Proceedings of IWA Specialist Conference on Leading Edge Strategic Asset Management (LESAM), 2022

Oliver Nachevski, Rita Salgado, Bénédicte Rulleau, Didier Sinapah

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Editors

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FOREWORD

The LESAMs, the 3-days key biannual conferences of the IWA Strategic Asset Management Specialist Group (SAM-SG), have established a consolidated leading-edge forum where utilities, consultants, regulators, researchers and asset managers identify and discuss the main challenges, new solutions and trends in strategic asset management for the water sector. After the pandemic, LESAM 2022 in Bordeaux, France, enabled the Asset Management (AM) community to get together face-to-face and enjoy both the technical and the social events.

The abstracts included in this publication covered several topics in asset management: the specificities of urban water infrastructure, the interdependencies between water and other urban services and infrastructures, the contribution of the management of the assets, communication issues, urban drainage asset management, the integration of nature based solutions, digital water, the economic, financial and organisational aspects, management systems, and examples in specific contexts.

The overall conference covered several other aspects, discussed in keynotes, roundtables, elevator pitches and a think tank: institutional and policy aspects, global change, the context of circular economy, thinking ahead inter-generationally, safety and security, and AM in developing countries.

Leading edge concepts, methods, technologies and application cases have been presented and discussed. This publication compiles a significant part of the conference papers, covering the whole span of topics.

On behalf of the scientific committee of the conference, I wish that the readers learn and enjoy as much as we did.

Rita Salgado Brito

On behalf of the LESAM Scientific Committee
Chair of the IWA SAM-SG

EDITOR'S NOTES

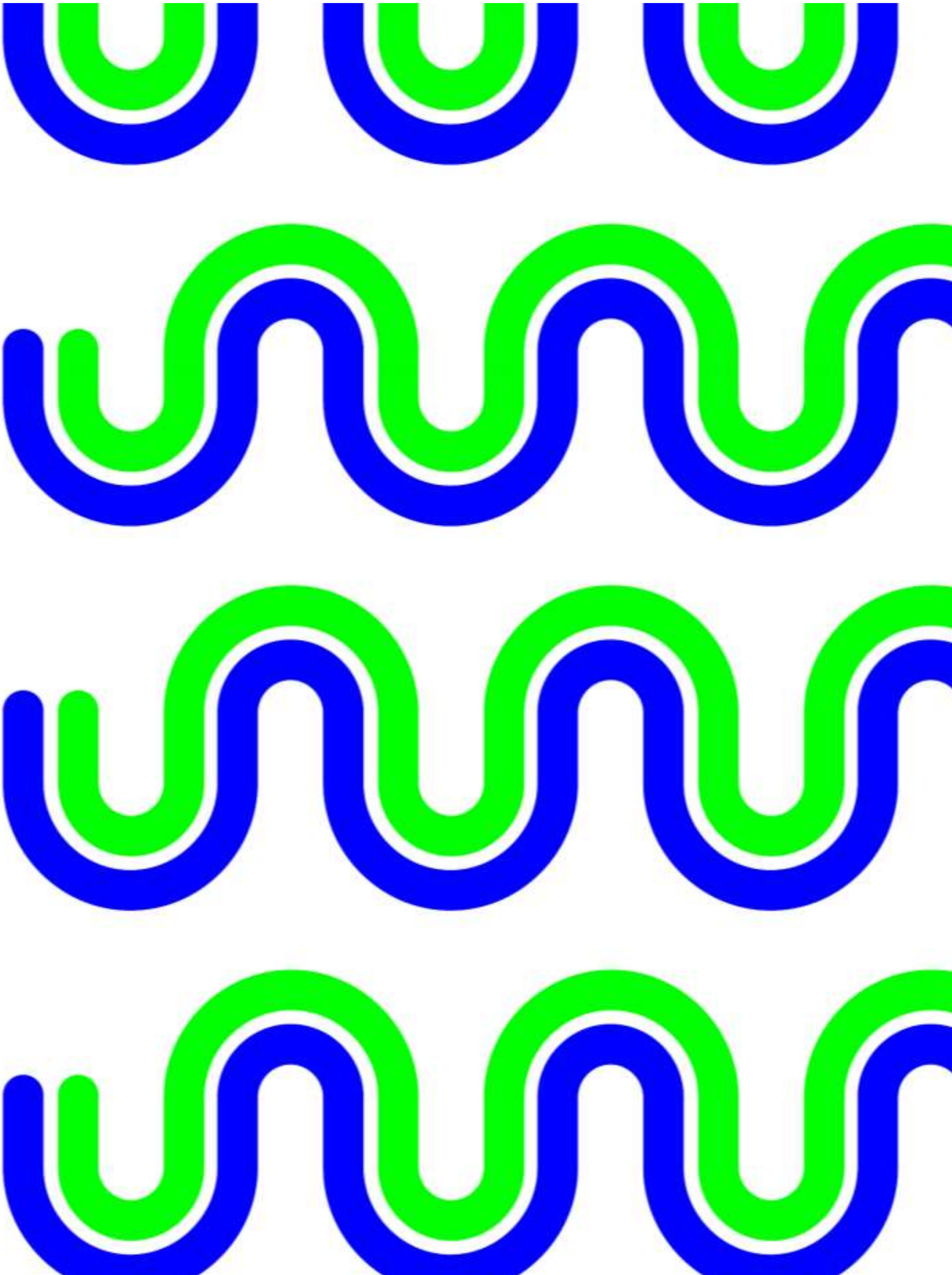
Readers can grasp the essence of LESAM 2022 with these proceedings, which present the abstracts or extended abstracts sent from the authors. For both cases, this was the authors' choice.

Some of the abstracts correspond to full papers that were proposed for publication in IWA Publishing journals. This was a proposal from the editorial team and had the agreement of the authors. This process is still ongoing. In such case, a specific reference is made so you can latter search for the full version of the document.

Oliver Nachevski

Vice-chair of the IWA SAM-SG

ABSTRACTS AND EXTENDED ABSTRACTS



Risk-based prioritization of inspections and rehabilitation of wastewater pipes

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Abstract
Reinvestments in wastewater pipe networks are expensive, and the process of prioritizing pipes is complex. With significant investments in the coming decades, water utilities have the potential to reduce the societal costs for rehabilitation by prioritizing the high-risk wastewater pipes and simultaneously increasing the quality of service. To enable this, useful decision support is needed. Hence, a hands-on risk-based model is presented for providing decision support and facilitating rehabilitation strategies for wastewater pipe networks. The model includes a first phase with the aim to identifying high-priority pipe candidates for TV inspection, and second phase used to prioritize pipe rehabilitation. The Swedish Closed-Circuit TV structural pipe grade is used in a multi-criteria decision analysis to describe the consequence of failure and to perform a risk assessment and prioritization of wastewater pipe rehabilitation. The model was applied to the wastewater pipe system in Kungsbacka municipality, Sweden, to demonstrate how it can provide water utilities with decision-support for renewal planning. After only half a year, it had successfully been implemented to manage the wastewater pipe network in Kungsbacka. As a result, the risk-based model has been used to evaluate the risk of failure for 97.3% of the pipes within the wastewater pipe network, and an inspection plan and rehabilitation priority have been developed.

Keywords: Asset management, wastewater pipe network, rehabilitation, risk-based model

Note from the editor: proposed for publication in IWA Publishing journals

Increasing the preparedness of water critical infrastructure operators against cyber and physical threats

Water critical infrastructure protection against cyber and physical threats: the STOP-IT approach demonstrated in a real environment.

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Abstract
Water critical infrastructures are undergoing a process of digital transformation which entails an increasing integration between the physical and cyber layers of the system. This integration brings efficiency and monitoring advantages, but it also exposes water systems to a new threat surface that includes cyber-attacks. Formed in 2017, STOP-IT (https://stop-it-project.eu/) is Europe's first project dedicated to developing cyber-physical security solutions tailored to the water sector. During the four years of collaboration, the STOP-IT team has co-developed an extensive list of technologies that integrates cyber and physical layers of infrastructure, allowing water utilities to prevent, detect, assess, and treat risks, as well as simulate scenarios of attacks and explore how to react to increase preparedness. This article first introduces the overall aim and main outcomes of the STOP-IT project and then focuses on the risk management integrated framework composed of modelling solutions developed to help water utilities identify vulnerabilities and protect critical parts of their systems. The solutions are presented along with the results from the demonstration activities performed by a selected water utility.

Keywords: critical infrastructure protection; cyber-physical systems; cyber-physical attacks; digitalisation; risk management; water systems and services.

Strategic Asset Management and stakeholder's communication. The use of the Infrastructure Value Index (IVI), the Infrastructure Degradation Index (IDI) and Infrastructure Histogram (H_I)

Strategic Asset Management and Stakeholder's communication. The use of IVI, IDI and H_I.

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Abstract
The state of water infrastructure is becoming a concern as they are being aging without being properly renovated. They are capital intensive assets with a long operational life. Besides, they are generally buried. Therefore, it is not immediate to assess their condition and stakeholders are not aware this urgent need of renovation. The development and implementation of tools that ease stakeholder's communication is a crucial step for guaranteeing the sustainability of the infrastructure in the long term. This work analyses the results obtained in 60 networks by three tools specially designed for this purpose and the benefits they provide when they are used complimentarily to evaluate the state of water networks. These three tools are the Infrastructure Value Index (IVI), the Infrastructure Degradation Index (IDI) and Infrastructure Histogram (H_I).

Keywords: Infrastructure Degradation Index (IDI), Infrastructure Histogram (H_I), Infrastructure Value Index (IVI), long-term planning, stakeholders' communication, water services.

Note from the editor: proposed for publication in IWA Publishing journals

Efficient sewer assets management strategies to avoid financial risks

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Abstract
Currently urban drainage stakeholders are facing critical challenges to apply proactive management strategies while considering budget limitations, urban planning regulations, and municipal water infrastructure benefits. In the literature there are promising methodologies to support rehabilitation investments and the optimization of maintaining sewage infrastructure to extend the technical service life of the sewer networks. Usually, these methodologies do not consider the financial risks that may occur due to inconsistencies between the financial and the technical service life of sewer assets and the evolution of the net asset value is neglected. This paper illustrates the strategies developed at STEIN Infrastructure Management, avoiding these financial risks in Sewer Asset Management by extending the technical service life of the sewer assets. The extension is achieved by carrying out rehabilitation activities timely, considering the available budget and urban plans of the municipalities. The replacements of pipelines can be postponed significantly until they are need. According to the results, the optimized strategy improves the condition of the sewer network and the net asset value, which gains in comparison to the current strategy.

Keywords
Decision Analysis, Financial and Technical service lifetime, Financial Risk, Sewer Asset Value, Management strategies, Sewer Asset Management.

Note from the editor: proposed for publication in IWA Publishing journals

Benefit of long-term forecasts for cross-network coordinated rehabilitation

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Abstract
In maintenance of municipal road infrastructures and pipe-based supply/ disposal networks, it is difficult to establish an efficient and sustainable maintenance management due to the long service life, where efficiency stands for weighing the technical and legal requirements against the resulting financial needs, aiming for optimal use of resources. This task is made more difficult by the fact that there are often several maintenance options for the infrastructure objects, which differ in time of intervention, costs and resulting gain in service life, Additionally the optimization of a maintenance strategy for a single network may be differently focused than optimization of a combined or coordinated, cross-network maintenance strategy, driven by municipality views and public interests. Due to inhomogeneous construction activity and different demands on the infrastructures, reliable and sustainable rehabilitation planning is rather difficult without a qualified long-term forecast of the actual situation, that covers at least the average (re-)investment cycle of the addressed infrastructures. A maintenance strategy therefore needs to consider the current structural situation as well as the potential size and speed of changes of this situation in order to sufficiently and efficiently meet the rehabilitation needs of the networks and activate cost saving potentials.

Keywords: coordinated rehabilitation, strategic asset management, fabric deterioration classification, wear reserve, long-term forecast.

Note from the editor: proposed for publication in IWA Publishing journals

BN-based methodology for selecting feature hierarchically

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Abstract
Several deterioration models have been developed to predict or forecast the condition of the sewer network, however most of them depends on the data collection. Usually, the collected data are related to sewer characteristics and CCTV inspections reports to train the models. In the last studies (Guzmán et al., 2020), it was shown the advantages of using Bayesian Networks to build a methodology to find and identify the minimal number of variables required to achieve a suitable performance in the structural prediction of the sewer assets. According to the findings of this methodology, the stakeholders could reduce the quantity of information to collect and therefore, diminishing the amount of investment resources for data collection. Based on the above study, this paper illustrates a second version of this methodology, which, in addition to identifying the most influential variables on the structural condition, establishes relationships with structural condition in different important levels: first, second and third-grade relation. According to the results, it was possible to determine which are the variables that influence in the structural deterioration of the sewer assets hierarchically and find in which way the quality of prediction reduces or increases depending on management objective and the case study. As well, it was found that the sewer characteristics and age are influential variables in more than one case study, however the importance varies depending on the case study.

Keywords
Feature Selection; Influential variables; Sewer Asset Management; Structural deterioration.

Note from the editor: proposed for publication in IWA Publishing journals

Monitoring water quality in urban streams using spectrophotometry

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Abstract
Quality of service of stormwater and wastewater services ought to be assessed with a holistic perspective, considering the impact on local urban streams and their water quality. Protecting surface waters from the effects of sanitary inflows has become increasingly important in the context of urban drainage. The detection of an anomalous inflow, regardless of its origin, enables a timely reaction by the wastewater utilities.

Water quality monitoring of urban streams is mainly based on short duration campaigns, which may identify possible pollutant discharges of domestic wastewater, but does not allow immediate action from the utility. The use of spectrophotometric techniques enables continuous monitoring of water quality. UV-Vis spectra can be used as a fingerprint, for a qualitative detection of changes in water quality matrix. The use of this technology in urban streams can contribute to early warning systems and to support operational control of urban drainage infrastructures.

This article reports a test carried in a case study near Lisbon. The authors believe this procedure is valid for the detection of undue stormwater inflows into small urban streams. The availability of an on-line probe will enhance the capabilities of the implemented methodology.

Keywords
Monitoring, sewer, urban stream, UV-Vis spectra, water quality.

INTRODUCTION

The Water Framework Directive (WFD, Directive 2000/60/EC) establishes that the necessary measures must be implemented to achieve a good physical-chemical and ecological status of surface water bodies. It has recently been recognized by the European Commission (EP, 2020) that the WFD will not be revised (European Parliament, 2020); even though this target was aimed for 2015, important shortcomings in the implementation were found (good chemical and ecological status has been achieved for only 38% and 40% of surface water, respectively) and the deadline is now postponed to 2027. The main point source of water pollution in the EU is the discharge of untreated or inadequately treated urban and/or industrial wastewater. Inadequate funding, slow implementation, insufficient enforcement and broad use of the Directive exemptions are stated as the reasons why the objectives of the WFD are still to be reached.

Traditionally, pollutant load data is acquired in campaigns involving composite or grab sampling, sample conservation, transport, and analysis using standard methods. This approach implies considerable resources and does not allow for real-time decision. Some parameters are frequently subject to continuous monitoring (e.g. temperature, pH, conductivity) but the information provided is also quite limited with regard to decision making (Vanrolleghem *et al*., 2003). Indirect determination of specific parameters has been possible for some time, namely of total organic carbon (TOC), total suspended solids (TSS) and chemical oxygen demand (COD). However, water quality real-time monitoring in sewers is still considered a challenge and a knowledge field where future advances are anticipated (EPA, 2018).

Spectrophotometric techniques have been used to estimate these parameters (Van der Broeke *et al*., 2006; Torres *et al*., 2008). A spectrum results from the incidence, on a water sample, of a radiation beam covering the required wavelength range. When passing through the sample, the incident radiation will undergo scattering and absorption phenomena. For each wavelength, absorbance is determined, resulting in a spectrum for the absorbance range. The spectrum can thus be considered as a fingerprint of the sample's characteristics, varying with its chemical and physical composition. Spectroscopy in the ultraviolet-visible range (UV-Vis, for wavelengths between 190 and 800 nm) has been previously used for wastewater and stormwater quality monitoring (Van der Broeke *et al*., 2006; Lourenço *et al*., 2008; Torres *et al*., 2008), since organic compounds and soluble minerals (such as nitrate) may absorb in the UV-Vis region (Vaillant, *et al*., 2002).

In urban streams, water quality can vary with precipitation events or undue sanitary or industrial wastewater discharges. The shape of the UV-Vis spectrum is altered by such occurrences. In sewers, the shape of spectra strongly depends on the wastewater source (Pouet *et al*., 2004). Stormwater inputs result in dilution of the dissolved matter and an increase in the suspended solids content (Thomas *et al*., 2005). An UV-Vis spectrum can be considered as an indicator of water quality, applicable to the various phases of the urban water cycle. An illustrative example of this broader application was the city of Vienna, where UV-Vis spectrophotometry was used to monitor water supply sources, the water supply system, the wastewater treatment plant discharge and the receiving waters, in the Danube river (Van den Broeke, *et al*., 2008). On-line UV-Vis submersible sensors have already been used in wastewater treatment plants (Vanrolleghem *et al*, 2003) and robust submersible commercial devices are becoming available. Preliminary applications of UV-Vis spectra as a surrogate method for microbiological data was recently reported (Huang *et al*, 2021).

Spectroscopy is a promising tool for fast and simple evaluation of water quality, as it delivers spectra that may correlate to various aggregate wastewater quality parameters, such as TSS and COD (Thomas *et al*., 2005). Even if these parameters are not determined, the spectrum shape can change as a response to water quality variations, for example due to an organic load variation, because of stormwater inputs into sanitary sewers (Brito *et al*., 2013), or of industrial inflows (Pouet *et al*., 2004, Brito *et al*., 2017). In such case, the shape of the spectra itself can be used to pinpoint changes (Pons *et al*., 2017).

Scope and significance of acquired spectral data can be enhanced by statistical models. Chemometric methods using advanced multivariate analysis are applied to extract information from spectra, such as quality fingerprinting through Principal Component Analysis (PCA). Searching for trends in series, PCA can be implemented to identify different patterns. A spectrum can, after being submitted to a PCA model, be represented in a space of reduced dimensions, by the score values relative to the first principal components. PCA makes it possible to identify, against a group of spectra, if they all have the same format or if there is a sub-group that, for whatever reason, stands out in the scores chart. This approach has been used in wastewater successfully (Brito *et al*., 2016), and in river monitoring (Yu *et al*., 2015; Assaad *et al*., 2017).

The performance of a wastewater system cannot be entirely assessed by considering the sewers, the treatment plants and the pumping stations, while neglecting the impact induced by undue inflows into the receiving waters. A system approach is required, in alignment with infrastructure asset management (IAM). Regarding urban streams, these are subject to several pressures from the urban water systems, as there are numerous interactions between the components of the sewer infrastructure and the natural environment: cracked sewer joints, fissures in manholes and pipes, blockages, by-passes and weirs may cause wastewater to reach the stream or the natural waters to enter the sewer system.

Ultraviolet-visible (UV-Vis) spectroscopy application in urban streams has scarcely been reported and is a step forward in water quality monitoring, with regard to the guidelines of the Water Framework Directive. This paper aims to evaluate the applicability of UV-Vis spectroscopy to relate drainage systems and urban streams, and in particular to examine whether UV-Vis spectra can be used to fingerprint changes in urban streams' water quality, due to wastewater discharges.

METHODOLOGY

The implemented methodology follows a three-step process: identification of locations in urban streams with evident wastewater pollution and implementation of monitoring campaigns; determination of water quality parameters and UV-Vis spectra acquisition; spectral analysis.

Monitoring stations and sampling campaigns

Case study stream extensions are selected given their prospective to contribute with spectral changes from upstream to downstream, due to changes in the water quality matrix. For this purpose, locations are selected provided wastewater discharges were previously identified. For diversity, 3 locations are selected. Monitoring should occur in dry weather, after at least 5 days without rainfall. Lasting rainwater contributions have a dilution effect, which tend to dampen the undue wastewater inflow and the corresponding spectra. When undue inflow occurs in an urban stream, average TSS and COD are usually higher in dry weather. Water samples are taken in the stream (upstream and downstream the sewer discharge), and also in the incoming sewer. Three samples are collected in each station.

Hydraulic and water quality parameters and UV-Vis spectra

The water samples are analysed for TSS and COD, and UV-Vis spectra is acquired. TSS and COD analyses were performed by an external laboratory, using the Standard Methods for Examination of Water and Wastewater 2540-D and ISO 6060:1989, respectively. Results are expected to be significantly higher in the sewers. As an example, according to the Portuguese applicable national legislation, the limit values for TSS and COD for a wastewater discharge are, respectively, 60 and 150 mg/L. Values in the streams are expected to be lower than these limits; if not, and if the values increase from upstream to downstream, it means that the incoming discharges are likely to already having a significant impact in the stream's water quality.

To simulate the acquisition of in situ spectra, UV-Vis spectra are acquired off-line with a UV-Vis portable submersible probe (Spectro:lyser, S:can), between 200 and 750 nm with a 2,5 mm optical path length and 5 nm interval. For each sample, duplicate sub-samples are subject to spectra acquisition. For each wavelength, the difference in absorbance between duplicates is calculated, and 95% confidence intervals are determined. The pairs of spectra with more than 95% wavelengths outside the 95% confidence interval are considered outliers, and a new pair of spectra is determined. Flow estimates are made based on velocity, flow height and cross-section geometry measurements, in the stream and in the sewer pipes. Average velocity is estimated by measuring velocity at several locations in the cross-section in the stream, and in the flow centre in the pipe, with a portable Doppler velocity meter. The flow height was measured using a graduated ruler. Measurements are taken before, during and after water sample collection. Due to the uncertainty associated with these measurements, both in relation to the geometry of the section and to the hydraulic variables, these results are considered indicative. Flow is estimated using the continuity equation (Equation 1).

$$Q = U \cdot S \tag{1}$$

where Q: flow (m^3/s); U: average velocity (m/s); S: flow cross-section (m^2).

When wastewater samples are available, dilution tests can be prepared. Laboratory samples, with a varying percentage of wastewater added into upstream water volume, are prepared. Spectra are acquired from these composite samples. Comparing the spectra from the composite samples (for which the percentage of wastewater is known) with the spectra obtained in the downstream stations, it is possible to estimate approximately the percentage of undue wastewater in the streams. This estimate can be endorsed by the flow determinations given by equation 1.

Spectral analysis

Spectral analysis aims to support comparison of spectra from upstream to downstream. In this study, it was performed based on spectral graphical analysis for fingerprinting water quality changes. Spectra are expected to have higher absorbencies in samples more contaminated with wastewater. If so, samples collected upstream are expected to be placed below, in a spectral graph, sewer spectra are expected up above, and downstream samples in-between, as the wastewater inflow will be diluted by stream waters.

Case study

Three locations were selected in the outskirts of Lisbon, in Portugal. In all the locations, the sewer networks are sanitary and designed to flow into wastewater treatment plants. Wastewater discharges into the streams are not supposed to occur.

Site A, a medium size stream with less than 1.3 m width, is in the surroundings of a small village. A small wastewater discharge was documented. Three stations were monitored: upstream (A_{up}), downstream (A_{dw}) and in the sewer pipe (A_{pp}) (Figure 1a). Site B (Figure 1b) is a larger stream, with up to 10 m width, crossing farms along a small village. Several small wastewater discharges were documented. Four stations were monitored: upstream (B_{up}), downstream (B_{dw}) and two intermediate stream sections (B_1 and B_2). Several incoming sewers were acknowledged: two between stations B_{up} and B_1, five between stations B_1 and B_2 and four between stations B_2 and B_{dw}. These sewers were not monitored. Site C surroundings are mostly urban, with consolidated buildings and a small stream crossing the area, mostly buried in a 1.5 m diameter pipe. An undue inflow had already been identified. Four stations were monitored: far upstream (C_{up}), downstream (C_{dw}), one intermediate stream section (C_1) and in the sewer pipe (C_{pp}) (Figure 1c).
Monitoring campaigns occurred in December 2014 and were used to support the identification of priority locations for rehabilitation works. For each monitoring station, three samples were retrieved, with a 5-minute interval. For one of the samples, TSS and COD were determined by standard procedures. For each sample, UV-Vis spectra were acquired in duplicate. Flow estimates for water in the streams were made. For sites A and C, where access to the incoming sewers pipes was available, wastewater flow estimates and dilution tests were done. Dilution testes were made for samples with 5, 10, 25, 50 and 75% of wastewater and the remaining volume with stream water from the closest upstream sections (A_{up} and C_1, respectively).

a) Site A b) Site B c) Site C

Figure 1: Sites and respective monitoring stations a) site A, b) site B, c) site C

Geometry and hydraulic measurements took place sites A and C. These did not occur in site B, as data on sewers is not available. Flow estimate is moderately accurate, less so in the streams, as the cross section is more irregular than in the pipes. This is namely the case in site A, even though measurements were taken under the bridge (Figure 1a, after station A_{up}). In site C, the rectangular concrete section in station C_1 was used (Figure 1c). Four measurements on hydraulic variables were made, one before and one after each water sampling.

RESULTS AND DISCUSSION

TSS and COD were determined in laboratory, as already defined. Results are presented in Figure 2. The sewer values (A_{pp} and C_{pp}) exceed national legislation emission limits for wastewater discharges, implying that a considerable amount of untreated wastewater is present in the sewer.

In site A, both the upstream and downstream stream values are below the limits; parameters present very low values, a bit higher downstream, naturally due to the incoming sewer.

In site B, stream values are quite low and similar to each other. COD is always below the detection limits. TSS presents a slightly unexpected variation, somewhat increasing from B_{up} to B_1, decreasing to B_2, and increasing again to B_{dw}. This might present some constraints to the interpretation of results. Apparently, the water quality matrix, in the stream, does not change meaningfully on its progress downstream.

In site C, stream values are higher than in the other sites, which is probably expected, as this site is more urban. Values significantly increase from upstream to downstream; downstream, values are clearly above the legislation limits for a wastewater discharge, meaning that the stream is already quite polluted.

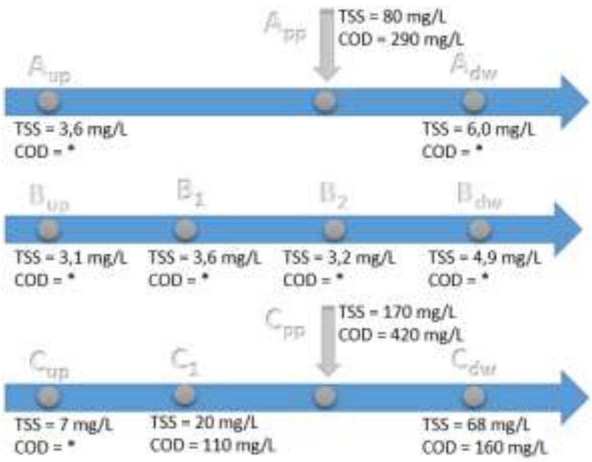

Figure 2: TSS and COD results in sites A, B and C
(* below the method detection limit of 30 mg/L)

Regarding UV-Vis spectra, it was not necessary to reject data on lower wavelengths, as absorbance in this region did not exceed the equipment saturation limit. Outliers were investigated between duplicates, as explained. The pairs of spectra acquired from the three samples from site C_{pp} were rejected, and for these samples a new pair of spectra was determined. A preliminary spectrum on tap water was acquired, for reference.

UV-Vis spectra acquired in sites A, B and C are presented in Figure 3. For sites A and B, in Figure 3, a zoom into lower absorbance is provided, for a better insight.

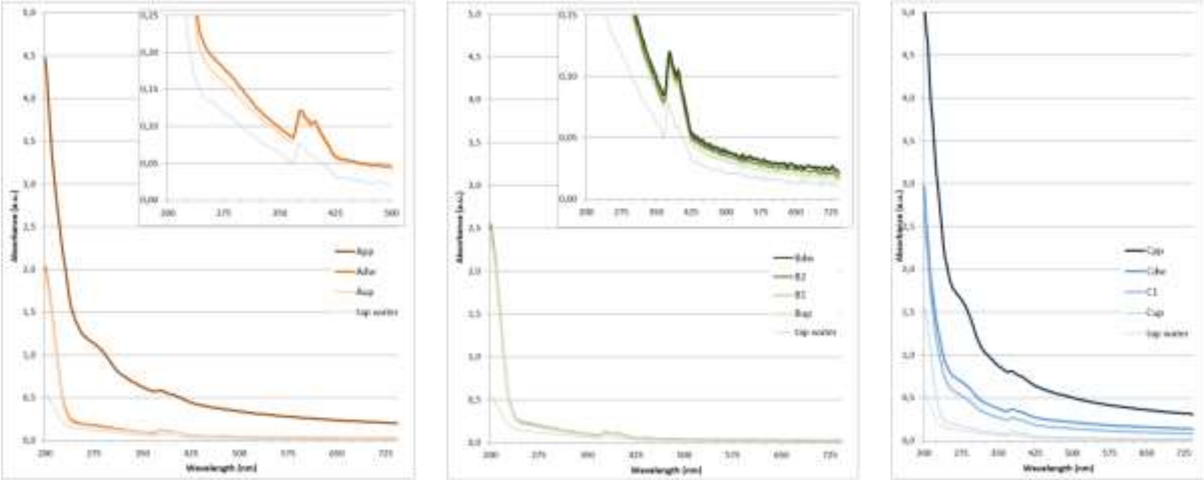

Figure 3: Spectra in sites A, B and C (from left to right)

Graphical analysis shows that spectra followed a similar pattern for most samples, but that patterns differed for samples collected upstream or downstream the wastewater contribution, which was more obvious in site C.

Is was evident in site C, and also in site A (although less clear), that the wastewater discharge can be fingerprinted visually, from spectral comparison. Spectra taken downstream the discharge are closer to the sewer spectra than the ones taken upstream. Downstream spectra are placed in-between the sewer and upstream spectra, suggesting that the water quality parameters are also in-between. Wastewater discharge changed the streams water quality, with the organic load increase translating into an absorbency increase. This was particularly evident at lower wavelengths in site A, in higher wavelengths in site B, and across the spectrum in site C.

As suspected, in site B this graphical analysis was not encouraging, as the spectra are much closer to each other, although also evolving to higher absorbance from upstream to downstream. This is probably due to lack of sample representativeness. With just a location for water sampling, in a larger stream the water quality heterogeneity is perhaps not sufficiently characterised. The locations chosen for intermediate sampling could have not been sufficiently close to the dispersion plume of the wastewater discharges. Another explanation might be that, given the stream's largest cross sections, the wastewater discharged volume was irrelevant when compared to the stream's water volume, making the wastewater discharge more challenging to trace.

Hydraulic data was collected in sites A and C. In site A, flow was estimated around 0,65-0,69 L/s in the sewer and 9,5 and 15,2 L/s upstream, leading to a 4,3-6,4% of wastewater downstream. In site C, flow was estimated as 1,8-2,5 L/s in the sewer and 19,2-24,4 L/s upstream, leading to a 6,7-10,9% of wastewater downstream. Flow is expected to change during the monitoring campaign in each site.

Regarding the dilution tests, UV-Vis spectra acquired in composite samples from sites A and C are presented in Figure 4. Respectively for sites A and C, samples are identified as A_{05}, A_{10}, etc., or as C_{05}, C_{10}, etc., to represent the percentage of wastewater included (i.e., 5%, 10%, etc.). In these graphs, the three spectra acquired for the downstream stations (A_{dw} or C_{dw}) are also represented.

