IMPLEMENTATION PLAN

Implementation plan of each digital solution and methodology for quantification of the benefits provided by digitization (DWC-WP2)

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Abstract	The Implementation Plan (D2.1) is a document, which outlines how and where different digital solutions for water infrastructures will be demonstrated and assessed in the scope of WP2 of the DWC project. It is the first of three deliverables and followed by demonstration and assessment of performance and return of investment by means of key performance indicators (KPI) also defined in this deliverable.

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

Versioning and contribution history

Version*	Date	Modified by	Modification reasons
D1	Nov. 2019	WP2 partners	Draft versions of selected sections of the report
R1	Jan. 2020	Mathias Riechel (KWB)	Feedback for D1 sent back to task leaders
D2	2020-03-30	WP2 partners	Draft versions of all report chapters
R2	2020-04-24	Mathias Riechel (KWB) and WP2 task leaders	Feedback for D2 sent back to task leaders
D3	2020-05-14	WP2 partners	Full revised versions of all report chapters
D4	2020-05-18	Mathias Riechel (KWB)	Merged all chapters into latest report template, adapted and supplemented text
S1	2020-05-29	Hella Schwarzmüller (KWB)	Final check of document; minor adaptations

* The version convention of the deliverables is described in the Project Management Handbook (D7.1). *D* for draft, *R* for draft following internal review, *S* for submitted to the EC and *V* for approved by the EC.

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Table of content

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List of figures

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List of tables

Glossary

COP - Communities of practice

CSO - Combined sewer overflow

DSS - Decision support system

DTS - Distribute Temperature Sensing

EC - Electrical conductivity

IC - Illicit connections

ICT - Information and communications technology

IUWM - Integrated urban water management

AIC - Advanced integrated control

KPI - Key performance indicator

ML - Machine learning

ORP - Oxidation reduction potential

RTC - Real-time control

TN – True negatives

TP – True positives

TRL - Technology readiness levels

UAV - Unmanned aerial vehicle

VRC - Variable rate controllers

VRT - Variable rate treatment

WWTP - Waste water treatment plant

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Executive summary

The present report summarises the approaches and methodologies developed to demonstrate ten different digital solutions for four different domains of the urban water system: drinking water wells, sewer networks, wastewater treatment and water reuse. It further outlines how the benefits of the different solutions, ranging from the minimisation of environmental impacts to the improvement of long-term management of infrastructure capital assets, will be quantified. The implementation Plan is the first of three deliverables of DWC-WP2 and is followed by a detailed description of the different technologies (draft version in M18, final version in M36) and a report on their assessed performance and return on investment (draft version in M30, final version in M42). More information on the digital solutions and on DWC can be found on the project homepage: www.digital-water.city.

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1. Introduction

European cities face different challenges to achieve sustainable management of urban water systems, e.g. the over-exploitation of surface water bodies 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 (WP2) of the DIGITAL-WATER.city (DWC) project, ten digital solutions are tested in four metropolitan areas and assessed regarding their potential to improve the performance and return on investment of water infrastructures. In general, a three-step procedure is followed:

1. In the *implementation phase*, the test of the solutions is prepared by selecting appropriate demo sites, planning the installation, operation and data transfer and defining roles, responsibilities and key performance indicators for assessing their benefits. In some cases, the solutions themselves are developed.
2. In the *demonstration phase,* the solutions are put into operation to solve real-world problems of the urban water cycle. Data on their performance and return on investment, e.g. their potential to minimise environmental impacts or improve long-term management of infrastructure capital assets, is collected.
3. In the *assessment phase*, the benefits of the different solutions are quantified by means of the defined key performance indicators. The results will help stakeholders of different cities to find suitable solutions for their problems and open up a broader market for the tested solutions.

The present report summarises the approaches and methodologies developed during the implementation phase and outlines how the demonstration and the assessment of the solutions will be realised. The report is structured along the ten digital solutions of work package 2, which are grouped to a total of six areas of application. Figure 1 shows the ten solutions, their demo cites and their respective report chapters.

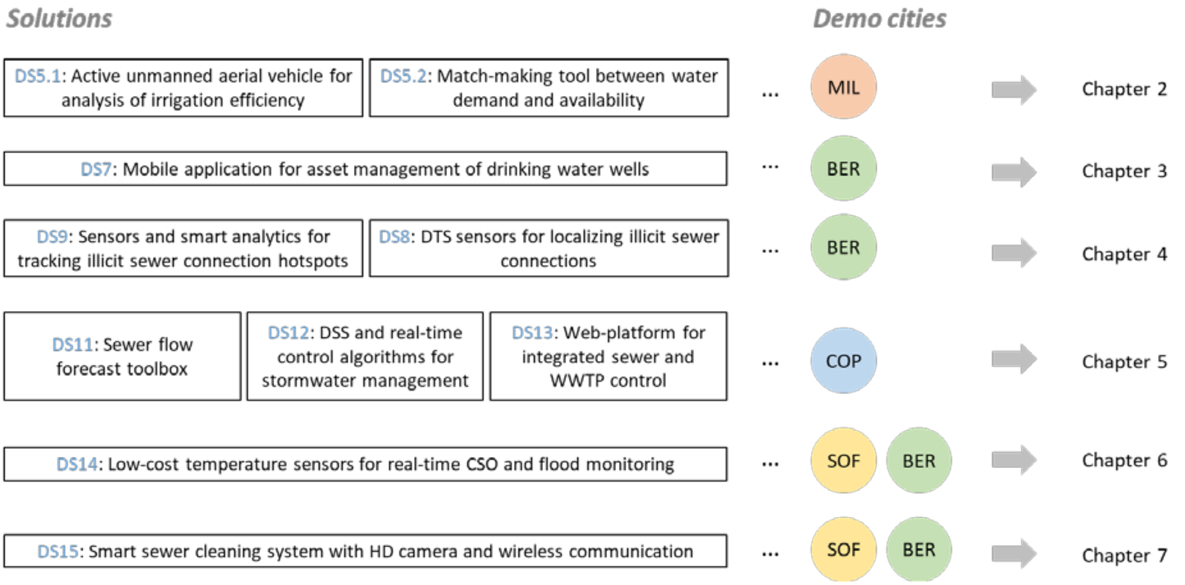

Figure 1. The ten digital solutions of DWC-WP2 with their respective demo cites and report chapters. The demo cites are abbreviated as follows: MIL - Milan, Italy; BER - Berlin, Germany; COP - Copenhagen, Denmark; SOF - Sofia, Bulgaria.

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In each of the six following chapters, background information on the proposed solution is given (subsection 1). Further, the demonstration site, the local issues and the current practice is described - the latter being the baseline for the assessment of the digital solution (subsection 2). After a brief description of the technology (subsection 3), the role of the demo partners (subsection 4) and the planned actions and their timeline (subsection 5) are outlined. Each chapter closes with a definition of key performance indicators (subsection 6), which will be used to quantify the benefits of the solutions (they may be slightly adapted during their quantification). Please note that the presented timelines are still subject to uncertainties due to COVID-19.

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2. Water stress monitoring and match-making tool for safe water reuse (DS5)

2.1. Background and proposed solutions

According to the European Agricultural Machinery Association, (CEMA), “Agriculture 4.0 paves the way for the next evolution of farming consisting of unmanned operations and autonomous decision systems”, while “Agriculture 5.0 will be based around robotics and (some form of) artificial intelligence”[1]. It is clear how agriculture is experiencing a “Copernican Revolution” where multi-disciplinarity is the engine of this revolution. In this context, the topic of Variable Rate Treatments (VRT) is central.

A VRT application relies on prescription maps that consider a spatially and temporally variable application of agrochemicals as fertilizers, pesticides, herbicides, etc. The rate is defined by the agronomist considering the local needs, e.g. of a fertilizer or weed treatment, instead of applying the same rate to all. Today agronomists generate these prescription maps considering their knowledge of a given field, augmented with data acquired by using advanced platforms as Unmanned Aerial Vehicles (UAVs) or satellites. Prescription maps are then executed by tractors using Variable Rate Controllers (VRCs) that apply a given quantity of product on a given region. The generation of correct prescription maps requires the definition of specific management zones that reflect areas and their status.

The application of fertilizers is not the only primary task to properly manage a crop. For a wide range of crops, an improved irrigation technique that minimizes evaporation and runoff is a key aspect to consider, too, in particular in regions with water scarcity. To manage water demand and supply, it is possible to implement a Variable Rate strategy according to irrigation prescription maps. Moreover, relevant management practices that impact the socio-economic context and by that result in water savings should be considered, e.g. awareness-raising, diffusion of best practices, regulations, pricing or financial incentives.

A key solution to reduce water stress in peri-urban agricultural areas is the reuse of the effluent water of a wastewater treatment plant (WWTP) for irrigation purposes. Water reuse is a promising technique, since it conserves freshwater resources and so tackles water scarcity, on the one hand. On the other hand, it allows to recover nutrients that would otherwise be emitted to receiving surface waters with associated ecological impairments. However, water reuse is also associated with potential risks for human health, related to the presence of pathogens and chemicals, although they can be largely limited by adopting effective treatment methods to remove them.

In recent years, the competition for water uses has increased (also in region rich of water). In combination with climate change, water scarcity phenomena have been experienced more recurrently than in the past. This is partly due to the limited flexibility of the irrigation systems —where water is conveyed by open, unlined channels and is applied on the fields using surface irrigation methods— which however are functional to the present economic structure and provide a number of additional and valuable functions (environmental, landscape, historical, recreational).

[1] CEMA (2017). Digital Farming: what does it really mean? https://www.cema-agri.org/images/publications/position-papers/CEMA_Digital_Farming_-_Agriculture_4.0__13_02_2017_0.pdf (last access Feb 2020)

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Increased water availability that can be obtained by reusing treated wastewater could help to mitigate some critical situations, but cannot be a game-changer unless it is accompanied by a coordinated rehabilitation of the irrigation infrastructure and innovations in the agricultural practices, e.g. the before-mentioned VRT concept that is also applicable to the irrigation case (this requires smart irrigation systems that could manage different irrigation schemes according to several measured agronomic variables used to generate prescription maps). Therefore, the main challenge in reusing water obtained from the sanitation will be to induce a change in the way of using water and nutrients and, possibly, in the selection of crops and in the economic structure of the farms.

Within the DWC project, two digital solutions are developed and demonstrated to investigate the wastewater reuse in peri-urban agricultural areas. The proposed solutions aim at i) monitoring online water demand and irrigation efficiency of the agricultural fields with novel remote sensors (DS5.1) and ii) optimizing the use of the treated wastewater for irrigation by matching the demand of water and nutrients of the farmers with the water availability and associated water quality at the WWTP (DS5.2).

The first digital solution named *Active unmanned aerial vehicle for analysis of irrigation efficiency* (DS5.1) wants to demonstrate the capability to optimize the irrigation efficiency of crops in peri-urban areas by re-using WWTP effluent. The use of aerial, satellite and ground technologies will support the development of strategies to evaluate how the re-used water could be applied into real agricultural scenarios with high efficiency. The (re)use of water will be in terms of quantity and quality from the point of view of farmers. The quality is mainly oriented to the contents of primary nutrients from WWTPs (nitrogen, phosphorus) reducing the necessity of farmers to make fertilization operations that consume energy (i.e. tractor fuel) and fertilizers, also considering the safe use of water (linked to other digital solutions developed in the DWC project, i.e. DS3: Early Warning System for safe reuse of treated wastewater for agricultural irrigation). The safety aspects will be taken into account by trying to link digital solutions DS3 and DS5.1. The quantity of water will be decided from the real needs of crop that will be calculated and monitored by using the technologies described in section 2.3.

DS5.1 provides a new method for remote detection of water stress by unmanned aerial vehicle (UAV) with multi spectral imagery combining ground, aerial and satellite data. The integration of UAV data and ground sensors plays a key role in the accurate and early assessment of water stress and the definition of prescription maps, especially at the district scale. At the same time, it is possible to detect if nutrient stress is affecting the crop by using algorithms that start from a set of spectral bands (in particular red-edge and near infrared) and put in evidence the differences.

The second digital solution linked to the topic of water-reuse in the agriculture domain is a *match-making tool between water demand for irrigation and safe water availability* (DS5.2). The current standard working procedures do not follow the precision farming approach yet, and there is a need of a smart promotion of the awareness and involvement of stakeholders in this safe and sustainable practice. The re-use of water from WWTPs represents a great opportunity to show how precision farming, and irrigation and nutrient management, can open new perspectives. The currently existing gap in putting in practice the above principles is the availability of a match-making tool (that will be designed and developed in DS5.2) able to find an optimum between the needs from end-users (i.e. farmers) in terms of quantity and quality and the capability of the WWTP.

The match-making tool will delineate a new scenario where the “new water” made available by the WWTP does not represent a mere addition of water available to the traditional structure, but a chance for establishing new opportunities.

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2.2. Demonstration site and current practice

The two digital solutions will be demonstrated at the WWTP of Peschiera Borromeo, located in the eastern part of the municipality of Milan, Italy, and surrounded by an agrarian context typical of the Lombardy Padana Plain. The agricultural fields in this area are mainly cultivated with fodder crops (especially maize) and irrigated using traditional techniques, mainly border irrigation, that require about 1.5-2 L s^{-1} ha^{-1} of average continuous flow over the agricultural season. Currently, the water for irrigation is diverted from rivers and distributed to the individual fields through a network of open unlined canals of different sizes, relying on gravity as the driving force. The scarce efficiency of water distribution on the fields is combined with significant losses in the distribution networks.

The irrigation canal network and the irrigation deliveries at the study site is managed by the irrigation consortium Est Ticino Villoresi, one of the most important irrigation consortia in Italy. The water for irrigation is supplied to the farmers under rotation. Although not yet severely affected by water scarcity, farmers were facing a decrease in water availability in the last decade, especially in the summer period, when the water needs of crop are high. In light of this concern, farmer associations, irrigation and reclamation consortia as well as regional authorities seem more than willing to exploit alternative water sources for irrigation, to complement or substitute the traditional one.

The experimental plot is located inside the WWTP area and is constituted by an artificial embankment, specifically built for the purpose, of 1,250 m^2 (25 m x 50 m, Figure 2). Soil characterization was performed through soil surveys and geognostic investigations. The former was carried out at six points and one depth (from 20 to 40 cm), and the latter was performed using the Geonics electromagnetometer profiler (to explore greater depths). The soil texture is sandy loam and the differences between the different sampling points are not significant. The electromagnetometer provides electrical conductivity maps (in mS/m) at different depths in accordance with the frequency settings. The electrical conductivity can be considered as a proxy of soil water content as well as a signal of the capacity of the soil to retain or drain water. The results show quite homogeneous soil characteristics in all explored horizons (from 5 cm to 6 m), except a small central portion of the plot (about 10 m^2) where the soil appears more retentive.

The plots will be cropped with maize and standard good agricultural practices will be applied. The plot will be divided in two parts (of 625 m^2) respectively irrigated by border and drip methods. The water for irrigation will originate from Line 2 of the WWTP and a new irrigation plant will be built specifically for the purpose of the project, including pump, filters, pipes and dripping lines. As already mentioned before, the border irrigation plot is representative of the common agricultural practices in the area, while drip irrigation is representative of the alternative practice that can be introduced in combination with the introduction of the digital solutions. In fact, drip irrigation is better suited to provide a timely and precise supply of water and nutrients to the crop, according to the indications provided by the match-making platform.

Sub-surface drip irrigation was also considered as an eligible solution, having distinct advantages in the elimination of any contact between water and the epigeal part of the plant, minimizing contamination risks. However, sub-surface drip irrigation is not suited for coarse soils, where water retention and capillary rise are limited. Given the special characteristics of the two experimental plots - that are located on an artificial embankment specially created to host them - it was decided to adopt traditional drip irrigation for the first year. The feasibility of shifting to subsurface drip during the second year will be evaluated based on the analysis of the monitoring data.

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Figure 2. Test site area inside the WWTP of Peschiera Borromeo.

2.3. Technology description

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

This digital solution consists of an unmanned aerial vehicle (UAV or drone), which is used to evaluate the status of crop that can be affected by nitrogen or water stress. The solution is complemented with other data acquisition techniques (ground sensors and satellite data) that ensure the capability to monitor larger areas. The use of remotely sensed data (visible, near infrared and thermal data) with ground sensors (probes and weather data) enables the capability to map the water (thermal data and moisture probes) and nutrient stress (using red-edge and near infrared images). The following subsections give further details on the digital solution and the complementing data acquisition techniques.

Aerial Data Acquisition:

The unmanned aerial vehicle (UAV) for analysis of irrigation efficiency and nutrient demand will be equipped with a multispectral camera that acquires images in the visible and near-infrared bands. The camera is also able to collect thermal data (e.g. Micasesen Altum is able to acquire 5 bands + thermal). Data will be acquired over relevant agronomic checkpoints and will be integrated with other sources as satellite and ground data (see below).

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Figure 3. Left: multispectral camera (5 bands (VIS-NIR) + 1 thermal + incident light sensor) - (image source micasense.com). Right: multi-rotor UAV with Altum camera.

Acquired data are a set of images that will be orthorectified and then calibrated by using custom software and other commercial tools (as. PIX4D) in order to evaluate the water stress.

The aerial data acquisition workflow will consist of the following main steps:

1. Plan the mission (deciding take-off and landing area considering also weather forecast and conditions)
2. Calibrate the camera (before the mission) by using a reflectance target board
3. Execute the mission (duration of mission will be no more than 5 mins)
4. Post-process data to generate orthorectified multi-spectral images (data will be shared on the cloud to see the acquired data over time).

This workflow (that corresponds to a flight/mission) will be executed several times a year according to the agronomic calendar. Weather conditions could affect the scheduling considering that flying in rainy and/or windy conditions is not allowed.

