D2.4: TECHNOLOGY REPORT

Technical documentation of the digital solutions and key requirements for successful deployment

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Abstract	In DWC, different digital solutions will be tested and assessed regarding their potential to improve the performance and return on investment of water infrastructures. The present report (D2.4) describes the individual solutions with their technical specifications, their addressed challenges and their added value in the form of fact sheets. The document aims to help cities and water utilities in finding appropriate solutions for their operational, environmental or public health deficits.

Dissemination level of the document

X	PU	Public
	PP	Restricted to other programme participants
	RE	Restricted to a group specified by the consortium
	CO	Confidential, only for members of the consortium

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Executive summary

This report contains a detailed technical description of the 11 digital solutions under WP2 containing technical specifications, expected benefits, and recommendations for replication. **Section 1** introduces the solutions and their targeted impacts, followed by **sections 2 to 12** containing specific information on each digital solution (DS). The detailed information for each DS includes a description of the technical specifications consisting of the type of the solution and their specific modelling approaches, data requirements, and information on the system integration in the utility's processes. Furthermore, each solution is introduced by a short factsheet containing general information (i.e., IPR holder, main contacts, achieved improvements on the technology readiness level (TRL) during the project, and information on the target audience). Moreover, the factsheets include information on the addressed challenge, a short description of the solution, its main benefits and added value, the key innovation of the solution beyond the state-of-the-art, and each solution's impacts.

The baseline for implementing and demonstrating the DS is detailed in the D2.1 Implementation plan (M12). The demonstration outcomes of the 11 DSs are presented in the D2.2 Performance report. This report describes each solution's demonstration site and challenges, the achievements in terms of performance and returns on investment, and the approach to assess and quantify the benefits via solution-specific key performance indicators (KPIs).

This document is an update of the last performance report delivered in M36. Updates as suggested by the external reviewers include:

Each technical solution includes now a user-friendly technical factsheet as introduction, containing general information, the challenge addressed, a short description, its main benefits and added value, the key innovation, and impacts. Additionally, the factsheet mentions the target audience. Furthermore, DS5.1. and DS5.2 include additional paragraphs explaining that end-users (i.e., farmers) do not have to use complex data assimilation algorithms, and that the MMT is originally in Italian, but can be translated easily by design into English, which is also planned in the near future.

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1. Preface

European cities face different challenges to achieve sustainable management of urban water systems, e.g., the over-exploitation of surface waters and the effects of climate change competing with a growing demand for liveable and resilient cities. Mobile devices, real-time sensors, machine learning, artificial intelligence and cloud solutions can significantly improve the management of water infrastructures. They can boost the quality of services provided to citizens, as well as the level of awareness and collaboration between utilities, authorities and citizens. In work package 2 of the digital-water.city project (DWC), eleven digital solutions are tested and assessed regarding their potential to improve the performance and return on investment of water infrastructures [1]. Figure 1 shows the eleven solutions and their addressed domain in the water cycle.

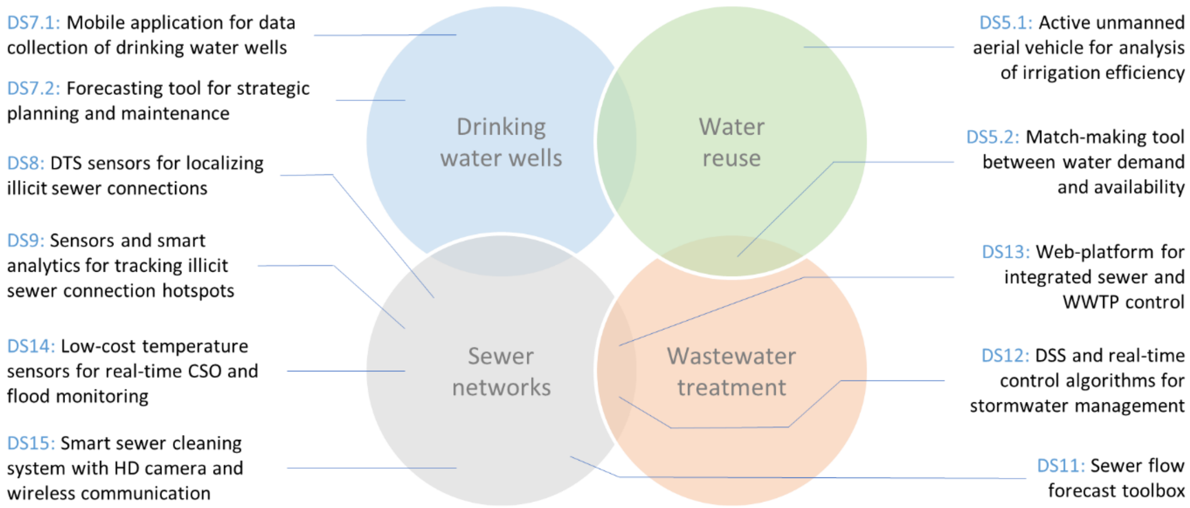

Figure 1: The digital solutions of DWC-WP2 and their addressed domain in the water cycle.

The present report describes the digital solutions with their technical specifications and requirements, their addressed challenges and the solutions' added value in the form of fact sheets.

The document aims to help **cities and water utilities** in being aware of the latest technological development and finding appropriate solutions for their operational, environmental or public health challenges. The document also targets the **scientific community** by providing a comprehensive description of the principle and concepts of the innovations as a starting point for future implementation and developments. Finally, it addresses the **industry and private sectors** by highlighting DWC developments within the innovation landscape and facilitating future synergies with other innovators.

[1] The full list of digital solutions can be consulted at https://www.digital-water.city/digital-solutions

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This report is the final version of the technology report (D2.4). Further information on how the solutions are demonstrated and assessed within DWC can be found in the implementation plan (D2.1). The performance of the solutions, quantified via defined key performance indicators, is presented in the performance report (D2.2). For further information on the market for each solution, please refer to deliverable D5.1 (Exploitation plan).

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2. Active unmanned aerial vehicle for analysis of irrigation efficiency (DS5.1)

Factsheet
General information IPR holder: UNIMI-UNIVPM-CAP Main contacts: Gian Battista Bischetti (UNIMI), Adriano Mancini (UNIVPM) TRL improvement: 5 to 7 Target audience: Farmers and farmer associations
Challenges Today, peri-urban irrigation for agriculture in the south of Milan suffers from water scarcity. Treated water from the WWTP can be reused for irrigation. As outflows and demand vary continuously, the system would highly gain efficiency by linking and matching environmental information from various sources. In this task, novel remote sensing technologies operating in the SWIR band mounted onboard unmanned aerial vehicles will map the water stress for the soil-plant-atmosphere.
Description The solution combines three technologies for remote water stress detection: 1) ground sensors, 2) unmanned aerial vehicles with spectral imagery, and 3) satellites. It improves the real-time knowledge of water stress in the soil-plant-atmosphere system and enables analysis of the efficiency of irrigation schemes.
Benefits and added-value The solution has been tested in an agricultural field in Milan. Local data analysis has shown a significant improvement in data accuracy and spatial and temporal resolution. The monitoring performance compared to solely visual inspection doubled, and the performance compared to visual inspection plus ground sensors increased by 43%. Consequently, the combined use of the three technologies provides better outcomes than classical visual assessment or even the simple use of standard ground sensors, as common practice in agriculture. Furthermore, only the smart combinations of the three technologies compensate for the drawbacks and limitations of single techniques.
Innovation The key innovation is the combination of three technologies for the remote detection of water stress. It provides a new efficient tool to monitor water (irrigation) and nutrient (fertilizer) needs to optimize water consumption in reuse scenarios.
Impacts The solution will be deployed further by UNIMI and UNIVPM to support precision farming. The integrated approach is the key to minimizing the use of critical resources such as fertilizers and water (in the case of irrigated crops); this aspect is vital, especially in areas subjected to drought opening new opportunities to farmers and utilities.

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2.1. Addressed challenge

The efficient and sustainable use of water for irrigation has become a core-requirement in modern agriculture, especially in warm countries were droughts and water stress are an issue. In this context, the concept of Variable Rate Treatment (VRT) has been introduced. VRT aims to automatically and accurately allocate water (and also nutrients) to agricultural fields and thus to increase yields, while at the same time saving water for other demands, e.g. for drinking and recreation. However, in practice the relevant data and tools to implement VRT are often missing.

Attempts towards the automation of irrigation have been made by using ground sensors in combination with weather forecasts. However, ground sensors (e.g., volumetric water content probes) are expensive (from 70 to 250 € for each sensor and up to 4 or 5 units/ha could be required for irrigated crops, especially in horticulture domains) and the coverage they provide is limited. The use of remote sensors in combination with ground sensors, instead, could help to obtain real-time knowledge on crop status and irrigation needs at a broader spatial scale and at a cheaper price, avoiding water stress and crop losses. The use of remotely sensed data from satellites as Sentinel-2 is a free and medium resolution solution, while, in the case of Unmanned Aerial Vehicles (UAVs), the cost could range from few hundreds to thousands of Euros (in case of water stress a multi-spectral payload with VISible (VIS) - Near-InfraRed (NIR) and thermal capabilities would be needed, which could cost up to 10-12 k€).

The integration of water stress estimates from remote sensing with information from the Match Making Tool (MMT) (DS5.2) represents a novelty that could improve water use efficiency in agriculture in areas in close proximity of WasteWater Treatment Plants (WWTPs).

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Figure 2: Ground sensors and Unmanned Aerial Vehicle to detect water stress.

2.2. Technical description of the solution

2.2.1. Type of solution

Digital solution DS5.1 provides a new method for the remote detection of water stress using an active UAV and multi spectral imagery, in combination with ground and satellite data. The solution includes several hardware components:

- UAV with mounted multi-spectral cameras;
- satellite data (Sentinel-2 and PlanetScope) provided by external providers (i.e. Sentinel-hub and Planet);
- a set of ground sensors;
- a weather station.

A software for data exchange and storage completes the solution. The data obtained from ground and aerial (both UAV and satellites) sensors are used in an integrated way to estimate the real water needs and detect areas under stress. The weather station provides data to calculate evapotranspiration rates (using the Food and Agriculture Organization (FAO) Penman-Monteith equation)[2], which are then coupled with crop coefficients to estimate crop water needs. Sensors that measure the soil volumetric water content are also used to evaluate the water availability and the effectiveness of irrigation; when used with agro-hydrological models (as in DS5.2 -the MMT), ground sensors are also used to validate model

[2]FAO Introduction to crop evapotranspiration, https://www.fao.org/3/x0490e/x0490e06.htm#fao%20penman%20monteith%20equation (last access Nov 2020)

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outputs. UAVs and satellites can map the areas that are under stress starting from state-of-the-art spectral indexes that combine different spectral bands. Aerial data provided by drones are suited for small fields where the spatial resolution is a key factor (and in the case of horticulture), while in case of large fields the medium spatial resolution provided by satellites is sufficient.

The estimation of real crop water needs for the near future can be performed using soil-crop models. These forecasting models are run and calibrated using both static (e.g., soil composition at the test site that is evaluated at the beginning of every season) and dynamic data (from the ground sensors and weather station). This estimation is strongly connected with DS5.2, where it is key for mapping the real needs of farmers.

It has to be mentioned that the algorithms behind DS5.1 and DS5.2 dealing with soil-crop-atmosphere interactions are complex. However, processing remotely sensed data over a region of interest (field) does not require direct user interaction. Therefore, farmers do not need to pre-process the data with data assimilation and fusion algorithms elaborately.

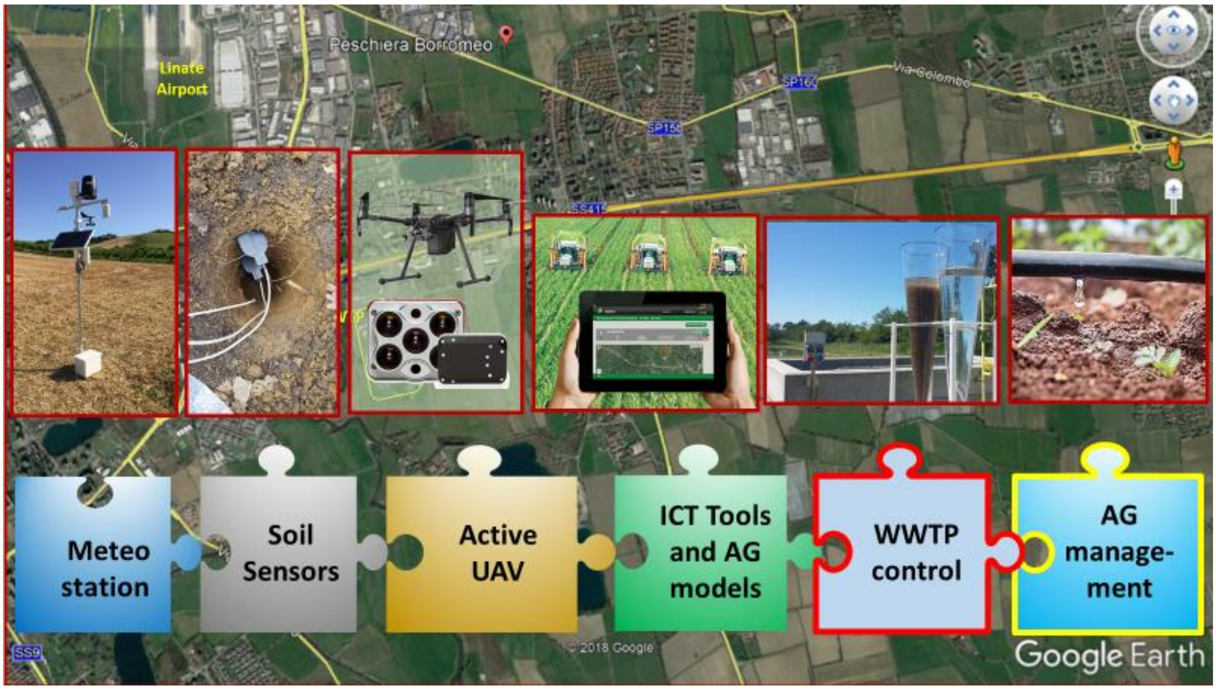

Figure 3: Integration of sensors and tools to support an efficient irrigation in strong connection with DS3 and DS5.2

2.2.2. Technical specifications

For the digital solution to work properly, it is necessary to measure several parameters related to the *crop*, *weather* and *soil water* status.

It is of fundamental importance to estimate **crop water needs**, and this is achieved using meteorological stations provided with sensors to detect the variables used to estimate evapotranspiration (solar radiation, wind speed, air humidity) and rain; the latter is involved in the balance of soil water availability. The **soil water content** is measured through sensors

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that detect the amount of water present in the soil and therefore available for the crop; by identifying appropriate threshold values of soil water content it is then possible to assess if there's enough water to support crop growth or if water must be supplied through irrigation. Finally, the use of piezometric monitoring wells allows to evaluate the **water table depth** and estimate the possible contribution of the shallow aquifer in the replenishment of the soil root zone.

Water and nutrient stress are also monitored by using remotely sensed data. The water and nutrient stress are detected using multi-spectral payloads on aerial vehicles or satellites. These kinds of sensors are suitable to cover large areas, and this is a great advantage over ground sensors. These sensors capture the reflectance of objects (in our case the leaves of the selected crop) in the VIS, NIR and Thermal InfraRed (TIR) regions of the electromagnetic spectrum. VIS-NIR bands are useful to detect nutrient stress while NIR and TIR bands are used to detect water stress. The radiometrically-corrected and orthorectified data (multi-spectral images) are used to calculate stress indexes such as the Normalized Difference Red Edge (NDRE) and the Crop Water Stress Index (CWSI). The indexes can have different values depending on the crop considered and the specific thresholds for stress detection, but their extrema generally highlight the severity of issues. For example, Normalized Difference Vegetation Index (NDVI) values close to 1 mean that (nutrient) stress is limited.

The results are visualized as raster images that highlight areas with high/low vigor, which is strictly bonded connected to with water and nutrient stress. These data support the decision of end-users (i.e., farmers) to detect areas of the field showing with different behaviors.

The **multi-spectral cameras mounted on the UAV** are able to sense VIS+NIR+TIR range. Data acquired using UAV are characterized by a Ground Sampling Distance (GSD, the pixel size of the final product) that is in the range of 2-10 cm, depending on the flight altitude and the kind of camera (we rely on Micasense Altum, a six bands sensor). Regarding the (unmanned) aerial platform, a multi-rotor UAV is used that is able to map up to 20-30 ha in a single flight with a maximum endurance of 20 min with weak wind (< 5m/s).

Satellite data can cover larger areas but are characterized by a GSD ranging between 3 and 20 m. The following sources are used in this project:

- Sentinel-2 (free service provided by ESA): 10/20/60m GSD, 12 bands (VIS-RE-NIR-SWIR)
- PlanetScope (commercial service provided by Planet[3]): 3/3.5m GSD, 4 bands (R, G, B, NIR)[4]

[3] Planet satellite provider, https://www.planet.com

[4] SWIR means Short Wave InfraRed; R, G and B are the red, green and blue channels; and RE means RedEdge.

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where SWIR means Short Wave InfraRed; R, G and B are the red, green and blue channels; and RE means RedEdge. Satellites can provide images with a temporal resolution of 1 to 5 days, but they are sensitive to clouds and this is one of the main issues of using this kind of data.

The **ground sensors**, buried in the soil at the depth of the root zone, are able to acquire data such as the volumetric water content. The probes are provided with a battery, which can power the sensor for long periods (depending on the acquisition interval, but at least for an entire season), and a data-logger unit to record the measured values. Moreover, the probes are provided with a General Packet Radio Service (GPRS) unit which allows a remote connection for reading values and setting up the probe. Probes were checked every 3 months, for cleaning and maintenance. Ground data were used to calibrate the aerial and satellite data for those points with installed probes. DS5.1 integrates the following ground sensors (Figure 4):

- Soil water content probes were installed at two locations, at two depths each, to measure soil moisture in the crop rooted zone. The selected probe is a Frequency Domain Reflection (FDR) probe, with a metallic body, which is suitable for soils that are rich in gravel, such as that within our plot;
- Piezometric wells equipped with pressure transducers to evaluate the effect of irrigation on the groundwater table;

Figure 4: Installation of ground sensors within the Peschiera Borromeo test area

The ground sensors are equipped with a pole on which antennas, batteries, a solar panel (where used) and logic unit are mounted. This pole, usually painted in a bright color, indicates the sensor position, and helps to avoid damages to the sensors by tractors or other vehicles. In case of auto-steering tractors, the sensors' location can be known and the tractor can avoid getting too close. In case of row crops, the risk of damages is mitigated by positioning the

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sensors along the rows. With tree crops, seeing the sensors and poles is usually not a problem. In any case, the risk of damages to the sensors (including vandalism) exists. The most prevalent threat is represented by rodents.

The deployed **weather station** is equipped with a data logger to monitor solar radiation, air temperature, air humidity, rainfall, wind intensity, and wind direction; the station is powered by standard AA batteries which are recharged through a small solar panel a. A periodical inspection of the weather station was required (every 3-6 months) to clean the rainfall sensor from obstructions. The weather station is provided with a modem so that the data can be accessed remotely. Weather data are needed to estimate evapotranspiration rates, which, in turn, are used to calculate water needs. In this case, the use of ground sensors plays a key role in refining the estimation of water needs. Models are integrated into the the Soil Water Atmosphere Plant (SWAP) software[5].

Regarding the deployed **software**, the digital solution is a set of interconnected micro-services (some of them also present in DS5.2) that allow to acquire, pre-process, process and visualize data. A wide set of sensors are interfaced using a dedicate cloud architecture that integrates also the FIWARE ecosystem to simplify the data analysis. The main output of this digital solution is the capability to map water stress and estimate water needs for a given field to optimize water use. This information is a main input for the Match Making Tool (DS5.2).

2.2.3. Data requirements and transmission

The data acquired through the multi-spectral camera mounted on the UAV is stored within a SD card. At the end of a flight, the operator downloads the images and performs the generation of orthophotos using a dedicated cloud service (3rd party). Satellite data are available as a free or commercial service and are downloaded from the internet. Ground sensor and weather station data are transmitted online.

This digital solution also interacts with other digital solution DS5.2; the stress map is a geographical layer that the Match Making Tool could show for both data-sources (i.e., satellite / UAV). The geographical layer are integrated within the Match Making Tool using a customized Web Map Service (WMS) / Tile Map Service (TMS) that provide historical and current data on the stress condition.

2.2.4. System integration

DS5.1 integrates different system. UAV and satellites are integrated using custom Jupyter notebooks that interacts with the image providers using a dedicate set of Application Programming Interfaces (APIs)[6]. Data from the MMT are fetched to evaluate the list of operations related to the irrigation (HyperText Transfer Protocol (HTTP) REpresentational

[5] Soil Water Atmosphere Plant (SWAP) - https://www.swap.alterra.nl/

[6] Sentinel-hub API https://www.sentinel-hub.com/develop/api/ and PlanetScope API https://developers.planet.com/docs/data/planetscope/

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State Transfer (REST) API). Data from sensors and weather stations are the fetched from an external provider through dedicated APIs[7]. We integrate also other data from external data sources that provides data as soil features, weather forecast through a set of APIs.

2.3. Added value and potential replication of the solution

2.3.1. Benefits

The solution gives a key contribution towards overcoming the knowledge barriers that are currently limiting the uptake of water reuse practices and is crucial to optimize the use of water while avoiding crop stress conditions. In addition to these more general and strategic benefits, the implementation of the digital solution also leads to measurable impacts on sustainability; for example:

- it reduces water use (up to 40-50 % if combined with a proper irrigation method). The water stress information provided by the solution is shared with the MMT (DS5.2), contributing to an overall reduction of the water used for irrigation compared to the uncontrolled general practice;
- it minimizes water stress. This aspect is crucial to guarantee the expected yield. In fact, water stress conditions, if not properly managed, can lead to significant yield and profit losses.
- it optimizes the use of fertilizers by designing variable rate maps that differentiate the amount of product as a function of the estimated stress (this also has an important impact from the carbon footprint perspective).

2.3.2. Site requirements and potential obstacles / drivers for replication

In general, the solution can be of great support in peri-urban areas used for agriculture and located in regions affected by water scarcity. There are no specific site requirements, except that the field should be suitable for growing crops. Areas with a consolidated agronomic history (more than 3-4 years) may be easier to examine, as previous knowledge on the site might be available (e.g., management of soil, nutrients, irrigation needs) to optimize the agronomic operations (e.g., fertilization). However, the return of investment strongly depends on the crop type and field location. For instance, in cases where crops generate low profit due to market price variability, the benefits of using smart sensors or aerial technologies may not cover the related investment costs, especially in small areas. The use of satellites could mitigate this issue considering that some data products are provided free of charge to all data users, including the general public, and scientific and commercial users. Nonetheless, the solution could be applied to different crop types, preferably those which are sensitive to water stress and need additional irrigation like corn and tomatoes, for example.

One of the main obstacles to transfer and replicate this digital solution in other cities is represented by the **complexity and cost of technologies**. Nonetheless, it is expected that

[7] ZENTRA CLOUD API https://zentracloud.com/api/v1/guide

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technology costs will shrink going forward, considering that every year the number of users and installations (e.g., Internet of Things (IoT) agronomic sensors) is growing[8]. A main driver and potential obstacle to transfer and replicate this digital solution is the availability of funds that support farmers and agronomists for investing in new technologies. This requires a cost-benefit analysis based on crop type, field size, soil type and water availability.