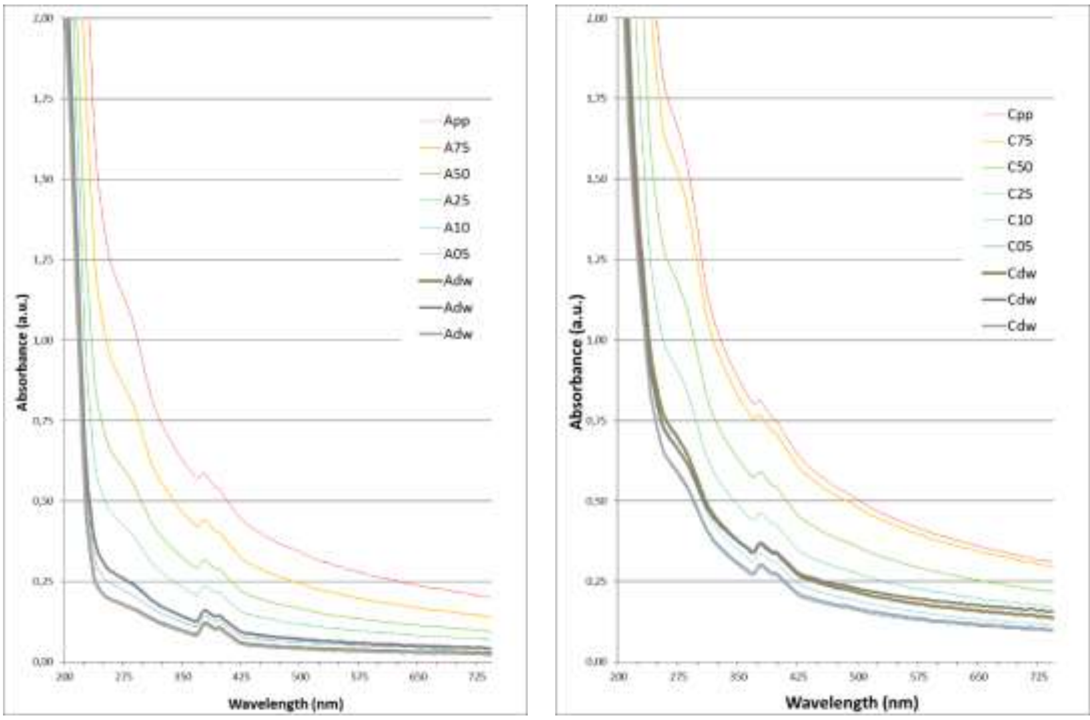

Figure 4: Spectra from dilution tests in sites A (left) and C (right)

Comparing the spectra acquired for the downstream stations with the composite samples, wastewater percentage in the streams can be implied. In site A, wastewater percentage is estimated at below 5% up until 10% (as the A_{dw} spectra range from below A_{05} and almost overlap with A_{10}). In site C, wastewater percentage is estimated as slightly above 5% up until 15-18% (as the C_{dw} spectra range from above C_{05} and stand between C_{10} and C_{25}). These ranges are broader than the ones estimated from hydraulic calculations, but are still quite close, putting this spectral comparison forward as a usable approach for estimating pollution inputs in urban streams.

CONCLUSIONS

Continuous monitoring is a very relevant contribute to comply with the WFD deadline of 2027, even more when considering that climate change can have an important negative impact on freshwater sources, with droughts causing depleted river flows, and intense rainfall inducing increased urban and agricultural run-off (European Parliament, 2020).

Within the scope of this study, the application of UV-Vis spectrophotometry to urban streams is evaluated, namely for the detection of undue inflows. The results allow to conclude that, for narrower streams, the UV-Vis spectrum of the stream changes just as wastewater is discharged, even when the change in terms of TSS is not excessive. This change in the spectrum shape occurs for the inflow of a reduced percentage of wastewater, having been detected for less than 5%. It was also found that a graphical comparison of spectra allowed the estimation of the percentage of wastewater inflow.

This experimental application of spectrophotometric techniques to urban water streams was proven to be quite interesting for an enhanced comprehension of the connections between natural and constructed drainage systems, and it could be a useful tool for continuous monitoring of the receiving waters and of the performance of wastewater drainage infrastructure. However, it should be noted that the developed work is based on a reduced number of samples. The evolution of knowledge will have to be supported by broader monitoring campaigns, in different flow and precipitation contexts.

This study allows to anticipate the use of the submersible probe for online monitoring, with all the advantages of real-time acquisition of UV-Vis spectra. This strategy would enable early warning alarms in a discharge situation, and has a great potential for the operational control of urban drainage systems, the protection of water bodies and the safety of public health. The on-line UV-Vis monitoring has an improved potential for larger streams. The need for extra monitoring stations and the demand to track the wastewater dispersion plume might benefit from the use a probe that can, in a limited amount of time, collect spectra from a greater water mass.

Following these campaigns in the case study, focused inspection and detection of the undue inflows were performed. In 2022, most of the predicted construction works to adequately deviate wastewater into the wastewater system will be concluded. After completion, the utility intends to implement similar campaigns in the same locations to evaluate whether the implemented actions had the expected impact in the streams' water quality. The same strategy will be implemented in other catchments.

The following step of this project is to implement principal component analysis, PCA, to support the spectra analysis and consolidate their use for early detection of undue inflows into small dimension streams.

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Impact of inspection data quality on structural substance assessment of sewers

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Abstract
Both the well-established condition assessment and the newly developed assessment of a sewers structural substance are based on visual (CCTV)-inspection and defect coding, and thus a prone to errors and incomplete inspection data. In this study, we aim at understanding the sensitivity of structural substance assessment of sewers to several sources of uncertainties in the inspection procedure. We identified main uncertainty sources in the assessment procedure and propagated this uncertainty in the structural substance assessment of 80,000 sewer pipes. By comparing original inspection data with manipulated one, the effect of specific error types became quantifiable. It was observed that the use numerical assumptions for defect severity instead of performing a single case defect evaluation had a smaller impact on the substance assessment than on the condition assessment. However, the structural substance is more sensitive towards errors related to the extension of defects. While some errors can change the substance value / substance class of single reaches significantly, the mean impact is much lower. The substance assessment of a whole sewer network is thus quite robust against the here considered errors of inspection data.

Keywords
CCTV Inspection, Condition assessment, Pipeline, Sensitivity analysis, Substance assessment, Wear

INTRODUCTION

For the rehabilitation planning of sewer systems, a condition assessment is carried out using a standard methodology in Germany (DWA-M 149-3). It provides information on the rehabilitation urgency of sewers and thus supports short-term rehabilitation planning. However, it has been shown that the data is not suitable for setting up long-term rehabilitation strategies and for identifying the best rehabilitation technique (Kerres et al., 2020). To fill this gap, as a supplement to the traditional condition assessment, a standardized structural substance assessment was developed in the SubKanS project. In contrast to the condition assessment, the structural substance is not based on the assessment of the most severe individual defect of a reach. It considers mainly the defect density and distribution and is defined as the structural wear of a reach. The note lies between 0 % (sewer in new condition) and 100 % (completely worn). Both ratings assign a class between 0 (very low condition/substance) and 5 (very high condition/substance) to a reach and are based on the visual inspection and the defect coding according to NS 13508-2 (EN 13508-2:2003+A1:2011).

The CCTV visual data is evaluated manually. To each of the detected defects a severity class is assigned afterwards that is linked to the defect code. Errors can occur during coding that affect the subsequent assessment. Caradot et al. (2017) found, that the condition of 20 % of pipes in bad condition was overestimated. Furthermore, for some of the defects the severity class needs to be assigned on an individual basis by qualified engineers. The substance algorithm however was aimed to be automated. Therefore, these case-by-case decisions were replaced by numerical values suggested in the BFR Waste Water Guidelines (2019).

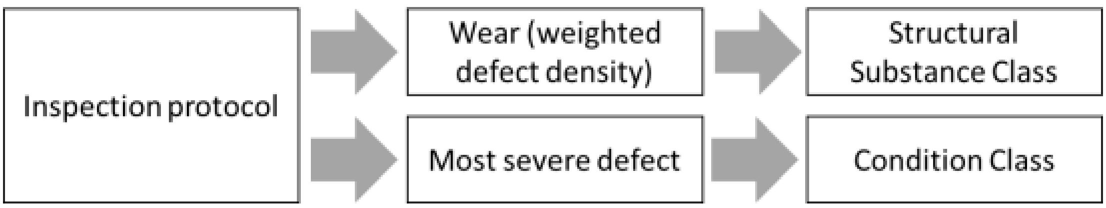

Figure 1: Simplified Structural Substance and Condition assessment based on inspection protocols

In the presented sensitivity analysis, the extent to which errors in defect coding and falsely assumed numerical values influence the calculation of the wear and the subsequent substance classification. The analysis was also performed comparatively for the condition classification.

METHODOLOGY

In the project, a set of inspection data from approx. 80,000 damaged sewers from various large German cities was collected. First, the consortium identified typical coding errors based on expert knowledge. The frequency of occurrence of errors was roughly divided into four classes: "frequent", "occasional", "rare" and "unpredictable". Subsequently, sewers were selected on which these errors could potentially occur and the inspection data of these sewers were manipulated to simulate the presence of the errors. Lastly, the assessment results with and without the manipulation have been compared to understand the sensitivity of both assessments (condition and substance) to input data errors. The type of errors and the manipulation procedure are listed in table 1.

Table 1: Inspection error types and manipulation of a data set.

Error type	Manipulation
False numerical assumptions for defect severity	All Pipelines with a defect requiring a case-by-case decision were selected. Instead of the numerical standard assumption a different severity class was chosen. Four different cases were evaluated separately: the numerical assumption was decreases by two classes, decreased by one class, increased by one class, increased by two classes
Missed defect	This was analysed for each defect severity class separately. All Pipelines with at least one defect of the corresponding severity were selected. One defect was randomly removed from the inspection data.
False defect code	For some defects there is a tendency for them to be incorrectly coded more often. Pipelines with such defects were selected and the defects were changed to a code they are frequently confused with. (i.e. spalling (BAF B) is coded as collapse (BAC))
False defect type	Pipelines with a coded longitudinal defect, that can by definition only be a punctual defect, were selected. The longitudinal defect was changed into several punctual defects. The number of punctual defects depended on the kind of defect.
False pipeline length	The manhole might be falsely added to the sewer length in the inspection protocol, leading to an increased pipeline length and thus lower defect density. All pipelines were selected. The pipeline length was decrease by 1 m.

The probability of the manipulation leading to a different classification of the sewer was calculated. For the wear, a mean deviation due to the manipulation was calculated, as well as the 20 %, 50 %, 80 %, and 95 % quantiles around the mean.

RESULTS AND DISCUSSION

In this section two examined error types are described in more detail. The full analysis is available in the project report (Kerres et al., 2021).

According to the estimation in the project consortium, an underestimation of the severity by using numerical assumptions is “frequent”. If the severity assumption was indeed too low by 2 classes, this would as a consequence underestimate the wear of a reach on average (median) by 4.2 % (Figure 2). However, there are also reaches where the wear is underestimated by more than 40 %. This depends on the reach length and the type of defect. For 42 % of all considered reaches, this assumption would result in a different substance class. Within the condition classification, however, the effect is much higher. A closer look at the class distribution reveals that most of the 72 % wrongly classified reaches are distributed especially to the two most critical classes.

An automation with numerical values has an impact on both classifications but is clearly less critical with the substance classification.

The overlooking of severe defects has a particularly strong effect on the condition classification. Here, the substance classification is more robust, as it considers the entirety of all damage. However, extreme defects are rarely overlooked. This happens more frequently with medium severe defects (classified as “occasional”), which has only a minor impact on the condition classification. By removing medium damage, only 11 % of all sewers changed their condition class, which is distributed among pipelines with medium to good condition (Figure 3). Defects over the entire reach, however, have a large effect on the density of defects. In the dataset, almost 40 % of the medium longitudinal defects spread over the whole pipeline length. The wear and substance classification react here particularly sensitive. Overlooking these damages leads on average (median) to an underestimation of the wear by 12.7 %. This error is by far the one with the greatest effect on the substance assessment. All remaining error types resulted in an average wear deviation of less than 5 % (data not shown).

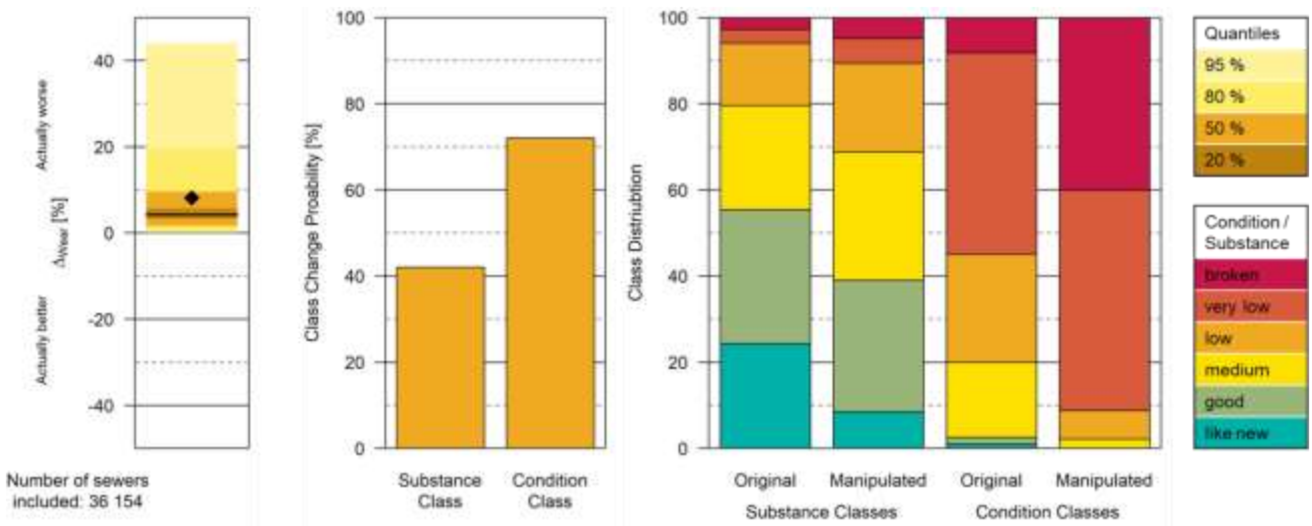

Figure 2: The effect of the use of a false blanket value when defect is actually more severe by two classes. Diagrams show the impact on the wear, the probability of a resulting change of substance class and condition class and the class distribution (original: blanket value used; manipulated: Severity two classes higher).

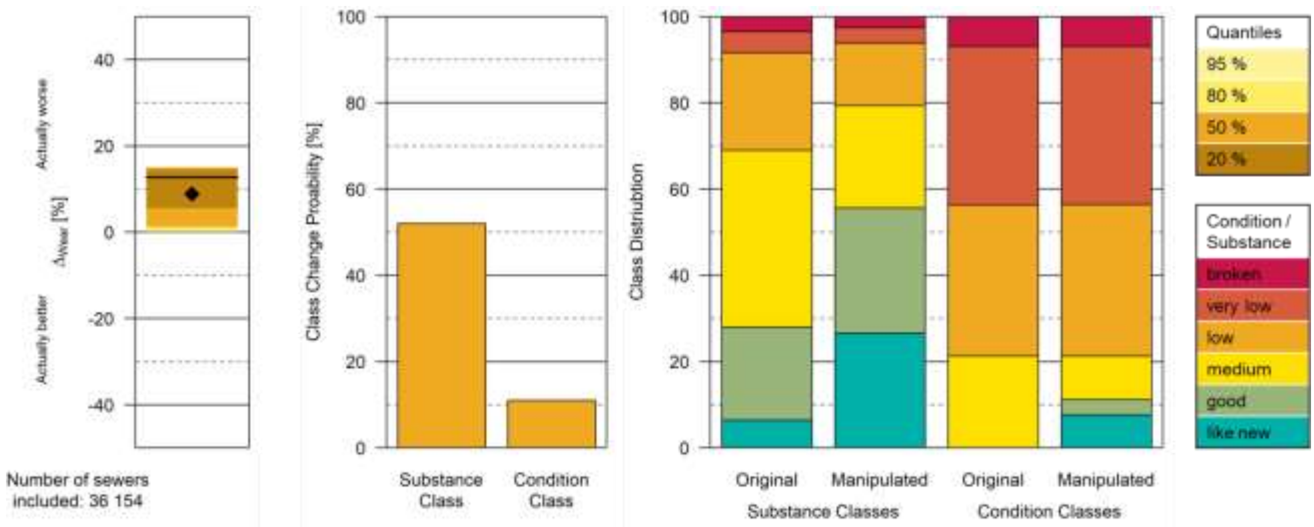

Figure 3: The effect of an overlooked medium severe longitudinal defect. Diagrams show the impact on the wear, the probability of a resulting change of substance class and condition class and the class distributions (original: defect observed; manipulated: defect missed).

CONCLUSIONS

The sensitivity analysis shows that uncertainties in the inspection data, which were previously negligible in terms of the condition assessment, can be of greater significance for the substance classification and vice versa. The use of numerical values for defect severity without considering the individual case can have a significant impact on the condition assessment, especially for the most critical condition classes and thus might lead to a false prioritisation of rehabilitation measures. The substance classification, however, is more robust, which justifies the use of numerical assumptions and allows for an automated assessment. Errors or false estimations can have a large effect on the wear of a single pipeline, however, in average the deviation of wear is less than 5 % except for the presented overlooked medium severe longitudinal defects.

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SPOT^{2023} burst reduction: SUEZ performance and operational optimization approach for an effective water distribution

Distribution Water Network burst reduction within a comprehensive OPEX and CAPEX optimization strategy

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Abstract
In 2019, SUEZ launched SPOT project (SUEZ Performance and Operational Transformation). One of the main results of this project is the delivery and application of an integrated and comprehensive framework for improving Suez's core activities' performance. Within this framework and in order to address physical losses, a methodology has been developed by SUEZ and Optimatics for optimizing operating and investment costs considering the overall objectives of the technical performance improvement plan. The solution is already being implemented in more than 100,000 km of network managed by SUEZ in four continents, and the present document describes its main stages and components.

Keywords
Distribution Water Networks, Performance improvement, Investment and operational strategy, Network Health Score, Predictive asset condition modelling, Sustainable waternetwork, Infrastructure, Water distribution network optimization.

INTRODUCTION

The lack of sufficient investments on critical water infrastructures are one of the paramount factors on the decision-making process of water companies. The maintenance of these networks and the optimization of their operation – including the reduction of physical water losses and minimization of network supply interruptions are hence two never ending tasks carried out by water companies.

Water networks are ageing, and in the face of urban densification and expansion, managing these networks is an expensive and time-consuming endeavour as it becomes increasingly difficult to provide an acceptable level of water service while meeting the budgetary constraints faced by utilities. Therefore, optimizing the chain of action for the management of water distribution systems represents a major economic opportunity for operators to achieve a sustainable level of performance, particularly when the resource is limited. An integrated approach must therefore build a bridge between the long-term investment strategy, aiming to improve resilience and to support growth, and the daily operating strategy for the network which is focused on optimizing OPEX while maximizing the level of service in the system.

This paper presents this integrated approach developed by Suez and Optimatics and applied on several water networks in France; namely Beziers, Issoire, Nouvelle Aquitaine, Valenciennes, Montargis, Est Libournais, Durance Ventoux, Feucherolles, le Vésinet, Croissy, le Pecq, Montesson and the South of Ile de France.

METHODOLOGY

Bursts and water losses in the distribution networks are two related consequences of poor asset condition due to their age and interaction with internal and external stress factors, including the pressure regime and pressure variations in the network (Pearson, 2019).

Therefore, as prescribed in by the IWA (Lambert, 2003), pipe renewal and pressure management are two strategies to help reduce the operational costs related to physical losses and bursts in the system.

Once these potential improvement actions are identified, the challenge is to take informed decisions on how and where they need to be applied. This entails questions on how and where to replace/rehabilitate pipe and how and to which extent manage network pressure. The estimation of the impacts of these actions is also a challenge that their interrelationships make more difficult to grasp. Finally, factoring in these interactions induces an exponentially more complex decision process that needs to be handled efficiently.

To address these questions, Suez and Optimatics developed a three-step framework consisting of the stages illustrated in Figure 1.

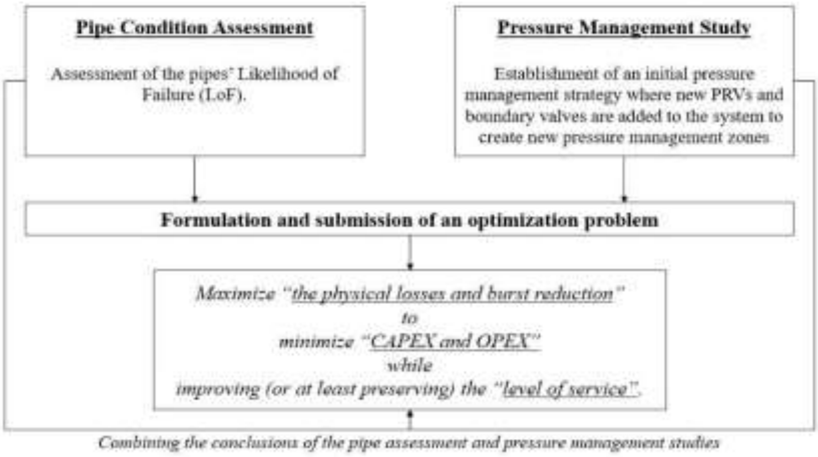

Figure 1: Framework of the Optimized Burst Reduction SPOT methodology

1.1. Pipe Condition assessment

Pipe condition assessment was derived using Netscan^{TM}, an in-house SUEZ solution undertaking a condition-driven analysis based on compiling in-depth information on infrastructure, environmental, and operational conditions (pipes age, material, diameter, soil characteristics, road traffic, pressure, burst history…), by selecting the most representative pipes through clustering, and then extending these results to the entire network for a more comprehensive diagnosis.

Within the SPOT framework, a machine learning algorithm is utilized to generate a forecasting model establishing the link between the influential factors collected and the likelihood of failure of the pipes.

1.2. Pressure Management study

Using a precise hydraulic model, the pressure management study identifies the areas of the network where the pressure can be reduced without impacting the level of service, while complying with regulatory fire flow constraints. For each area, it then defines where the PRVs and boundaries valves must be placed, and which pressure settings are to be considered.

1.3. Optimization problem formulation and resolution

The aforementioned optimization problem[1] is formulated and solved using Optimizer^{TM}, a multi-objectives optimization software based on evolutionary algorithms, developed by Optimatics and adapted for hydraulic systems. Optimizer^{TM} considers different actions to help generate optimal plans with respect to the set of defined objectives and boundary conditions.

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[1] Minimizing physical losses and bursts, while optimizing OPEX and CAPEX, and improving (or at least preserving) the level of service

For the SPOT project, the objectives were defined as follows:

- CAPEX: pipe replacement investment plus pressure management investment
- OPEX: marginal cost of the water lost in the distribution network plus repair cost for the bursts
- Network Health Score: Score estimated using the age of each pipe, their Likelihood of Failure score and the new operational pressure

The criteria used to evaluate the performance of the plans are the reduction of the physical losses, and the respect of a minimal pressure for every node in the network.

The optimization process considers at the same time and in parallel: 1-decisions on pipe replacement; 2-installation of new PRVs and boundary valves to define new pressure zones; and 3-determining the best setting for the existing and new PRVs.

The impacts of the decisions on the performance criteria are:

- The replacement of a pipe removes the physical losses related to this pipe and resets the likelihood of failure for this section of the network to 0.
- The reduction of the pressure reduces the likelihood of failure and the leakage rate of the pipes in the area but can cause a violation of the pressure constraint for the nodes in the same area.

The resolution of this optimization problem aims to find the best configuration of the infrastructures to minimize the CAPEX, the OPEX and improve the condition of the network. It uses the Optimizer^{TM} optimization algorithm which runs thousands of simulations for different scenarios based on the hydraulic model, in an evolutionary process to generate a set of optimal solutions in a Pareto front. Each Solution is a plan depicting a set of replaced pipes, and new PRV and pressure settings. Each plan is represented by a point in the pareto front.

Figure 2 displays three plans (in green) allowing a good OPEX benefit (similar x values) with different asset value (the CAPEX Objective is halved between the plans in this case), illustrating how there are different ways to improve the operation today. A deeper, and more detailed look indicates, within the pareto front, the best trade-off to improve the OPEX as well as the state of the assets.

Based on these results, the final strategy is then established after a discussion with the different stakeholders of the water system.

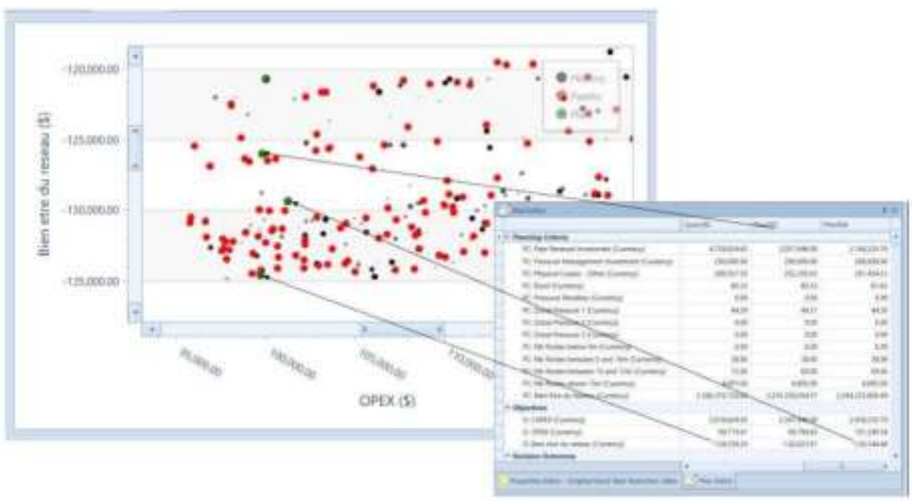
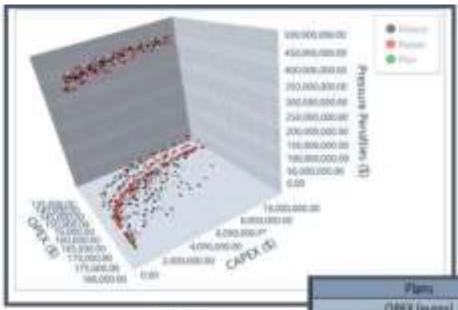


Figure 2: Illustration of three plans/solutions allowing OPEX benefit with different asset value

RESULTS AND DISCUSSION

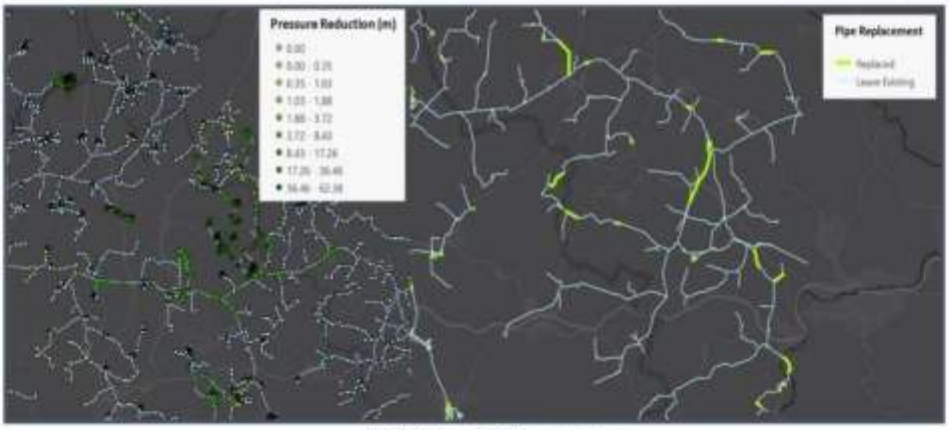
The SPOT Burst reduction project covers more than 100,000 km of network, on distribution systems in Europe, Asia, Latin America and Africa. 21 pilot projects of the full methodology were launched. The first results show a reduction of about 25% in OPEX while maintaining the same or a better service level and improving overall condition of the asset stock. The following figures (cf. Figure 3) illustrate the obtained results for a network in the south of France, for each of the framework's steps. Additional results will be provided in the presentation/full article, including those with additional optimization modules which were defined to tackle other loss reduction levers, namely bursts on connections, fraud and leakage detection…



Pareto

Plans	Input Model	Pressure Management Plan	SPOT 2023 Goals Plan	0.5% (Annual) Pipe Replacement Plan	0.8% (Annual) Replacement Plan
OPEX (euros)	177992.59	173010.84	148911.78	157739.56	153766.46
OPEX Reduction (euros)	0	4981.75	29080.81	20253.03	24226.13
Number of PRVs to installed (nbr)	0	5	5	5	5
Pipe Renewal (km)	0	0	67693.87	32222.99	52720.25
Pipe Renewal (year)	0	0	11	8	8
Pipe Renewal (%)	0	0	0.008	0.005	0.008
Pipe Burst reduction (nb)	142.25	138.65	118.83	126.19	123.08
Physical Losses (m3/year)	1167583.76	1122301.14	982878.81	1030478.78	1002351.49
Physical Losses Reduction (m3/an)	0	45282.62	184704.95	137104.98	165232.27

Optimal plan selected to be considered for implementation



Definition of a final strategy

Figure 3 Visualization of the SPOT methodology

CONCLUSIONS

Distribution network problems are interlinked and solving one issue may induce other types of problems. The aforementioned comprehensive approach developed and applied on more than 100,000 km of physical networks around the world within the SPOT project in Suez shows that an optimized implementation of multiple solutions at the same time within the framework of a comprehensive formulation makes it possible to propose adequate responses to improve the network performance without violating operational or regulatory constraints.

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A serious game for supporting communication in asset management

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Keywords: Asset management, serious game, communication, culture.

INTRODUCTION

KWR Water Research Institute conducts the Joined Research Programme for drinking water utilities in the Netherlands and Flanders. Within the research theme of Integrated Asset Management, a maturity measurement was conducted by seven utilities. The assessment results emphasized the need to improve the communication between the strategic level (asset owner) and tactical level (asset manager) in order to enhance asset management performances. Based on a further investigation on the nature of the current communication and technological options, the development of a serious game was considered as a way to address this need for improved alignment in joint decision-making between asset owners and asset managers. At present, researchers and representatives of the utilities are jointly developing a serious game. At the moment of submission of the paper, the game will be in the testing phase and the first learning experiences of playing the game at water utilities will be presented.

THE COMMUNICATION PROBLEM TO BE RESOLVED

According to ISO 55000, asset management is based on four principles, relating to (1) creating value, (2) alignment of organizational objectives with decisions, plans and activities, (3) leadership and commitment and (4) assurance that assets fulfil their required purpose. To fulfil these principles, good communication between the strategic level and the tactical level is a prerequisite. This interaction is necessary to translate organisational goals into decision-making on investments and maintenance. As a result, utilities are more able to achieve sustainable management of the assets in a rapidly changing society. This interaction is also important for the development of an holistic vision on asset management from source to tap and over their entire asset life cycle. People working at the strategic and tactical level of an asset organisation often have different objectives, perspectives and responsibilities. Whereas managers at the strategic level tend to communicate more qualitatively, abstractly and intuitively about a changing environment, asset managers at the tactical level communicate more in quantitative terms about system behaviour and daily problems.

This problem of communication was also identified at a workshop with the Dutch and Flemish water utilities held in 2019. In this workshop, the results of a maturity measurement on the quality of asset management processes at drinking water utilities was discussed in detail. It was concluded that serious games could be a valuable approach to support better communication and alignment between strategic and tactical levels of decision-making.

WHAT SERIOUS GAMES CAN OFFER AND HOW THIS IS APPLIED?

Various definitions of serious games exist but that there is general consensus in both academia and by practitioners that serious games are used for a professional purposes other than mere entertainment (Savic et al. 2016). Savic et al. (2016) claim that using serious games offers potentially transformative capabilities to strategic decision-support tools to provide better management of complex water systems, this compared to purely technical simulation or optimisation methods that have difficulty in capturing the socio-technical challenges of complex systems. These socio-technical challenges often lead to conflicting interests due to multiple economic, environmental and ecological objectives, as well as due to conflicting goals and views held by multiple stakeholders. These conflicting interests are often experienced in asset management decision-making.

In 2020, a research project was performed that was aimed at exploring the application of a serious game for strategic decision-making in asset management. This project resulted in a literature research on serious games, the definition of the target group, the nature, the objective and the key elements of the game. Furthermore, a first web-based version of the game was made. This version contained amongst others the stakeholders and their main interests, the asset groups involved, the possible activities, the scoring mechanism and the looks and feels of the game.

At present, further developments of the game are forthcoming and a playable version will be available by the end of 2021. In 2022, this version will be played with the utilities participating in the Joined Research Programme. Based on these experiences, further improvements of the game will be implemented.

THE GAME SET-UP

The serious game is played with three to five persons, divided in asset owners and asset managers. It consists of five rounds. Each round represents a period of five years. Each round starts with three steps of the planning phase, see the green steps in Figure 1 (top left), and a fourth step representing the implementation phase. The game starts with a water service coverage goal, a share of renewable energy, a score and a budget. The objective of the game is to end the game with the highest possible score. This can only be achieved by taking decisions that comply with the interest of different stakeholders and safeguard a good performance of the assets during the entire game's length.