Data from multi-spectral sensor installed on board of UAV will be uploaded after the flight to a proprietary cloud service that will generate the final radiometrically and geometrically corrected orthophoto.

Risks associated to use this technology in the periurban area of Peschiera Borromeo and possible solutions are discussed in section 2.5.1.

Satellite Data Acquisition:

Satellite data is used to increase the feature set for the evaluation of nitrogen and water stress as well as the effectiveness of irrigation. We plan to use the following sources:

- Sentinel-2 (free service provided by ESA): 10/20/60m GSD, 12 bands (VIS-NIR-SWIR)
- Planet Scope (commercial service provided by Planet[2]): 3/3.5m GSD, 4 bands (R, G, B, NIR)
- RapidEye (commercial service provided by Planet): 5m GSD, 5 bands (R, G, B, RE, NIR)

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

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Where VIS means Visible, NIR means Near InfraRed, SWIR means Short Wave InfraRed, R, G and B mean red, green and blue channels and RE means RedEdge. Other satellites as Landsat-8 cannot be used due to low spatial resolution.

Data from satellites will be collected by using a dedicated application that runs on the cloud. This application periodically checks and fetches images over the study area.

Ground Data Acquisition:

Ground data acquisition is essential to establish a correlation with data collected by using UAV. In particular, the experimental plot will be equipped with the following devices:

1. Four soil water content probes are installed at two locations and two depths each to measure soil moisture in the crop rooted zone. The selected probe is a Frequency Domain Reflection (FDR) probe, with a tough metallic body, suitable for the plot's soil, which is rich in gravel.
2. A weather station comprehending sensors to measure air temperature, relative humidity, vapor pressure, wind speed, solar radiation, precipitation and other variables, in order to calculate reference evapotranspiration and hence crop's water needs.
3. Four piezometric wells equipped with pressure transducers to evaluate the effect of irrigation on the groundwater table.
4. Field water level sensors (only the border irrigated plot: for further information please refer to section 2.2) located in four points of the field.
5. Porous cups installed at two depths to allow soil water sampling in order to evaluate the microbial contamination and the nutrient content in the circulating solution.

Data from these sensors (except for piezometers) will be collected by dataloggers connected to the internet. Weather and soil moisture content data will be available in the producer proprietary cloud. Groundwater depth data will be manually downloaded and, together with other data, sent to the CAP cloud to be accessed at any time by the project partners.

Data management and integration:

All data will be uploaded to a cloud service that will be used as a repository, where raw and processed data are stored, also as maps.

Data from the different sources will be coupled and used for the match-making tool that gives online-information on water and nutrient demand at the field and availability at the WWTP (see DS5.2, below). Satellite data will be processed following the approach described in Mancini et al. (2019)[3]. Aerial data will generate a geo-referenced orthophoto that overlaps with the satellite data, but is of course characterized by a higher resolution. Ground data will be used to monitor the water content in the soil and owing to these data it will be possible to establish a correlation with remotely sensed data.

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[3] A. Mancini, E. Frontoni and P. Zingaretti, "Satellite and UAV data for Precision Agriculture Applications," 2019, *2019 International Conference on Unmanned Aircraft Systems (ICUAS)*, Atlanta, GA, USA, pp. 491-497, doi: 10.1109/ICUAS.2019.8797930

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2.3.2. Match-making tool between water demand for irrigation and safe water availability (DS5.2)

The current standard working procedures do not follow the precision farming approach yet, and there is a need of a smart promotion of the awareness and involvement of stakeholders in this safe and sustainable practice. The re-use of water from WWTPs represents a great opportunity to show how precision farming, and irrigation and nutrient management, can open new perspectives. The currently existing gap in putting in practice the above principles is the availability of a match-making tool (that will be designed and developed in DS5.2) able to find an optimum between the need from end-users (i.e. farmers) in terms of quantity and quality and the capability of the WWTP. The match-making tool, then, will delineate a new scenario where the “new water” made available by the WWTP does not represent a mere addition of water available to the traditional structure, but a chance for establishing new opportunities. In any case it is necessary to clarify the context of such tool.

The match-making platform is a web-based application to manage the demand of treated wastewater for agricultural irrigation. It is based on the assessment of irrigation needs using remote sensed data (DS5.1) and on the amount and quality of available reuse water (DS3). The tool will be tested by using simulated scenarios that reflect the surrounding area of the Peschiera Borromeo WWTP. Different farmers will be involved along the project even if dedicated irrigation networks from the WWTP are/will not be available. Testing of end-users will provide feedback to improve the tool that should not be “another app” but a useful way to improve the way end-users “consume” water with focus on re-used water. The stakeholders include farmers, farmers’ associations and irrigation consortia that, with different roles, are involved with the use and management of water for agriculture.

The agricultural area (irrigation district) where the WWTP could provide irrigation water has been preliminarily identified and information on crop and soils have been collected from existing regional data sources. Precise information on the current irrigation practices, including actual water use, must still be retrieved.

Well-structured information on the WWTP irrigation district (irrigation methods, crop types, soil characteristics, etc.), along with real-time information on amount and quality of available water, and estimations of water and nutrient requirements of the crops, will be useful for all of the following stakeholders:

- Farmers and more in general farmer’s associations, who will derive a support for irrigation and fertilization scheduling;
- Irrigation Consortia, who will use the information to manage the irrigation distribution network;
- WWTP manager, who will use the information to control the quality of the treated effluent in order to comply with the farmers’ requirements.

The Match Making Tool aims to:

1. Map the current situations in the WWTP surrounding area in terms of i) crop type, ii) soil type and iii) irrigation type, considering the practice to schedule irrigation (M1-M2.3), available local resources (S1-S4) and irrigation systems (T1-T7).
2. Estimate the real needs of end-users considering a basic set of information provided by the end-user; this could include local ground sensors, if available. Otherwise, the tool will rely on default values specified by the user or derived from regional databases and scientific literature.

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3. Collect information on drought, water or nutrient stress at end-user side.
4. Inform the end-users regarding the availability and quality of water from WWTP over times also suggesting the best slot to take water; the end-user will be in any case free to decide to take or not to take the water. Irrigation consortia could be engaged, if they are able to share information regarding the status of the irrigation networks.
5. Inform the end-users regarding the presence of a stress related to water / nutrients. This information could also be used to prioritize end-users over other ones, but as in point 3, the users are free to take their decision.

2.4. Role of partners

The development of digital solution DS5.1 (active unmanned aerial vehicle for analysis of irrigation efficiency) involves UNIMI, UNIVPM and CAP. UNIVPM will lead the acquisition of data by using Unmanned Aerial Vehicles. UNIMI designs the experimental plots and ground sensor monitoring system, coordinates cultivation operations, operates and validates the field-testing. UNIVPM and UNIMI will agree on a protocol to properly set-up and monitor the experimental test area. CAP will support UNIMI and UNIVPM for ground operations also providing operational support to enable the execution of planned activities.

The development of digital solution DS5.2 (Match making tool between water demand for irrigation and safe water availability) involves UNIMI, UNIVPM and CAP. UNIVPM and CAP will design and develop the match-making tool. UNIVPM and CAP collaborate to define rules of the decision support system to optimize wastewater treatment. UNIMI will cooperate with UNIVPM and CAP to integrate the ground data with the aerial ones on the identified test site. UNIMI and UNIVPM will agree on a protocol to properly set-up and monitor the experimental test area. In support of the ICT tool, UNIMI will develop soil-plant-atmosphere modelling. UNIMI will also cooperate with CAP and UNIVPM to test the match-making tool in simulated scenarios. In particular, the set of fields close to the WWTP will be considered as they could be future end-users to re-use the water for irrigation (WWTP irrigation district).

2.5. Actions and timeline

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

The active unmanned aerial vehicle for theanalysis of irrigation efficiency is tested in the Peschiera Borromeo site described in section 2.2. In this test area, agronomic operations are scheduled to manage the selected crop. All the technologies described in section 2.3.1 will be used.

The following figure represents the time schedule for the experimental setup and the agricultural operations:

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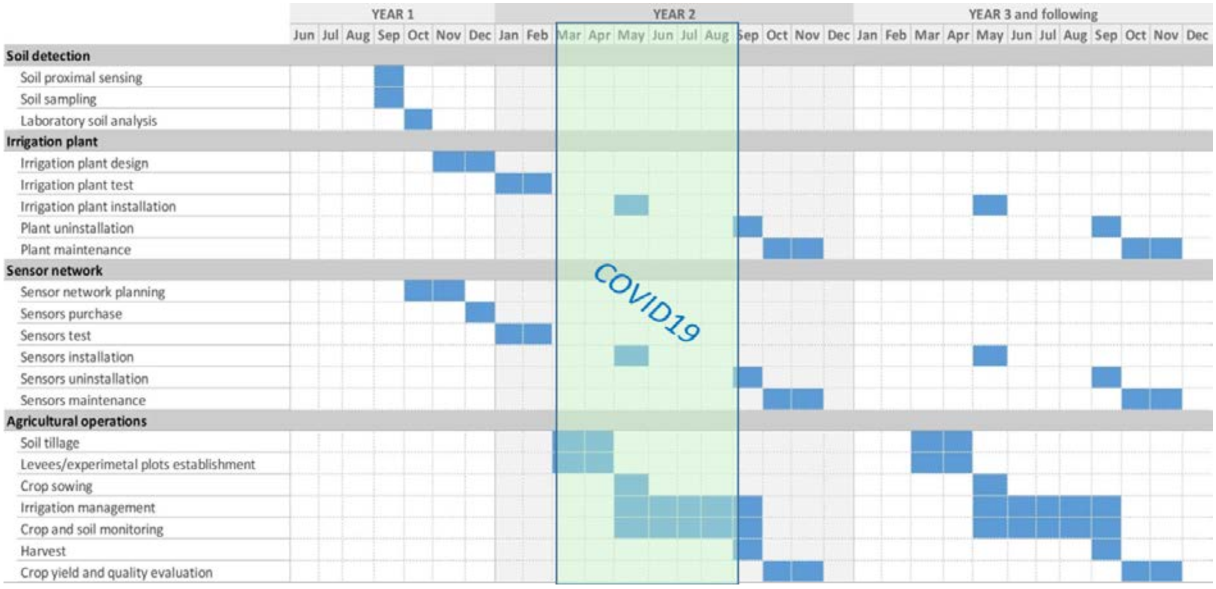

Figure 4. Gantt chart for the agronomic operation in the Peschiera Borremeo test site. The light green box highlights the period affected by the COVID19 lockdown; related activities are partially reprogrammed. Along with the described workflow, benefits and return on investment of the solution will be evaluated.

The flights with the unmanned aerial vehicle (UAV, as part of the sensor network) will be scheduled with a frequency that could change from 1 flight/ month to 2 flights/ month depending on weather condition and phenological stages.

The use of UAVs for commercial applications is actually regulated by each country. There are several working groups to regulate the use of UAV in critical and non-critical areas and also in so-called "Beyond Line of Sight" (BLOS) scenarios. Flight of UAVs will be evaluated by the Italian Civil Aviation Authority (ENAC)[4]. Flights in the Peschiera Borromeo test site must be authorized by the ENAC considering the proximity with the Linate International Airport (IATA: LIN, ICAO: LIML). There are options to mitigate the risks of a missed authorization by ENAC:

- fly by using a UAV with a radio-controlled flight terminator designed for critical areas;
- fly by using a UAV constrained with a cable;
- fly by using a blimp-like system;
- install the payload (camera) on a long-pole
- acquire UAV data in another test-site to validate the algorithms / models to evaluate the water stress starting from calibrated data.

In case of no authorization from the local agency, data will be acquired (at the same time) by:

- Using a pole system that can host a payload at 10-15m above the ground (this solution is applicable in the case of bad weather conditions or in case of denied flight authorization, Figure 5);

[4] https://www.enac.gov.it/en (last access May 2020)

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- Acquiring data with a similar experimental scheme at another test-site close to UNIVPM. This test site is located at Agugliano Experimental farm "Pasquale Rosati" (43°32'41"N, 13°21'50"E) belonging to the Polytechnic University of the Marche located in Agugliano, Italy (Figure 6).

Figure 5. Camera mounted pole-system up to 15m

Figure 6. Alternative Test site #1 - Agugliano - Italy (43.546211, 13.365541)

2.5.2. Match making tool between water demand for irrigation and safe water availability (DS5.2)

The match-making tool between water demand for irrigation and safe water availability (DS5.2) will be tested in the Peschiera Borromeo area as described in section 2.2. Monitoring data will be available for the experimental plots, while it will be possible to simulate other “virtual” fields with soil and crop characteristics typical of the area surrounding the WWTP. Trade associations will be involved in different forms (interviews, meetings, structured questionnaires), in order to discuss the current practices and to simulate scenarios with and without using the ICT match-making tool evaluating the results according to the identified KPIs.

The issue of water reuse involves different levels of stakeholders. In the study context, in fact, the great part of water for agriculture is managed by irrigation and reclamation consortia, which are responsible for providing the farmers with water for irrigation and for draining water from the fields. The activity of the irrigation and reclamation consortia is under the supervision of the Regional Authority, but it receives the inputs also from municipalities and farmers association.

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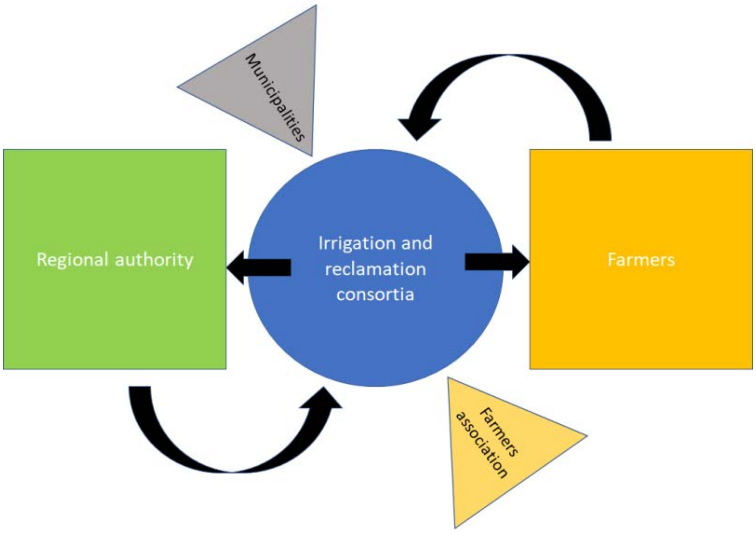

Figure 7. Involved stakeholders for a digitalized irrigation architecture

To involve the stakeholders, a three-level engagement will be adopted inviting: 1) stakeholders specifically involved in the case of the study area, 2) stakeholders greatly interested in water reuse, forming the local Community of Practice (CoP), and 3) stakeholders that are interested in water reuse, forming the enlarged Community of Practice (stakeholders, see Table 1) .

Table 1. Multi-level engagement of stakeholders as part of the community of practice (COP).

Level of engagement	Type of stakeholder	Role of stakeholder
first level	bodies operating in the area and which will benefit of water reuse	1. Est Ticino Villoresi irrigation consortium (ETV) which directly manages irrigation in the area 2. most representative farmers' associations (Coldiretti and Confagricoltura) and few selected farmers
second level	stakeholders that are not operating in the study area, but which are greatly interested in water reuse as an option to be introduced in other areas	1. ANBI Lombardia, the association representing all the Consortia of Lombardy 2. CdB Muzza Bassa Lodigiana, a Consortium operating in another portion of the area managed by CAP 3. Regional Authority in the specific areas of competences (Directorate General Agriculture - responsible of irrigation and reclamation consortia, Directorate General Territory - responsible for water quality and CAP Holding activities, and finally Directorate General for Local authorities, responsible for water diversion licenses) 4. Città Metropolitana of Milan, responsible for licensing domestic wastewater discharge 5. farmers organisations active in Lombardy (CIA, Coopagri)
third level	stakeholders that could be weakly interested in water reuse	1. Other Consortia of Lombardy and neighboring Regions 2. Parco Adda Sud, the authority managing the Regional protected area in southern part of Milan 3. The Municipalities of the study area.

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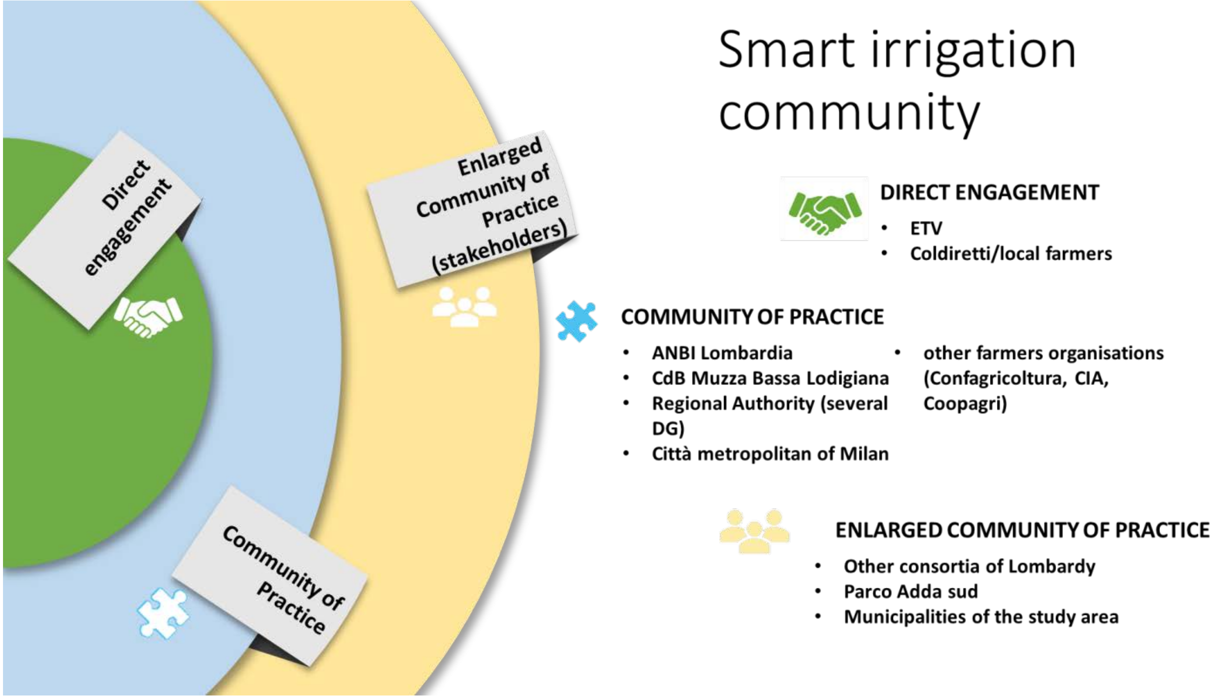
Stakeholder engangement will start with the two groups of the first level working separately. In a second step, they will jointly discuss and exchange. The community of practice will then be established involving the first two levels, and later be extended to the third.



