# WATER 4.0

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# WATER 4.0 – Made in Germany

The water sector is constantly looking for ways of adapting to changing conditions, and for solutions to global challenges that are both effective and efficient. For example, urbanization and climate change – two major drivers of global transformation – are continually placing greater strains on scarce water resources. Digitalization is increasingly making available practices, tools and other resources that are in turn ushering in a new era of water management.

Like other industries, the water sector is seeking to improve its future viability and competitiveness, for example through automation using intelligent networks. The increased use of IT, sensor technologies and modelling applications is creating opportunities to more accurately perceive water-management systems in all their complexity and interconnectedness, and to integrate this information into production, early-warning and decision-making processes. In addition, opportunities for new digital business models are emerging, in part through the use of so-called cloud-computing technologies (that is, the use of decentralized IT services).

Digitalization in the water- and wastewater-management sectors holds great potential. Digital solutions can lead to savings and optimization in many areas, from data collection, the use of assistance systems, and the networking and integration of individual system components to service decentralization and even autonomy for whole infrastructure systems. According to Global Water Intelligence's (GWI) "Water's Digital Future,"[1] there are three major drivers of digitalization in the water sector:

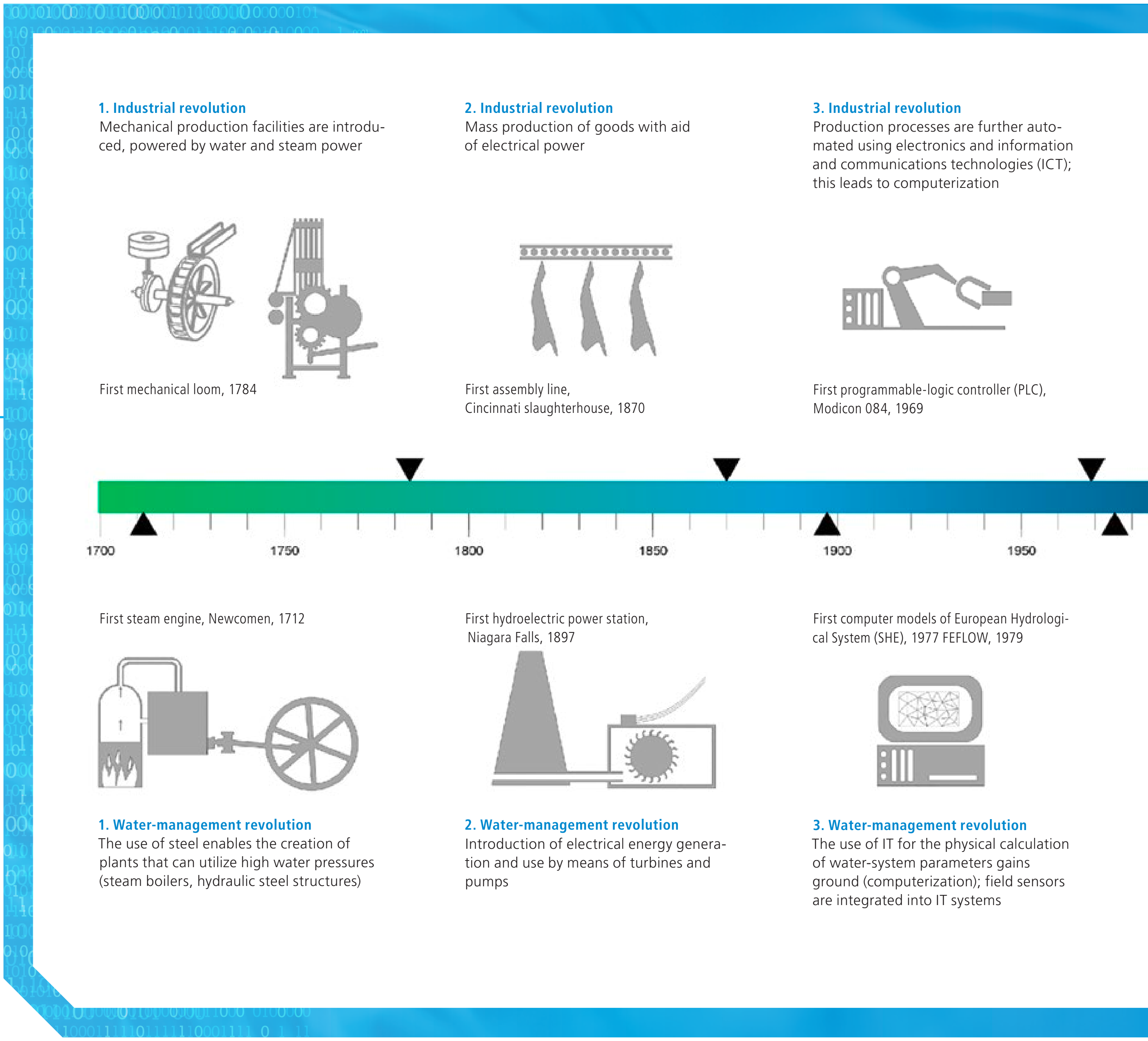
HOLISTIC APPROACH

Water 4.0 describes the interactions between innovative current and future networked technologies.