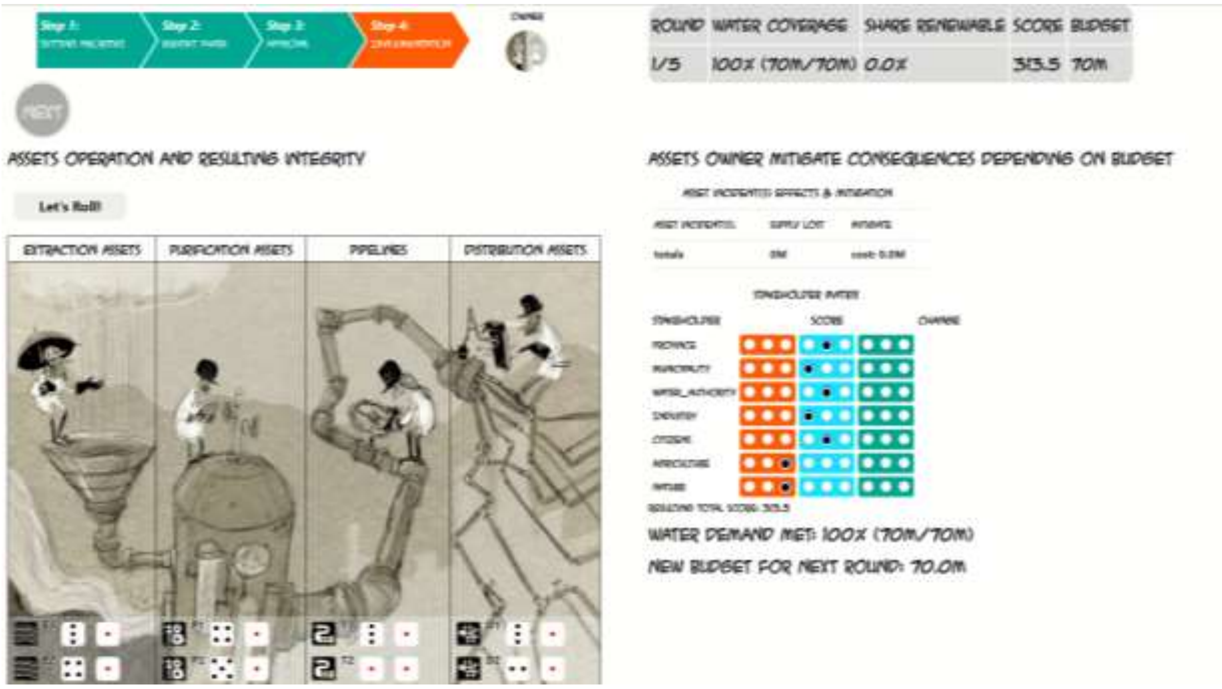

Figure 1: Screenshot of the serious game, status October 2021.

The first step represents setting the priorities. The asset owner selects which stakeholder's interests are to be met in the current round, interprets how these interests are translated into goals and defines the priority of the selected goals. The stakeholder satisfaction is represented in a table. In Step 2 the asset manager plans activities on the various asset groups (i.e. extraction, purification, transport and distribution). These activities (build, close, upgrade, upgrade sustainably, maintain) are to be in balance with the impact on a risk matrix, the contribution to stakeholder's interests and the available budget. The asset manager is able to compile three so-called action packages, which are bundles of different activities and a short message to the asset owner. In Step 3 the asset owner choses which action package will be adopted. The implementation phase, step 4, represents the regular asset life. Assets can fail, and failure is introduced as a random event. However, the likelihood of failure is lower as the asset manager succeeds to keep the assets in a good condition. If the asset manager has sufficient budget, he or she is able to mitigate the impact of the failures. An asset failure that is not mitigated has impact on certain stakeholders and will reduce their satisfaction. At the same time, if the interests of the stakeholder are met their satisfaction will increase. The situation at the end of round will be the new starting point of the next round.

By playing this game, it is expected that the participants will obtain a better understanding of the asset management decision-making processes, better understand the different roles and responsibilities, have a more holistic perspective on the asset system in relation to a changing environment and be more aware of the specific contribution they can make in their daily work.

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Innovations in the decision-making process for end-of-life assets: the case of water and sewerage systems

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Abstract
The question of how to decide on end-of-life infrastructure assets is increasingly raised and, in some cases, is vital for the sustainability of services and operations. The problems have an internal origin in companies (investment policy, reduction of available CAPEX, short-term vision) but also external (financial crisis, regulation, reduction in demand, pricing pressures, etc.).

On the other hand, in the field of operations, some factories tend to think that it is always worth keeping the equipment for a lifespan much longer than that at which there is an economic interest in replacing it. Indeed, it has now been demonstrated that the optimal technique and economic timing for replacing assets at the end of their life depends more on the characteristics of the future asset than on the o ne in operation, the object of the problem.

This presentation will demonstrate this innovative principle of penalties around the ideal time to replace equipment in the water sector such as water and sanitation plants.

It will be richly illustrated using concrete cases with tangible results. Prospectively, the author will show the benefits that a deployment of this solution can bring to the sector.

Keywords
Asset Management, End-of-Life Assets, Asset Life-Cycle Costing, useful and mature life, Capex delayed, Capex/Opex Trade-off, monetizing risk.

INTRODUCTION

The problem addressed concerns the proportion of end-of-life assets in water and sewerage facilities in many countries. Sectoral studies in different countries as well as government work (OECD, WEFORUM, …) show that at least 20% of public infrastructure assets are in a mature stage of life, that is, assets that are no longer able to succeed with any maintenance as its degradations moved from the elastic phase (maintainable assets) to the plastic phase (no longer cost-effectively maintainable assets).

This paper will focus on an oft-neglected segment of the life of industrial assets, namely the management of their *end-of-life*. This topic is undoubtedly a vast one, since it is characterized by a massive lack of solutions rather than by a profusion of precise problems. Objectively, most of the industrials do not regard the issue of end-of-life as a serious problem. Yet, let us elect to dig a little deeper. In order to bring into light, the subjacent rationales which have led this segment to be so poorly equipped until this day.

From the perspective of the general management, it is clear that this line of questioning may appear unseemly. All things considered and from the point of view of corporate leaders, assets are made to fulfill their function and as long as the organizations pay the price for their operation and maintenance, they are entitled to expect that the operational agents ensure that the asset is kept in func- tion for the longest possible time, without facing unexpected issues. However, this posture turns a blind eye to the fact that it is altogether much more profit- able to operate cost-effective assets rather than high-longevity assets.

On the opposite end of the organizational model, one must keep in mind that the efforts of operators and maintenance agents are complete with a real professional pride; hence, admitting that an asset has entered its mature phase may sometimes feel like an admission of failure. This implies that to engage a discussion on the management of the mature life, one must be prepared to bring into question the cultural perceptions that agents may have when dealing with the end-of-life.

What do the concepts, tools, practices, and methods derived from the Asset Management culture have to offer in terms of novel and truly pertinent insights in the treatment of this issue?

METHODOLOGY

At the outset, it is appropriate to expose the key possibilities for improvement in the daily labor of maintenance professionals informed by the practical and conceptual knowledge of Asset Management. We will therefore discuss the necessary discernment -between contradictory parameters on the one hand and separate realities on the other- which maintenance managers must acquire in order to improve their standards of decision-making.

In terms of contradictory parameters, we will come back to the notion of trade-off and particularly on the most useful of these trade-offs in the maintenance phase, that which sets out to evaluate the relationship between risk and cost. However, to discuss this topic in a coherent fashion, it seems crucial to begin by guiding maintenance engineers towards a more pertinent application of trade-offs approaches in order to ensure that they focus “on the right targets.”

In more prosaic terms, let us consider the case of a machine in its mature life, which is very demanding in terms of maintenance labor but over which all attempts at repair are already relatively ineffective because of its obsolescence. As we know, it is highly unlikely that reactive actions could ever return this asset to its intrinsic level of reliability. It would therefore be pointless for a maintenance agent to proceed, as is often the case, to try and “maintain” this specific asset regardless of the expenses.

We will not discuss in any more detail the corporate pressure which perpetually demands that failing machines work anew, nor of the specific pride tied with the maintenance line of work, which brings maintenance agents to refuse to accept the failure of a repair action for fear of coming off as incompetent. Our goal here is to provide operators and maintenance profession- als with the necessary tools to orientate their maintenance strategies based on the character (efficient, or not) of the act of maintenance itself.

In other words, why should we accept that so many technical interventions be conducted without proceeding to preliminary analyses which would allow us to determine whether the asset is still in its useful life (and therefore repairable) or already well into its mature life (which would make its repair infinitely more complex)?

If we were to synthetize the major conceptual inputs of Asset Management, it would be relatively easy to identify several strong arguments and valid reasons promoting the modification of our relation to the management of the end-of-life of assets.

Let us therefore consider the argument of the “systemic gaze,” or in other words, that of the holistic perspective which characterizes the vision of Asset Management. In this context, it is transparent that one cannot continue to promote the notion that assets in their mature lives, which present very different performance signals from those presented by assets in every other segment of their life cycles, do not require a specific form of management. Indeed, these negative signals are impossible to neglect if one considers the totality of the available data.

Let us now focus on another primordial notion: that of the distinction between the useful and mature lives that we’ve already discussed. It is this differentiation which provides us with the demonstration that the signals emitted by assets in their end-of-life are indeed dissonant.

Finally, let us reflect on the notion of "extraction of value on the totality of the asset's life cycle." Even if we depended on this restrictive definition of Asset Management, it would transpire that one cannot overlook the management of assets in their end-of-life, since it would be dishonest to exclude the mature life from the life cycle which Asset Management has elected to manage.

However, we think it is more effective to demonstrate the robustness of the Asset Management rationale in favor of an improved management of the end- of-life of assets through a recourse to an analogy which we believe is particularly founded. Indeed, this debate is extraordinarily similar to the very contemporary question of the best ways in which to handle climatic change and the environmental transition. Deep down, these problematics depend on a necessity for behavioral transformation (a complex reaction to induce from agents) and on a long-term focus (which is definitely unusual in the industrial world, even more so when a "short-term" behavior can generate harm on the longer course and for which the accountable agent will not necessarily suffer consequences).

The list of these parallelisms is undoubtedly a long one, and we could easily enumerate plenty more arguments which would be completely analogical to the environmental issue. Thus, we can only invite you to consider, whenever you are faced with arguments promoting the protection of the environment and the maintaining of the value which we all extract from the planet, how similar this problematic is to the question of the management of the end-of-life of industrial assets.

All assets are mortal. To enumerate the potential ways in which one could improve the manner in which assets in their end-of-life are dealt with, we will first have to reassert a number of conceptual points. The first of these conceptual reminders will be to bring into question what we mean when we discuss "assets in their end-of- life," since every organization is faced with different types of assets and different types of lives.

Figure 1 represents individual assets, which are often subject to replacement since they only have a relatively short lifespan. As soon as they are grouped on the basis of their function (since it has been observed that these assets may have identical purposes and therefore operate the same productive function) they are described as "asset systems." These asset systems are generally endowed with longer lifespans than individual assets. The third section presents what is known as an "asset portfolio," or, in other words, a bundling of asset systems which share a common macro-function

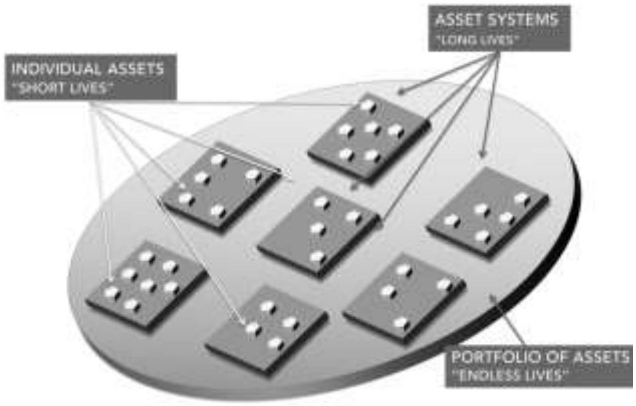

Figure 1: Various categories of assets according to their various lifespans

within the productive system; undoubtedly, our reader will recognize that one or plural asset portfolios exist within his own organization. Asset portfolios boast an *infinite* lifespan; of course, this lifespan is not *intrinsically* infinite, but it can be regarded as such based on the fact that the individual assets and the asset systems whose bundling make up a portfolio are replaced on such a regular basis that it ensures the survival of the portfolio *ad vitae aeternam.*

One should however be wary of confusing this artificial effect of "infinity" with infinity itself: if managers regarded their portfolios and industrial plants as infinite by nature, they could, in a politico-strategic maneuver, cease to treat individual assets and asset systems specifically.

This remark should not be taken lightly, as indeed one frequently hears managers brag, in international conferences and congresses, about the infinite lifespans of their plants or infrastructures (*"Our airport is eight decades old and still works like a charm," "our refinery was endowed with an infinite lifespan"*) with- out saying a word about the millions of dollars spent and invested on a daily basis to keep their installations in an acceptable condition of operationality and competitivity.

Now that we've clarified this issue, it seems fitting to evoke the latest methodological trends in the field of end-of-life Asset Management. In this domain as well, a rigorous distinction between the assets' useful and mature lives is essential in order to clearly identify the objects discussed, and more specifically to improve our perception of an organization's asset fleet, which will always be the object of analysis regarding its technical and economic lifespans from a business perspective.

The trade-off techniques which involve risk/cost and CAPEX/OPEX parallels constitute one of the major trends in the analysis methods deployed in the management of the end-of-life. Indeed, the CAPEX/OPEX trade-off allows us to envision scenarios for extending the lifespan of industrial assets.
But the most considerable input in defining the optimal time of replacement of an asset by another asset or by various candidates to its replacement was provided by the emergence of what are now known as "double V" analyses or the "W principle."

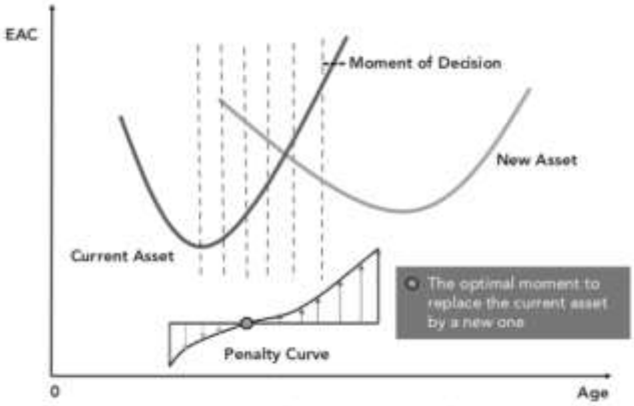

FIGURE 11.3 Principle of the algorithm "W" of Assets Value

The principle of the W-shaped Life-Cycle Costing curve presented in Figure 11.3[1] shows the following phenomenon: the V-shaped curve to the left represents the functioning asset at the time of the analysis. We must keep in mind that all too often within organizations, operational managers and maintenance managers attempt to pinpoint the optimal time of replacement of their end-of-life assets by focusing on the shortcomings inherent to the assets' aging. However, we can demonstrate that the optimal point of replacement of a present asset by a new one is much more strongly determined by the advantages featured on the V-shaped curve to the right of the figure (representing the asset which will replace the current one) rather than by the drawbacks caused by the declining performance and condition of the current asset. Indeed, based on these three variables (the EAC curve of the current asset; that of the future asset; and the time at which the issue of replacing the current asset emerges)

[1] Source: figure extracted from *Celso de Azevedo, "Asset Management Insights" – Phases, Practices and Values, Industrial Press Inc. New York, 2019, 186p.*

we can pinpoint a point, located between the two minimal inflections of the EAC curves, which represents the most opportune moment for abandoning the current asset in favour of the new one.

The innovation of this simulation approach lies in the use of few input data using the elicitation process with company specialists. Associated with the principle of uncertainty management, this type of tool guarantees the robustness of the result and a speed of carrying out studies compatible with the deadlines of corporate decisions

RESULTS

It is now known that the opportune moment to exchange an industrial asset at the end of its life is determined in 80% of cases by the new assets that are candidates to replace it.

Thanks to the monetization of risks and the consequent trade off simulation with the costs of the various competing projects, it is possible to assess how the penalties of late replacements (Capex delayed) help to prioritize those decisions where, in the short term, investments create more value for your enterprise.

There are three aspects that we take into account for this analysis:

1. the current asset.
2. the active candidate; and
3. the moment when the possibility of substitution is considered.

From the association between the three aspects, we determine the best moment to replace the current asset by the candidate, represented in the figure X by the minimum replacement penalty point. After this optimum moment, the more the current asset is preserved, the more it is lost money compared to the acquisition of the candidate asset, since the cost of maintaining the current asset (Opex) has a Total Economic Impact (IET) much more expressive than the Capex + Opex of the candidate asset.

In the case of a replacement before the minimum penalty point, money is also lost, either because the replacement asset (candidate) is technically not so much better to justify the exchange, or because it has a very high price - and, in this case, it would be worth postponing its replacement for a few more years. Another possibility that exists in simulations of this type is to study ways to extend the life of the current asset, an alternative in case the company does not have the money to invest in the short term. Just as medical resources have contributed to increasing human life expectancy decade after decade, Asset Management also has resources to extend the life of an asset – for example, reviewing preventive maintenance or the inventory policy to reduce Opex costs. The caveat is that we need to do this while the asset is healthy. The asset manager's action must be focused on what we call “sustainable cost reduction”, an indispensable condition so that, after Opex grows, we can strategically organize the asset decommissioning in the name of the company's business continuity.

Another possibility of the simulation is to consider a series of candidates to replace the current asset, which generates several other minimum penalty points. There is usually a concentration of these points in a certain region of the curve of the current asset, making it easy to see which is the most opportune time for replacement.

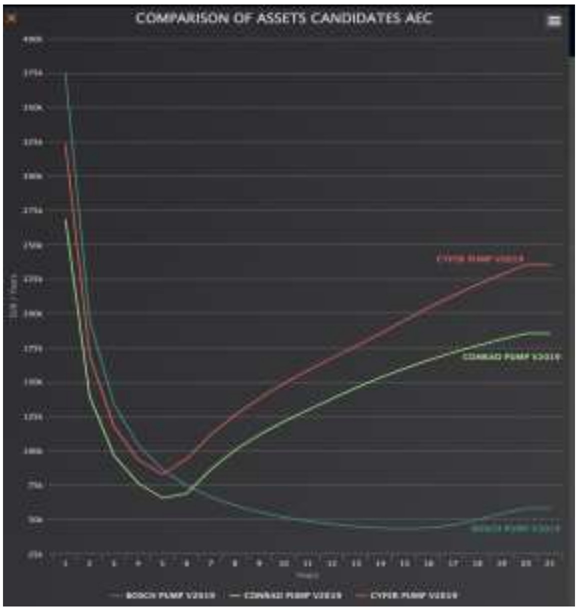

Figure 2: Equivalent Annual Cost of asset candidates

Now let's look at a case. A sewage treatment plant used water pumps whose physical life expectancy was about 15 years (CO pump). When they reached 5 or 6 years of use, however, they began to show failures that required repair at a relatively high cost. The company raised the following questions:

- "Is it worth changing the pumps from this moment on?
- Would it be interesting to change the manufacturer?"

What you see in Figure 2 are the estimated equivalent annual cost curves for three replacement candidates.

Curve BO pump corresponds to a new pump from another manufacturer as the current pumps, while curve CO and CY corresponds to the pumps from the same and another manufacturer, respectivly. The simulation makes it clear that, despite having a higher Capex, option BO pump is economically more interesting, as the point that determines the economic life is approximately 15 years (compared to 5 or 6 for a new pump from the current and another manufacturers) and has significantly lower maintenance costs in the second half of life (most likely due to superior reliability). Figure 3, on the other hand, shows the best time for replacement: within three years for the same pump as the current one and within one year for the BO pump and five for the CY pump from another manufacturers.

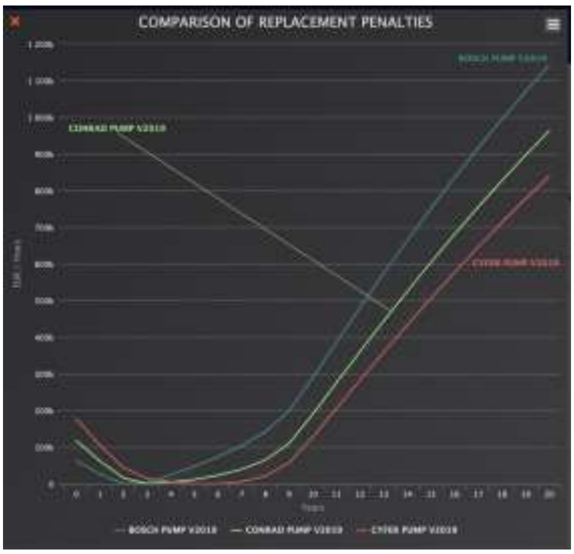

Figure 3: Economic Total Impact of asset candidates (penalties curves)

Do you agree that while maintenance is thinking about "keep a piece of equipment running for as long as possible" opportunities like this are ignored? This is why we argue that we need to look both at the aging asset and at the replacement opportunities that arise. The experience of dozens of end-of-life asset replacement studies has given us the conviction that the “right time” to change an asset depends much more on the virtues of potential candidates than on the problems of the old machine. And that's really innovative, as we said before.

DISCUSSIONS

Based on these different perspectives, one is inclined to reflect on the following question:
Why do organizations behave so inadequately in the face of the management of the end-of-life of their assets? Or, as a corollary, why is this segment deprived of having its own dedicated manager, as all other segments in the life cycle do?
Until when will short termism cause these penalties?
Why the innovations available today do not offer more flexibility than fixed rules, especially regarding asset life?

This question seemed to perplex a vast majority of industry leaders. It would seem that this issue is relatively easy to resolve, but that the main difficulty lies *in its very acceptation*. One must therefore ask the question: why is it so hard to accept that the asset’s end-of-life must be managed differently from its useful life? Why won’t organizations acknowledge that the treatment demanded by “mature” assets differs from that demanded by “useful” assets?

In order to address this topic in its most crucial aspect, it is necessary that we consider the creation of value by the organization. Without coming back to the matter of the optimal practices to be developed by management, it seems fit- ting to compare the noble ideals put forward by the organizations’ statements of intent when describing their “vision,” their “commitment,” and their “mission” on the one hand, and the manner in which these very organizations choose to handle the question of the mature life on the other. In this regard, Asset Management represents a considerable tool for positive transformation since it embodies a manner for organizations to finally walk the talk. This potential for change does not depend on a theoretical discourse, but on the global realization of the veracity of our approach to value: namely, that organizations may only create value on the entirety of their life cycles, whatever else they may pretend in their annual balance sheets. Hence, the real value extracted from the assets can only make sense if it is sustainable and if the management of these assets is inscribed in the long term, including, in this context, in the end-of-life.

CONCLUSION

The end-of-life is one of the segments where the largest deficiencies in terms of organizational policies and strategies is observed. We have stated managerial faults, and shortcomings of the implemented prioritization models. Life cycle costing is a boost for the realization of the necessary alignment between the operational field and corporate finance in an Asset Management perspective. Furthermore, it has been demonstrated that every single asset will sooner or later reach its zero-profitability point in the long term. Let us also consider that organizations whose cash flow allows them to respond positively to every yearly CAPEX Sustaining project are very rare. Therefore, establishing priorities on objective grounds is a required measure. Multi-year rankings allow for a mitigation of risks and costs relative to the choices in investment projects adapted to the available budget.

The explanation that has just been given, based on the concepts of Life Cycle Costing, will then allow us to highlight how, thanks to Asset Management, we are able to develop aid scenarios technical and economic decision on the end of life of assets. If what has been described could be used so that, in the future, the end of life of industrial assets is considered from the start of its cycle and regularly all along the path marked out by the benchmarks that 'we mentioned, I would be delighted.

The asset management concept, which incorporates the powerful tool that is Life Cycle Costing, shows that extending the life of an asset is something that needs to be done with criteria of interest and opportunity. Insofar as they see the life cycle of a business from this point of view, production and maintenance professionals and asset managers can provide the company's management with subsidies to invest well, maintain and replace the asset. This is their true role, not the utopian and strategically incorrect ideal of "keeping assets as long as possible."

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Cost saving potential in integrated multi-infrastructure asset management

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Abstract
The cost of rehabilitating municipal infrastructure represents a huge investment need that most utilities struggle with, as the required rehabilitation rate is often not reachable with their available budgets. Joint intervention on co-located different infrastructure assets is one way to efficiently spend the budget in rehabilitation. It has the potential of cost sharing of common works among the different urban infrastructures such as roads, sewer, water, gas, electricity, etc. This study proposes a metric to quantify the direct cost saving potential of practicing joint interventions. The results of a case study with a population of 200,000 people show an overall potential of around 40% of road resurfacing and 12% excavation and backfilling costs that can be shared among the utilities. The assumptions related to this work, possible enhancements and applications and future directions are discussed.

Keywords
Asset management, cost savings, infrastructures, interdependencies, GIS

INTRODUCTION

The ageing municipal infrastructures require a significant amount of investment to be rehabilitated. Infrastructure managing authorities usually face the gap between the required and the available budget to take actions on all the assets in need. To counter this, efficient budget expenditure plans are necessary to get the maximum value from what is spent. One way of efficient budget expenditure is to practice integrated multi-infrastructure asset management (IMAM) when- and wherever possible. IMAM is the practice of joint intervention on multiple infrastructure assets by delaying or advancing the interventions if needed and possible. Utilities can share the costs that are spent on common works on the different, but geographically interdependent, infrastructure assets, i.e., roads and the underground infrastructure networks. Three factors mainly affect the cost sharing among the authorities: (1) the shared volume of a trench that is needed for intervention on a road and its underground assets, (2) the time an authority is able and willing to delay or advance its intervention on asset(s) to practice IMAM, and (3) the costs of this coordination. To know how much time is feasible to advance/delay interventions, one needs to know the current or future condition of assets and their deterioration rate over time. The costs of coordination depend on how much the environment is prepared for the coordination. For instance, if tools are available to share data among the utilities and estimates the time of integrated intervention, coordination cost would be minimum. But if there are no tools and the utilities need to meet and discuss every time, the cost of coordination can be significant. This study focuses only on the first factor, the shared trench work needed for interventions as a proxy for the cost sharing potential in an ideal setting, as it assumes advancing/delaying intervention is ideally possible and no coordination cost is incurred.

Additionally, the study's scope is on pavements, sewer, and water distribution pipes but the method can also be applied on other infrastructure networks which share similar layouts.

Few literature examples can be found to quantify the cost savings of IMAM. Carey and Lueke (2013) quantified cost savings for each infrastructure managing authority in a hypothetical case study. Their result showed that the road infrastructure managing authorities can benefit from the savings more than of sewer or water utilities. Tscheikner-Gratl (2016), in a case study quantified the overall savings of practicing IMAM. The result shows 15.6% of total costs can be saved. Other related studies include the work of Mair et al. (2017), and Islam and Moselhi (2012). Mair et al. (2017) analysed the correlation of the location of water, sewer, and road networks. The study found that 80%-85% of sewer/water network has some overlapping area with roads. Islam and Moselhi (2012) analysed the geographical interdependencies among sewer, water, and road networks by use of ArcGIS functions and Python scripts. The study used the shared area as the indicator for assessing the degree of co-location. Our study uses a similar approach but uses not only shared area, but it also adds the depth to find the shared trench volume among the assets. The trench volume that needs to be excavated and backfilled is a significant part of expenditures in rehabilitation works, and when it is combined with the resurfacing of roads, it takes the lion's share of rehabilitation costs.

METHODOLOGY

The shared trench work of municipal infrastructure assets is analysed in ArcGIS Pro environment using Buffer and Intersect functions (ESRI, 2021) and Python scripts. For doing so, the following types of data are necessary: (1) network layout of the three infrastructure assets with their attributes of width/diameter, and (2) the depth of the trench for rehabilitation of each asset, and (3) the total cost associated with opening a road and bringing it back to its initial state (i.e., excavation, backfilling, resurfacing, marking). This cost depends on the assets' geometry and depth. For roads, the width and the segment length represent the surface area of excavation, but the depth varies depending on the condition of the road which determines whether all the load bearing layers to be reconstructed or only few layers. This study considers those interventions that include the reconstruction of all the load bearing layers for showing the maximum possible cost savings. For the water and sewer pipes, except minor repairs, the surface area of the trench is the length of the pipe multiplied by a width which is more than the diameter of the pipe but depends on the diameter and on the depth. The width is usually specified by the standards of each country. The depth of the trench is normally up to the bottom of the pipes. Using Buffer function in ArcGIS Pro, the width of the trenches needed for each asset can be represented. Using Intersect function, the shared surface area of trenches among the infrastructure assets can be estimated. The shared volume of trench between the roads and pipes is then calculated by multiplying the shared surface area by the depth of the pipe or the depth of the pavement that needs to be excavated, whichever is smaller. The shared volume of a trench between sewer and water pipes is calculated by multiplying the shared surface area by the depth of sewer or water pipes, whichever is smaller. These numbers can then be used as a proxy for possible shared works between the individual infrastructures. Figure 1 illustrates possible shared volumes among the assets that is calculated by this method.

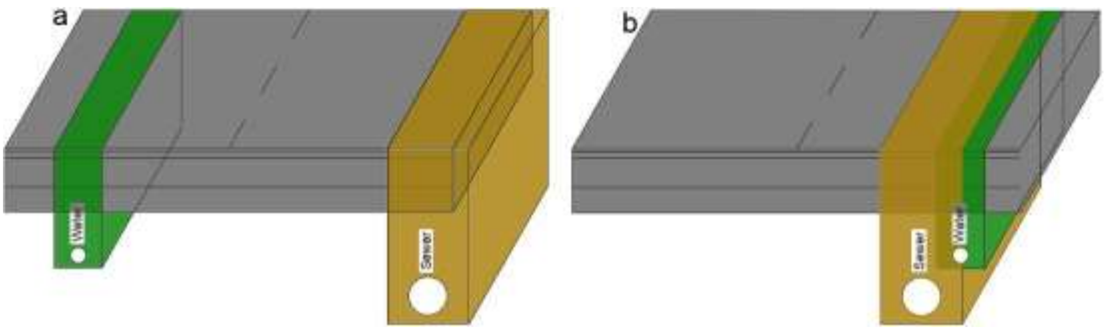

Figure 1: an illustration of possible shared trench volumes
(a) between road and pipes (b) between sewer and water pipes

CASE STUDY

The method has been applied to a city in a Scandinavian country with population of around 200,000 inhabitants. The available data consists of a road network with around 11,000 segments in polygon shapefile representing the surface area of the roads, including parking lots. The depth of the roads that need to be excavated for full reconstruction is assumed to be 75 cm. This is an average depth according to Huang (2004) in which considers a depth range of 43 cm to 105 cm for a typical flexible asphalt pavement. The sewer and water pipe network data consist of around 31,000 and 11,000 segments respectively. The higher amount of sewer pipes consists of combined, wastewater and stormwater pipes. The sewer and water pipes are represented by polylines, unlike the roads (which are represented as polygons).

The depths of the pipes are not directly available but are assumed to be of the same depth as the connected manholes. To consider both manhole depths that are connected to both sides of the pipes, the average depth of the two manholes is assigned to the pipes' depths. For a network level application, the average depth seems reasonable, although it introduces some degrees of uncertainty.

Having all the data prepared and mapped, the model is ready for buffering. The Buffer function was applied to water and sewer pipes to represent the trench surface area. The road data is already provided as polygon shapes and represents the trench that needs to be excavated for the roads, so there is no need for buffering the roads. The next step is to calculate the overlapping area among the infrastructures. The overlapping area is calculated using the Intersect function. Figure 2 shows the result of buffering and intersection. In the third step, the overlapped area is multiplied by either the depth of the corresponding pipe or the depth of the road, whichever is smaller, in case of pipe-road shared trench. In case of sewer-water pipe shared trench, the smaller depth between the two pipes is used.

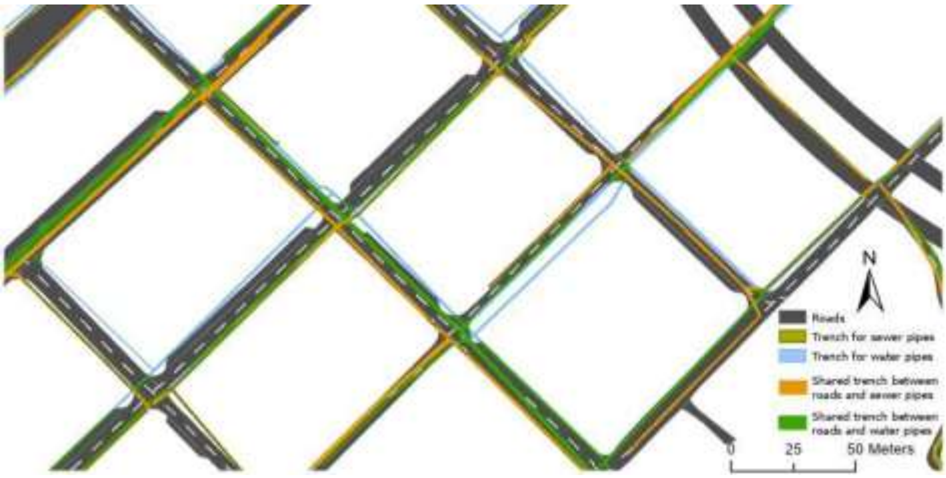

Figure 2: the overlapping and nonoverlapping of sewer/water trenches with road network

RESULTS AND DISCUSSION

Table 1 shows the results of calculation of total and shared trench area and volume with roads.