2.6. Key performance indicators

The following table shows the key performance indicators (KPIs) defined to assess the benefits and return on investment for both digital solutions DS5.1 and DS5.2:

Table 2. Key performance indicators for DS5.1 and DS5.2

KPI	**Unit**	**Equation**	**Description**
DS5.1: Active unmanned aerial vehicle for analysis of irrigation efficiency			
Saved Fertilizer	%	NFW / NFF * 100	NFW means nutrients from re-used water over the season. NFF means nutrients from standard fertilizers over the season using a standard rate for the chosen crop.
Saved CO2	t/year	NFW*coeff - WWTP_CO2 *FDW	Saved CO2 is the difference of CO2 from saved fertilizer (by using a conversion factor coeff) by using re-used water from WWTP and the CO2 of the WWTP to supply the FDW - that is the field demand of water over a season. WWTP_CO2 is the amount of CO2 from the WWTP to output a m^3 of re-used water.

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KPI	Unit	Equation	Description
Seasonal Water Stress	Unitless	Field size, crop, bands (UAV/SAT), water stress index	The seasonal S_{idx} evaluates the water stress as weighted average over time. S_{idx} varies from 0 (maximum stress) to +1 (minimum stress). Weights are determined by the agronomists considering the crop and period (in some period drought is not a critical issue). This index is calculated by using a set of bands (*B_1…B_n)* and sensors (*S_1,…S_2*).
DS5.2: Match-making tool between water demand for irrigation and safe water availability			
Saved water	%	DW/OAW*100	Saved water by using match-making tool. The saved water is amount of water provided by WWTP drained by the farmer (DW) over the overall amount of water (OAW) that field requires over the overall season. *)*. The irrigation is controlled by using the matchmaking tool.
Seasonal Water Stress	Unitless	Field size, crop, bands (UAV/SAT), water stress index	The seasonal S_{idx} evaluates the water stress as weighted average over time. S_{idx} varies from 0 (maximum stress) to +1 (minimum stress). Weights are determined by the agronomists considering the crop and period (in some period drought is not a critical issue). This index is calculated by using a set of bands (*B_1…B_n)* and sensors (*S_1,…S_2*).

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3. Mobile application for asset management of drinking water wells (DS7)

3.1. Background and proposed solution

Berliner Wasserbetriebe (BWB) is operating about 650 groundwater abstraction wells and more than thousand observation wells. Together with another hundreds of observation wells owned by Berlin's water authority (SenUVK) they form the subsurface assets for drinking water production in Berlin.

Well data consist of static information such as design and construction as well as operational data such as current discharge rates, water levels, previous maintenance, and water quality data and are typically stored in well management database(s). However, in the field, paper format is still widely used to record monitoring and maintenance data and these work reports are later on transferred manually to the database(s). The provision of digital well information and work reports on site by a mobile device application will improve guidance and on-demand information for field workers and facilitate interactive flow of information enhancing performance and resource efficiency in monitoring and maintenance. On a strategic level, the planning of well rehabilitation and renewal can be improved by providing indicators on well condition derived from algorithms using available operational data and enabling data-driven decision making for well rehabilitation and renewal.

The envisioned digital solution comprises of two separate applications:

- A mobile application for the operation of drinking water wells which aims at improving business processes and data record management and thus providing BWB with a streamlined, more efficient flow of information (called ”Well diary”), and
- An asset management and reporting toolset (called ”well management app”) which aims at improving maintenance planning and decision making, ultimately leading to lower costs of operation and an improved status of the drinking water well network.

The proposed solutions take inspiration from 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,
- Preventive maintenance tasks or process replacement.

3.2. Demonstration site and current practice

In nine water works, BWB is operating approximately 650 wells in the Berlin Area, producing up to 1 million cubic meters of drinking water per day. Well operation is automated and controlled from the water works. In order to secure a reliable water supply 24 hours a day, the wells are regularly inspected and maintained. This includes laboratory analysis of well water quality, pumping tests to test well capacity, CCTV inspection for visual diagnosis, mechanical cleaning as well as chemical regeneration procedures to remove for example iron ochre deposits. More and more, wells are equipped with a set of sensors to monitor flow, water level and heads. Sensor equipment varies depending on site and age of the well installation.

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As iron ochre formation is unavoidable, well capacity decreases with time. However, well capacity decrease varies depending on well location, site-specific factors and also operating conditions[5]. Approximately every 5-7 years, each well is regenerated using mechanical or chemical cleaning. With an average age of 34 years, wells have reached the end of their service life and will be replaced by new wells. Scheduling of well maintenance and investment planning of well re-construction is done based on the results of pumping tests and the amount of raw water produced, but has to consider the availability of human and financial resources, too.

3.3. Technology description

3.3.1. Well diary

The proposed solution consists of a multi-faceted connection to currently available data pools that are managed through a core backend to provide process, data transformation and user management functionality. This backend is administered through a web interface. Mobile devices access data and services via a (web-)frontend that provides data, visualisation and trends on demand as well as on-site data validation for input records.

The exact amount of business processes and data to be included in the Well Diary will be specified prior to development and in discussion with the concerned operational units of BWB. On-site data to be recorded via the mobile app will include well-specific information on sensor installation, variable frequency drives and the according dynamic data. Centrally stored data, which will be made available via the mobile app in the field, include the time of construction and last rehabilitation date, pump type, last pumping test results as well as further operational data. In addition, information currently not available in digital form will be recorded and documented in the Well Diary, too. The planned data architecture of the Well Diary is shown in Figure 8.

3.3.1. Well management application

The proposed application offers information on the condition of drinking water abstraction wells regarding iron ochre formation and their capacity. Based on available data, key performance indicators for well condition will be developed and visualized to enable condition-based rehabilitation. This strategic planning tool will give decision support for investment and rehabilitation strategies. User requirements and specifics of the Well management application will be detailed in the first implementation phase and available in project month 18.

[5] Schwarzmüller, H. and Menz, C. (2013). WELLMA-2 Synthesis report, https://www.kompetenz-wasser.de/wp-content/uploads/2017/05/d_6_wellma-2_synthesis_report_v02.pdf

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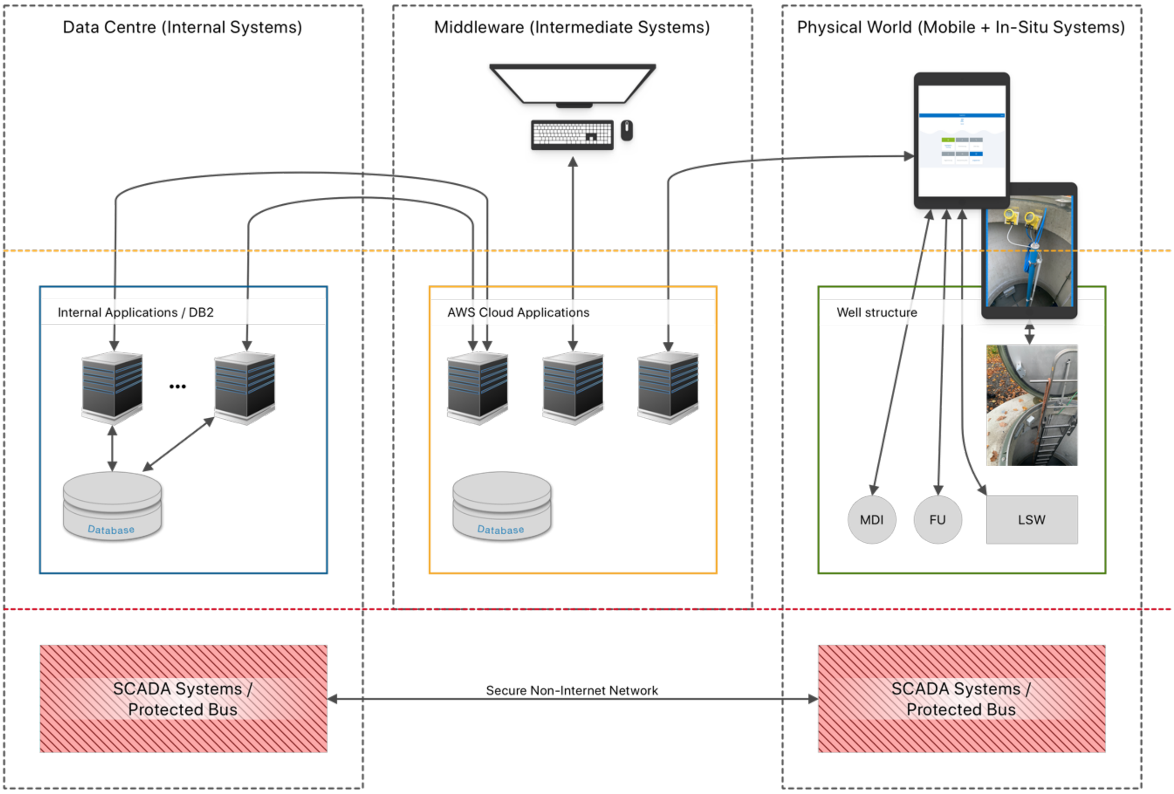

Figure 8: Planned data architecture for the Well Diary application

3.4. Role of partners, actions and timeline

Below, the roles of the partners with regards to defined tasks as well as the timeline for both solutions are described in more detail.

3.4.1. Well diary

Task 1 –Definition of requirements:

- BWB: data provision, evaluation of business processes and data requirements
- Vragments: assist in business process analysis, detailed user requirements definition
- KWB: definition of parameters and data analysis procedures to extract decision support

Task 2 – Development of software architecture, interfaces and suitable data formats:

- Vragments: (i) Compose requirements definition of services, interfaces and formats; (ii) Outline initial system architecture; (iii) Plan use of existing technologies and outline necessary adaptions or own development
- BWB: data provision; definition of formats and requirements
- KWB: setup of data management plan;

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Task 3 – Testing and implementation and application of service:

Three consecutive feedback loops are planned in which a prototype will be tested by future users and feedback is given to the developers. Based on this, an adapted and improved version of the prototype is developed.

- Vragments: (i) Integration of data sources, processing and provisioning; (ii) Implementation of messaging platform; (iii) facilitation of functional and performance tests with regards to the specifics of secure mobile communication, implementation of mobile app, data ingestion, mobile app security, Prototype roll-out
- BWB: data provision, provision to functional and performance tests and testing
- KWB: check procedures against data management plans

Task 4 – Feedback loops to include user feedback into development:

- BWB: Feedback to developers
- Vragments: Evaluation of testing feedback forms, further development of Well Diary

Task 5 – Deployment and assessment of performance:

- BWB: preliminary and final evaluation of app after deployment, benchmarking against previous solution
- Vragments: Final deployment

Figure 9 shows a Gantt chart for the development and implementation of the Well Diary.

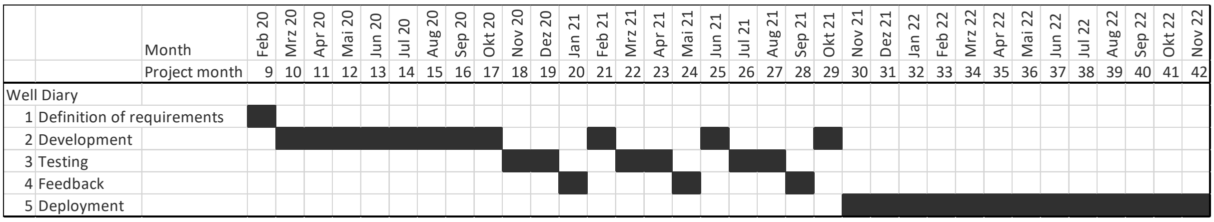

Figure 9: Gantt chart for the implementation of the Well Diary

3.4.2. Well management application

Task 1 –Definition of requirements:

- BWB: evaluation of business processes and data requirements
- KWB: definition of parameters

Task 2 - Development of algorithms and visualization tools for well condition assessment:

- BWB: data provision, co-development and feedback during algorithm development
- KWB: formulation of equations for well condition assessments, development of decision support

Task 3 – Testing:

Three consecutive feedback loops are planned in which a prototype will be tested by future users and feedback is given to the developers. Based on this, an adapted and improved version of the prototype is developed.

- BWB: organizing functional and performance tests, evaluation of prototypes
- KWB: Prototype roll-out, development of testing protocols

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Task 4 – Adaptation and Integration of user feedback:

- BWB: Feedback to developers
- KWB: Evaluation of testing feedback forms, further development of Well Management application

Task 5 – Deployment and assessment of performance:

- BWB: preliminary and final evaluation of app after deployment, benchmarking against previous solution
- Vragments: Final deployment

Figure 10 shows a Gantt chart for the development and implementation of the Well Management application.

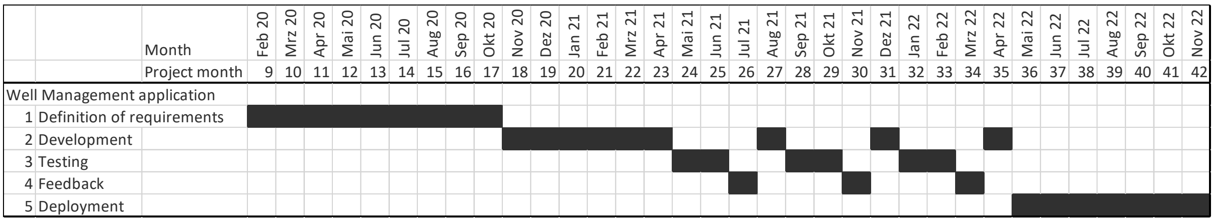

Figure 10: Gantt chart for the implementation of the Well Management application

Both solutions will be developed iteratively over the course of approximately 20 months. Various feature milestones will be set up to determine the goals of each iteration cycle. These feature milestones include for example multi-faceted data connectors, process and intermittent database, user management, etc. The solutions will be either deployed in a BWB-managed AWS space using service components and newly developed solutions or alternatively on internal BWB servers. The mobile application will be made available via (progressive) web or native app, depending on the requirements of online or offline usage. Testing and evaluation will be done by key personnel that is actually involved in the business processes of drinking water well maintenance and asset management, investment and rehabilitation planning. Thus, the project gets qualified feedback and usage metrics to provide a user-centric and value-driven solution.

3.5. Key performance indicators

Table 3 shows a list of key performance indicators to assess the benefits and potential return on investment for both solutions.

Table 3. Key performance indicators for DS7

KPI	**Unit**	**Equation**	**Description**
Well diary			
Time saved during well maintenance	-	$1 - \frac{t_{maintain,DS}}{t_{maintain,0}}$	Time for well maintenance after the DS is deployed will be estimated ($t_{maintain,DS}$) and related to today's time required for well maintenance ($t_{maintain,0}$)

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KPI	Unit	Equation	Description
Time saved for data transfer	-	$1-\frac{t_{data\ avail,DS}}{t_{data\ avail,0}}$	Time until pumping test data appear in the database after the DS is deployed ($t_{data\ avail,DS}$) will be related to today's time until data are available in the database ($t_{data\ avail,0}$)
Increase in job appeal	-	$1-\frac{JA_{DS}}{JA_0}$	Job appeal after the DS is deployed (JA_{DS}) will be estimated from user group testing (JA_0)
Well management application			
Benefit of the well condition assessment	-	B_{WMA}	The benefit of the well management application B_{WMA} will be measured by a user survey (to be specified after the definition of the user requirements).

The well diary is also expected to reduce the number of data errors originating from the manual copying of data from paper to database which is the current practice. While this is an expected benefit of the digital solution, it can however not be quantified and is thus not included in the KPIs.

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4. Sensors and analytics for tracking illicit sewer connections (DS8, DS9)

4.1. Background and proposed solutions

In highly urbanised areas receiving water bodies are under permanent stress from different sources. Beside the discharge of wastewater treatment plants and combined sewer overflows, separate storm water effluents can also be an important source of pollution. This is particularly the case, when stormwater sewers are subject to illicit connections of industrial or municipal wastewater.

Illicit connections are illegal false connections between the sanitary sewage system and the storm sewer system, which result in raw sewage entering the storm sewer and later the receiving water body without treatment. The main reasons for the existence of illicit connections are mistakes during the construction of the sewer system or during rehabilitation. Negative impacts of illicit connections can range from acute ammonia toxicity or oxygen depressions to impairments in bathing water quality and aesthetics.

Different technologies have been established for identifying illicit connections, e.g. dye testing, visual inspection, smoke testing or flow monitoring. However, the main challenge in searching for illicit connections still 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: the storm sewers are hundreds of kilometres in length, and illicit connections only discharge irregularly and intermittently. Therefore, an effective methodology is needed.

In DWC, a two-step procedure for the identification of illicit connections in storm sewer networks is demonstrated. The first step is a hotspot screening method for identifying parts of a catchment with a strong indication for illicit connection (DS9). The solution consists of a network of electrical conductivity (EC) sensors and multi-parameter sensors (T, pH, EC, ORP) coupled to machine-learning algorithms. The second step consists in deploying distributed temperature sensing (DTS) within a designated hotspot region to identify the exact location(s) of illicit connection (DS8).