Another potential obstacle is represented by the **required level of digitalization**. Farmers are the solution's main end-users. It will be necessary to train farmers and agronomists at analyzing the data from ground and aerial/satellite sensors. This will require an interaction with local/national farmer associations to provide a basic data analysis knowledge level to optimize their operations. However, farmers could be supported by companies that provide the services to integrate the data into the proposed architecture. Financial support for farmers to digitalize their farms could also be a positive driver.

In some areas close to cities or critical infrastructures there could be **restriction to flights** to preserve the airspace.

Even if the digital solution can work independently from a WWTP, using it with water from a WWTP would open new opportunities for different stakeholders (e.g., farmers, irrigation consortia, water utilities, citizens). Indeed, the ideal setup that would allow to maximize the benefits of the solution is the creation of independent irrigation districts close to WWTPs supplied directly (possibly exclusively) with the treated wastewater through a dedicated pressurized distribution network and where very efficient and highly automatized irrigation methods (e.g., subsurface drip irrigation) are used. This is expected to promote new agricultural productions in the area that could benefit from the proximity to the city that often characterizes large WWTPs and could be marketed directly (0 km, circular products). Public support would be needed to create the distribution infrastructure, but funding should be accessible through European funds for rural development given the adherence of the solution to the EU-Farm to Fork Strategy and to the circular economy paradigm.

Use of the digital solution when the water from the WWTP is discharged into an existing distribution network and blended with water from other sources is also viable, but it requires the same control of the quantity and quality of these sources as for the treated wastewater. Additionally, the MMT needs to be expanded to deal with multiple sources, to determine the characteristics of the blended waters and to simulate their circulation in the existing network.

Finally, one potential barrier related to the use of reused water for irrigation in agriculture is represented by regulations and the acceptance by end-users.

2.3.3. Recommendations for successful implementation

A successful implementation of this solution requires an interaction between different stakeholders. The establishment of a local Community of Practice (CoP)makes the understanding of real needs easier. Of course, farmers and farmer associations must be

[8] http://www.fao.org/3/i6583e/i6583e.pdf

engaged, and providing farmers with appropriate training is a key aspect considering that they have to adapt their decision-making processes to the data from remote and ground sensors. In this case, we recommend favoring the uptake by farmers by demonstrating the benefits of these technologies in real-world scenarios (e.g., the Peschiera Borromeo area). In fact, a demo farm could provide a good context to approach the technologies hands on. It is also necessary to train users to use the novel tools as data from drone and satellites that support the “smart” monitoring of a given field to optimally plan/schedule actions. High-value (irrigated) crops are of course good candidates to exploit the benefits of this solution. The use of data from the field and from remotely sensed platforms maps the overall history of the field in terms of phenological curves that represent a powerful tool to optimize agronomic operations as irrigation and fertilization.

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3. Match Making Tool between irrigation water demand and safe water availability (DS5.2)

Fact Sheet
General information IPR holder: UNIMI-UNIVPM-CAP Main contacts: Gian Battista Bischetti (UNIMI), Adriano Mancini (UNIVPM) TRL improvement: 5 to 6 Target audience: WWTP managers, farmers
Challenges Reuse of treated wastewater for irrigation purposes is a measure to reduce water stress and overexploitation of freshwater resources. The new EU Regulation 2020/741 has introduced minimum requirements for water quality and monitoring along with rules on risk management for the safe use of treated water in agriculture. Hence, new digital solutions need to be tested to assist water utilities and other interested stakeholders during the decision-making process in water reuse.
Description This match-making tool (MMT) is a web-based application to manage the demand for treated wastewater for agricultural irrigation. It is based on assessing irrigation needs using remotely sensed data (DS 5.1) and on the amount and quality of available reused water. The platform will inform farmers about the possible water supply and wastewater treatment plant (WWTP) managers about the current irrigation needs (quantity and quality).
Benefits and added-value The solution allows the deployment of precision drip irrigation scenarios compared to standard border irrigation. Local model assessments in Milan have highlighted the potential of 68% water saving, 48% of saved fertilizers, and a 90% reduction of CO2 emissions.
Innovation The innovation resides in the digitalization of the match-making between utilities and farmers. The match-making tool is bi-directional: 1) It provides the farmers with a tool that combines water provision, quantitative irrigation advice, and safety warnings. 2) It communicates the farmers' needs and the actual use of water (both in terms of quantity and quality) to the WWTP managers.

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3.1. Addressed challenge

Modern agriculture aims to optimize the use of nutrients, chemicals, and water to produce more with a lower impact on the environment, while delivering greater food quality and safety. To reach such goals, new digital solutions using unmanned operations, autonomous decision systems and artificial intelligence, are needed to help farmers optimize the amounts and distribution of fertilizers and water, while increasing their yields. This is what is also often referred to as “precision farming”.

In terms of reducing (fresh)water consumption, the reuse of treated wastewater represents a key opportunity leading to the implementation of precision farming. However, to implement it in practice, data on water stress and irrigation needs from the fields and data on water quality and availability from the wastewater treatment plants are required, as well as a tool to interconnect such data and create a communication channel between the water provider and the agricultural final users.

While some basic forms of water reuse might already be in place, these are seldom supported by digital tools like the one we developed here within a water-food-energy nexus perspective. Moreover, the current standard working procedures still rarely follow the precision farming or sustainability-based (e.g. carbon and energy footprint) approach, and there is an urgent need to promote awareness and engage stakeholders regarding this safe and sustainable practice. The sustainable reuse of water from WWTPs (from technical, economic and environmental perspectives) represents an important opportunity to demonstrate how precision farming, irrigation, and nutrient management, can open new promising perspectives. The main bottleneck towards putting the above principles in practice is represented by the lack of solutions enabling interaction among water utilities, irrigation network managers and farmers, capable of finding an optimum between supply and end-users' needs.

Therefore, a MMT would delineate a new scenario where the “new water” made available by the WWTP in peri-urban areas does not represent a mere addition of water available within the traditional system, but a chance for establishing new sustainable opportunities, that can allow for new cultivation schemes and a lower carbon and energy footprint. In such areas, in fact, on the one side water for irrigation is generally provided on a weekly basis, which represents a constraint in terms of crop type, with a preference for the so-called commodities (characterized by a low added value); on the other side, citizens are increasingly asking for horticultural crops (with a high added value), as well as increasingly sensitive towards environmental issues.

A Match Making Tool, finally, would connect the different stakeholders. On the one side, it would match farmers’ water needs with the water utilities’ water availability by means of the Reclamation Facility Operator. On the other side, the MMT and serious game developed in the context of WP3 (https://www.seriousgame4dwc.eu/) could be used also by the citizens to

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understand how the re-use of water in agriculture opens new ways to support local agro-districts also in peri-urban areas.

3.2. Technical description of the solution

3.2.1. Type of solution

This digital solution is a software, that can be used on different platforms and operating systems, including as a mobile friendly web app/webpage (https://d29to6rwtqv285.cloudfront.net/). The following figures shows some of the available data in the Match Making Tool. The solution allows to exchange information between farmers and the water utilities, to optimize irrigation water uses and water treatment operations. The MMT requires a reduced amount of data and the farmer must provide details regarding the area, crop, irrigation system and soil type (these data are needed to estimate the water needs over the agronomic season). The app has been developed in Italian, considering that the language often represents a barrier for some users. However, the app is structured in a way that makes translation easy into another language; the English version will be soon released.

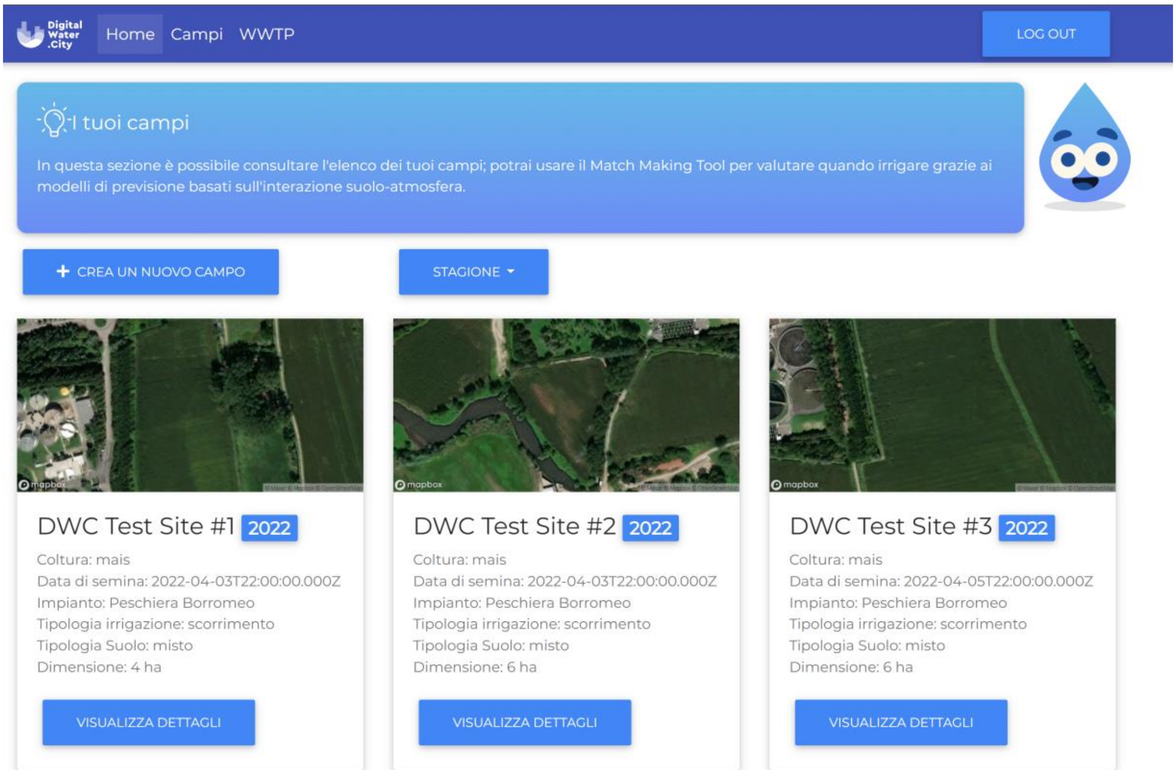

Figure 5: List of available fields linked to the Peschiera Borromeo district.

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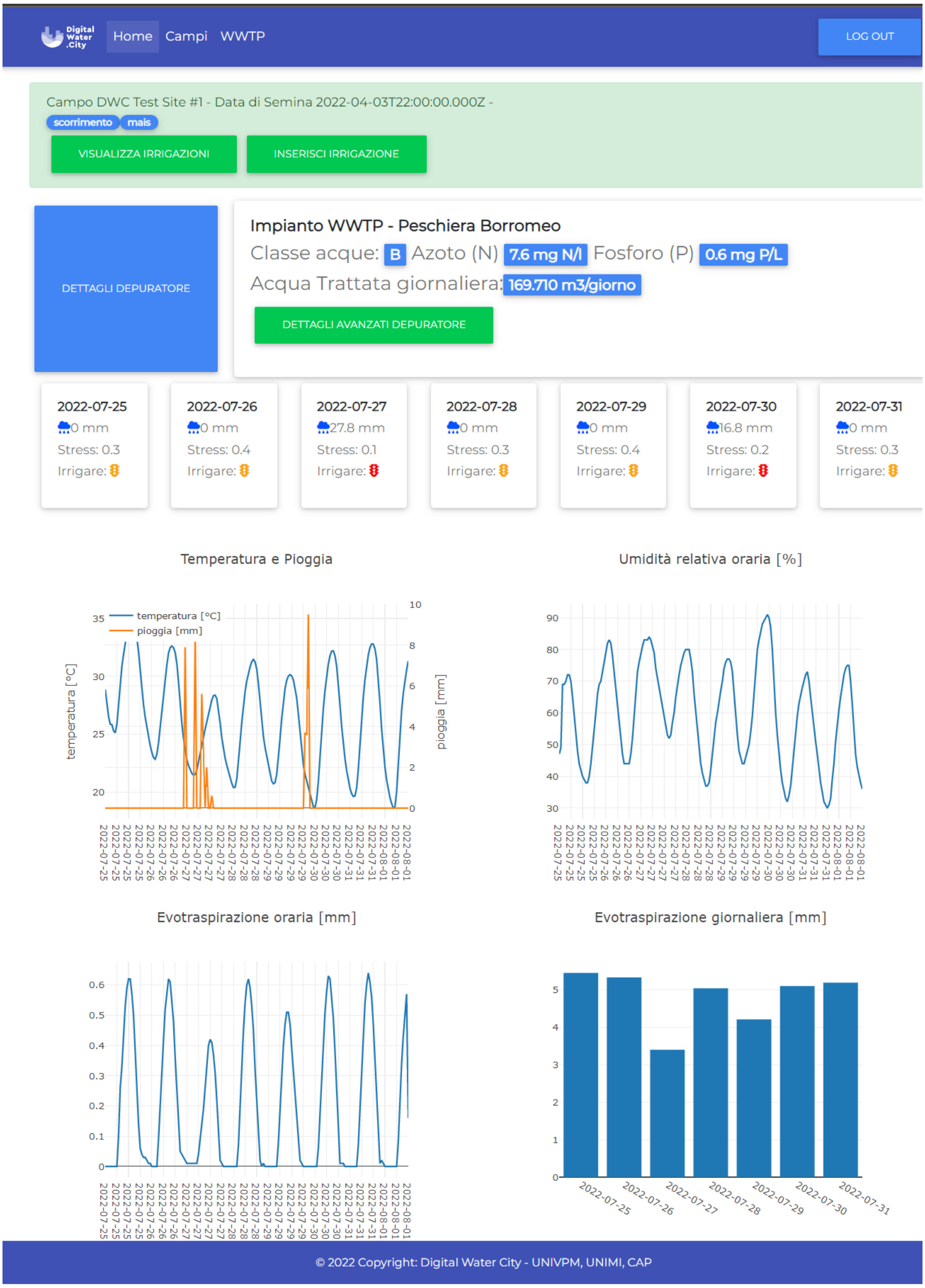

Figure 6: Details for a given field with the irrigation windows according to weather forecast and estimated stress.

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According to the European regulations on the minimum requirements for water reuse, crop type and irrigation method used determine the water quality class needed, which in turn determines the required treatment technology and performance, as well as the water utility and reclamation facility operator decisions. Specifically, the reclamation facility operator is a new role introduced by the (EU) regulation 2020/741 of the European Parliament and of the council of 25 May 2020 on minimum requirements for water reuse, whose task is to support the best sustainable water reuse practice[9]. Ultimately, the MMT can support several key stakeholders: water utility, reclamation facility operator, irrigation network operators; farmers (see Figure 7).

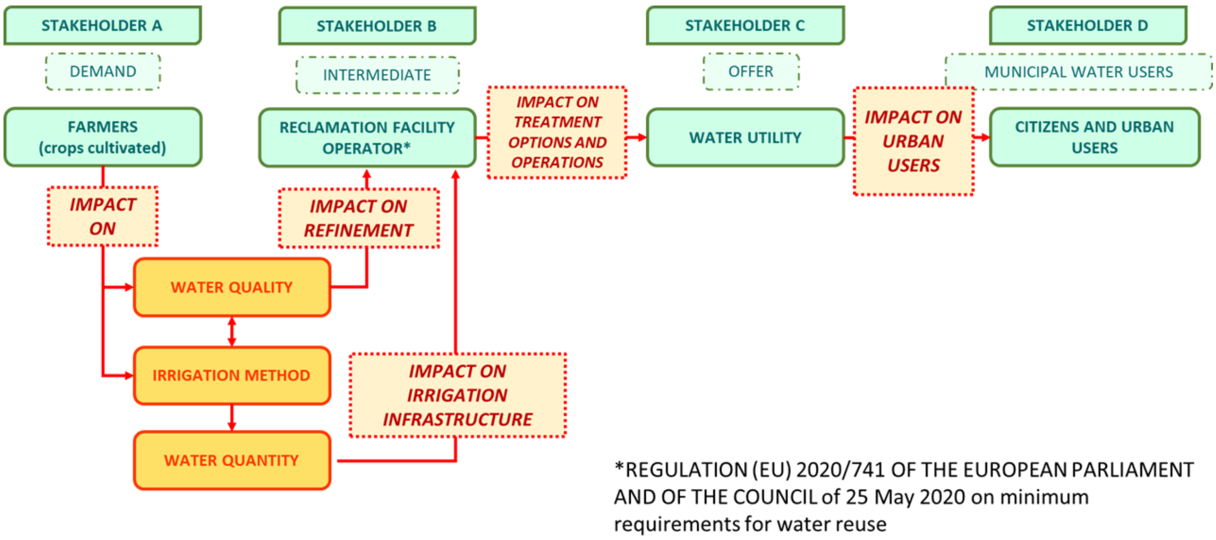

Figure 7: Stakeholders and their relationships in the context of the Match Making Tool

This digital solution also interacts with digital solutions DS5.1 and DS3 to share data regarding the safety of water. This integration exploits the benefits of the FIWARE ecosystem; it is possible to define also complex rules evaluated in real-time data that could trigger dedicated micro-services that will be used to notify end-users in case of relevant (positive or negative) changes.

3.2.2. Technical specifications

DS5.2 is based on the integration of WWTP data (variables acquired by probes installed at each stage of the waste water treatment process) and information on the configuration of fields (in terms of soil type, seeding/transplanting date, area, irrigation method) in order to map, match and monitor the different user needs. Water needs of farmers are estimated by using a hydrological model that allows to simulate the water content in the root zone and to estimate the water available for crop development. The model can be driven by weather

[9] EU regulation 2020/741 https://eur-lex.europa.eu/eli/reg/2020/741/oj

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forecasts in order to predict the soil water content over the following days, allowing to match the user irrigation needs with the water availability at the WWTP.

The Match Making Tool interacts with the end-user with a reduced and user-friendly interaction. The front-end development is inspired by the modern material design approach trying to engage the user with a UI/UX that is similar to other modern web applications. The following data are managed by the MMT:

- Weather information
- Crop data
- Soil information
- Field Location
- WWTP data

These data are pre-processed using the Soil Water Atmosphere Plant (SWAP) software, which was adapted to run in a *dockerized* environment, considering that the back-end of the MMT runs in a serverless environment. SWAP simulates the transport of water, solutes and heat in unsaturated/saturated soils. SWAP enables the simulation of flow and transport processes at the field scale, during growing seasons over long periods. It offers a wide range of possibilities to address both research and practical questions in the domains of agriculture, water management and environmental protection. The serverless function is triggered by the front-end through a REST API considering the field of interest and the optional data provided by the farmer, such as the crop development stage. The output of the developed function consists of the water needs for the following days.

Another relevant aspect behind the MMT is the link with the WWTP: farmers can check if treated wastewater is available for reuse and its related water class in real time. In particular the field has a link with the WWTP to check the current status of water.

The back-end infrastructure exploits the benefits of the FIWARE ecosystem. In particular, the system is based on the integration of different systems with different technologies to ingest data. Message Queues Telemetry Transport (MQTT) is used to implement a bi-directional communication between the tool and the WWTP control room. FIWARE agents are also responsible for translating data from other data-sources into the FIWARE applications (e.g., Quantumleap). The use of FIWARE enables the capability to make uniform the data format (FIWARE data-models[10]) opening to a faster integration in other plants. Other data-sources, such as UAV and satellite imagery (DS5.1) to estimate water and nutrient stress, are integrated within the tool using a customized Web Map Service (WMS) / Tile Map Service (TMS) that provide historical and current data on the stress conditions. For this purpose, the services developed within DS5.1 are integrated and provided as layers in a map view that the user can switch-on/off as a light Geographic Information Service (GIS) (this is linked to the WebGIS platform for improved decision making in water reuse – DS4).

[10] FIWARE Data Models https://www.fiware.org/developers/smart-data-models/e https://fiware-datamodels.readthedocs.io/en/latest/Environment/WaterQualityObserved/doc/spec/index.html; last access Nov 2020

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3.2.3. Data requirements and transmission

The solution is based on an exchange of data from different sources, which are categorized as follows.

Required information from the WWTP:

- Output of the early warning system (DS3), which monitors water continuously and gives rapid notice of variations in quality (see deliverable D1.1). Specifically, this information merges together:
    - Water quality: information derived from the correlation of online probes / meters data in the WWTP (e.g. pH, redox, OD, conductivity, turbidity/TSS, ammonia, nitrate, temperature, ORP, UV transmission, TOC, E.coli / total coliform, flow meters: Q influent, Q bypassed, Q secondary treatments, Q backwash, Q effluent, Q biogas production, Energy meters, UV dosage / intensity)
    - WWTP schedule: information derived from maintenance registers to map any potential planned service interruption
- Water Quantity: amount of treated wastewater available for reuse purposes
- Energy-carbon footprint: quantitative information about the energy consumption and associated equivalent carbon dioxide emissions generated to produce the treated wastewater destined to irrigation

All the above-mentioned information from the WWTP side comes from the CAP control room, to which all the basic data are directed, and integrated using FIWARE.

Required information from the irrigated crop:

- Food or non-food
- Consumed raw / processed / cooked
- Harvesting practice
- Water needs in terms of quantity (see DS5.1) and quality
- Irrigation period
- Irrigation frequency

Required information from the irrigated soil:

- Concentration of Heavy metals
- pH
- Concentration of Nutrients
- Salinity
- Distance from local communities
- Access restrictions
- Physical barriers

The following table summarizes the types of information, the info direction, as well as the frequency with which to provide it and the potentially complex aspects for end-users.

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Table 1 Data Requirements for the MMT; E2T means End-user to MMT; W2T means WWTP to MMT, T2E means MMT to End-user (i.e., farmer); T2W means MMT to WWTP.

Data	Direction	Frequency	Complexity for end-users	Support Required
Early warning	W2T	Continuous	null	WWTP has to provide this information (related to the water quality)
WWTP Water Quantity	W2T	Daily	null	WWTP (or reclamation facility operator) has to provide this information
Carbon and energy footprint of the available treated wastewater	W2T	Every month	null	WWTP (or reclamation facility operator) has to provide this information
Meteorological data	T2E	Every day	null	No
Irrigation needs (in terms of volume)	E2T and T2W	Weekly	Low	Farmer/Agronomist could manage
Irrigation practice for that field/crop	E2T	At the beginning + every season	Low (select from a list of crops)	Partial. Farmer/Agronomist could manage.
Irrigation available local resources	E2T	At the beginning + every season	Low (select from a list of options)	Partial. Farmer/Agronomist could manage.
Irrigation systems	E2T	At the beginning + every season	Low (select from a list of options)	Partial. Farmer/Agronomist could manage.
Water Stress Issues (end-user side)	E2T	Event based	Low (select from a list of options to specify the magnitude of the issue)	Partial. Farmer/Agronomist could manage.
Nutrient Stress or Excess Issues (end-user side)	E2T	Event based	Low (select from a list of options to specify the magnitude of the issue)	Partial. Farmer/Agronomist could manage.
Water Stress Notification	T2E	Every x days	Low (just check if a water stress problem is notified to the end-user)	Integration of satellite platforms as Sentinel-2 to map nutrient and water stress
Nutrient Stress Notification	T2E	Every x days	Low (just check if a water stress problem is notified to the end-user)	Integration of satellite platforms as Sentinel-2 to map nutrient and water stress
Water quality notification	T2E	Every x days	Low (just check if a water quality problem is notified to the end-user)	From the early warning system

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3.2.4. System integration

DS5.2 is integrated benefits from the FIWARE ecosystem and the interaction is achieved through the FIWARE REST API with an appropriate level of authentication and authorization. In particular, as mentioned before, the WWTP data are integrated via MQTT with the CAP Data warehouse decoupling the CAP internal system (for internal monitoring) and the MMT. In this way, the developed tool is fed with all the relevant data from the WWTP and can be easily inter-connected with other digital solutions (e.g. DS5.1 and DS3) through FIWARE.