Table 1: result of the calculation of shared trenches

	Total Area [10^3 m^2]	Shared area with roads [10^3 m^2], and in [%]	Shared area with sewer [10^3 m^2], and in [%]	Total trench volume [10^3 m^3]	Shared trench volume with roads [10^3 m^3], and in [%]	Shared trench volume with sewer [10^3 m^3], and in [%]
Roads	11 940	-	-	8 955	-	-
Trench for sewer pipes	1 133	469 (41%)	-	3 011	331 (11%)	-
Trench for water pipes	650	255 (39%)	29 (4%)	1 556	185 (12%)	67 (4%)

41% and 39% areas of all the trenches for sewer and water pipes are shared with the road network, whereas the corresponding shared volume is 11% and 12%, respectively. The lower volume percentage compared to area percentage is because the shared depth is 75 cm (depth of the road) or less than 75 cm if a pipe is placed between 0-75 cm depth (refer to Figure 1). The shared area of the trenches between water and sewer is 4% and their corresponding volume is also 4%. The total shareable cost can be found by multiplying the shared area with the cost of road resurfacing per square meter plus the shared trench volume multiplied by the cost of excavating and backfilling per cubic meter. These costs are of course case study/utility dependent. Another case study dependency is the possibility of different excavation profiles and depths depending on the soil conditions present and local norms for trench design.

The shared trench surface area (4%) and volume (4%) between water and sewer network is much lower than the shared trench with roads, but there is a high potential of saving costs if the neighbouring pipes that even do not share a trench is still grouped for an integrated intervention. Mobilization, site office and demobilization costs are the shared items that can be distributed between water and sewer utilities. This study does not consider asset neighbourhoods at this state.

CONCLUSIONS

This work proposes a promising method to calculate the potential of direct cost savings in an IMAM practice. The method is easy to apply as it uses ArcGIS Pro functions and Python scripts to quantify the shared area and volume between road and sewer pipes, road and water pipes, or sewer and water pipes in a network level. The obtained result from the application of the method on a city shows that there is a high of cost sharing potential. It is to be noted that only direct cost savings is calculated in this study. Indirect cost savings as a result of practicing IMAM such as reduced community and service disruptions are not considered here. Furthermore, the direct cost saving potential derived from this method assumes coordinated intervention taking place on every project in which a pipe and a road section has some degree of co-location interdependency. In reality, the coordinated intervention is not always possible due to the different life cycles of the asset types. However, there are possibilities to delay/advance the interventions on assets in order to combine the intervention with other co-located assets if we model the condition of assets and know how much flexibility we have from the time of preferred intervention until the time of absolute needed intervention. Future research is needed to model the condition of assets and the flexibility time range. Furthermore, the method should be applied to other cities and see the comparability among the cities and the infrastructure designs applied in terms of cost sharing potential.

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The data-loop problem and what we can do about it

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Abstract
This communication aims to raise awareness on the "data loop" problem, or in other words, why many utilities are still missing important data on their infrastructure and not invest in data collection. Despite the global trend of gathering more data, water utilities in paradox often have a very limited useful set of data, limiting their ability for rational decision making on the medium to long term. Although the situation is very dependent on the size of the utility and the country considered, certain trends can be observed. To outline these, we will shortly discuss the advent of the data centric era and then present the "data loop" problem, with potential ideas to overcome it.

Keywords
Data; loop; problem; and; what; to; do.

THE EMERGENCE OF THE DATA CENTRIC ERA

Approximately one decade ago we entered the *data centric era*, as shown Figure 1. In less than a century, the progress in informatics, electronics, longer battery life and telecommunications, and more recently Artificial Intelligence have opened up new and affordable possibilities to produce, store, access and process data. This shift has been seen in all sectors: construction, energy, healthcare, automotive, environment… and as well in the water sector, although due to the inherent conservatism of the sector at a slower pace.

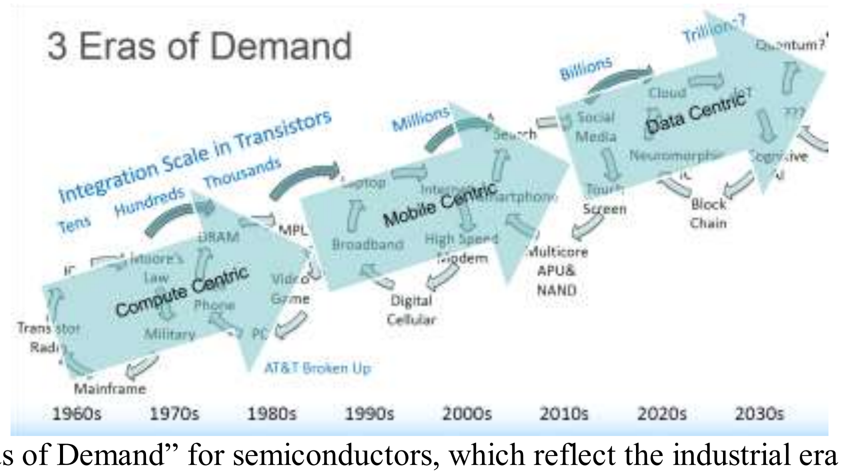

Figure 1: "3 Eras of Demand" for semiconductors, which reflect the industrial era in many sectors, including the water sector (VLSI Research, Industry Strategy Symposium keynote, US, January 2018 cited by https://semiengineering.com/dawn-of-the-data-centric-era/)

This era has been substantiated by the myriad of software developed and commercialised for design, modelling, and data management. Also, data is a vital component of any asset management strategy (Tscheikner-Gratl, 2020). Given the importance of data for operation and decision making, "data life cycles" such as the one proposed in Figure 2 were developed more than a decade ago to describe the data research process with the idea of shareability of data.

Figure 2: The data life cycle proposed by UK Data Service (https://ukdataservice.ac.uk/learning-hub/research-data-management/)

Recently, in our data centric era, a new milestone was achieved with the generalisation of the FAIR principles (Figure 3) where data should be findable, accessible, interoperable, and reusable.

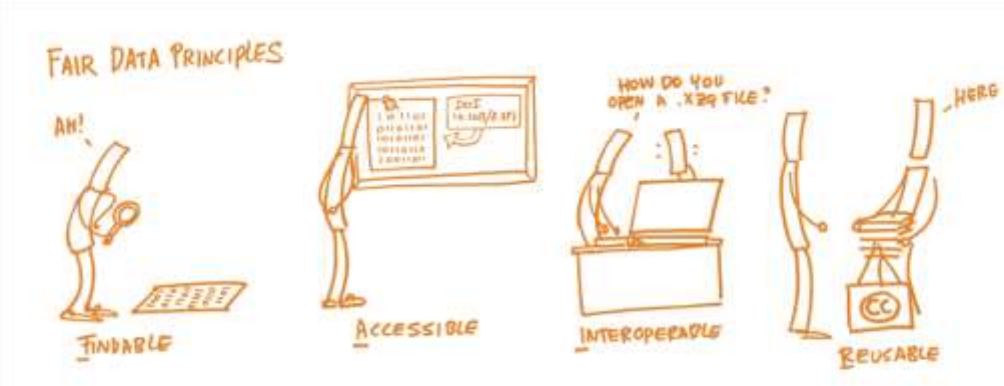

Figure 3: The FAIR (Findable, Accessible, Interoperable, Reusable) data principles (https://www.openaire.eu/how-to-make-your-data-fair)

THE DATA LOOP PROBLEM REMAINS

Yet, data application remains scarce or non-usable in large parts of the water sector depending on the location, size, budget and motivation of the utilities or organisations. A recent Swedish study (Okwori *et al.*, 2021) confirms the "low availability, integrity and consistency" for urban water pipe networks, and "lack of interoperability between asset management tools". There is a staggering difference between market trends (oriented towards data management and processing software) and the actual data availability and usage within utilities. Data scarcity concerns both the quality and the quantity of data. The problem is not only the incompleteness of data (inaccessible or unavailable) but also the challenges caused by the use of unverified, uncertain, or imprecise data. The data scarcity problem is being progressively dealt with but at a pace that is hampering many asset management strategies which will negatively influence our decision making for decades to come.

The authors believe that the data scarcity problem can be conceptualized as a loop and propose to call it the "data loop" problem, see Figure 4. Moving from the *status quo* situation where almost no data is available requires demonstrating the benefits from data usage, which is not possible without data. As investing in data gathering is very often an onerous activity, a utility manager won't consider data gathering without "immediate" tangible benefits, and the little data that may be available will not have been verified as it is insufficient to run a model. Consequently, the utility manager will not invest in models or tools or will not use data to support decision-making. This brings us back to the *status quo* situation and so on.

Figure 4: The “data loop” problem

Like many practitioners, the authors have often faced the “data loop” problem and consider it as one of the major obstacles to an efficient and long-term asset management approach. As one anonymous commenter rightly wrote, “a pivotal root of the data loop relates to the lack of medium- and long-term vision of asset managers”. However, vision alone may not be sufficient to overcome all the barriers. These barriers are found at all levels ranging from the individual to the organization (Manny *et al.*, 2021). Some barriers are also directly connected to the organization’s characteristics (Sun *et al.*, 2016)

Based on our experience, we have gathered ideas on how to overcome the “data loop” problem, see Figure 5. Among the solutions for the “data loop” problem, some are already gaining attention and traction: monitoring is more and more based on cheaper and easier to use sensors (Bartos *et al.*, 2019; Cherqui *et al.*, 2021) and models tend to be less data intensive. Okwori *et al.* (2021) proposed a conceptual framework to enable increased data-driven asset management in pipe networks. Previous research has also shown that, when considering important but unknown variables, imprecision could be better than no data (see for example Ahmadi *et al.*, 2015). Training of utility managers is also a key component to explain the importance and benefits of data and models for a more rational decision making.

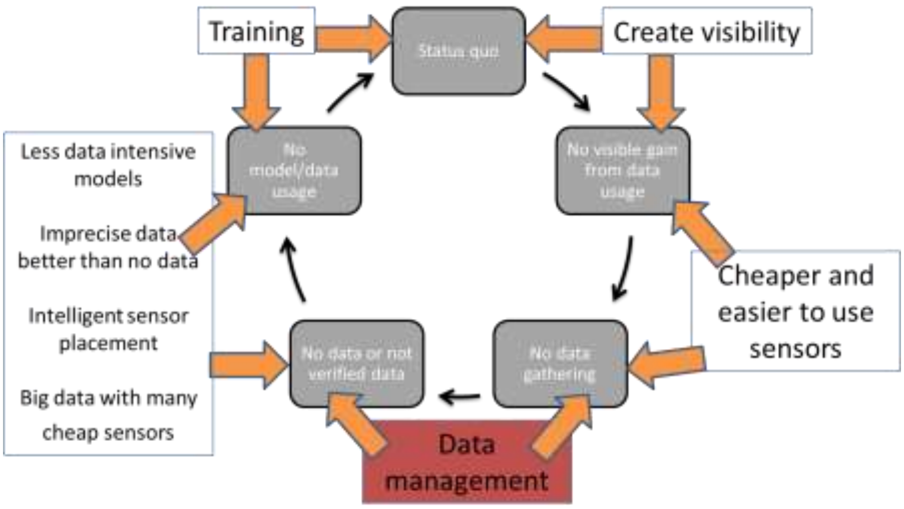

Figure 5: How to overcome the “data loop” problem: a non-exhaustive list of potential solutions.

On another level, local or national regulation is also a strong incentive (or a hinderance depending on the regulator) toward utility databases containing a minimum set of data. Similarly, Surbakti *et al.* (2019) have identified seven main themes of factors that may influence effective use of big data: “organizational aspects; systems, tools, and techniques; people aspects; data privacy and security and governance; data quality; process management and perceived organizational benefit”. As no exhaustive list of solutions can be presented at the moment, this communication aims to encourage the discussion regarding the “data loop” problem to share experience and good practices.

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Statistical modelling of water service line failures and decommissioning with time-dependent factors: Application to the Bordeaux water network

Modelling of service line failures and decommissioning with time-dependent factors

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Abstract
Modelling pipe failures is an indispensable part of any water network asset management policy. In this paper, the computational difficulties due to the introduction of time-dependent variables within the "Linear Extension of the Yule Process with Selective Survival" (LEYP2s model) are exposed. The method proposed to overcome these difficulties is applied to the Bordeaux black polyethylene service line network. By doing so, we were able to estimate the effect of time-dependent variables such as the pressure modulation and the type of disinfectant. In comparison with the LEYP2s model, this new LEYP2s model with time-dependent variables, called LEYP2sZt model, did not provide a better ranking of the service lines, but did provide better one-year predictions of the annual total leak rate.

Keywords
Failure modelling; Linear extension of the Yule process; Selective survival; Time-dependent variable; Water network asset management; Water service lines

INTRODUCTION

The aim of drinking water network asset management (AM) is to guarantee a high-quality service to users while reducing as far as possible our environmental impact. These two objectives melt into one: to prevent pipe failures. As a consequence, the modelling of the pipe failure phenomenon occupies an important place in the AM literature, as shown by Shamir and Howard [1979], Walski and Pelliccia [1982], Goulter et al. [1993], Le Gat and Eisenbeis [2000], Kleiner and Rajani [2001], Saegrov [2005], St Clair and Sinha [2012], Le Gat [2014], and Giraldo-González and Rodríguez [2020]. Among all these models, the present article deals with the "Linear Extension of the Yule Process" (LEYP) presented in Le Gat [2014] which proposes to model the failure phenomenon at the pipe scale via a counting process approach. A major issue was to address the truncation (events, removal or failure, occurring before the beginning of the observation window) and the censoring (observation stopped either because of the removals occurring during the observation window, or because of the end of the observation window) inherent in the data. Because the decommissioning and failure phenomena are not independent, the truncation and censoring cannot be eluded without biasing the model calibration. The "Linear Extension of the Yule Process with Selection Survival" (LEYP2s) proposed by Le Gat [2016] overcomes this issue by jointly modelling the failure and decommissioning processes. Another improvement of the LEYP model was made by Babykina and Couallier [2014] by considering a time-dependent variable. Therefore, the present article aims (1) at showing that both these potential sources of bias, namely the selective survival and time-dependent variables, can be dealt with simultaneously, which gives rise to the LEYP2sZt model; (2) at judging the interest of this new LEYP2sZt model with the case study of the Bordeaux water supply network; and (3) at showing that LEYP-family models are relevant for service lines too, despite having been applied mostly to water mains so far.

METHODOLOGY

In the following, the water network is supposed to be described as a set of segments, more colloquially named "pipes", which can either be water mains or water service lines. Each pipe is characterised by a set of variables gathered into a vector further denoted $\boldsymbol{Z}$. The starting point of the present article is the LEYP2s model [Le Gat [2016]] which formalises each pipe failure process by a counting function $N(t) \in \mathbb{N}$ of the pipe age t, and each pipe decommissioning process by a counting function $R(t) \in \{0,1\}$:

$$
\begin{aligned}
&\forall t \in \mathbb{R}_+,\\
&N(0) = 0\\
&\mathbb{E}(\mathrm{d}N(t) \mid N(t-), \boldsymbol{Z}) = \left(1 + \alpha N(t-)\right)\lambda(t, \boldsymbol{Z})\mathrm{d}t\\
&R(0) = 0\\
&\mathbb{E}(\mathrm{d}R(t) \mid N(t-), \boldsymbol{Z}) = \left(\psi(t, \boldsymbol{Z}) + \phi N(t-)\right)\mathrm{d}t\\
&\text{with:}\quad \alpha > 0, \quad \lambda(t, \boldsymbol{Z}) \geq 0, \quad \psi(t, \boldsymbol{Z}) \geq 0, \quad \phi > 0.
\end{aligned}
$$

From a mathematical point of view, allowing the covariates to be functions of time does not change the expression of the likelihood needed to calibrate the model, nor does it change the distribution needed to compute the predictions, both given in Le Gat [2016]. On the contrary, from a computational point of view, it does affect the way the likelihood is computed since several integrals, appearing in the likelihood expression, involve $\boldsymbol{Z}$ which has become $\boldsymbol{Z}_t$. It is now required to integrate, for each pipe, the above-mentioned $\lambda(\cdot)$ function, which depends on the pipe age t and on the covariate vector $\boldsymbol{Z}_t$ via the scalar parameter δ and the parameter vector $\boldsymbol{\beta}$ of covariates effects: $\lambda(t, \boldsymbol{Z}_t) = \delta t^{\delta-1} \exp(\boldsymbol{Z}_t^T \boldsymbol{\beta})$. For each pipe, the integral $\Lambda(s, \boldsymbol{Z}_t) = \int_0^s \lambda(t, \boldsymbol{Z}_t)\mathrm{d}t$ is to be computed from its installation, at age $t = 0$, until age s, either at the beginning of the observation window, or at its end. Luckily, this integral is the same for pipes installed in the same year and having undergone synchronous changes, allowing therefore to spare redundant calculations. For other integrals, which require numerical integration methods, high-order methods cannot be used anymore since, with time-dependent variables, the integrands are not smooth enough. Instead, the rectangle rule has been used. In order to show that these new computational difficulties do not prevent the LEYP2s model with time-dependent variables, or LEYP2sZt model, from being calibrated, it has been applied to the black polyethylene water service lines of Bordeaux Métropole (English: Metropolitan Bordeaux), in South West France. 23496 service lines, 3849 failures, and 2505 renewals have been observed from 2009 to 2015. The model has been assessed on a test window ranging from 2016 to 2019. Three time-dependent variables have been introduced in the model: the daily maximum air temperature [Klein Tank et al. [2002]] averaged by month, the implementation of pressure modulation (which has been progressive), and the type of disinfectant (which has changed over the time, from chlorine dioxide to chlorine). The parameter vector has been estimated in the R environment (R Core Team [2018]) via the maximum likelihood estimation method and using the Nelder-Mead algorithm.

RESULTS AND DISCUSSION

The Nelder-Mead algorithm used to calibrate the LEYP2sZt model on the Bordeaux black polyethylene service lines converged within a reasonable amount of time, which obviously depends on the computer used, but which was on the order of hours in our case, proving the practicability of the LEYP2sZt model. Following its calibration, the performances of the LEYP2sZt model have been assessed and compared with a LEYP2s model. As regards the ability to detect the pipes the most at risk, the Lorenz curves proposed in Le Gat [2016] have been drawn: both the LEYP2sZt ($AUC = 0.65$) and LEYP2s ($AUC = 0.66$) models performed better than naive approaches (ranking based on the number of past failures: $AUC = 0.58$; ranking based on each pipe age: $AUC = 0.59$), which supports the use of LEYP-family models on service line networks. The LEYP2sZt and LEYP2s Lorenz curves are too close for the superiority of either of the models to be decided as for the ranking objective. As regards the ability to forecast for the years to come the overall state of the network, one-year predictions of the annual total number of failures were computed for both the models: the LEYP2sZt predictions follow the evolution of the real leak rate (first a decrease until 2016, then an increase); contrary to the LEYP2s model which forecasts a continuous increase in the total leak rate (cf. Figure 1). Therefore, the LEYP2sZt model represents an improvement over the LEYP2s model as for the objective of forecasting the overall network state. Finally, the LEYP2sZt model allows to quantify the effect of the time-dependent variables: we now know that the instantaneous failure rate (number of failures per unit of time) of any modulated service line is 32% below the one of its not modulated counterpart ($p < 1e-16$); and that, with chlorine, the instantaneous failure rate is 48% lower compared to what it would be with chlorine dioxide, all others things being equal ($p < 1e-16$).

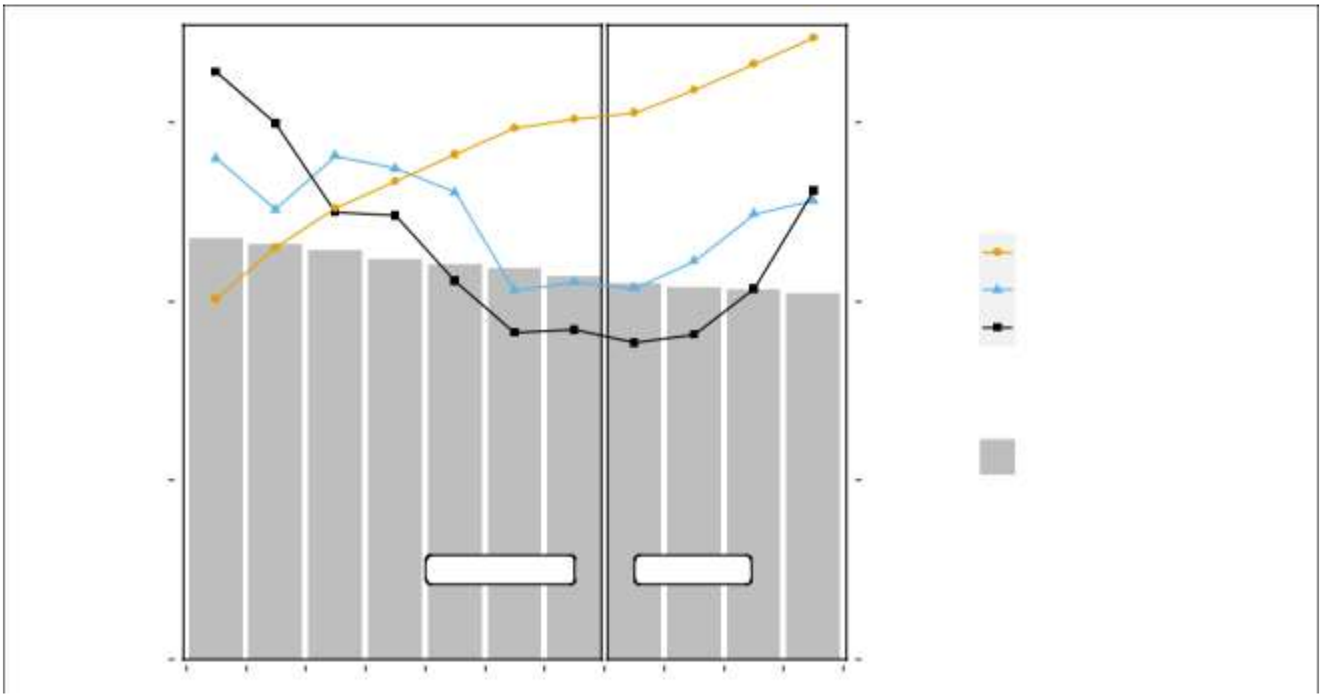

Figure 1: Predictions for the annual leak rate of the Bordeaux black polyethylene service lines

Notes: For each year, the service lines in service at the beginning of the year have been considered. The number of failures expected to occur during the year, knowing the number of past failures, has been computed for each service line, then summed by year, divided by the total number of service lines, and finally multiplied by a factor of 1000. The result is, for each year, the numbers of failures expected to occur during the year for each 1000 service lines.

CONCLUSIONS

In this paper, we have proposed a method to consider time-dependent variables within the LEYP2s model. This new LEYP2s model with time-dependent variables, named LEYP2sZt model, has been applied to the Bordeaux black polyethylene service lines, proving the possibility of such a model to be calibrated within a reasonable amount of time. Both the LEYP2sZt and LEYP2s models performed better than naive approaches in detecting the service lines the most at risk, which encourages us to continue using LEYP-family models on service line networks. The LEYP2sZt model did not provide a better ranking of the service lines, in comparison with the LEYP2s model. This result depends most certainly on the discriminating power of the time-dependent variables being considered: further research is needed to assess if other time-dependent variables or other distribution of the same time-dependent variables could lead to better results. On the contrary, the one-year predictions of the annual total leak rate did improve with the introduction of the time-dependent variables. This latter result is likely due to the changes in the operating conditions (pressure modulation being implemented, and the type of disinfectant being changed) that benefit the LEYP2sZt model. Consequently, if major changes in the operating conditions occurred during the observation window, these time-dependent variables should be introduced in the LEYP2s model for it to be able to produce relevant medium-term predictions. Nonetheless, to complete this result, the long-term predictions, with a time horizon of more than one year, of the LEYP2sZt model need to be assessed. Finally, a major advantage of the LEYP2sZt model is its ability to provide an estimation of the effect of time-dependent variables, improving our technical knowledge.

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Kampala, Uganda asset management project: growing a failure database with data collection apps for machine learning and failure risk prediction

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Abstract
An 18-month operational asset management project to improve the condition state and efficiency of the water distribution network of the Kampala metropolitan area, Uganda, is being carried out by French company Altereo. The core challenge of the project is to build a sufficiently robust database to run machine learning algorithms to predict the risk of network failure and design an efficient network replacement plan.

The Kampala water utility has existing GIS and partial network failure information. The data is however not fully ready for machine learning and the failure history is insufficient. The first step was to deploy a very simple mobile application with a unique feature: capturing the location, date and standard description of every leak repaired. With an average of 4,000 leak repairs per month, the potential for rapid growth of a failure database is promising.

This paper will present the initial data and tools, the mobile data collection tool deployed at the start of the project and the preliminary diagnosis of the data gathered over the first 6 months in the perspective of machine learning. The aim of this communication is to expose data-related constraints for advanced asset management in cities of the Global South and solutions to overcome them.

Keywords
Asset Management, Climate change, Demographic boom, Drinking Water, Non-Revenue Water, Water Networks, Leaks, Data, Mobile, Machine Learning, Artificial Intelligence, Failure Prediction, Likelihood of Failure, Targeted Replacement

INTRODUCTION

As the majority of Africa's metropolitan areas, Kampala (3.5 million inhabitants and over 3,000 km of water networks) is experiencing a demographic boom with a population growth of 5% per year. While water network extension seems to be a necessity to face the water demand increase, leakage on the existing mains compromise both the availability of drinking water resource and the investment capacity of the city's public water utility – Kampala Water, a branch of the National Water and Sewage Corporation (NWSC). Indeed, 35% of the water injected into Kampala's network is lost through leaks. The cost of leakage is estimated to 13 million euros, as the water has previously been pumped and treated. As up to now, the NWSC followed a curative strategy regarding its asset management, repairing mainly visible leaks. Conscious of the challenges of the next decades, the utility wants to adopt a predictive strategy and replace the pipes before they break.

Such predictive approaches, undertaken with statistical models in the past decades, are now handled by Artificial Intelligence (AI). Machine learning algorithms, for example, are able to learn from the past failures to calculate the likelihood of failure of every water main composing the network.

DATA CONSTRAINTS

Machine learning requires good quality and quantity of data on assets, their environment and most importantly, past leak records to learn from. At the start of the project, an initial network failure database running on 2019 to 2021 was obtained. It contained 77,000 records, geolocalised but not attached to a precise network component. Oral information from field staff indicates that most of these incidents occurred on service connections. Direct geographical association of leaks from this database to precise network components was not always obvious. The database was cross-checked and cleaned as much as possible to allow the use of these 3 years of failure history. The existing failure history was however clearly insufficient in terms of precision, quality and depth.

CAPITALISING ON LEAK REPAIRS TO COLLECT FAILURE DATA WITH MOBILE APPLICATIONS

The African Continent is the theatre of a well-known technological leap in the field of civil communications, going from nothing to the omnipresence of mobile technologies in the last decade. Within Kampala Water, the use of mobile phones by field staff is already acquired and mapping and reporting tools are in place. The latter however did not fit the exact requirements to build the failure database with sense and simplicity. The information needed was the date and location of the leak, precision on the component, material, diameter, type and cause of failure as a minimum. Additional information describing the condition state, coating and immediate environment are optional.
The HpO Collect mobile application was proposed. It was designed to simplify and secure field data collection and favour massive uptake by field staff. It proposes a minimal interface, large buttons and lists (Figure 1) so that the report is made in less than a minute. It does not require training.

Figure 1: The HpO Collect mobile application and screen sequence

The application was first tested as from February 2022 with 8 leak repair teams specialised on water main breaks. The application was then deployed as from March 2022 within all the leak repairs teams, mostly handling service connections and fittings. The average of 4,000 leak repairs per month is a promising potential for rapid growth of the failure database.

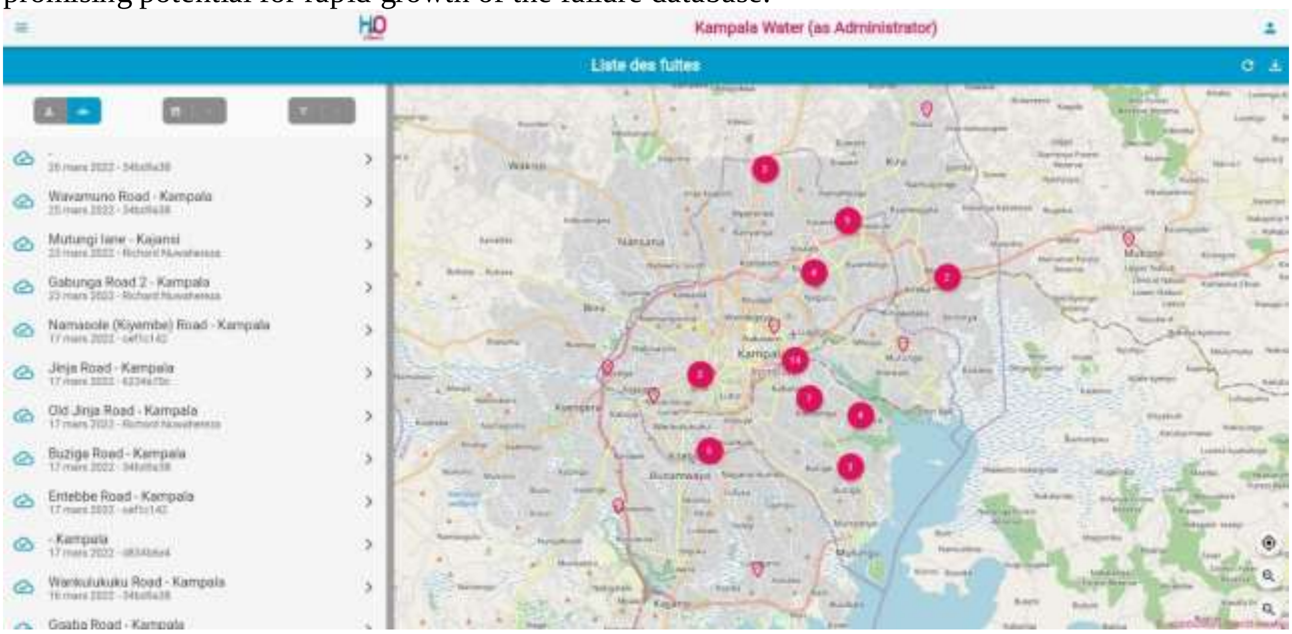

Figure 2: The HpO Viewer interface on Kampala showing the first leak repairs recorded

INTERMEDIATE RESULTS ON THE KAMPALA DATA SET

At the time of this paper, the data collection process with the newly deployed HpO Collect mobile application is too recent to be analysed. The existing 3-year failure historic can be analysed though it is not as rigorous as required. Figure 3 shows a grid-type heat map of failures across the Kampala Metropolitan area. Darker areas are identified, showing higher failure frequencies. They indicate zones to be compared with potential factors for failure. Preliminary analysis of context data highlights higher failures rates in the presence of 2 soils types (Figure 4).

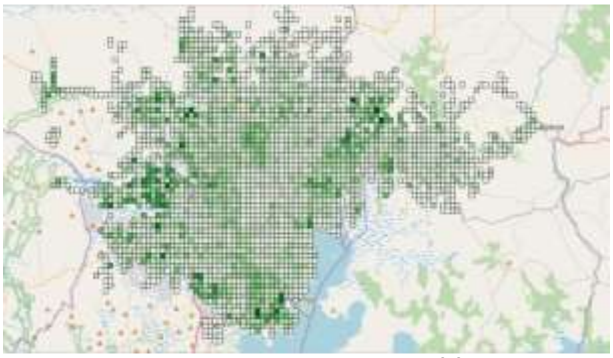

Figure 3: Grid-type heat map of failures

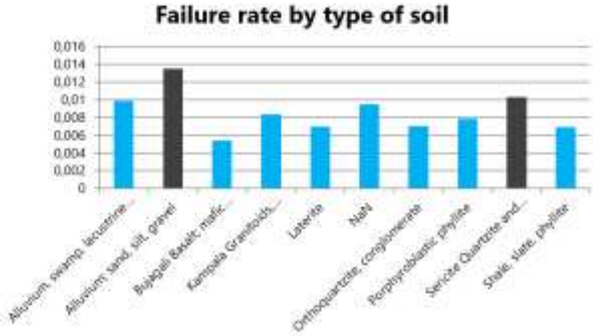

Figure 4: Failures rates by types of soil

Analysis of the existing data is being continued for more insights. Rigorous leak repair data collected with the mobile application will provide by end 2022 a more robust database to investigate and attempt failure prediction.