4.2. Demonstration site and current practice

Both solutions will be demonstrated in a separate sewer system located in the central-western part of Berlin, Germany, which is part of the catchment “Wilmersdorf”. It is the stormwater catchment of the small urban lake Fennsee with major water pollution, recognized as regular algae blooms, a very low visibility depth and generally reduced amenity.

The stormwater catchment has an area of 220 ha, a sewer length of 39 km, around 800 manholes and approximately 1500 house connections. The settlement structure with 27,000 inhabitants represents a variety in population density and land use. The southeast is characterised by an old residential area, the southwest is a relatively new housing estate and the northern part of the catchment is dominated by a hospital and a large cemetery.

There are three stormwater outlets to the lake and the catchment can basically be divided into three sub-catchments (green, blue and red in Figure 11). In the red sub-catchment, there is a stormwater treatment plant at the outlet to reduce the pollutant emissions into the lake. The operation of the stormwater treatment plant is actually hampered by operational and technical problems caused by sewage solids in the storm water making the presence of illicit connections in the sewer network obvious. However, their origin is not located yet, which makes it a good case study for the demonstration of the developed solution.

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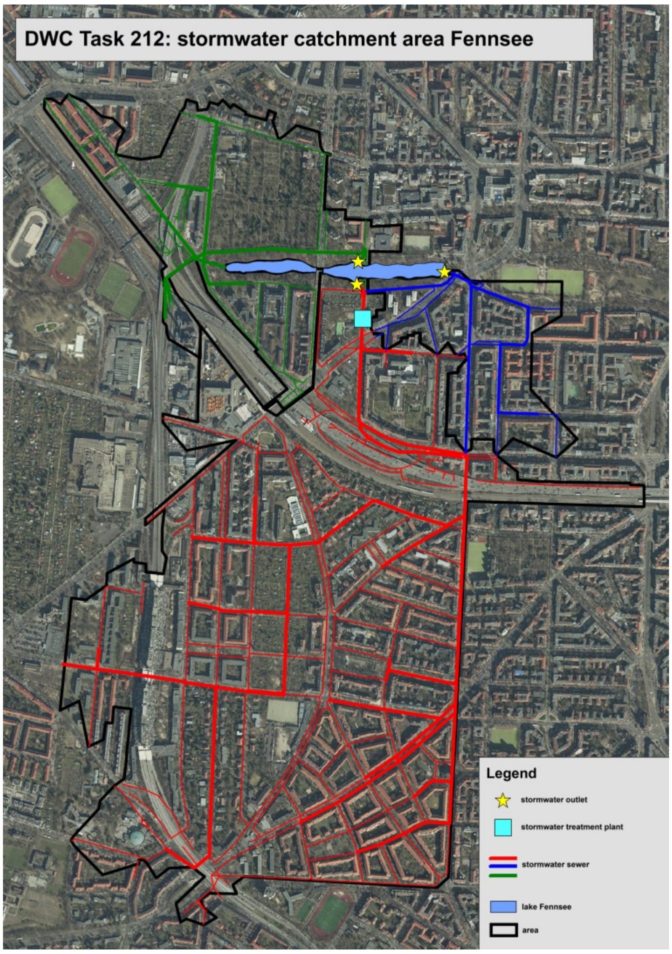

Figure 11. Storm water catchment area of the urban lake Fennsee.

The current practice to find illicit connections in Berlin consists of two steps:

First, visual inspections at the manholes are carried out to get an indication of sewage contaminations in the storm sewers by looking for faeces, toilet paper or odour. This costs a lot of time and effort for the operational team and the results are often unclear and depend on the weather condition and the daytime of sewage discharge.

If pipes with a strong indication for illicit connections are identified, in the second step elaborate CCTV inspections are carried out to locate them. CCTV inspections provide a detailed picture of the sewer condition over the length of a pipe at a given time, but they are very costly and may fail to discover dynamic wastewater discharges from illicit connections if not coinciding in time.

The conclusion is that the current approach is time-consuming and not very reliable. Therefore, a different and more effective methodology is needed.

4.3. Technology description

As mentioned, the developed digital solution is a two-step method that i) identifies a part of a catchment area with an indication for illicit connection by hotspot screening (DS9) and ii) locates them by detailed monitoring within the hotspot region (DS8).

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4.3.1. Sensors and smart analytics for tracking illicit sewer connections hotspots (DS9)

DS9 consists of the combination of two different sensor systems for the initial catchment rough screening. Those are:

Electrical conductivity sensors: The electrical conductivity (EC) indicates how easily electricity can flow through the water. It gives information on how many dissolved ions are present in the water. Dissolved ions are mainly inorganic substances that can enter the stormwater in multiple ways. As electrical conductivity varies largely between storm and wastewater, it is a suitable tracer for detecting illicit connections. Wastewater is typically rich in ions, which lead to a relatively high electrical conductivity of more than 1000 µS/cm. Depending on the drainage area, this is mainly due to urine and faeces but can also have other sources like industrial wastewater. Stormwater is commonly poor in ions and has lower values of electric conductivity of less than 200 µS/cm. Due to this difference, an elevated EC and also variation and spikes in a stormwater pipe on a dry day can give an indication for the presence of illicit connections.

Multiparameter sensors: In addition to the electrical conductivity of the water, there are other parameters for differentiating between wastewater and stormwater. The multiparameter sensor system is a technique for measuring different water quality and water dynamic characteristics within one system to identify irregularities and thus possible illicit connections to the stormwater sewer network. A wireless controller is combined with off-the-shelf water quality and water dynamics sensors that are packaged into a robust, self-powered IoT unit to collect stormwater data and stream it to the cloud. Every unit is configurable to match the stormwater network's characteristics and will include sensing capabilities such as pH, EC, temperature and oxidation reduction potential (ORP).

Starting at the stormwater outlet and going up through the sewer network, 5 EC sensors and 6 multiparameter sensor systems are installed at 11 key points of the system to detect and quantify sewage contaminations in the stormwater by changes of the electric conductivity depending on the ratio of the mixture of stormwater and sewage. Quantification of water quality at key points of the network will help to find those parts of the catchment area with stronger indication for sewage contaminations caused by illicit connections.

Data gathered by the sensors are processed within a web-based analytics engine to detect patterns and irregularities. Findings from the analytics engine include pollution events and network health statuses, which are displayed via map dashboards. The KANDO team analyses the requirements and characteristics of the analytics engine, in order to relocate the sensor units at the next strategic point. This method provides maximum information while ensuring minimum hardware use.

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

DS8 consists in the application of a detailed detection tool for the precise location of illicit connections. This tool is known as Distributed Temperature Sensing (DTS). DTS is a technique to detect and locate illicit connections and extraneous inflows in sewers and stormwater systems [6].

[6] Hoes, O. A. C., Schilperoort, R. P. S., Luxemburg, W. M. J., Clemens, F. H. L. R., & van de Giesen, N. C. (2009). Locating illicit connections in storm water sewers using fiber-optic distributed temperature sensing. Water Research 43 (20), 5187–5197.

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A DTS monitoring campaign generates long-term and high-frequent temperature measurements at many locations along a sewer or stormwater pipe. Using the monitoring results, in-sewer processes that have a significant effect on in-sewer temperatures can be studied in detail. For instance, illegal wastewater discharges to storm sewers can be localized because of their relatively high temperatures.

DTS uses a fibre-optic cable that is installed in the sewer or storm pipe, see Figure 12. A DTS unit (laser/computer instrument) sends pulsed laser light into the fibre-optic cable and processes the reflected signals into temperature values. As the DTS unit is generally installed outside the sewer system (in e.g. a pumping station or small container), no electrical equipment is introduced in the sewer environment. Temperature readings are typically obtained every 30 seconds for every 50 cm of the fibre-optic cable.

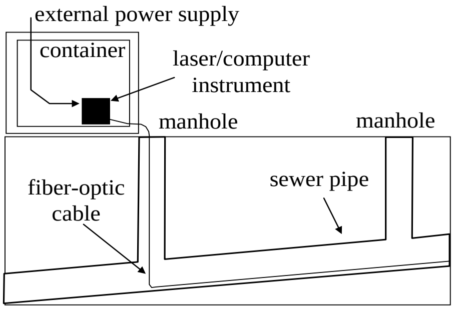

Figure 12. Schematic monitoring set-up for in-sewer Distributed Temperature Sensing.

DTS is often used to search for illicit connections: locations where wastewater is illegally discharged to a storm sewer. Figure 13 presents typical DTS monitoring results (from an earlier application, not from Berlin) for a storm sewer with illicit connections. The horizontal axis represents the length along the fibre-optic cable in the sewer system, in this case a sewer section of approximately 100 meters in length; the vertical axis represents a time-span of roughly 1 day in April 2011. At x = 369m and x = 391m illicit connections can be observed. At these locations, in-sewer temperatures intermittently rise to significantly higher values (> 15°C) than the fairly constant normal in-sewer temperatures (13-14°C).

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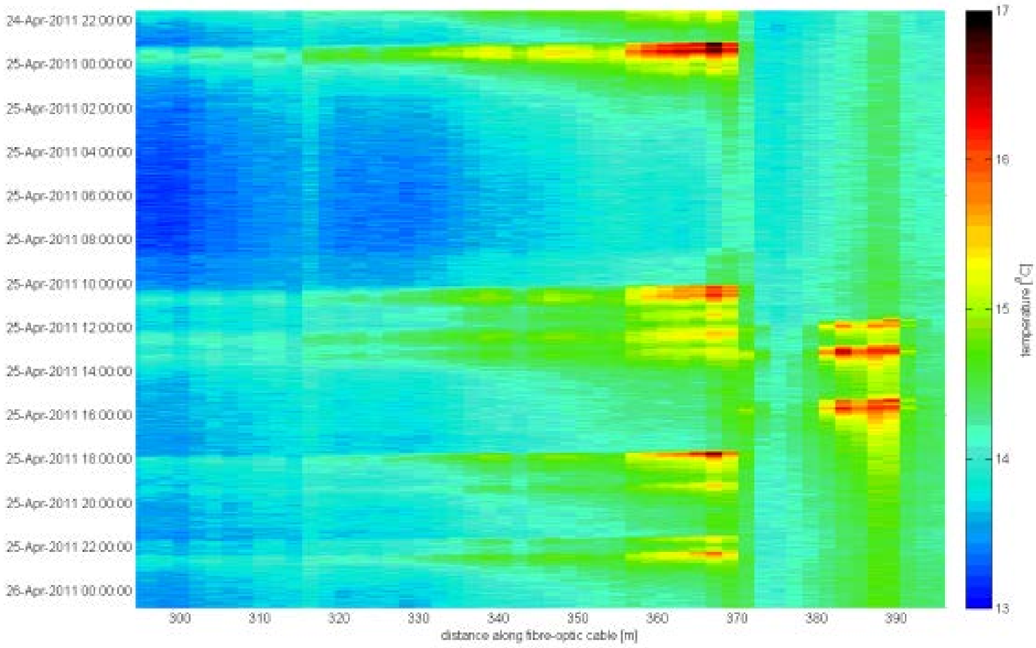

Figure 13. Results of DTS monitoring in a storm sewer with two illicit connections at x = 369m and x = 391m.

4.4. Role of partners

Berliner Wasserbetriebe (BWB) will develop the EC solution, provide EC sensor equipment, carry out data transfer and processing and evaluate the solution for hotspot screening. As the water utility of Berlin, BWB will support all sensor installations (DS8 and 9), its operations and evaluate advantages for a wider use.

KANDO is the provider of the multi-parameter solution for hotspot screening. KANDO will provide the sensor equipment and is responsible for the data transmission. KANDO will develop machine-learning algorithms to evaluate the data and will support the processing for the hotspot screening.

P4UW is the lead partner for DTS activities in Berlin. P4UW will provide the equipment on loan from Pecher AG and will accompany and supervise the field campaign. P4UW will care for data processing and evaluation.

4.5. Actions and timeline

The demonstration of DS 8/9 was planned for early summer 2020. Due to the actual corona situation, activities in the field are postponed for an unknown period to protect the operational staff. As shown in Figure 14 there are some obscurities in the timeline.

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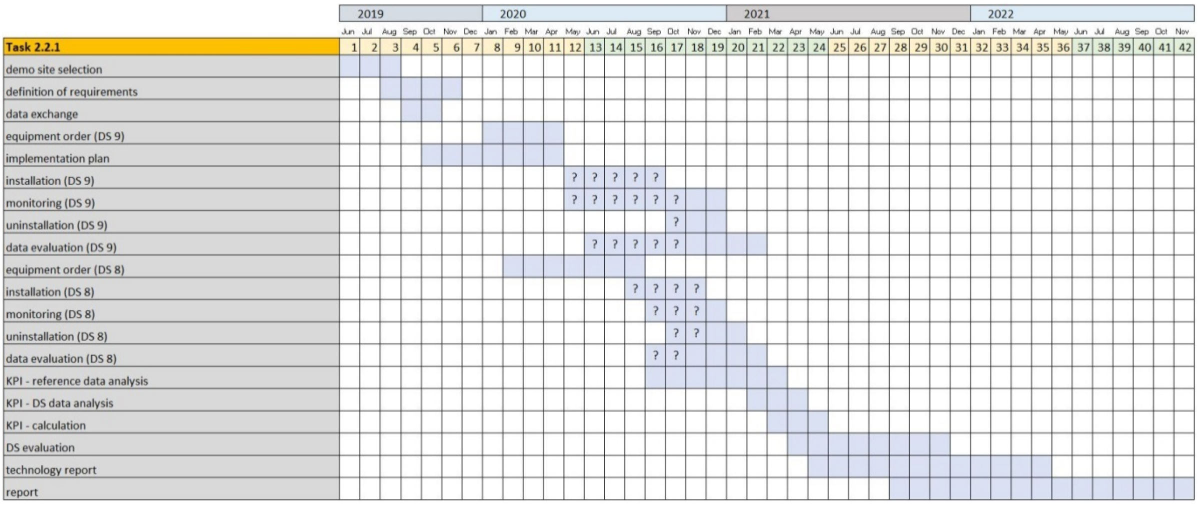

Figure 14. Gantt chart for demonstration of DS 8/9.

4.6. Key performance indicators

Three different indicators for the efficiency of the detection method, the value-for-money and necessary effort will be determined. The digital solutions are compared to results from CCTV inspections as the current practice reference method. Therefore, existing CCTV data for the studied catchment are evaluated regarding the occurrence of illicit connections. Additionally, effort, time and costs for currently used methodology in Berlin (visual inspections, CCTV inspections) will be estimated.

Table 4. KPI overview for DS 8/9.

KPI	Unit	Equation	Description
Additional IC detected	%	$100 * (\frac{Detected\ IC_{DS}}{Detected\ IC_{Ref}} - 1)$	Ratio of detected illicit connections (IC) compared to existing CCTV data • Hotspot screening: sensor results compared to the sum of all illicit connections detected by CCTV inspections of the upstream pipes • DTS results compared to detected illicit connections by CCTV inspections at pipe level
Cost reduction	%	$100 * (\frac{Cost_{DS}}{Costs_{Ref}} - 1)$	Costs (OPEX & CAPEX) for monitoring with 2-step digital solution compared to classical methodology (visual inspections and CCTV inspections)
Time saving	%	$100 * (\frac{Time_{DS}}{Time_{Ref}} - 1)$	Time required to find an illicit connection compared to CCTV inspections

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5. Integrated stormwater modelling and management (DS11, DS12, DS13)

5.1. Background and proposed solutions

'Øresund' is the receiving water body for two of the three wastewater treatment plants (WWTP) operated by BIOFOS, the largest WWTP utility in Denmark. To comply with the EU Water Framework Directive (EU 2000), in 2027 for 'Øresund' the total annual emissions of total nitrogen (N) have to be reduced by 240 tons[7]. According to the new upcoming WWTP discharge permit, BIOFOS has to reduce 200 t of the 240 t required N reduction, amounting to ca. 25% of the current BIOFOS' total nitrogen emissions (ca. 800 t) from the two WWTP discharging to Øresund. The reduction of nitrogen will be obtained by a combination of different actions. One important measure is the reduction of bypass water (mechanically treated wastewater) since this water contains a large amount of nitrogen. This constitutes one connection to the DWC project.

Besides sharper environmental and economic regulations, a constantly growing city and the general need for adaptation to climate change, put pressure on Greater Copenhagen's utilities to find new ways to optimize the sewer system across its many shareholders.[8] Integrated Urban Water Management (IUWM) and Advanced Integrated Control[9] (AIC) between the sewer system and the Waste Water Treatment Plant (WWTP) are imperatives in this context to reduce adverse impacts on surface waters and minimize future investment costs.

While IUWM and AIC are challenges per se, the complex shareholder structure of the utilities in Greater Copenhagen makes their implementation particularly difficult. There are seven utilities responsible of the sewer network, fifteen municipalities responsible for delivering plans for wastewater, climate change adaption and cloudburst, and there is BIOFOS, responsible for the treatment of wastewater at its three plants and owned by the above-mentioned utilities or municipalities directly.

This complexity results in only limited coordination of planning activities and AIC across shareholders. Therefore, tools that enhance a better understanding of the flow dynamics in the sewer system, control instruments, decision support, visualisation of the current status of the system, and forecasting as well as communication between shareholders are needed.