3.3. Added value and potential replication of the solution

3.3.1. Benefits

As previously mentioned, the MMT involves the following stakeholders:

- Municipal water users (the citizens and users that are connected to the public sewers system)
- WWTP manager
- Reclamation facility operator (can be from the WWTP or the irrigation infrastructure manager)
- Irrigation consortium (irrigation infrastructure manager)
- Farmers in the area surrounding the WWTP

The MMT for these stakeholders can:

1. **Map** the current conditions in the WWTP surrounding area in terms of:
    a. Crop
    b. Soil
    c. Irrigation practice
2. **Estimate** the real needs of farmers considering a basic set of information provided by them with no real-time feedback from local (ground sensors) – this can be done only for a sub-set of crop-soil systems otherwise the tool would rely on default values specified by the user or taken from the literature.
3. **Collect** info regarding potential farmer issues related for example to drought and water/nutrient stress (DS5.1 supports this action)
4. **Inform** farmers about the **risk, availability** and **quality** of **water** from the **WWTP** over time (DS3 - Early Warning System), also suggesting the best time slot to use for taking water (farmers are still obviously free to decide whether or not to take it / to follow the advice).
    a. The reclamation facility operator could be engaged if they are able to share information regarding the status of the irrigation networks.
5. Inform farmers about weather forecasts.

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6. **Inform** farmers about the **presence** of a water/nutrient **stress (or even nutrient excess)**. This information could be used to prioritize supply to certain farmers over other ones, but -as in Point 3- farmers are free to make their own decision.
7. Inform farmers and citizens (water tariff payers) regarding the environmental sustainability of the adopted irrigation solutions (energy-carbon footprint)

3.3.2. Site requirements and potential obstacles / drivers for replication

Many cities are reaching high wastewater treatment standards for reusing water in agriculture. Aside from policies (i.e., EU regulation 2020/741), the **acceptance level** of the water reuse practice is also an important factor to consider among potential obstacles. The latter mainly refers to the potential psychological barrier - mainly of secondary and tertiary stakeholders, such as the food industry and consumers - of directly using wastewater, although treated, to irrigate crops. This calls for extensive awareness campaigns aimed at demonstrating how the water reuse practice can be carried out safely and at explaining its associated benefits.

The solution requires farmers to provide inputs regarding their crops, irrigation schemes and a few other details. However, it is known that the **digitalization level of farmers** is limited, which could represent an important barrier. Although the use of Information and Communications Technology (ICT) among farmers is expected to grow going forwards.

In order to integrate the relevant data, the water utility would be asked to monitor the quality and quantity of treated wastewater, which could require additional **technical and financial effort** on their side, and thus should be carefully evaluated.

Drivers for a successful replication of this digital solution include the ability of WWTPs to provide an acceptable water quality to allow reuse in agriculture, as well as investments in local infrastructure in terms of distribution networks / channels. The solution as it is can be used as a template for other cities, without specific site requirements.

3.3.3. Recommendations for successful implementation

The solution could be used in other cities where water reuse in peri-urban areas could improve the irrigation practice. Engaging all the relevant stakeholders and making the tool as much as possible easy to use represent important keys to success.

The establishment of a CoP is crucial to present and promote the use of the tool, while better understanding the needs of local communities. To this end, using the serious game (https://www.seriousgame4dwc.eu/) developed in the context of Task 3.2.4 and the webGIS platform (DS3) as additional tools for increasing awareness among the general public, as well as water utilities and farmers, will be essential.

The MMT could be used to train farmers to optimize the use of water understanding the real needs and the potential benefits of re-using water from WWTP. The support of local governments and agriculture associations is strongly recommended to have a considerable impact.

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A successful implementation also requires the capability to invest on dedicated infrastructures to distribute the water from WWTP to local farmers also understanding/metering the consumption. The MMT could be used to estimate real needs suggesting the best period to irrigate also considering the requirements of each farmer. This gives a bigger picture integrating the needs of a community of farmers to optimize as much as possible the use of water in agricultural scenarios.

The tool could support existing or new short and km 0 supply chains; the capability to re-use water from WWTPs supports farmers and the optimization of this additional resource requires (digital) tools to map user needs that have to match with the offer (from WWTP/reclamation facility operator). The engagement of farmer associations, local food distributors is a key aspect to support green local economies; of course, it is also necessary to inform consumers regarding the safety aspects of food to establish a strong *trust* between producers and consumers.

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4. Mobile application for data collection of drinking water wells (DS7.1)

Factsheet
General information <u>IPR holder:</u> BWB, VRAGMENTS <u>Main contacts:</u> Alex Sperlich (BWB), Stephan Gensch (VRAGMENTS) <u>TRL improvement:</u> 6 to 9 <u>Target audience:</u> drinking water well managers
Challenges Managing drinking water abstraction assets is a complex and wide-reaching core activity of utilities. Well data consisting of static information such as design and construction and operational data such as current discharge rates, water levels, previous maintenance, and water quality data are typically stored in well management databases. However, the paper format is still widely used in the field to record monitoring and maintenance data, and these work reports are later transferred manually to the databases. Further, technical specifications of the well or previously registered information on well maintenance are not fully accessible while in the field.
Description This solution (DW Well Diary) comprises a software application for mobile devices that facilitates efficient data provision and collection in the field for drinking water well operation and maintenance.
Benefits and added value The application was tested in Berlin and showed to save time and improve employee satisfaction during preliminary assessment. Electronic documentation eliminates the need for data transfer and allows for the implementation of automatic plausibility checks during data entry. Further benefits are the reduction of manual errors in the database and the presence of all data in central storage, readily available for further data processing.
Innovation The application enables data interoperability across various departments within utilities and across additional stakeholders and eases data processing routines and visualization of well condition characteristics.
Impacts VRAGMENTS now propose this solution to water utilities. BWB will use the solution further to improve data management practices and allow the future development of data-driven predictive maintenance solutions.

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4.1. Addressed challenge

The management of drinking water abstraction assets (wells) is a complex and extensive core activity of utilities. The lifetime of such drinking water wells typically ranges between 20 and 50 years. Statistical evaluation of well data from drinking water wells in Berlin showed for example an average well age of 34 years (Orlikowski and Schwarzmüller, 2009[11]). The capacity of wells, that is the yield for a given drawdown, often decreases with time of operation. This effect is called well aging and is due to the formation of deposits of biochemical origin (e.g., iron oxides formed by iron bacteria) or particulate matter (clogging with silt or sand). Maintenance, such as cleaning the pump and filter screen as well as gravel pack, prolongs the functioning by removing these deposits.

Both maintenance as well as planning of decommissioning of old and construction of new wells is a recurring task of water utilities. During maintenance and monitoring activities, technical information is frequently needed by utility staff in the field and has to be retrieved from its storage in digital or paper form. This includes technical asset documentation (e.g., depth of filter screen, pump type and power) and essential monitoring data (e.g., date of last maintenance, well capacity).

The mobile application “DW Well Diary” was therefore developed to provide easy access to data in the field and to allow on-site documentation of equipment changes or other technical data, eliminating the need for transcription of paper notes in the office. In addition, former paper-bound processes were replaced by digital processes and the documentation database extended. Although the process of groundwater abstraction for drinking water production has not changed for decades, the related work processes have evolved. Well operation has been automatized and remote controlled and a focus on energy efficiency has led to the introduction of permanent magnet synchronous motor submersible pumps and variable frequency converters (Sperlich et al., 2018[12]; Beck et al., 2018[13]). For well management and documentation, digital data repositories have been set up, but data remain fragmented across several sources, both digital and paper-bound. Another important objective developing the “DW Well Diary” was therefore the seamless and safe integration of the digital solution into the existing IT-infrastructure.

The Berliner Wasserbetriebe (BWB) are operating about 650 groundwater abstraction wells and more than one thousand observation wells. Together with another hundreds of observation wells owned by Berlin’s water authority (SenUVK) they form parts of the

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[11] Orlikowski, D. & Schwarzmüller, H. (2009) Advanced statistical analyses of well data. Kompetenzzentrum Wasser Berlin (unveröffentlicht)

[12] Sperlich, A.; Pfeiffer, D.; Burgschweiger, J.; Campbell, E.; Beck, M.; Gnirss, R.; Ernst, M. Energy Efficient Operation of Variable Speed Submersible Pumps: Simulation of a Ground Water Well Field. Water 2018, 10, 1255. https://doi.org/10.3390/w10091255

[13] Beck, M.; Sperlich, A.; Blank, R.; Meyer, E.; Binz, R.; Ernst, M. Increasing Energy Efficiency in Water Collection Systems by Submersible PMSM Well Pumps. Water 2018, 10, 1310. https://doi.org/10.3390/w10101310

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subsurface assets for drinking water production in Berlin. For the maintenance of these wells, BWB employs designated teams that carry out maintenance of submersible pumps, well condition and capacity monitoring, cleaning of pump and filter screens as well as the gravel pack, among others (Orlikowski and Schwarzmüller, 2010[14]).

The information on well maintenance actions, design and constructive properties of the well and operational data such as current discharge rates, water levels, and water quality data is stored in a well management database, also called Computerized Maintenance Management System (CMMS). However, as a major shortcoming this information is usually not accessible during maintenance in the field. On the other hand, data collected during field operations, e.g., information on well-specific sensor installations, variable frequency drives, or local site-specific operational constrictions, is currently only available on paper and transfer to the database is time consuming and also prone to errors.

With the developed digital solution "DW Well Diary" (DS7.1), a working prototype has been developed that makes these technical data easily available to staff in the field and can be fully integrated into the existing operation and maintenance work processes as well as the asset management system. In particular, it receives and feeds data to the internal well management database in which operational and maintenance data is stored.

4.1. Technical description of the solution

4.1.1. Type of solution

The digital solution "DW Well Diary" comprises of:

- a mobile device solution (frontend) using a browser technology-driven progressive web application (PWA) for in-the-field workflows, and
- a backend solution to facilitate exchange of data between the internal well management database and the mobile application. This backend also includes account and access management, as well as providing statistical and administrative data.

It provides access to a series of data points from drinking water well management database(s) to be available in the field. A series of workflows and processes around drinking water well maintenance are supported by the DW Well Diary, such as updating device information, recording the general status of a well and logging device-specific information, such as a replacement date.

The developed solution is inspired by concepts of Reliability-Centered Maintenance (RCM), Reliability, Availability, Maintainability, and Security (RAMS), Total Productive Maintenance (TPM), and Value-Driven Maintenance (VDM). Specific focus is put on the following criteria:

- Operational range and performance standards of equipment,
- Failure sources, consequences and impact,

[14] Orlikowski, D., Dauchy, L., Schwarzmüller, H. (2010). Ergebnisse der bundesweiten DVGW-Umfrage zur Instandhaltung von Brunnen; Bericht, Kompetenzzentrum Wasser Berlin.

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- Preventive maintenance tasks or process replacement.

Figure 8 shows the architecture of the integration and application of DS7.1 at BWB, serving as an example for integrating the DW Well Diary at other water utilities.

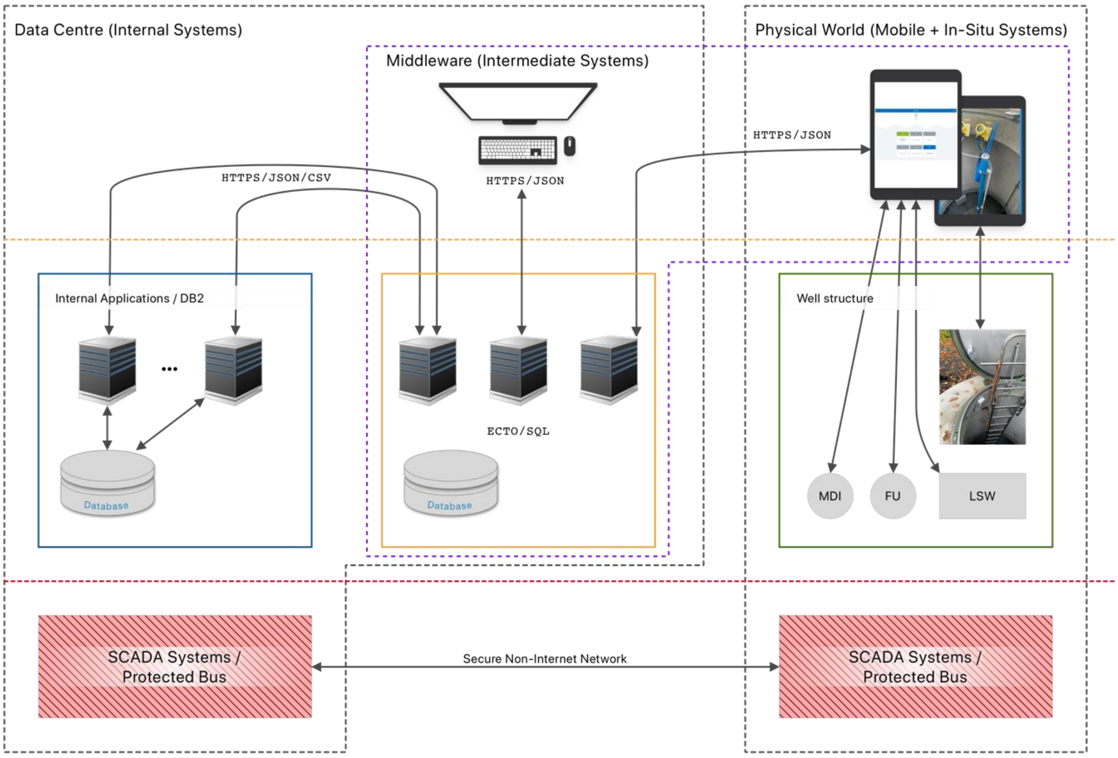

Figure 8: Architecture of the integration and application of DS7.1 at BWB

4.1.2. Technical specifications

The DW Well Diary frontend solution consists of a mobile web application (well diary) to substitute and extend current data assessment and reporting with a digital solution. It includes views of the entire water well infrastructure in hierarchical components from water works to gallery to individual well level. It is designed as a Progressive Web App (PWA) to allow for local data storage in case of limited or no network connectivity. It is provided via a Docker container and is served to mobile devices via a virtual private network. A Docker container image is a standalone, executable package of software that includes everything needed to run an application. Containers isolate software from its environment and ensure that it works uniformly despite differences for instance between development and staging. The state between the mobile application and the internal well database is managed through a sophisticated backend that allows for delayed data exchange and transitional synchronization.

The DW Well diary backend solution is deployed at the utility's premises. The interconnection between backend and mobile application is made over a Virtual Private Network (VPN) to ensure a secure data exchange. The backend solution is connected to the internal asset and

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event database (e.g., the well database of BWB) via a customized connector to allow secure read and write operations between the two.

The backend solution is an Elixir/Phoenix application with a local PostgreSQL database that runs inside a dockerized environment as well. It contains an administrative dashboard for user and data management. The data model used for driving the PWA is a subset mapping of relevant data from the internal well database of the water utility. This data exchange is facilitated through a custom connector.

Currently, all technical components of DS7.1 have been deployed using visualization methods for ease of maintenance and increased operational uptime.

DS7.1 employs methods of human centered design to ensure usability and acceptance of the solution. A variety of processes and tasks around drinking water well maintenance are being tackled, such as general assessment of the well condition (surface, housing) and the status of devices.

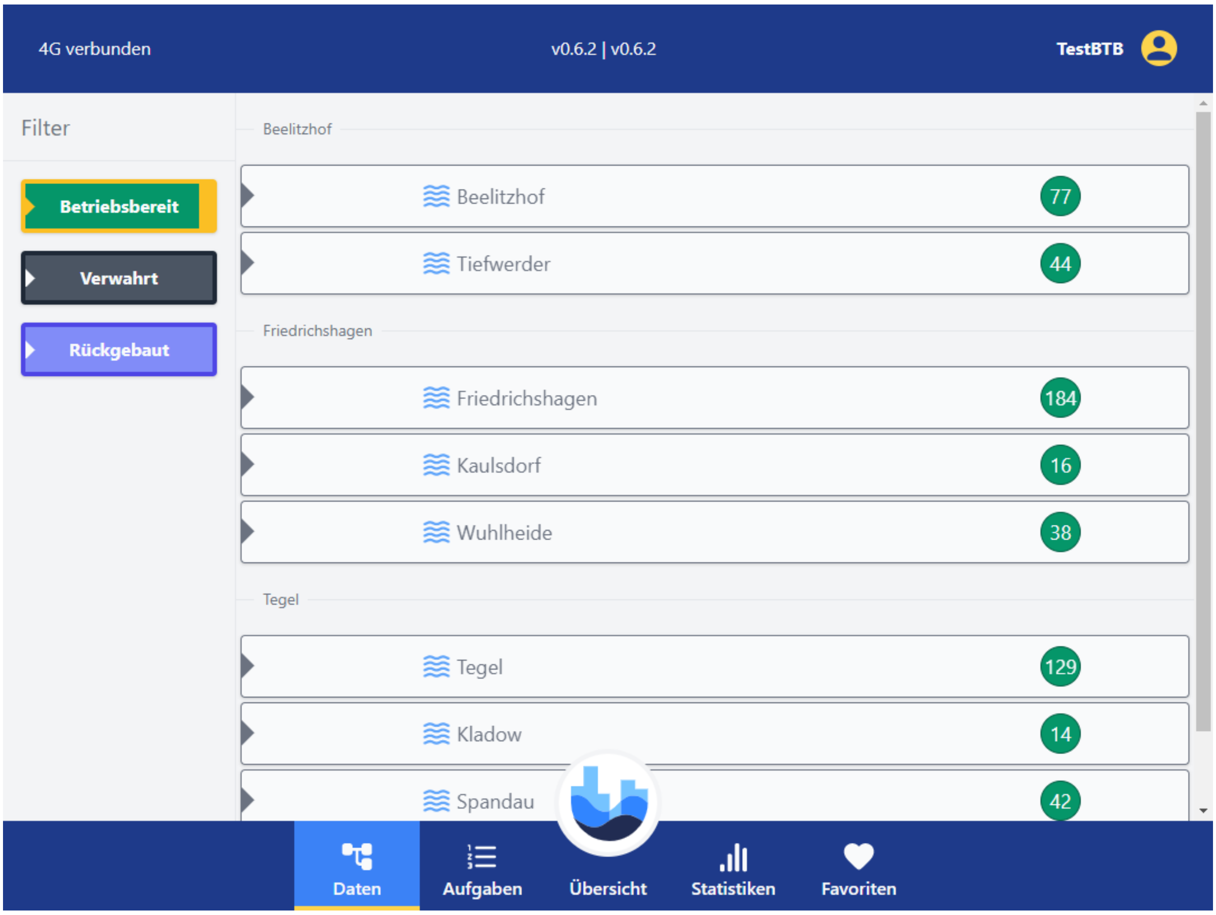

Figure 9: DW Well Diary dashboard

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4.1.3. Data requirements and transmission

The DW Well Diary has been implemented with a backend providing connections to data providers (from the water management network of BWB) while the frontend communicates with the mobile devices that are used for well monitoring and maintenance. The backend has a web interface for administration. There are two major data exchange paths:

- between the mobile devices' PWA and the backend; and
- between the backend and the internal well database of the utility.

The mobile PWA accesses the backend functionality via an API that is secured via Secure Sockets Layer (SSL) and accessible only from within a VPN. The system has been designed to allow for delayed and transactional synchronization in case of loss of network connectivity. However, the current demonstrator requires mobile devices to have a permanent connection.

The backend exchanges data with the internal database using Structured Query Language (SQL) and a custom connector for read and write operations. The secure design and development of this connector has been developed in a collaborative approach between the BWB technical departments and Vragments. The internal data model of the backend has been designed with industry standards (Building Information Model (BIM), Industry Foundation Classes (IFC)) in mind to further enhance compatibility and follow proven methods.

4.1.4. System integration

The components of the "DW Well Diary" are provided to the utility through a Docker Registry. As such, feature updates and bug fixes can be effectively propagated and deployed by using an updated image. To further increase availability, thorough testing and eased integration, we have been following a four-staged scheme during the project:

There have been two stages of the deployed well diary application at a server owned by Vragments. These instances are for development and functional testing purposes (named `dev` and `test`) and operate on well-formed mock data before its deployment to the utility's internal infrastructure. This ensures that the type and format of data is the same as in the productive database, but no critical or real-time state is exposed beyond the premise of the utility. Once a tagged version from current development had been reviewed positively, it was deployed to `dev` for unit testing and after passing these was further deployed to test for functional and initial user acceptance testing with actual users from the utilty. A successful test from the 2nd stages allows the successfully tested Docker image(s) of the DW Well Diary to be deployed to the utility's internal infrastructure.

At the premises of BWB serving as test utility, there are two further environments for integration testing and productive operation, namely `stage` and `prod`. On `stage`, all final integration testing has been done on current data of the utility's internal database within all working parameters of the infrastructure and environment. A successful implementation finally triggers the deployment of the fully revised and tested DS7.1 to the `prod` productive system. A working prototype of the "DW Well Diary" has been deployed on stages 1 and 2 of the Vragments dedicated DWC system and also on stage 1 of the BWB environment. Transfer

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to productive operation is planned after integrating the mobile app into the existing Lightweight Directory Access Protocol (LDAP) user authentication and after adding of additional features which where defined during user workshops in DWC but could not be finished within the project.

4.2. Added value and potential replication of the solution

4.2.1. Expected benefits

The "DW Well Diary" (DS7.1) greatly **reduces the time needed** to get data from drinking water well field operations into the database. From a paper-based process that at times takes days to update data, this reduces to almost real-time, given that connectivity is established. This makes DS7.1 a prerequisite for DS7.2, where high data quality in terms of correctness and timely availability is a key necessity for predictive maintenance. DS7.1 also aims at **reducing errors** and allowing field workers to **operate safely** and with most recent information available.

While the solution currently has a limited scope with regards to the class of assets managed (drinking water wells), the solution can be efficiently extended to other types of assets that are maintained in the field. The provisional scheme using Docker images is a lightweight integration that does not require deep expert knowledge and can be implemented by any IT department of a utility.

4.2.2. Site requirements and potential obstacles / drivers for replication

A potential obstacle for the transfer is the applicability of the solution to the infrastructure at hand. If local drinking water production does not rely on water wells, DS7.1 cannot be directly applied, of course. Potential barriers are **connectivity to field operators, user acceptance and the integration into a secure productive environment**. Also, the availability of mobile devices is a prerequisite for the use of DS7.1. Apart from that no further site requirements have to be fulfilled.

A potential driver is that the Well Diary can be extended and modified efficiently to cater to other assets in the field, due to its standardization potential (e.g., using BIM/IFC as an internal model). As such, partners have expressed interest in the proposed solution.

4.2.3. Recommendations for successful implementation

Successful implementation to different contexts needs to carefully consider the specific character of the planned use. For instance, for implementation at a different drinking water utility, the existing business processes and data flows need to be mapped and the solution adapted accordingly. Also, early feedback from the operators should be given a high-priority during app development to ensure acceptance and provide valuable input into the development. A strong focus should also be set on the integration into the existing local IT

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infrastructure to secure compliance with local security standards and ensure secure data transfer.

