megatrends mentioned in section 3.3.5 and how it specifically relates to their sites both now and in the future.

To test the effectiveness of the approach, a pilot of the proposed megatrend exercise was carried out with the three project partner sites (Table A2.1) prior to engagement with wider industrial organisations. A template was devised to identify the key drivers, challenges and opportunities related to analysing the potential impact of the megatrends on organisations' water management at their sites, on their business models and in their catchments.

The project team then held an industry-wide workshop at the Water Stewardship Ireland Community of Practice Meeting on 12 May 2022. The workshop involved presenting the preliminary research findings from the Industrial Water 4.0 project and discussing the collective challenges and opportunities facing industrial water management in Ireland. The future state scenario planning (megatrend analysis) template was presented to 16 CoP members followed by the distribution of a worksheet asking participants for written feedback on the potential impact of each megatrend on their site. Responses were received from participants across a diverse range of sectors – the food and beverage, pharmaceutical and life sciences, healthcare and transport sectors – and national agencies. A summary of responses about each megatrend is shown in Table A2.2. Participants were also asked to rank the megatrends in terms of perceived importance to their industrial sites. The order was as follows:

1. climate adaptation and water supply risk;
2. zero pollution;
3. decarbonisation;
4. circular economy;
5. emerging technologies and new supply routes.

Notably, the two most important megatrends to industrial sites, namely climate adaptation and water supply risk and zero pollution, reflect the top-down policy emphasis that each of these megatrends receives at the EU level and national level in Ireland.

A2.2 Lessons Learned

Insights from workshop participants from the industrial sites into the relevance of each megatrend to their site are outlined in the sections below and summarised in Table A2.2.

A2.2.1 Megatrend 1: climate adaptation and water supply risk

As noted at the start of this report, access to water is vital for continued business operations, and lack of water is a limiting factor in production (i.e. no water = no production). Findings from stakeholder engagement activities suggest that sites in Ireland are acutely aware of this, from the perspectives of both potential climate change impacts and upcoming legislation, namely the newly proposed water abstraction bill, which will require large water users that currently abstract water to apply and adhere to more stringent water abstraction licences. The proposed General Scheme of the Water Environment (Abstractions) Bill 2018 provides draft legislation aimed at ensuring that Ireland complies with its obligations under the WFD, with abstractions of 2000 m^3 or more per day requiring EPA licensing under the proposed legislation (DHPLG, 2018). In addition, abstractions of 250 m^3 or more per day may require licensing if they are deemed by the EPA to represent a significant abstraction pressure to an "at risk" waterbody, while it will be compulsory to register an abstraction of 25 m^3 or more per day.

The EPA estimates that 6% of waterbodies are potentially at environmental risk because of abstraction pressures (DHPLG, 2018), a figure that may increase in future as a result of pressures such as increasing population, and industry and agricultural activities.

Table A2.1. Application of template by three project partner sites to identify drivers, challenges and opportunities across identified megatrends

Megatrend	Drivers	Challenges	Opportunities
Climate adaptation and water supply	**Operational –** Water temperatures over 25°C cause issues with discharge into rivers (typically requires cooling) **Operational –** Storm water could affect quality of abstracted water, while river abstraction and discharge may present issues where water shortages occur (rivers are becoming drier) **Operational –** Potential for flood risks increasing **Operational –** Business Continuity – No Plan B for Water; all sites have limited water storage capacity on sites **Reputational –** Stakeholders noted growing need to showcase their environmental credentials through verifiable, impact-based reporting to stakeholders across their value chains. Customers are increasingly educated in this space and place added emphasis on organisations that are able to communicate their sustainability credentials. Consumer pressure was identified by stakeholders as a key reason for suppliers' increased engagement in schemes such as Origin Green and Science-Based Targets	Behavioural change required, e.g. "we're not going to be affected in Ireland so why conduct risk assessments/mitigate risks?" Assessing potential impact of climate change on water from a quality as well as a quantity perspective	Putting water on the agenda – communicating the need to protect and conserve water on site as an issue of material importance to the organisation
Zero pollution	**Operational –** Water temperatures over 25°C cause issues with discharge into rivers (typically requires cooling) **Financial –** Additional costs of wastewater treatment **Regulatory –** EU Regulation on Zero Pollution and CSRD will drive change **Regulatory –** Recurring theme among partner sites is the quest to "go beyond compliance" **Reputational –** Going beyond compliance resonates with consumers, stakeholders, investors and the EPA and other regulatory bodies	Cost is an issue – can get to 95% treatment but getting the extra 5% towards zero pollution presents financial and technical challenges (e.g. UV treatment) Buy-in from senior management is an issue in going beyond compliance	To project a positive image of the site

Table A2.1. Continued

Megatrend	Drivers	Challenges	Opportunities
Decarbonisation of the water lifecycle	**Operational –** Stakeholders identified the “first mover” advantage with new technologies as a key driver. Technologies such as heat pumps in the pharmaceutical sector are gathering pace as there is growing awareness that supply grid access is important. Stakeholders noted with caution that second movers may face issues around grid support access **Financial –** Characterising the electricity intensity of water to identify significant water and heat/thermal users in the water lifecycle. As identified in the True Cost of Water section, the actual cost of water can multiply when heating, pumping and other energy costs are taken into account, creating a stronger business case to reduce energy intensity across the water lifecycle. Other stakeholders noted that the cheaper it is to produce a product, the cheaper it becomes to sell to customers to remain competitive **Regulatory –** Expectation from stakeholders to develop roadmap to net zero by 2050. For example, one site has scope 1 and 2 targets of 47% reduction by 2030, while another has a 2030 decarbonisation target of 30% reduction from 2018 baseline	Grappling with water-energy intensity How to engage with scope 3 emissions, commonly the biggest footprint but “not our problem” Cost of transition/cost of carbon	Cost reduction is seen as a strong opportunity at site level Reputational benefits from decarbonisation of processes
Water circularity	**Operational –** Availability of water: evidence at partner sites is that water is becoming scarcer at certain periods of the year more consistently (1 L shortage is just as big an issue as 1000 L shortage) **Financial –** Consider water and heat circularity together and cost accordingly	Water needs to be fit for purpose; not just recycled water as recycling too costly Treatment technology will determine circularity potential Culture is also an issue (product is priority, not resource efficiency) Decoupling resource use from production – intensity-based targets don’t really work Biggest complexity – multiple processes with no understanding of where resources are consumed	Numerous opportunities can be identified for water circularity projects, but the key challenge is having a strong business case. Understanding the true cost of water is therefore critical
Emerging technologies and new supply routes	**Operational –** Supply and distribution challenges – even when organisations try to source from local suppliers as much as possible, distribution challenges exist **Operational –** Capitalising on new technologies to generate a competitive advantage **Reputational –** Greener technologies and a greener supply chain	Closing knowledge, competencies and skills gaps Cost and quality will be the main factors considered in new technologies and supply routes	To project a positive image of the site

Table A2.2. Summary of Water Stewardship Ireland Community of Practice participant responses to megatrends

Megatrend	Summary responses – key drivers	Summary responses – key challenges
Climate adaptation and water supply risk	Water is vital to site operations. "No water = no production" needs to be communicated to management, colleagues and customers. Most sites have 2–5 days of water storage on-site. A number of sites have experienced some water well depletion or low river levels, but this has not impacted operation to date. This could change in future as a result of climate change, and population and economic activity growth. The cleaner the initial water supply sources for a site, the less additional processing is required for treatment (e.g. energy, chemicals).	Many sites depend on national water supplier. Need for better communication between industry and suppliers identified, particularly relating to disruption of services and pollution events. Better understanding is needed of the future water stresses for industry.
Zero pollution	Most industrial sites consulted must comply with EPA emission licences to operate. Deterioration of waterbody quality is generally seen as the most direct impact of industry on waterbodies, with good water quality important to positive stakeholder relationships at catchment level (i.e. nobody wants to be on the EPA national priority site list relating to wastewater).	Future regulations may require higher treatment standards that may increase pollution indirectly due to energy, chemical or new equipment production and manufacturing requirements. Upcoming regulations from the Zero Pollution Action Plan will impact sites (e.g. stricter emission limits, contaminates of emerging concern); however, no perceived immediate impacts on site operations.
Decarbonisation	Need for EWC nexus awareness and training to show the hidden costs and environmental impacts associated with water use and treatment. Prioritise types of water and match with use, i.e. not all water needs the same level of treatment.	Sites should use renewables and biomass sources where possible to reduce GHG emissions associated with water use and treatment. Sites should use most efficient equipment and process where possible to reduce energy/other resource requirements. A need for significant investment and grants (SEAI Exceed for water projects).
Circular economy	Indirect water circularity needs more attention as a potential opportunity for alternative water sources to reduce supply constraints (e.g. using wastewater for heating/cooling without wastewater coming in direct contact with product).	Current lack of awareness/consensus on what water circularity means (e.g. is rainwater harvesting for graywater applications considered circular?). Perceived as difficult to practically reuse water on-site because of existing site configurations and the associated cost and disruption to operations from construction/retrofitting activities. Difficulty in directly reusing water on-site due to regulatory requirements, particularly in food/beverage and pharma sectors (e.g. Food and Drug Administration approval needed).
Emerging technologies and supply routes	Hydrogen production is seen as a potential solution to decarbonise the economy, especially relating to heating applications. Concerns raised over water impacts of this emerging solution. Many opportunities for deploying new water technologies on-site (e.g. water efficiency and reuse), but low cost of water limits water project implementation compared with energy projects.	Platform for information exchange with water service providers (i.e. better data exchange with Irish Water and industry).

Although a number of sites have experienced some well water depletion and low water levels in rivers, this has not curtailed production to date, but this may change with the more extreme hydroclimatic events projected for the future. The need for guidance on the specific water stresses that industry is projected to face was identified as pertinent by stakeholders.

A2.2.2 Megatrend 2: zero pollution

A key insight from the consultations was the varying degrees of awareness that stakeholders had of the EU Zero Pollution Action Plan and the potential for more stringent wastewater discharge pollution limits, and monitoring requirements for contaminants of emerging concern. Those who were aware saw no immediate impacts on their sites. From the perspective of external stakeholder engagement in the catchment, deterioration of waterbody quality because of pollution events caused by industry is highlighted as the most direct and contentious issue, and all sites seek to avoid this through responsible industrial water management (i.e. nobody wants to be on the EPA national priority site list relating to wastewater).

In relation to the zero pollution megatrend, sites said that they would not be allowed to operate without complying with their EPA-regulated industrial emissions licence, which covers wastewater discharges.

A2.2.3 Megatrend 3: decarbonisation and the transition to net zero

While decarbonisation as a megatrend has received significant attention from industrial sites in pursuit of corporate-wide GHG emission reduction targets, the focus has primarily been on energy efficiency, the substitution of energy sources with low-carbon alternatives and the deployment of renewable energy sources to help reduce scope 1 and 2 emissions under the international Greenhouse Gas Protocol. Upstream and downstream emissions associated with water supply and treatment beyond the site boundary (scope 3) are poorly understood in an Irish context because of the lack of national emission factors.

Those consulted noted that the EWC nexus is poorly understood, with greater awareness and training needed to identify the links between the energy needs for water abstraction, pumping and treatment and also the significant role that water plays as an energy carrier on-site. A better understanding of this would allow for water savings and efficiency improvement measures to be linked to energy and associated carbon emission savings. This would help to justify water projects that are deemed economically unviable where only water costs alone are considered. This is because water has a relatively low cost compared with energy. The establishment of funding support instruments for water efficiency technologies and processes (e.g. SEAI Exceed), similar to those offered for energy, was highlighted as a potential enabler of greater uptake of water efficiency improvement projects at industrial sites.

Based on engagement with industrial sites in Ireland throughout this project, a request for additional guidance from national agencies in Ireland surrounding the upstream and downstream energy and carbon impacts of water supply and wastewater treatment was identified, with a methodology proposed by this project team to facilitate EWC assessment nationally (Trubetskaya *et al.*, 2021b). The lack of emission factors for company reporting relating to water limits Irish industrial sites' ability to meet their water stewardship certification reporting requirements because of the poor understanding of upstream and downstream emissions. There is significant uncertainty surrounding process emissions (e.g. CH_4 and NO_2 from biological treatment processes) from wastewater treatment at industrial sites, with no methodology currently being applied in Ireland.

A2.2.4 Megatrend 4: circular economy

Of the megatrends identified during stakeholder engagement activities, the least understood was the circular economy megatrend. Questions were asked about what constitutes circularity in the water domain; for example, is rainwater harvesting considered a water circularity measure, given that rainwater collection and discharge avoid upstream water abstraction, treatment and distribution and associated GHG emissions? Traditionally, risk assessments for rainwater at industrial sites have focused on industrial effluent run-off and storm water management, with limited consideration of the co-benefits for other organisational policies such as water circularity and GHG emission savings.