To overcome these limitations three digital solutions will be demonstrated. The goal of DS11 ("*Improved machine learning (ML) sewer inflow forecast*") is to enhance the performance and accuracy

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[7] Baseline for reduction of contaminants, Environmental Agency Denmark. https://mst.dk/media/122171/revideret-vandomraadeplan-sjaelland-d-28062016.pdf

[8] Cloudburst Plan Copenhagen: https://en.klimatilpasning.dk/media/665626/cph_-_cloudburst_management_plan.pdf; City development: https://international.kk.dk/; EU- Water directive. Specifically for Denmark (periode 2015- 2021): https://www.retsinformation.dk/Forms/R0710.aspx?id=208641; BIOFOS' ownership structure: https://biofos.dk/om-os/ejerforhold/

[9] Advanced Integrated Control between the WWTP and the sewer system means that the WWTP interchanges information about its biological treatment capacity to the sewer system's operator/ controls. The core idea is that the hydraulic load from the combined sewer system does not exceed the biological treatment capacity of the WWTP. Water is stored in the sewer system as long as overflow and/or flooding does not occur. AIC also includes online measurements in the system and at the plant, a very simple flow forecast model and an advanced software at the WWTP which changes operation mode 'dry/ wet weather' automatically based on measurements and flow forecast.

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of the inflow forecast to the WWTP, so that control strategies between the utilities' storage volume and BIOFOS' WWTP can be optimized to reduce bypass. The solution will provide short- and medium-time forecasts (up to 48 h) of inflow timeseries and so enables more flexibility for emptying the storage basins compared to a strict 24-hours rule[10]. This is relevant when the biological capacity at the plant is compromised or local rainfall results in runoff exceeding the biological capacity.

Using the results of DS11, solution DS12 ("*DSS for real-time control of WWTP operations and in-sewer retention*") screens a range of alternative control strategies of the sewer and drainage system to identify the optimal strategy according to the following objectives, in priority order: avoid flooding, avoid CSO, balance inflow to the WWTP. The 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.

The Decision Support System (DSS - DS12) will be incorporated in a web-visualization platform (DS13: "*Web-based prototype platform for decision support at city scale*") to provide a full overview of key data and processes to all involved share- and stakeholders. The platform includes both, a GIS-like overview with selected timeseries, and a dashboard with key data, e.g. on rainfall predictions, associated uncertainties, hydraulic capacity of sewer pipes and storage tanks as well as the status of treatment processes. The solution fosters stakeholder engagement and rational decision making based on real-time data, accurate modelling and scenario analyses. 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.

The aim is to advance the digital solutions DS11, DS12 and DS13 to Technology Readiness Levels (TRL) 8-9 by demonstrating their potential under realistic field conditions.

5.2. Demonstration site and current practice

BIOFOS is operating three wastewater treatment plants, treating water for 1.2 million inhabitants from 15 municipalities. Figure 15 shows a map of BIOFOS' catchment.

The study site for DWC is the catchment to the WWTP Damhusåen, covering an area of approximately 55 km^2 and six municipalities (Copenhagen, Frederiksberg, Gladsaxe, Herlev, Rødovdre and Hvidovre). The sewer system is operated by three utilities, i.e. HOFOR, NOVAFOS and Frederiksberg, while BIOFOS is in charge of operating the WWTP.

[10] 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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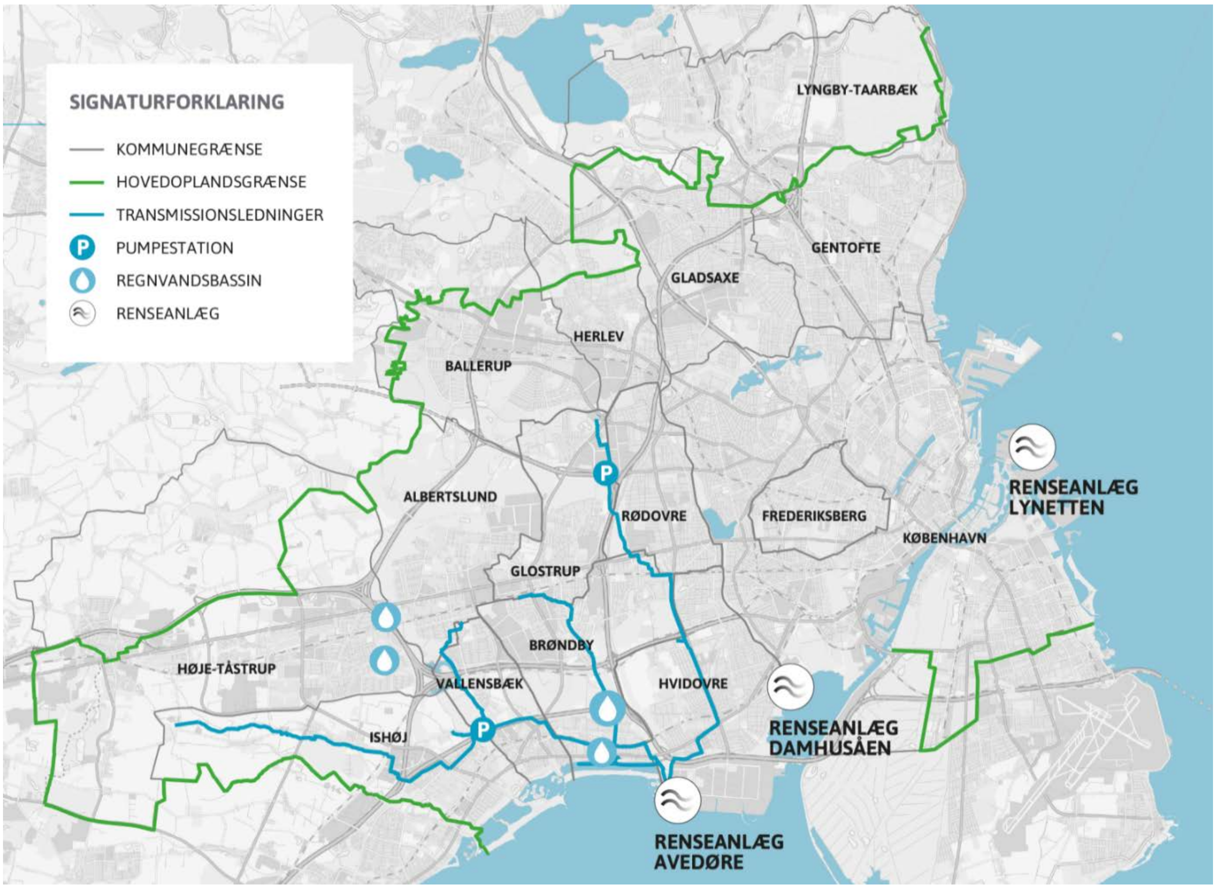

Legend (Signaturforklaring) translation: Kommunegrænse = municipality boarder, Hovedoplandsgrænse = main catchment boundary, Transmissionsledninger = big transportation pipes, Pumpestation = pumping station; Regnvandsbassin = rain water basin; Renseanlæg = Wastewater treatment plant.

Figure 15. Main catchment area (ca. 350 km^2) of BIOFOS including municipality names, WWTP locations and, BIOFOS owned sewer infrastructure.

The catchment's sewer system is mainly combined (85%), with ca. 200,000 m^3 established storage volume and ca. 86 CSO structures across the catchment, representing 45% of all CSO structures in BIOFOS total catchment area. Stormwater runoff and wastewater is primarily transported by gravity and control options are limited. Maximum inflow to the WWTP (by pipe design) can be as high as 28,000 m^3/hour while the plant's biological treatment capacity is limited to 10,000 m^3/hour. This leads to frequent bypass events, in average more than 75 times per year, with only mechanically treated sewerage discharged to Øresund.

Figure 16 illustrates the catchment of the WWTP Damhusåen with existing data sources for inflow modelling. There are eleven rain gauges, four flow sensors and four water level sensors used in predicting inflow to the plant. Besides, the WWTP registers hydraulic inflow [m^3/ hour] and pollutant concentrations [g/m^3] since 2000, and the data is used actively in BIOFOS' advanced integrated control system STAR. Radar data and numerical weather prediction data is purchasable/ available from the Danish Meteorological Institute (DMI).

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Figure 16. Damhusåen catchment and available data sources. Eleven rain gauges, four flow sensors, four water level sensors, inflow data at the WWTP (flow [m^3/ hour] and concentrations [g/ m^3]).

STAR integrates flow forecast based on a simple hydraulic model with built in auto calibration and radar data, which the system uses to automatically change from dry to wet weather flow operation. The currently implemented stormwater real-time control is hampered by the lack of accuracy of WWTP inflow forecast and the lack of interoperability between BIOFOS and the utilities' data management systems. This results in wrong switching between dry and wet weather operations at the plant compromising the optimal operation of the WWTP and possibly causing unnecessary pollutant loads to the water bodies.

BIOFOS is promoting IUWM and AIC in the catchment since 2011, specifically between WWTP and the sewer system. However, progress is slow and implementation of specific projects across utilities is just starting. BIOFOS is leading an '*IUWM and AIC- group*', consisting of participants of all utilities and has the aim to generate implementable projects.

In 2020 the first project between HOFOR and BIOFOS is launched, where the emptying of two big storage volume pipes (44,000 m^3) is coordinated with the biological capacity of the WWTP (44,000 m^3 is almost equivalent to dry weather daily inflow). The aim is to maintain the inflow to the WWTP to 10,000m^3/ time during a rain event, while storing as much water as possible in the utilities' basins. Before, the utilities would only store water in the basins when the inflow to the WWTP reached its maximum.

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Modelling results show that using this approach, total bypass volumes (= only mechanically treated water) from the plant can be reduced by 20%. This will significantly reduce the discharge of water with high concentrations of N and other pollutants to Øresund. The approach of AIC between WWTP and the utilities is facing one main concern by the sewer operators which is, that by optimizing operation between WWTP and storage volume with respect to the WWTP's biological capacity, the local overflow requirements could be jeopardized/ cannot be met. Therefor it is crucial to improve the inflow forecast, build a DSS and visualize common data, which is the aim of DWC.

5.3. Technology description

5.3.1. Sewer flow forecast toolbox (DS11)

DWC will develop a machine-learning (ML) based probabilistic forecast model for forecasting[11] flow in the sewer network and inflow to WWTP with forecast lead time up to 48 hours. The ML model will be trained using real-time water level and flow sensor data from the sewer system, rain gauge data, weather radar observations and nowcasts, and weather forecasts from numerical weather prediction (NWP) models. The potential of including also hydrodynamic model simulations of the sewer system in the training of the ML model will be investigated. The ML model will produce forecasts to be used for the decision support system (DSS) and real-time control algorithms (DS12) for both dry and wet flow conditions.

The benefit of the modelling methodology is an "end-to-end" approach where all intermediate models and their related parameterisations are implicitly described by the ML model. For instance, in the case of using weather radar observations and nowcasts, 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 modelling, and hydrodynamic modelling of the sewer system for flow prediction. The ML model uses radar rainfall directly to predict flows. We explore a range of ML algorithms, including different deep neural network configurations and random forests. The probabilistic forecast model will utilise available ensemble weather forecasts and include a statistical error forecast and bias adjustment methodology to produce predictive uncertainty estimates.

ML forecast models will be developed and analysed for the Damhuså study site. Data available for the modelling are shown in Figure 17.

[11] Forecasting is a technique that uses historical data as inputs to make informed estimates that are predictive in determining the direction of future changes. The forecast technique to be deployed depends on the desired forecast length and available historical data. When based on accurate advance information (the forecast) the decisions will be better or more accurate, than without forecast. The transformation process, using the forecast information to decide for actions, requires some sort of information or knowledge sharing. In a fully automated control system, data is shared and used directly between the forecaster and controller. In the current demonstration project, we will not implement automated control (in excess to what already exists), but rather communicate forecasted values and suggested decision actions using visual tools, like web-based mapping and dashboards.

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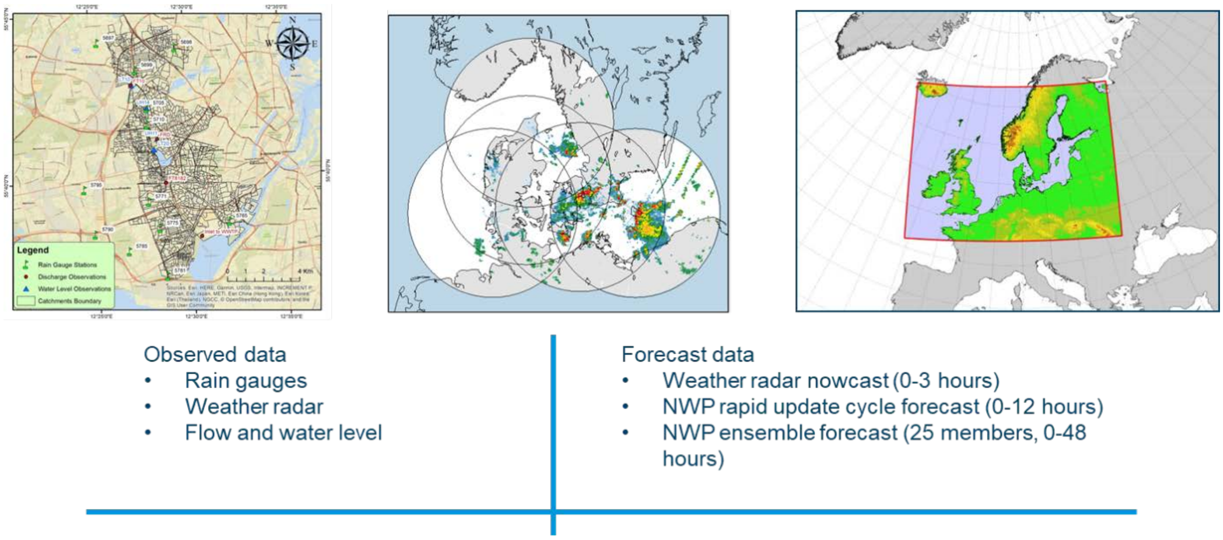

Figure 17. Data used for developing the ML forecast model for the Damhuså study site. Left: Map with rain gauges, flow and water level sensors that provide data to the SCADA system. Center: weather radar nowcast data obtained from the Danish Meteorological Institute (DMI) radar network. Right: Numerical Weather Prediction (NWP) data, here: rainfall intensity, from two DMI forecast products, including (i) NWP rapid update cycle forecast that is updated every hour with weather radar data and satellite-based cloud data, and (ii) NWP ensemble forecast.

5.3.2. Interoperable DSS and real-time control algorithms for stormwater management (DS12)

A Decision Support System (DSS) for operation of the integrated wastewater system will be developed that uses the ML forecast model (DS11). The DSS will include real-time control strategies for the WWTP and sewer system under different operational conditions, such as

- Switching between dry and wet weather flow operation of the WWTP based on short-term inflow forecasts and
- Management of in-sewer retention capacity and emptying of retention basins based on long-term inflow forecasts.

The DSS will include calculation of different indicators relevant for the control as illustrated in Figure 18 for switching between dry and wet weather flow operation of the WWTP. The DSS will be a software component (module), that enables simulations of different scenarios and compiles results and KPIs to be visualised in DS13. User interaction with the DSS takes place in the web interface (DS13).

The DSS will be set up and tested for the Damhuså study site. In this regard, simulated real-time tests will be carried out using historical weather radar and NWP forecasts to produce probabilistic flow forecasts for screening and evaluating real-time control algorithms for WWTP operations and management of retention capacity in the catchment. The results will be compared with a detailed deterministic (high-fidelity and physically based) urban drainage simulation model of the Damhuså catchment as reference, which would be too slow for real-time management. In addition, the DSS will be linked to the web platform as part of DS13.

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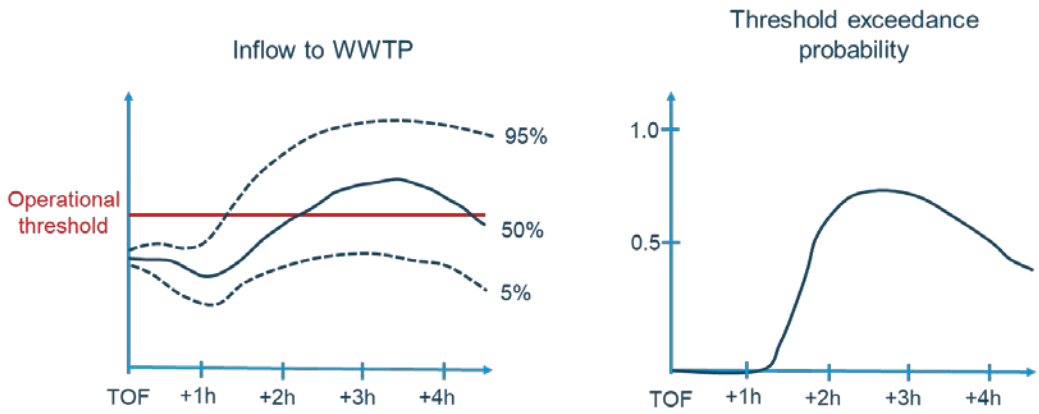

Figure 18. Illustration of probabilistic inflow forecast to the WWTP and calculation of an indicator that quantifies the probability for exceeding the operational threshold level for switching between dry and wet weather flow operation of the WWTP.

5.3.3. Web platform for integrated sewer and WWTP control (DS13)

BIOFOS already use a prototype web-platform for showing selected key monitored data. This includes data from all the connected sewer network utilities, which is stored in a central database (back-bone system). Figure 19 shows the data flow and structure.