The realized incremental development including early prototyping and continuous delivery enabled the user-centric development of the “DW Well Diary” and can be recommended for transferring the result to other utilities. Valuable user feedback was collected in digital workshops and enabled further development of the prototype. Users’ needs and perspectives were assessed and fed back into product development. The benefits were a high acceptance of the potential end-users as well as high expectations of the end-users regarding features provided to help them in their daily work. Additional features were identified showing the potential of the digital solutions but unfortunately exceeding the available capacity of the project. Thus, additional resources should be planned to adequately react to additional feature requests defined in the co-development process.

This process also made it possible that the features could be prioritized according to end-users needs. The practical needs and precise requirements of the utility end-users was made available to technology providers and enabled them to tailor digital solutions and develop a business case. However, it was also shown that standardization is a prerequisite for digitalization. Additional, unplanned effort for standardizing of procedures and the extension of internal databases proved to be a barrier for implementation of the digital solution. It is recommended to improve mapping and standardizing of work processes as much as possible prior to implementing the “DW Well Diary”.

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5. Forecasting tool for strategic planning and maintenance of drinking water wells (DS7.2)

Factsheet
General information <u>IPR holder:</u> KWB <u>Main contacts:</u> Michael Rustler (KWB) <u>TRL improvement:</u> 5 to 7 <u>Target audience:</u> drinking water well managers
Challenge Well rehabilitation represents a significant element of annual investments and expenses to maintain service quality. Scheduling monitoring activities are typically based on the long-term practical experience of waterworks staff. Utilities need methodologies to prioritize operation and maintenance. They could benefit from using sensors and available data to identify and prioritize wells rehabilitation at the right time and in the correct location.
Description The solution is an open-source machine-learning-based prediction tool that supports utilities in shifting from time-based maintenance of single wells to condition-based maintenance with a view to all available wells and the target capacities of the utility. It combines automated data processing and machine-learning approaches to identify well ageing and prioritize maintenance or reconstruction needs.
Benefits and added value The solution has been tested in Berlin in cooperation with BWB. Overall, it has proven the applicability of data-driven machine learning to support well managers in predicting ageing rates and prioritizing maintenance efforts. The data processing routine has been automatized in the form of an R-package. Results reveal a higher prediction accuracy compared to the current methods used by the financial department of BWB for wells rehabilitation planning. For example, the classification accuracy of wells in poor condition (recall) increased by more than 94%
Innovation The developed model describes existing well data better than the existing approach and can thus improve the prediction of well ageing. This solution is the first available open-source tool to optimize the asset management of drinking water wells.
Impacts BWB will further implement the solution in Berlin together with KWB. KWB is interested in further developing the tool and assessing the added value in terms of OPEX and CAPEX reduction. The goal is to deploy the solution among water utilities and to link the asset management of wells with other infrastructures such as sewer and drinking water networks.

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5.1. Addressed challenge

Drinking water production from groundwater requires wells. These can be horizontal or vertical filter wells. The lifetime of such drinking water wells typically ranges between 20 and 50 years.

To identify and prioritize maintenance needs, well condition is monitored during operation usually in regular intervals or on demand and comprises parameters such as flow rate, water levels, water quality, power consumption, etc. Standards and technical rules recommend to trigger maintenance, when the capacity of the well has decreased to below 80% (DVGW, 2007[15]). In routine operation, however, water level sensors are often not in place and pumping tests are scheduled depending on the availability of human and/or financial resource. Thus, well capacity is often already below 80% at the time of measurement. Maintenance is then known to be less effective.

The DW Well Diary combines automated data processing of routine monitoring data with Machine-Learning (ML) approaches to identify well aging and decreasing well capacity in routine operation and prioritize maintenance or reconstruction needs. The ML approach is transferred from sewer aging modeling.

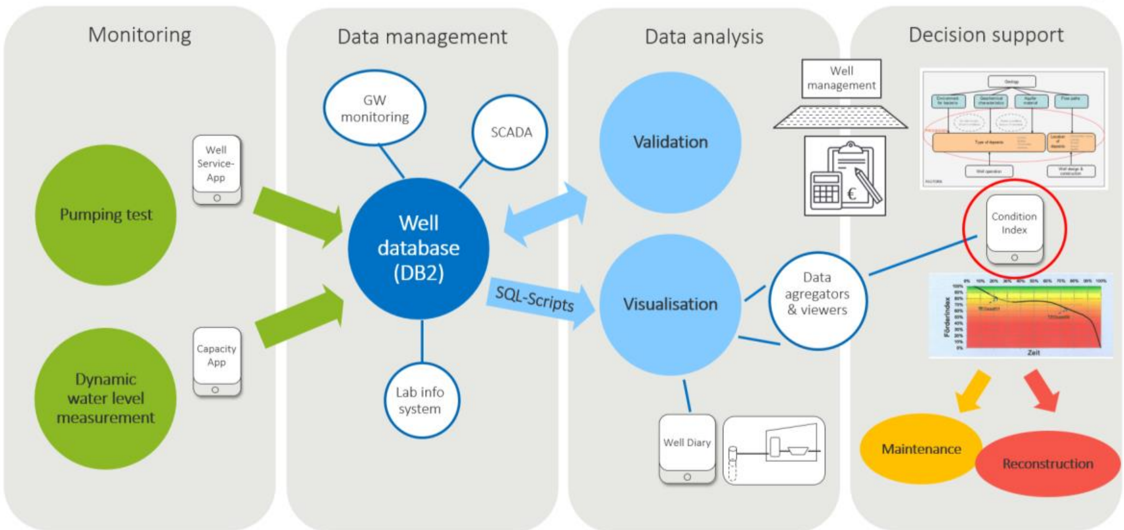

Figure 10: DS7.2 (red circle) in the context of the digital well management at BWB

5.2. Technical description of the solution

5.2.1. Type of solution

DS7.2 is a decision support system visualizing and predicting data to predict the development of well aging based on site conditions, constructive properties, hydro-chemical parameters of

[15] DVGW (2007) Arbeitsblatt W130 Brunnenregenerierung

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the abstracted water and operational parameters. Challenges were the (i) limited data availability of Qs values (i.e., production rate per meter drawdown) as these were only determined during pumping tests after well construction and before/after well rehabilitation) and that (ii) well aging can differ quite significantly between two production wells (Figure 11:).

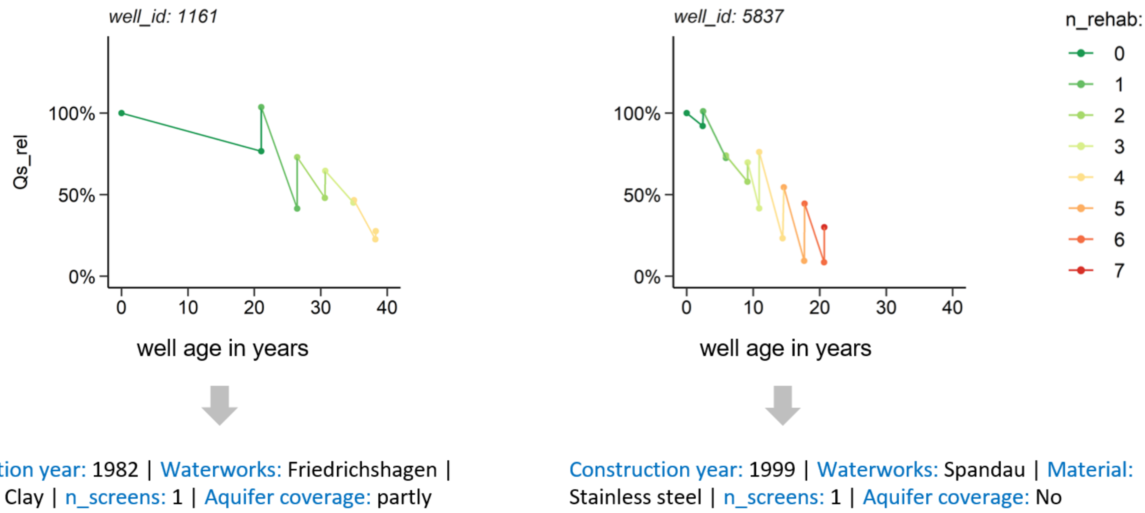

Figure 11: Visualization of relative Qs-curve (compared to pumping test after construction), which is determined at pumping tests before and after well rehabilitation, for two production wells with different aging patterns

DS7.2 consists of a ML approach (i.e., gradient boosting) to predict mid-term aging behavior based on well characteristics and monitoring data and comprises the following components:

- Qs-curve visualization (Figure 11:): all capacity data per well were visualized as a typical Qs-curve, that is capacity related to initial capacity at the time of construction against time (well age).
- Analysis of past maintenance events: the curves were divided into maintenance intervals separated by well regeneration events (Figure 11:). Loss of capacity was evaluated per time as well as per volume of abstracted water, and the intervals were compared for their gradients. However, this analysis has been only partially successful, because of data availability issues (complete dataset of yearly production rates since starting of well operation were only available for wells younger than the year 2000).
- Well clusters and aging parameters: whilst in previous R&D projects, wells have been clustered according to constructive or hydro-chemical parameters to describe their aging behavior, in DWC wells are clustered according to their Qs gradients and statistical methods were applied to find explanatory variables (i.e., well age, time since last rehabilitation, number of rehabilitations, daily variation in abstraction volume) from site and well characteristics. These variables are then the input parameters for the prediction of future well aging behavior.
- Prediction of future well aging rate: analogous to a sewer management approach developed at KWB, different statistical models including ML approaches (i.e., decision

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trees, random forests, gradient boosting, linear and logistic regression) were tested to predict the loss of capacity. These predictions can then be used by the well managers to plan maintenance and by the controlling department to decide on reconstruction needs.

Thereby, DS7.2 basically closes the time lag between scheduling pumping tests to assess current well capacity and further loss of well capacity below the recommended benchmark of 80% of initial capacity, after which maintenance is known to be less effective and improves data availability and usage of available data to make better informed decisions. DS7.2 provides recommendations for routine monitoring and reactive and/or preventive maintenance. In addition, key parameters for fast or slow well aging were identified from correlations between the gradient of loss of capacity and site and well characteristics.

5.2.2. Technical specifications

Input data for DS7.2 were queried by BWB from its central well database, which stores data from various sources such as the groundwater monitoring system to manage hydrogeological and well specifications (each bore log is archived with its geological and constructive properties), groundwater data loggers storing sensor data (water levels), laboratory data, operational data from the Supervisory Control and Data Acquisition (SCADA) system (flow volumes, flow rates, operational hours etc.).

These data were exported by BWB and provided to KWB as CSV files for developing the ML-algorithms. Data pre-processing and ML-algorithm development at KWB was done within R (R Core Team, 2020[16]), which is an open-source statistics programming environment. For this the R package "dwc.wells" was developed within DWC, which contains functions (for data-preprocessing based on provided BWB CSV files) and workflows (e.g., for ML-model development). All wells had a unique identifier, with which data from the different source tables were linked. Out of initially 36 possible model input features – in order to reduce the risk of overfitting, improve the model accuracy, reduce training time and in order to keep the models simple, explainable and transferable – the following 11 features were discarded due to:

- **Intercorrelation** (numerical: Chi-Square statistic; categorical: Spearman correlation): well depth, dry residue concentration, total phosphor concentration, standard deviation of abstraction volume, name of waterworks, name of surface water body
- **Low information content** (i.e. low impact on model accuracy): number of filter screens, filter length, copper concentration, presence of inliner
- **Increasing model transferability**: name of well gallery

Thus, in total 25 features (20 numeric, 5 categorical) were used as input data for the ML-models, which can be grouped into the following five categories:

[16] R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

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- **Well Characteristics:** well age, construction year, screen material, diameter, drilling method, admissible discharge, initial specific capacity
- **Site Properties**: aquifer coverage, groundwater level variations, surface water distance
- **Operational Data:** mean abstraction volume, standard deviation of abstraction volume
- **Rehabilitation Data:** number of well rehabilitations, years since last rehabilitation
- **Water quality:** mean values of parameters electrical conductivity, dissolved oxygen, temperature, pH, redox potential, total iron, manganese, nitrate, phosphate, sulphate, total suspended solids

Finally, these **25 features** were used for 994 production wells of BWB and resulted in a dataset of 6603 observations and one predictor variable **relative Qs** (i.e., for each well a relative Qs at pumping tests after construction and before/after well rehabilitations). This dataset was split randomly into a training (80% of data) and a testing dataset (20% of data) for of each of the five ML models that were developed for the following two objectives:

- **Regression**: predicting the **relative Qs** before/after well rehabilitations for each well and
- **Classification:** determine whether the relative Qs of the wells will be either **low** (< 80% of relative Qs) or **high** (> 80% of relative Qs) before/after well rehabilitations.

Table 2 shows the performance for both tasks for the three advanced machine-learning algorithms (i.e., decision trees, random forests, gradient boosting) and two simpler statistical (i.e., linear and logistic regression) algorithms, which were tested within D7.2 and implemented by using the software R. The best model for both tasks (i.e., regression and classification) is gradient boosting (xgboost), a tree-based ensemble learner that builds multiple trees iteratively, each time giving more weight to the datasets with high prediction error in the previous tree. For the workflow on how this ML model is trained and tested the reader is referred to the documentation website of the R package "dwc.wells" (see: https://kwb-r.github.io/dwc.wells/articles/prediction_xgboost.html).

Table 2: Performance of the tested the five algorithms for regression (prediction of relative Qs) and classification (i.e. low < 80% or high > 80% relative Qs) predictions

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	Regression		Classification	
	R^2	RMSE	Sensitivity	Precision
Linear regression	0.41	24.3%	0.965	0.738
Logistic regression	-	-	0.879	0.797
Decision tree	0.52	22.2%	0.897	0.801
Random Forest	0.75	16.3%	0.965	0.842
Gradient Boosting	**0.78**	**14.8%**	**0.940**	**0.880**

5.2.3. Data requirements and transmission

Required input data typically comprise flow rate or water volume per time unit, static and dynamic water level, chemical composition of the raw water, constructive condition of the well, power consumption of the pump and pressure at the well head. These data are available for more than 650 wells since 1973 in different timely resolutions ranging - depending on the type of data and the parameter – from daily to annual time steps. First step was a descriptive analysis and documentation of available data sets and data gaps.

R programming language was used to implement the data pre-processing for Qs calculation, correlation with site and well data and statistical models and ML predictions. No integration of this tool into the database of BWB was done within this project.

5.2.4. System integration

Integration into the BWB IT infrastructure was initially planned but not realized within this project. The ML algorithm works as a standalone application using R and relies on a pre-processed dataset (also done in R based on CSV files and R scripts). The CSV data-preparation was done by BWB using SQL queries from their internal database. Afterwards, the machine learning model is applied on the pre-processed CSV files.

Furthermore, BWB currently uses a tool for investment and cost planning of well rehabilitations (CO-tool), which uses a general aging curve for all wells, but with limited predictive accuracy ($r^2 = 0.52$, RMSE = 20% vs. gradient boosting ML: $r^2 = 0.78$, RSME: 14%). For this BWB-tool an integration of the mean general well aging curve of the gradient boost ML-model would be possible (in case an explicit formula is provided to BWB from the results) in order to:

(i) evaluate if the predictive performance of the CO-tool increases and

(ii) check if the annual CAPital EXpenditure (CAPEX) for well rehabilitations would increase, decrease or stay the same for the KPI report

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5.2.5. Expected benefits

As each drinking water abstraction well is interfering with the natural hydrogeological and hydro-chemical settings and subsurface processes, well aging is a worldwide phenomenon. Numerous standards and textbooks from Germany, the Netherlands, UK or US (Cullimore, 1996[17]; Driscoll, 1986[18]; Houben and Treskatis, 2007[19]; McLaughlan, 1996[20]; NWWA et al., 1988[21]) identify aging processes, types and recommendations for routine monitoring and reactive and/or preventive maintenance.

The DW Well Diary provides key parameters for fast or slow well aging, which were identified from correlations between the gradient of loss of capacity and site and well characteristics. These algorithms and key parameters are transferable and can help utilities to efficiently allocate investments in the rehabilitation and renewal of wells. In parallel to the technical development of the solution, in WP5 exploration paths and usability for other utilities are assessed.

5.2.6. Site requirements and potential obstacles / drivers for replication

The DW Well Diary is applicable for and transferable to utilities producing drinking water from vertical filter wells. However, to apply the solution, basic well data need to be available over a certain period of time in order to be able to train the ML algorithms. Data should comprise constructive properties (filter length, material, position of intake area, etc), basic hydrochemical characteristics of the raw water (pH, redox potential, electric conductivity, oxygen and iron concentration and others) and water level and flow data. Potential obstacles are thus a lack of data, data gaps or a too short history of well data.

Drivers for transfer and replication can be the increasing usage of (i) sensors delivering continuous measurement of key parameters such as water level and flow, (ii) database storage solutions for well data, and (iii) increasing experience with semi-automated data processing and ML approaches in other fields of water infrastructure management as data science has been gaining momentum in recent years. These technologies are for example already applied for failure prediction of drinking water (and sewer) pipe networks, where in a similar approach factors for fast or slow aging and certain constructive and operational parameters are set into relation to identify and prioritize maintenance needs. The fact that wells need regular preventive or reactive maintenance in order to keep their capacity and constructive integrity is widely acknowledged nowadays and data-driven prioritization of needs will thus help to schedule limited human and financial reports for the highest return on investment.

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[17] Cullimore, D. R. (1996) Perception of a functioning water well.

[18] Driscoll, F. C. (1986) Groundwater & Wells, 2nd ed.

[19] Houben, G. & Treskatis, C. (2007) Water well rehabilitation and reconstruction. Mcgraw-Hill Publ.Comp.

[20] McLaughlan, R. (1996) Water Well Deterioration, Diagnosis and Control. Sydney, Australia: University of Technology

[21] NWWA, Lehr & Jay, H. (1988) Design and Construction of Water Wells: a Guide for Engineers. New York: National Water Well Association

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5.2.7. Recommendations for successful implementation

For a successful implementation and integration of the method, two necessary prerequisites have to be fulfilled: First, historical data has to be available for the wells of interest and the most important input parameter (e.g., time series of Qs curves and explanatory variables). Second, implementation of innovative data processing and the machine algorithms (e.g., by using a programming language like R) requires agile IT management that guarantees the integration into daily business processes beyond SQL database queries.

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6. DTS sensor for tracking illicit sewer connections (DS8)

Factsheet
General information <u>IPR holder:</u> P4UW <u>Main contact:</u> Remy Schilperoort (P4UW) <u>TRL improvement:</u> 6 to 9 <u>Target audience:</u> wastewater utilities, network operators, sewer maintenance staff
Challenge Illicit connections or sanitary sewage to the storm sewer system, usually due to unintentional errors during sewer construction or rehabilitation, are a significant source of pollution for surface waters and can threaten human health in the case of bathing waters. Finding these illicit connections is like looking for a needle in a haystack, as illicit connections usually occur at selected points within an extensive sewer network and happen intermittently.
Description Distributed temperature sensing (DTS) is used to detect and locate illegal connections and extraneous inflows in sewer systems. DTS uses fiber-optic cables installed in the sewer system connected to a centrally located measuring unit. Using the principle of laser light reflection, the fiber-optic cables can serve as large temperature sensors and detect illicit connections in the form of anomalies in the temperature signal.
Benefits and added value The solution has been demonstrated in a separate sewer system in Berlin. The main advantage of the technique is its high precision: it can pinpoint illicit connections to their location in the sewer. Hence, the success rate in identifying illicit connections is 100 %. The main drawbacks are the relatively great effort (and thus costs) associated with the technique. The solution’s costs are around 3.5 times more expensive than conventional visual inspection (e.g., manhole inspection); considering a complete equipment rental, OPEX amounts to > 40 k€/km.
Innovation The innovative use of temperature to track illicit connections allows unmatched precision compared to other market solutions.
Impacts The solution is a concrete answer to tackle the issue of illicit connections in urban areas and implement entirely European directives such as the Water Framework Directive and the Urban Wastewater Treatment Directive. DWC partners have shown interest in new tests in Paris and Milan. P4UW further commercializes the solution.

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6.1. Addressed challenge

Urban drainage systems are a major pollutant pathway to surface waters, in part due to illicit connections between the sewer and stormwater networks. Illicit connections are illegal connections between the sanitary sewage system and the storm sewer system, which lead to raw sewage discharges into the storm sewer and later into the receiving water body without treatment. The main reasons for the existence of illicit connections are unwanted mistakes during the construction of the sewer system and during renovations.

The general presence of illicit connections within the storm water sewer system is usually known by the utility. Their exact locations, however, are rarely precisely identified. Technologies currently used to track illicit connections in sewer systems include Closed-Circuit TeleVision (CCTV) sewer inspection, manual inspection from the manholes, color marking of household effluents, smoke detection, and outfall reconnaissance inventory (field assessment after walking the banks of the river or lake). However, these methods have two important drawbacks. On the one hand, they provide only snap-shots of usually dynamic situations and therefore often yield poor accuracy for tracking illicit connections (i.e., have a small chance of actually finding and locating an illicit connection with intermittent discharges). On the other hand, they require high operating expenditure due to the extensive operational staff resources needed.

Distributed Temperature Sensing (DTS) offers an alternative technique to detect and locate illegal connections and extraneous inflows in sewers and storm water systems.

6.2. Technical description of the solution

6.2.1. Type of solution

DTS uses a fiber-optic cable that is installed in the sewer or storm pipe to generate long-term and high-frequent temperature measurements over the entire length of a sewer section, typically several km. A DTS unit (laser/computer instrument) sends pulsed laser light into the fiber-optic cable and processes the reflected signals into temperature values. Temperature readings are typically obtained every 30 seconds for every 50 cm of the fiber-optic cable, allowing a very detailed assessment of in-sewer processes. Based on temperature differences typically observed between storm and wastewater, in-sewer processes such as illicit connections can be studied and localized in detail. In contrast to the current practice, the DTS method is expected to identify the precise locations of illicit connections in the area. Figure 12 shows a monitoring truck with DTS equipment.

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Figure 12: Mobile DTS unit with fiber-optic cables for detecting and localizing illicit connections in sewer (left) and container with DTS unit and fiber-optic cables (upper right picture) and actual DTS unit in container (lower right picture).

6.2.2. Technical specifications

The application of fiber-optic DTS in sewer systems is performed with a standard fiber-optic cable in combination with a standalone DTS measuring instrument that contains a dedicated laser instrument, sensing opto-electronics and a computer. Figure 13 shows a typical monitoring setup.

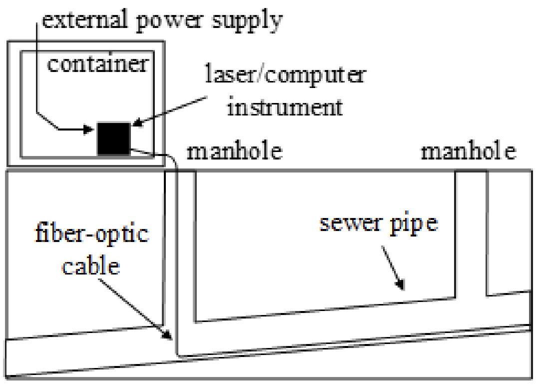

Figure 13: Schematic monitoring set-up for in-sewer DTS

The fiber-optic cable is laid out at the invert of a storm drain. The fiber-optic cable follows a route that includes all storm sewer conduits in the study area to be examined. An important assumption is that the route is 'clean', i.e., not blocked by sediments or other obstacles. For an optimal operation of the measurements, it is also recommended to keep sewer systems as empty as possible during the measurements.