Stakeholders from all sites agreed that water circularity was a worthwhile goal in theory but said that its practical application is often limited by existing site configuration and the associated cost and disruption to operations due to construction/retrofitting activities.

Another challenge is the strict licensing requirements for water quality at industrial sites, particularly in the food and pharmaceutical sectors, which must adhere to quality approval standards. However, it was noted that indirect water circularity has significant potential where heating or cooling applications may be supplemented by energy potentials in wastewater without coming into direct contact with the final product.

A2.2.5 Megatrend 5: emerging technologies and supply routes

In the transition to a more climate-neutral and resource-efficient economy, new technologies and associated supply routes will need to be developed. The hydrogen economy was the most frequently discussed emerging technology that may affect water management on a national scale. The lack of understanding of the hydrogen economy's possible impact on water resources underlines the importance of developing a coherent hydrogen economy strategy for Ireland; currently, this is in the consultation stage (DECC, 2021a). The need for greater communication between industrial sites and the national water services provider was highlighted as possibly benefiting from emerging technologies such as a platform for information exchange, with potential future applications including early warning alerts and "real-time" information exchange about service outages, pollution events and hydroclimatic event impacts.

Appendix 3 Industrial Water Greenhouse Gas Emission Accounting and Case Studies to Inform Decarbonisation Technology Deployment in the Irish Industrial Water Sector

As shown in Figure A3.1, the main GHGs associated with wastewater treatment are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), with various research study scope boundaries (e.g. within parameters of the wastewater treatment plant, supporting wastewater treatment plant infrastructure), while some studies make different assumptions about the sources of biogenic carbon and their inclusion in calculations (Li *et al*., 2022).

A3.1 Industrial Water Lifecycle Greenhouse Gas Accounting

From a national GHG emission accounting perspective, Ireland's National Inventory Report 2021 (EPA, 2021a) estimated CH_4 and N_2O emissions from wastewater treatment and discharge collectively as 147.87 kt CO_2 equivalent in 2018. On arriving at this estimate, it was assumed that centralised wastewater treatment plants also treat all commercial and industrial wastewater and for that reason all industrial wastewater emissions were assumed to be included in domestic wastewater emissions (EPA, 2021a). This highlights the coarseness of the model employed, which may be improved by bottom-up data collection on wastewater process emissions from the industrial sector.

According to the CRU, Irish Water is the largest consumer of electricity in the public sector in Ireland based on the SEAI monitoring and reporting scheme (CRU, 2021). The CRU decided to include two new metrics in the Irish Water Performance Assessment Framework 2020 to 2024 to monitor Irish Water's

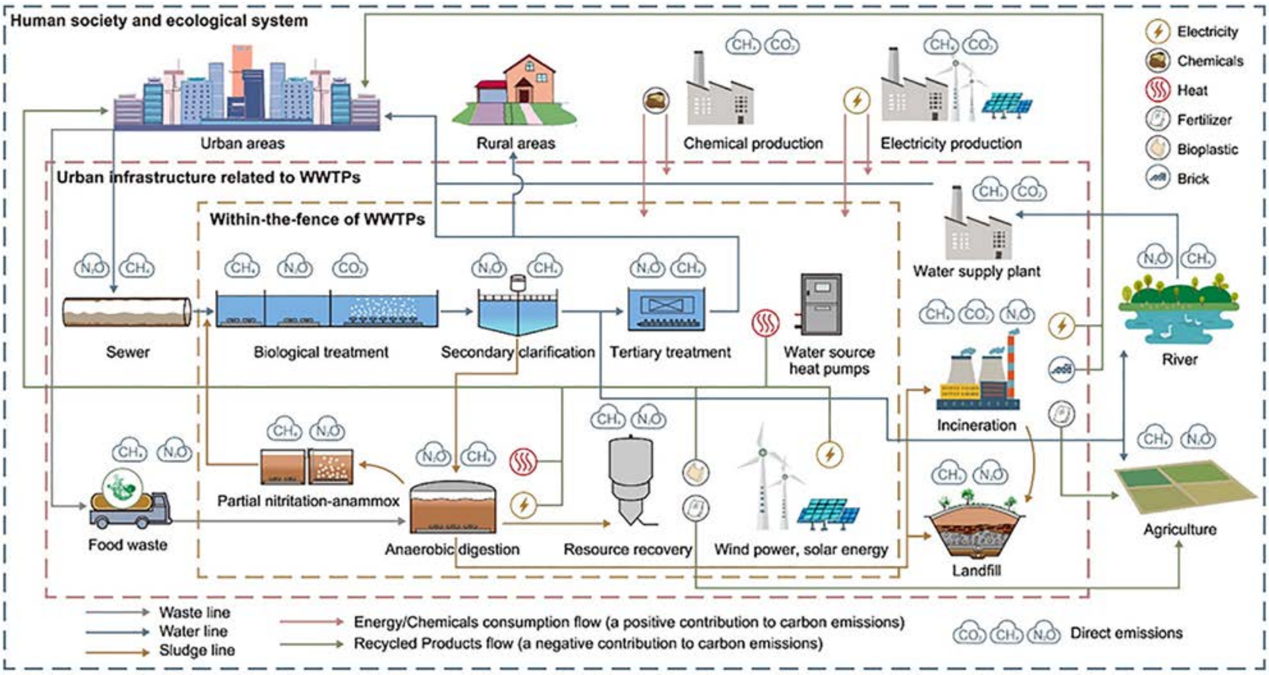

Figure A3.1. Scope of carbon accounting in the field of wastewater treatment can be gradually expanded from wastewater treatment processes to the whole of human society and the ecological system. Source: reproduced from Li *et al*. (2022); licensed under CC BY-NC-ND (http://creativecommons.org/licenses/by-nc-nd/4.0/).

energy consumption and GHG emissions in CO_2 equivalent, as shown in Figure A3.2 (CRU, 2021).

While the SEAI public sector monitoring and reporting system (SEAI, 2022) provides data on total carbon emissions from energy generation and consumption by the public water service provider (i.e. Irish Water), it does not differentiate between emissions associated with supply (i.e. water treatment plants, pumping for water supply distribution) and those associated with wastewater treatment (i.e. wastewater treatment plants, pumping for wastewater collection), which are important factors for helping industrial sites to understand the upstream and downstream climate impacts associated with water. The UK offers a useful methodology (DBEIS, 2021a) for calculating emission factors associated with energy use for both water supply and wastewater treatment that may inform the development of similar emission factors in Ireland. Uncertainty surrounding the definition of emissions considered "within scope" for national targets was noted in the Commercial Semi-State Climate Action Framework, with targets likely to become more challenging to meet if the scope is broadened (NTMA, 2022).

In contrast to the SEAI's methodology for defining and measuring GHG emissions in public sector water and wastewater treatment plants, which focuses on energy-related emissions (fossil fuel combustion on-site, purchased electricity and fleet transport), the Danish EPA (2021) also includes scope 1 process and fugitive emissions from water and wastewater treatment plants, which include CH_4 and N_2O. The UK Water Industry Research (UKWIR) provides a methodology for estimating operational emissions in the water industry, which includes process emissions relating to N_2O and CH_4 (UKWIR, 2022a); however, the carbon accounting workbook provided by the UKWIR is behind a paywall. The US EPA also provides guidance on estimating biogenic carbon emissions from wastewater treatment plants (US EPA, 2010). A roadmap for a climate-neutral Nordic water sector highlights data availability issues relating to parameters that are significantly important to GHG emission estimations, such as biogas and process emissions (Larsen *et al*., 2022) (see Figure A3.3). Each of these methodologies and approaches offers valuable insights into the development of a GHG emission accounting template for the industrial water sector in Ireland and the data availability issues that may need to be overcome.

The UKWIR provides a framework for whole life carbon accounting for the water sector, which accounts for embodied emissions associated with initial asset construction, maintenance and renewal, and emissions associated with future operations of water infrastructure. This approach is particularly useful for enabling consistent whole-carbon assessment at the planning and design stage of new water infrastructure projects and allows for better decision-making about capital investment that has the lowest carbon impacts possible (UKWIR, 2022b).

A3.2 Decarbonisation Opportunities for Industrial Water Sector

Feasibility studies and pilots of the deployment potential of technologies to reduce GHG emissions associated with industrial wastewater treatment include the SEAI Ambigas Project on the potential of low-temperature anaerobic digestion for treating industrial wastewater and biogas generation for CHP (O'Flaherty *et al*., 2016); a trial at ABP Lurgan in Northern Ireland of low-temperature anaerobic digestion developed by NUIG and NVP Energy with the potential to offset 40% of natural gas usage

Metric Name	Metric Definition	Update to 2016 Framework	Target 2024
Energy Consumption	The CRU will monitor Irish Water's Total Primary Energy Requirement (TPER) in GWh	N/A - not included in 2016 Framework	>40.71 GWh reduction
Greenhouse Gas Emissions	The CRU will monitor Irish Water's energy-related emissions in CO_2 equivalent in line with its reporting to the Sustainable Energy Authority of Ireland (SEAI)	N/A - not included in 2016 Framework	To be determined when scope of emissions target decided by the SEAI

Figure A3.2. Energy consumption and GHG emission metrics for the Irish Water performance assessment. Source: CRU (2021).

	Parameter	Data availability	Importance		Comments	Suggested result
WW	Consumption of electricity and heat	Good	Medium		Typically, low consumption, easy to evaluate	
	Consumption of chemicals	Good	Low	Medium	Typically, low consumption, easy to evaluate	
	Handling of residues	Good	Low		Typically, low production, easy to evaluate	
	Transportation	Good	Low		Typically, low contribution, easy to evaluate	
	Afforestation	Medium	Medium		Not a typical parameter for the water sector, but might be relevant	
	Other CO_2 reducing activities	Variable	Medium	High	New reduction measures in relation to N_2O emissions from WWTP. Important to reach climate neutrality	
Sewers	Consumption of electricity and heat	Good	Medium		Typically, relatively low consumption, easy to evaluate	
	Production of pipes	Not relevant, since the focus is on the operation phase				
	Construction	Not relevant, since the focus is on the operation phase				
	Handling of filter materials	Good	Low		Typically, low consumption, easy to evaluate	
WWTP	Consumption of electricity and heat	Good	Medium	High	High consumption, but varying EF for production, e.g., high in Denmark, low in Sweden.	
	Consumption of fuel	Good	Low		Typically, low consumption, easy to evaluate	
	Sold energy	Good	High		Typically, high amount, easy to evaluate	
	Consumption of chemicals	Good	Medium	High	Variable amounts, e.g., low chemical consumption in Denmark, high in Sweden. Easy to assess.	
	Consumption of filter materials	Good	Low		Typically, low consumption, easy to evaluate	
	Sludge handling	Medium	Medium	High	Typically, low contribution, relatively easy to evaluate	
	Transportation	Medium	Low		Typically, low contribution, but might be tricky to evaluate transportation distances (e.g., for sludge disposal)	
	CH_4 emissions (biogas)	Low*	High		High contribution, typically. Bad data availability unless the emissions are measured at the specific WWTP	
	N_2O emissions (process)	Low*	High		High contribution, typically. Bad data availability unless the emissions are measured at the specific WWTP	
	N_2O emissions avoided	Not relevant, since the focus is on the operation phase				
	CH_4 from septic tanks	Medium	Medium		Significant contribution, but variable importance due to variations in number of septic tanks in different areas	
	P recycling (subs. of virgin P)	Medium	Low		Typically, small amounts of recovered P	
	N_2O emissions, effluent	Low	Medium		Not a lot of specific data, but might be significant	
	Emissions, use of sludge	Variable	Variable		Large variations depending on the use (use on land, incineration, pyrolysis etc.). Significant contribution	
	Avoided emissions, use of sludge	Variable	Variable		Large variations depending on the use (use on land, incineration, pyrolysis etc.). Significant contribution	
	CH_4 emissions, effluent	Medium	Medium		Not a lot of specific data, but might be significant	
	Carbon binding	Medium	Medium		Not a lot of specific data, but might be significant	
New	CH_4 from sewer systems	Low	Low	Medium	Not a lot of specific data, but might be significant	
	CH_4 from WW	Low	Low	Medium	Not a lot of specific data, but might be significant	
	Chemicals, sewer	Good	Low		Typically, low consumption, relatively easy to evaluate	

Figure A3.3. Data availability for water GHG emission parameters for Nordic countries. Source: Larsen *et al*. (2022).

on-site with biogas (SEAI, 2017), and heat recovery from wastewater through the preheating of incoming feedwater; and a pilot heat pump for recovering heat from wastewater at ABP Cahir in collaboration with Dŵr Uisce (Dŵr Uisce, 2019). Industrial waste heat recovery for water heating is also being demonstrated at ABP Cahir, with waste heat from refrigeration and air compressors being used to supplement water heating (14% saving on natural gas) for use in production, as well as the installation of a large buffer tank for hot water storage (ESB, 2022). Another successful case study of anaerobic digestion for wastewater treatment and biogas generation is the Dairy Gold Mitchelstown site in collaboration with ADI Systems, where the biogas from wastewater is used in a dual-fuel boiler to produce hot water to heat the digestor reactor, while surplus biogas is used to supplement heating requirements in a plant boiler or burned in a waste gas flare (Evoqua, 2022).