>> 1. The desire to increase efficiency in water- and wastewater-treatment, water-distribution, and wastewater-disposal activities, as well as in communications with consumers.

>> 2. The desire to achieve cost savings through better monitoring of water-supply and wastewater-disposal networks, and by operating systems and plants in a demand-based manner.

>> 3. The need to meet rising legal requirements for water and wastewater quality, as well for the security and quality of supply and disposal functions.




A recent survey of municipal enterprises additionally indicated that new business models that expand service portfolios are regarded as an opportunity.[2] In all these areas, better networking between facilities, digitalized system components (e.g., intelligent pumps and online measurement technologies), and planning and operational data in particular can contribute to optimizing water- and wastewater-management processes further, and can help them become more flexible overall.

Using intelligent hardware and software to ensure continuity between planning and operations processes will thus increasingly become a necessity in the water sector, as will the autonomous exchange of information (from users to individual components all the way to suppliers and disposal entities). Such techniques will improve resource productivity and efficiency. For processes managed in real time, modern sensor technologies and the internet of things and services (IoTS) also play an important role. Thanks to such tools,

**4. Industrial revolution**
Intelligent end devices in intelligent global network enable the persistent availability and analysis of data and information. The internet of things and services (IoTS) emerges. Physical and virtual worlds merge into cyber-physical systems (CPS)


**4. Water-management revolution**
Real and virtual water systems are networked together (CPS); real-time and predictive models reduce risks and costs; supply and disposal systems integrate internet-based networking functions all the way to the end user (smart sensoring)

Figure 1: Comparison of four industrial stages of development; based on acatech[3] with water-management steps based on DHI[4]

data on water-relevant processes and water quality are increasingly available and usable at any time, from any location. Furthermore, this information can be cross-linked with other data (e.g., weather data) to create forecasts that can be used in managing water-relevant plants and networks.

Borrowing from an analogous developmental trend in the industrial-manufacturing world, which is referred to as Industry 4.0,[3] GWP refers to this digital-technology-driven transformation as WATER 4.0 (see box on pg. 7). Figure 1 shows a comparison of key technical developments in the industrial-manufacturing sector and the water sector. However, when categorizing developmental steps in the water-management field, a number of different interpretations and timeframes are possible. A key feature of the current fourth stage of development in both sectors is the fusion of the real and virtual worlds into so-called cyber-physical systems (CPS). This term describes the combination of sensors, computer models and real-time control systems with real-world water systems, supported in vital ways by intelligent global networks, and intranet and/or internet functions.

Cross-cutting technologies enable a holistic view of the water in the overall system, no matter whether it is falling to the ground as precipitation; is being pumped through a piping network to supply drinking water; is being transported through a sewage network to a wastewater treatment plant to be purified, and then reused for irrigation if necessary; or used in an industrial process as a solvent, a cleaning agent, or for cooling or heating purposes (Fig. 2). These are not independent systems. Rather, they combine processes, actions and technologies into a single information-technological unity, and include traditional, well-proven methods as well as new innovative approaches. In this regard, both centralized and decentralized solutions are possible.

Figure 2: Visualization of a digitalized and networked water-management sector in three levels: A) Generate data, B) Collect data, C) Consume data; from FiW/IWW[5]

Neverthless, the following must apply:

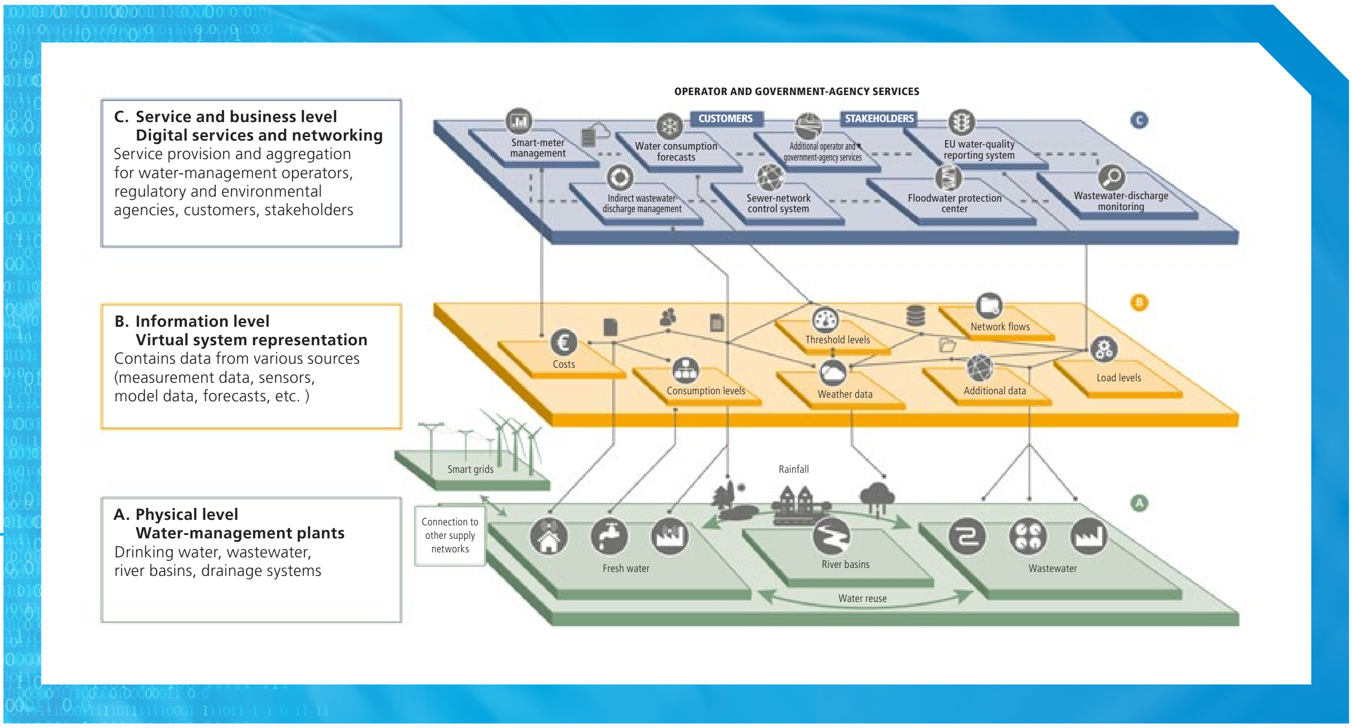
- Data and information must be exchanged, whether this is collected online or input and output offline (manually).
- A digital representation of the system to be observed must be created, enabling reciprocal influence between the virtual and real systems.

The result is a control loop that represents the natural water cycle and the anthropogenic influences upon it, puts these factors in relation to one another, continually records and depicts them, and thus helps produce a holistic view that enables strong decision-making.

Thanks to cognitive model functions allowing for goal-oriented adaptation, modification and partial self-organization, today's automation solutions are likely to evolve into systems with greater autonomy. Research and development projects are focusing on the further development of self-organizing cognitive systems today. The results are cyber-physical water systems (CPWS) that are capable of continuous, sustainable observation, and which enable interaction between virtual and real environmental systems while taking changed and changing processes into account.

Regarded in this way, WATER 4.0 is not a specific technology; that is, there is no rigorous definition in the scientific sense. Rather, WATER 4.0 describes the interaction between innovative current and future networked technologies. Within this framework, water remains the focus – as a natural resource, product or production input; with the goal of sustainable, risk-minimized management and use; and with the interests of all direct and indirect users and stakeholders taken into account. Linking measurement and control systems with data-analysis and modelling functions transforms data into information that can be used to prepare, support and/or carry out decisions and actions, while allowing the effects within the water system to be monitored. Moreover, the information collected over a period of time can lead to new insights into how water can be better used across its various fields of application.

WATER 4.0 is thus a holistic, strategic approach that depends on digital data in networked systems. This data is evaluated and used in forecasts, but such systems also draw on data from other fields, thus providing a more complete view and enabling correspondingly sustainable decisions. WATER 4.0 does not limit itself to the here and now; rather, it follows the course of technological development, and takes advantage of new opportunities as they arise. The approach primarily depends on the functioning of the system as a whole entity, and the comparison between the virtual and real-world water systems, rather than on individual innovative elements.