At one end, the cable is connected to the DTS unit that is stored outside the sewer system in a container or truck to protect it from weather and theft. For measurements, a continuously pulsing laser emits light into the fiber-optic cable. At many locations along the cable each laser pulse is partially reflected by imperfections in the glass fibers. The reflected signals are 'read'

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by the opto-electronics in the measuring unit and interpreted by the computer software. For each reflected signal, both the location of the reflection can be determined (using the measured travel time and known travel speed) as well as the temperature at the location of reflection (using Raman backscattering). This way, each laser pulse yields temperature values at many locations along the fiber-optic cable. As the DTS unit is generally installed outside the sewer system, no electrical equipment is introduced in the sewer environment.

The results of all pulses emitted during a certain time span that are reflected over a certain length along the cable are used to obtain a single temperature value for that specific time and location. Hence, results are 'averaged' over typical time and space resolutions, typically one value per 30 seconds for every 50 cm of the fiber-optic cable.

The temperature resolution of the measurements is typically 0.1 °C. Absolute temperature values can be calibrated using two Pt100 temperature sensors at the beginning and at the end of the fiber-optic cable. However, to detect and localize discharges with a different temperature, the accuracy of the measured temperature gradients is more important than the absolute temperature.

The accuracy of the localization depends on the dispersion of measured temperature differences along the cable. The dispersion of measured temperature differences along the cable due to the DTS measuring technique (in the direction opposite to the flow direction) is typically less than 1 m. This makes localization of the temperature change possible within 1 m of the actual discharge location, assuming that the exact location of the cable in the sewer system is known.

A common 4-weeks campaign using 5 km of cable yields approximately 10^9 individual temperature readings. For processing these amounts of data, visual data analysis is supported by signal detection software.

6.2.3. Data requirements and transmission

The DTS solution is a stand-alone application. To get the application installed and ready to use, the following system information must be provided by a utility before the installation:

- Storm sewer layout in GIS: conduit lengths, invert levels and diameters;
- Preferably: foul water sewer layout in GIS: conduit lengths, invert levels and preferably diameters;
- Preferably: lateral connections from gullies and buildings in GIS.

Other data required for the correct interpretation of the measuring results are obtained during the measurement campaign. After installation of the fiber-optic cable in the storm sewer, the initial localization of the cable is established with a warm water test. A few liters of warm water are discharged at each manhole. Each specific discharge (each manhole) is measured as a temperature rise at a specific distance along the cable. This way, each manhole along the cable route is linked to a specific cable distance.

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A DTS measuring unit collects the raw DTS data (Stokes and anti-Stokes values) locally at the monitoring site. The data are zipped into smaller 'packages' and sent to a database. Access to the database is only possible when a computer is part of the VPN. From the database, the data are converted to temperature values.

With the use of pattern recognition software, the temperature measurements as a function of both time and distance along the cable are translated to suspect locations in the storm sewer system. The output of the DTS measurements can be accessed via the web-based viewer for which a login is required.

6.2.4. System integration

The DTS solution is a stand-alone application. There is no connection needed with the utilities' systems, except for the power grid and an internet connection. The results (i.e., the suspect locations in the area) are presented in a web-based viewer. Naturally, the viewer is secured with a login and password.

6.3. Added value and potential replication of the solution

6.3.1. Expected benefits

Current practices to address illicit connections in sewer system, based on visual inspections (odor, faeces, toilet paper) and CCTV inspections have been applied for several decades, but have ultimately proven to be insufficiently effective to tackle the problem of illicit connections. DTS has proven to be a much more effective and powerful tool to find illicit connections in sewers.

The large-scale application of DTS measurements and the consequent repair of illicit connections in existing and new storm sewer systems could result in a great reduction of emissions from these systems on local urban surface water systems. Especially for largely stagnant receiving water systems, like ponds and canals, this could lead to a significant water quality increase.

6.3.2. Site requirements and potential obstacles / drivers for replication

In general, there are no specific site requirements to consider for the solutions, except that the application is limited to separate sewer systems.

Cost is probably the main potential obstacle for the transfer and replications of the DTS solution on a large scale to other cities (DTS unit and fiber-optic cables). The willingness to invest in such equipment requires a strong and long-term drive to solve problems associated with illicit connections in an area. In cities where illicit connections represent a significant contribution to environmental impact or an impediment to water uses such as swimming, the solution becomes much more cost effective, in view of the massive investments required to upgrade the network.

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A minor potential obstacle is the availability of data. Since DTS measurements can only be usefully interpreted if the sewer system layout is sufficiently known, it is not recommended to apply DTS if the sewer object database is not reliable or lacks entirely. For most urban environments, however, geodata of sufficient quantity and quality is available in the municipal sewer data administration.

Potential drivers for the application of DTS in other cities will be successful demonstrations of the solution in different settings, dissemination of the acquired knowledge in pilots and cost reduction through innovations (e.g., fibre-optic cable connectors) and larger scale applications.

A potential driver might also be a growing interest in water quality and biodiversity in European, national, and regional politics, although the European Water Framework Directive primarily focuses on large scale water bodies, and less on smaller urban surface water bodies.

6.3.3. Recommendations for successful implementation

The following recommendations for successful implementation of the DTS solution in different contexts can be given:

- The construction of a DTS monitoring network is a high-tech solution that requires trained personnel. For a first-time implementation of DTS in a certain context, start with a pilot project to train a local contractor with the matter and to find out practical obstacles.
- For an optimal operation of the measurements, it is recommended to keep the storm sewer system of interest empty during dry weather. As an alternative, the application of floating cables might be considered.
- A typical monitoring campaign period lasts four weeks. The choice of a measurement period depends on the probability that discharges from all present illicit connections can be measured within this period. Optimal measurements are only possible during dry weather. A rainy season (monsoon) might not be the best monitoring period, since the wet weather inflow will disturb the signal from discharges via illicit connections. A low or absent building occupancy (e.g., during holidays) further reduces the probability of detecting illicit connections from those buildings. In case of suboptimal conditions, longer monitoring periods might be required.
- Due to the large amounts of data generated by a DTS unit, it is recommended to support visual data analysis with automatic signal detection software.

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7. Sensors and smart analytics for tracking illicit sewer connection hotspots (DS9)

Factsheet
General information <u>IPR holder:</u> BWB <u>Main contacts:</u> Michel Gunkel (BWB) <u>TRL improvement:</u> 5 to 8 <u>Target audience:</u> wastewater utilities and network operators, sewer maintenance staff
Challenge Illicit connections or sanitary sewage to the storm sewer system, usually due to unintentional errors during sewer construction or rehabilitation, are a significant source of pollution for surface waters and can threaten human health in the case of bathing waters. Finding these illicit connections is like looking for a needle in a haystack, as illicit connections usually occur at selected points within an extensive sewer network and happen intermittently.
Description The solution uses two types of sensors, electrical conductivity (EC) and multiparameter sensors, combined with an IoT unit (KANDO's smart unit). The sensors measure the electric conductivity of the flow in the storm sewer network. Based on the continuously measured EC signal and prior knowledge of typical EC values of stormwater (~ 200 µS/cm) and sanitary sewage (> 1000 µS/cm), it is possible to differentiate between both flows and hence identify illicit connections of sanitary sewage in the upstream storm sewer system.
Benefits and added value The solution has been demonstrated in a separate sewer system in Berlin. While DTS (DS 8) is ideal for tracking the location of illicit connections, this solution is a cost-effective technique to identify hotspots region and narrow down investigations at the catchment scale. The solution has proven to be ten times more efficient than conventional visual inspection (e.g., manhole inspection) to narrow down hotspots of illicit connections in the network. Respectively, monitoring costs have proven to be 2/3 less expensive than visual inspection.
Innovation This solution is a smart concept to address the issue of illicit connection at the city and catchment scale. It provides a methodological guideline to start solving the associated challenges.
Impacts The solution is a concrete answer to tackle the issue of illicit connections in urban areas and implement entirely European directives such as the Water Framework Directive and the Urban Wastewater Treatment Directive.

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7.1. Addressed challenge

Illicit connections are incorrect connections between the sanitary sewage system and the storm sewer system, which lead to raw sewage discharges into the storm sewer and then to the receiving water body without treatment. In most cities, illicit connections are a significant source of pollution for surface waters and can threaten human health when receiving waters are used for bathing. Illicit connections primarily originate from unintentional errors during the construction of the sewer system or during renovations.

The main challenge in searching for illicit connections is the time and effort required to investigate large lengths of storm sewer systems. The search is like looking for a needle in a haystack: storm sewers can easily extent to a length of several hundred kilometers, and discharges from illicit connections happen irregularly and intermittently. The number of illicit connections in an area is generally unknown and can vary widely.

The goal of the presented solution DS9 is to develop a cost-effective and time-saving method to identify hotspots of illicit connections.

7.2. Technical description of the solution

7.2.1. Type of solution

The newly developed method is the first element of a two-step-approach. It aims to identify hotspot regions with strong indications for the presence of illicit connections with two different sensor systems. In a second step, it is combined with DTS (DS8) to localize the exact point of discharge. The general idea of DS9 is to carry out temporary measurements with two types of sensors installed at several points in a storm water catchment area and to develop a smart algorithm for data evaluation and field campaign processing. Figure 14 shows the two different types of sensors.

Figure 14: KANDO's smart unit and sensor (left), the EC sensor and logger (right) as well a sensor installed at a sewer manhole (middle).

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7.2.2. Technical specifications

The solution makes use of two types of sensors, Electrical Conductivity (EC) offline-sensors and MultiParameter (MP) sensors combined with an IoT unit (KANDO's smart unit).

The **EC sensors** measure the electric conductivity of the flow in the sewer network. The EC indicates how easily electricity can flow through the water and gives information on how many dissolved ions are present in the water. Based on the continuously measured EC signal and prior knowledge on typical EC values of stormwater (~ 200 µS/cm) and sanitary sewage (> 1000 µS/cm), it is possible to differentiate between both flows and, hence, identify illicit connections. In a typical use case, sensors are initially installed at the stormwater outlet at the river or lake and then subsequently moved to manholes in upstream sewer sections to systematically narrow hotspot areas with strong indications for illicit connections.

The sensor system consists of (i) an EC sensor and (ii) an offline data logger. Both devices are attached to a string in the manhole. Additionally, a sandbag is installed, which dams up the water and enables the measurement in the water. The EC is recorded every minute and thus provides a high temporal resolution of the event. The installation of the system can be carried out without going downstairs. The batteries are changed every two to three weeks.

KANDO's smart unit is an innovative solution to track industrial discharges and illicit connections in sewer networks by leveraging Internet of Things (IoT) technology and data analytics (e.g., Auto-Regressive Neural Network, Hydraulic Modeling, Scoring algorithms, etc.). The solution is built upon 10 years of industries wastewater monitoring as part of pretreatment program execution including sampling analysis, flow measurements and wastewater quality detection. It combines several flexible units for real-time water quality monitoring with MP sensors and automatic sampling (not in the scope of this project). The solution enables reduction of pollution impacts by continuously detecting sources of pollution across the city. It can provide estimation of the location of illicit connections and automatically identify pollution events using distributed predictive analytics, cloud transmission and visualization.

The deployed IoT-units are battery powered and have four available ports (digital and analog) allowing for a number of parameters to be measured in different configurations. Tests indicate that a combination of EC, pH and temperature gives a good signal to characterize if a specific observation is sewage or not. In some cases, it will also allow to discriminate the discharge source between sanitary and industrial, which is crucial information not only for trying to estimate the impact but also for the "hunt" for the source. The smart units are specially designed to work under the ground regarding ruggedness and robustness, ability to communicate and battery lifetime (of around 9 – 12 months depending on the local conditions). All installations do not require work underground and one person is able to do a standard installation in about half an hour.

The data is acquired every 5 minutes and sent to the cloud either regularly three times a day or in case of a relevant incidence (the relevancy objective function for finding sewage

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discharges is different than the regular one used for identifying industrial waste in wastewater collection systems). For that purpose, a combination of anomaly detection techniques is used.

7.2.3. Data requirements and transmission

The EC is measured with a sensor and the data is temporarily stored in the data logger. In intervals of 2 to 3 weeks these data are read out via Bluetooth with a laptop. The data sets are saved as CSV files and can be further processed as desired.

Regarding the EC values an evaluation scheme to classify the sensor locations according the likelihood of upstream illicit connections has been developed. For each location, the data of four weeks during dry weather are considered. Wet weather is defined as the time interval from one hour before to three hours after a rain event. Rain events were evaluated from a rain gauge near by the demo area. Exceedances of the limit values 600 µS/cm and 4000 µS/cm are considered and classified into three categories based on a traffic light system, as shown in Table 3.

Table 3. Evaluation scheme

colour	number of peaks > 600 µS/cm / 4 weeks	meaning
(red)	> 4 (or peak > 4.000 µS/cm)	Illicit sewer connection is likely
(orange)	2 - 4	Illicit sewer connection is possible
(green)	0 - 1	Illicit sewer connection is unlikely

Based on the outlined scheme, a Python script for an automatic evaluation has been developed. Measurement data, which fits with rain events will be eliminated and the script counts the number of relevant peaks above the limit values. Following on this, the program gives an advice of the classification of the measurement site in *likely*, *possible* or *unlikely*.

KANDO's smart system sends data to the cloud regularly and data is automatically processed and shown in dashboards/maps (see Figure 15) and alerts sent to the relevant users.

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Figure 15: Dashboard for visualization of data from KANDO's smart unit

7.2.4. System integration

The EC sensors system is comfortable in use. After a positive demonstration of the method during the project the solution will be provided to the operational team or an operational task force for identification of illicit connections in the utility. The sensors are currently deployed as standalone solution and data processing takes place offline in the office.

Kando's smart unit, being made for operators of water and wastewater utilities in mind, is intrinsically easy to use and operate. Over that, all the data and insights can be consumed automatically in a Machine to Machine scheme, making this data available for integration by other decision support systems that may already be in use in the utility.

7.3. Added value and potential replication of the solution

7.3.1. Expected benefits

The advantages and innovation of the demonstrated solution is the easy handling and the benefit of a higher efficiency in detection for illicit connections. There is no need to enter the manhole, which reduces the operational effort to identify illicit connections. Only an uncomplicated installation of the sensors with a time expenditure of about half an hour and a battery change combined with the readout of the data in two to three-week cycles is necessary. The material costs are only the purchase price of the sensor system. The maintenance requirement is low. The digital aspect makes time-consuming and costly visual

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inspections unnecessary. In comparison, visual methods only provide a snapshot of the current situation. The technology is relatively easy to operate and no great previous knowledge and long training periods are necessary.

In summary it can be said that the presented method is a worldwide applicable method due to the easy operational manageability as well as the low cost and effort. Illicit connections in the storm water sewer system can be identified and subsequently eliminated with a reasonable effort. This is accompanied by an improvement in water quality and thus also an increase in the quality of local recreation areas for the population.

7.3.2. Site requirements and potential obstacles / drivers for replication

The application of the demonstrated solution is primarily designed for use in storm water sewer networks. The existence of a separate sewer system is therefore a prerequisite. Apart from that, no further site requirements.

The main driving force for the implementation of the solution is the poor water quality still found in many urban lakes and rivers and the increasing willingness to use water bodies for swimming or recreation. The easy operational manageability and the low expenditure is an advantage of this solution.

The starting points are always the rainwater outlets into the receiving water. In progress of campaign planning, a GIS-analysis is necessary, to detect main sewers and key manholes for installation of the sensor system as well as the differentiation of the sewer structure into upstream subcatchments with respect to highpoints in consequence of the respective measured values. To reduce the operating expenses, it is recommended to select manholes in traffic-calmed streets and outside parking lots, if possible.

7.3.3. Recommendations for successful implementation

A prerequisite for the successful implementation of the solution is a close cooperation between the utility and the operators. In particular, data on the network structure must be shared and access to the manholes must be given. In the spirit of a fast progress, it is useful to use as many sensors as possible, depending on the measurement site.

Since the sensors remain permanently inside the manholes, they have to be robust, protected against entering rainwater and need a long-lasting battery supply. Both used systems showed a few performance problems in terms of robustness. To avoid damages, it is helpful to use a protection suitcase for the logger and to fix the sensors and loggers strictly by wires. In addition, periodic calibration testing is necessary to ensure the good quality of the measurement data. The installation of a sandbag together with the sensors, as mentioned in 7.2.1 is essential for the measurements.

A further expansion of the solution that can support results accuracy could be the implementation of automatic sampling alongside the quality sensors units to collect samples as the sensors identify a potential pollution event. Samples could then be analyzed to evaluate the presence of sanitary sewer vs. other pollution sources.

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8. Sewer flow forecast tool box (DS11)

Factsheet	
General information IPR holder: DHI Main contact: Sten Lindberg (DHI) TRL improvement: 7 to 9 Target audience: sewer network and wastewater treatment plant operators	
Challenge The integrated management of the sewer network and the wastewater treatment plant (WWTP) is crucial to minimize sewer overflow emissions, WWTP bypasses, and pollutant loads emitted via the WWTP. To better control the filling and emptying of retention basins and treatment processes at the WWTP, forecasts of the inflow to the drainage system and the WWTP are required. However, inflow forecasts from more straightforward methods are typically highly uncertain and have relatively short forecast times.	
Description The sewer flow forecast toolbox is a machine-learning (ML) based tool for forecasting flow in the sewer network and inflow to the wastewater treatment plant (WWTP), with a forecast lead time of up to 48 hours. The tool is based on a combination of (1) real-time water level and flow sensor data from the sewer system, (2) rain gauge data, (3) weather radar observations and nowcasts, and (4) weather forecasts from numerical weather prediction models. The solution provides an accurate flow modelling forecast and horizon to support the integrated management of the sewer network and WWTP. The accuracy for flow modelling improved by more than 30% compared to the current methods used in Copenhagen, potentially leading to a reduction of wrong switches at the WWTP of more than 90%.	
Innovation Most approaches for sewer modelling are based on complex and extensive hydrodynamic models. The machine learning methodology is a simplified “end-to-end” approach where the model implicitly describes all intermediate models and their related parameterizations. The sewer flow forecast toolbox increases forecast horizons and provides more accurate predictions than the hydrodynamic approaches that are currently available.	
Impacts DWC’s experience has built a strong business case for implementing ML forecasts at other WWTP in Denmark operated by BIOFOS and other utilities. More generally, the solution will facilitate the implementation of real-time control solutions and foster the integrated management of sewer and WWTP.	

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8.1. Addressed challenge

Increasingly stringent environmental and economic regulations, constantly growing cities and the general need for adaptation to climate change put pressure on utilities to find new ways of optimizing the sewer system across its many shareholders. Integrated urban water management is imperative in this context to reduce adverse impacts on surface waters and minimize future investment costs. In particular, real-time control provides a range of alternative strategies for the integrated management of sewer networks and WWTPs. It can support the reduction of flooding and environmental impacts and enhance the capacity of the treatment plant by defining different operation schemes for dry- and wet-weather situations.

The goal of DS11 ("Improved machine learning (ML) sewer inflow forecast") is to enhance the performance and accuracy of the inflow forecast to the WWTP, so that control strategies between the sewer system and the WWTP can be optimized and Combined Sewer Overflows (CSOs) and bypasses of untreated sewage to receiving waters can be further reduced. The solution will provide short- and medium time forecasts of inflow timeseries (3-4 h) and rainfall (up to 36 h) and so enables more flexibility for emptying the storage basins compared to a strict 24-hours rule[22]. This is relevant when the biological capacity at the plant is compromised or local rainfall results in runoff exceeding the biological capacity. The 4 h inflow forecast is sufficient to change the waste water treatment plant operations from dry- to wet-weather control, where the adjustments just need around 1 1/2 h to be fully functional.

8.2. Technical description of the solution

8.2.1. Type of solution

The sewer flow forecast toolbox is a software package, including the different components for data processing, deployed in a real-time environment. The core is a ML based probabilistic forecast model for forecasting flow in the sewer network and inflow to WWTP with forecast lead time up to 4 hours. The ML model has been trained using real-time water level and flow sensor data from the sewer system, rain gauge data, weather radar observations and now-casts. In parallel with the ML inflow forecasts, a hydrodynamic model of the catchment has been developed in MIKE+. This model runs on an hourly basis, and provides a 3 h forecast for the inflow, as well as flows, levels and overflows in the entire catchment. Both —the ML model and the hydrodynamic model— produce forecasts to be used for the Decision Support System (DSS) and real-time control algorithms (DS12) for both, dry and wet flow conditions.

8.2.2. Technical specifications

The flow prediction pipeline is composed of a deep learning model that extracts rain related features and an ML model that takes these as input to predict flow amongst other features. We have explored a range of deep learning architectures including *convolutional long short-*

[22] 24- hour rule means that the utilities empty their basins within 24 hours and are not storing water for longer time, i.e., 28 hours. If the biological capacity of the WWTP however is lower than the inflow while emptying the basins, the WWTP goes into bypass.

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term memory, *pure convolutional*, *auxiliary target branch*, *custom*, and *existing networks*. Likewise, we have compared several ML models including *random forests*, *neural networks*, *Gaussian processes*, and *gradient boosting*.

The best deep learning model to forecast precipitation based on radar images turned out to be an architecture containing *Conv2DLSTM*, *time distributed*, and *fully connected layers* (trained using Keras). The architecture is shown in Figure 16.

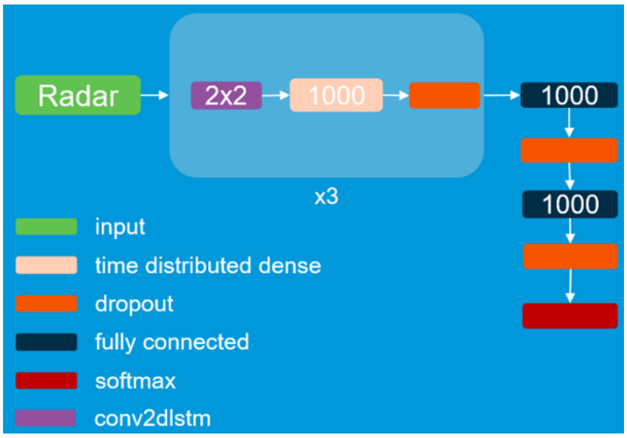

Figure 16: Architecture of deep learning model that outputs rain category based on radar image input.

The deep learning model predicts one of four rainfall categories (*no*, *little*, *medium*, or *high rainfall*) in different locations in the catchment. These predictions are given as input along with sensor measurement of flow, level, and volumes in storage basins to a gradient boosting model (from the LightGBM Python package), which provides the flow forecasts. The hyperparameters in the gradient boosting model were tuned using the Azure ML Studio through the Python SDK with the random sampling strategy. Table 4 shows the hyperparameters that were tuned and the distributions the values for each hyperparameter were sampled from. These ranges were selected because past experiments had shown that hyperparameters in these ranges resulted in the best prediction performance.

When using weather radar observations and now-casts, the traditional model chain comprises the Marshall-Palmer relation for translating radar reflectivity to rain intensity, bias correction of radar rainfall using rain gauge data, rainfall-runoff modeling, and hydrodynamic modeling of the sewer system for flow prediction.

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Table 4: Specification of hyperparameter sampling distributions used for training the gradient boosting model.