Appendix 4 Interplay between Water and Production

Resource mapping, particularly water mapping, plays an import role in value-stream mapping or the calculation of the true costs of water for production processes. In addition, it clarifies details of process flows and their integration with the production process, and allows management to gain deep insights into resource flows. Generally, the analysis of the interplay between water and production considers five main components: (1) the quantities of fresh water and wastewater, (2) the quality of water, (3) collection and treatment systems, (4) the purpose of the treatment steps in terms of loops and recycling and (5) the handling and monitoring of data. A suggested template can be found in section A4.1.

In addition to the general analysis of the water–production interplay, holistic approaches should take stewardship concepts into account. These would include (1) the consideration of the whole catchment area, (2) key performance indicators (KPIs) for "smart water" operational performance and (3) control of specific water- or efficiency-related key parameters. A suggested template can be found in section A4.2.

A CEN workshop agreement, "Sustainable integrated water use & treatment in process industries – a practical guidance (SustainWATER)", from 2016 (CWA 17031–2016) summarises the outcome of the E4Water case studies. The main objective of the E4Water project was to develop, test and validate new integrated approaches, methodologies and process technologies for the more efficient and sustainable use and treatment of water in the chemical industry with potential to transfer these technologies to other sectors. This agreement aims to provide guidance primarily for company stakeholders to support the implementation of sustainable integrated water use and treatment practices. Such sustainable integrated water systems are essential for efficient water use and treatment in any plant, including those in the chemical and process industries. In its most advanced form, it can also be described as integrated industrial water management or even as integrated water management when urban and industrial waters are managed together. This industrial approach has various dimensions, from measures directly linked to single production processes to measures and cooperation that go far beyond one industrial unit or even one site. With an increasing range of scale to be considered in industrial water management, the number of actors that will be involved is growing (e.g. neighbourhood industrial sites, municipal wastewater treatment units, water resource management institutions up to catchment scale) and technology options are becoming manifold, so there is a clear need to consider them in an integrated way (CWA 17031–2016).

The CEN workshop agreement is therefore divided into:

1. non-technical aspects, such as catchment- and site-related aspects and stakeholder inclusion;
2. technical aspects on the industrial scale, such as technology plus validation and evaluation methods.

In the E4Water case studies, a few lessons relating to using digital tools have been learned and should be highlighted:

- Data acquisition and storage are essential for good technological monitoring.
- Grab samples are not always enough for monitoring water quality fluctuations (if possible, apply continuous measurements).
- Using relevant KPIs is important, since experiments may develop over long periods under changing conditions (process, season, people, equipment, etc.), to allow the proper and non-biased evaluation of results.
- Design of Experiments and Six Sigma methodologies are advantageous for keeping the number of experiments to a minimum while acquiring critical information.
- Hiring pilot installation from technology providers should include provisions for support/modification of the pilot.
- The period of piloting on-site should be long enough to deal with unexpected delays. If the first step of a treatment train fails, the downstream equipment can be damaged. Stepwise start-up is preferred.

A4.1 Template Proposal for Mapping the Interplay between Water and Production

Freshwater use
1. Water-dependent production processes • Indicate process/product • Batch or continuous • Cycles of product changes • Does the production process require a specific conditioning beyond tap water? If so, please characterise • Do you have water treatment technology installed for process water? If so, please characterise 2. Quantity and quality control • Required quantity (m^3/h) • Limits regarding quantity of freshwater • Required quality (please list relevant parameter with corresponding limit values) • How and how often are these parameters monitored? 3. Actual handling of monitoring data • Storage and processing (information-based control) • Contribution to automated process control
Wastewater generation in production
1. Wastewater generation per production processes • Source treatment/centralised treatment (wastewater treatment plant) 2. Quantity and quality control of wastewater directly released from production • Released quantity (m^3/h) and fluctuation/bandwidth • Released quality (please list relevant parameter and fluctuation/bandwidth with corresponding limit values) • Where, how and how often are these parameters monitored? 3. Actual handling of monitoring data • Data handling and processing • Information-based control • Contribution to automated process control
Wastewater collection
1. Characterise your wastewater collection system • Direct wastewater treatment plant connection, knotted/centralised collection system • Monitoring points in system • Monitoring parameters and frequency 2. How is storm water management integrated into the wastewater collection and treatment system?
Wastewater treatment system
1. What is the treatment purpose? • Water reuse target – if so, what amount and for which purpose? • Release to public sewer system, river, lake, sea 2. Which wastewater treatment technologies are in place? • Please characterise • What is the capacity? • Specific energy demand?

3. Which auxiliary materials are needed?
   - Wastewater treatment chemicals
   - Chemicals for cleaning

4. Treatment process control
   - Which parameters are controlled?
   - Where, how and how often?
   - Data handling and processing (information-based control)
   - Contribution to automated process control

5. Effluent quantity and quality control
   - Released quantity (m^3/h) and fluctuation/bandwidth
   - Released quality (please list relevant parameter and fluctuation/bandwidth with respective limit values)
   - Where, how and how often are the effluent parameters monitored?

6. Actual handling of monitoring data
   - Storage and processing
   - Information-based control
   - Contribution to automated process control

A4.2 Background for Template Proposal for Mapping the Interplay between Water and Production

External requirements and conditions

1. Are you located in an area considered to be water stressed?
   - How are you evaluating this (e.g. by using some specific evaluation and classification tool, such as WWF or Eurostat)?

2. What is the origin of your water supply?
   - Shares in groundwater (own wells/public supply), surface water, reuse of water reclaimed from processes on-site, alternative resources (e.g. rainwater, municipal wastewater)

3. What are the requirements from authorities on water issues
   - Water withdrawal limits?
   - Requirements on effluents?

4. What are your reported parameters to authorities or other external stakeholders on
   - Water withdrawal?
   - Emission regulation?

5. Are there other parameters/KPIs in addition to questions 3 and 4 that you use?

6. How do you plan actions when parameters and/or KPIs exceed the limits?

Internal actions, monitoring and control

7. What are your targets on water saving (or other water-related objectives)
   - At corporate level?
   - At site level?

8. Which water related parameters/performance indicators (KPIs) are you currently monitoring and/or reporting from your plant?
   - Are these parameters and KPIs measured or estimated?

9. To whom are which metrics and KPIs reported?
   - Corporate management
   - Site management
   - Department
   - Official sustainability report
   - Authorities

10. How are the results of the metrics and KPIs used in your work with water issues?
    - By corporate management
    - By site management
    - In the departments
    - In the official sustainability report
    - By authorities

11. Do you report according to a standard, e.g. GRI (Global Reporting Initiative), Dow Jones or similar?

12. Do you have a water management plan, including e.g.
    - water balance
    - water use mapping per activity
    - emission control and measurements?

Effluent treatment and recycling

13. Please describe your effluent treatment (including approximate volumes and type of effluent for each treatment)
    - On-site treatment
    - External treatment
    - Treatment method
    - Recipient
    - Do you currently do any water recycling? If yes, please describe.

Technology characterisation		
	Specific application	Range at on-site installations (if multiple of same application)
Application on-site		
Origin of influent		
Relevant inflow parameter		
Control/key parameter (pH, cond., COD, BOD, TPM, T, etc.)		
Concentration of dissolved substances in inflow (organic/ inorganic)		
Analytical requirements		
Special requirements for follow-up treatment steps		
Required minimum quality/concentration		
Maximum residues of disturbing substances		
Process parameter (pH, cond., T, etc.)		
Requirements to total technology (chain)		
Required final water quality		
Required final water quantity		
Boundary conditions for application		
Performance characteristics of technology		
Potential KPIs?		

Energy demand (kWh/m³), permeate or dilute
Electric thermal
Concentrates, valuables, residues
Which concentrates, valuables, residues are generated? Volume/mass flux? Expected composition and quality?
Space requirements (limited relevance for holistic system)
Plant Required utilities
Specific costs (€/m³), permeate or dilute
CapEx OpEx Others

COD, chemical oxygen demand; T, temperature.

A4.3 CEN Workshop Agreement (CWA 17031–2016)

Non-technical aspects

Catchment-related aspects and boundary conditions (broader picture):

- Wider integral water concept: Which natural water resources are available (surface water, groundwater)? Which relevant water users are present (industry, urban, agriculture) and how do they act (water demand, established interactions)?
- Alternative water resources: Are alternative water resources available (already established or potential)? How are they characterised (industrial wastewater, municipal wastewater, rainwater)? Where are they localised (site/local/regional)?
- Knowledge of spatiotemporal stress and sensitivity of water supplies: Where in the catchment does water stress or scarcity exist or can occur? Is the situation changing by monthly/seasonal/periodical variations and peaks? What renewable and fossil water resources are involved? Do sensitive ecosystem services exist?
- Synergy potentials beyond water: Are there starting points for circular economy/industrial symbiosis elements (e.g. use of heat/energy or effluents (sludge, residuals, solid waste, etc.) as a source for other applications)?

Site-related aspects (local picture):

- Water availability (supply): What water quantities are available and what is their quality? Are qualities and quantities constant or varying (e.g. weather, climate or process dependent)? Where is the available water located?
- Water requirements (demand): What water quantities and qualities are required? Are required qualities and quantities constant or varying? Where are the water users located?
- Comparison of water demand and supply characteristics: Does a matrix of water demand and supply characteristics show synergy potentials? Are these potentials still feasible under spatiotemporal aspects? (Is the spatial situation between/at supply and demand locations suitable? Are supply and demand congruent over time?)
- Legal, organisational and financial aspects: Are there legal boundaries (e.g. classification of aqueous streams as waste)? What liabilities have to be regulated? How will CapEx and OpEx be distributed between supply and demand side?

Modelling of the broader picture (e.g. related to industrial symbiosis, be sure that all the non-technical barriers are included in the technical model):

- Conceptual model of the catchment and site actual status (quantity, quality and heat)
- Model and identify demand and supply gaps
- Identify opportunities for combination of sources
- Link with modelling of technical solutions

Acceptance of solutions by different stakeholders:

- Society: It is necessary that the solution takes into consideration its impact on potentially affected communities. This requires a minimum social understanding of the problem and also, to some extent, an idea of society's expectation in relation to it.

- Administration/regulation: The choice of technical solutions should consider the existing regulations and the ability of the administrators/authorities to make them effective. Ideally the administrators/authorities should be involved in the solution to some extent.
- Decision-makers: Companies' decision-makers should first of all recognise the complexities of water economics, including the power of economies of scope. An economy of scope exists when a combined decision-making process would allow specific services to be delivered at a lower cost than would result from separate decision-making.
- Collaboration between actors (companies, municipalities/society): It is essential to point out that the final decision and acceptance of the technologies/solutions should not consider separately the information and views of all the different stakeholders mentioned so far. Instead, all these stakeholders should exchange information, and the resulting choice of technology/solution should derive from the concerted interaction between them.

Technical aspects at industrial scale

Definition phase – aspects to consider:

- Available water sources and water demands. Normal daily and seasonal fluctuation (quality and quantity). Examples: temperature, algae growth, rainfall, production runs, cleaning activities, maintenance periods.
- Determine the match and gap (quality and quantity) between water sources and water needs.
- Consider third neighbouring partners as possible suppliers and users for water (symbiosis).
- Special processes/circumstances that can influence flows/quality. Examples: change of production process, incidents.
- Explore options for water saving. Determine the water quality requirements for the different water users and cascading water users. Use the water-fit-for-purpose concept when upgrading water quality.
- Integrate resource recovery, reuse of energy, water and components (circular economy).
- Discharge limitations: legal (quantity, e.g. (near) zero liquid discharge, quality), assess the effect of water reuse itself (more concentrated streams).

Technology selection:

- Technical feasibility of the new or existing technology based on literature search and expert judgement (simulations of treatment trains).
- Maturity of the technology (technology readiness level): timeline for implementation and availability of pilot scale technology.
- Economic aspects like cost for development of new technologies and total costs of ownership.
- Environmental aspects: energy consumption, chemical consumption, recovery/water foot print and waste (quality and quantity). Explore options for water saving. Determine the water quality requirements for the different water users and cascading water users. Use the water-fit-for-purpose concept when upgrading water quality.
- Integrate resource recovery, reuse of energy, water and components (circular economy).
- Discharge limitations: legal (quantity, e.g. (near) zero liquid discharge, quality), assess the effect of water reuse itself (more concentrated streams).