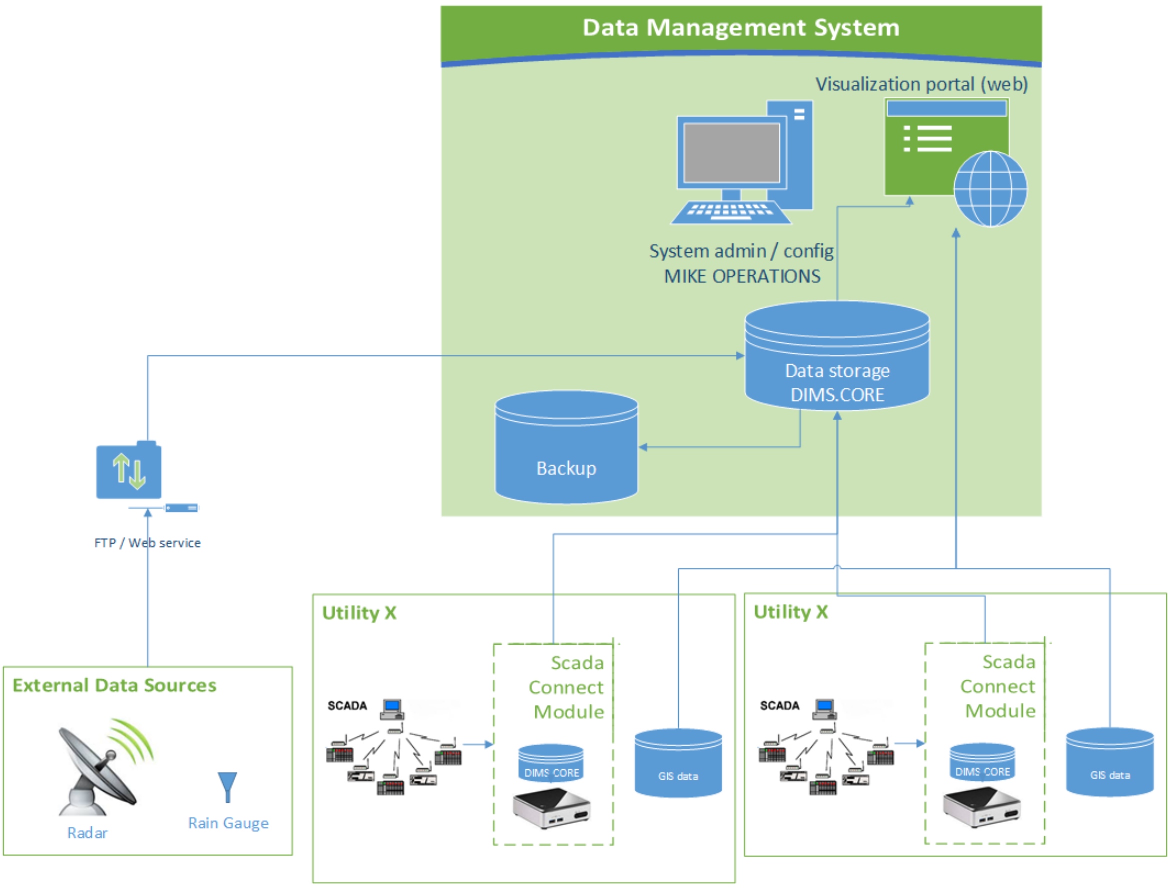

Figure 19. Existing platform of BIOFOS Data Management System.

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An initial activity will be to decide for the most suitable web-platform. We intent to look into two options. An extension of the existing prototype, or integration with another water utility web platform, developed and deployed in a number of Swedish cities. Selecting criteria include handling, maintenance efforts and sustainability.

The selected web-based platform visualizing the hydraulic network condition will be further developed in an online decision support tool. This tool will visualize the total system dynamics and facilitate real-time decision-making between all utilities and entities for high-flow events (DS13).

In addition to the GIS based web platform, DS13 will also include design and configuration of a limited number of dashboards. The dashboards facilitate efficient communication of key parameters, could be numbers like inflow rates over the next 30 min, 1 h, 4 hours and similar information. A sample dashboard is included in Figure 20 (for illustration purposes only).

Figure 20. Sample dashboard with key values

5.4. Role of partners

BIOFOS is the city leader for Copenhagen and task leader for subtask 2.2.3 (associated with DS12). BIOFOS has, as city leader, the responsibility to involve the local Community of Practice (CoP) as well as to facilitate the successful demonstration and long-term uptake of the solution. The already existing IUWM- group will act as CoP in Copenhagen. Regarding subtask 2.2.3 ("DSS- for real-time control of WWTP operations and in-sewer retention"), BIOFOS' responsibilities lie in purchasing sensors and meteorological data, deploying those sensors in the utilities sewer network together with the utilities, and facilitate the data exchange between the utilities' IT-systems and the digital solutions developed in DWC.

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DHI is technology supplier and provides the competences and tools to be included in the three digital solutions. DHI is responsible for driving the design, implementation, testing and documentation, and for facilitating end-user engagement, which is planned to start mid 2020. DHI leads subtasks 2.2.2 (associated with DS11) and 2.2.4 (associated with DS13).

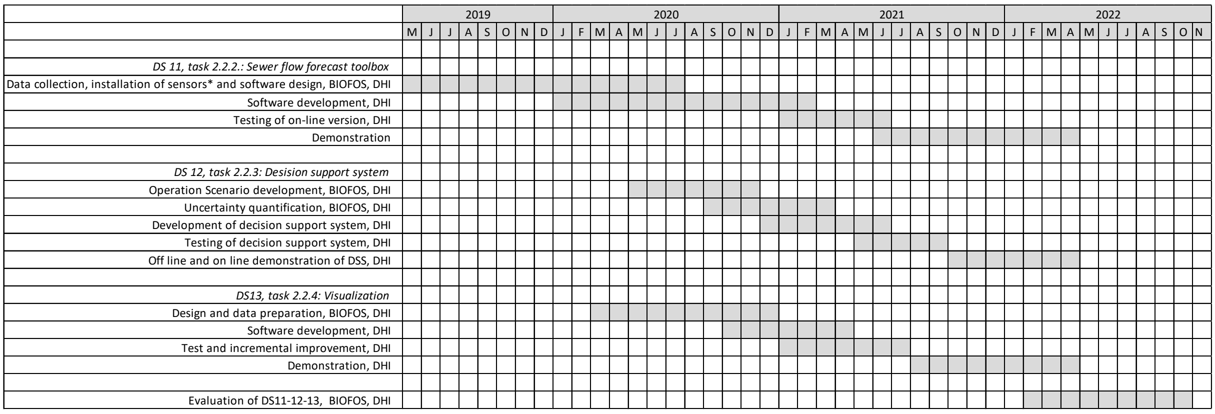
HOFOR is official associated partner in DWC, while the utilities of NOVAFOS and Frederiksberg both have agreed on supporting the project actively by sharing data, installing sensors in their system, deliver an updated hydraulic model of the catchment to DHI and participating in meetings.

The Community of practice for DWC is the same as the already established working group '*IUWM and AIC- group*'. This is very advantageous since the group meets once a month, is interested in new digital solutions, can be updated about the progress of DWC regularly and willing to participate in the project where relevant. BIOFOS also has focus on informing the boards of directors of the utilities via steering committee meetings under the '*IUWM and AIC- group*'.

5.5. Actions and timeline

While there is already a data collection system installed, the need for additional level and flow data have called for an upgrade of the sensor network. Identification of suitable sites, instruments and integration with the existing system is initiated. Data from the additional sensors will be available by end of July 2020. In total it is planned to install approx. 10 IoT level sensors and 10- 13 flow sensors.

Further, the detailed hydrodynamic model will be updated and made available for the DS11 by the end of April 2020. DS11 (ML) is designed, developed and tested during 2020 and 2021, with a scheduled completion date of April 2021. At that time, the DS11 will be evaluated as an integrated component with DS12 (DSS). DS12 (DSS) is developed during 2020 and 2021 with a scheduled completion date of April 2021. At that time, the DS12 will be evaluated as an integrated component with DS11 (DSS). DS13 (Web) development is initiated in the second quarter of 2020 and completed for test and evaluation in August 2021. The evaluation of the complete solution (DS11-12-13) continues until end of April 2022. A more detailed time plan is provided in the Gantt chart, Figure 21.



* Data collection and installation of sensors is pending due to Covid-19. There is no access to collect historical data at the moment and limited access for installing sensors

Figure 21. Gantt chart for DS11, 12 and 13.

5.6. Key performance indicators

The following indicators will be quantified to assess the benefits and return on investment for the three solutions:

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Table 5. Key performance indicators for DS 11-13

<table>
<tr><th>KPI</th><th>Unit</th><th>Equation</th><th>Description</th></tr>
<tr><td colspan="4">DS11: Sewer flow forecast toolbox</td></tr>
<tr><td>Improved forecast during wet weather</td><td>Percent [%] reduction</td><td>Two performance statistics are calculated as a function of forecast lead time.
Mean error:
$$ME = \frac{1}{N}\sum_{i=1}^{N}(SIM_i - OBS_i)$$
Root mean square error:
$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(SIM_i - OBS_i)^2}$$
SIM_i is the forecasted inflow and OBS_i is the observed inflow.</td><td>Calculate ME and RMSE for different forecast lead times for existing and new inflow forecast models.
Goal: ME and RMSE are reduced by 30% compared to existing inflow forecast model.</td></tr>
<tr><td>Reduction of wrong automatic switching between dry and wet weather operation at the WWTP</td><td>Percent [%] reduction</td><td><table><tr><th></th><th>Real flow above limit</th><th>Real flow below limit</th></tr><tr><td>Prediction starts ATS*</td><td>(A)
OK, Positive</td><td>(B)
False start. Possible high N and P out</td></tr><tr><td>Prediction does not start ATS*</td><td>(C)
False negative. Higher bypass. Risk of sludge escape</td><td>(D)
OK, No action</td></tr></table>*ATS = Aeration Tank Settling

Equation for KPI:
Fault percent (FP): (B+C) / (Sum(ABCD)) x 100
Probability of detection or hit rate:
POD = A/(A+C)</td><td>Description/Procedure on how to calculate the KPI of reduced wrong switches:
(X)
a. Historic rain series and Old Prediction Model.
b. Comparing prediction to actual flow at plant inlet*.
c. Count A, B, C, D
(Y)
a. Historic rain series and New Prediction Model.
b. Comparing prediction to actual flow at plant inlet*.
c. Count A, B, C, D
* for each rain incident
KPI: FP(Y) is lower than half of FP(X).
This means that the fault switches have been halved or better, with the new prediction model.</td></tr>
</table>

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KPI	Unit	Equation	Description
		False alarm rate: FAR = B/(A+B)	
Accuracy of forecast time for dry weather – 48 h	Percent [%] categorized as correct dry weather forecasts	Evaluate dry weather forecasts for the next 12h, 24h and 48h. Flow forecast is categorized as correct dry weather forecast if the observed flow is less than 110% of forecasted flow in the forecast period (12h, 24h and 48h). Probability of correct categorized dry weather forecast: P = (No of correct forecasts) / (Total No of dry weather forecasts)	Knowing about dry weather conditions is useful to execute ad hoc renovation/ maintenance work/ TV-inspections etc. on tanks, basins, pumping stations, pipes etc. Another application is in situations of distributed coupled rain events. For example: it rains in the whole catchment, but coupled events are only predicted in some geographic areas. With dry weather forecasts, it is possible to increase the retention time in dry areas, while emptying the basins where it is expected to rain again. KPI: P(12h) > XX P(24h) > YY P(48h) > ZZ
DS12: Interoperable DSS and real-time control algorithms for stormwater management			
Reduction of nitrogen (N) emissions	% reduction	%= $(N_{old}- N_{new})/ N_{old}$ x100	Objective of the project is to reduce the amount of only mechanically treated bypassed water, thereby reducing nitrogen emissions from the WWTP, while CSO are not compromised using ML- forecast. Data used for the calculation consists of measured, modeled and estimated data and will include emissions from both, the WWTP and CSO. The effect will be correlated with the type of rainfall year (was it a very dry, a very rainy year, a year with high intensive rains etc.; The Danish meteorological institute has defined a 'normal' year for Greater Copenhagen which we can use as reference)

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KPI	Unit	Equation	Description
CAPEX reduction for constructions to reduce bypass	Money - €	Once calculated the reduction of bypass obtained with the new solution, reduced cost for constructions necessary to obtain the same results, can be calculated.	During the project, specific situations/scenarios will be chosen to evaluate the effect. Changes in future loads, like climate changes, population changes, industrial load changes etc. will be discussed.
Reduction of annual by-pass volume [m³]	X % of bypass volume [m³]	$\% = (Bypass_{(old)} - Bypass_{(new)}) / Bypass_{(old)} \times 100$	Optimizing integrated wastewater management in the catchment is supposed to reduce the amount of only mechanically treated bypassed water, while not compromising the CSO- volumes. For the analyses, measured and modeled data will be used. Reporting will also include an overall water balance including bypass volumes *and* CSO- volumes. The effect will be correlated with the type of rainfall year (was it a very dry, a very rainy year, a year with high intensive rains etc.; The Danish meteorological institute has defined a 'normal' year for Greater Copenhagen which we can use as reference)
DS13: Web platform for integrated sewer and WWTP control			
Increased usage, utility buy-in	80% of the utilities are participating in workshops There are registered users from 80% of the utilities 50% of registered users are active every month	There will be organized 2 workshops with relevant employees of the WWTP and the utility staff directly included in DWC.	To ensure interoperability of the platform with BIOFOS' other two plants and 4 utilities, another workshop will be hold in a broader forum.

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KPI	Unit	Equation	Description
Dashboards used by top management	Number of monthly active users	The user behavior in the web platform will be tracked through software and analyzed.	The target number of relevant top-management users will be defined after the workshops
Co- creation on functional design	Design workshops held with the Local Community of Practice (utilities)	At least one relevant employee per utility takes part in the co- creation workshop	Objective with a co- creation workshop on functional design is to enhance acceptance and up-take of the web-platform from the LCoP.

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6. Low-cost temperature sensors for real-time CSO monitoring (DS14)

6.1. Background and proposed solution

Combined sewer systems consist of an underground sewage collection system composed by a network of pipes and tunnels designed to collect both wastewater and stormwater. During heavy rainfalls, the drainage capacity of the sewer pipes and the pumping station is not able to transfer all the volume of mixed wastewater and rainwater to the treatment plants or retention tanks. Then the excess of combined sewerage is discharged directly to the receiving water body in an event called combined sewer overflow (CSO). CSO are a source of contaminants for the receiving water bodies, e.g. for solids, organic matter, nutrients, metals, organic compounds and pathogenic microorganisms. CSO events can cause several detrimental effects such as oxygen depletion, decreasing water quality, toxicity effects on phytoplankton from heavy metals, stress on aquatic organisms, etc [12], [13].

Traditionally there has been a lack of reliable data about the occurrence of CSO [14]. Two of the main limitations with regard to CSO to date 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 CSO. These two factors have delayed the implementation of extensive monitoring of CSO. It is crucial to know how CSO occur and behave to develop appropriate actions to prevent them. 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 described above to achieve and maintain a good ecological status of the receiving media [15].

To tackle the limitations stated above, a new low-cost method for detecting occurrence and duration of CSO will be demonstrated in DWC task 2.2.1. The detection method consists in installing a low-cost temperature sensor at the overflow crest of a combined sewer. In case of dry weather, the sensor measures air phase, whereas in 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 storm and wastewater.

6.2. Demonstration site and current practice

The new low-cost CSO sensor will be demonstrated simultaneously in the cities of Sofia, Bulgaria, and Berlin, Germany.

6.2.1. Case study 1: Berlin

The solution will be demonstrated in Berlin's biggest combined sewer catchment "Wilmersdorf" located in the central-western part of the city. The catchment has an impervious area of 921 ha, a total area of 1651 ha and drains sewerage of approximately 265,000 inhabitants.

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[12] Harremoes, P. (1982). Immediate and delayed depletion in rivers. Water Res. 16, 1093 - 1098.

[13] Riechel, M., Matzinger, A., Pawlowsky-Reusing, E., Sonnenberg, H., Uldack, M., Heinzmann, B., Caradot, N., v. Seggern, D., Rouault, P. (2016). Impacts of combined sewer overflows on a large urban river – understanding the effect of different management strategies. Water Research 105, 264-273.

[14] Montserrat A, Gutierrez O, Poch M, Corominas L. 2013. Field validation of a new low-cost method for determining occurrence and duration of combined sewer overflows. Science of the total environment 463, 904-912

[15] EC of the Water framework directive (WFD) 2000/60/EC

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Part of that sewerage is received from a neighbouring separate sewer system. The settlement structure shows a high variety in population density with little industry and is, therefore, representative of municipal wastewater in Berlin. During dry weather conditions, around 40,000 m³ of wastewater are generated each day and pumped to the wastewater treatment plant. Maximum pumping capacity during wet weather conditions is twice the peak dry weather flow (2 x 750 L s^{-1} = 1.5 $m^3\ s^{-1}$). Excess water is discharged via 19 overflow crests, which are connected to the receiving river via three CSO outlets. Figure 22 shows a map of the catchment and the overflow structures.

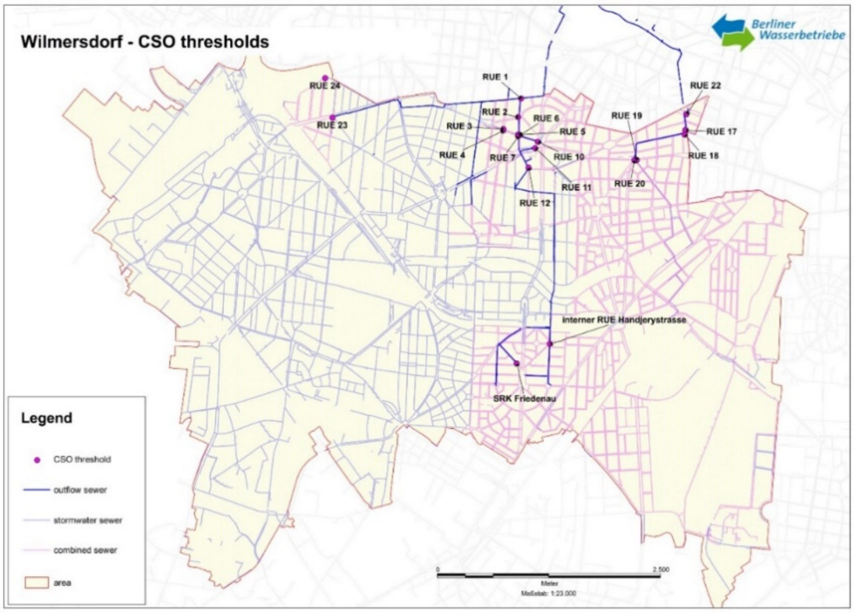

Figure 22. Catchment area of the Berlin case study.