APPLICATIONS IN OTHER CITIES

Dissemination of the HpO Collect mobile application for network failure data collection

The HpO Collect mobile application was created early 2022. On the occasion of the 9th World Water Forum in March 2022 in Dakar, Senegal, Altereo, together with the French Water Partnership, the Mediterranean Water Institute and the Solar Impulse Foundation Altereo, donated the application to the international community. The objective is to massively disseminate the data collection application so as to favour the emergence of data worldwide to enable a maximum number of water utilities to access advanced asset management and better performance.

Results from machine learning failure prediction with a robust data set

The HpO machine learning technology has previously been applied in several cities in France: the Paris Greater Area (SEDIF), Orleans, Chartres, Limoges, Annecy and Noumea. The case of Noumea, a French territory in the Pacific Ocean, is particularly interesting. The water utility had accumulated an 18-year failure history (2000-2018). A predictive model is always verified by truncating the history to learn from the first period (2000-2014) and verify the prediction against the second period (2015-2018). This verification process demonstrated that the predictive model was able to sort the pipes by likelihood of failure so that replacing 5% of the network in length would avoid 50% of failures in the second period (2015-2018). The potential and promise of such machine learning technology is thus very significant and positions advanced asset management and targeted network replacement as a tangible solution to reduce leakage on the short/medium term.

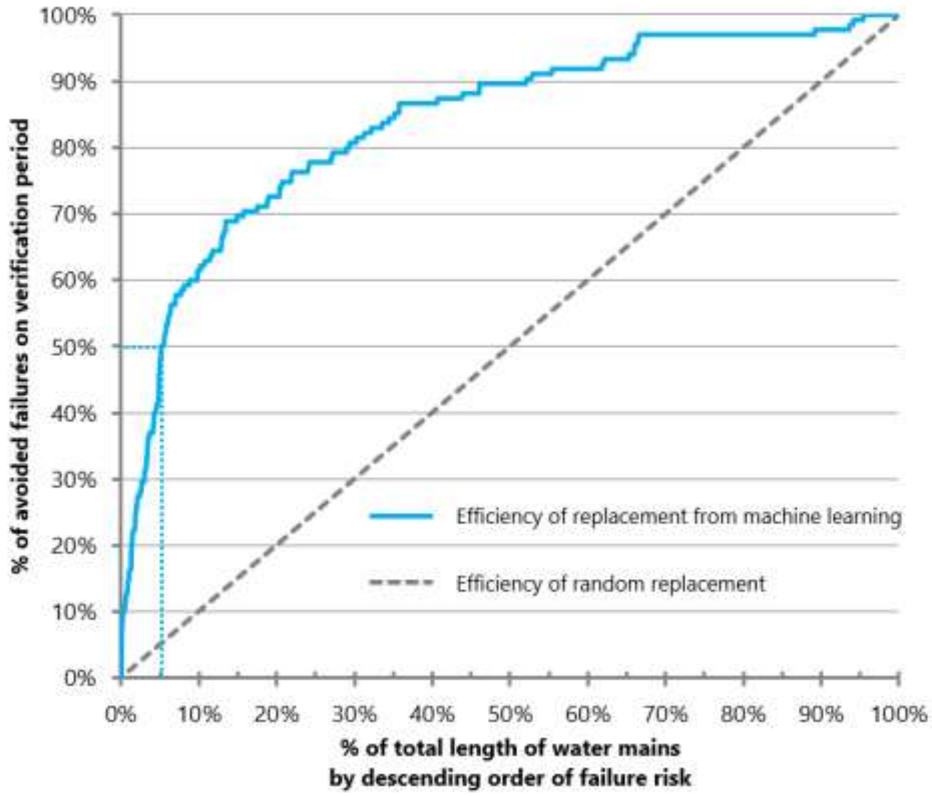

Figure 4: Efficiency of machine learning failure prediction model on Noumea

CONCLUSIONS

The demographic boom observed in cities the Global South makes the need for infrastructure increasing faster than the ability of governments to finance it. It is especially true for water networks, where the ageing of the asset coupled with climate change severally compromise the access to this vital resource which is water. In this context, optimising and smoothing network replacement investments are an absolute necessity. AI-based solutions, through the use of machine learning algorithms, have a great potential to help governments to do so. Unfortunately, whether AI is being adopted in cities of the North, it remains unsuitable for the cities of the South, where data is often insufficient.

The deployment of the HpO Collect application in Kampala provides a strong example of the possibilities offered by simple digital solutions to fill the gap. Such experiences should be replicated in other cities of the Global South as they allow water utilities to build databases and sink into predictive asset management to increase the performance of their water networks on a medium timeframe, while remaining in adequacy with their financial capacities.

The usefulness of a typical condition data set for modelling sewer condition and life span

The usefulness of a typical condition data set for modelling sewer condition and life span

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Abstract
In this paper, we compare two different modelling methods, one statistical method and one machine learning method, for predicting sewer condition and life span. We analyse the impact of predictor variables on poor condition using partial dependence plots, which are a valuable technique for this purpose. We propose a method for estimating the range in which the actual network survival curve lies. In order to reach reliable results, we conclude that a life span model needs to be constructed based on a random sample of pipes instead of inspections focused on pipes in poor condition. For modelling the pipe condition, the bias in the data set has a lower impact, since the threshold for poor condition can be adjusted.

Keywords
deterioration modelling; machine learning, sewer condition; sewer life span; statistical analysis; survival models.

INTRODUCTION

The earliest parts of the urban water infrastructure in Finland were built in the 19th century but most of the networks in use today date from the 1970s or after. As a result, large-scale network renovations are just starting to become commonplace at all utilities; the oldest parts of the networks have already been renovated, but continuous renovation resulting from the construction boom in the 70s and after has not yet begun. The networks' need for renewal is a similar concern elsewhere in Europe and North America, where substantial proportions of the pipelines are reaching the end of their useful life (Duchesne et al., 2014).

Water and wastewater infrastructure is buried underground which makes it difficult to inspect their condition. However, insights on network condition can be derived from data analysis to support the decision-making related to the networks. Recently, there has been a growing interest in data-driven sewer asset management (see for example, Laakso 2020, Okwori et al. 2021, Noshahri et al. 2021).

In this study, two modelling approaches were applied to the same data set on sewer condition. In the first approach, the goal was to predict condition on pipe level. In the second approach, the network life span was modelled. The aim of this presentation is two highlight the insights gained from the two approaches, to assess the suitability of the methods applied and to present how different explanatory factors are linked with condition. Additionally, the suitability of a typically available network condition data for such modelling purposes set is discussed. The research presented here is based on the articles by Laakso et al. (2018) and Laakso et al. (2019).

METHODOLOGY

The analyses of pipe condition and life span were carried out with a data set on a sewer network of approximately 1200 km in length. The oldest pipes in the network date from the year 1955 with intensive construction starting in the mid-1960s and continuing until today. The network only contains foul sewers. Approximately 30% of the sewers was CCTV inspected between 2001 and 2016. Pipe condition was modelled as a dichotomous variable (good/poor), where pipes in condition classes 0 to 2 represented good condition and pipes in condition classes 3 and 4 poor condition.

A statistical method and a machine learning method were applied for modelling both pipe condition and network life span. In modelling current condition logistic regression (see, for example, Agresti 2013) and random forests (Breiman, 2001) were applied. Network life span was modelled using Weibull survival and random survival forests (Ishwaran, 2008). The impact of explanatory variables was studied using partial dependence plots (Friedman, 2001).

Results and Discussion: The random forest and logistic regression methods applied for modelling pipe condition provided reasonable results in terms of predictive ability. The validation data included a random selection of 30% of the pipes in the original data set. The random forests performed somewhat better in predicting the condition of the pipes in the validation data set. The maximum accuracy of the random forest model was 62% after setting the false negative rate to 20%, whereas for the logistic model it was 56%. In practice, the desired false negative rate was achieved by adjusting the threshold for poor condition.

The impact of different explanatory factors was studied using partial dependence plots (Figure 1).

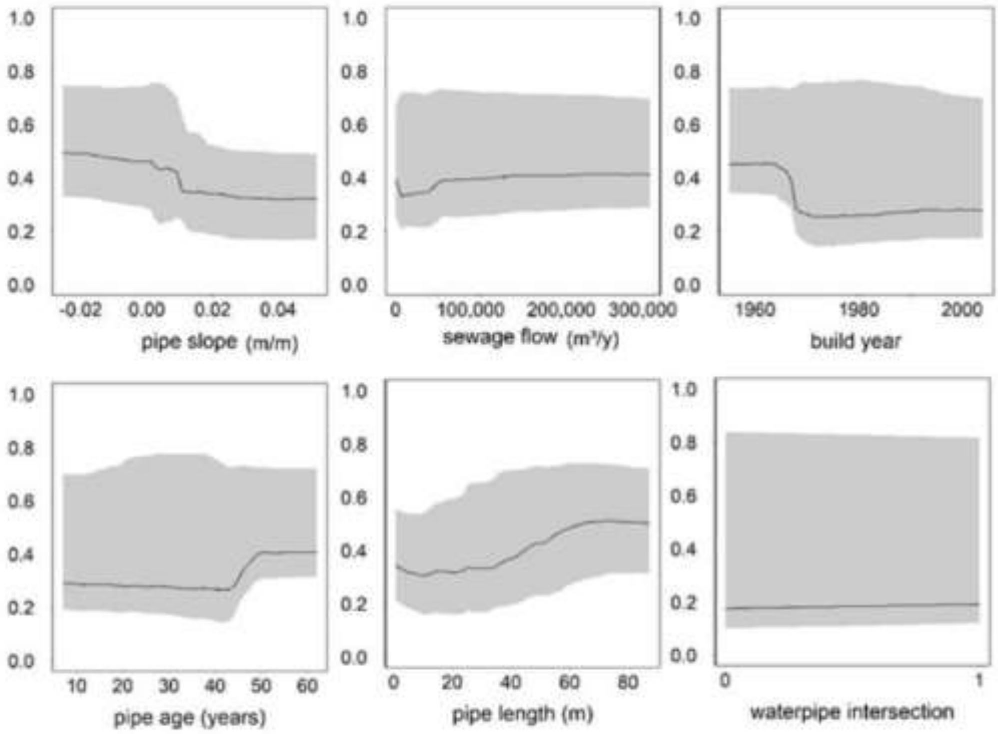

Figure 1: Partial dependence plots of six of the studied variables.

The partial dependence plots in Figure 1 reveal how, for example, pipe slope, sewage flow, build year, pipe age and pipe length were the variables with the strongest connection with poor condition. A negative slope had a higher effect on the condition than a positive one and both very small and large sewage flows affect condition negatively. Pipes built before 1970 tended to be in worse condition than others, as do pipes of more than 45 years old. In the data set studied, the longer the pipe, the higher was the tendency for poor condition.

When the data were used to predict network life span, the random survival forest and Weibull estimates resulted in similar-looking survival curves until approximately pipe age 50, where the two estimates diverged. Figure 2 presents the curves together with a Kaplan-Meier curve.

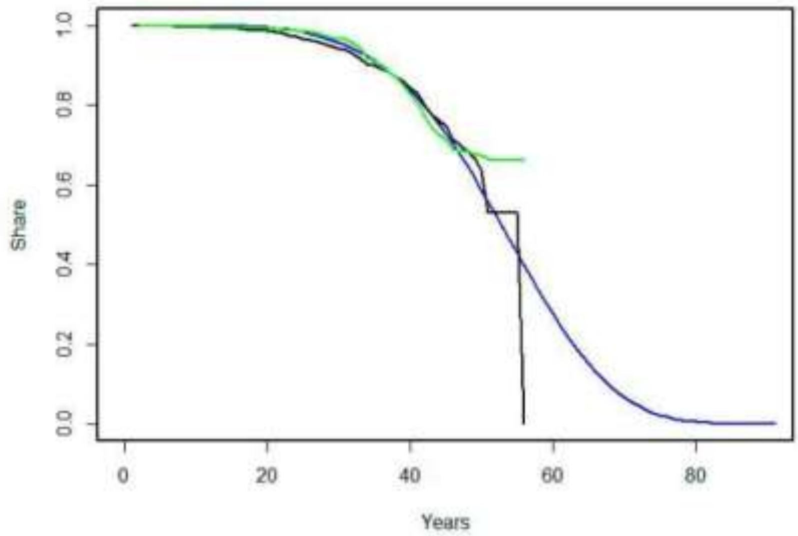

Figure 2: The survival curves estimated by random survival forest (green curve) and Weibull survival (blue curve) and the Kaplan–Meier estimate (black curve).

Both the random survival forest and the Weibull model estimated that by the age of 50, ca. 30% of the network has reached the end of its useful life. Since the Weibull model is a parametric model, it can predict beyond the age of the oldest inspected pipe and estimates that whole network will need renovation by the age of 85 years. Since random survival forest is not a parametric method, the estimate does not continue beyond the maximum pipe age of 56 years.

Since the data set contained more pipes in poor condition than the rest of the network, an optimistic and a pessimistic curve were created. In the optimistic estimate, the selection of pipes for inspections is assumed to have succeeded fully and the sample is assumed to hold all pipes in poor condition in the whole network. In the pessimistic estimate, the selection of pipes for inspection is assumed to have failed and the sample hold pipes approximately in the same condition as the rest of the network. The two life span curves (Figure 3) show a difference of ca. 45 years in estimating the time when 50% of the network has reached the end of the life span: The estimate is approximately 55 years in the pessimistic case and approximately 100 in the optimistic case. In the pessimistic case, all pipes will need renovation by the age of 85, while the optimistic curve predicts the entire network will reach the end of useful life by the age of 170.

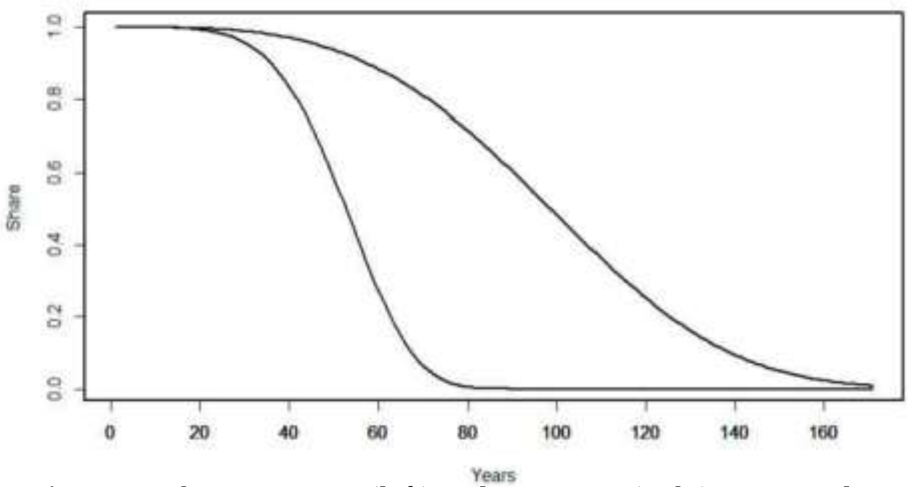

Figure 3: The pessimistic (left) and optimistic (right) curves indicating the range where the actual survival curve is estimated to settle.

In addition to the method comparison, the suitability of the data set for condition and life span modelling purposes was assessed. The condition data used in the analyses regarded pipes selected for inspections due to suspected or experienced poor condition. Therefore, presumably pipes in poor condition were overrepresented in the sample. When predicting the condition of individual pipes, this issue can be tackled by adjusting the discrimination threshold for poor condition. If the threshold is set high, the model will only identify pipes that are very likely to be in poor condition. However, a sample where poor condition is overrepresented is not equally useful for life span prediction – it will provide a more pessimistic prediction than what the reality is. A random sample would be needed in order to predict life span reliably.

CONCLUSIONS

A data set where pipes in poor condition are over-represented is more useful for finding pipes in poor condition in the network than for predicting future deterioration of the whole network. In order to make reliable life span estimates, the survival model needs to be created with a random sample of pipes inspected successively. This calls for changes in targeting sewer inspections. The optimistic and pessimistic life span curves were found to provide a means of estimating the range of network life span based on a data set where pipes in poor condition are over-represented.

The machine learning methods random forest and random survival forest applied in the analyses slightly outperformed the statistical methods used, logistic regression and Weibull regression.

The partial dependence plots were found to provide a useful way to studying the impact of explanatory variables on pipe condition.

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Water supply performance and asset management strategies: a cost-benefit analysis

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Abstract
Renewal of drinking water pipes is a societal challenge. Due to ageing networks, water utilities must implement strategies to maintain the quality of the service they provide their users. This consists in adopting a long-term approach called "Asset management" (AM) usually based on 3 dimensions of the service performance: service continuity, integrity of the network, and water quality. We propose to carry out a Cost-Benefit Analysis (CBA) in order to compare 3 AM strategies leading to the same amount of work but each focusing on one specific dimension of service performance. These scenarios take the form of 3 competitive scenarios compared to a reference situation. The study analyses internal and external costs and benefits in order to determine the scenario that satisfies both supply services constraints and society expectation, i.e. the most beneficial scenario. For the water utilities, some criteria might significantly impact costs (environment, pipes length, levelling works). The impacts of externalities vary across scenarios and are thus expected to be determinant in the final CBA result. In the short term, renewal costs are expected to exceed operating and maintenance costs but this tendency might be balanced by positive externalities in the long-term, i.e. 10 years.

Keywords
Asset management strategies; Cost-benefit Analysis; Pipe renewal; Internal costs; Externalities; Contingent Valuation Method

INTRODUCTION

Drinking water networks are a high-value asset with a long service life; their management must thus adopt a long-term approach and adapt to changes in their environment, mainly connected to global change and new technologies. The key challenge of this Asset Management (AM) is the annual renewal of a small portion of pipes in order to mitigate the effects of ageing on their performance, and to prevent the deterioration of service quality.

Currently, health risks (in particular linked to the presence of Vinyl Chloride Monomer (VCM) in PVC pipes) and the limitation of water loss are usually driving the decision regarding water pipes renewal. However, the methodological reflection remains focused on risks of service interruptions and impacts of malfunctions on the urban environment. And it is mainly based on multi-criteria decision-making. A major challenge for research thus lies in taking into account the other dimensions of the water supply service performance, namely integrity of the network (resource protection) and water quality (among which the issue of VCM). This is especially true since, in most cases, actions undertaken to satisfy one axis of performance are sub-optimal for the others. It appears that technical sciences are able to generate new knowledge on each axis taken separately. However, their integration, which is an operational necessity, requires a more complete picture of the issue and the resort of economics. To achieve this goal, we propose to perform a Cost-Benefit Analysis (CBA), which seems to allow taking into account the multi-objective character of AM. It compares 3 AM strategies leading to the same amount of work but each focusing on one specific dimension of service performance (water quality; service continuity and protection of the urban environment, that is to say, prevention against breakages; limitation of water loss) while considering the water price. Our CBA is implemented in the surroundings of Limoges, in western France. The French territory is a widespread area with towns' characteristics varying according to typologies (rural, urban, touristic areas, etc.). This requires a large water network to connect dwellings to the pipes (e.g. 56 lm/user in the Région Nouvelle-Aquitaine against 37 lm/user on average in France).

METHODOLOGY

So far, a limited number of studies performed a CBA focusing on issues related to drinking water networks AM: water loss reduction (Malm et al., 2015), leakage control (Venkatesh, 2012), improvement of ageing pipes (Jun et al., 2019) or limitation of health risk (Bergion et al., 2018). And almost all pay attention only to one dimension of AM. On the contrary, we built 3 competitive scenarios that are compared to the current AM strategy. Scenario 1 is about water quality with a focus on water quality. Pipe renewal prioritises issues related to VCM. Scenario 2 is oriented toward service continuity and urban environment preservation. Pipe renewal aims to limit burst and associated flooding risks. Scenario 3 is dedicated to water resources and natural ecosystems. Pipe renewal aims to control water losses with a focus on diffuse leaks from pipes and connections. The study has been implemented in six towns located in the Haute-Vienne department where drinking water pipes are mostly made either of PVC involving VCM concern or ductile iron more likely to break or leak.

CBA is a widely used method for comparing the costs and benefits of a project and its alternatives to a baseline (Atkinson et al., 2018). In this study, the baseline is the current AM situation. We assume that the local urbanisation plan does not evolve throughout the timeline of the study (i.e. 10 years). Operating expenses are not taken into account.

The study analyses internal and external costs and benefits separately. Regarding internal activities, costs and benefits are those of the water utility. For each scenario, work-types have been identified to reflect actions and their associated costs/benefits. For instance, Scenario 1 mainly focuses on sample analysis for VCM test and preventive purge; Scenario 2 on burst repairs and associated interventions like curative purge and pressure management; Scenario 3 on network segmentation and leak detection. Each action is assessed in monetary terms with a determining weight (decisive, support, additional). This assessment is based on data gathering, expert judgement, analysis of documentary sources (such as annual reports and Unit Price Bulletins – UPB), etc. A strategic roadmap was then designed in order to group the work-types into 6 categories: (i) network knowledge and management (e.g. GIS-based inventory, work statement and records); (ii) service to third-parties (e.g. claims processing); (iii) preparation and organisation of the work area (e.g. pipes location, trench and levelling, pavement); (iv) works on pipes (e.g. pipe furniture and laying, repair connectors, purge and pressure management); (v) specific VCM management (e.g. sample analysis and preventive purge); and (vi) leakage detection (e.g. network segmentation, remote data collection). Finally, internal costs have been organised in categories of activities including furniture and laying, work intervention, equipment maintenance, and administrative management. Besides, internal benefits are also considered as avoided costs that reflect gains from water production yield and water savings (e.g. on maintenance or from loss reduction).

As for the external activities, externalities have seldom been included in drinking water AM studies. Nevertheless, each renewal has environmental and social costs that must be included in the CBA (Lambert and Lalonde, 2005). For instance, when occurring on a busy road, it might generate traffic congestion or noise affecting neighbours' well-being. In our study, 7 externalities have been identified: water losses, urban environment disturbance, roadworks related disturbance, public health risk, quantitative restriction of consumption, water pressure, and water service interruption. As there is no market to estimate their monetary value, the Contingent Valuation Method has been used and a paper-pencil survey sent to inhabitants of the 6 towns. As the 3 scenarios are competitive, respondents had to rank them in order of preference. Such an approach has seldom been used in environmental economics (see Olsen et al. (2005) for health care). Once the 3 scenarios ranked, respondents were asked to state their willingness-to-pay (WTP) in an open-ended format. Finally, an econometric model will be used in order to estimate respondents' WTP and determine variables that significantly impact these WTP.

RESULTS and DISCUSSIONS

A first result provides costs and benefits for both the internal and external parts. Those results will then be gathered in order to perform the CBA.

The internal part proposes a framework that models the main AM operations. The analysis quantified the operating and renewal costs for the reference situation and each scenario in order to assess variations in costs. Renewal costs vary primarily with the environment typology (rural vs urban), the length of laid pipes and the section specificities (circulation, roadway constitution, type of trench, special condition). More precisely, various criteria were identified based on a multi-criteria analysis to depict the importance of trench, levelling work and pavement design involved in roadwork. These are type of ground, deepness, environment typology, traffic class and aggressivity coefficient, road class, trench width and pipe diameter. As an example, levelling works-types were built for each class of road so that rehabilitation plans and associated costs depend on 3 groups of roadway traffic (hard, medium, weak). Finally, the computation of costs for the 10-year period is achieved in a table figuring categories of costs, year-by-year data and cumulative total projected costs. From a short-term perspective, we expect that scenarios based on operating and maintenance works would be chosen in comparison to renewal because of the high costs of roadwork. Nevertheless, the long-term projection will show that operating and maintenance costs rise with time, while actualised costs of renewal tend to decrease.

Regarding the external part, we first validated the representativeness of the sample in order to guarantee reliable estimates using data from the French National Institute of Statistics and Economic Studies. WTP estimates will then be calculated using an econometric model, as well as the respondents' characteristics, perceptions or motivations that impact them. By multiplying the estimated WTP by the number of households in the area we will compute total benefits. However, the identified externalities do not impact scenarios in the same way. For instance, one could expect that water loss will be a significant determinant in the costs and benefits for Scenario 3. As leaking pipes are difficult to identify, a high quantity of water is lost and impacting the environment (e.g. ecosystem disturbance).

Once costs and benefits quantified, the next step will be to compute the Net Present Value (NPV). In fact, the objective is to determine the most beneficial scenario i.e. the one for which costs are lower than benefits. Lastly, sensitivity tests will be performed on parameters likely to affect the final result (e.g. on the discount rate) in order to ensure its accuracy.

CONCLUSIONS

Drinking water networks are a high-value asset with a long service life. Their management concerns technical, organisational (service), economic and financial (costs and benefits), environmental (resources), and societal (territorial governance, users) issues. This study proposes to consider all these aspects and integrate them into a CBA. Through this economic analysis, we compare composite AM scenarios combining 3 dimensions of water supply service performance. Each scenario confronts pipes renewal investment and service maintenance in comparison with the current AM strategy. So far, this study is the only one that compares 3 scenarios and includes both internal and external aspects. For the water utilities, some criteria might significantly impact costs (environment, pipes length, levelling works). The impacts of externalities vary across scenarios and are thus expected to be determinant in the final CBA result. In the short term, renewal costs are expected to exceed operating and maintenance costs. Therefore, assuming that this tendency would be balanced by positive externalities in the long-term, the study considers a 10-year period. In the end, we will determine which scenario should be applied i.e. the most beneficial one for society.

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Multi-actors and multi-scales costs analysis of maintenance of green stormwater infrastructures

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Abstract
Urban drainage management is a major issue for all public authorities. For years, increasing urbanization and climate change have been raising the rate of soil waterproofing inducing greater volumes of storm water to be managed. Sewerage systems are therefore sometimes overloaded, and it is economically and technically not sustainable to increase the size of the assets, pipes and treatment plants. So new solutions, Green Stormwater Control Measures (GSCMs) (alternatives to the classic "all-pipe" system, and nature-based solutions) were developed. They are based on the following general principles: temporary storage, controlled flow drainage and infiltration but bring also multifunctionality (hot spots reduction, landscape and recreational aspects…) because they are on surface and generally green. Their specificity is also that several departments are involved in the maintenance and so we developed a costs analysis approach to evaluate the maintenance costs, looking both academic methods and practices in the utilities at the GSMC individual level or at the global service level. The reliability and relevance of the methodology depends on the quality of the data availablility. The goal is to have better visibility and control over spending. It is essential to ensure that the information entered upstream is as accurate as possible. The question arises of how to "capture analytical information" as close as possible to its source, depending on the organization in place and the complexity of the entity and the information system. The method is thus applied and adapted according to the context, the organization, the means and tools concerning GIS, maintenance and accountancy tools or self-made developments.

Keywords
Green infrastructure, storm water control measures, costs analysis, infrastructure scale, utility scale, decision tool, multi-actors' maintenance, nature based solutions

INTRODUCTION

Urban drainage management is a major issue for all public authorities. For years, increasing urbanization and climate change have been raising the rate of soil waterproofing inducing greater volumes of storm water to be managed. Sewerage systems are therefore sometimes overloaded, and it is economically and technically not sustainable to increase the size of the assets, pipes and treatment plants. So new solutions, called best practices BPMs or storm water control measures SCMs (Fletcher et al. 2014), Green Storm water Infrastructures or Green Storm water Control Measures (GSCMs) (Werey *et al.*, 2019) (alternatives to the classic "all-pipe" system, and nature-based solutions) were developed. There are based on the following general principles: temporary storage, controlled flow drainage and infiltration (Chocat et al, 2018; CUB, 2014). GSCMs are based either on a retention capacity or on an infiltration possibility. A distinction is also made between GSCMs, decentralized (as close as possible to where the rain falls, limiting runoff) such as rain garden or swales and centralized GSCMs (dry basins dry or in water basins associated with large areas of watersheds). GSCMs and SCMs have been increasing for several decades in France and internationally for various reasons: flood prevention, pollution control but also multifunctionality: fight against heat spots, combination with other urban functions (landscape, recreational functions…), sustainable management. Indeed, all the infiltration GSCMs play a role of reducing pollution, because the "infiltration makes it possible to treat a large part of the particulate rain pollution by trapping and degradation in the 1st centimetres of soil, in particular heavy metals and carbon pollution (including hydrocarbons)" as mentioned in *ville permeable* project at Grand Lyon (2017). There are several types of SCMs: sometimes green, sometimes not, wet or dry, generally open air but sometimes buried, so maintenance costs vary more or less strongly depending on their specificity. Buried basins require maintenance which generates a higher cost than other types of GSCMs (swales, basins, drainage trenches, etc.). In addition, for the same type of GSCMs (eg. swale type), the choice of vegetation can have significant consequences in terms of maintenance (regular and preventive) and therefore cost variation depending on the choice of plantations. The analysis of GSCMs maintenance costs also feeds into decision support for investment choices (GSCMs/pipes) and asset management; cost analysis is a good decision tool to help water managers. The idea is to go from the individual GSCM maintenance costs (Bahy, 2017, Werey *et al*, 2019) to the global maintenance cost at the utility level; a guideline document is under work (Fussler *et al.*, 2021).

METHODOLOGY

The current work focuses on deepening the cost analysis method of GSCMs (full cost method), in multi-service cost accounting (sanitation, green space, public roads, cleaning) and multi-budgets (main budget and annex budget sanitation). Indeed, the multifunctional nature of GSMCs involves the intervention of several departments, the number of which differs according to the distribution of activities within each utility. This is also why it is important to identify all the departments (whose names vary depending on the utility organization involved and impacted by operating costs and expenditure of investment).

This full cost method (Dubrulle, 1987; Brown *et al.*, 2007; ASTEE, 2017) allows all charges to be taken into account: direct and indirect charges, whether fixed (insurance, equipment maintenance, etc.) or variable (raw materials, sludge treatment, electricity, etc.). Direct charges can directly or easily be assigned to the cost object. As for indirect charges, they cannot be assigned to the product without intermediate calculations (application of a ratio or distribution key).It give an annual cost valuation.

As part of a first cost analysis on several different GSCMs, each taken individually (F. Bahy, 2017, Werey *et al.*, 2019), our method is based on the hours of labour and use of machinery, and on the breakdown of indirect costs (insurance, depreciation of machinery, supplies, etc.) according to a key (maintenance time of the GSCMs compared to the annual time of all jobs in the sanitation utility, for the maintenance of the hydraulic part). The method is applied in each department involved in GSCMs maintenance. This therefore involves for all interventions, labour time (frequency of short or long mowing for example, category of personnel mobilized) and use of machinery (manual or motorized mower, etc.) as well as labour costs and hourly costs of use of machinery for each service. In addition, the corresponding indirect charges are added. We can thus obtain the maintenance cost of a given GSCM, and relate the result to the surface of this precise structure, to end up with a unit cost (€/m^2/year) including all differences actors' maintenance.

Following the application of this method on several types of GSCMs, the following question arises today: how can we scale up this method to the scale of all the GSCMs assets of the utility? This study, carried out on several specific types of works, provides a reflexion on the cost of maintaining GSCMs in these individual cases which maybe cannot be easily extrapolated to general cases. Indeed, it is it necessary to establish a specific methodology. In addition, it should be noticed that the analysis of indirect costs can be carried out relatively easily on the specific sanitation budget (separate and dedicated to the sanitation service and paid by the users) while the precise analysis of indirect costs from the general budget are more difficult to identify for cleaning or parks departments. Then, concerning the maintenance of GSCMs, the indirect costs considered also take into account the operating costs of the service(s) directly involved, as well as the overheads and support service costs (structural costs). Finally, as part of the cost analysis, we also distinguish between operations and outsourced interventions. In the case of works carried by inside agents, it is registered all the time by the utility agents mobilized in each department. While in the case of outsourcing, the total amount of the relevant expenditure made via the public contract is sought, while taking into account the time taken for the control, monitoring and management of contracts awarded by agents of the utility. The method used to assess costs may also differ depending on the concerned department: first data are recorded by intervention on an identified structure, the present record of agent time and material/machine time, associated with hourly costs, with the addition of taking into account the amount of supplies taken out of stock, and then the inclusion of indirect structural costs (deliberate rate applied). However, in our investigations (in 2 French utilities), other full cost methods were identified. These involve, for example, calculating the cost of maintaining green spaces per m2, carried out by a department (including salary, external services, equipment and indirect costs). Then this cost (€/m2/year) is multiplied by the total area of GSMCs maintained within the perimeter of the competent department. The GSCMs inventory occupies an important place in this process: needs to use the accurate data (area, type of GSCMs, location, etc.) for the application of the method.