Validation of the technology:

- Technological (confirmation of laboratory tests, fouling, scaling, seasonal effects, achievable water quality).
- Representative scale for translation to full-scale application.
- Infrastructure.
- Regulatory requirements.
- Contract with water supplier.
- Availability of right amount and quality of water sources in line with the pilot requirements.

Evaluation of pilot results and translation to full-scale application:

- CapEx and OpEx are used to calculate the total costs of ownership; cost of development of novel technologies is taken into account.
- Environmental aspects like energy, including heat and chemical consumption, water footprint and produced waste (quality and quantity) are evaluated.
- Integration into existing installations, enabling new applications/redesigning existing treatment systems.
- Evaluate effect on site water balance (accumulation of components in water cycle/disposal of concentrate stream).
- Optimisation/scale effects (e.g. from modular process skids).
- Legislation.
- Infrastructure.
- Contract with water supplier.

Appendix 5 Detailed Literature Review: The Emergence of Industrial Water 4.0

A5.1 Global Water Risks

> If climate change is a shark, water is its teeth. (WWF, 2016)

Water-related risks are consistently ranked among the top global environmental and societal risks (WEF, 2020), and businesses are increasingly experiencing significant associated financial impacts (CDSB, 2021). Currently, 17% of the global population reside and 10% of GDP is generated in water-stressed regions; these figures are projected to increase to 51% and 46%, respectively, by 2050 (WWF, 2020). Several factors are expected to affect water availability and quality in the coming decades, with competition for water exacerbated by various natural and anthropogenic factors such as changing demographics, industrial and agricultural activities, pollution and climate change (CDP, 2021; CDSB, 2021).

The global hydrological cycle includes many different components reacting in complex, dynamic and often non-linear ways to external forcings such as climate change. While the hydrological impacts of climate change, such as spatial and temporal alterations in water balance, streamflow and extreme events (floods, droughts), typically occur on regional or local scales, they can trigger modifications that lead to larger-scale or even global changes in the water cycle (ECRA, 2018).

Temperature rises due to climate change are projected to significantly intensify the global hydrological cycle, resulting in more powerful storms, increased flooding and drought conditions (IPCC, 2022). The JRC Global Drought Observatory of the Copernicus Emergency Management Service reported on drought conditions throughout the European continent in 2022, when record high temperatures, low precipitation and low waterbody depth levels led to water scarcity impacts among Member States, as shown in Figure A5.1 (Toreti *et al*., 2022).

A5.2 Operational Impacts

Table A5.1 lists some examples of the disruption to industrial activity resulting from extreme hydrological events in 2022; these impacts may have been amplified by climate change.

A5.3 Financial Impacts

Between 1980 and 2020, total economic losses from weather- and climate-related events among the 32 European Environment Agency member countries was between €450 billion and €520 billion. This is forecast to increase in the coming decades as a result of climate change and the associated impacts on the hydrological cycle (EEA, 2022a). In response to these challenges, the EU has introduced a new Climate Adaptation Strategy (EC, 2021a). This aims to gather better data on current and projected climate-related risks and losses from meteorological events (e.g. storms), hydrological events (e.g. floods) and climatological events (e.g. heatwaves, cold waves, droughts), which will inform holistic responses to climate change adaptation.

According to a study carried out as part of the JRC PESETA project, exposing the global economy to global warming of 3°C would result in an annual welfare loss of at least €175 billion (1.38% of GDP). Under a 2°C global warming scenario, the loss would be €83 billion/year (0.65% of GDP), while restricting warming to 1.5°C would reduce the loss to €42 billion/year (0.33% of GDP) (Szewczyk *et al*., 2020). From an Irish and UK perspective, the study suggests that the main economic losses will be associated with coastal flooding, river flooding and drought, with losses to GDP of almost 0.5% under a 3°C warming scenario, as shown in Figure A5.2.

A5.4 EU Policy Response

Two of the European Commission's six priorities for 2019–2024 (EU, 2019a), "A European Green

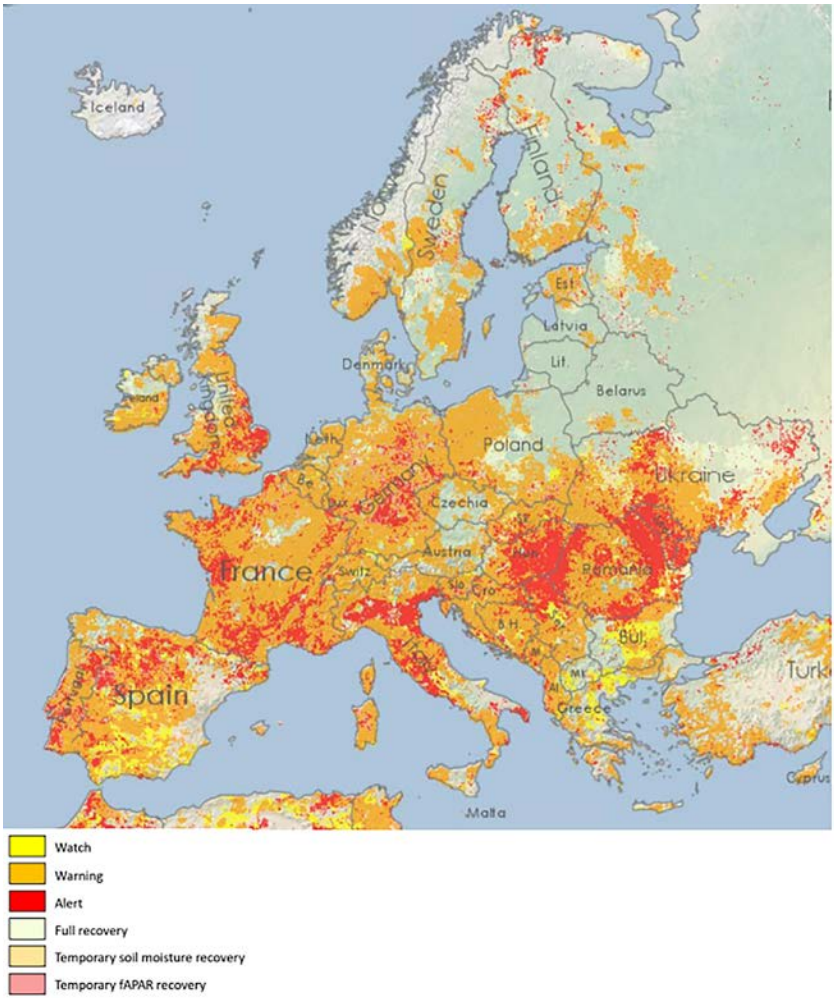

Figure A5.1. JRC Global Drought Observatory of the Copernicus Emergency Management Service – 22 August 2022. Source: reproduced from Toreti *et al.* (2022); licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

Deal" and "A Europe fit for the digital age", are directly relevance to IW4.0 management through their promotion of a carbon-neutral and resource-efficient economy enabled by a new generation of technologies. Both priorities inform "A New Industrial Strategy for Europe" (EC, 2020a), which aims for Europe to lead the twin green and digital transitions that will transform the EU into a fairer, more prosperous society with a modern, resource-efficient and competitive economy with no net emissions of GHGs by mid-century. The 8th EAP, building on the European Green Deal, sets out priority objectives for 2030 and the conditions needed to achieve these (EU, 2022b). The 8th EAP aims to speed up the transition to a climate-neutral, resource-efficient economy, recognising that human wellbeing and prosperity depend on healthy ecosystems.

A desk review was undertaken to identify relevant EU-level policies and legislation that support achievement of the European Commission's priorities and industrial strategy with relevance to water; these are listed in Table A5.2. This analysis suggests that water policy and legislation at EU level is narrowly focused on preventing environmental pollution, avoiding water resource overconsumption in water-scarce regions and adapting to hydroclimatic extremes.

The European Commission (EU, 2022a) has made progress in more systematic policymaking that accounts for water dimensions by placing greater emphasis on responsible water and marine resource management, reporting disclosures by businesses in the proposed CSRD, and by linking wastewater

Table A5.1. Impacts of global extreme hydroclimatic events on industrial activity in 2022

Country	Impact	Source
China	Record heatwave and high temperatures led to drought conditions and consequently the shutdown of industrial organisations to conserve water for the residential population; reduced hydropower capacity; and lower crop yields. The heatwave was followed by heavy, intense rainfall from a typhoon, causing flash flooding in certain regions	CMA, 2022; WMO, 2022
France	Worst drought on record, which resulted in reduced agricultural yields affecting production. Moreover, temperature limits of water discharged from a nuclear powerplant were increased to avoid powerplant shutdown as a result of low water levels and the associated high temperature of waterbodies	Météo France, 2022; Reuters, 2022
Germany	Summer heatwave led to record high temperatures and drought, resulting in disruption to cargo shipping on the Rhine due to low water levels	DWD, 2022; Reuters, 2022
Ireland	Heatwave and drought conditions led to increased demand for water resources and low reservoir levels, which in turn led to residential and business water conservation notices being issued	Irish Water, 2022; The Water Forum, 2022
Norway	Hydropower reservoirs ran low because of low rainfall and needed to be regenerated in summer, leading to a halt in electricity exports to the EU	*New York Times*, 2022
Pakistan	Heatwave temperatures affected agricultural yields and were followed by heavier than usual monsoon rains, resulting in over 1000 fatalities and the shutdown of industrial activity in affected areas	FT, 2022; WMO, 2022
USA	Exceptional drought conditions in western and central USA led to record low water reservoir levels, with impacts on energy production through reduced hydroelectricity production and biofuel feedstock, and on manufacturing output as a result of lower yields of crops such as cotton, soybeans and flax	NOAA, 2022

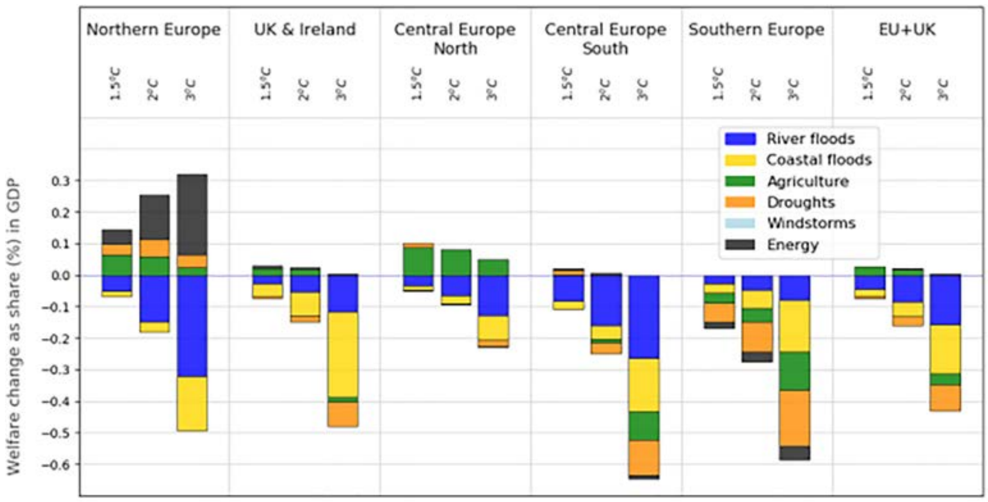

Figure A5.2. Projected losses in GDP due to impacts of climate change in Europe under 1.5°C, 2°C and 3°C global warming scenarios. Source: reproduced from Szewczyk *et al*. (2020); licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

Table A5.2. EU policies and legislation with relevance to water

EU plans and strategies with relevance to water	EU directives and regulations with significant relevance to water
Zero Pollution Action Plan (EC, 2021e)	WFD (EU, 2000)
Climate Adaptation Strategy (EC, 2021a)	Drinking Water Directive (EU, 2020a)
Biodiversity Strategy (EC, 2020c)	Bathing Water Directive (EU, 2006)
"Fit for 55" package (EU Emissions Trading System, Energy Efficiency and Renewable Energy Directives) (EC, 2021f)	Groundwater Directive (EU, 2014)
REPowerEU plan (EC, 2022b)	Urban Waste Water Treatment Directive (EU, 1998) – revision proposed by European Commission in 2022 (EC, 2022a)
Circular Economy Action Plan (EC, 2020b)	Industrial Emissions Directive (EU, 2010)
Hydrogen Strategy (EC, 2020d)	Environmental Policy Quality Standards Directive (EU, 2008a)
Bioeconomy Strategy (EU, 2018)	Nitrates Directive (EU, 1991)
Sustainable and Smart Mobility Strategy (EC, 2020e)	Sewage Sludge Directive (EU, 1986)
Chemicals Strategy for Sustainability (EC, 2020f)	Marine Strategy Framework Directive (EU, 2008b)
Strategy for Sustainable Textiles (EC, 2022c)	Sustainable Use of Pesticides Directive (EU, 2009a)
Forestry Strategy (EC, 2021g)	Birds Directive (EU, 2009)
Soil Strategy (EC, 2021h)	Habitats Directive (EU, 1992)
Farm to Fork Strategy (EC, 2020g)	Water Reuse Regulation (EU, 2020b)
Strategy for Sustainable Built Environment – proposal not yet finalised (European Parliament, 2022)	Nature Restoration Law – proposal stage (EC, 2022d)
	CSRD – proposal stage (EU, 2022a)
	European Pollutant Release and Transfer Register Regulation (EU, 2019b)
	Floods Directive (EU, 2007)

management to achieving broader EU policy objectives in the proposed update to the Urban Waste Water Treatment Directive rules in 2022. The European Commission's proposal for the Urban Waste Water Treatment Directive aims to:

- make the wastewater sector energy neutral and move it towards climate neutrality by reducing energy use, using the larger surfaces of some wastewater treatments plants to produce solar or wind energy, encouraging water reuse and using sludge to produce biogas, which can replace natural gas;
- make industry responsible for treating toxic micropollutants (under the "polluter pays" principle) that are released into the environment from the use of their products, especially harmful residues from the pharmaceutical and cosmetics sectors;
- improve access to sanitation in public spaces and for the 2 million most vulnerable and marginalised people in the EU;
- require the monitoring of health parameters in wastewater to enhance the EU's preparedness for pandemics or other major public health threats, as is currently being done in relation to COVID-19.