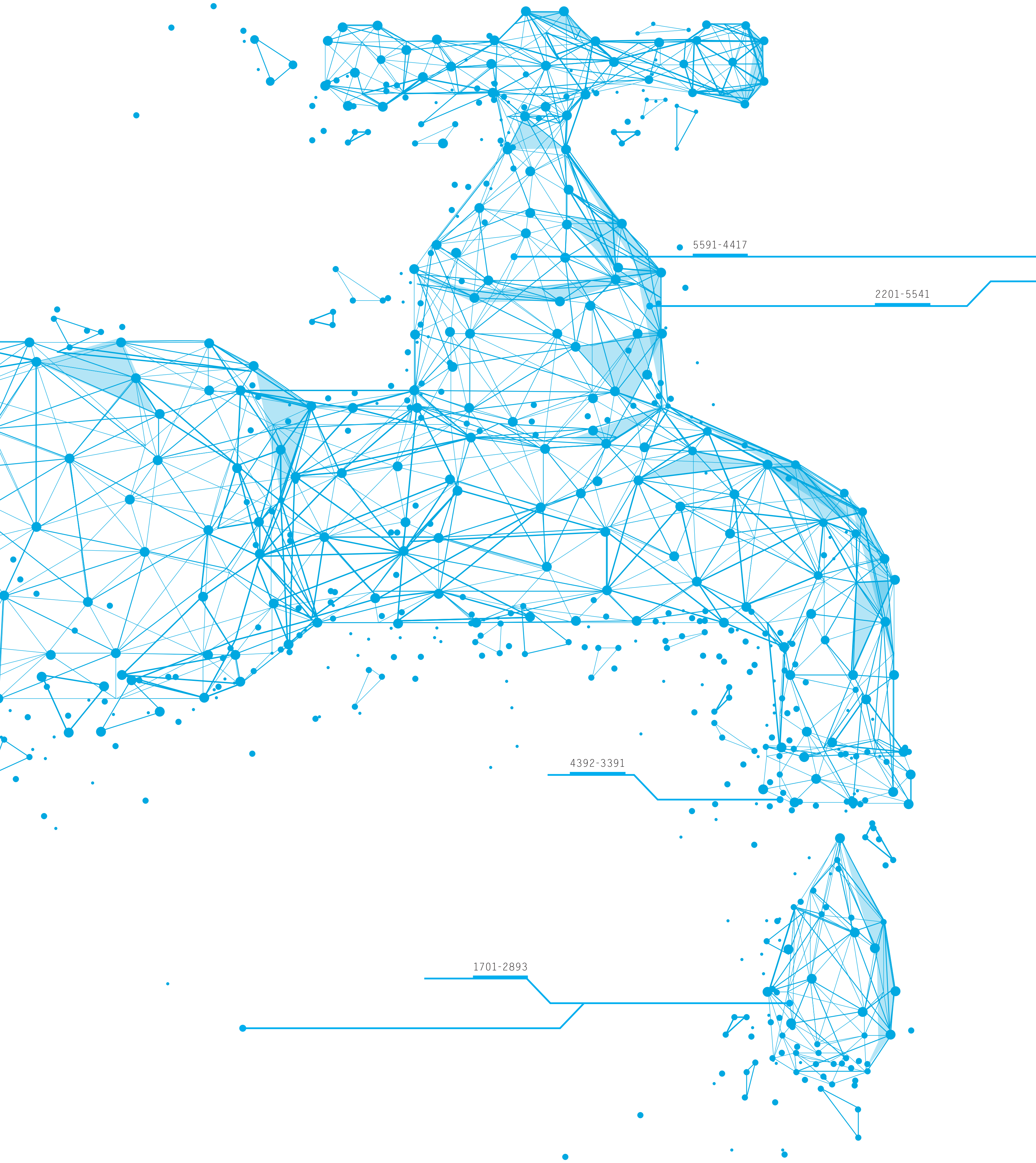



STRATEGY FOR THE WATER SECTOR

# GWP conception of WATER 4.0

WATER 4.0 focuses on digitalization and automation as the core aspects of a strategy for resource-efficient, flexible and competitive water management. In this regard, and in analogy to the Industry 4.0 initiative, WATER 4.0 refers to core characteristics and concepts of this industrial revolution such as the networking of machines, processes, storage systems and operational resources, along with smart grids and the internet of things and services. As an umbrella term, WATER 4.0 brings these elements into a systematic relationship within the water-management context.

In the implementation of WATER 4.0, cyber-physical systems (CPS) produce an optimal level of networking between virtual and real water systems, in which software tools are used throughout the planning, construction and operations phases. This will enable the creation of an intelligent network that links water users (i.e., agriculture, industry and households) and components within a sustainable water infrastructure, while also drawing on data from the environment and the water cycle, allowing for a holistic approach along the entire value chain. In addition, WATER 4.0 provides a high level of transparency for water users, thus covering current needs, while also providing opportunities for creative, future-focused jobs in the water sector.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# Potential, benefits and challenges of the digital transformation

As noted in Chapter 1, the potential held by digitalization in the water sectors is significant. Digital solutions can lead to savings and optimization in many areas, from the collection of data, the use of assistance systems, and the networking and integration of individual system components to service decentralization and even the autonomy of whole infrastructure systems. The German water industry, with the participation of the GWP, is developing ideas and approaches aimed at using digital technologies to facilitate the long-term support of domestic and foreign system operators with regard to plant operation and maintenance, as well as employee training. Projects in this area include, for example, the "Sustainable Utility Partnerships 4.0" innovation forum.[6]

THE POTENTIAL IS SIGNIFICANT

With digital solutions,
plants are optimized,
employees trained,
savings achieved,
and whole infrastructures
rendered autonomous.

## Opportunities provided by networking, modelling and simulation

By networking and cross-connecting process, planning and operations data, a water-infrastructure system's entire technical and organizational process and value chain can be represented using digital models of structures and plants. The endpoint of this procedure is a digital twin – a data-based facility model that consolidates the entirety of a plant's planning and operations data across its full lifecycle. This facilitates active maintenance of this information, and enables ongoing optimization of planning, operations and servicing functions. Having this digital twin at the plant level enables processes to be easily modeled and simulated (see Fig. 3). For example, this might entail the intelligent cross-connection of data from the sewer network and from weather-measurement stations, enabling improved decision-

Figure 3: The digital twin at a test bed facility at TU Berlin, working in an R&D context, will demonstrate the possibilities of this new technology for the water-management sector [Siemens, 2018]

Figure 4: Modern tools enable the 3-D integration of real-world plants and planning data [Siemens, 2018]

making in periods of heavy rain. A number of current solutions allow water-management entities to combine and evaluate data from various sources, both locally and on a cross-location or full-system basis by using a secure cloud-computing environment. This allows special modes of operation to be simulated in advance, so that they can be called up and put into action in an emergency. This contributes not only to efficient wastewater handling, but also to municipal safety. In order to optimize energy costs, plant operators can use appropriate tools to optimize pump schedules, detect leaks or pipe breaks at an early date, or even act in time to avoid such problems. The up-to-date and dynamic information on plant conditions obtained in this way helps to improve the efficiency of plant operations. Better plant transparency also helps maintenance teams fix problems. For example, detailed information on the location and type of disruption can be provided to maintenance staff members as needed. In this way, digital solutions also contribute to improving plant availability and the security of supply.