Hyperparameter	Distribution sampled from	Range sampled from
Number of leaves	Quantized uniform	40 to 120 in steps of 10
Maximum depth	Quantized uniform	20 to 80 in steps of 10
Learning rate	Uniform	0.005 to 0.1
Number of estimators	Quantized uniform	100 to 200 in steps of 20
Subsample for bin	Quantized uniform	150000 to 300000 in steps of 10000
Minimum split gain	Uniform	0.005 to 0.055
Minimum child weight	Uniform	0.001 to 0.01
Subsample proportion	Uniform	0.55 to 0.95
Column sample by tree	Uniform	0.5 to 0.95
Regularization alpha	Uniform	0 to 0.5
Regularization lambda	Uniform	0 to 0.25

The data-driven modeling workflow described above provides various advantages over the traditional approach. Once the data-driven models have been trained, they can give predictions in real-time. The speed advantage of the ML routine, is typically reducing calculation time from hours to seconds. This speed allows for a multitude of predictions for a single time point, enabling variations on the input to the models to derive a probabilistic forecast representing the uncertainty contributed by uncertainty in the input data. Another advantage provided by the speed of predictions compared to traditional simulation approaches is that lead time of predictions is not decreased due to long simulation running times after weather radar data is received. An additional advantage of data-driven modeling is that a once a good modeling approach has been found, it is likely that the identified approach can be applied to similar problems with small effort apart from re-running training with data applicable to the new problem. In the current project, we have not addressed the uncertainty issues by using the probabilistic methodology. However, as part of the KPI reporting, forecasts are compared with actual measurements — in hindsight.

While data-driven modeling offers multiple advantages as described above, there are also disadvantages. For example, data-driven modeling is entirely dependent on availability of representative high-quality data. One possible way to circumvent this challenge in well understood physical problems is to simulate training data. Another difficulty with complex data-driven models is understanding why they make certain predictions. While it is still an active research area, various approaches to interpreting complex models have been proposed in the last decade. Additionally, data-driven models are only able to learn patterns present in

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the training data. This implies that changes to the physical system after the training data period are highly likely to negatively impact model performance. One way to mitigate this issue is to continuously compare predictions to observations with an automatic system that alerts users to increasing prediction errors. These basic principles for re-training have not been deployed and tested during the project. If and when major changes are implemented in the catchment, re-training can be done, using a combination of measurements and simulations. The advantage of using the hydrodynamic model, is that data can be produced for a range of events, without having to wait for extended periods, until the events happen in real.

8.2.3. Data requirements and transmission

All data for the ML and hydrodynamic models are provided from a central database, harvesting the sensor data from several different locations. The water levels and flows are retrieved from three different utilities every 5 minutes, and the data has typically a 1-minute resolution.

Weather radar data is retrieved from the Danish Meteorological Institute (DMI) and stored continuously in Azure blob storage as new data become available since DMI does not store this data. The retrieval is handled by an Azure Logic App. Rain gauge data is retrieved as needed from DMI through a Python script leveraging an executable made available for this purpose by DMI. If the supply of rainfall data fails, the ML and hydrodynamic models are unable to provide forecasts. An alarm is sent to DS12 and DS13, and when data again are available the forecasts will resume.

8.2.4. System integration

The flow forecast toolbox includes different elements. The two prime components are the ML engine and the MIKE+ (formerly known as MIKE URBAN) hydrodynamic simulation engine. Both engines are fed with primarily rainfall data, although the ML also is trained on more parameters. The MIKE+ engine, requires a calibrated model of the physical network. Additional smaller, yet important functions in the toolbox, are the data interface links between the external data sources and the engines. Both the engines and the services functions are implemented in separate executable modules. In the project content, the toolbox DS11 is integrated within the DSS (DS12). Being a separate module, it can be used in other frameworks, provided the necessary input data (rainfall data and hydraulic network model) are available in the prescribed formats. Radar data follows the standard format HDF5, (see https://en.wikipedia.org/wiki/Hierarchical_Data_Format, for example). Other required input file formats, are documented in details here: https://docs.mikepoweredbydhi.com/core_libraries/dfs/dfs-file-system/.

8.3. Added value and potential replication of the solution

8.3.1. Expected benefits

The goal of DS11 ("Improved machine learning (ML) sewer inflow forecast") is to enhance the performance and accuracy of the inflow forecast to the WWTP, so that control strategies

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between the utilities storage volume and BIOFOS' WWTP can be optimized to reduce bypass. Hence, the benefit or value is improved operations of the WWTP, expressed simply: the value is to provide better treatment of more water. These benefits will be scalable and applicable for other cities and utilities.

8.3.2. Site requirements and potential obstacles / drivers for replication

While the DS11 is a generic and adaptable module, there are a number of requirements that needs to be fulfilled to justify implementation. These includes relevant instrumentation, availability of operational devices/structures, and available retention storage, in order to justify implementation of inflow forecasts as an operational tool. A fundamental requirement for producing the inflow forecasts, is reliable rainfall forecast data, whether from radar or weather prediction models. The concentration time (time from the rain hits the surface till it reaches the WWTP) is typically quite limited (few hours), which underlines the need for forecasted rainfall values. The DS11 will primarily be relevant for combined sewer catchments, or for separate sewer systems with high rates of rainfall dependent inflow/infiltration. Apart from that, there are no further site requirements.

The immediate attraction for a utility to implement an inflow forecasting tool, may be challenges by organizational aspects in some cases, where the operations of the sewer network and the WWTP are managed in different departments depending on the individual goals.

A potential obstacle for running a real-time flow forecast in the cloud can be the running service costs involved. After running the models in the cloud for some time, it became visible that costs were considerable higher than expected. That means that alternatives to a cloud solution should be investigated and may become attractive.

8.3.3. Recommendations for successful implementation

The ML based inflow forecast routines depend on reliable timeseries of flows, levels, and rainfall for a preceding period, preferably for a minimum period of 2-years. The justification for the relative long period is to encounter for seasonal variations in groundwater infiltration, often a significant share of the total flow, and to secure that a number of rainfalls with varying intensities and depths are monitored. In lack of long-term timeseries for training, it is expected that shorter periods, like 3 months (under the assumptions a number of rain events occur), will still provide reasonable results. The preparation work of identifying the data, retrieving and quality checking, can be a laborious, tedious, and time-consuming process, which carefully need to be planned and executed in advance.

During the project implementation and first period of performance testing, some issues came up – that would suggest adjustments in dataflows both in the current and future applications. The real time mode, or process, is a chain of single, individual events. Starting with the radar sensor and ending with some flow rates for the forecasting period. In between, different sub-activities take place, like retrieving raw data from the met office, filtering and cropping the data set to fit the catchment size, and finally executing the engines, transforming expected

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rain to expected inflow. Each of the downstream processes depend on success from the upstream process, and we have assumed a stable execution throughout this chain of processes. In practice though, several disturbances occur, from power failure, stack overflow, machine overload, and other incidents, that interrupts the process flow, and in some cases require manual intervention to restart the system. A recommendation for future implementations, will be a thoroughly analyze possible outfall and define mitigating actions – to secure a continuous functionality. From the developers/supplier's side, we would likely also design the system slightly different, trying to lump some of the individual instances into a more integrated approach. However, we still believe that the concept has proven its value, the learning is a likely a leaner architecture.

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9. Interoperable decision support system and real-time control algorithms for stormwater management (DS12)

Factsheet	
General information IPR holder: DHI Main contact: Sten Lindberg (DHI) TRL improvement: 6 to 8 Target audience: sewer network and wastewater treatment plant operators	
Challenge The integrated management of the sewer network and the wastewater treatment plant (WWTP) is crucial to minimize sewer overflow emissions, WWTP bypasses, and pollutant loads emitted via the WWTP. To better control the filling and emptying of retention basins and treatment processes at the WWTP, forecasts of the inflow to the drainage system and the WWTP are required. However, inflow forecasts from more straightforward methods are typically highly uncertain and have relatively short forecast times.	
Description The Decision Support System (DSS) is an innovative tool for the sustainable operation of the integrated sewer network and wastewater treatment plant (WWTP). It is based on a series of level and flow sensors within the sewer network, WWTP operation data, and an accurate flow forecast at the inflow of the WWTP (solution 11).	
Benefits and added value The DSS has been fully implemented and tested in the catchment area Damhusåen in Copenhagen. Analysis for the reference year 2021 has shown that the real-time control solution saved 25% of sewer overflow volume and 20% of nitrogen emissions. Obtaining an equivalent effect through new storage volume at the WWTP would cost the utility around 75 M€ investments.	
Innovation The DSS provides a fully interoperable platform, including WWTP and sewer system data and models.	
Impacts The solution will be further used in Copenhagen to document BIOFOS’ compliance with the municipality concerning the actual discharge permit on annual nutrient discharge reduction and reduced bypass volumes. It will also be used to monitor the effects of the implemented control strategy continuously and, in case of decreasing effects, find the cause and evaluate other necessary measures to comply with the discharge permit, such as building more retention basins or, if possible making changes to the control strategy implemented in the catchment after a rain event.	

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9.1. Addressed challenge

Increasingly stringent environmental and economic regulations, constantly growing cities and the general need for adaptation to climate change put pressure on utilities to find new ways of optimizing the sewer system across its many shareholders. Integrated urban water management is imperative in this context to reduce adverse impacts on surface waters and minimize future investment costs. In particular, real-time control provides a range of alternative strategies for the integrated management of sewer networks and WWTPs.

The primary objective of DS12 is to assist the operators in better control of the wastewater treatment plant (WWTP). Using the results of DS11, solution DS12 ("DSS for real-time control of WWTP operations and in-sewer retention") screens two alternative control strategies of the sewer and drainage system, to identify the optimal strategy according to the following objectives, in priority order: (i) avoid flooding, (ii) avoid CSO, (iii) balance inflow to the WWTP. The limitation to two alternatives, can later be expanded to more scenarios, if desired by BIOFOS. The specific goal with DS12 is to optimize control strategies based on a more accurate and frequent flow forecast expected from the ML-model (DS11). Thereby it would be possible to reduce the amounts of false starts of 'dry/ wet weather' operation at the BIOFOS WWTP and to optimize the in-sewer storage under wet weather conditions.

9.2. Technical description of the solution

9.2.1. Type of solution

This solution is a decision support system, integrated with DS11 and DS13, all three working seamlessly in one modular software package. For the physical pipe network system, a limited number of control actions and strategies have been analyzed. The effects of these strategies were evaluated in a screening process, using the detailed hydraulic model. For implementation in the real-time system, two different controls were selected, one being a baseline, the second one being the strategy performing best in the screening process. The two alternatives are simulated in parallel together with the ML forecast; the DSS works as the execution environment for the DS11. Hence, DS12 enables the operators of the WWTP to evaluate the effects on the forecasted inflow rates, for the two pre-defined different operational strategies. User interaction and presentations related to the DSS takes place in the web interface (DS13).

9.2.2. Technical specifications

The DSS has been set up and tested for the Damhuså study site. The DSS functions as an execution environment for DS11 – the ML module and the hydrodynamic model running the two pre-defined scenarios. Rainfall forecast data from the weather radar is processed and provided to the hydrodynamic model, with new forecasts every 10 minutes, looking three hours ahead. This data flow is similar to how the ML routine (DS11) is updated.

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To enhance the operational stability and robustness in case of missing data, the hydrodynamic model is configured to work with different sources of rainfall data. In priority order the data sources are:

a) Radar data, hind-cast and forecast
b) Rain gauge data, hind-cast
c) Numerical weather prediction model for hind-cast and forecast

The DSS detects the data source availability automatically.

In addition to predicting the inflow to the treatment plant, the hydrodynamic model is also capable of predicting risks for overflow and flooding. Selected data from the simulations are extracted from the model, and displayed in DS13, to further support operators in the decision-making process. For comparison of the different methods the forecasts are compared in the DS13. For each of the forecast periods of 30, 60, 90 and 120 minutes, a diagram shows the forecast, including also the history from the past days. Further, the accuracy of the forecast is compared with the measurements, and KPI tables summarizes the accuracy of the forecasts. No further assessment of uncertainties and probabilities are included.

The 3 h radar forecast is provided by the Danish Met Office (DMI). The forecast principles are simple, numerical predictions, based on the past 3 h history. No further meteorological data are considered in the radar forecast. The radar forecast data are included in both the ML predictions and in the hydrodynamic prediction.

For longer rainfall prognoses, used to issue up to 36 h of forecasts, DS12 and DS13 retrieve data from a numerical weather prediction model managed by the Swedish Met Office (SMHI). These data are presented in DS13, and used to daily management of retention storages.

9.2.3. Data requirements and transmission

The data requirements for DS12 are very similar to DS11. The driving data sources are rainfall, from either radar, rain gauges or numerical weather predictions model (or a combination). The two different control strategies for the hydrodynamic model are predefined in the model setup file. Changes to the control strategies, including introduction of new strategies, require an update of the model input file, which is done in the modeling system. The DS12 monitors the continues flow of real time data, and when data is missing, the time and missing source is logged. Information about missing data and transmission failures are reported to the operators by a notification email, and the visual effect is that no forecasts are displayed in DS13.

9.2.4. System integration

The system integration of DS12 is fully integrated with the system integration of DS11.

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9.3. Added value and potential replication of the solution

9.3.1. Expected benefits

The DS12 provides the treatment plant operators with a tool to assist in improving the WWTP operation and to enhance the dialog and implementation of integrated control between the sewer system and the WWTP. The aim is to ensure the most optimal usage of the entire system. The solution helps to evaluate whether one control strategy is better than another with the final goal to make the best decisions to reduce bypasses of the WWTP and reduce pollutant loads to the receiving water body.

We expect that showing the effects of alternative operational set-ups will contribute to system understanding and make the possibilities of digitalization and model-based forecasting visible and understandable.

More precisely, the following benefits from the solution are expected which will be quantified with more precision throughout the demonstration:

- Reduction of bypass at the WWTP by ca. 20% by volume [m^3/year], which is a reduction of approximately 500,000 m^3 per year. The reduction is achieved by an enhanced integrated control between the WWTP and the catchment's basin volume, especially regarding the emptying of the retention basins as a function of the biological treatment capacity at the WWTP. CSO in the catchments and their respective requirements must not be compromised by this optimization, but remain status quo. There is no expectation that we reduce CSOs in the catchment.
- Reduction in total nitrogen discharge via bypass from the WWTP equivalent to ca. 12 tons/year. The average concentration of N in the bypass lies at ca. 24 mg N/L.
- Optimized rain-operation at the WWTP using a better flow forecast, that results in a reduced number of wrong start/stop of rain controls of approx. 50%.
- Optimization between sewer system and WWTP, thereby reducing the overall investment costs for the utilities in the order of 15 Mio. €. We approach the calculation by assuming that a reduction of 20% by-pass volume is equivalent to establishing a ca. 10,000 m^3 big basin at the WWTP, which will cost approx. 15 Mio. €.

9.3.2. Site requirements and potential obstacles / drivers for replication

The site requirements are very similar to DS11. The DSS can also be deployed and valuable if only one of the two forecast methods are implemented/available. If real-time data and a hydrodynamic model is available, the DSS can be configured with a relative minor effort. For larger systems, say more than 50 km^2 area, the model may be so large that simulations are too slow to produce forecast, in which case the much faster ML routine can be considered.

The attraction of using a hydrodynamic model, provided it runs fast enough to produce forecasts in due time for the operators to execute actions, is that it provides a complete picture of the flows and levels in the entire system. This is opposed to the ML, which only

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provides forecasts for one location, in this case for the inlet to the treatment plant. By supplementing the ML with a hydrodynamic model, the operators can evaluate the risks for overflow and even flooding before the events happen, although the actual mitigation options may be few, it at all possible.

The immediate attraction for a utility to implement an inflow forecast tool, may be challenges by organizational aspects in some cases, where the operations of the sewer network and the WWTP are managed in different departments depending on the individual goals.

9.3.3. Recommendations for successful implementation

As for DS11, the quality of the real-time data as well as stability in data flow are essentials. The data should be reliable and flow in a steady stream. If that is not the case, the utility should rather work on these issues before implementing a DSS system. One may argue, that the DSS can assist in detecting the flaws in the data, which may be correct, but then the expectations to the value of the DSS must be adjusted, the DSS will not produce reliable results until the input data are trustworthy. However, with a robust SCADA system and continuously validated data, a DSS may prove significant value to the operators. By including a hydrodynamic model, the operators can "see" the effects and consequences before they actually happen and adjust the controls to the more desirable situation. The hydrodynamic model running in real-time functions as a digital twin of the physical network, and allows for analysis of multiple scenarios in real-time, given that the model is not too large and too slow to run forecasts. For active control, a DSS may give value, if the physical system contains larger storage volumes and options for controlling and retaining the flow and volumes. Additionally, to on-board operational personal it is necessary to allocate time for training and regular follow ups.

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10. Web-platform for integrated sewer and wastewater treatment plant control (DS13)

Factsheet
General information <u>IPR holder:</u> DHI <u>Main contact:</u> Sten Lindberg (DHI) <u>TRL improvement:</u> 6 to 8 <u>Target audience:</u> planners, operators, and middle management of water utilities
Challenge The management of the urban water infrastructure is a complex multi-stakeholder mission. In many major cities, several operators manage different parts of the sewer network and the WWTPs. As a result, various utilities establish individual sewer management plans and control strategies, but they need a complete overview of the total sewer and WWTP behaviour and performance. The sharing of data and decisions between stakeholders is crucial at the urban scale to maximise the performance of the single infrastructures and manage the networks and WWTPs in a coordinated way.
Description The web-based tool Future City Flow (FCF) is an interoperable visualisation platform that provides data and analytics to all stakeholders responsible for the integrated management of sewer networks and wastewater treatment plants (WWTPs) in an urban area.
Benefits and added value The solution has shown so far to foster stakeholder engagement and rational decision-making using real-time data, modelling outcomes, and scenario analyses. All shareholders can download the processed data and integrate them into their control strategies based on the same data sources. Typical users for the platform will be planners, operators, and middle management of water utilities.
Innovation The platform enables the sharing and visualisation of data from sensors, models, and decision support systems. It integrates the system dynamics and facilitates real-time decision-making across all utilities, increasing preparedness for high-flow events.
Impacts This solution is expected to empower the collaboration between BIOFOS and sewer utilities in Copenhagen. More generally, the business case of DWC has illustrated the CAPEX savings achieved by implementing specific integrated control strategies between existing storage volumes in the catchment and the WWTP. Outcomes will support the future implementation of real-time control strategies in large cities. At the beginning of 2023, several utility managers will perform a usability test of the solution and its dashboard to highlight further improvement and adaptation needs.

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10.1. Addressed challenge

The management of the urban water infrastructure is a complex multi-stakeholder mission. In many major cities, several operators are in charge of managing different parts of the sewer network and the WWTPs. As a result, different utilities establish individual sewer management plans and control strategies but none of them has a complete overview of the total sewer and WWTP behavior and performance. The sharing of data and decisions between stakeholders is crucial at the urban scale in order to maximize the performance of the single infrastructures and manage the networks and WWTPs in a coordinated way. To overcome these gaps, a web platform for data collection, sharing and visualization among different urban water stakeholders (DS13) is developed.

10.2. Technical description of the solution

10.2.1. Type of solution

The solution DS13 ("Web-based prototype platform for decision support at city scale") is a web platform, enabling implementation, execution and visualization of DS11 and DS12. It provides a full overview of key data and processes to all involved stakeholders. The platform includes both a GIS-like overview, with selected timeseries and a dashboard with key data, e.g., on rainfall predictions, hydraulic capacity of sewer pipes and storage tanks as well as the status of treatment processes. The solution allows for stakeholder engagement and rational decision making based on real-time data, accurate modeling, and scenario analysis. Important in this context is the goal, that all shareholders can download the processed data and integrate them in their own control strategies based on the same data sources.

10.2.2. Technical specifications

The web platform is based on a generic platform, developed by DHI. The platform is called Future City Flow (FCF). In order to fit the requirements, the FCF has been modified. FCF is an Azure cloud-based solution, where the users have their individual logins, and personal data repository, all managed by Microsoft. The KPI reports are configured as Power-BI web tables.

Below are selected screen-shots (Figure 17 to Figure 24), showing the layout and functionality of the DS13.

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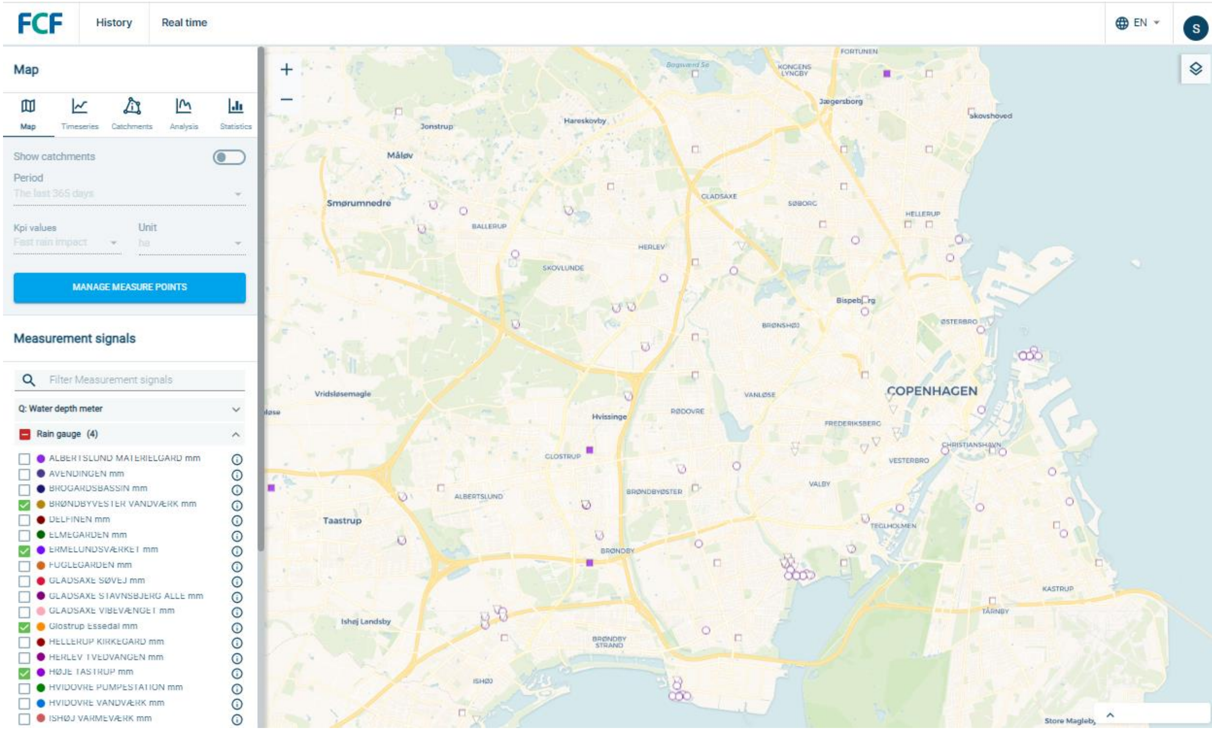

Figure 17: History View. Sensor location (flow, levels, rain gauges, water quality) for Greater Copenhagen. The features includes presentation and analysis of historical timeseries (up to the current moment).