RESULTS AND DISCUSSIONS

There are several types of maintenance on GSCMs: "hydraulic" maintenance, maintenance of the "green spaces" part as well as cleaning and waste collection. In practice, there is little "hydraulic" maintenance on GSCMs and only some GSCMs have hydraulic components. The hydraulic components concerned and therefore to be maintained can typically be short pipes (between two swales for example), sumps (on certain swales), valves (on certain basins), flow restrictors, settling tanks, etc. In these cases, we generally find a preventive check, lubrication and/or cleaning (with frequency around once/year). Otherwise, interventions carried out on the GSCM at the hydraulic part are quite seldom and only take place when there is a dysfunction (for example: colmatage). The maintenance of GSCMs essentially concerns the green spaces part. In general, mowed twice a year (preventive maintenance) or other types of interventions (mowing, sloping, cleaning, pruning, etc.) are carried out depending on the site and the plantations. In addition, over the years, it has been observed that maintenance practices and the frequency of certain interventions have been reduced. The current feedback from utilities shows that when there is a significant dysfunction observed on a GSCM, there is a curative maintenance of the GSCM or most of the time a renewal of the GSCMs. This therefore led us to look into the issue of depreciation of structures. Recommendations (ASTEE, 2015) of depreciation periods indicate depreciation periods varying from 20 years (swales, landscaped basins) to 100 years (basins in civil engineering) depending on the types of GSCMs.

Depending on the departments concerned, interventions are managed and/or outsourced. To trace technical and accounting data, the tools used are various: spreadsheet files, computer-assisted maintenance management (CMMS), geographic information system (GIS), integrated management software (ERP), specific software (for requests work for example). The CMMS makes it possible to trace the history of interventions with, depending on their configuration and use, data such as: agent and equipment hours, types of equipment, types of work, date and place of intervention, concerned structure. Appropriate tools facilitate data collection and analysis at the scale of the entire asset park as close as possible to reality. The GIS makes it possible to extract various data, linked to the characteristics of GSCMs structures (date of creation, type of GSCM, municipality of location, surface area, public/private domain, date of integration, etc.). It is possible to extract from the GIS the areas by type of GSCMs. This tool is also used to view GSCM works (2D display). The capacities and implementation of GIS vary by utilities. The ERP will make the link with the accounting data. But self-made applications can also be connected.

CONCLUSIONS

The choice of the cost analysis method for GSCMs depends on the issue and the reason for which this cost is valuated. What we want to do with the amount obtained? There are several issues. This analysis is first of all part of an asset management approach. In a context of integrated rainwater management and sustainable development, the number of GSCMs is increasing and this trend will continue. It is therefore interesting to be able to anticipate what this increase will represent in terms of costs. Investigation of financial flows and practices (maintenance of GSCMs s, tools deployed for recording information, organization of the utility in relation to GSCMs management) makes it possible to understand how storm water management (including GSCMs) is currently financed. The cost research may also aim to choose between several types of GSCMs depending on the context. The issue can also be to choose between GSCMs or classic sanitation system ("all-pipe" or networks). The analytical approach shows that GSCMs can often prove to be more advantageous and economically interesting in terms of maintenance and "overall cost" in the medium and long term (Grand Lyon, 2017 and Werey et al., 2016). We note that some communities identify the maintenance costs of GSCMs while others have more a "total cost" approach of GSCM (including investment, operating, and maintenance and end-of-life costs). Analysing the costs of GSCMs at the utility level for the entire portfolio requires an information system (GIS, CMMS, and/or ERP, etc.) for technical and accounting data to be able to make the link between these different data. It is also important to relate the maintenance cost analysis feedback to the GSCMs inventory. We note that the asset park of the GSCMs varies depending on the utilities and their scale and objectives: some have a large number of basins (Nantes Métropole, Grand Lyon Métropole) while others have more swales and infiltration wells (Eurométropole de Strasbourg).

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Detecting vulnerabilities of a wastewater system by eliciting local knowledge

Engaging local agents to explore ways of improving the resilience of a wastewater system.

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Abstract
We present lessons learned from proposing and testing a holistic vulnerability- and resilience assessment to a wastewater utility. In this approach, local agents (from within and outside of the utility) are invited to define their view of resilience and to explore ways to reduce the vulnerabilities they perceive. Their views are elicited in interviews and depicted through the use of Fuzzy Cognitive Maps. For each of the maps, the process allows the agents to develop a causal understanding of vulnerabilities and to reveal how their proposed interventions may propagate through their map. The comparison across multiple maps allows a holistic view of resilience to emerge which may widen the scope of action for senior utility managers. The tool can thus provide useful information for screening of overall risks and act as a precursor for more technical and quantitative analyses.

Keywords
Causal network, Fuzzy Cognitive Map, narratives, resilience, vulnerability, wastewater utility.

INTRODUCTION

The aim of this work was to develop a holistic approach for resilience assessment of a wastewater system in co-production with utility representatives. Traditional resilience assessments have a strong focus on technical aspects and are typically conducted in a quantitative top-down style with pre-established criteria (Juan-García *et al.*, 2017). The development of this more bottom-up driven methodology proposed in our work took place within the European project ALICE (AcceLerating Innovation in urban wastewater management under Climate changE) under the Marie Sklodowska-Curie Actions, Research and Innovation Staff Exchange (RISE) programme which is a programme that funds staff exchanges between academic and non-academic institutes. In this case, the secondee (A. Tepes) was able to conduct several months' worth of secondments at Northern Ireland Water, the water and wastewater utility of Northern Ireland to develop and test the methodology.

METHODOLOGY

The methodology was developed within the utility setting. It involved firstly a review of scientific literature as well as a review of the technical literature and of the current standards on resilience assessment in the wastewater sector. This was followed by an analysis of how a wastewater utility is structured and the way it functions internally as well as how it is embedded in the wider landscape of municipal and regional institutions. Both the literature reviews as well as the institutional analysis revealed the need for more holistic assessments of resilience and the need of engaging multiple local actors. Inspired by the Safe and SuRe approach undertaken by Butler *et al.* (2016) combined with previous work on the holistic assessment of heat wave impacts (Olazabal *et al.*, 2018) the authors decided to test the Fuzzy Cognitive Mapping (FCM) approach, originally proposed by Kosko (1986) and promoted for use in ecological modelling by Özesmi and Özesmi (2004). FCM elicits a semi-quantitative belief network in an interview with a domain expert revealing their mental model in the form of a causal network. In addition, the interviews were summarised through short narrative accounts with the help of voice recordings. This process was tested for the wastewater section of NI Water, where 20 maps were developed with a wide range of internal and external agents (Tepes and Neumann, 2020). Internal agents included staff from operations, strategic planning, capital works, environmental regulation, human resources and finance among others. External agents included staff from sister departments such as infrastructure, urban planning, the regional environmental agency and the consumer council. To test its transferability to other contexts, the methodology was then validated in Murcia, Spain.

RESULTS AND DISCUSSIONS

The literature review revealed a clear lack of methods that take a "reflective", "inclusive" and "integrated" view of resilience (Juan-García *et al*., 2017), that is, a view that takes into account both practitioners experience as well as the complexities present in a utility, such as those that arise due to strong connections with other urban sectors, institutions or to entities at other hierarchical levels (such as the regional government).

Our approach, which tries to overcome some of these issues, begins with an open ended question that can be put to any number of internal or external agents. Here, in our case study, the central question asked was "*According to your experience, knowledge and expertise how are drivers and characteristics of the system affecting resilience of wastewater management at NI Water for the Belfast area in the short, medium and long term?*" A follow up question then asked agents to propose interventions that would improve resilience of the system. The agents were selected together with the senior management of the utility whereby a wide diversity of expertise was sought as well as representatives from many different departments and across hierarchical levels.

In this way we were able to obtain a wide variety of views as exemplified through the maps obtained for each of the interviews (see Figure 1 as an example). Each map and narrative provide a unique view of the system with respect to resilience. The maps were found to resolve closely the domain of expertise of the agents but at the same time they showed which links to other domains were considered crucial. Each map and narrative therefore provides valuable information about various latent risks and potential unintended consequences. Then, when comparing themes across maps, a rich view emerged encompassing infrastructure operability and capacity; costs, finance and investment; governance; behaviour and responsibility of system users; standards and regulation; human capital and knowledge and uncertainties that provide different drivers of various sources of risk as well as shared and conflicting views about vulnerabilities.

Conducting the validation exercise in Murcia proved that the context specificity (water scarcity, wastewater reuse, desalination in the case of Murcia) is allowed to be revealed through the open and flexible methodology (open interview question and no pre-definition of vulnerability and resilience). Also, the experience that the analyst gained in Belfast when conducting the interviews and analysing the material allowed the process to be conducted more efficiently in the validation setting.

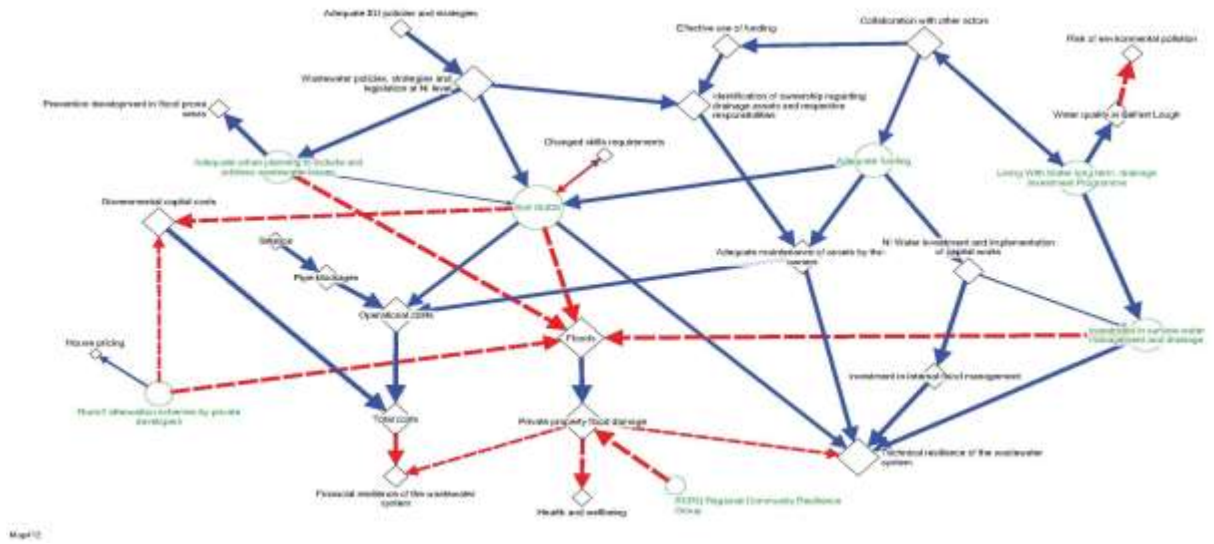

Figure 1 Example of a Fuzzy cognitive map obtained in one of the interviews. Full (blue) arrows indicate positive impact while red (dashed) arrows indicate negative impact. Round nodes (green) indicate intervention measures to improve resilience (source: Tepes and Neumann (2020)).

CONCLUSIONS

Eliciting diverse views from local practitioners allows insights that are not necessarily obtained by single and tightly defined analyses. We made use of the subjectivity of local agents to obtain a better appreciation of the complexity of the wastewater system with its various drivers of vulnerability and propagation mechanisms. The approach allowed to collect a wide range of different possible levers to reduce vulnerability as well as to gain insights on potential unintended consequences. The proposed approach of interviewing a diverse group of internal and external agents to obtain a holistic overview on resilience of the wastewater system, serves to widen the scope of senior management before deciding to conduct more detailed, traditional, quantitative and technical risk assessments.

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Prognosis of the long-term ageing behaviour of drinking water abstraction wells using machine-learning approaches

Forecasting tool for strategic planning and maintenance of drinking water wells

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Abstract
The Berliner Wasserbetriebe (BWB) are operating more than 650 vertical filter wells supplying the drinking water for the city's nearly 3.7 Mio. inhabitants from groundwater resources within the city limits. In order to keep performance and water quality as high as possible, these wells require regular monitoring and maintenance. The main reason for inefficient well performance is so-called well ageing caused by deposit formation due to multiply correlated biological, chemical and physical clogging processes in and around the well that decrease the yield for a given drawdown. In order to better understand the key drivers for well ageing and to project the loss of capacity for a given time ahead, machine learning (ML) approaches were applied to selected data from routine well monitoring. The statistical programming language R was used for automated data processing, feature selection and assessment of the importance of the selected variables, and finally for model training and prediction of future loss of well capacity. Four variables were identified to be highly significant predictor variables. Multivariate linear regression, logistic regression, decision tree, random forest and gradient boosting were applied, the latter performing best with a sensitivity of 94% and precision of 88%. The approach is now transferred into a well condition index to be included in a well management and reporting tool box developed in the frame of the H2020 project digital-water.city.

Keywords
drinking water wells, machine learning, rehabilitation efficiency, well ageing, well maintenance

INTRODUCTION

Drinking water production from groundwater is done with horizontal or vertical filter wells. The lifetime of such drinking water wells typically ranges between 20 and 50 years. Statistical evaluation of well data from drinking water wells in Berlin, Germany, showed for example an average well age of 34 years (Schwarzmüller et al., 2010). The capacity of wells, that is the yield for a given drawdown, however, decreases with time of operation. This effect is called well ageing and is due to the formation of deposits of biochemical origin (e.g. iron oxides formed by iron bacteria; Figure 1) or particulate matter (e.g. clogging with silt or sand).

Figure 1: left: clogged well, ochre deposits inside the screen; right: clogged pump, ochre deposits at the pump intake, both ©BWB

Maintenance, such as cleaning the pump and filter screen as well as gravel pack, prolongs the functioning by removing these deposits. To identify and prioritize maintenance needs, well condition is monitored during operation in regular intervals or on demand and comprises parameters such as flow rate, water levels, water quality, power consumption, etc. These data are stored in a well management database together with static information such as well design and construction, geological information, and analytical data from raw water samples. Goal was to combine automated data processing of routine monitoring data and well characteristics, site properties and operational data with machine-learning (ML) approaches to identify well ageing and decreasing well capacity and prioritize maintenance or reconstruction needs. The application was developed as one of 15 digital solutions implemented in the H2020 project digital-water.city (DWC) aiming at leveraging the potential of data for boosting water management in cities.

METHODOLOGY

The ML approach considered 6.308 data sets of a total of 994 currently operated and abandoned wells operated by the Berliner Wasserbetriebe (BWB) since the 1950s. Data were obtained from a db2 database with SQL scripts and transferred to csv files. The statistical programming language R (R Core Team, 2021) was used to define the core algorithms to (i) pre-process the well data turning them into a data structure providing the explanatory variables to the ML model, (ii) assess the importance of the variables and select model features, and (iii) train the ML model and predict future loss of well capacity based on selected well characteristics. 36 features (26 numeric, 10 categorical) were initially tested describing well characteristics (e.g. well age, construction material, screen diameter), site properties (well location, aquifer coverage, groundwater level variation), operational data (abstraction volumes, flow rates), past maintenance events (number of rehabilitation events, time since last rehabilitation) and raw water quality (e.g. total iron, dissolved oxygen, total phosphate).

Target variable was the prediction of a numeric value for the specific capacity (that is the quotient of flow rate and drawdown) relative to the capacity at the time of initial operation (Qs_rel; Figure 2).

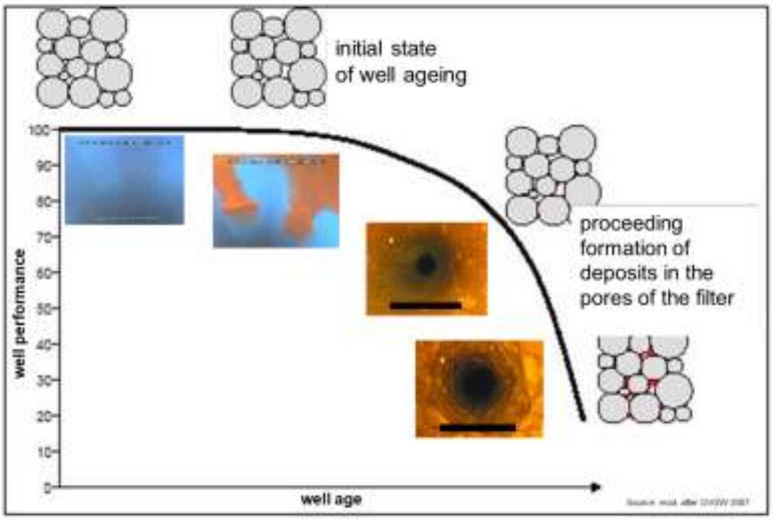

Figure 2: Typical Qs-curve (ageing curve) with decreasing specific capacity with time in operation (modified after DVGW, 2007)

RESULTS AND DISCUSSIONS

Based on the intercorrelation and variable importance tests, six of 36 variables were discarded as highly intercorrelated, another four were not contributing to the model accuracy. Of the remaining features, top five predictor variables were extracted from the random forest resulting in (i) well age, (ii) time since last rehabilitation, (iii) location, (iv) number of previous well rehabilitation events and (v) coefficient of variance in daily abstraction volume (Figure 3 left). ‘Location’ was further discarded in order to make the solution transferable to other well settings.

Training the model and applying it to the test data yielded a root mean square error (RMSE) of 15% and a coefficient of determination of $r^2 = 0.78$. The classification accuracy for specific capacity values < 80% was 94% (recall), with 12% wrong warnings (1 – precision) and 20% false positives (1 – specificity). The ML approach was thus rated well- applicable to forecast well ageing based on well and site-specific data (Figure 3 right). The trained model was subsequently used to predict the ageing curves for each single well of the test data set. Here too, the model showed a good fit to pumping test data from before and after past maintenance.

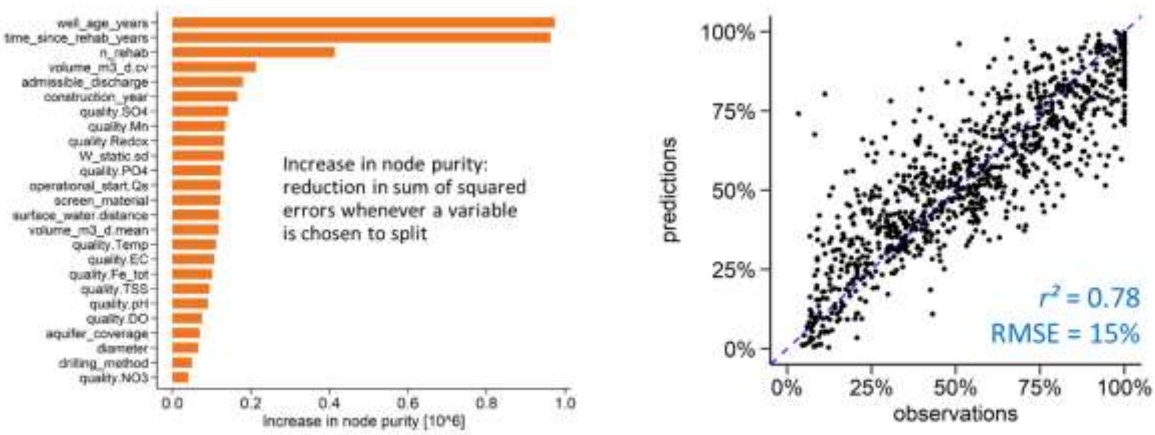

Figure 3: left: Results of random forest variable importance ranking; right: Model performance of gradient boosting approach with more than 78% of the variance in the observations explained by the model

CONCLUSIONS

Extended data collection and processing in combination with ML approaches provides data-driven analysis and identification of key variables related to the specific capacity development. One of the main advantages of the ML approach is that many variables could be included in the analyses and subsequently be narrowed down to a set of key variables, while no direct correlation was observed for single variables in previous research.

Gradient boosting showed a highly satisfying sensitivity and accuracy in the prediction and can assist well operators in planning well rehabilitations and renewals. Refinement of the solution within the DWC project will include further analyses such as clustering the ageing curves to narrow down preferred site conditions and factors that accelerate well aging. Data availability and remaining data gaps and/or pre-aggregated data showed to be a barrier and remain as crucial steps in proactive well maintenance.

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Coordinated long-term structural and hydraulic rehabilitation strategies of sewer systems

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Abstract
Climate change and urban development are usually leading to an increasing hydraulic load on [KK1] sewer networks. The consequences, such as an increase in urban flooding, can already be observed today.

To address this, in many cases hydraulic rehabilitation of the sewer network may be appropriate. Measures can range from rehabilitation of single reaches to the hydraulic redesign of complete (sub)networks.

When designing long-term hydraulic rehabilitation strategies, both the long service life of the sewers and the long-term development of precipitation should be taken into account.

The main tasks of the presented research project is therefore to develop:
- a generally appliable method for determining the development of hydraulic loads, considering climate change and urban development
- design a long-term hydraulic rehabilitation strategy and
- combine this long-term hydraulic rehabilitation strategy with a long-term structural rehabilitation strategy into a holistic approach.

The developed approach allows an automated localization and evaluation of connected areas with a hydraulic deficit. As a next step, this information will be extended by a flood risk assessment by means of the evaluation of heavy rainfall hazard maps.

The purely theoretical-scientific approaches used up to this point are difficult to transfer to practical planning. The developed methods are therefore combined with expert knowledge to develop an integral and generally applicable concept.

Keywords
climate change, hydraulic rehabilitation strategy, holistic approach, sewer system, structural rehabilitation strategy, water-sensitive urban development

INTRODUCTION

Climate change and urban development (soil sealing) lead usually to an increase in the hydraulic load on sewer networks. The risk of flooding is increasing. Thus, in many cases a hydraulic rehabilitation of drainage systems as well as a modification of the public sewer (sub)systems will become necessary (water-sensitive urban design). For various reasons, future hydraulic loads, and the temporal devolvement of hydraulic loads in sewers cannot be taken into account in the preparation of long-term rehabilitation strategies:

- Validated evaluation criteria for future hydraulic loads and the associated flood hazards do not exist.
- Procedures allowing either an estimation of the expected flood risks in future or their development over time do not exist.
- Generally applicable procedures for combining long-term structural and hydraulic rehabilitation needs do not exist.

In addition to the need for hydraulic rehabilitation, the structural condition development creates an ongoing need for structural rehabilitation. In the future, this need will increase due to the deterioration of the sewer networks' condition (ageing). A modelling of the long-term development of the sewer condition becomes possible if the results of the condition assessment in connection with the age of the drainage system and further master data are integrated into a prognosis model.

Accordingly, long-term structural rehabilitation strategies can and will be developed and optimised for the purpose of substance conservation (Kerres, 2006; Kerres 2013). The cost, fee and asset developments associated with the rehabilitation strategy can be estimated. As a rule, these long-term considerations ignore long-term hydraulic aspects. In summary, the long-term strategy is incomplete from a hydraulic point of view, as only structural aspects are considered.

Ideally, a long-term rehabilitation strategy should be drawn up for both economic and ecological reasons (DIN EN 752, 2017). The structural and hydraulic aspects should be considered equally, and a suitable measure be derived. The increasing renovation costs for drainage systems due to inappropriate renovation decisions should be minimised. In addition, structural and hydraulic failure should serve as an equal basis for decision-making for the development of long-term maintenance strategies (Figure 1).

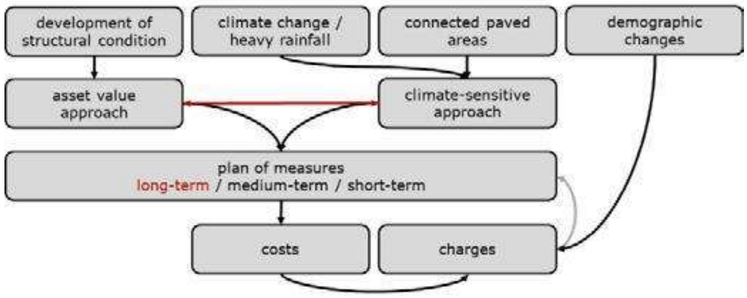

Figure 1: Long-term action plan for structural and hydraulic maintenance considering mutual interactions

The basic idea of the project is to estimate the development of hydraulic load of sewer systems (hydraulic aging) as well as the structural aging as a basis for decision-making for the development of long-term maintenance strategies considering reciprocal interactions. The aim is to blend the different adaptation paths with one another to enable decisions to be made under uncertainty and to allow cost-effective combinations of measures.

In summary, the objectives of this research and development project are:

- The development of a generally applicable method to estimate the development of hydraulic load of sewer systems, considering climate change scenarios and expert knowledge.
- The development of an integral and generally applicable concept for decisions under deep uncertainty, in which structural aging and hydraulic aging are equally considered in the design of long-term rehabilitation strategies and which is thus suitable for minimizing improper rehabilitation decisions.

METHOLOGY

An overview of the methodology is shown in figure 2. For each of the three levels of action

- structural rehabilitation,
- hydraulic rehabilitation and
- flood protection,

goals are defined and deficits as well as possible countermeasures are identified both at the network level and at the single element level as it is shown in figures 3 and 4. The developed methods are evaluated with expert knowledge to develop a generally applicable holistic strategy.

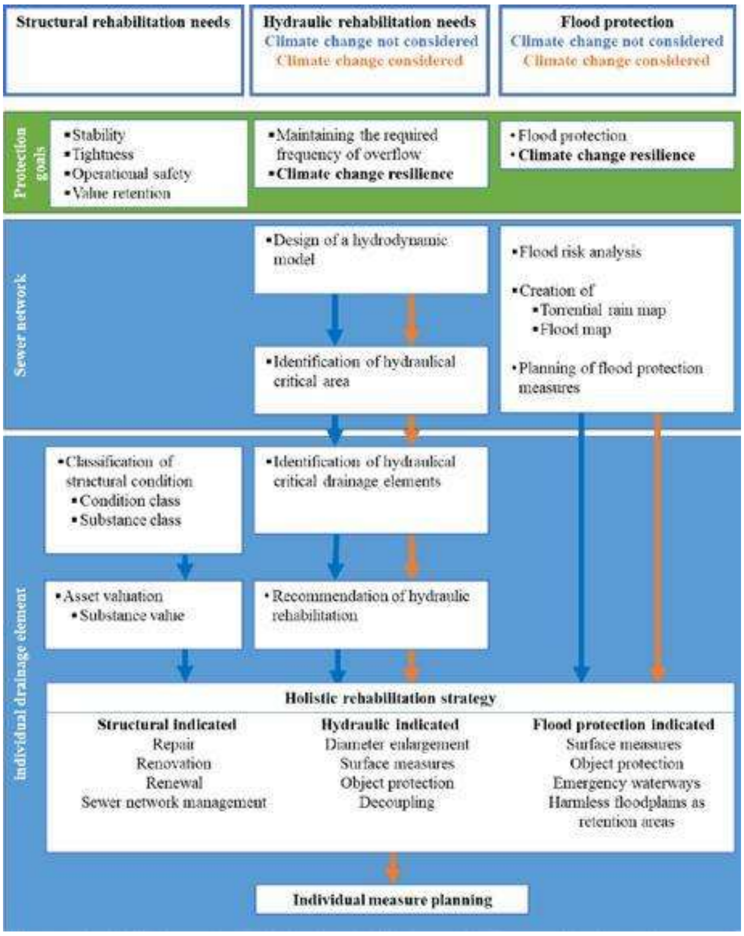

Figure 2: Methodology overview

IDENTIFICATION OF HYDRAULIC REHABILITATION NEED

The developed approach allows an automated localisation and evaluation of connected areas with a hydraulic deficit. First, the sewer network reaction on hydraulic load is simulated by a hydrodynamic model, taking climate factors into account. The analysis of the hydraulic load makes it possible to identify interconnected overflow events. These hotspots, extended by the flow paths, describe the relevant sewer sections for hydraulic rehabilitation (see figure3). Sections outside of these areas can be rehabilitated under purely structural aspects.

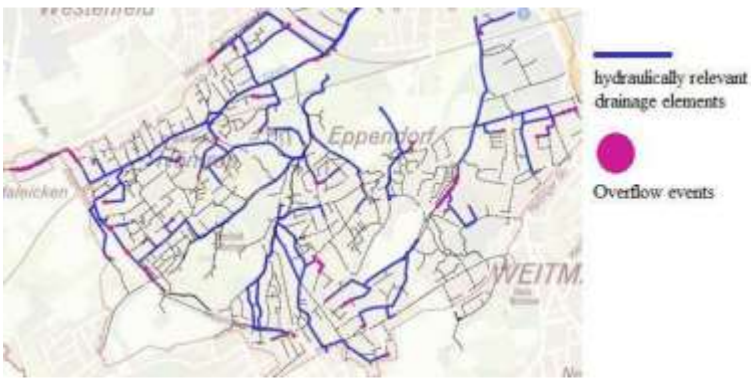

Figure 3: Relevant sewer sections for hydraulic rehabilitation

IDENTIFICATION OF FLOOD PROTECTION NEED

As a next step, this information will be extended by a flood risk assessment by means of the evaluation of heavy rainfall hazard maps. The results of a 30-year return period (T = 30 a) flood analysis were used to define the flood hazard (figure 4).

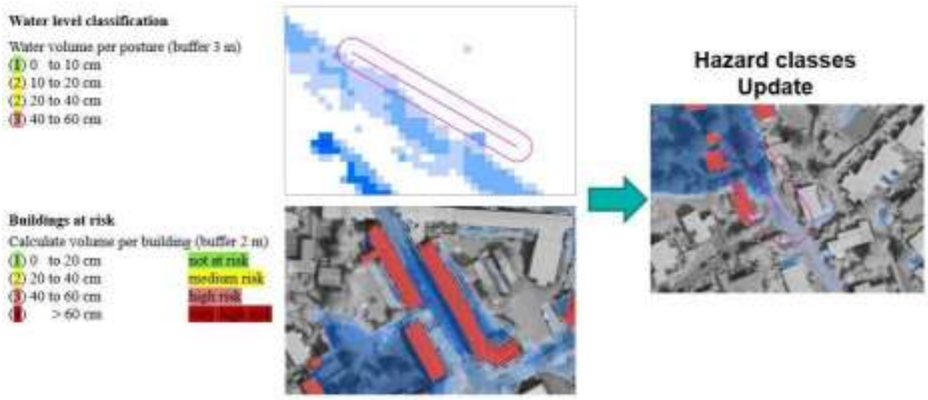

Figure 4: Evaluation process of heavy rainfall hazard maps

Based on the buildings at risk, the enclosure-specific hazard classes are adjusted at the end. The circuits belonging to hazard class 2 and meeting an endangered building at 15 meters are upgraded to hazard class 3. The hazard class 1 postings are unchanged, regardless of whether there is a vulnerable building within the buffer. Hazard class 1 is not updated because there is no water flowing above the corresponding posture (WS ≤ 10cm). This means that with high probability the water level of the endangered building results from another source, regardless of the surface of the investigated attitude.

RESULTS AND OUTLOOK

The methods and results for the development of a prognostic-supported holistic rehabilitation strategy will be presented and discussed at LESAM 2022.

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Performance assessment to support asset management in urban drainage systems

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Abstract
Urban drainage systems are one of the essential infrastructures in our societies. These network systems are capital intensive infrastructures, mostly buried, and crucial to ensure the health and safety of populations, continuity of socioeconomic urban functions, and protection of the environment.

The continuity of these complex services is of utmost importance; despite the long expected useful life (Covas et al., 2018; Burn et al., 2009), deterioration of system components can result in failures with negative consequences. Collapses, obstructions, or limited flow transport capacity can cause disruptions to other services as mobility (people and vehicles), commercial activities, and other urban infrastructures (e.g., roads, rails, water supply). Development of asset management (AM) plans is considered a way to structure the renovation of an aging infrastructure in a scenario of lack of funding and of reliable data on assets condition (Harvey et al., 2017).

Many approaches in the literature are focused on condition and criticality of assets (e.g., WRc, 2011; Laakso et al., 2018) but, while important, these only represent a part of the relevant points of view.