## Opportunities to cross-connect plant information across the life cycle

An integrated approach to plant planning, operations and maintenance provides for optimal data transfer between the planning and operations phases, allowing for generally consistent and transparent data. However, it also provides valuable services in the operations and maintenance phrases. When planning water-infrastructure systems, plant planning data and the results of automated projections can be combined to enable parallel work processes and sequences.

This decreases project durations, while simultaneously providing for higher project quality. Similarly, by integrating engineering functions and process-control technology, the data collected during the engineering phase can continue to be used in the operations phase, and supplemented with operational data. The automatic updating of planning data during the course of plant operation makes it possible to base maintenance and modernization decisions on the actual state of the plant and systems at all times. Projects can thus be realized more efficiently and effectively (see Fig. 4).

Even existing plants that lack planning data in digital form, or for which this data is incomplete or outdated, can take advantage of these benefits. With appropriate tools, even large and unstructured data sets can be inserted into a unified database structure and verified. In addition, the integration of 2-D and 3-D data using tools created for this purpose allows plants to be digitalized and connected with imported planning data in a database structure. In this way, data can be verified, giving the plant operator an up-to-date digital representation of the plant (see Fig. 3).[7]

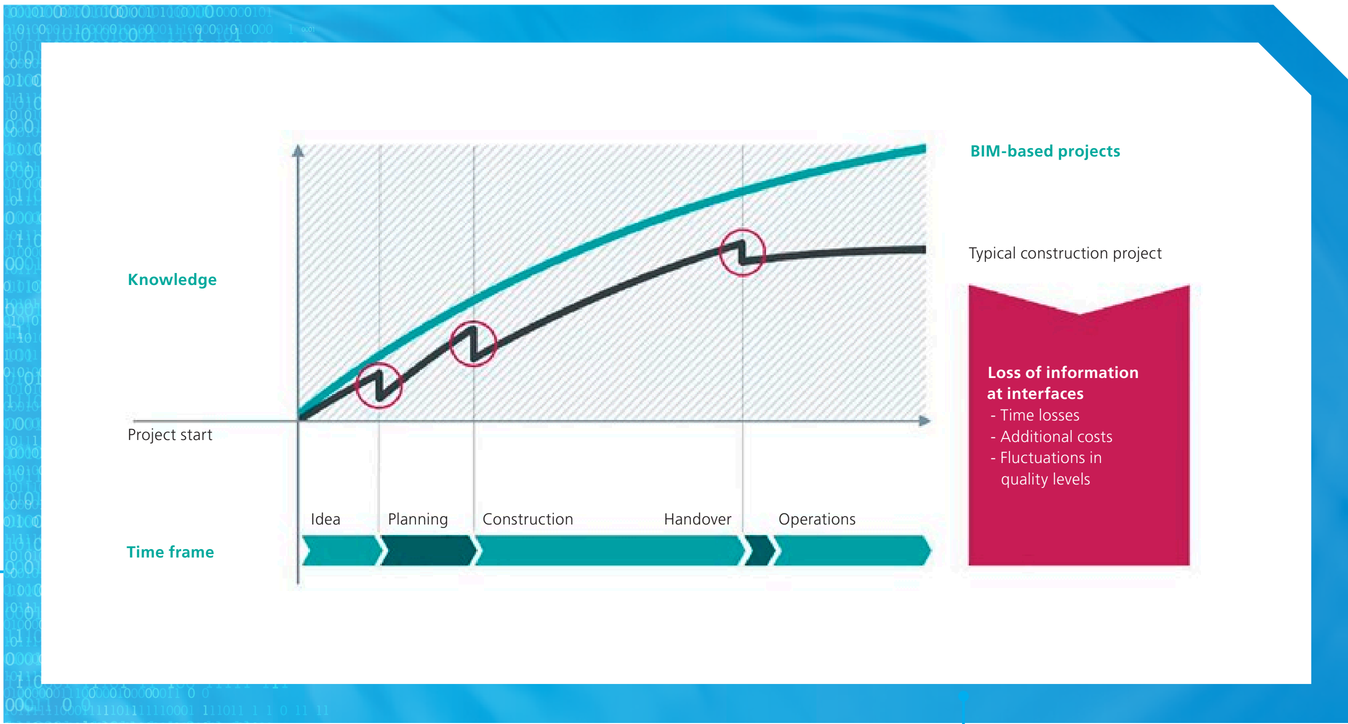



Figure 5: Consistent data handling reduces information loss [Siemens, 2018]