In an average rainfall year, around 20 CSO events are observed in the studied catchment with a total volume of ~700,000 m³ and a duration of ~140 hours. These numbers have been obtained based on hydraulic simulation models. Currently, four of the 19 CSO structures are equipped with water level sensors to measure CSO occurrence and duration. The CSO volume can be estimated via the Polleni formula (for the four monitored CSO structures) or simulated with a hydraulic model (for the entire catchment). Model calibration has been performed with the mentioned water level sensors and a water level sensor at the main pumping station. In addition, field campaigns were carried out to yield water quality data for dry and wet weather conditions and refine model calibration.

6.2.2. Case study 2: Sofia

The catchment area of the city of Sofia has a total surface of 13,640 ha. It is divided into six main sub-catchments: Kakach, Suhodolski, Vladayski, Perlovski, Slatinski and Trunk, named after the main rivers crossing the city (Figure 23). It is a combined sewer system with the main sewer collectors located on the two sides of the rivers. A total of 232 CSO structures are present and help to unload the sewer system during rain events. Under dry weather conditions, wastewater is drained to the Kubratovo wastewater treatment plant mostly by gravity. Kubratovo WWTP treats 300,000 m^3/day, which is 70% of its full capacity.

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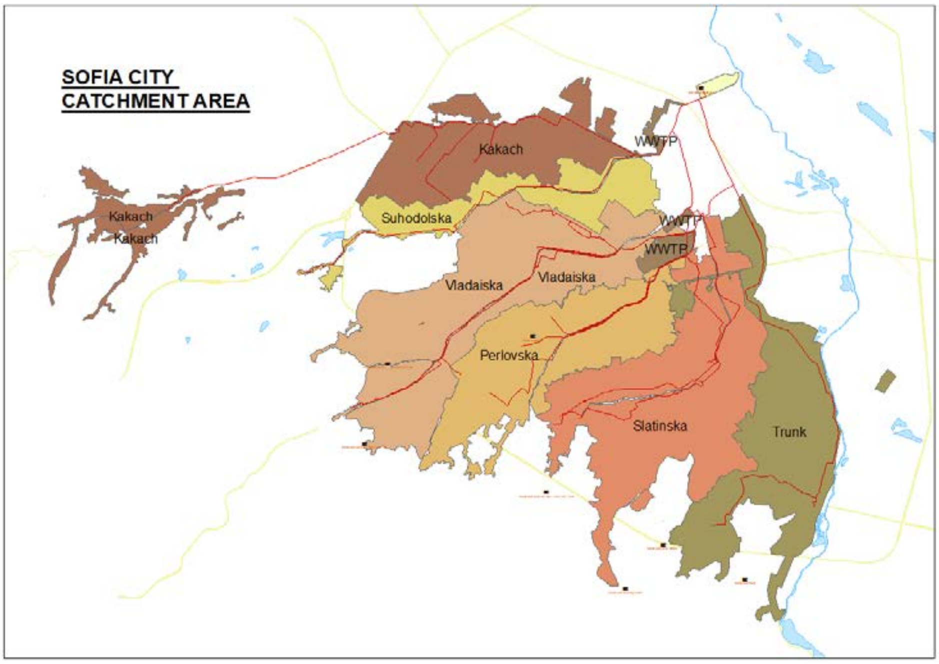

Figure 23. Sewer catchments of Sofia City

To date there is no direct monitoring of CSO events as no specific sensors have been deployed yet. Thus, the occurrence and frequency remain vague. Overflows structures in Sofia are designed to discharge a six times diluted domestic outflow and they are inspected twice a year by the specialist field team of Sofiyiska Voda (SV).

6.3. Technology description

CSO are generally measured using standard flow meters or level sensors installed in CSO chambers or pipes. Both ,flow meters and level sensors are costly and not always reliable due to the harsh conditions in sewers. Hence, it makes the simultaneous monitoring of several CSO structures within the same sewer system unreliable and very expensive. The technology applied here consists of innovative low-cost temperature sensors installed at the overflow crests to estimate CSO emissions in a large number of points. In case of dry weather, the sensors measure air temperature, whereas in 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 [16]. The measurement concept is visualised in Figure 24.

[16] Montserrat A, Gutierrez O, Poch M, Corominas L. 2013. Field validation of a new low-cost method for determining occurrence and duration of combined sewer overflows. Science of the total environment 463, 904-912

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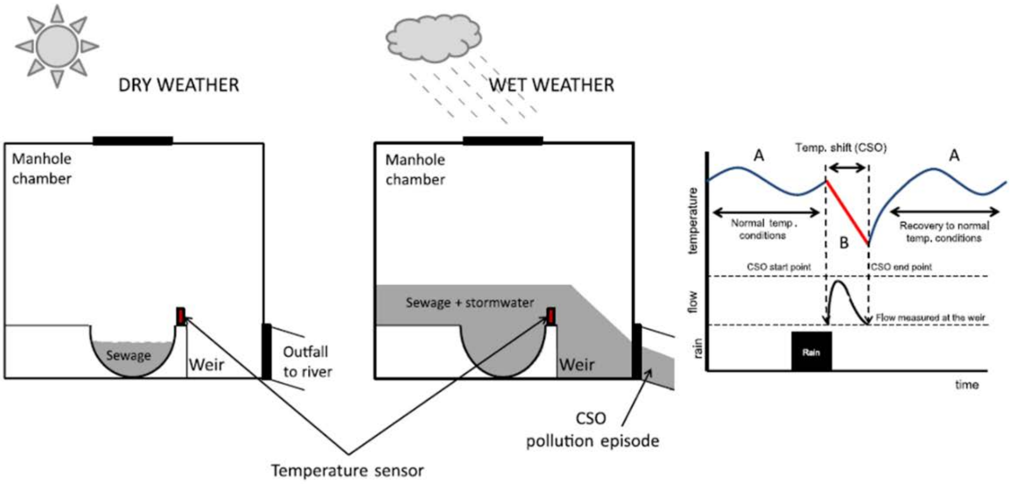

Figure 24. Concept of CSO measurement using temperature sensors.

The simplicity of the sensors allows to deploy it at a high number of sites while still keeping the CAPEX and OPEX cost at a fraction of current practice. There are two versions of the technology available: Offline sensors and online sensors. The offline sensors are very small, cheap and easy to install but require a manual data download every few months. The online sensors on the other hand can remotely provide real-time overflow information through Lorawan/2G communication protocols. The technology can be especially useful to improve the accuracy of hydrodynamic sewer modelling by providing high spatial and temporal distribution of reliable data [17].

6.4. Role of partners

Five partners will participate in the demonstration of the described digital solution.

ICRA is the provider of the technological solution described above. ICRA has developed the concept of the low-cost CSO sensors, will construct the sensors together with IoTsens, will collaborate with SV and BWB during installation and test of the sensors, give support regarding functioning and data collection and, together with KWB, will integrate CSO data in hydraulic modelling. ICRA will also validate the data obtained and develop algorithms for CSO characterisation.

IoTsens is in charge of constructing the hardware of the sensors and its communication capacities. IoTsens will develop the wireless communication and cloud data transmission through data-shared platforms to allow online visualization and data processing. IoTsens will implement data transmission and storage and proposes a platform for data and anomaly visualization.

Sofiyska Voda (SV) is the water utility in charge of the management of the sewer system of Sofia. SV will support sensors installation on site. SV will also perform regular checks of the physical condition of the sensors and apply the required maintenance with the assessment of ICRA. At the end of the trial, SV will evaluate the advantages/performance of the technology in their systems in the vision for wider use.

[17] Montserrat A, Hofer T, Poch M, Muschalla D, Corominas L.2016. Using the duration of combined sewer overflow events for the calibration of sewer hydrodynamic models. Urban Water Journal 14 (8), 782-788

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Berliner Wasserbetriebe (BWB) is the water utility in charge of the management of the sewer system of Berlin. BWB will support sensor installation in Berlin, will also perform regular checks of the physical condition of the sensors and apply the required maintenance with the assessment of ICRA. SV will also evaluate the advantages/performance of the technology in their systems in the vision for wider use.

Kompetenzzentrum Wasser Berlin (KWB) will use the data generated during the monitoring campaign and improve the calibration of an existing hydraulic model. They will also run simulations to formulate CSO and flood management rules in the frame of task 2.3.1.

6.5. Actions and timeline

DWC-Task 2.2.1, which is associated with DS14, is divided into seven subtasks:

Subtask 1 - Selection of the CSO points to monitor, construction-assembling of the sensors: ICRA, IoTsens, SV, KWB and BWB (June 2019- Feb 2020).

Site visits will be carried out to inspect and select the CSO structures to be monitored and to train the SV and BWB teams about the installation and maintenance protocols of the sensors. The structures to be monitored will be shortlisted and the number and type of sensors (offline + online) will be chosen depending on the features of the selected sites both in Sofia and Berlin.

The sensors will be constructed by ICRA and IoTsens.

Subtask 2 - Installation-deployment of the sensors in the Sofia and Berlin CSO selected points; ICRA, IotSens, SV and BWB (March-June 2020):

This task consists in the physical installation of the sensors. The sensors constructed in Spain will be sent to Berlin and Sofia for their installation. Pending on unexpected delays, it is planned to have all sensors installed by June 2020.

Subtask 3 - Data collection, transmission and storage in the cloud; IoTsens, ICRA, SV and BWB (June 2020 – Nov 2022):

This task corresponds to the activation of the sensors and the monitoring of the CSO events over a long period of time (>1.5 years) to obtain representative data of both case studies.

Subtask 4 - Advanced analysis of gathered data; ICRA and KWB (June 2021– May 2022):

Artificial intelligence and predictive analytic techniques will be developed and applied to extract accurate real-time knowledge from the raw temperature measurements.

Subtask 5 - Improve the accuracy of hydrodynamic sewer modelling; KWB and ICRA (June 2021- Jan 2022):

The newly available knowledge with high temporal and geographical resolution will be used to improve the calibration accuracy of hydrodynamic models for the Berlin case study.

Subtask 6 - Simulation of management scenarios with the calibrated model, KWB and ICRA (Jan – May 2022, actually part of DWC-Task 2.3.1):

The calibrated hydraulic models will be used to generate highly accurate predictions of CSO behaviour in the Berlin catchment.

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Subtask 7 - Data transfer back to Users: IoTsens, ICRA, SV, BWB and KWB (June – Nov 2022):

For each case study, a user-friendly set of rules for optimal CSO prevention will be developed and transferred to water utilities. The sensors will be dismantled and transferred back to ICRA.

The timeline of the different subtasks is visualised in Figure 25.

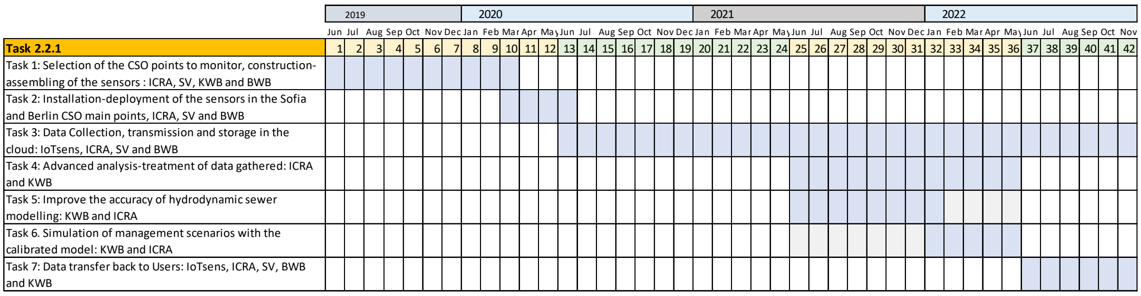

Figure 25. Gantt chart for DS14.

6.6. Key performance indicators

The described solution will be assessed with the following set of key performance indicators (KPI, Table 6). Further comments on the different KPI are made below.

Table 6. Key performance indicators for DS14

KPI	Unit	Equation	Description
Detection accuracy for CSO frequency	(Number of overflows/mm rainfall year · catchment area)/ %	$F = \frac{1}{m} \cdot \sum_{i=1}^{m} \frac{Number\ of\ overflow\ detected}{mm\ rainfall \cdot year}$ $\Delta F = 1 - \frac{F_{DS}}{F_0}$ *m – number of monitoring points*	Comparison of number of events before and after solution is applied, relative to total rainfall
Detection accuracy for CSO duration	(Time of discharging/ mm rainfall year · catchment area) / %	$D = \frac{1}{m} \cdot \sum_{i=1}^{m} \frac{Time\ of\ overflow\ detected}{mm\ rainfall \cdot year}$ $\Delta D = 1 - \frac{D_{DS}}{D_0}$ *m: number of monitoring points*	Comparison of time of CSO discharging before and after solution is applied, relative to total rainfall
CAPEX reduction	(€/catchment Number of measured points/fixed Budget-€) / %	$CAPEX = \sum_{i=1}^{m} cost\ of\ sensor + cost\ of\ installation$ $\Delta CAPEX = 1 - \frac{CAPEX_{DS}}{CAPEX_0}$ *m: number of monitoring points*	Reduction of capital costs related to the CSO monitoring.
OPEX reduction	(€/sensor · year €/catchment · year) / %	$OPEX = \sum_{i=1}^{m} \begin{matrix} Energy\ consumption \cdot \frac{€}{h} + \\ hours\ of\ maintenance\ works \cdot \frac{€}{h} \end{matrix}$ $\Delta OPEX = 1 - \frac{OPEX_{DS}}{OPEX_0}$ *m: number of monitoring points*	Reduction of operational costs related to the CSO monitoring.

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KPI	Unit	Equation	Description
Increase in model accuracy	% of accuracy	$ACC = \frac{1}{m} \cdot \sum_{i=1}^{m} \frac{n_{TP} + n_{TN}}{n}$ $\Delta ACC = ACC_{DS} - ACC_0$ *m: number of monitoring points* *n_TP: number of correct CSO signals* *n_TN: number of correct non-CSO signals* *n: number of total observations*	Increase of hydraulic model accuracy thanks to data provided by the CSO sensors; can be calculated on event-basis and for different time instances.

Comments:

KPI 1: Detection accuracy for CSO frequency: It would be interesting to specify the method used to detect before the solution, to compare the capability of different methodologies. If sensors are already in place, the different scenarios should be compared/normalized with the same conditions (i.e. same rainfall). For the Sofia site, overflows under no rain conditions will be specially considered. No rain, there should not be CSO events.

KPI 2: Detection accuracy for CSO duration: Same as above, specify the method used to detect before the solution to compare different methodologies. Different scenarios should be compared/normalized with the same rainfall conditions and for the Sofia site, overflows under no rain conditions will be specially studied.

KPI 3: CAPEX reduction: We need the number of CSO structures/catchment. If there are sensors already installed, we need the cost of these current sensors. If no sensors are installed, we might need to assume an average cost/structure. Can be translated into the number of CSO structures equipped with sensors (for a given budget, compared to existing water level sensors).

KPI 4: OPEX reduction: Operational cost for the current sensors are needed. To be provided by BWB and SV.

KPI 5: Increase in model accuracy: the model accuracy procedure will be carried out the following way. Two models will be validated: a) a model calibrated with water level measurements at ~ 4 monitoring points (status quo); b) a model calibrated with binary signal CSO y/n at ~ 17 monitoring points (DWC solution). Both models are validated with binary signal from temperature sensors (CSO y/n) for ~ 17 monitoring points. Validation result is the number of correct CSO (True positives, TP) and non-CSO signals (True Negatives, TN), e.g. at a 5-min time step, divided by the total number of observations -> % accuracy. Both validation results will be compared and % accuracy increase will be assessed. Validation and accuracy assessment can also be done at event-level regarding the frequency of CSO (to be tested and discussed)

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

7.1. Background and proposed solution

The proposed solution addresses two important tasks in sewer operation and maintenance: cleaning and inspection.

Cleaning of sewer system is important for a number of reasons of which the most important are:

- Sewer cleaning improves system performance providing better flow conditions, which allow better transport of sediments. It reduces the fouling process leading to less odor and less corrosion. With regular cleaning, the sewer system can work with its full storage capacity, enabling combined sewer overflows to work in the designed manner;
- Removing blockages reduces the flood risk and the level of other operational events over the sewer system, which leads to other main benefits: utilities can focus on well-planned and scheduled preventive works and at the same time customer satisfaction level increases together with fewer complaints;
- Inspection of the sewer system is preceded by cleaning. Good cleaning quality is the main factor for satisfactory inspection results.

Visual inspection of sewer systems provides additional high-valued information about the sewer assets managed by the utility, improving the planning and prioritization of rehabilitation and replacement projects. It can reduce the level of emergency repair costs and can be a good source of study of the infiltration levels and locations, also finding the location of illegal connections.

The knowledge gained with the visual inspections and the proactive actions taken after them improve customers' satisfaction level avoiding transport disturbance, environmental and property damages due to a failure of sewer sections.

The digital solution "Smart sewer cleaning system with HD camera and wireless communication" (DS15) is a video nozzle for sewer jetting. The system consists of a High Definition camera that transmits the video signal from the nozzle to the inspector's tablet by wireless connection. The technology will be 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;
- Make a selection of sewer pipes that need a precise robot-camera inspection;

The solution will be demonstrated i) in Sofia, Bulgaria, where a new device will be installed and tested, and ii) in Berlin, Germany, where the technology is already in occasional use but not thoroughly assessed so far. During the demonstration phase, predefined key performance indicators (KPI) will be quantified to assess the benefits and return on investment of the solution.