The ISO 55000 (ISO, 2014) series of standards provide global guidance on AM, defined as the activity to balance cost, risks, opportunities, and performance benefits from assets while acting to achieve organisational objectives (ISO, 2014; IAM, 2015). In urban water systems, AM is key to the provision of good quality of service, ensure utilities sustainability and protect the environment. An essential component is the adoption of a dedicated performance assessment system (PAS), allowing a more effective and efficient response to these challenges from the water utility asset management perspective, aligned with the organisational objectives (Cardoso et al., 2016). The AM PAS (the tailored performance assessment to support asset management) besides supporting diagnosis of the systems allows monitoring the utility asset management strategy, supports the planning of AM tactics and associated decision making.

The presentation introduces a novel PAS to support AM in face of new challenges as climate change, resilience enhancement, and resources limitation. Integration or compatibility with other infrastructures managed by the same utility, as is often the case in municipalities, is also considered in a case study.

Keywords
Asset management, urban drainage systems, performance assessment

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Urban drainage asset management – also for blue-green infrastructures!

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Abstract
Urban drainage systems have developed way beyond the traditional piped combined or separate sewer systems. Many 'new' systems are being introduced, ranging from stormwater infiltration facilities to green roofs. Sewer asset management is, despite its shortcomings, well established for piped systems, while the widely advocated blue-green infrastructures are typically overlooked by asset managers, which will very likely have detrimental effects on their performance and service life. In this contribution the working group on Urban Drainage Asset Management (UDAM - https://udam.home.blog/) of the IWA and IAHR Joint Committee on Urban Drainage discusses whether the state-of-the-art knowledge is sufficient to develop asset management for blue-green infrastructures. The discussion is structured around the 5 preconditions for effective control/asset management.

Keywords
asset management; blue-green, urban water infrastructure

INTRODUCTION

Asset management can be defined as coordinated activities of an organization to realize value from assets (ISO 55000). Asset management of piped infrastructures, such as drinking water and sewers, has been extensively investigated over the last decades, while stormwater control facilities has only recently received the first research consideration for their operation and maintenance and their long-term performance (Werey et al., 2017). The aim of this paper, based on the experiences of a working group on Urban Drainage Asset Management, is to discuss whether current knowledge suffices to introduce the asset management principles for blue-green infrastructures by assessing whether the 5 prerequisites for effective control /(asset) management (De Leeuw, 1974) can be met. The full paper will describe the research questions and challenges to be met to fully benefit from the potential added value of asset management.

Condition 1. The controller has an objective and an evaluation mechanism to check whether the goals are met. Many urban drainage systems are expected to fulfil several functions related to the city or the environment. Such expectations have emerged from the concept of Sustainable Urban Water System (SUWS) and have been translated in terms of functions (Belmeziti et al., 2015). However, there is still an important gap between these functions and the means (indicators) to assess them, either because of lack of knowledge or because of lack of monitoring methods and capabilities. Some recent initiatives are trying to answer this issue (Soerup et al., 2019), while some of the objectives of blue-green infrastructures, such as resilience or contributing to climate proofing, are still hard to evaluate.

Condition 2. The controller has a model of the controlled system. The last decade has seen the emergence of guidelines dedicated to stormwater control measures (https://mind4stormwater.org/2018/10/25/om-guidelines-for-stormwater-control-measures/).

However, there is still a strong need for a better understanding of these complicated systems in order to justify the actions, and to adapt them to the context. It is, for example, still not possible to accurately predict the evolution of hydraulic parameters such as filter-media permeability (Gonzalez-Merchan et al., 2012).

Condition 3. The controller has information about the environment, and the controlled system. Information about the environment and controlled system can be difficult to obtain for non-piped systems such as infiltration facilities due to their inaccessibility. Regular inspection techniques and schemes are still missing for nature-based solutions.

Condition 4. The controller has sufficient control actions to cope with the variability of the system. For sewers, operators have a large number of well-known control actions to deal with issues such as a blockage or cracks. For blue-green systems, this is less obvious. For example, recent research on infiltration via pervious pavement showed that many cleaning techniques cannot restore the initial infiltration capacity, while others even destroy the top layer. The lack of attention for maintainability has regularly resulted in a situation where the operator has no other options than to replace the pervious pavement.

Condition 5. The controller has sufficient information processing capacity to transform incoming information into effective control actions that are in line with the objectives. Blue green solutions are often applied at a small scale, e.g. on household level where operation and maintenance (O&M) must be taken care of by the house owner, who thereby becomes the controller. O&M requires the capability to interpret current performance and to address signals of various kinds to predict future performance or maintenance needs. Thus, the level of complexity of the blue green infrastructure easily goes beyond the capacity of the controller.

CONCLUSION

The confrontation of the state of the art on management practices and knowledge of blue green infrastructures revealed that currently the preconditions for effective control and asset management cannot be met. However, as the deterioration processes of blue-green infrastructures may be significantly faster than those of piped infrastructures, the learning curve in asset management of blue green solutions may be much faster than the decades it took to develop sewer asset management. This development is supported by the revolution happening in the monitoring field supported by falling costs, miniaturisation, easy-to-access, modularity and open-source programming (Cherqui et al., 2019). Remaining key challenges are dealing with the diversity of solutions and conditions and the lack of resources to conduct the necessary dedicated research in this emerging field.

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The operational benefit of condition forecasts on pipe-level in Berlin, Germany

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Abstract
The localisation of pipes with short-term rehabilitation need within the sewer network is one of the most challenging tasks for a network operator as only a part of the network is annually inspected. An augmented localisation of critical sewers leads to less risk of network failures and a better present and future network condition. Berliner Wasserbetriebe developed the SEMA-plus pipe simulator as a support for the inspection strategy for localising critical pipes in cooperation with Kompetenzzentrum Wasser Berlin. The random-forest based simulator increases the hit-rate in localising pipes with severe defects by a factor of ~4 according to evaluations during the development phase. Currently, the preparation and implementation of necessary process steps is underway at Berliner Wasserbetriebe. The implementation of the pipe simulator is planned for the beginning of 2022. Figures on its actual benefit are expected to be presented during spring 2022.

Keywords
Asset management, sewer localisation, CCTV inspection, machine learning, random forest

INTRODUCTION

The localisation of pipes with short-term rehabilitation need within the sewer network is one of the most challenging tasks for a network operator. The knowledge about how to identify critical pipes affects the risk of network failure and has a considerable influence on the present and future network condition.

In Germany, operators annually inspect a small part of their network, approximately 5 to 10 percent, following German regulation. As there is no standardised process nor a regulation for the preselection of critical pipes to be considered in the inspection strategy, operators usually rely on the network knowledge of their workforce. The operating personnel prioritises those pipes for inspection that are regarded as critical out of their longstanding, subjective experience. Due to missing alternatives this approach has been best practise for many years. Its lack of transparency and its ”non-reproducible data base” in combination with the upcoming generational change in the workforce has increased the need for a strategic planning tool.

Since 2016, the Berlin water utility “Berliner Wasserbetriebe” has been developing simulation tools for the forecasts of sewer network development under consideration of rehabilitation measures (Riechel et al. 2021). One incentive was to develop a pipe-level simulator in addition to the network-level tool SEMA-plus strategy simulator to support inspection strategy in localising critical pipes.

It is planned to implement the self-developed SEMA-plus pipe simulator at Berliner Wasserbetriebe with the beginning of 2022. Its forecast results will then determine a part of an adapted inspection program to increase the location of pipes with short-term rehabilitation need. In this paper, first operational experiences in implementing the SEMA-plus pipe simulator forecast results at Berliner Wasserbetriebe including a first outlook on the estimated benefits will be presented.

METHODOLOGY

The core of the pipe simulator is a machine learning model based on the Random Forest algorithm (Breiman 2001). Random Forest is an ensemble learning method that consists of a multitude of decision tree classifiers (Breiman et al. 1984) used for classification and regression tasks. In our case the random forest model is trained with pipe features and historical inspection data to predict the current sewer condition of all individual pipes of the network. The input and output data of the pipe simulator is summarized in Table 1.

Table 1: Model input and output of the pipe simulator

Type of data	Variable
Model input	*Structural characteristics*: Construction year, material, sewerage type, shape, length, width, soil coverage, slope, rehabilitation year and type; *Environmental factors*: Soil type, groundwater coverage, trees in the surrounding of a pipe, city district.
Model output	Probabilities for the structural condition of a pipe distinguishing good, fair, bad and very bad condition. The condition of a pipe is derived from its severest defect considering, e.g., cracks, root intrusion, misplaced joints, corrosion.

The pipe simulator was trained with inspection data of the years 2001 to 2018 (n = 116 929). Its capacity to correctly prioritize pipes with immediate need for rehabilitation was assessed with inspection data of the year 2019. In a first step, the condition distribution of the pipes that were inspected with the aim to find defect pipes was determined (n = 12 168, 5.5% of the network). In a second step, the observed condition distribution was determined for the top 5.5% after combining inspection and model prediction results and ranking according to the predicted probability of having a severe defect.

The implementation of the pipe simulator comprises several process steps. In a first step, the pipe simulator forecasts current and future probabilities for sewer conditions with a lead time of up to ten years for all pipes. In a second step, those pipes with ongoing rehabilitation measures are excluded from the forecast. Subsequently, the residual pipes are ranked according to their probability for short-term rehabilitation need. Finally, by displaying the forecast results within the sewer network clusters of critical sewers can be identified as hotspots. These hotspots then are prioritized in the inspection program. In Berlin, approximately 10% of the annual inspected length will be aligned with the pipe simulator forecasts for hotspots with the beginning of 2022.

RESULTS AND DISCUSSIONS

To estimate the benefit of the pipe simulation before implementation during development phase, forecasts were compared with current inspection results. In theory, the capacity of the pipe simulator to correctly prioritize pipes with severe defects is shown in Figure 1 with regards to current inspection practice. In the historical inspection practice, 6% of the inspected pipes (737 pipes with a total length of 36 km) were found to have a severe defect. Virtually inspecting the pipes after prioritization with the pipe simulator, in contrast, would yield a detection rate for severe defects (“very bad”) of 25%, augmenting the pool of pipes for short-term rehabilitation by a factor of ~4. Another, 36% of the ranked pipes was found to be in the second-worse condition (“bad”), also having serious defects which require short-term action.

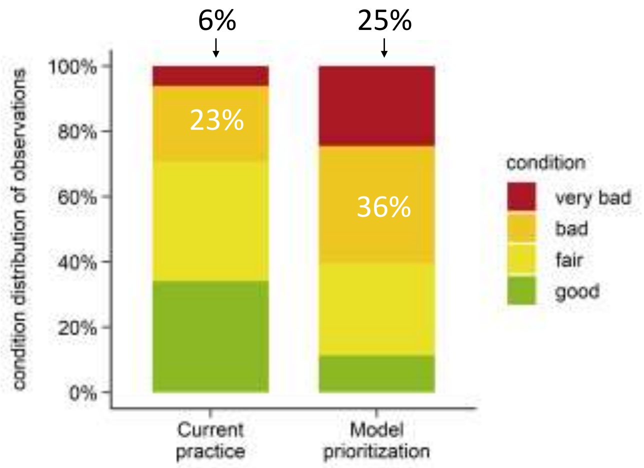

Figure 1: Comparison of the condition distribution obtained i) with the current inspection practice and ii) after model prioritization. The higher the share of pipes in very bad condition, the more efficient the inspection program.

Currently, the preparation and implementation of the above-mentioned process steps is underway at Berliner Wasserbetriebe. The exclusion of pipes in ongoing rehabilitation measures has proved to be the most challenging part so far. The basis for this exclusion is a detailed daily report on ongoing rehabilitation measures which had to be programmed separately by compiling data from several data sub systems. The forecast probabilities on pipe level can be displayed by using standard GIS functions. Nevertheless, Berliner Wasserbetriebe decided to develop an additional asset map to display the forecasts of the pipe simulator. As a first approach, a share of approximately 10% of the inspection length was fixed for inspection of forecasted hotspots.

The completion of the preparations is foreseen for the end of 2021. The subsequent implementation is planned for the beginning of 2022.

CONCLUSIONS

The forecast results of the pipe simulator show to increase the hit-rate in localising pipes with severe defects by a factor of ~4 according to pre-implementation evaluation during development phase.

During the preoperational phase for implementing the pipe simulator forecasts the exclusion of pipes in ongoing rehabilitation measures proved to be the most challenging step. The corporate benefit of the pipe simulator forecasts is therefore dependent on additional data compilation concerning rehabilitation measures.

First results to derive corporate benefit of the pipe simulator in figures are expected during spring 2022 a few months after implementation.

The pre-implementation evaluation during development phase has led to the decision of Berliner Wasserbetriebe to implement the pipe simulator including all necessary process steps. For Berliner Wasserbetriebe the question is not whether the expected benefits will be confirmed. The question is to what degree the results will be achieved.

The following benefits are expected:
An increase in localising critical pipes will reduce the risks for public life, infrastructure, and the environment by sewer collapses. The knowledge and experience of the operational personnel concerning the estimated rehabilitation need of pipes can be reproduced by the pipe simulator. The pipe simulator will support the knowledge transfer in the context of the upcoming generational change of the workforce. It will provide the exclusive knowledge of the workforce concerning rehabilitation need of sewers as a transparent digital tool for the whole company.

The implementation of the objectives of the rehabilitation strategy depends on the success of the inspection strategy in locating sewers with severe defects. This success defines the maximum achievable future target network condition distribution. An objective for future activities is to integrate the results of the pipe simulator into the network-level strategy simulator and hence produce more accurate network development forecasts.

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Uncertainties in sewer deterioration and rehabilitation modelling

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Abstract
In the city of Berlin, strategic decisions on sewer rehabilitation and associated investments are made on basis of the self-developed simulation tool SEMAplus that predicts the long-term condition development of the sewer network. However, as any mathematical model SEMAplus is subject to uncertainties. In this paper, eight potential sources of uncertainty have been investigated and ranked according to their effect on the model output. In addition, the overall effect of the relevant uncertainty sources has been quantified. Results indicate that major uncertainties result from the inspection data used in the model calibration process, e.g. from the subjective assessment of pipe defects and the under-representation of defect pipes, the so-called survival bias. Overall model uncertainties with regards to the predicted share of pipes with severe defects range from 4 to 14% for a do-nothing simulation (over an 81-year forecasting horizon). For a liner-dominated rehabilitation strategy, uncertainties further increase as assumptions on liner lifetime become an additional uncertainty factor. The results cannot only assist decision makers in developing more reliable rehabilitation strategies. They also allow to derive measures to reduce model uncertainties in the future, e.g. AI-supported inspection processes or further investigations on the lifetime of liners.

Keywords
Asset management, deterioration models, model uncertainties, sewer rehabilitation.

INTRODUCTION

In the past decade, deterioration models have gained increasing importance for the development of effective sewer rehabilitation and investment strategies (Tscheikner-Gratl et al., 2019). In this context, the Kompetenzzentrum Wasser Berlin (KWB) and the Berlin water utility (BWB) developed the SEMAplus strategy simulator (Riechel et al., 2021). The strategy simulator consists of a statistical deterioration model that simulates the structural condition of the pipes as well as model components that mimic the effect of different rehabilitation techniques. On this basis, it allows to predict the future condition of the sewer network under consideration of investment and rehabilitation scenarios for several decades ahead.

However, as any mathematical model, the SEMAplus strategy simulator is subject to uncertainties originating from i) the data used as model input (pipe characteristics), ii) the data used for model calibration (results from CCTV inspections) and iii) the model structure and the underlying assumptions (e.g. regarding the ageing behaviour of repaired pipes or liners). These uncertainties are scarcely acknowledged and communicated in sewer asset management practice, to date.

In this paper, eight potential sources of uncertainty in the developed model tool have been investigated and ranked according to their effect on the simulated share of pipe with severe defects. In addition, the cumulated effect of the main identified uncertainty sources on the long-term network condition has been quantified. The results can help stakeholders in developing more reliable rehabilitation strategies and derive measures to reduce uncertainties in the future.

METHODOLOGY

The core of the investigated simulation tool is an adapted version of the statistical deterioration model GompitZ (Le Gat, 2008). GompitZ uses the so-called survival curves, which are calibrated from inspection data, to predict a pipe's probability of being in a certain condition. In our case, four different condition classes, derived from the severest defect of a pipe and ranging from good (no rehabilitation need) to very poor condition (immediate rehabilitation required), are distinguished. The original GompitZ model was adapted in such a way that it uses a random generator to derive a specific condition class from the simulated condition probabilities. This adaptation makes it possible to selectively rehabilitate pipes in very poor condition in the model, which is in line with the local rehabilitation practice.

To simulate the effect of rehabilitations on the condition of a pipe, the deterioration model is combined with model components for renovations and repairs. For renovations (= lining), hypothetical survival curves were developed based on a literature review on the robustness and expected lifetime of liners. For repairs, an offset model was developed that modifies the calibrated survival curves over an effect time of 10 and 50 years (for closed- and open-trench repairs, respectively), temporarily reducing the probability of a pipe of being in very poor condition.

The survival curves for the Berlin sewer network were calibrated from inspection data of the years 2001 to 2018 (116 929 datasets) independently for ten different cohorts of pipes (distinguished by material and sewerage type). Inspection data for old pipes of certain materials (≥ 70 years for concrete pipes, ≥ 90 years for clay pipes and ≥ 80 years for marginal materials) were excluded from the calibration process to correct for the survival bias, which would lead to too optimistic survival curves (Scheidegger et al., 2013). For cohorts for which old pipes were not represented in the inspection data (PVC, Asbestos cement, reinforced concrete; 25% of all pipes), the survival curves were partly built upon assumptions to avoid extrapolation errors. Missing information on material and construction year of pipes were estimated with methods described in Riechel et al. (2019).

Different sources of model uncertainty have been identified for the chosen modelling approach which are associated with i) the inspection data used for model calibration, ii) the pipe characteristics used as model input and iii) the deterioration and rehabilitation model components. An overview of the uncertainty sources and the method used for quantification is given in Table 1.

Table 1: Investigated uncertainty sources and applied quantification methods (MC: Monte Carlo, SC: scenarios)

Group	Uncertainty source	Quantification method
Inspection data	Survival bias correction	Shift of cut-off criteria by ±10 years (SC)
	Subjectivity of condition assessment	Analysis based on double inspections after Caradot et al. (2017) (MC)
	Data availability / assumptions for survival curves	Shift of assumed condition probabilities by ±10 years in tine (SC)
Pipe characteristics	Estimated construction year (13% of pipes)	Prediction error from model attributed to estimated construction years (MC)
	Estimated material (16% of pipes)	Prediction error from model attributed to estimated material (MC)
Deterioration + rehabilitation model	Statistical model error (condition class instead of probabilities)	Repeated simulations for constant simulation settings (MC)
	Model representation of liners	Variation of assumed liner lifetime by ±15 years (SC)
	Model representation of repairs	Variation of probability offsets and effect time (SC)

The different sources of uncertainty were investigated via Monte Carlo simulations (100 repetitions) or selected scenarios (optimistic / pessimistic, 10 repetitions per scenario) for an 81-year do-nothing simulation without rehabilitations (2020 to 2100). For each uncertainty source, the model uncertainty U was calculated from the 95% confidence interval (in case of Monte Carlo simulations) or from the absolute differences in the share of pipes in very poor condition (for the scenarios), averaged over the simulation period. The relevant uncertainty sources with $U > 1\%$ were later combined in a Monte Carlo simulation (2600 repetitions) to estimate their overall effect on model output. All computations were carried out in the statistical programming language “R” (R Core Team, 2021).

RESULTS AND DISCUSSION

Of the eight investigated uncertainty sources, four have a relevant effect on the simulated share of pipes in very poor condition (U > 1%). A 10-year shift of the cut-off criteria used for survival bias correction, as an example, leads to a variation in the simulated share of pipes in very poor condition between 2 and 6% over the 81-year forecasting horizon (mean U: 4%). Similar uncertainties originate from the subjective assessment of pipes during the inspection process, although with smaller temporal variations. The assumptions made for the survival curves of cohorts with low data availability are in the range of 3%. The uncertainties associated with the lifetime and effect of liners are in the range of 1% and thus play a minor role for the do-nothing simulation (only 2% liners in the current network). However, their effect becomes dominant for a liner-dominated rehabilitation strategy as also investigated for Berlin (liner rate: 0.6%/yr, mean U ~ 4.5%; results not shown).

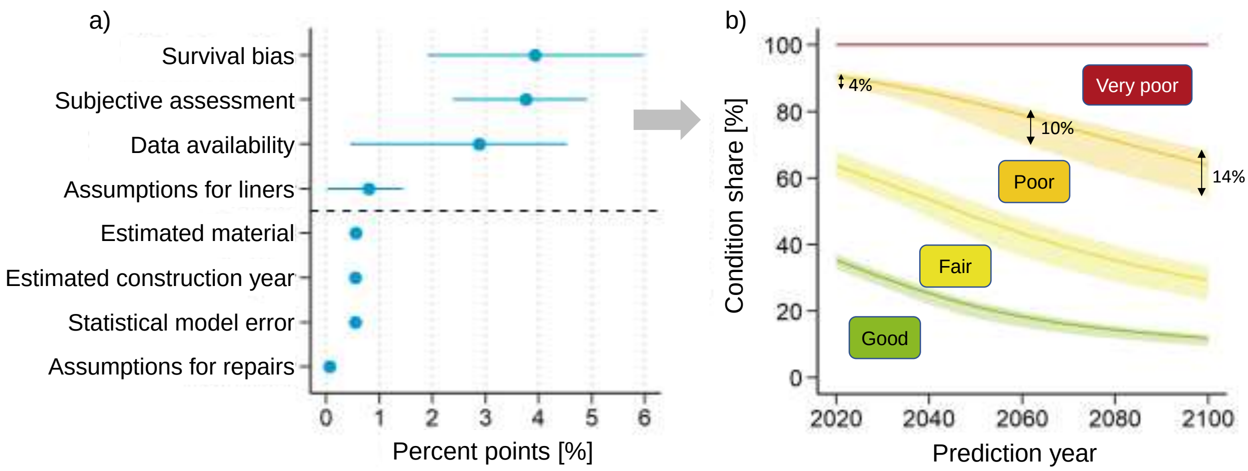

Figure 1: a) Model uncertainty U for each individual uncertainty source. The lines represent the range of U over the simulation period, whereas the points represent the mean. b) Overall effect of the four major uncertainty sources on the condition distribution for a "do-nothing" simulation. The lines represent the default simulation, whereas the shaded areas represent the uncertainty range.

The overall effect of the four relevant uncertainty sources is higher than each individual effect (mean U: 10%) but does not add up completely. The uncertainty increases over time (in accordance with the share of pipes in very poor condition in the network) and reaches values of up to 14% at the end of the simulation period. For a liner-dominated rehabilitation strategy, overall uncertainties even reach values of up to 20% (mean U: 11%; results not shown), due to the increasing importance of the assumptions on liner lifetime. In general, the default simulation seems to be too optimistic as it is likely to have a higher share of pipes in poor condition when uncertainties are considered. That means that rehabilitation rates and budgets derived from default simulations are probably not sufficient. Note that all reported uncertainties are expressed as absolute shares of pipes in very poor condition and relative uncertainties are considerably higher (around 40% for overall uncertainties).

CONCLUSIONS

In the presented work, four major sources of uncertainties in deterioration and rehabilitation modelling have been identified. The uncertainties for a do-nothing scenario are mostly associated with the inspection data which is used for model calibration, in particular with the under-representation of old defect pipes (survival bias) and subjective assessment of pipe defects. For a liner-dominated rehabilitation strategy, assumptions on the lifetime of liners also play a major role. The uncertainties have a significant impact on the model outcomes and on the decisions made thereupon. It can be concluded that rehabilitation rates and allocated budget need to be higher than assumed from the default simulation in order to safely achieve a desired condition in the network.

Besides the knowledge on the effect of uncertainties on model outcomes and decisions, some recommendations can be made to reduce uncertainties in the future. First, the evaluation of CCTV inspections could be assisted with AI-based image recognition techniques as current attempts are very promising (Meijer et al., 2019). Second, all performed rehabilitations and the condition of the pipes prior to rehabilitation should be documented consistently to allow for a more reliable correction of the survival bias, e.g. with statistical methods. Third, knowledge on the long-term performance of liners must be gathered by means of monitoring and liner-focused inspection programs. The same applies to pipe cohorts with low data availability, e.g. pipes in trenchless construction, which have been used in Berlin relatively recently.

The investigations have been made for the Berlin sewer network and the developed strategy simulator. Nonetheless, we assume that the main uncertainties (inspection data and liner lifetime) also apply to other cities. To verify this, we motivate researchers and utilities to apply the presented approaches to their data and models and further communicate the uncertainties in sewer deterioration and rehabilitation modelling.

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Digitalization of integrated asset management approaches at water utilities - A case study with two utilities

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Abstract
In the path towards service digitalisation, water utilities greatly rely on digital management tools that support decision making processes. For the case of asset management, such digital tools can support water utilities by delivering tools that are adaptable to the local context and independent of the internal capacity. In this article, a comparison is made between two utilities – one Chilean and one Portuguese. Whereas the Portuguese utility underwent a decade long capacity building process, based on Aware-P's methodology, the Chilean utility made very limited use of asset management tools and only assessed two performance indicators. In common, both utilities have limited capability in terms of the level of detail of the analyses carried out, with assessments only being made at network- and DMA-wide levels; additionally, both utilities miss the tools to carry out multi-criteria analysis. Infrawise, an asset management tool developed by AGS, was piloted in both utilities. Infrawise supports multi-criteria analysis made at various levels, from individual pipe level to network wide. We show that Infrawise can shorten the implementation path of modern asset management approaches, regardless of a utility's baseline capacity and this evaluation is made by comparing the impact of the pilot in both utilities.

Keywords
Asset management; Cloud-based monitoring solutions; Digital water; Efficiency projects; Water supply.

INTRODUCTION

In a context of climate change water utilities have the need to improve their level of resilience or service by optimizing network management and rehabilitation processes (IWA, 2021; US EPA, 2021). It is thus crucial for water utilities to implement smart and innovative water solutions to collect and analyse data in a more efficient and coherent manner (Alabi et al., 2019; Cassidy et al., 2021). This data-driven decision-making, a process entitled Water 4.0 by the German Water Partnership (German Water Partnership, 2017, 2019), aims to leverage the digitalisation process and is regarded as a vehicle for the improvement of processes and efficiency (Sarni et al., 2019). However, utilities have different capacities and needs regarding data analysis and reporting. Therefore, this process will profit greatly from using tools and approaches that are easily tweakable.

AGS, owned by Marubeni, is a privately held company responsible for the operation and maintenance of several water and wastewater treatment facilities; for the management of 13 utilities in Portugal and Brazil under concession agreements, public–private partnerships; and for the service provision of engineering services to water utilities in Europe, South America and Asia (Cassidy et al., 2020). Making use of extensive R&D on integrated asset management (Alegre, 2012; Leitão et al., 2016; Volta et al., 2004) AGS has developed a suite of water utility management applications. One of these applications – Infrawise – monitors, analyses, and reports relevant asset management performance indicators prioritizing needs for investment based on internal strategies. Infrawise's implementation is independent of the utility's internal capacity management and the application can be tweaked to the local context. It can be hypothesized that Infrawise can leapfrog internal capacity at a utility's level, i.e., by allowing utilities with different capacities to reaching similar levels of asset management internal capacity. Therefore, this article compares the procedure of implementing Infrawise in two utilities – one in Portugal and one in Chile – which have very different baseline capacity level in terms of asset management: whereas the Portuguese utility underwent and multi-year capacity building process to increase internal knowledge in asset management, the Chilean did not have access to such structured capacity building program.

METHODOLOGY

The two utilities involved in this study have different dimensions both in terms of service connection density, mains length, and performance, with Utility 1 having a much lower level of non-revenue water (NRW) (Table 1).

Table 1: Characterization of the two utilities involved in this study. For both utilities the year of reference is 2019

Indicator	Units	Utility 1 (Portugal)	Utility 2 (Chile)
Revenue water	m^3/year	16,636,326	17,975,134
Service connections	no.	43,923	84,656
Mains bursts	no./year	401	542
Mains' length	km	1,391	860
Non-revenue water (NRW)	%	11%	32%

Infrawise, based on Aware-P methodology (Alegre, 2012; Alegre et al., 2013), receives as input raw monthly data for a set of predefined variables (e.g., number of pipe failures), hierarchy relationships between pipes, DMAs and systems, and GIS data. Infrawise then calculates performance, cost and risk indicators at the various hierarchical levels. Finally, the indicators are given weights and aggregated into indices. This multi-criteria analysis methodology allows prioritizing asset rehabilitation through ranking.

RESULTS AND DISCUSSION

Before the implementation of Infrawise, Utility 1 had implemented Aware-P methodology, performed at global system and DMA level. However, analyses were solely carried out at DMA level and the capacity to carry-out multi-criteria analysis was limited. Utility 2 solely analysed one performance indicator at pipe level, the number of supply interruptions (Table 2).

Table 2: List of indicators used by Utilities 1 and 2 before the implementation of Infrawise

Indicator	Units	Utility 1 (Portugal)	Utility 2 (Chile)
Non-revenue water	%	x	
Mains bursts	no./year	x	
Supply interruptions	no./year	x	
Unplanned supply interruptions	no./year		x
Supply interruption complaints	no./year	x	

With the implementation of Infrawise, both utilities grouped the selected indicators in four main goals with the implementation of these pilots, which are defined directly or indirectly by each country's water services regulator body, 1) infrastructural sustainability and integrity, 2) service quality, 3) economic sustainability, and 4) environmental sustainability (Table 3). Furthermore, there are intrinsic driving forces for Utility 1 and Utility 2. The main reasons for Utility 1 (Portugal) were the following:

- Network rehabilitation: due to the fixed available amount for rehabilitation there is a need to optimize the network rehabilitation planning towards increasing service levels.
- Non-revenue water: there was an increase (11% to 17%) in the period of 2019-20, due to apparent water losses. Although this trend is reverting, the utility believes that an integrated asset management tool can support in further reducing this indicator.
- Service quality: the utility is interested in better serving the clients - beyond regulator's benchmarking – and in reducing the number of complaints due to service interruption.

As for Utility 2 (Chile) the main reasons were:

- Network rehabilitation: unplanned network design due to population's fast growth led to a supply system with several operational constraints. Thus, it is crucial to implement an asset management methodology in order to systematize the analysis of the network according to current demands and urban mesh requirements.
- Non-revenue water: currently above 36%. Similarly, to Utility 1, this utility believes that an integrated asset management tool is crucial to support the reduction of this indicator. Additionally, as a measure towards climate adaptation and resilience Chile defined, within the scope of UN's Sustainable Development Goals, the reduction of NRW to values below 25% by 2030 (Gobierno de Chile, 2020).
- Avoid regulator penalties: water utilities with more than four yearly unplanned service interruptions, per neighbourhood block, are fined by SISS, the national regulator (https://www.siss.gob.cl/, accessed on 09 November 2021).

Detailed information about the performance indicators selected by each utility is given in Table 3. Beyond a small overlap in indicators for both utilities – NRW, IVI and main bursts – whereas the focus of Utility 1 is supply interruptions, i.e., quality of service, while the focus of Utility 2 is in operational indicators. With Infrawise both utilities have the capacity to analyse more indicators, at four levels (single pipe, DMA, system, and global network) and carry our multi-criteria analysis.

Since Infrawise has been implemented at Utility 2 for a longer period, it is possible to quantify its impact in the utility´s performance. The progression of NRW before and after the start of the project is depicted in Figure 1 and there was a clear reduction in NRW after the start of the project (December 2019) from 36% to 31%. In 2021, at the height of the Covid-19 pandemic there was a slight increase in NRW but at the beginning of 2022 NRW levels had reached pre-pandemic levels. This reduction in NRW happened due to Infrawise which:

- Allowed the identification of problematic areas given its capacity to evaluate the performance at area level (DMA/system) instead of solely pipe level.
- Supported operational planning by sending active detection teams to areas where despite the network being apparently in good condition (i.e., newer) there were high physical losses.