New rules on urban wastewater treatment are to include the following (the timeline for implementing the new rules is indicative, as these will be progressively applied until 2040, as shown in Figure A5.3):

- reduce GHG emissions in the sector by over 60% compared with 1990;
- decrease water pollution (organic matter, nitrogen and phosphorus) by more than 365,000 tonnes per year by 2040;
- cut microplastics emissions by 9% per year between now and 2040.

A5.5 National Water Risks

A5.5.1 Water stress

In Ireland, high-level impacts of water stress due to climate change are projected to be more limited than in the rest of Europe (EEA, 2021), with the Water Exploitation Index estimating that water use accounted for only 3% of the nation's renewable freshwater resources in 2017 (EEA, 2022b).

However, there are local-scale mismatches between resource provision and end users in Ireland that may

	2025	2030	2035	2040
Storm water overflows and urban runoff (rain waters)	Monitoring in place	Integrated plans for agglo. > 100.k p.e. + areas at risk identified	Integrated plans in place for agglo. at risk between 10 and 100k p.e.	Indicative EU target in force for all agglomerations > 10.000 p.e.
Individual appropriate systems	Regular inspection in all MS + Reporting for MS with high IAS	EU standards for IAS		
Small-scale agglomerations	New thresholds of 1.000 p.e.	All agglo.> 1.000 p.e. compliant		
Nitrogen and phosphorus	Identification of areas at risk (agglomerations 10 to 100k p.e.)	Interim target for N/P removal in facilities > 100 000 p.e. + New standards	N/P removal in all facilities above 100k p.e. + Interim target for areas at risk	N/P removal in place in all areas at risk (between 10 and 100k p.e.)
Micro-pollutants	Setting up extended producer responsibility schemes	Areas at risk identified (10 to 100k p.e.) + Interim target for facilities above 100.k p.e.	All facilities > 100k p.e. equipped + interim targets for areas 'at risk'	All facilities at risk equipped with advanced treatment
Energy	Energy audits for facilities above 100k p.e.	Audits for all facilities above 10k p.e. Interim target	Interim target for energy neutrality	Energy neutrality met and related GHG reduction met

Figure A5.3. Implementation planning for the main measures of the proposed revision to the Urban Waste Water Treatment Directive. Source: EC (2022a).

lead to regional and local impacts being exacerbated by climate change, for example as seen in west Cork in summer 2022, with water conservation notices issued to deal with increased demand for water and low water levels in reservoirs (Irish Water, 2022). Similar observations were made in 2018, when drought conditions resulted in conservation orders being issued for domestic public water supplies and on commercial premises for non-commercial activities because of the prolonged drought conditions (Hammond Antwi *et al*., 2021).

A5.5.2 Water quality

From a water quality perspective, the EPA's report *Water Quality in Ireland 2016–2021* highlighted that over half (54%) of Ireland's surface waters are in good or better ecological condition, with, concerningly, nearly half (46%) in unsatisfactory condition (EPA, 2022). Of groundwaters, 91% are in good condition. As shown in Figure A5.4, only 5% of waterbodies in unsatisfactory condition are directly affected by industry. However, the agriculture, forestry, mines and quarries sectors represent a significant proportion of upstream impacts that serve as inputs for industrial activities, while the impacts of urban wastewater may in some cases be attributed to the downstream effects of industry.

Irish Water will develop a suite of tools for water source risk assessment that account for risks to

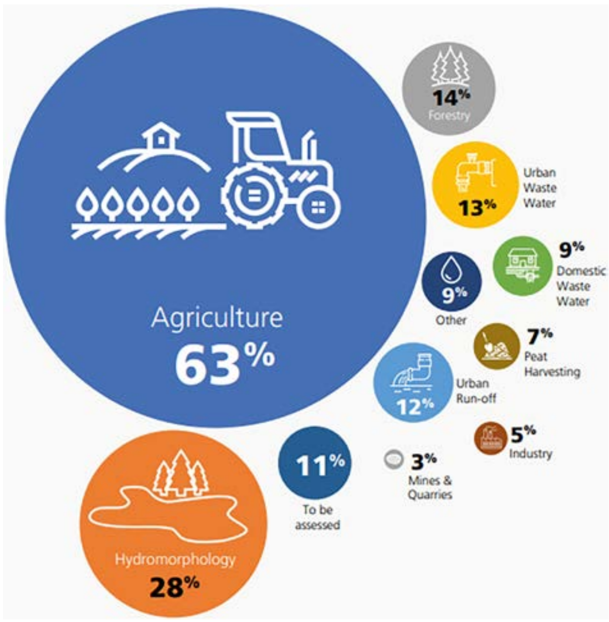

Figure A5.4. The percentage of waterbodies in unsatisfactory condition affected by different actives in Ireland (EPA, 2022a).

surface waters and groundwater such as risks posed by microorganisms, pesticides, metals, nutrients and organic matter (Irish Water, 2021a). The aim of these tools will be to inform catchment-level raw water monitoring programmes, identify areas needing catchment intervention and establish treatment requirements (Irish Water, 2021a). Without appropriate action to mitigate water risks, water quality is projected to decline as a result of factors such as increased population, increased commercial/industrial activity, flooding events mobilising pollutants, and lower river water levels due to water stress during the summer months limiting the dilution of wastewater concentrations (Irish Water, 2021a).

A5.5.3 National policy

Project Ireland 2040 is the Irish Government's long-term overarching strategy to make Ireland a better country for all and to build a more resilient and sustainable future (Government of Ireland, 2018). The National Planning Framework (NPF) and the National Development Plan 2021–2030 (NDP) combine to form Project Ireland 2040. The NPF sets the vision and strategy for the development of our country to 2040 and the NDP provides the investment needed to implement that strategy.

The NPF outlines a high-level strategic plan for shaping future growth and development to the year 2040 and identifies the sustainable management of water, waste and other environmental resources as a national strategic outcome, with water infrastructure a strategic investment priority (Government of Ireland, 2019b). As outlined in the NPF, National Policy Objective 57 aims to enhance water quality and resource management by:

- ensuring that flood risk management informs policymaking by avoiding inappropriate development in areas at risk of flooding in accordance with the Planning System and Flood Risk Management Guidelines for Planning Authorities;
- ensuring that river basin management plan objectives are fully considered throughout the physical planning process;
- integrating sustainable water management solutions, such as sustainable urban drainage, non-porous surfacing and green roofs, to create safe places.

In addition, National Policy Objective 63 of the NPF aims to ensure the efficient and sustainable use and development of water resources and water services infrastructure to manage and conserve water resources in a manner that supports a healthy society, economic development requirements and a cleaner environment.

The NDP National Strategic Outcome 9 is sustainable management of water and other environmental resources, with specific priorities relating to water quality, conservation and future-proofing (Government of Ireland, 2021), as shown in Figure A5.5.

The Irish Government, through its climate change sectoral adaptation plans for (1) water quality and water services infrastructure (DHPLG, 2019) and (2) flood risk management (OPW, 2019), highlights the significance of climate change impacts on the hydrological cycle and on associated water management practices.

As shown in Figure A5.6, the main impacts of climate change on water quality and water service infrastructure will be increased surface and sewer flooding, leading to mobilisation of pollutants and spread of pathogens due to high levels of precipitation and increased storminess, while longer and more intense dry conditions will reduce the availability of water and reduce the dilution of contaminants. Of particular concern for industrial sites is the predicted impact of extreme precipitation events and storminess leading to flooding and loss of assets from the water service infrastructure, which will affect business continuity through loss of supply.

The National Water Resources Plan developed by Irish Water identifies various risks to and constraints on water infrastructure management, such as performance issues during extreme whether events such as storms, drought periods and freeze–thaw events, asset performance in terms of the standards for risks to water quality, asset performance including high leakage, and funding constraints (Irish Water, 2021a). As part of the plan, a framework was developed that outlines the approaches and methodologies for water demand forecasting to identify the risks associated with weather event planning and potentially climate change (Irish Water, 2021a).

Current EU policy and legislation relating to water is focused on preventing environmental pollution,

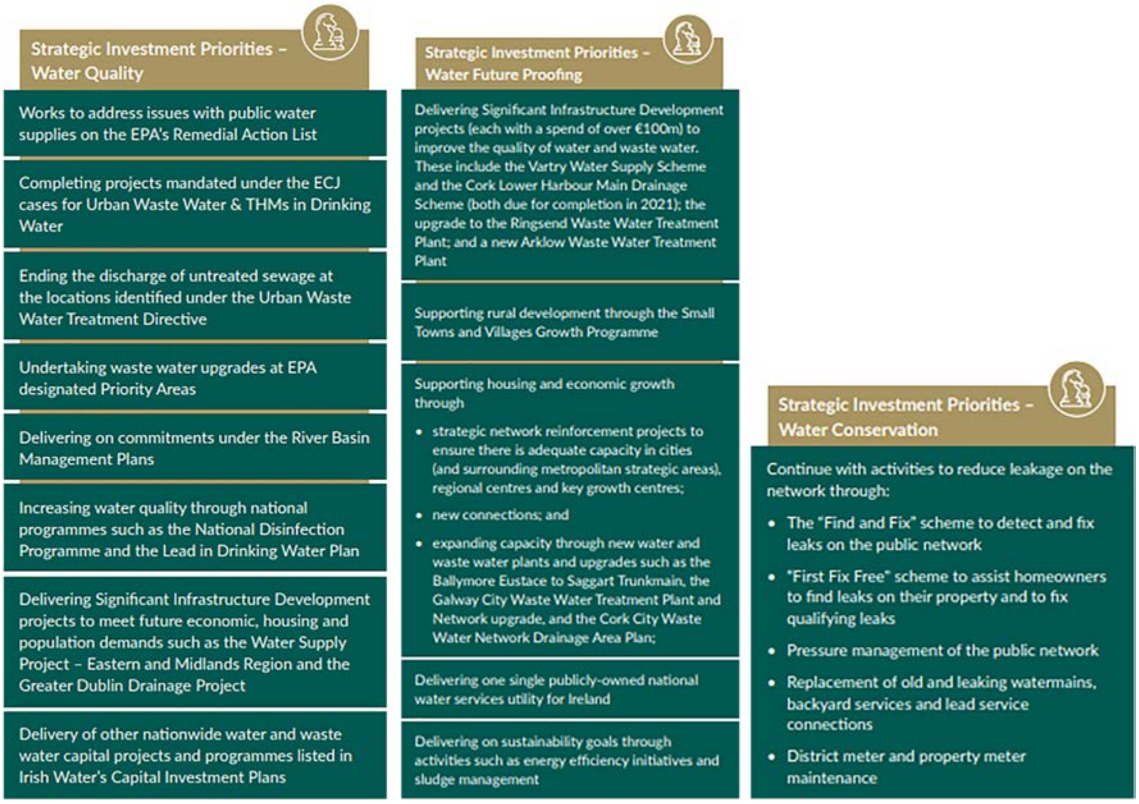

Figure A5.5. NDP strategic investment priorities relating to water. Source: Government of Ireland (2021).