## "Building information modelling" (BIM) as a cooperative working methodology

In some areas, the creation of a digital twin of this kind is already an integral part of the planning process. For example, the German Federal Ministry of Transport and Digital Infrastructure (BMVI)[8] and the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) have called for the use of data- and software-supported methods for the planning and execution of infrastructure projects beginning in 2020. This "building information modeling" (BIM) approach requires the creation of a digital twin of the proposed structure, or in the context of process technology, of a complete plant or facility (see Fig. 5). Under this model, many planning, construction and operations processes can be conducted in parallel, and the results examined with reference to the digital twin – all the way up to the point of gaining support from political decision makers or the public at large. The model can additionally be used to create a 3-D visualization, which can even be directly experienced or explored by using smart glasses. This can help support decision-making, and shorten the time needed for participation processes. Later, during the course of operations, information can be made available directly on the object itself through the use of smart glasses, eliminating the need for a manual, time-wasting review of company and inventory documents. Similarly, the visualization enables early introductory training to be carried out using the digital twin. This lets workflows be tested, and if necessary adapted and optimized in advance. Modeling structures or infrastructures before they are built also supports project execution. Optimizing processes and reducing the quantity of interfaces significantly increases planning quality and reduces the effort needed for collision testing. The better data quality and availability reduces project durations. Moreover, the opportunities provided by simulation and modelling reduce non-calculable costs during the construction phase as well as ongoing operating costs (Fig. 5). The expectations for BIM are accordingly high. For example, the EU BMI Task Group[9] forecasts that savings of between 13 percent and 21 percent on planning and construction costs can be achieved by 2025 through the full digitalization of planning processes, as well as savings of 10 percent to 17 percent in operations phases.

## Cybersecurity challenges

German Water Partnership (GWP) along with the German Association for Water, Wastewater and Waste (DWA)[10] have stressed in numerous research projects and publications that the cybersecurity challenge extends beyond simply improving automation, process-management and process-control technologies. Digitalization is affecting virtually all areas of the water sector, from planning tools to plant technologies to employee-training standards and citizen consumption patterns. A strategic approach must consider opportunities and risks within all of these areas, taking into account all potential costs and benefits. Relevant risks associated with digitalization can be found particularly in the areas of data protection and IT security.[8]

Even in the water sector, automation systems today are more tightly connected with the broader IT landscape than many plant operators are aware. While this brings a number of benefits, the advancing degree of connectivity also carries risks. Whereas proprietary networks used to be the norm, the office and automation worlds are today growing ever closer together on the basis of modern standards such as Ethernet and TCP/IP. This also renders systems used in process-control technologies more susceptible to external attacks. Given these developments, lawmakers in many counties have called for action on the part of plant operators. For example, Germany's "Act on Increasing the Security of Information-Technology Systems" came into force in 2015. It requires operators of particularly vulnerable infrastructure – so-called critical infrastructures in the areas of energy, water, health and telecommunications – to protect their networks more robustly from attacks. For some of the critical infrastructures covered by this measure, such as wastewater-treatment plants serving more than 500,000 people, the law created reporting obligations for security-related incidents as of November 2016, along with minimum IT-security standards that took effect in May 2017.