7.2. Demonstration site and current practice

7.2.1. Case study 1: Sofia

Sofia City has a combined sewer system, which drains waste water mainly by gravity to the main wastewater treatment plant (WWTP) Kubratovo.

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Four pumping stations help to drain remote areas with lower altitude levels. There are six rivers that cross the city and divide Sofia's sewer network into six main sub-catchments. On the two sides of each of the rivers, the main sewer collectors are located. There are 232 combined sewer overflow structures overflowing during intense rainfalls (see Figure 26). The length of the sewer network operated and maintained by the utility is more than 1750 km, and the main pipe material is concrete.

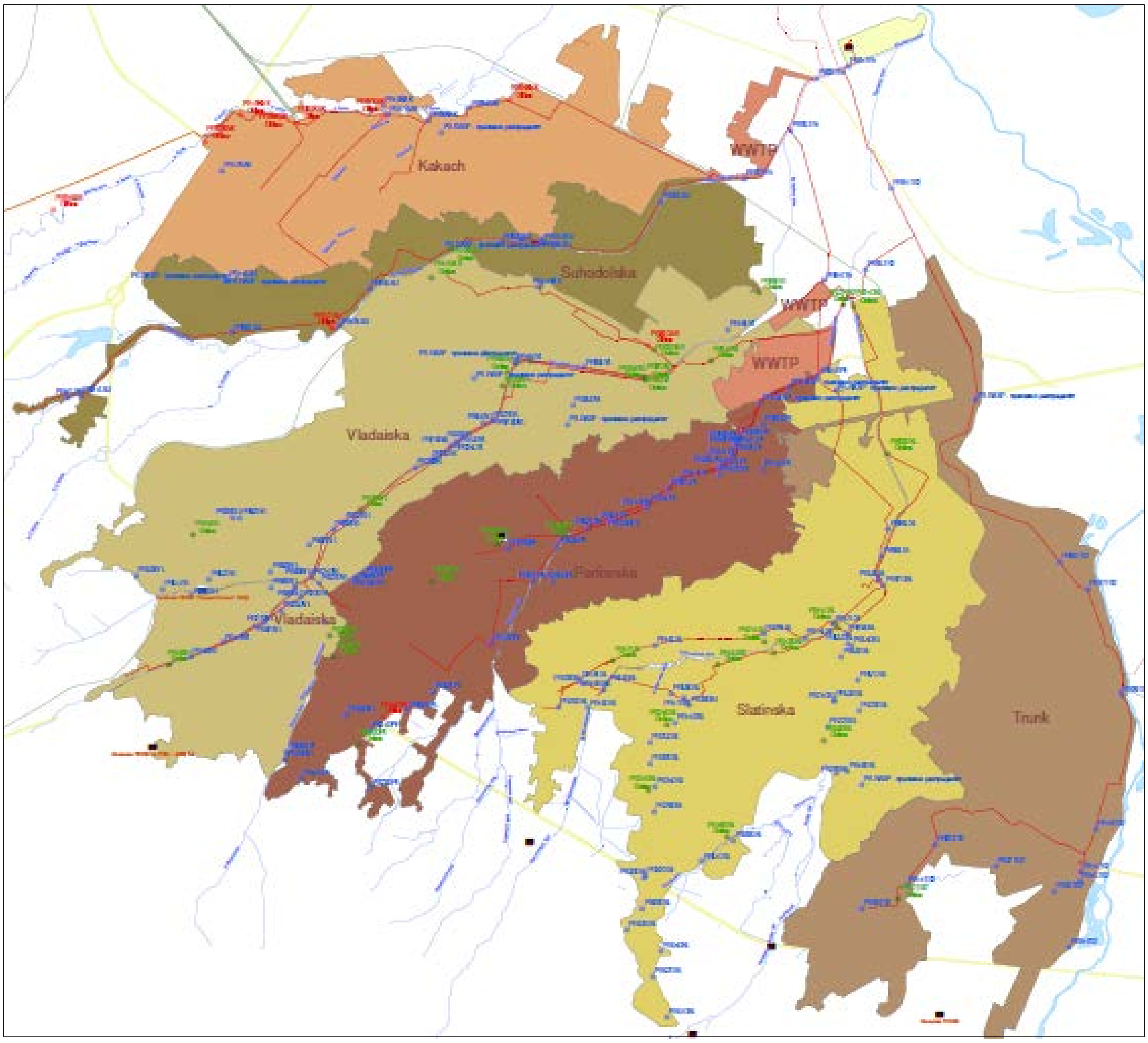

Figure 26. Sofia city catchment area

Sofiyska voda AD performs both, periodical "preventive cleaning" of sewer sections, selected by an analysis of past operational issues and "high priority cleaning" bound to present operational signals and blockages. Preventive cleaning of the sewer network of Sofia city is related to the implementation of the annual plan for cleaning and video inspection. Sofiyska voda AD does not follow any specific cleaning frequency requirement. The leading criteria for selecting the zones for cleaning has been the number of operational events, e.g. reported blockages or odour. Since 2017, the clean-up of sewer sections has been documented in a GIS layer and can be used for further analysis.

The current sewer cleaning practice is associated with some problems:

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- To date, the Sofiyska voda AD cleaning team performs “blind” cleaning with a standard nozzle. The quality of cleaning is left to the cleaning team expertise. Sometimes the following video inspection cannot be performed because of the low cleaning quality of the specific sewer section;
- The schedules of the camera-robot inspection team and the cleaning team cannot always be tightly overlapped. Sometimes there is a difference of several days from cleaning to inspection. It happens that the sewer section is again contaminated to a degree unsuitable for robot-camera inspection;
- Egg-shaped pipes in Sofia are only examined by a telescopic camera. There is a high possibility of the robot-camera overturning, at the same time the push-cameras are sinking into the relatively higher water level of this cross section;
- SV team can difficultly perform cleaning through manhole covers, which are not located on the channel axis but laterally. Preventive cleaning is not performed here.

7.2.2. Case study 2: Berlin

The proposed solution will be demonstrated in the city’s biggest sewer catchment “Wilmersdorf”, located in the central southwest of Berlin (see Figure 22 in section 6.2.1). The catchment comprises a major combined sewer system to which several smaller sub-catchments with separate stormwater and sanitary sewers are connected. This city area has a population of 265,000 and encompasses a total area of 31 km², including both combined and separate sewers. The settlement structure shows a high variety in population density with little industry and is therefore representative of municipal wastewater in Berlin. The wastewater reaches a total volume of approximately 40,000 m³ per day during dry weather conditions. The whole sewer network is generally very flat, which leads to increased problems with sediment transport. Further, the sewer pipes show a high variability in diameter, shape, slope, material, effluent type and age and therefore make the catchment an appropriate demo site for the proposed solution.

The proposed solution can help in different use cases for which the current practice is as follows.

- *Standard cleaning*: Standard sewer cleaning process is usually done “blindly” from the top of the street by operational experience. A visual support could reduce the number of cleaning processes per sewer and potentially increase the motivation of the employees by getting an optical impression of their actions.
- *Pre-cleaning for CCTV inspection*: Elaborate CCTV inspections are compulsory in Berlin to record and assess sewer damages and cannot be fully substituted by the proposed solution. However, CCTV inspections usually require a preliminary cleaning of the pipe, which can be supported with the proposed solution.
- *Observation of known sewer damages:* Currently sewer damages cannot always be repaired right after their detection, due to the high quantity of operational tasks incurring every day. These known sewer damages need to be observed constantly by the operational team until the damage is resolved. Observation is currently carried out by CCTV inspections, by electronic mirrors or manually, but the proposed solution could facilitate this activity.
- *Visual control of obstacle removal in sewers*: The removal of obstacles, e.g. roots, is a frequent operational activity in the sewer system, but is usually difficult and time consuming. A visual tool as the proposed solution may simplify this process.

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7.3. Technology description

The advanced sewer cleaning and inspection technology, called "XPECTION" is a wireless live HD video nozzle for efficient sewer cleaning and sediment removal in sewer pipes with diameters from 200 to 1500 mm. The cleaning length depends on the length of the sewer flushing hose. The system consists of a camera in High Definition (HD) quality, which transmits the video signal wirelessly and can be modularly mounted onto various nozzles. This product was specifically developed for high-pressure sewer cleaning and enables both, good cleaning performance and simple visual inspection in one single work step. The different hose guides with repeater and meter counters transmit the signal to the surface. At the control panel it is possible to view and record live HD video and pictures from the cleaning job and meter counter.

7.4. Role of partners

The different partners and their respective roles in the demonstration are as follows:

Partner	Responsibility
SV (task leader)	• Perform demonstration on site • Perform the analysis of the results (KPI) • Organise and support task meetings • Write and coordinate deliverable sections for D2.1 (implementation plan) and D2.2 (report on performance of solution)
IPEK	• Deploy and install the technology on cleaning trucks in Sofia • train the teams of SV to work with the technology • take part in KPI discussion and results of the project • Write and coordinate deliverable section for D2.3/D2.4 (technology report) • Contribute to deliverables D2.1 (implementation plan) and D2.2 (report on performance of solution)
BWB	• Provide information about their experience with the technology to SV (to support their demonstration campaign) • Perform a demonstration on site • Take part in the analysis of the results (KPI) • Contribute to deliverables D2.1 (implementation plan) and D2.2 (report on performance of solution)
KWB	• Support the project process • Support SV in assessing the performance of the solution compared to status quo

7.5. Actions and timeline

7.5.1. Case study 1: Sofia

The advanced sewer cleaning technology will be tested in the catchment of Sofia city, following the company's "Cleaning and Inspection Plan for 2020".

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The total selected length for proactive and high priority cleaning for 2020 is 140 km with i) approx. 60 km high-priority cleaning, e.g. after blockages and ii) approx. 80 km of proactive cleaning with subsequent video inspection. 10 km of the pipes approved for proactive cleaning will be cleaned and inspected with the proposed technology.

The selected pipes mostly have a circular cross section. The technology will also be tested in egg-shaped cross sections. The size range of selected diameters is from 200 to 800 mm. The need for proactive preventive cleaning of the selected pipe sections will be proved by inspection with a telescopic camera, just before the preventive cleaning is carried out.

The organization of cleaning works will follow the assignment to Sewage Services Areas (Figure 27), this is an internal division of areas with approximately the same operational and maintenance workload. In each zone, districts with the highest values of the ratio between the number of operational events in the time period of 2016-2019 and the length of the sewer network operated by SV are selected. Special attention will be paid to districts with increasing number of operational events.

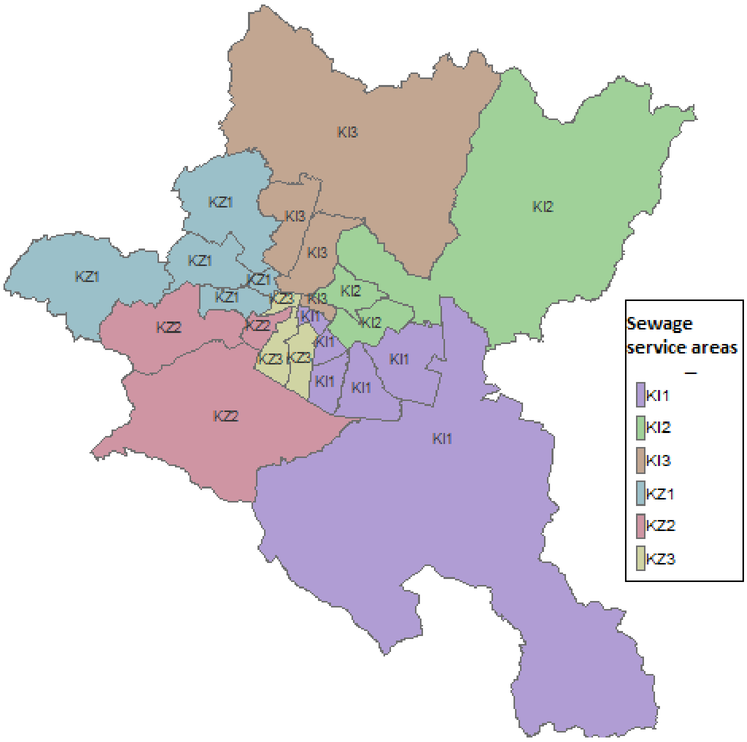

Figure 27. Sewage Services Areas 1 in Sofia City

The cleaning procedure of a selected pipe consists of the following steps:

- *Step 1*: Inspection by telescopic camera of the selected sewer sections proving the need for cleaning. Result („YES“- cleaning needed; "NO" – no need of cleaning)
- *Step 2*: If "NO", the team will record the field check and move to the next site, starting again with "Step 1"

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- *Step 3*: If "YES" –(perform a "blind cleaning" with standard nozzle) [18]
- *Step 4*: Perform cleaning and inspection with XPECTION;
- *Step 5*: Documentation of the sewage section cleaning according to the pre-defined KPIs.

The demonstration phase in Sofia is embedded in the Cleaning and Video Inspection Plan of SV for 2020, following the timeline in Figure 28.

Task 2.1.3 Advanced sewer cleaning with smart combination of HD camera and cleaning																							
2020												**2021**											
1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
		1		**2**	3	3	3	3						4	4	4	4	4	4	4	4		

Figure 28. Gantt chart for the demonstration of DS15 in Sofia. Numbers represent: 1. Delivery of the equipment (IPEK) - 06.03.2020; 2. One-week training in Sofia (IPEK/SV) – 10th-15th May 2020; 3. Demonstration phase in Sofia (SV) – summer period June-September 2020; 4. Assessment of performance and ROI.

NB! The calendar schedule is current as of the date of writing of the document. It is possible to undergo changes related to the state of emergency (COVID-19) on the territory of the country (for the time being up to 13.04.2020)

7.5.2. Case study 2: Berlin

Demonstration and evaluation of DS15 in Berlin is conducted for a variety of sewer pipes and different use cases (standard cleaning, pre-cleaning for CCTV inspection, observation of known sewer damages), as outlined in section 7.2.2. BWB will investigate the performance for the current practice and for using the new technology for a 4-6 week period each. The operational team will be accompanied during their daily work routine, especially regarding the following activities: standard cleaning, pre-cleaning before CCTV-inspection, observation of known sewer damages and visual control of obstacle removal in sewers.

For each use case, the performance in current practice and with implementation of DS15 will be analysed, evaluated and compared. Furthermore, the relevance of different sewer parameter (sewer type, diameter, sewer shape etc.) will be evaluated and the operational effort using DS15 will be assessed. Figure 29 shows a Gantt chart of the timeline for the demonstration in Berlin.

[18] The plan for Sofia city is to perform cleaning with XPECTION after blind cleaning with standard nozzle, because the sewer system is very silted and it happens to find stones in the pipes. It is also typical for the CCTV crew not to find well-cleaned pipes, so that it will be a kind of control of the standard cleaning. This plan may change after the training.

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Figure 29. Gantt chart for the demonstration of DS15 in Berlin; as in Sofia the start of the demo is currently uncertain.

7.6. Key performance indicators

Table 7. Key performance indicators for DS15

KPI	Unit	Equation	Description
Inspection efficiency	Number of defects per 100m sewer pipes	$IE = \frac{1}{n} \times \sum_{i=1}^{n} d_i$ *n – 100 m of sewer pipes* *d – number of defects per 100 m of pipe*	Number of major defects detected per 100 m inspected pipe length
Cleaning efficiency 1	%	$CE1 = \frac{A1 - C1}{A1}, \%$ *A1 - Total km cleaned pipes;* *C1 - km cleaned pipes with claims*	Cleaned pipes with claims are these pipes where the cleaning procedure with standard nozzle was repeated before the XPECTION could be used (only for Sofia)
Cleaning efficiency 2	Number of flushes per 100 m sewer pipes	$CE2 = \frac{1}{n} \times \sum_{i=1}^{n} d_i$ *n – 100 m of sewer pipes* *d – number of flushes per 100 m of pipe*	Number of flushes required with XPECTION per 100 m cleaned and inspected sewer pipes will be compared to the number of flushes required with standard nozzle (Berlin, Sofia)
CAPEX	€ / device	-	The investment costs for XPECTION technology will be compared with the investment costs of the technologies used in the current practices. These costs will be provided by BWB and SV.
OPEX	€ / 100 m cleaned sewer	$OPEX = \frac{1}{n} \times \sum_{i=1}^{n} Specific\ operational\ costs$ *n – 100 m of sewer pipes*	The operational costs for XPECTION demo will be compared with the operational costs of the standard practices of the utilities. Data will be provided by BWB and SV.
Comment: Operational costs will be distinguished into i) personal costs due to time saved, ii) costs for fuel saved and - for Berlin – costs for water saved for cleaning and inspection (in Sofia recycling cleaning machines are used).			

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8. Summary and outlook

The present report is the first of three deliverables produced in DWC-WP2. It summarises the approaches and methodologies developed to demonstrate ten different digital solutions for four different domains of the urban water system: drinking water wells, sewer networks, wastewater treatment and water reuse. It further outlines how the benefits of the different solutions, ranging from the minimisation of environmental impacts to the improvement of long-term management of infrastructure capital assets, will be quantified.

For most of the presented solutions, the demonstration will start in summer 2020, under reserve of the uncertainties related to COVID-19. First results on the performance and return on investment of the solutions can be expected for Nov. 2021 (M30), which is when the draft version of the assessment report (D2.2) will be published. The final results (D2.2, final version) can be expected for Nov. 2022 (M42, end of the project).

More technical details on the different solutions will be given in a technology report, which will be ready as a first draft in Nov. 2020 (M18, D2.3). The final version of the report (D2.4) will be ready in May 2022 (M36). In the meantime, more information on the digital solutions and on DWC can be found on the project homepage: www.digital-water.city.

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