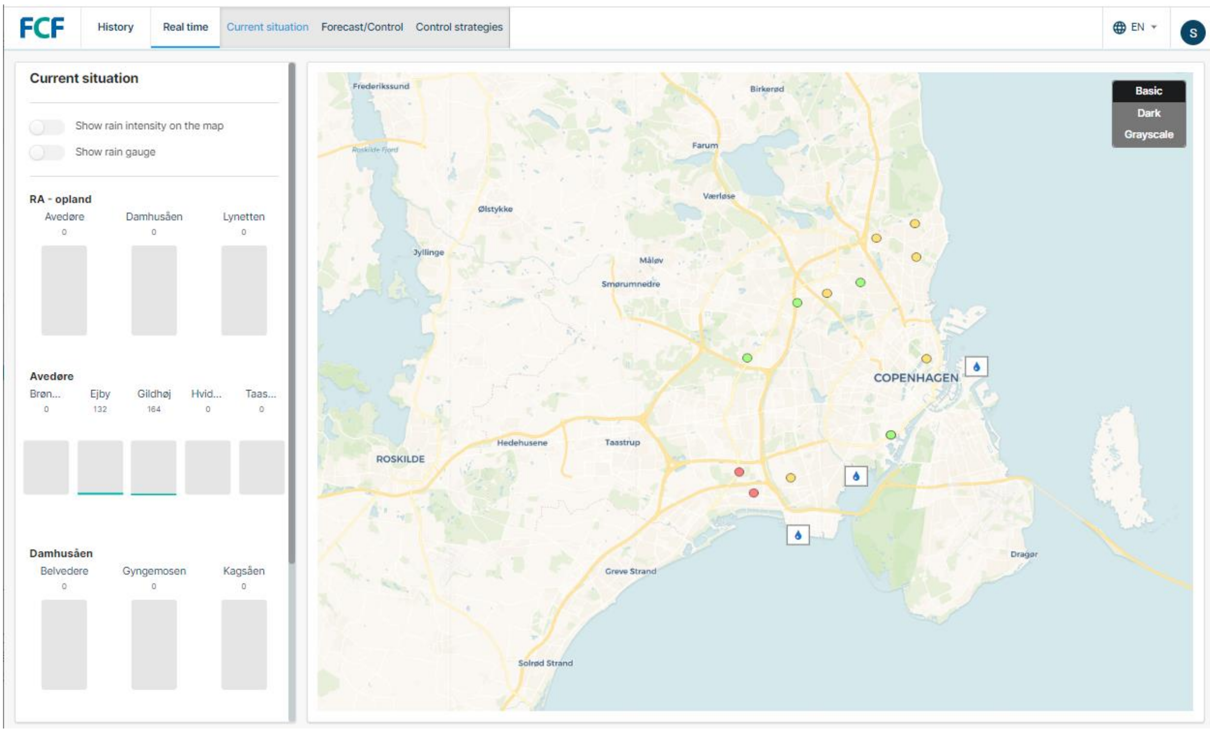

Figure 18: Real-time View. Current situation. Overview of actual fillings of all retention basins, as well as zoom-in features for looking at details for all three treatment plants

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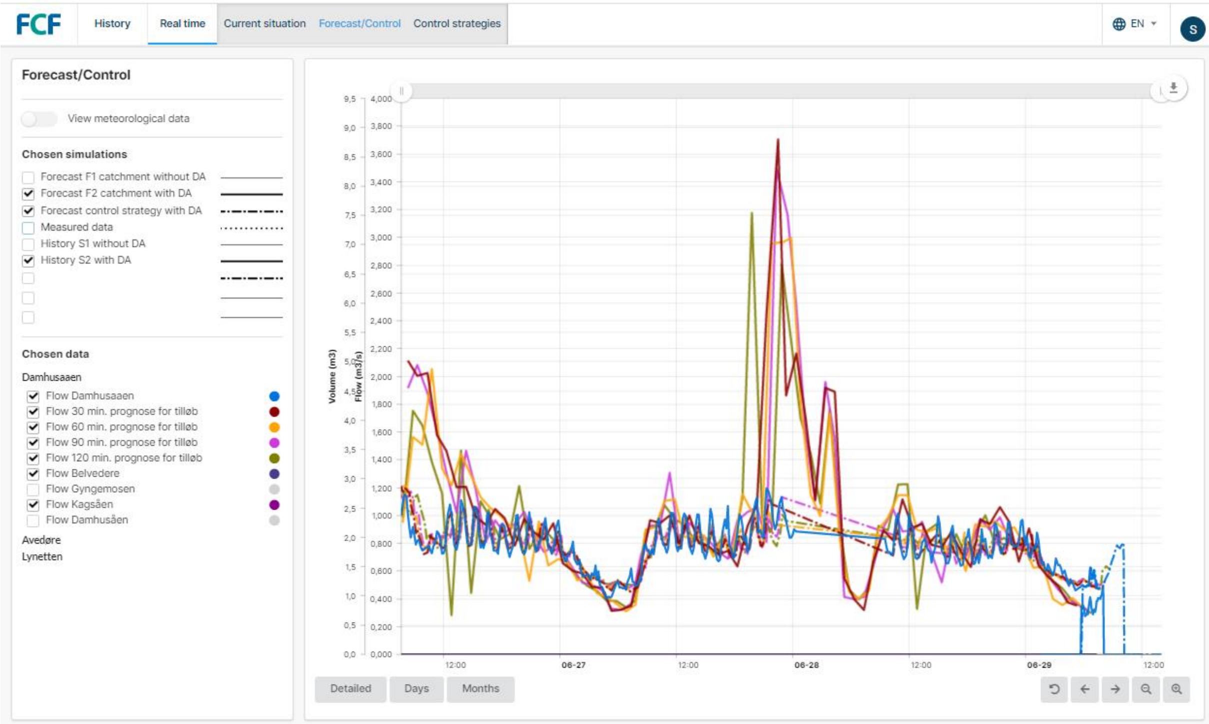

Figure 19: Real-time View. Forecast/Control. Visualization of inflow forecasts from ML and hydrodynamic models. Comparison of different forecasts periods, ranging from 30-120 min.

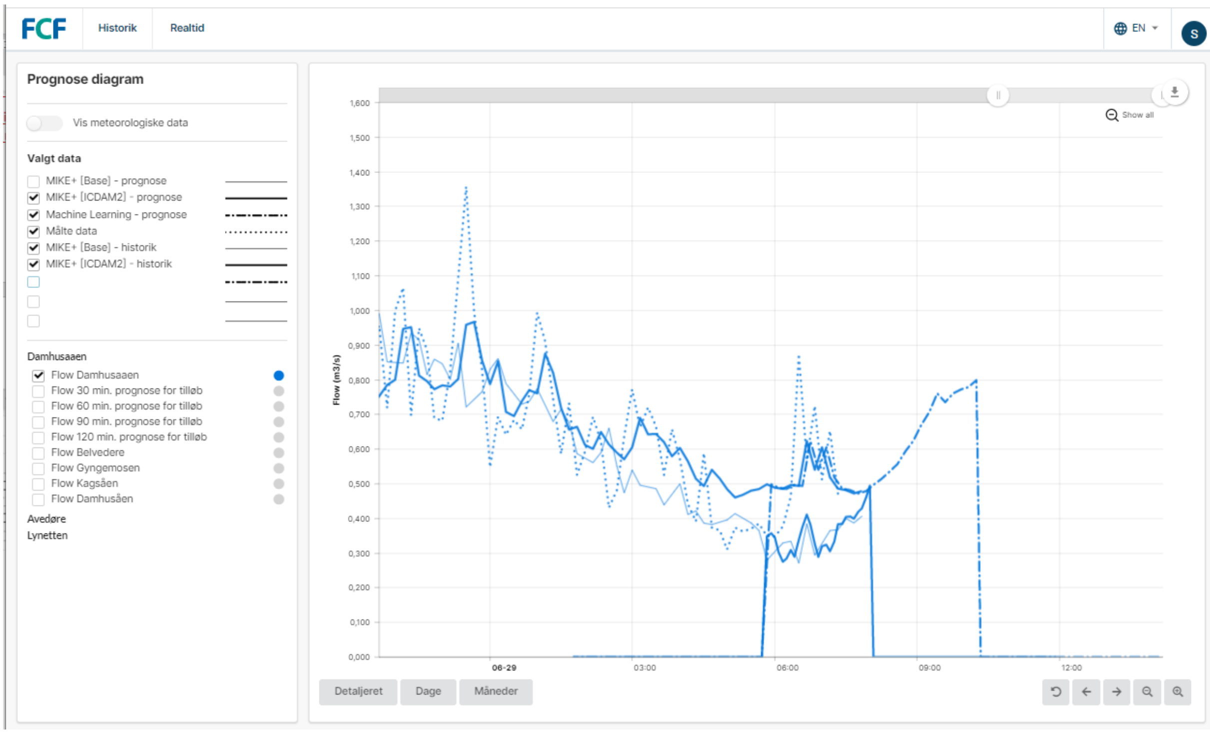

Figure 20: Real-time View. Forecast/Control. Latest forecasts and comparison of historical forecasts and measured inflow.

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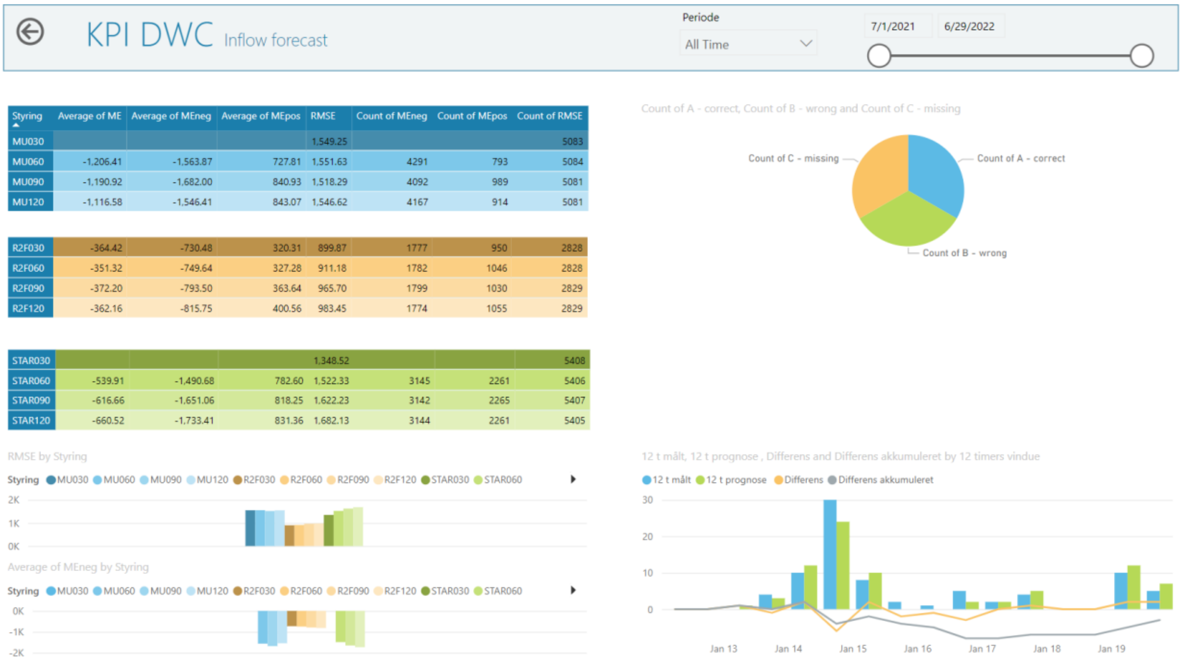
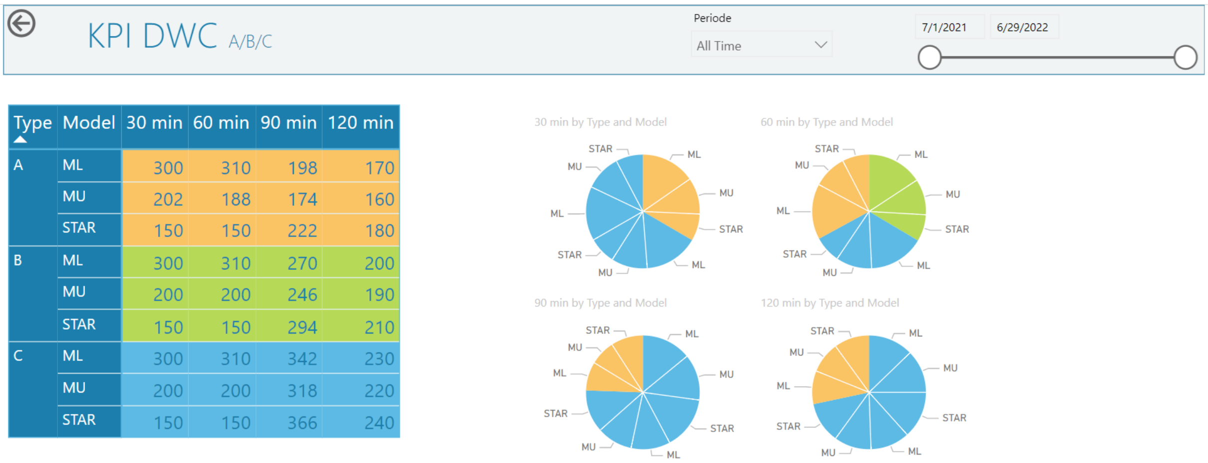


Styring	Average of ME	Average of MEneg	Average of MEpos	RMSE	Count of MEneg	Count of MEpos	Count of RMSE
MU030				1,549.25			5083
MU060	-1,206.41	-1,563.87	727.81	1,551.63	4291	793	5084
MU090	-1,190.92	-1,682.00	840.93	1,518.29	4092	989	5081
MU120	-1,116.58	-1,546.41	843.07	1,546.62	4167	914	5081
R2F030	-364.42	-730.48	320.31	899.87	1777	950	2828
R2F060	-351.32	-749.64	327.28	911.18	1782	1046	2828
R2F090	-372.20	-793.50	363.64	965.70	1799	1030	2829
R2F120	-362.16	-815.75	400.56	983.45	1774	1055	2829
STAR030				1,348.52			5408
STAR060	-539.91	-1,490.68	782.60	1,522.33	3145	2261	5406
STAR090	-616.66	-1,651.06	818.25	1,622.23	3142	2265	5407
STAR120	-660.52	-1,733.41	831.36	1,682.13	3144	2261	5405

Figure 21: Power-BI report. Presentation of forecasted inflow for the different forecast methods and forecast periods.



Type	Model	30 min	60 min	90 min	120 min
A	ML	300	310	198	170
	MU	202	188	174	160
	STAR	150	150	222	180
B	ML	300	310	270	200
	MU	200	200	246	190
	STAR	150	150	294	210
C	ML	300	310	342	230
	MU	200	200	318	220
	STAR	150	150	366	240

Figure 22: Power-BI report. Presentation of A/B/C categories for different forecasts methods and periods. A=forecast suggest change from dry to wet weather, and measured data confirm subsequently. B=Forecasts suggest change, measurements does not confirm. C=forecast do not show threshold exceedance, but measurements do. For full details, see section on KPI. Data not real, for illustration only.

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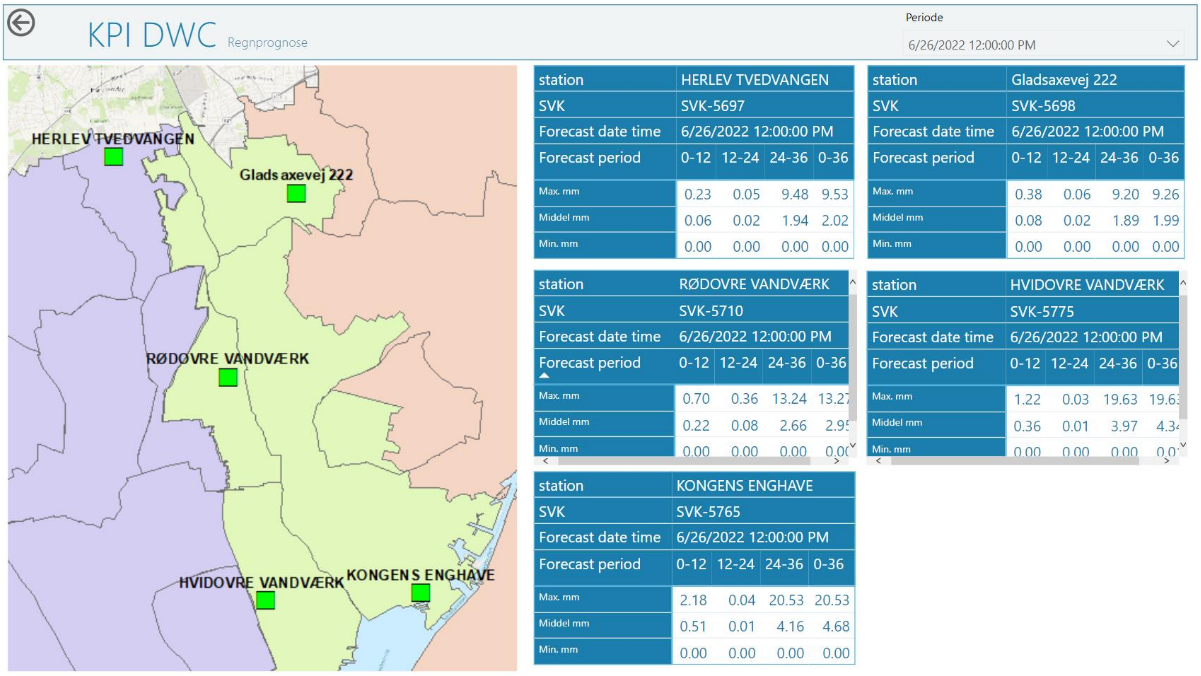

Figure 23: Power-BI report. Presentation of rainfall forecasts at 5 different locations within the catchment. The forecast supports the operations of the retention storages

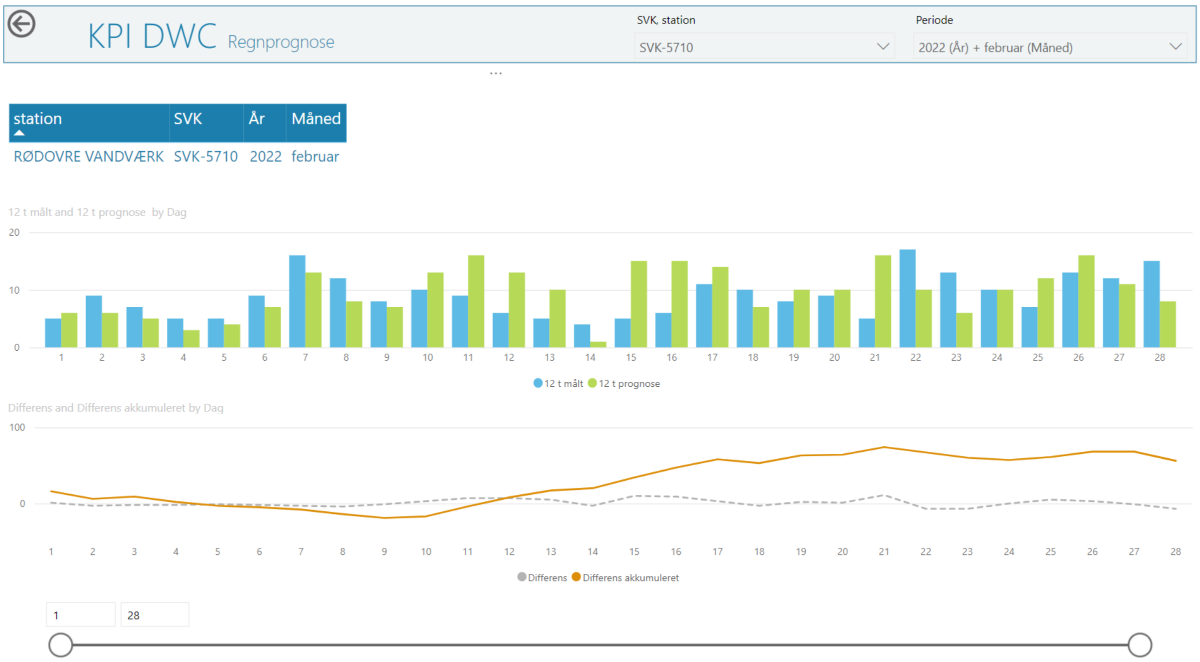

Figure 24: Power-BI report. For each of the 5 locations, comparison of forecasted and measured rain – and timeseries showing differences

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10.2.3. Data requirements and transmission

FCF is developed on the *MIKE OPERATIONS* DSS platform. The platform utilizes the PostgreSQL open-source database to store and manage multi-dimensional data and it includes built-in components for time-series data analysis and processing and plotting, two-dimensional data processing, analysis and mapping, as well as modules for managing scripts, tasks and jobs that are used to configure the system and automate the collection, processing and presentation of the data and modeling. The configuration tools and scripts are open and accessible for continuous and convenient development, improvement and expansion of the DSS. The hydrodynamic model is a MIKE+ model, and model execution are managed by DS12. Selected model results are retrieved and viewed in FCF.

10.2.4. System integration

The existing BIOFOS backend is expanded to include the forecasted data from the ML and MIKE+ models (DS11) as well as the met-office forecast data. Selected, relevant data are passed on to FCF, where further processing and visualization takes place. FCF runs on Azure, a cloud service provided by Microsoft.

10.3. Added value and potential replication of the solution

10.3.1. Expected benefits

By selecting the FCF platform for implementation of DS13, several inherent features become available and being a part of a larger community will give BIOFOS a better position for future maintenance and management of the system. Some of the inherent features support financial cost benefit analysis and real-time control — both of relevance for BIOFOS, as well as other future users. During the project DWC project period, other utilities have opted for FCF, and some of the DWC added features are already giving added values to other users. This includes time-series analysis features and some of the KPI reports.

The visualization and analysis of data in *one* place is a powerful communication tool for utilities and enhances system understanding across organizations and departments.

10.3.2. Site requirements and potential obstacles / drivers for replication

The requirements for using DS13 are flexible and vary with the overall aim. In its simplest deployment, FCF support visualization and analysis of measured time series, and it is full extent, if offers a efficient platform for operation decision support, including model forecasts, like implemented for Copenhagen. The platform is very scalable, so utilities may start with the simpler use, and gradually expand to the fully featured implementation.

Using an already developed and existing web-platform, lowers the costs for new users, wanting to deploy the same technology. With an existing community, and a maintenance/support apparatus in place, the risks are reduced. The possible downside, or obstacles for new utilities, may be that the used technology does not comply with whatever standards new users may have to stick to.

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10.3.3. Recommendations for successful implementation

A key for successful implementation and subsequent use, is a stable, well-working and proven back-end system, providing a steady stream of validated data. If that is in place, which often is much more challenging in real-life than it appears, a good and sound basis are available for implementation of both DS11, DS12 and DS13. Allocating enough training time for users is essential. Low-cost temperature sensors for real-time CSO and flood monitoring (DS14).

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11. Low-cost temperature sensors for real-time combined sewer overflow and flood monitoring (DS14)

Factsheet

General information

IPR holder: ICRA, IOTSENS
Main contact: Oriol Gutierrez (ICRA)
TRL improvement: 6 to 7
Target audience: sewer network operators

Challenge

Combined sewer overflows (CSOs) are a significant source of contaminants for receiving water bodies and can have various detrimental effects. Compliance with the Water Framework Directive (WFD) requires implementing CSO control measures and continuously upgrading sewer networks to avoid environmental contamination.

Description

This solution is based on deploying a network of innovative low-cost temperature sensors to estimate emissions from CSOs across many points in a sewer system. The sensors are installed at the overflow crest and measure air temperature during dry-weather conditions and water temperature when the overflow crest is submerged in case of a discharge. A CSO event and its duration can be detected by a shift in temperature.