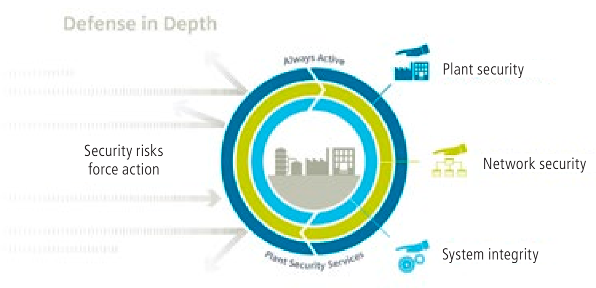
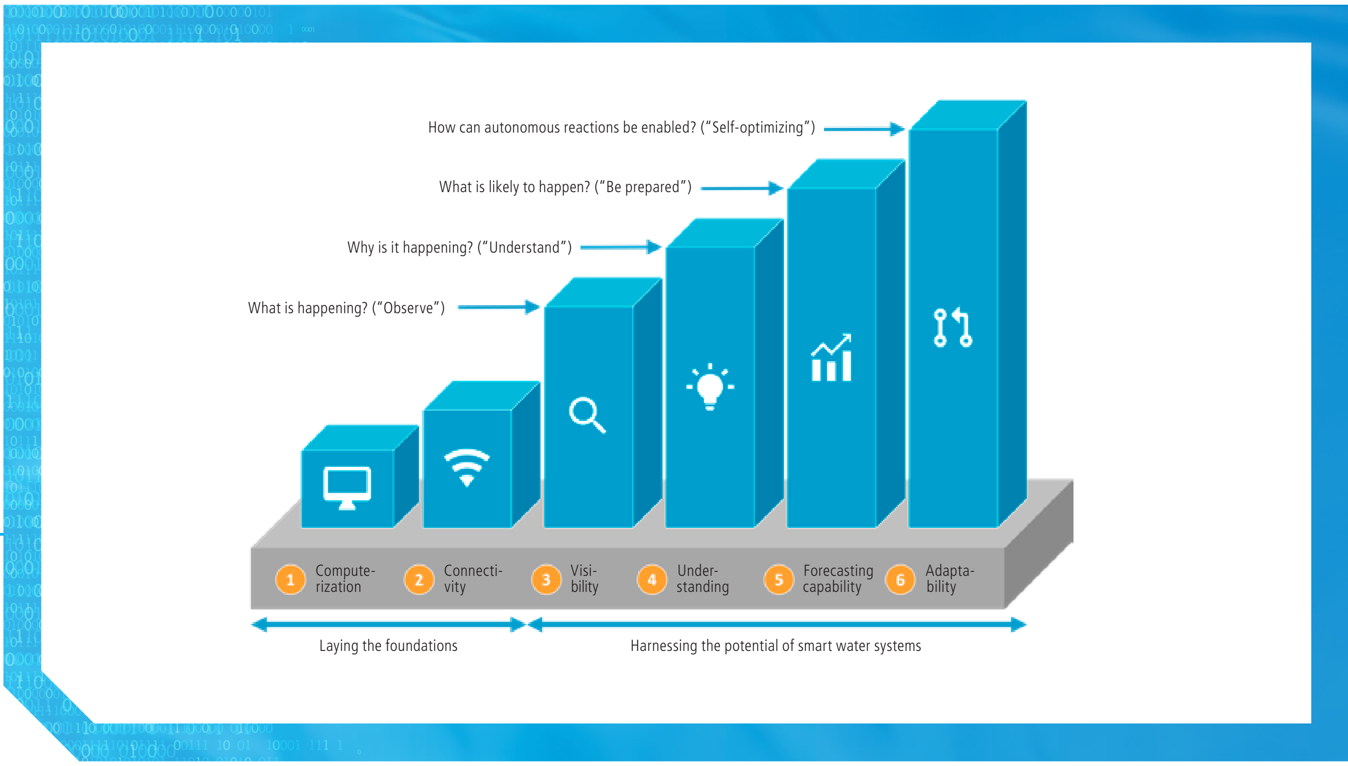



Figure 6: In order to protect industrial facilities against internal and external cyber-attacks, a deep, multi-level "defense in depth" strategy is recommended. This must be implemented at all levels [Siemens, 2018]

However, industrial facilities such as waterworks or wastewater-treatment plants require special IT-security solutions. Industrial security solutions and services must ensure unimpaired plant availability and the uninterrupted real-time capability of critical process-control systems, as well as comprehensive and continually updated threat protection. It is possible to fulfil both of these requirements by employing coordinated, broadly diversified and comprehensive concepts with appropriately industrial-grade components. In this regard, it is advisable to use a "defense in depth" system,[11] composed of multi-stage defense components that range from the operations level to the field level (see Fig. 6). Thus, if the appropriate tools are used, the security of water and wastewater plants can be continuously monitored, and attacks prevented, analyzed and documented, allowing companies to comply with their obligations to report security-relevant incidents to the authorities.




## Challenges of structural and organizational changes

In the future, digitalization will have a very strong impact on the planning, construction, operation and modernization of all facilities in the water sector, both from an organizational and structural perspective. Career- and work-activity fields will be transformed, as will be responsibilities within organizations. In addition, new business models will emerge, such as new engineering or optimization services. It is thus critical that job profiles, training and apprenticeship programs, and qualification measures be adapted to reflect the new challenges. Moreover, the teams and employees affected must themselves be involved in the digitalization process. By actively supporting process digitalization through changes in communication and internal work cultures, as well with measures enabling further development of staffers' technical and methodological skills, the water- and wastewater-management sector can preserve and even expand its employees' know-how, thus harnessing the full potential of Industry 4.0.[12]

## Being aware of digital maturity levels

In addition to considering specific opportunities and challenges, water sector stakeholders must also give thought to their individual points of departure. This will allow them to digitalize their processes and plants in a gradual and reasonably paced way. Using a maturity model,[13] water suppliers and wastewater-disposal entities can determine their company's current status with regard to digitalization. They can establish which company-specific goals have and should be set, and what path they should take to reach these goals. At its core, the maturity model consists of six successive steps (see Fig. 7), that help situate an entity's current state of development toward a "water system 4.0.". This evaluation is carried out using a survey of more than 30 features in the critical areas of resources, information systems, organization and internal culture. In most cases, the initial foundations for digitalization will already be in place. For example, a plant may already be partially networked for the purposes of visualization and process control. However, great potential remains to be realized in the analysis of process and plant data in order to identify interdependencies, as well as in the use of forecasting models. On this basis, strategies can be derived and developed in order to fully exploit the potential of digitalization with reference to each company's specific objectives.