	Impact chain / sectoral consequences[20]	Public Health	Environmental	Security of supply	Asset damage / loss	Service provision	Business continuity
Water quality	Increased surface and sewer flooding leading to mobilisation of pollutants	✓	✓			✓	
	Reduced dilution of contaminants	✓	✓			✓	
	Spread of / increased viability of pathogens	✓	✓			✓	
	Changes in species distribution and phenology		✓		✓	✓	
	Drying of peatland	✓	✓			✓	
Water service infrastructure	Hot-weather-related changes in demand (e.g. higher daily and peak demand)		✓	✓		✓	
	More frequent water/wastewater asset flooding, asset loss and potential for environmental pollution (high precipitation)	✓	✓		✓	✓	✓
	Increased drawdown in the autumn/winter for flood capacity, leading to resource issues in the following spring/summer			✓		✓	
	Reduced availability of water resources (surface water and groundwater sources)		✓	✓		✓	
	More frequent water/wastewater asset flooding, asset loss and potential for environmental pollution (increased storminess)	✓	✓		✓	✓	✓
	Business continuity impacts/ interruptions					✓	✓

Figure A5.6. Sectoral consequences matrix for the water quality and water service infrastructure sectors. Source: DHPLG (2019).

avoiding water resource overconsumption and adapting to hydroclimatic extremes, and this is reflected nationally in action plans and strategies developed by Irish state agencies. Box A5.1 shows the main plans and strategies in Ireland with relevance to water.

A number of these plans and strategies are relevant to both preventing water pollution and climate adaptation because of the interconnected nature of hydroclimatic extreme event impacts on water quality (i.e. lower dilution factors during drought and increased surface run-off during extreme precipitation events) resulting in more frequent pollution events.

Water is not a pillar of Ireland's Climate Action Plan 2021 (DECC, 2021a), with references limited to the sectoral adaptation plans, while the Waste Action Plan for a Circular Economy 2020–2025 (DCCAE, 2020) identifies water management as an area for research prioritisation, with a focus on the waste and circular economy challenges. The Waste Action Plan also highlights the food, water and nutrients value chain as one of seven key product value chains that should be prioritised. Unlike the EU, Ireland has yet to develop action plans and strategies relating to the hydrogen

Box A5.1. Irish plans and strategies with relevance to water

- River basin management plans (DHPLG, 2018) – draft 2022–2027 plan under consultation.
- Water Services Strategic Plan (Irish Water, 2015).
- National Wastewater Sludge Management Plan (Irish Water, 2016).
- National Water Resources Plan (Irish Water, 2021a).
- National Adaptation Framework (DCCAE, 2018).
- Water Quality and Water Services Infrastructure: Climate Change Sectoral Adaption Plan (DHPLG, 2019).
- Flood Risk Management Climate Change Sectoral Adaptation Plan (OPW, 2019).
- Catchment Flood Risk Assessment and Management Plans (OPW, 2018).

economy, bioeconomy, built environment, forestry and soil.

A5.6 Water Risk Assessment for Industrial Sites

Water risk assessments at industrial sites have traditionally been carried out in response to health and safety concerns (e.g. slips, trips and falls due to water spills, legionella prevention and control), operational concerns (e.g. the impact of water equipment failure on production output) and environmental concerns (e.g. limiting effluent concentrations to below the level required to comply with water quality regulations).

Such a narrow perspective on assessing water risks at the site level is no longer adequate (WWF, 2020). Industrial sites need to consider their operational and supply chain vulnerabilities to water stress and extreme precipitation events, vulnerabilities that will be exacerbated by climate change, the tightening of environmental regulations to limit cumulative impacts on water quality from increasing population and industrial activity, and increasing demands for ESG reporting by stakeholders and investors (WRI, 2019; WWF, 2020).

To promote increased awareness of the water risks facing companies, tools and methodologies have been developed, including the WWF Water Risk Filter (WWF, 2020), WRI Aqueduct (WRI, 2019), WBCSD Global Water Tool (WBCSD, 2019), GEMI Water Management Risk Assessment Questionnaire (GEMI, 2003) and CPD Water Watch (CDP, 2022). In addition, lifecycle assessments applied to specific risk assessments of water processes and technologies can inform science-based risk assessments of environmental or human health impacts. According to the WWF Water Risk Filter, it is useful to characterise the risks faced by companies as physical (e.g. scarcity, flooding, quality), regulatory (enabling environment, management instruments, institutions, governance) or reputational (media scrutiny, biodiversity importance, investor demands) (WWF, 2020).

The physical risks associated with water management at industrial sites have received the most attention (WWF, 2020) because of their direct impact on site operations and their relevance to future environmental reporting regulations such as the CSRD (EU, 2022a) and influential environmental reporting initiatives from organisations such as the Task Force on Climate-related Financial Disclosure (FSB, 2022) and Science Based Targets Initiative (SBTi, 2022). However, the complexity of water risk resilience planning means that it is important to account for the broader reputational and regulatory landscape risks in individual countries and regions that may limit the implementation of risk reduction measures (WWF, 2020).

A5.7 Policies Relevant to Industrial Water Management in Ireland

Figure A5.7 and Table A5.3 highlight the national plans and strategies in Ireland that offer insights to inform the proactive management of water at industrial sites. Based on the review of high-level policy at the EU level and national level in Ireland, reducing water pollution, reducing water consumption and climate adaptation have been identified as priorities in terms of policy and legislation with relevance to industrial water management.

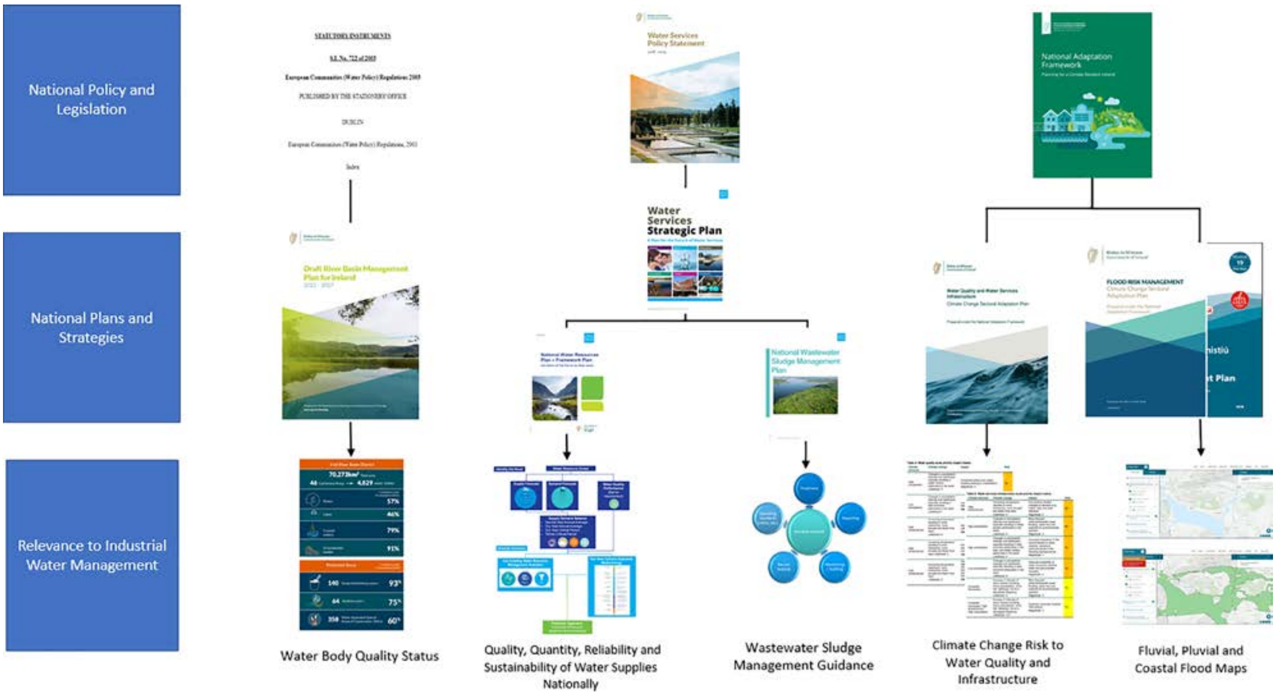

Figure A5.7. Relevance of Irish national policy and legislation to industrial water management.

A5.8 Industrial Water Stewardship

A5.8.1 Corporate-led water stewardship

Water stewardship has received significant attention in recent years, both globally and in Ireland, as businesses and communities respond to the increasing challenges and risks surrounding the shared responsibility of water resource management. To accommodate this rise in interest in water stewardship, several support resources, accreditation standards and educational programmes have been developed, with varying degrees of adaptation by the industrial sector.

> **Water stewardship** is defined as using water in a way that is socially equitable, environmentally sustainable and economically beneficial. This is achieved through a stakeholder inclusive process that involves site and catchment based actions. (UNIDO, 2022)

The term “water stewardship” has various meanings depending on the specific context. However, it is generally understood to encompass an approach that promotes water users taking responsibility for their own influence on a shared resource and working together to manage it sustainably (Water Footprint Network, 2021). This reflects the systems thinking perspective, namely that the challenges and risks associated with water resource management cannot be solved by individuals but can be addressed only through coordinated, collective action (GIZ, 2019). The successful implementation of water stewardship allows enterprises to engage with local stakeholders and understand their water-related challenges and opportunities they face, facilitating the development and integration of strategies to address social, environmental and economic concerns across the entire water lifecycle (Stockil *et al*., 2018).

Water stewardship to date has predominantly taken a bottom-up approach, with enterprises and local societal stakeholders leading implementation efforts. However, it is increasingly being promoted by national bodies and agencies to meet national resource efficiency and environmental protection objectives, while also contributing to meeting the broader SDGs of the United Nations.

Bottom-up efforts in water stewardship have been motivated by various drivers, such as improved resource efficiency, environmental protection concerns and ESG reporting and transparency requirements, which are increasingly demanded by enterprise shareholders, societal stakeholders and consumers. Because the scope of the proposed CSRD (EU, 2022a) is being expanded to include

Table A5.3. National water plans and strategies relevant to industrial water management

National water plans and strategies	Policy and legislation contexts	Relevance to industrial water management
River basin management plans	The EU WFD (2000/60/EC) requires all Member States to protect and improve water quality in all waters so that we achieve good ecological status by 2015 or, at the latest, by 2027. It was given legal effect in Ireland by the European Communities (Water Policy) Regulations 2003 (S.I. No. 722 of 2003). It applies to rivers, lakes, groundwater and transitional coastal waters. The Directive requires that management plans be prepared on a river basin basis and specifies a structured method for developing these plans.	The river basin management plans offer insights to industry on the quality of the rivers, lakes, coastal waters and groundwater that may serve as water sources for industrial sites and discharge points for wastewater, and what the main pressures are for the studied waterbodies. In addition, the plans provide insights into protected areas such as shellfish water, designated bathing areas and special areas of conservation near industrial sites that may be impacted by over-abstraction and pollution events that warrant substantial attention from industrial sites to avoid negative catchment stakeholder publicity.
Water Services Strategic Plan	This Water Services Policy Statement identifies high-level objectives and priorities for the delivery of water and wastewater services over the period to 2025. It has been prepared in line with the Water Services Acts to give clear direction to strategic planning and decision-making on water and wastewater services in Ireland (DHPLG, 2018). In response to the Water Services Policy Statement, Irish Water published the Water Services Strategic Plan, which outlines the short-, medium- and long-term objectives and strategies to deliver and upgrade water services nationally over the next 25 years (Irish Water, 2015). Encompassed within the Water Services Strategic Plan is the National Water Resources Plan (Irish Water, 2021a) and the National Wastewater Sludge Management Plan (Irish Water, 2016).	The National Water Resources Plan includes a framework that accounts for current levels of service, issues with source supplies, performance issues during extreme whether events such as storms, drought periods and freeze–thaw events, asset performance in terms of the standards for risk to water quality, asset performance including high leakage, and funding constraints. Insights from this framework will allow industry to plan future operation and expansion in line with the national water services providers investment plan. The National Wastewater Sludge Management Plan sets out a nationwide standardised approach to ensure that treated wastewater sludge across the country is effectively managed, stored, transported and reused or disposed of in a sustainable way, to the benefit of the public and the environment. From an industrial water management perspective, the plan offers guidance on recommended sludge treatment processes and best practice relating to technologies, operational standards, monitoring/auditing, record keeping and reporting.
Water Quality and Services Climate Change Sectoral Plan	The National Adaptation Framework outlines a whole of government and society approach to climate adaptation in Ireland that aims to improve the enabling environment for adaptation through ongoing engagement with civil society, the private sector, and the research community (DCCAE, 2018). Under the remit of the National Adaptation Framework relating to water management is the Water Quality and Water Services Infrastructure: Climate Change Sectoral Adaptation Plan (DHPLG, 2019). The Water Quality and Water Services Infrastructure: Climate Change Sectoral Adaptation Plan was developed which generates a baseline of current climate and weather-related impacts and associated consequences for the sector, and assesses how these sectoral impacts may change up to 2050 based on best available climate modelling and analysis data, while also setting out adaptive measures and where future adaptation efforts will be required (DHPLG, 2019).	The relevance of the Water Quality and Services Infrastructure sectoral adaptation plan to industry is that it identifies and characterises the likelihood and magnitude of risks (e.g. high/low precipitation, high/low temperatures, increased storminess) faced by the water services infrastructure that supplies water and collects wastewater from industrial sites. Industrial sites can use this information to better plan for challenges that they may face in future and the potential proactive role they may play in cooperating with their water supplier and wastewater treatment provider to adapt to climate change impacts.