Benefits and added value

The solution has been tested in two demo sites with 22 sensors in Sofia (Bulgaria) and 18 in Berlin (Germany). Experiments have shown that the measurement accuracy (in terms of occurrence and duration) is similar to traditional water level sensors. The solution provides significant CAPEX reductions of around 80% for offline sensors and 65% for online sensors compared to conventional water level sensors available in the market. OPEX savings could not be precisely assessed in the project, however, they are expected in the same order of magnitude as traditional water level sensors.

Innovation

The innovation resides in the simplicity and robustness of the method for CSO detection compared to traditional flow and water level measurement technologies.

Impacts

The solution deployment by ICRA can foster the implementation of European directives such as the Urban Wastewater Treatment Directive. Low-cost monitoring technologies are expected to increase the knowledge about sewer network behavior during storm events. The solution can be used to plan optimal sewer strategies at the city scale (better information on overflow locations and investment needs).

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11.1. Addressed challenge

The main type of sewer infrastructure in European cities is the combined sewer system: a single set of pipes that transports wastewater to the treatment plant while also draining excess rainwater to prevent flooding. In dry weather conditions, all water flows to the treatment plant to be treated before being released to the environment. However, when it rains heavily, the capacity of sewers is exceeded and the rainwater-wastewater mix gets released to the environment directly without proper treatment in an event called combined sewer overflow (CSO).

Traditionally there has been a lack of reliable tools and data about the occurrence of CSOs. Two of the main limitations are: i) the high number of CSO structures per municipality or catchment and ii) the high cost of the flow-monitoring equipment available on the market to measure CSOs, usually > 1500 € per equipped CSO structure. These limitations have become particularly relevant since recent regulations promote the appropriate monitoring of all CSO structures in order to control and avoid the detrimental effects and maintain a good ecological status of the receiving media[23]. To tackle the limitations stated above, a new low-cost method for detecting occurrence and duration of CSO is demonstrated in DWC project. The technology is based on the deployment of a network of innovative low-cost temperature sensors and data analytics to estimate emissions from combined sewer overflows in a large number of points in a sewer system.

11.2. Technical description of the solution

11.2.1. Type of solution

The solution consists of low-cost temperature sensors installed in specific locations of each CSO structure (**Fehler! Verweisquelle konnte nicht gefunden werden.**) that detect sewage discharge events via a drop in temperatures. The sensors are connected with a visualisation platform that allows monitoring what happens in each CSO point. The solution is able to monitor and send alarms from a high number of points, thus providing water utilities with crucial information of the performance of their sewer networks and detect critical contamination points.

[23] Updates of the EU Urban Waste Water Treatment Directive 91/271/EEC and the EU Water Framework Directive 2000/60/EC

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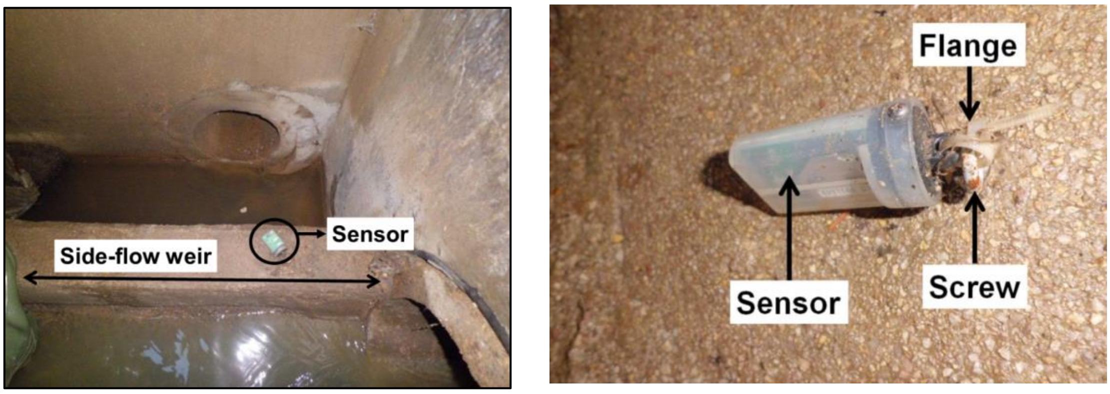

Figure 25: Monitoring setup for detecting CSO events with temperature measurements.

11.2.2. Technical specifications

DS14 is based on temperature measurements and on the principle that, in a CSO event, the temperature of wastewater discharged is significantly different than the ambient temperature in the sewer atmosphere. Thus, the strategic location of temperature sensors in overflow structures can efficiently detect the temperature changes and correlate them as discharging events (Figure 26). In case of dry weather, the sensor measures air phase, whereas in the case of CSO the discharged storm and wastewater is measured. The start and end of a CSO event can be determined via a drastic shift of measured temperature of the discharged wastewater.

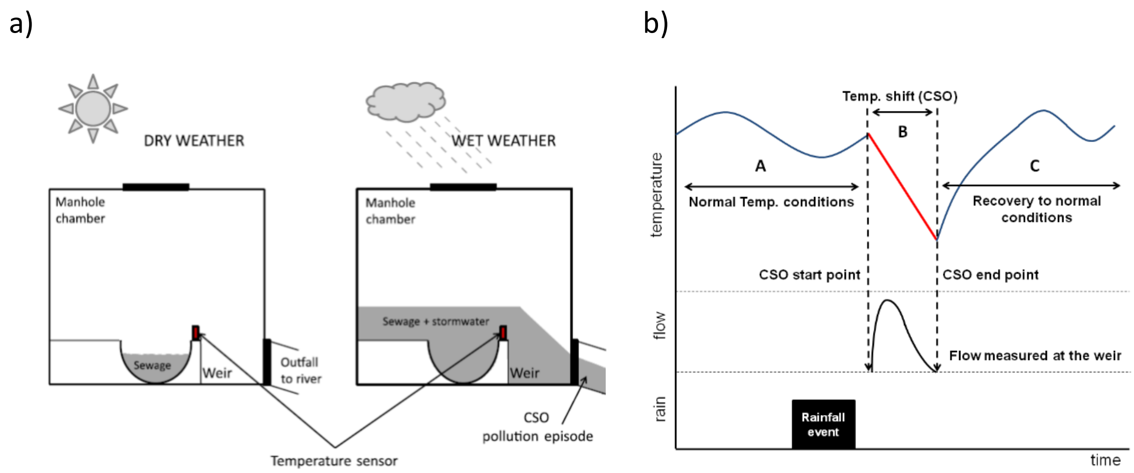

Figure 26: The principle of CSO detection with temperature measurements. a) location of sensor and water levels during dry and wet weather; b) observed temperature changes during a CSO event.

DS14 has two versions: offline and online. The offline version consists of two temperature loggers installed in the CSO point: one at the overflow crest which measures air temperature during dry-weather conditions and water temperature when the overflow crest is submerged in case of a discharge (Figure 26), and another logger constantly submerged into the main sewer channel which measures wastewater temperature. The combination of both temperature values is used for CSO detection by using an algorithm developed by ICRA. The offline sensors are very small (5 x 2 x 2 cm), reliable, cheap (~70 € per unit), and easy to install

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but require manual data retrieve every few months. They have a battery life of a minimum of 1.5 years and ingress protection index of 68[24]. Resolution and accuracy range are 0.14°C and ± 0.53°C respectively, operating in a range of -20°C to 50°C.

The online version consists of a real-time monitoring CSO device. It provides real-time overflow information and alarms of occurring overflow events. It can have up to three temperature loggers and also can incorporate a capacitive sensor (able to detect contact with water) and a level sensor to detect the height of the water column in the sewer. The online version is built with high-capacity Lithium-ion batteries to maximize its lifetime which is around two years, depending on the installation conditions, the number of sensors activated and the number of transmissions. Monitoring information is sent to the IoTsens platform either by GPRS M2M communication nodes or LoRaWAN, a low-energy consumption protocol which uses the EU868. In the platform, utilities can visualize the location and status of CSO points of their sewer network.

The architecture of the DS14 is presented in Figure 27. Based on a multi-tiered structure, data from offline and online sensors is collected, decoded, transferred, and stored to a database. Treatment of this data allows detecting CSO events which will then be shown in the visualization platform. The micro-services layer is the access point to the data, users, authentication, and authorization services. Finally, water utilities can access and incorporate this information into their systems using a 3rd party API that allows to extract and analyze data in the compatible format.

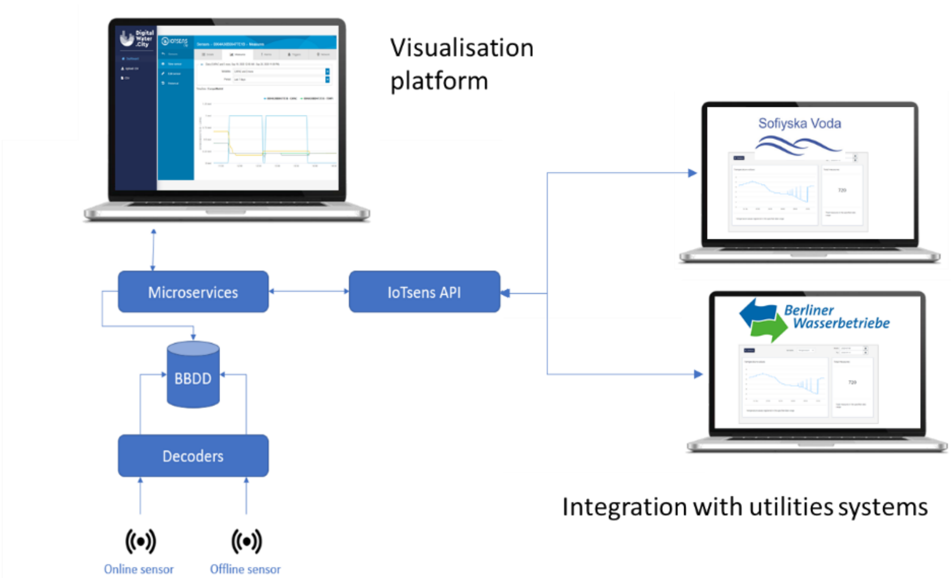

Figure 27: Architecture of the DS14.

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[24] Ingres Protection code international standards, resistant to harmful dust and immersion in water for more than 1 m.

11.2.3. Data requirements and transmission

The format used to exchange and communicate data is JavaScript Object Notation (JSON) schema. Transmission data is performed with LoRawan or GPRS communication protocol. These data is stored locally in the following formats: RDBMS (Micro services) and NoSQL (Elastic Search). The protocol to send data is HTTPS and MQTT with a data exchange pattern of one-way push. The utilities will receive processed data by REST API.

11.2.4. System integration

Utilities can integrate the solution via a REST API developed by IoTsens. DS14 does not provide direct integration with the SCADA systems, as the 3rd party API already allows access to data in compatible formats.

11.3. Added value and potential replication of the solution

11.3.1. Expected benefits

CSOs are a common problem in many cities worldwide and its inadequate monitoring has been around for a very long time. Despite its environmental impacts, there is a lack of affordable technologies to monitor occurrence and duration of CSOs. DS14 solution provides a simple, robust, and reasonably-priced method for CSO detection and duration. It reduces CAPEX and OPerating EXpanses (OPEX) for CSO monitoring and allows utilities to monitor their network extensively. DS14 benefits not only big cities with high budgets allocated to sewer surveillance but also smaller towns that face the same problems with fewer resources. Also, the solution can be especially useful to improve the accuracy of hydrodynamic sewer modeling by providing high spatial and temporal distribution of data for calibration.

Of course, the solution cannot quantify CSO volumes and so is not suitable for cities where CSO monitoring is mandatory to quantify pollutant emissions and associated fines for utilities. However, in any case the binary information can be used to gain spatially distributed information for model calibration allowing for more accurate emission estimations and scenario simulations. Further, the data can be used as an actuator in elaborate Real Time Control (RTC) strategies, e.g., for emptying storage tanks.

11.3.2. Site requirements and potential obstacles / drivers for replication

About replication obstacles, some cities/water utilities already have CSOs monitoring systems deployed. Those might be reluctant to change to DS14 while it does not outperform their current tools. Also, the current version of DS14 only provides information on the occurrence and duration of CSOs. Although this information is very relevant and complies with current regulations, some local/national policies could be stricter and ask also for volume and quality quantification. Another concern for water utilities is related to the installation and maintenance of the sensors as sewers are a harsh environment. Installation might indeed require an effort from the sewer field teams but once installed, the solution is designed to work steadily under sewer aggressive conditions, minimizing the maintenance and time of

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underground access. Finally, a common obstacle is the lack of budgets allocated for sewer monitoring, which is still the case in a considerable number of cities.

With regards to the drivers for replication, DS14 is very simple, cost-effective and robust. Thus, it is easy to replicate in a wide range of cities. CSO is a worldwide problem and there is a need to monitor CSOs both for environmental and legal reasons. In fact, within DWC the replication is already happening as Gruppo CAP from Milano is adopting DS14 solution in one of their sewer catchments.

In general, the solution can be of great support for any city with a combined sewer system with no further site requirements, given access to the overflow structures for sensor installation.

11.3.3. Recommendations for successful implementation

The most important point for a successful implementation of DS14 is to know the configuration of each CSO structure — including geographical location, type of overflow, dimensions, access to electricity, mobile reception for data transmission, etc. The major efforts would be then for the initial inspection of CSO structures, that will determine which is going to be the best combination of online-offline sensors to install in each network. DS14 concept is simple yet robust, therefore it is a highly flexible and easy solution to be implemented.

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12. Smart sewer cleaning system with HD camera and wireless communication (DS15)

Factsheet
General information <u>IPR holder:</u> IPEK <u>Main contact:</u> Martin Stümpfle (IPEK) <u>TRL improvement:</u> 9 to 9 (no improvement, only demo) <u>Main audience:</u> sewer cleaning and maintenance staff
Challenge Wastewater contains a variety of suspended solids and organic matter. When hydraulic conditions do not assure efficient transportation, sediments can accumulate in the network and diminish the hydraulic capacity of sewer pipes. Accumulated sediments are washed off during intense rainfalls and discharged to surface waters via combined sewer overflows (CSOs) and separate stormwater outlets. Utilities generally address the issue of sediments using reactive maintenance (sewers are cleaned after blockages occur) or regular sewer cleaning programs. This activity represents a significant expense for sewer operation and maintenance, and utilities need more solutions to support the planning of cost-effective programs.
Description The smart sewer cleaning system, called Xpection, combines a high-definition (HD) camera, a sewer-cleaning nozzle, and wireless communication technology.
Benefits and added value The solution exists on the market and is fully operational. It was tested in Berlin and Sofia in 2021 and 2022. It has proven to be a helpful additional tool for the cleaning teams in Sofia and Berlin. It was particularly useful for cleaning non-curricular pipe cross sections, where no other visual technology could be applied. It was a good assistant in finding hidden connections and manholes in small diameters, where the CCTV crawler could not be used.
Innovation The innovation lies in the smart combination of cleaning and CCTV surveying.
Impacts The uptake of the solution is expected to improve interoperability between cleaning and inspection teams and boosts the performance of sewer cleaning processes by saving time, fuel, and water compared to conventional cleaning processes.

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12.1. Addressed challenge

Wastewater contains a variety of suspended solids and organic matter. Under adverse flow conditions, sediments can accumulate in sewer pipes and diminish their hydraulic capacity. In case of intense rainfalls, blockages can cause flooding and severe damages at buildings. In England, about 75% of sewerage-derived flooding each year is due to blockages occurring in the sewer network (Arthur et al., 2009[25]). In addition to flooding, accumulated sediments which are re-suspended in case of intense rainfalls lead to pollution of surface waters when discharged via stormwater outlets of the separate sewer system or via CSOs. Furthermore, sediments in the sewer network are also responsible for H_2S gas formation, leading to unpleasant odors and corrosion and, as a consequence, to customer complaints and damages in the sewer infrastructure.

The issue of sediments is generally addressed by utilities by means of reactive maintenance (sewers are cleaned after blockages occur) or regular sewer cleaning programs. This activity represents a major expense for sewer operation and maintenance, and utilities lack solutions to support planning of cost-effective programs. Further, cleaning is usually done blindly, i.e., separated from the inspection process, which leads to unknown and often unsatisfactory cleaning efficiency. This lack of coordination between cleaning and inspections hampers operational performance and leads to high associated costs.

12.2. Technical description of the solution

12.2.1. Type of solution

The digital solution "Smart sewer cleaning system with HD camera and wireless communication" (DS15) addresses these challenges by combining a nozzle for sewer cleaning with an integrated digital High Definition (HD) camera. The HD camera transmits the video signal from the nozzle to the inspector's tablet by wireless connection. By that, the cleaning process can be continuously monitored and flushing results can be verified. The technology is deployed at a high-pressure sewer cleaning truck and it is expected to:

- Clean sewer pipes,
- Perform a live-control of the quality of the cleaning process,
- Detect major pipe defects, and
- Make a selection of sewer pipes that need a precise robot-camera inspection.

Figure 28 shows the device for smart sewer cleaning in operation.

[25] Arthur, S., Crow, H., Pedezert, L., & Karikas, N. (2009). The holistic prioritisation of proactive sewer maintenance. Water Science and Technology, 59(7), 1385–1396. doi:10.2166/wst.2009.134

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Figure 28: An iPEK XPECTION device for smart sewer cleaning.

12.2.2. Technical specifications

The smart sewer cleaning system consists of three components:

- the cleaning nozzle,
- the inspection camera and a
- control panel for visualization.

The **cleaning nozzle** has a maximum pressure of 350 bar and a flow rate between 60 and 500 L/min. It is connected to the hose of the cleaning truck via a 1”-BSPP-connection (British Standard Parallel Pipe). It has a weight of approx. 2 kg and dimensions of 150 mm (diameter) x 300 mm (length). It can be used for pipe diameters from DN 200 to DN1000.

The **inspection camera** has a resolution of 1080p or 1400p and a 124° (diagonal) angle of view. The entire video is recorded in HD quality in MP4-format. Video transmission can be done via Wi-Fi (wireless) or USB connection. Even under difficult reception conditions of the live video signal the entire video will be stored, so that no data of the previous cleaning process will be lost. It has 12 LEDs with ~ 1000 lumens cumulative. The material is stainless steel, aluminium and polypropylene. The camera has a weight of 1.13 kg and dimensions of 76 mm (diameter) x 186 mm (length).

The **control panel** includes a tablet / fieldbook with storage capacity of 64GB, a display resolution of 1080 x 1400 pixel and an 8-hour lithium-ion battery. It is equipped with the iPEK/ SEWERLINK software.

12.2.3. Data requirements and transmission

The XPECTION system features a wireless live transmission of video pictures from the cleaning nozzle to the control panel in HD quality. Also, download via USB stick or external drive is possible. The patented digital radio transmission technology is bi-directional and thus also enables the control of, e.g., camera and light functions comfortably through the control panel.

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12.2.4. System integration

The technology will be deployed at a standard high-pressure sewer cleaning truck. It can be used with any jetting machine or truck at a flow rate from 60 to 500 L/min and 150 to 330 bar pressure. Users will obtain a training from iPEK sales partners.

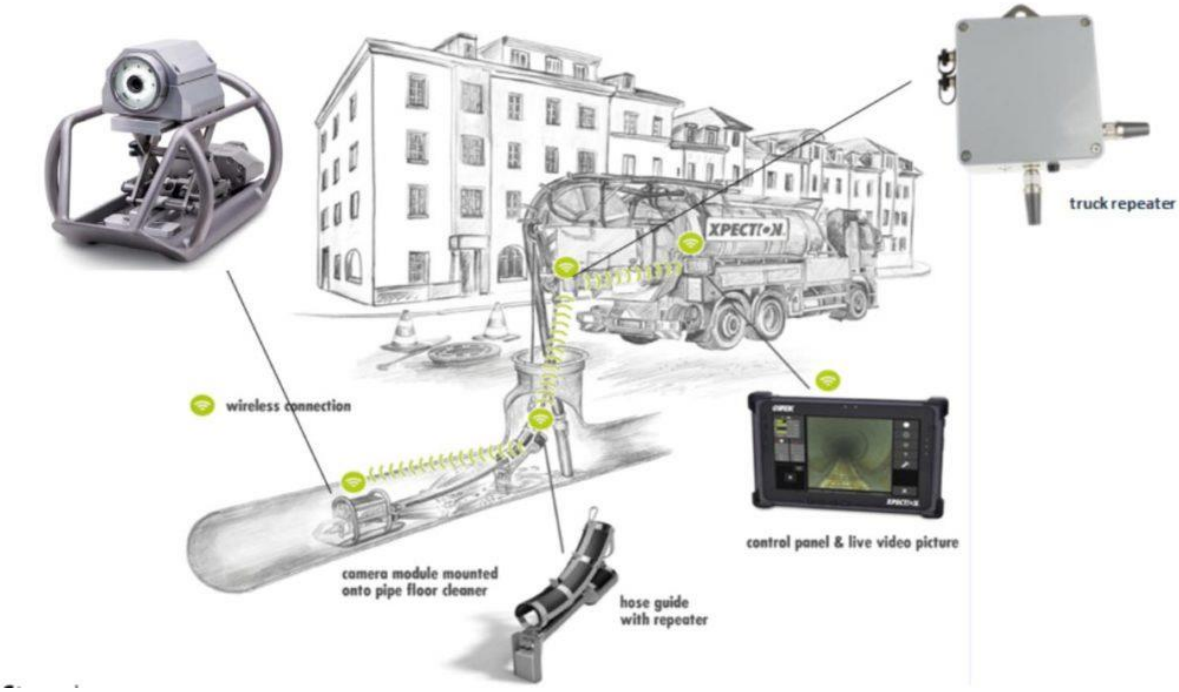

Figure 29: Setup of the XPECTION technology mounted to a cleaning truck.

12.3. Added value and potential replication of the solution

12.3.1. Expected benefits

XPECTION increases the performance of the sewer cleaning process by making more efficient use of time, fuel and water. As the operator can see the condition of the pipe during the cleaning procedure, they can identify cleaning needs, immediately analyze the efficiency of the cleaning procedure and communicate repair needs to the team in charge. Water pressure and cleaning speed, and hence energy consumption, can be adjusted during the cleaning process depending on the degree of pollution and the pipe condition. The combination of proactive cleaning and CCTV surveying will allow for a better allocation of resources engaged in sewer operation. Operators engaged in the control of sewer cleaning efficiency with a quick-view camera would no longer be needed for this task and could be allocated to other priority tasks.

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12.3.2. Site requirements and potential obstacles / drivers for replication

The solution can be deployed in any sewer network and applied to pipes with diameters from 200 to 1000 mm, given that the utility disposes of trucks for sewer cleaning. Apart from that, there are no further site requirements.

As with any new technique, end-users will have to adapt to the new technique. However, it is designed to be used without long special trainings. Especially in cities with large and flat sewer systems which are often subject to sedimentation and blockages, the benefits in saving water and energy can be very high.

12.3.3. Recommendations for successful implementation

No special recommendations are given. The solution is already in practice in the cities of Berlin, Erfurt, Ulm, München, Vienna, Luxembourg and New York, among others.

However, we recommend that the work with the equipment be performed under the supervision of a technically literate person. The same goes for draining videos from the device.

Furthermore, There may be interference with the video signal, with sewers with curves, and also with long sections without an inspection manhole between them. Nevertheless, the appropriate type of curves, as well as lengths of sections can be easily determined by practice.

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