List of sources: [1] Global Water Intel, "Market Research Report: Water's Digital Future: The Outlook for Monitoring, Control and Data Management Systems," 30 September 2016. [Online]. Available at: https://globalwaterintel-info.com/p/36G3-1K3/waters-digital-future-sample-online. [2] Verband Kommunaler Unternehmen e.V., "Umfrage Ländlicher Raum: Chancen der Digitalisierung nutzen!," 23 February 2018. [Online]. Available at: https://www.vku.de/umfrage-laendlicher-raum-chancen-der-digitalisierung-nutzen/. [3] acatech, "Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0," April 2013. [Online]. Available at: https://www.bmbf.de/files/Umsetzungsempfehlungen_Industrie4_0.pdf. [4] R. Vestner und P. Keilholz, "Was bedeutet der '4.0-Ansatz' für die Wasserwirtschaft? Gewässerschutz Wasser Abwasser," GWA – Gewässerschutz, Wasser & Abwasser Volume 239, p. 7/1 – 7/13, 2016. [5] FiW e.V. und IWW Zentrum Wasser, "Visionsbild der digitalisierten und vernetzten Wasserwirtschaft," April 2019. [6] German Water Partnership e.V. und inter 3 Institut für Ressourcenmanagement, "Innovationsforum 'Betreiberpartnerschaften 4.0'," [Online]. Available at: http://betreiberpartnerschaften.de/. [7] P.-U. Thamsen, "Vortrag und Vorstellung des Projektes Digitaler Zwilling an der TU Berlin," Technische Universität Berlin, Berlin, 2019. [8] BMVI, "Digitales Planen und Bauen: Stufenplan zur Einführung von Building Information Modeling (BIM)," [Online]. Available at: https://www.bmvi.de/SharedDocs/DE/Artikel/DG/digitales-bauen.html. [9] EU BIM Task Group. [Online]. Available at: http://www.eubim.eu/. [10] DWA, "Building Information Modeling (BIM) in der Wasserwirtschaft – Vorhaben Erarbeitung Merkblatt DWA-M 860-1," 30 November 2018. [Online]. Available at: https://de.dwa.de/de/regelwerksankuendigungen-volltext/building-information-modeling-bim-in-der-wasserwirtschaft.html. [11] ComputerWeekly.de, "Definition of Defense in Depth," 07 2016. [Online]. Available: https://www.computerweekly.com/de/definition/Defense-in-Depth. [12] E. Schaeffer, "Industrie X.0 – Digitale Chancen in der Industrie nutzen," Redline Verlag, 2017, pp. 213-215. [13] Hein, A. (2018), "Projekt zur Entwicklung eines Reifegradmodells Wasserversorgung 4.0: Wie kann man Digitalisierung im Wasserfach messbar machen?" energie | wasser-praxis 10/2018, pp. 2-3, Bonn: wvgw. [14] DECHEMA, "Wassermanagement," [Online]. Available at: https://dechema.de/wassermanagement.html. [15] Schuh, G., Anderl, R., Gausemeier J., ten Hompel, M., Wahlster, W. (Eds.): Industrie 4.0 Maturity Index. Die digitale Transformation von Unternehmen gestalten (acatech STUDIE), München: Herbert Utz Verlag 2017.

Figure 7: Maturity levels on the way to Water 4.0 supply systems; from FiW/IWW[13], derived from Schuh et al.[15]

## Toward fully digitalized systems

Digitalization connects people, plants and services, and thus demands both horizontal networking ("from raindrops to the customer") and vertical networking across all areas of the company ("from plant operations to the management level"). In municipal and industrial water systems alike, this vertical integration of all hierarchy levels[14] will in the future stretch from plant facilities and field sensors to the control, operations, management and monitoring levels. It will also encompass models and simulations on the network or the cloud using autonomous cyber-physical systems (CPS). At the end of this evolution will be systems that – thanks to cross-connections between a wide variety of data and the use of accordingly intelligent algorithms – will be able to react independently to requirements and improve themselves on an ongoing basis. Water and wastewater-treatment plants can thus become adaptive systems that interact with their environments.

In this way, plants in the future will be able to adapt themselves to upcoming heavy-rain events on the basis of current weather and radar data and the resulting runoff forecasts. This will allow them to minimize operational disruptions and environmental damage. Using online radar data in conjunction with radar forecasts, intelligent systems make it possible to calculate inflows into the sewer network and optimal control-system interventions. Similarly, events in the sewer network during operation can be simulated. Special optimization algorithms provide an optimal control target for every point in time, taking into account the parameters of the various structures and the operators' different objectives. In this way, plants' operating points can be dynamically and proactively adapted to current conditions, using existing capacities in an optimum manner.

Leading research institutions have also taken up the issue of digitalization in the water sector. A number of research projects in this area are being supported in the context of the European Research Framework Program Horizon 2020. For example, the Institute for Flow Mechanics and Technical Acoustics at Technische Universität Berlin will soon expand one of its test benches to include a complete digital twin, with the aim of researching and demonstrating the possibilities of digitalization using two pump test benches. The results of the work will be made available as an example project in a GWP reference booklet.

### Application examples

Additional application examples are categorized according to the maturity model, and published as a GWP reference booklet on the GWP website.

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