Table A5.3. Continued

National water plans and strategies	Policy and legislation contexts	Relevance to industrial water management
The Flood Risk Management Climate Change Sectoral Adaptation Plan	Under the remit of the Nation Adaptation Framework relating to water management is the Water Quality and Water Services Infrastructure: Climate Change Sectoral Adaptation Plan (DHPLG, 2019). The Flood Risk Management Climate Change Sectoral Adaptation Plan (OPW, 2019) was developed to identify the potential impacts of climate change on flooding and flood risk management in Ireland, identify the objectives for an effective and sustainable approach to adaptation as part of flood risk management for the future, and promote a coordinated approach to adaptation. The Flood Risk Management Climate Change Sectoral Adaptation Plan is informed by catchment flood risk assessment and management plans, which the OPW developed under the Catchment Flood Risk Assessment and Management programme. The plans detail the flood risk and proposed feasible mitigation measures for each of the 300 communities considered areas for further assessment in preliminary flood risk assessment from 2012 and identifies structural and non-structural proposed flood alleviation measures in 29 flood risk management plans for each river basin.	The relevance to industry is that it allows industry to get an indication of whether their sites are at risk from fluvial or coastal flooding under various scenarios of sea level rise, extreme rainfall depths and peak flood flows that are projected to occur because of climate change. The associated flood maps to inform the flood risk management plans can be freely accessed through the Flood Maps Viewer at floodinfo.ie (OPW, 2023). It should be noted that the purpose of flood maps is not to designate individual properties at risk of flooding, as they are community-based maps, but they should give an indication of whether an industrial site is located in a community that may be at risk of flooding.

all large companies and all companies listed on regulated markets (except listed microenterprises), it is envisioned that water stewardship frameworks and external accreditation will help businesses to meet their ESG reporting obligations (EU, 2022a).

Existing water stewardship standards and guidance such as the Alliance for Water Stewardship (AWS, 2019), European Water Stewardship (EWS, 2012) and CDP Water Disclosures (CDP, 2021) are increasingly being subscribed to by industrial organisations seeking to obtain external accreditation and demonstrate their competency to broader stakeholders in terms of water resource management and reporting water stewardship efforts.

A5.8.2 Nationally led water stewardship

Ireland

In response to the gap in national support for water stewardship, the CWS programme, developed by 20FIFTYPartners in partnership with Water Stewardship Ireland and the Lean & Green Skillnet, was established in 2019 and has been promoted by Irish Water (the national water service provider) to engage organisations across Ireland in water stewardship activities (Water Stewardship Ireland, 2021). It achieves this by supporting participants to commit to a water stewardship action plan; sites receive an externally accredited certification for their efforts (Irish Water, 2021b). The programme supports business customers with training on lowering water consumption and reducing operational costs, while also protecting the environment (Water Stewardship Ireland, 2021). As at 2022, over 600 organisations had participated in the programme, collectively representing over 30% of Ireland's water use. The successful implementation of over 1400 conservation projects has been attributed to the CWS programme. The programme's success has led to interest from the UK and other European countries in potential replication by national water service providers, tailored to different national contexts such as industrial sectoral characteristics and regional water stress conditions.

Finland

As part of its commitment to the United Nations Agenda for Sustainable Development, Finland's Water Stewardship Commitment challenges companies to assess water risks in their value chains and to engage in collective action to develop sustainable water use and governance (Ministry for Foreign Affairs of Finland, 2020). It links directly to national SDG implementation and engages the public sector, academia and non-governmental organisations. The commitment was founded by Finnish research institutes and ministries and WWF Finland in 2017 and has gained signatories from major Finnish companies and key water-using sectors. The aim of the commitment is to make Finnish companies the most responsible water stewards in the world by 2030.

Germany

The International Water Stewardship Programme (IWaSP) is implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit on behalf of the German Federal Ministry for Economic Cooperation and Development and the UK Department for International Development. It supports business, government and civil society to partner with each other and develop joint solutions to water-related risks through engagement of over 70 global companies. At the programme's end in March 2019, IWaSP and its partners had enabled water security for 2,722,179 direct beneficiaries and 10,134,960 indirect beneficiaries, with a focus on water-stressed regions in developing economies (IWaSP, 2019). Building on IwaSP's success, the Natural Resources Stewardship Programme was developed, enabling private–public–civil society partnerships to manage the natural resources (scope expanded beyond water) needed for sustainable growth and better livelihoods (NatuReS, 2020). This highlights the potential for water stewardship programmes to act as an introduction and catalyst to accelerate broader natural resource stewardship programmes.

A5.9 Digitalisation as an Enabler of Better Industrial Water Stewardship

A5.9.1 Digitalisation of the industrial water sector

While industrial water stewardship is gaining significant traction globally, another aspect of management that has received attention is the prospect of enabling digitalisation across the industrial water lifecycle. Various terms are used to refer to this water digitalisation, such as "Smart Water", "Water 4.0" and "IoT for Water". The main benefit of digitalisation in the industrial water sector is having more manageable water processes as a result of digital technologies, which improves resource efficiency by optimising processes and equipment while limiting pollution events through greater oversight of operations and associated early warning systems.

> Digitalisation of the water sector through technologies such as artificial intelligence (AI), digital twins, digital data spaces, disruptive technologies and instrumentation and circular economy digital water innovations can result in significant environmental, operational and economic benefits.
>
> Digital water solutions reduce the environmental impact of water operations via
>
> a) reductions in energy demand for water supply and sanitation services;
>
> b) better control of emissions from wastewater treatment plants;
>
> c) enhanced capabilities for real-time, in situ water quality monitoring; and
>
> d) increased water use efficiency across sectors and reduced leakages.
>
> Digitalisation is a critical tool in advancing global water security and protecting the planet's water resources sustainably. Overall, digital technologies provide a wide array of possibilities for achieving the zero pollution ambition in the water sector.
>
> The EU has recognised the link between ICT and water protection and promoted the possibilities digitalisation brings to the water sector by establishing the ICT4Water cluster, a community of 61 EU-funded research and innovation projects on digital innovations for water. In the context of the cluster, several studies and reports on digital water have been published in previous years. More recently, their reports look at the business models, research and innovation opportunities ("The need for digital water in a Green Europe", "Business models for digital water solutions" and "ICT4Water cluster: vision and showcases").
>
> European Commission staff working document Digital Solutions for Zero Pollution (EC, 2021b)

Water Europe has produced a white paper on the digitalisation of water management. This covers the whole lifecycle and identifies several regional drivers through the policy priorities “A European Green Deal” and “A Europe fit for the digital age”, with digitalisation of the water management sector seen as a way of jointly meeting these priorities and delivering a resilient and green economy (Water Europe, 2021). Water Europe’s recommendations for the digitalisation of the water sector include:

- adopting a common data platform for data valorisation and information sharing;
- supporting smart quantitative water management and water conservation through monitoring;
- supporting the upskilling of the workforce to diffuse digital culture in the water sector;
- optimising drinking and wastewater plants to reduce OpEx and CapEx;
- improving transparency and data sharing within the sector and with the public to promote multidisciplinary cooperation.

Over a 6-year period (2014–2019), the EU funded 255 water-related projects under Horizon 2020 with around 1 billion euros. These projects are divided into eight main thematic areas: (1) freshwater and aquatic ecosystems, (2) global water cycle, (3) water management, (4) water and people, (5) water and agriculture, (6) water and industry, (7) water and energy, and (8) water management (EC, 2020h). In recent years, digital aspects have increasingly been included in the research agenda with the aim of accomplishing the scientific goals shown in Table A5.4.

While digitalisation offers many possibilities for improving water management for responsible water stewardship, several challenges limit the uptake of digital solutions among industrial sites and water service providers. The ICT4Water EU cluster has developed two roadmaps and associated action plans. The intention is to define and deploy a group of actions for the development of digital water services in the single market. These will address digital water issues relating to services, data management, interoperability, intelligence, cybersecurity and standardisation, including synergies between the proposed solutions and other related sectors (e.g. circular economy, water reuse, transport, energy, agriculture and smart cities), while also considering social aspects (e.g. operators, consumers, legal issues, water value awareness) (EC, 2018).

A5.9.2 Digitalisation at catchment level

Beyond industrial site digitalisation and integration with municipal water management, digital technologies may be applied at the catchment and regional levels to facilitate development of decision support tools for industrial companies to identify site-specific on-site and off-site water risks.

Monitoring activity

In Ireland, publicly available data and maps relating to water information are accessible from various state agencies and departments, such as Catchments.ie, the EPA, local authorities, the OPW, the Electricity Supply Board, Geological Survey of Ireland, the Marine Institute, Met Éireann, Waterways Ireland, the Shannon Catchment Flood Risk Management Group, the National Parks and Wildlife Service and the River Agency Northern Ireland, while a number of national monitoring programmes are also in place, such as the Hydrometric Programme and National Water Framework Monitoring Programme. These datasets include data on water quantity and quality monitoring, water infrastructure and the status of waterbodies in relation to the WFD (EPA, 2022b).

National water databases across Europe tend to have low spatial resolution, in many cases only one or two sample points on a river, depending on the parameter being measured. Temporal resolution is relatively high for hydrometric data, with some parameters reported at 15-minute intervals (EPA, 2022c); however, temporal resolution is low for water quality data, ranging from 12 sample times per year to once every 6 years depending on monitoring and survey requirements (EPA, 2021b). Further study is required to assess the representativeness of these datasets to inform industrial water stewardship data collection efforts at specific sites.

Risk management activity

In relation to the potential impacts of climate change on national water systems, various data sources, including digitalised historical weather and climate observations (Met Éireann and the Copernicus

Table A5.4. EU-funded water projects with digital aspects, 2014–2019 (EC, 2020h)

Project	Description
ChemWater	The project focused on chemical processes and water industries, especially the key pan-European concern: the efficient management of water in process industry. The European chemical industry, which is an important water user and a leading technology supplier, can be a solution provider for the whole water management cycle, with a focus on the use of water for industrial purposes.
E4Water	E4Water has addressed crucial process industry needs to overcome bottlenecks and barriers for integrated and energy-efficient water management. The main objective was to develop, test and validate new integrated approaches, methodologies and process technologies for more efficient and sustainable water management in the chemical industry with cross-fertilisation possibilities to other industrial sectors.
R3Water	R3Water: Reuse, Recovery, Resource efficiency. R3Water aimed to support the transition from an urban wastewater treatment plant to a production unit delivering different valuables. Different types of technologies and innovative solutions were developed and tested at the demonstration sites in Belgium, Spain and Sweden.
WaterWatt	The WaterWatt project ("Improvement of energy efficiency in industrial water circuits using gamification for online self-assessment, benchmarking and economic decision support") had the main objective of increasing energy efficiency in industrial water circuits. The improvement of energy efficiency across European industry is crucial for competitiveness. So far, the measures for improving energy efficiency have been directed at primary production processes. In this project, the improvement of energy efficiency in industrial water circuits was addressed: auxiliary electric motor-driven systems with high optimisation potential. Currently, there is neither a benchmark on the energy consumption in industrial water circuits, nor tools for its systematic reduction, nor awareness of the saving potential. The WaterWatt project aimed to remove market barriers for energy efficient solutions, in particular the lack of expertise and information on energy management and saving potential in industrial water circuits.
INSPIREWater	The overall objective of the INSPIREWater project was to increase water and raw material efficiency in the process industry and support implementation of new resource-efficient technologies. This task was addressed with new and established technologies in innovative concepts, thereby reducing water consumption, energy and chemical demands and waste. This was underpinned by a holistic water management framework complementing companies' existing management structures. The development of Europe as a leader in green production and the industrial water treatment market was a focus, as was creating new highly skilled jobs in Europe, especially in small and medium-sized enterprises.
DynaWater4.0	The aim of DynaWater4.0 is to connect models and cyber–physical systems, sensor networks and data platforms as well as components of industrial water management and industrial production based on the concept "IndustrieWasser 4.0". This will be demonstrated and evaluated using practical examples from the chemical, steel and cosmetics industries. The degree of networking ranges from the digital linking of processes within a company, through the location, to the integration of municipal (waste) water management. In addition, the project partners want to show how other sectors can also exploit these results. In this way, the digital cooperation between industrial water management and production at different levels can be exemplified. In addition, the resulting optimisation potentials will be assessed.
W-Net 4.0	This is a web-based data platform for water supply companies to develop a modular and scalable platform that combines simulation software and a data analysis tool (KIT, Berliner Wasserbetriebe).
WaterGridSense4.0	A joint project involving academic, industrial and municipal partners that aims to develop an integrated solution based on power- and cost-efficient sensor devices as well as a scalable and fault-tolerant data analytics platform (KIT, TU Berlin).

ECMWF Climate Change Service (C3S)) and remote-sensing technology datasets, such as high-resolution satellite imagery datasets, are being used in climate and hydrological models to provide insights into current and projected risks to water management. The OPW in Ireland has made progress in this regard by developing detailed flood maps based on historical data and projected changes in the hydrological cycle due to climate change. Their flood maps comply with the European Communities (Assessment and Management of Flood Risks) Regulations 2010 to

2015 (the "Regulations") (Implementing Directive 2007/60/EC) for the purposes of establishing a framework for the assessment and management of flood risks, aiming to reduce the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods (OPW, 2018). It is worth noting that the flood maps provided by the OPW are not intended to designate individual properties at risk of flooding; they are community-based maps (OPW, 2018).

More detailed high-resolution mapping would be required to inform individual industrial sites of their flooding risks; however, technological limitations and uncertainties exist in terms of how to downscale climate models and integrate them with hydrological models. The operational service for the water sector of the C3S is accelerating progress in this area by providing state-of-the-art hydrological climate information and seasonal forecasts through datasets and interactive web applications that are intended for use in the fields of water allocation, flood management, ecological status and industrial water use (C3S, 2022a).

A5.10 Adoption of Industry 4.0 in Industrial Water Management

A5.10.1 Objectives of Industry 4.0

I4.0 describes a continued trend of automation and data exchange in manufacturing technologies and processes. This can include capabilities such as cyber–physical systems, cloud computing, artificial intelligence, IIoT, robotics and augmented/virtual reality and offers benefits to enterprises through cost efficiencies, operational agility and democratising data (IMR, 2022).

Ireland's Industry 4.0 Strategy 2020–2025 (DBEI, 2019) outlines I4.0 as a key output of Future Jobs Ireland, the government's new economic pathway aimed at ensuring that Ireland is well placed to prosper in a rapidly changing global economy.

The main goals of the strategy are:

1. to encourage firms to adopt and build capability in I4.0 technologies;
2. to encourage firms to harness the new opportunities enabled by I4.0 technologies;
3. to become a global leader in research, development and innovation, which underpins I4.0;
4. to help the current and future workforce to develop the skills to deliver the I4.0 transformation and exploit the new opportunities arising in manufacturing and supply chain firms through I4.0 technologies;
5. to establish a world-class business environment for I4.0 that is underpinned by appropriate regulatory legal standards and an internationally connected ecosystem.

Examples of how international I4.0 trends and drivers may impact on Irish manufacturing sites are shown in Figure A5.8.

A5.10.2 Challenges in implementing Industry 4.0

Key challenges and risks associated with I4.0 relate to, for instance, developing an I4.0 strategy; rethinking the organisation and processes to maximise outcomes; understanding the business case; conducting successful pilots; making an organisation realise that action is needed; considering change management, company culture and acceptance; and interconnecting departments and talent (i-SCOOP, 2020).

In addition to these challenges, there are several others, namely practical, technological and ecosystem-related challenges. These include challenges related to data compliance questions; managing risk and lowering costs; dealing with the complexity of the connected supply chain; developing a better understanding of information and operational technologies and, more importantly, how these can be leveraged; altering customer and industrial partner demands; addressing competition and the fact that I4.0 champions gain a competitive benefit fast; and eternal and extremely important human factors such as talent and the future of work and employment (i-SCOOP, 2020).

Process Industries	
Pharmaceuticals and Chemicals	**Pharmaceuticals** • Personalised healthcare is driving a shift towards more targeted products. • Information-based medicine and innovative monitoring and delivery mechanisms are being developed. • Flexible batch-manufacturing processes and patient data capture and analysis are becoming key enablers. **Chemicals** • Digitalisation is enabling the streamlining of complex processes and operations. • Value-added data services around chemical products are being developed (e.g. apps for providing technical recommendations to clients).
Food and Drinks	• directly with farmers and food manufacturers. Farmers and food producers are thus becoming retailers. • Product customisation is being enabled through the ability to adapt nutrient content to particular categories of customers.

Product Manufacturers	
Medical Devices	• MedTech products are moving towards end-to-end solutions for better care at lower prices, including connected health and drug delivery through data capture. • Personalised healthcare and customisation of medical products are being developed including combination products and diagnostics.
Computer and Electronics	• The Computer and Electronics Sector is becoming a key enabling sector for Industry 4.0, providing intermediate goods to other industrial sectors and making their products and services knowledge intensive.
Engineering	• Digitally enabled flexible batch-manufacturing processes will be required to address increased product customisation trends.

Figure A5.8. Example of international I4.0 trends and drivers in key Irish manufacturing sub-sectors. Source: DBEI (2019).

An Ghníomhaireacht Um Chaomhnú Comhshaoil

Tá an GCC freagrach as an gcomhshaol a chosaint agus a fheabhsú, mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ar thionchar díobhálach na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialáil: Rialáil agus córais chomhlíonta comhshaoil éifeachtacha a chur i bhfeidhm, chun dea-thorthaí comhshaoil a bhaint amach agus díriú orthu siúd nach mbíonn ag cloí leo.

Eolas: Sonraí, eolas agus measúnú ardchaighdeáin, spriocdhírithe agus tráthúil a chur ar fáil i leith an chomhshaoil chun bonn eolais a chur faoin gcinnteoireacht.

Abhcóideacht: Ag obair le daoine eile ar son timpeallachta glaine, táirgiúla agus dea-chosanta agus ar son cleachtas inbhuanaithe i dtaobh an chomhshaoil.

I measc ár gcuid freagrachtaí tá:

Ceadúnú

> Gníomhaíochtaí tionscail, dramhaíola agus stórála peitril ar scála mór;
> Sceitheadh fuíolluisce uirbigh;
> Úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe;
> Foinsí radaíochta ianúcháin;
> Astaíochtaí gás ceaptha teasa ó thionscal agus ón eitlíocht trí Scéim an AE um Thrádáil Astaíochtaí.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

> Iniúchadh agus cigireacht ar shaoráidí a bhfuil ceadúnas acu ón GCC;
> Cur i bhfeidhm an dea-chleachtais a stiúradh i ngníomhaíochtaí agus i saoráidí rialáilte;
> Maoirseacht a dhéanamh ar fhreagrachtaí an údaráis áitiúil as cosaint an chomhshaoil;
> Caighdeán an uisce óil phoiblí a rialáil agus údaruithe um sceitheadh fuíolluisce uirbigh a fhorfheidhmiú
> Caighdeán an uisce óil phoiblí agus phríobháidigh a mheasúnú agus tuairisciú air;
> Comhordú a dhéanamh ar líonra d'eagraíochtaí seirbhíse poiblí chun tacú le gníomhú i gcoinne coireachta comhshaoil;
> An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Dramhaíola agus Ceimiceáin sa Chomhshaol

> Rialacháin dramhaíola a chur i bhfeidhm agus a fhorfheidhmiú lena n-áirítear saincheisteanna forfheidhmithe náisiúnta;
> Staitisticí dramhaíola náisiúnta a ullmhú agus a fhoilsiú chomh maith leis an bPlean Náisiúnta um Bainistíocht Dramhaíola Guaisí;
> An Clár Náisiúnta um Chosc Dramhaíola a fhorbairt agus a chur i bhfeidhm;
> Reachtaíocht ar rialú ceimiceán sa timpeallacht a chur i bhfeidhm agus tuairisciú ar an reachtaíocht sin.

Bainistíocht Uisce

> Plé le struchtúir náisiúnta agus réigiúnacha rialachais agus oibriúcháin chun an Chreat-treoir Uisce a chur i bhfeidhm;
> Monatóireacht, measúnú agus tuairisciú a dhéanamh ar chaighdeán aibhneacha, lochanna, uiscí idirchreasa agus cósta, uiscí snámha agus screamhuisce chomh maith le tomhas ar leibhéil uisce agus sreabhadh abhann.

Eolaíocht Aeráide & Athrú Aeráide

> Fardail agus réamh-mheastacháin a fhoilsiú um astaíochtaí gás ceaptha teasa na hÉireann;
> Rúnaíocht a chur ar fáil don Chomhairle Chomhairleach ar Athrú Aeráide agus tacaíocht a thabhairt don Idirphlé Náisiúnta ar Ghníomhú ar son na hAeráide;
> Tacú le gníomhaíochtaí forbartha Náisiúnta, AE agus NA um Eolaíocht agus Beartas Aeráide.

Monatóireacht & Measúnú ar an gComhshaol

> Córais náisiúnta um monatóireacht an chomhshaoil a cheapadh agus a chur i bhfeidhm: teicneolaíocht, bainistíocht sonraí, anailís agus réamhaisnéisiú;
> Tuairiscí ar Staid Thimpeallacht na hÉireann agus ar Tháscairí a chur ar fáil;
> Monatóireacht a dhéanamh ar chaighdeán an aeir agus Treoir an AE i leith Aeir Ghlain don Eoraip a chur i bhfeidhm chomh maith leis an gCoinbhinsiún ar Aerthruailliú Fadraoin Trasteorann, agus an Treoir i leith na Teorann Náisiúnta Astaíochtaí;
> Maoirseacht a dhéanamh ar chur i bhfeidhm na Treorach i leith Torainn Timpeallachta;
> Measúnú a dhéanamh ar thionchar pleananna agus clár beartaithe ar chomhshaol na hÉireann.

Taighde agus Forbairt Comhshaoil

> Comhordú a dhéanamh ar ghníomhaíochtaí taighde comhshaoil agus iad a mhaoiniú chun brú a aithint, bonn eolais a chur faoin mbeartas agus réitigh a chur ar fáil;
> Comhoibriú le gníomhaíocht náisiúnta agus AE um thaighde comhshaoil.

Cosaint Raideolaíoch

> Monatóireacht a dhéanamh ar leibhéil radaíochta agus nochtadh an phobail do radaíocht ianúcháin agus do réimsí leictreamaighnéadacha a mheas;
> Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha;
> Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta;
> Sainseirbhísí um chosaint ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Ardú Feasachta agus Faisnéis Inrochtana

> Tuairisciú, comhairle agus treoir neamhspleách, fianaise-bhunaithe a chur ar fáil don Rialtas, don tionscal agus don phobal ar ábhair maidir le cosaint comhshaoil agus raideolaíoch;
> An nasc idir sláinte agus folláine, an geilleagar agus timpeallacht ghlan a chur chun cinn;
> Feasacht comhshaoil a chur chun cinn lena n-áirítear tacú le hiompraíocht um éifeachtúlacht acmhainní agus aistriú aeráide;
> Tástáil radóin a chur chun cinn i dtithe agus in ionaid oibre agus feabhsúchán a mholadh áit is gá.

Comhpháirtíocht agus Líonrú

> Oibriú le gníomhaireachtaí idirnáisiúnta agus náisiúnta, údaráis réigiúnacha agus áitiúla, eagraíochtaí neamhrialtais, comhlachtaí ionadaíocha agus ranna rialtais chun cosaint chomhshaoil agus raideolaíoch a chur ar fáil, chomh maith le taighde, comhordú agus cinnteoireacht bunaithe ar an eolaíocht.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

Tá an GCC á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóir. Déantar an obair ar fud cúig cinn d'Oifigí:

1. An Oifig um Inbhunaitheacht i leith Cúrsaí Comhshaoil
2. An Oifig Forfheidhmithe i leith Cúrsaí Comhshaoil
3. An Oifig um Fhianaise agus Measúnú
4. An Oifig um Chosaint ar Radaíocht agus Monatóireacht Comhshaoil
5. An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tugann coistí comhairleacha cabhair don Ghníomhaireacht agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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