Table 3: Indicators selected by Utilities 1 and 2

Goal	**Indicator**	**Units**	**Utility 1 (Portugal)**	**Utility 2 (Chile)**
Economic sustainability	Non-revenue water	[%]	x	x
Economic sustainability	Main reparation costs	[$/km]	x	x
Economic sustainability	Service connection reparation costs	[$/km]		x
Environmental sustainability	Real losses per connection	[L/1000 service connections/day]		x
Infrastructural sustainability and integrity	Infrastructure value index (IVI)	[-]	x	x
Infrastructural sustainability and integrity	Mains bursts	[no./100 km/year]	x	x
Infrastructural sustainability and integrity	Service connection bursts	[no./1000 service connections/year]		x
Infrastructural sustainability and integrity	Asbestos cement in the network	%		x
Service quality	Supply interruptions	[no./year]	x	
Service quality	Client complaints due to service interruptions	[no./year]	x	
Service quality	Unplanned supply interruptions	[no./year]		x

Service quality	Critical clients	%		x

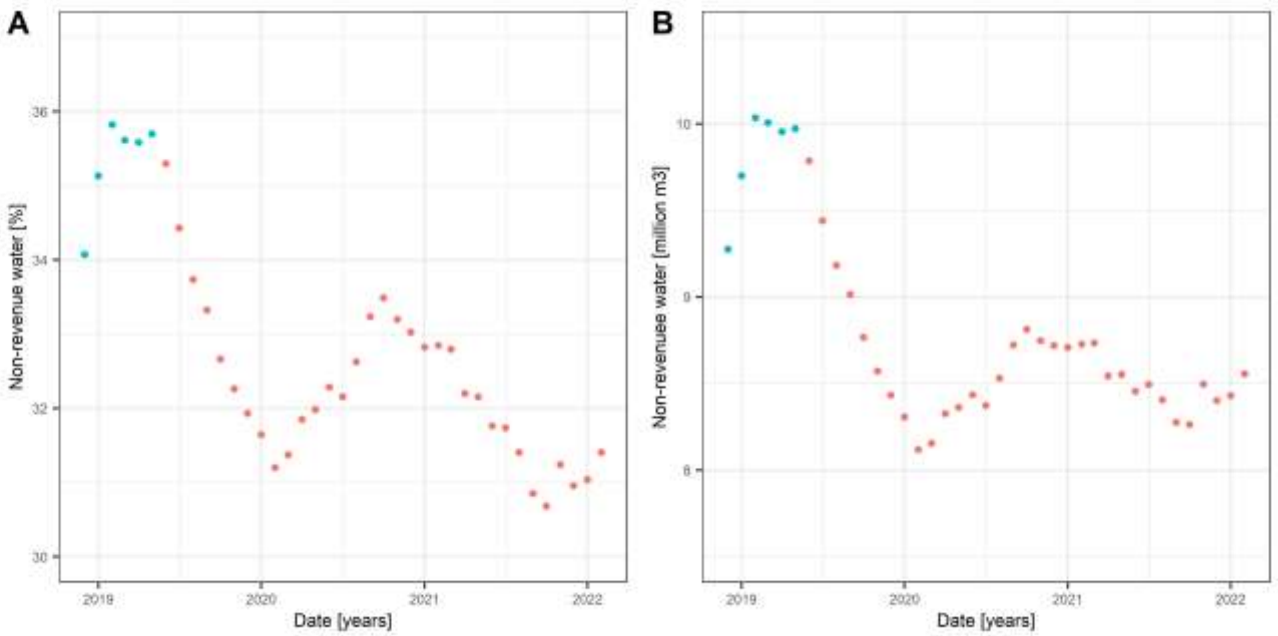

Figure 1: Progression of non-revenue water as percentage (A) and volume (B) before (blue) and after the start of the project (red) for Utility 2 (Chile). The project started in December 2019.

In a context of climate change and corresponding push towards service sustainability and resilience, smart online tools can support decision making process at water utilities. It is thus expected that service digitalisation will play a major role in the coming years and decades. However, tools should be adaptable enough so that the needs of different utilities can be covered.

The implementation of Infrawise, in both utilities, has led to the collection and analysis higher volumes of data, with great benefits to the utilities. Using these data, Infrawise supports multi-criteria analysis and thus utilities in implementing of asset management approaches by shortening the implementation path regardless of their maturity level in terms of asset management. For the case of a Utility in Chile, Infrawise was leveraged to greatly reduce NRW levels by supporting direct rehabilitation through the identification of problematic areas and operational planning by identifying the best areas for active leak detection.

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Understanding the leakage process for multi-scale water infrastructure asset management: necessity for a dialogue between sociological and data sciences

Understanding the leakage process: a dialogue between sociological and data sciences

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Abstract
Reducing water losses is one of the most pressing issues for modern water utilities. To that end, improving the efficiency of the pipe leakage and repair process and aiding the selection of the pipes that are to be renewed or rehabilitated are essential. To help addressing these tasks, in thiswork, we develop a model predicting the probability of a pipe to be leaking. This work is set in the context of a multidisciplinary project with Société Wallone des Eaux and it is aligned withtheir goal to improve their Infrastructure Asset Management in the short and the long terms. Developing and feeding this leakage probability model relies on an intense data processing phase, mobilizing data and water engineering sciences, since the raw data from SWDE is not ready to be used in the model. Complementarily, we thus employ techniques from sociology (e.g., interviews, analyses of the human/non-human actors and of the tools, sociotechnical translations) in order to complete the data, to improve our understanding of its production, andto increase its value and its availability for the prediction of the pipe leakage probability. This model will be implemented in SWDE's information system and used for strategies to reduce water losses.

Keywords
Data, Human/non-human actors, Infrastructure Asset Management, Pipe leakage model, Sociology, Sociotechnical translation

INTRODUCTION

Water supply systems are designed to provide drinkable water with a flow and pressure that should be sufficient for each point of consumption. Water losses occur mainly due to pipe leaks,which are caused by deteriorating infrastructures. They may affect the water distribution network performance and therefore, may lead to an increase in the abstraction of raw water from drinkable water sources. One of the most pressing issues in the management of water utilities is to reduce leaks in order to ensure a sustainable use of water resources (Hafskjold, 2010; Renaud and Charriere, 2016). Thus, water systems operators are moving towards developing strategies to control leakages in pipe networks. Apart from service pressure reduction or modulation, such strategies are focused on two major types of action: the implementation of research campaigns which aim at leaks detection and repair as soon as possible; and rehabilitation/renewal of parts of the distribution network which are characterizedby the highest frequencies of leakage occurrence (Renaud et al., 2014, 2012; Rokstad, 2012). The cost of those shares, especially the expense of replacing pipes, may raise the operating cost of water utility, hence water price. Thus, the implementation of an efficient leakage control strategy could be based on tools that assist in the selection of actions that are better suited for water utility management and its goals for short and long terms. An example could be a leak prediction model for water distribution networks, for which an efficient and well-documented water leakage (or failure) detection and repair process generating accurate data is essential.

Data from many sources and in varying formats are collected, stored, and used by water utilitiesfor most of their administrative and business processes (e.g., data on the hydraulic characteristics of the network, its structure, data on the network environment, failure history). Infrastructure Asset Management (IAM) relies on detailed and structured technical informationon the water infrastructures and operations involved in supplying water to users, but even moreon the understanding of the rationale behind the organization of water utilities and the work practice of its many employees. Yet, these data, when available, are not tailored for the construction of probabilistic models. This is often due to their production and exploitation methods (processing to which they are subject, archiving methods, recording in databases, etc.).Therefore, the pipe leakage state may not be obvious in the raw data, leading to uncertainties.

Based on the experience from an applied research project, called GePaME (Multi-scale IAM),led in collaboration between Société Wallonne des Eaux (SWDE) and INRAE-Bordeaux, this paper presents a set-up of research tasks designed to extract pipe maintenance (e.g., inspection,repair) data embedded in SAP (Enterprise Resource Planning software) records and Geographical Information Systems (GIS) data from SWDE in order to infer a pipe leakage probability model. The goal of this model is to help SWDE improve its long-term IAM process. The originality of this work lies particularly in the link between pipe leakage detection and repairs, as well as in the inter-disciplinary work involved to process the available raw data.

METHODOLOGY

In fact, the raw data provided by SWDE cannot be used to supply a probabilistic model. In order to make better use of these data, we propose to study and analyse its production and exploitation process in it whole sociotechnical dimension, meaning: actors, tools and technical artefacts (software, databases, instruments, etc.), and current practices in leaks detection and repair, in order to complete and transform existing raw data into information suitable for IAM.This analysis is partly based on planned interviews with actors involved in generating the raw data at different levels.

For this, analyses mobilizing four disciplines are combined: (i) Data science, to cleanse and connect network segment description and localisation data to leakage detection operations and pipe leak repairs; (ii) Drinking water engineering science, to exploit DMA monitoring data; (iii) Sociology (sociology of Sciences and Technology, sociology of work) to understand how DMA, and pipes within a DMA, are practically selected for leakage inspection, and how inspection data are produced and reported; (iv) Probability and statistics, for building amodelling tool that could account for this cumulated knowledge and the associated uncertainties.

Mainly three problems can be a hindrance to exploiting the vast amount of data that water utilities generate on a daily basis for IAM (Okwori et al., 2021; Rokstad, 2012). First, water utilities may not always store the crucial metadata describing how, when, and by whom the datawere recorded (or updated) and validated. Therefore, the data can contain redundancies and inconsistencies, making the accuracy and priority given to the information not always clear. In addition, various technical terms (e.g., District Metered Area (DMA), pipe section, leak, and failure) can have different meanings for different operators involved in the data production. Second, many technical details linked with work practice and experience are not reported due to the administrative procedures that historically framed the data collection (data overwritten or not archived). Again, extracting information useful for IAM from raw data is difficult, evenwith the most advanced data mining techniques. Finally, the data may not be structured as a unique and consistent database (Rokstad, 2012). Ideally, all technical objects (such as pipes) and technical tasks (such as pipe leak repairs) are represented as entities, that is, tables with primary keys (IDs which are not duplicated nor null), attributes (characteristics) which are categorized (not free text), and foreign keys (links to other entities). This structure allows a seamless use of the data by merging different tables to create information useful for probabilistic modelling.

We therefore develop advanced data processing algorithms that overcome these difficulties inherent in the data, with the R software language (R Core Team, 2020).

We eventually develop a statistical model of the pipe leakage state probability based on the Linear Extension of the Yule Model with selective survival (LEYP, Le Gat, 2014) and feed it with the processed data combining the network characteristics, DMA, and the leakage detectionand pipe leak repair (technical and sociological data).

RESULTS

This multidisciplinary approach allows a better understanding of the technical and social context in which SWDE's leak detection strategy is employed. The production and exploitationof the data are indeed oriented by the finalities of leak inspection process (regulatory, environmental, economic, administrative, etc.). This process implies many tools/instruments used to generate data and individuals/organizations to implement these tools and interpret thesedata. Taken into consideration, the production and exploitation data can be presented as a "chainof translations" which links human and non-human entities (Akrich et al., 2006). By moving from one entity to another during production and operation, data undergoes transformations andtakes on meaning. Actually, these issues of finalities and the attribution meaning are not knownvery well.

From the clarification of the chain of translations related to leakage and break detection and repair, we expect a better understanding of how to filter, cleanse and interconnect available rawdata in order to identify which DMA, and which pipes inside these DMA's, were inspected andwhen, and which pipes among these were found to be subject to leakage or breakage. This willthen make it possible to build a leakage probability model, as well as a break intensity model, both usable within a long-term simulation framework devoted to assessing the relevance of pipe inspection and renewal strategies.

This mobilization of inter-disciplinary skills requires a common vocabulary and thus sharing different epistemological cultures, from the field agents to the data scientists, via sociology of work. The study of the translation chains along the data course adds essential information that was not recorded in the current database. Assessing the adequacy of this database design and identifying its areas of improvement on a short and long-term perspective for IAM heavily depends on a clear understanding of the organization of SWDE on both on a governance level and on an operational level, which pertains again to sociological practice.

Finally, the shift of temporalities (from daily basis for operational work on the pipe to long- term strategies of network renewal) is taken into account to make sure that the SWDE will be able to make use of and adapt the tools produced and integrate them in their daily practice of data acquisition.

CONCLUSIONS

This study thus highlights the need to better understand the processes that underlie the leakage detection operations both technically and sociologically. On the one hand, the leakage detection operations could answer multiple objectives (administrative, financial, technical, regulatory…)that may influence the technics used and/or the data stored. On the other hand, these detection operations are carried out by human field operators, and the question of the impact of their perception and understanding of where and how to implement an operation remains open. Thedialogue between sociology, data science, water supply engineering and probability is also at the core of the comprehension of the mutual influence between the technical tools and the realization of the leakage detection operations, as well as their evolutions in order to take into account possible biases in the statistical model.

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Impacts of demography on drinkingwater supply networks in Gironde (France)

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Abstract
To consider the long-term management of the water resources used to produce drinking water in Gironde (south-west of France), the SMEGREG (public watershed establishment in charge of deep aquifers in Gironde, France) and INRAE (French public research institute) are leading a collaboration which, in order to forecast changes in the level of water losses, focuses on the impact of demography and urbanization on the assets of drinking water supply networks (DWSN). Analyses are carried out at the scales of the Gironde County and the Bordeaux metropolitan area (BM), based on demographic and geographic databases, French observatory of water services database and the GIS of the BM's DWSN.

The first results obtained show that an increase in the population served by a DWSN translates into a much smaller increase in the length of pipes and a comparable increase in the number of service connections. They also show thatthe higher the urban density of an area, the lower the impact of population growth on the increasing of pipes length.

Keywords
Demographic and geographical data processing, Drinking water supply networks growth forecasting, Geographic information system, Water infrastructure asset management, Water losses, Water resources

INTRODUCTION

The Gironde County (GC), located in the south-west of France and whose main city is Bordeaux, is mainly supplied with drinking water produced from deep groundwater, some of which are overexploited. To consider the long-term management of these water resources, in addition to the drinking water consumption of users, it is necessary to take an interest in the needs of the system, most of which consists of water losses from the drinking water supply network (DWSN). Thus, estimating the evolution of these water losses requires taking an interest in the evolution of pipes networks, from a qualitative standpoint but also from a quantitative point of view.

To move forward on this question, the SMEGREG (public watershed establishment in charge of deep aquifers in Gironde, France) and INRAE (French public research institute) are leading a research collaboration to develop a prospective approach of water losses from the DWSNs in Gironde (Renaud & Husson, 2021). While the first part of this study examines the links between urban density and the performance of services in terms of water losses, the second, which is the subject of this contribution, examines the influence of demography and town planning on the evolution of DWSNs assets.

METHODOLOGY

The study is being carried out at two spatial scales, the territory of the GC (which includes the city of Bordeaux) and the territory of the Bordeaux metropolitan area (BM).

Approach at the GC scale

This first approach is based on the one hand on data from SISPEA, the French observatory of public drinking water services (SISPEA, 2021), and on the other hand on municipal demographic data from INSEE, the French institute of statistics (INSEE, 2021). The asset information available within SISPEA is, for each DWSN, the total length of pipes excluding service connections (L) and the number of subscribers (N) (generally close to the number of service connections). In addition to the population, the INSEE data includes, for each municipality, information on housing (type, occupation). After concatenation of demographic data at the DWSN level, the usable data cover the period 2010-2017. For each relevant variable *X*, an annual average change ratio *RA-X* is calculated. These ratios are then compared with each other.

Approach at the BM scale

This second approach mobilizes the GIS of BM's DWSN, the demographic data of the INSEE at the level of the IRIS which is an infra-municipal statistical subdivision (INSEE, 2021), as well as European land use mapping (Corine Land Cover, 2018) and IGN (French geographical institute) building mapping (IGN, 2021). After geoprocessing, the available data make it possible to study, at the IRIS scale and by land cover classes, the changes in the variables from 2006 to 2017.

RESULTS

GC scale

In 2017, the GC had 1,584,000 inhabitants, or 703,000 subscribers served with drinking water by 19,000 km of pipes managed by around 100 DWSNs. For each service, the annual average changes in demographic indicators, network length (*L*) and number of subscribers (*N*) between 2010 and 2017 were calculated. For most services, the evolution of *N* is very close to that of the population (*POP*). On the other hand, it appears that, for most services, the length of the network grows much slower than the population. Figure 1 represents the annual average ratio of changes in length ofpipes (*RA-L*) as a function of that of the population (*RA-POP*). It shows that most services with a growing population have a growth in the length of pipes lower than that of the population (groups G4 and G5 in green).

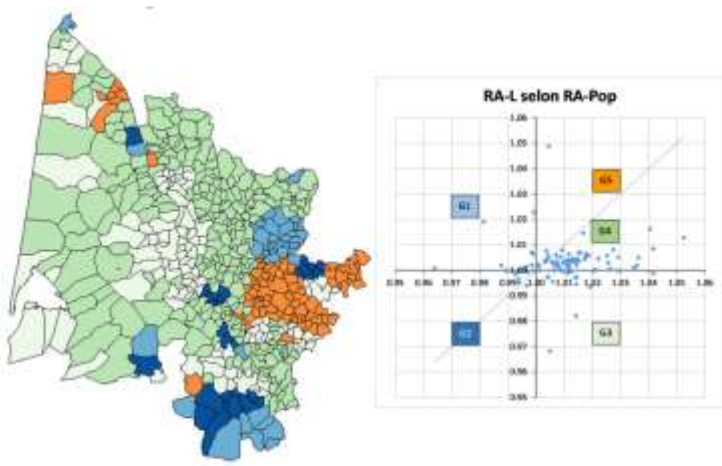

Figure 1: Comparative evolution of population and length of pipes for GC's DWSNs from 2010 to 2017

BM scale

The types of land use in the Corine Land Cover inventory have been grouped into five classes: CLC 1 Continuous urban; CLC 2 Discontinuous urban; CLC 3 Artificial; CLC 4 Agricultural and CLC 5 Natural. Each IRIS of BM has been assigned the class which covers the largest part of its territory (Figure 2).

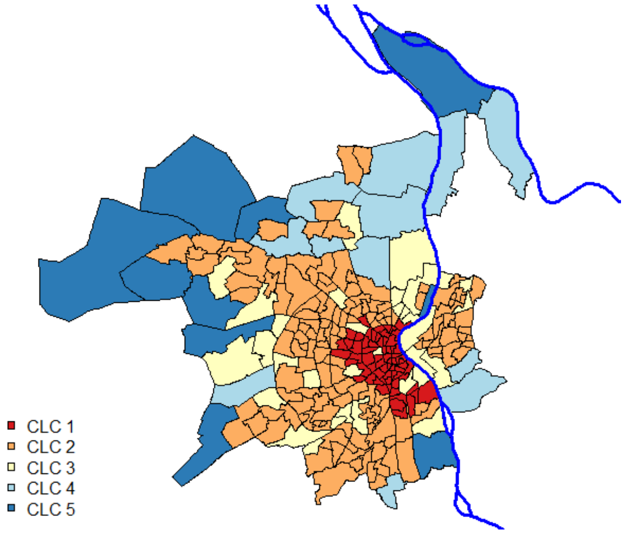

Figure 2: Mapping of BM IRIS by land use class

The surface area of BM is 504 km², more than half of which concerns predominantly agricultural or natural areas (Table 1). Logically, the population, which rose from 670,000 inhabitants in 2006 to 744,000 in 2017, resides mainly in the most urban areas.

Table 1: BM. Population and surface areas by land use class

	IRIS	Surface area		2006 population		Density
	u	km²	%	u	%	u/km2
CLC 1 - Continuous urban	65	21.7	4%	179 870	27%	8 304
CLC 2 – Discontinuous urban	143	156.3	31%	384 688	57%	2 461
CLC 3 - Artificial	32	70.0	14%	56 866	8%	812
CLC 4 - Agricultural	12	100.5	20%	27 456	4%	273
CLC 5 - Natural	10	155.1	31%	20 911	3%	135
BM	**262**	**503.6**	**100%**	**669 791**	**100%**	**1 330**

Table 2 summarizes the first results obtained. For the studied period (2006 - 2017), BM's population (*POP*) increased by 11%. In number of inhabitants, this increase mainly concerns the "Discontinuous urban" and "Artificial" IRIS (classes CLC 2 and CLC 3), but in percentages, theless urbanized IRIS (CLC 3 to CLC 5) experience the strongest population growth.

If we look at the network lengths (*L*) we see that for all the classes their increase is in proportions very much lower than that of the population (which confirms the results obtained at the GC scale). Moreover, while more than half of the new pipes (nearly 30 km) were installed in "Agricultural" and "Natural" IRIS (classes CLC 4 and CLC 5), these only received a little more than 10% of the additional inhabitants. These observations are also reflected in the length of pipe required to serve a new inhabitant, which is increasing significantly from classes CLC 1 to CLC 5.

The variations in the number of service connections (*Nsc*) remain close to those of the population except for the "Artificial" IRIS (class CLC 3) for which the average increase in *Nsc* is much lower than that of the population (12% for 32%).

Table 2: BM. Comparative evolution of DWSNs and population between 2006 and 2017

	Variation between 2006 and 2017 (%)			Evolution between 2006 and 2017 (units)		Pipe length per inhabitant L/POP (m/capita)		
	POP (%)	*L* (%)	*Nsc* (%)	*POP* (u)	*L* (m)	2006	New	2017
CLC 1 - Continuous urban	4%	0%	3%	6 408	-797	2.31	-0.12	2.23
CLC 2 – Discontinuous urban	11%	1%	9%	40 658	20 066	4.31	0.49	3.95
CLC 3 - Artificial	32%	3%	12%	18 084	9 248	6.20	0.51	4.83
CLC 4 - Agricultural	19%	4%	20%	5 170	10 103	9.94	1.95	8.67
CLC 5 - Natural	20%	9%	22%	4 115	19 881	10.55	4.83	9.61
BM	**11%**	**2%**	**9%**	**74 435**	**58 501**	**4.36**	**0.79**	**4.00**

CONCLUSIONS

The study conducted by SMEGREG and INRAE at the scales of the Gironde County and the Bordeaux metropolitan area to assess the influences of demography and urbanization on the evolution of drinking water supply networks leads to the first following results:

- For the vast majority of DWSNs, an increase in the population translates into a much smaller increase in the length of pipes and a comparable increase in the number of service-connections;
- The level of urbanization of the area concerned (assessed according to land use) has a strong impact on the influence of demography on the evolution of pipes length. This influence is zero for continues urban areas and increases when the level of urbanization decreases;
- Seen from another way, the additional pipes length per additional inhabitant is significantly lower than the average length per inhabitant of the service. For all land use classes average pipes length per inhabitant decreases as the population increases.

The study will now be extended to two other DWSNs within the GC (one on the outskirts of BM, the other on the coastline). Other geographic factors that can potentially impact the effects of demography on pipes length growth will be analysed (roads, structure of buildings, etc.). The impacts of demography on the characteristics of the network (materials, diameters, ages, etc.) will also be considered.

Ultimately, by combining these results with those obtained in the first part of the research collaboration (influence of urbanization on the performance of networks in terms of losses), orders of magnitude of water losses from drinking water supply networks associated with different demographic scenarios will be calculated.

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Real-time low-cost water level monitoring for nature-based stormwater solutions

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Abstract
Traditional underground drainage infrastructure (i.e. pipe networks) offers the benefit of conveying excess rainwater from urban centres quickly, but with negative impacts for receiving waters. Consequently, many cities are introducing stormwater control measures (SCMs) to retain and infiltrate excess stormwater, reducing the peaks that can overwhelm networks. Most common SCMs include swales, trenches, infiltration basins, green roofs and porous pavements. Until recently, research often focussed on the design of such systems, with less focus on long term performance and maintenance. Given the scarce data available, monitoring is a priority for Operation & Maintenance (O&M) activities, and to gather the necessary knowledge for asset management. Real-time low-cost monitoring provides an opportunity to meet this need. This communication presents an open-source water level monitoring system which is already deployed in the field. The paper also discusses key elements of design related to low-cost monitoring systems.

Keywords
Low-cost; monitoring; nature-based solution; real-time; stormwater control measures; water level.

INTRODUCTION

Stormwater control measures asset management

According to Raymond *et al.* (2017) “nature-based solutions (NBS) are solutions to societal challenges that are inspired and supported by nature”. They offer great potential in addressing a variety of challenges in many domains (H2020, 2015), and providing ecosystemic services (Nesshöver *et al.*, 2017). Regarding urban water, “NBS can contribute to sustainable urban water management by increasing infiltration, enhancing evapotranspiration, providing storage areas for rainwater and removing pollutants” (Raymond *et al.*, 2017). Such solutions are often applied at or near to the source of runoff: swales, infiltration trenches, green roofs or porous roads, etc. They have emerged worldwide in the last 30 years under many names such as stormwater control measures (SCMs), best management practices or sustainable urban drainage systems (Fletcher *et al.*, 2015). SCMs are integrated within the urban landscape, most often open-air and thus have high visibility and public accessibility. Since the emergence of SCMs, operational and research questions have largely focused on their design. After several decades, there is, however, a growing concern regarding their medium and long-term performance and maintenance, putting at risk the adoption of SCMs, with local government at risk of withdrawing from SCM implementation, driven by concerns about the long-term financial and operational sustainability of such systems (Morison *et al.*, 2010). Most of the present management of SCMs is based on the run-to-failure approach, partly due to resource limitations and lack of knowledge. Shifting to proactive management in the short-term is only possible by drastically increasing the monitoring (more asset monitored more frequently). This will allow anticipating failure and providing a better understanding of their behaviour. The monitoring and alert system will assist operational management with early detection of dysfunction. Long-term monitoring will provide important data on the assets’ behaviour and assist tactical management.

Toward low-cost solutions

Low-cost technologies have emerged few years ago in other fields, such as agriculture (Fisher, 2007) and air quality (Morawska *et al.*, 2018). They are emerging now in our urban drainage community (Santos et al., 2021; Shi et al., 2021). Their advent opens up the potential for entirely new approaches, where numerous sensors measure various aspects of SCM state and performance, generating alerts to those involved in their maintenance. Such sensors could control changes to system configuration to optimise performance relative to operating conditions and maintenance state of the system. Delivering on this potential will require investigating new challenges and imagining innovative ways of monitoring. Among the other challenges, it will be necessary to consider the reliability of the monitoring system, the skills related to customised hardware and programming and the management of large data sets. Low-cost solutions will, however, improve monitoring possibilities with real-time data acquisition, processing, and alert, along with the increase of spatial resolution. A key challenge is to optimise the use of new technologies, rather than simply replacing the functionality of existing monitoring systems.

Regarding SCMs asset management, the review of scientific literature and operational guidelines, associated with exchanges with stakeholders, has proven that the water level is the best solution to inform on the overall operation of the system. The paper presents a low-cost and real-time water level monitoring system and discusses some of the key elements of design (Figure 1).

Figure 1: Key elements for the design of a real-time low-cost monitoring system

How to build a low-cost monitoring system?

Monitoring specifications and choice of the sensor. The proposed system aims to monitor the water level in SCMs to inform O&M activities. The objective is to minimize the costs of design, construction, installation, data management and monitoring system maintenance. The expected maximum water level range is below 2 m with an acceptable accuracy of 2 cm. The system provides real-time data to raise alerts (high / low water level, low-battery level, absence of new data). To reduce cleaning needs, the sensor is not in contact with the water; this constraint drastically limits the choice of sensor (Morris and Langari, 2012).

Power management and communication. Power management and communication are key elements of the system. To avoid frequent site visits, the system needs to be self-powered. Low power management is a frequently discussed topic and can involve a variety of hardware or software solutions. Easy-to-implement solutions include decreasing the measurement time, increasing the sleep time between measurements, and decreasing the communication consumption. LPWAN (low-power wide-area network) communication facilitates minimum energy consumption and maximum range for communication, when compared to cellular (GSM) communication. These solutions are however often one-way communication, with a limited bandwidth (Mekki *et al.*, 2019), which is acceptable for the present project (no image or video to be sent). Based on the existing coverage, the LoRaWAN technology is used where available (no subscription fees) or alternatively Sigfox (subscription fees).

Optimal measurement cycle. Each measurement cycle can be broken down into two phases: an active phase and a sleeping (passive) phase. The active phase consists in the initialisation (powering of the sensors), the measurement, the communication of data, and a termination (power down of the sensors). During the sleeping phase, the system consumes as little energy as possible until the next active phase. The number of cycles per hour represents a trade-off between power management (more measures mean more energy consumption), communication constraints (LPWAN often limits the number of messages per day) and the monitoring requirement. In the present case, a measure is sent every 15 minutes. The duration of the measurement phase is very important because of its high-energy consumption. It is again a trade-off between the quality of the measurement (improved when using the median of *n* measurements) and the total measurement duration (*n* times the duration of one measurement). This trade-off is highly depending on the sensor chosen and the measurement performance expected.

Testing the sensor and the measurement procedure. Following laboratory tests (Cherqui *et al.*, 2020), the ultrasonic sensor JSN-SRT04 has been chosen because (i) it is one of the most commonly available sensors, (ii) it is waterproof, (iii) it is easy to install, and (iv) it provides an expected accuracy within a compatible range of measure. The fact that a sensor is very commonly used is very important because it implies mass production and consequently very low cost (<$7 AUD for the JSN-SRT04), but also a large community of users and potentially a high number of open-source projects and extensive knowledge to aid deployment and troubleshooting. According to the lab results, the sensor shows low variation between repeated measurements: approximately 0.01 m. It has thus been decided to calculate the median of 25 measurements (maximum measurement duration of less than 10 seconds). The total active cycle lasts less than 20 seconds: initialisation, measurements (distance, air temperature, air relative humidity and battery voltage), communication and termination. The system is thus active less than 3% of the time when using a 15-minute time step (20/920 seconds).

Field installation. The system is encapsulated in a 100 mm PVC pipe in order to provide a cheap waterproof case and make it less noticeable, with the aim of reducing the risk of vandalism. The enclosure also allows easy removal/replacement without changing its location. Figure 2 presents the system deployed on site. The system runs on three AA rechargeable batteries and a 0.5 W solar panel.

Figure 2: System installed on the field (on the left of the pole) and photos of the encapsulation system made for easy fixing and removal without changing the location of the sensor

Performance of the system. Data can be accessed in real time using the online platform http://mind4stormwater.online. One of the first system deployed in the field has been running for more than a year and has provided almost continuous time series. Figure 3 presents the water level and battery voltage (peaks of voltage are due to the solar panel) time series. According to initial tests without the solar panel, the system can run more than two weeks without sun.

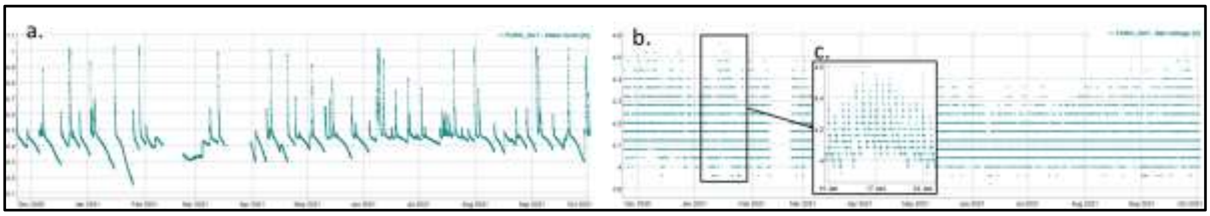

Figure 3: Data gathered in real time for an Australian monitoring system installed in a wetland in Melbourne: water level (a) and battery voltage (b.) with a zoom (c) to see the daily pattern.

CONCLUSIONS

Several low-cost water level monitoring systems have been successfully deployed under real *in situ* conditions both in Melbourne (Australia) and Lyon (France). Key design elements are i) choice of the sensor, ii) measurement cycle, iii) power management, and iv) communication. Other low-cost systems have already been built, showing the flexibility provided by DIY development of monitoring systems and open-source material. Nature-based solution asset management offers new opportunities for the water sector. Existing thinking and practices will need to be adapted to such particular assets, leading to new research and business prospects. It is already clear that more monitoring will be required to shift from a run-to-failure approach to a proactive management. At the same time, low-cost technologies are opening new potentials for the monitoring of asset with the miniaturization and falling costs, allowing better spatial and temporal resolution. Such technologies can be the start of this "out of the box thinking".

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Pardon my trench: reflections on the uptake of trenchless technologies in the Norwegian water sector

Trenchless technology market uptake in the Norwegian water sector

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Abstract
Trenchless pipe renewal can, in many cases, be a more cost-, time- and environmentally effective alternative to traditional trenched pipe renewal. It reduces service disruptions for surrounding infrastructures and is often cost effective, especially when extensive excavation works are necessary. Yet, the uptake of trenchless technologies is rather limited in the Norwegian market. In this study, a set of interviews were conducted with different, representative actors in the Norwegian water industry (water utilities, contractors and consultants), withthe aim of revealing how the technology for renewal of a pipe is selected in the planning and identifying hindering and enabling factors for trenchless technology uptake in the market. Relevant factors identified include market conservativism, lack of trust between stakeholders, missing guidelines about the distribution of risk, lack of knowledge/specialization in utilities and consultant offices, as well asissues pertaining to the project delivery method chosen and tendering process. These factors give an indication of which measures could be implemented to increase the uptake of trenchless technologies in the market.

Keywords
No-dig; trenchless technologies; pipe rehabilitation; pipe renewal

INTRODUCTION

The Norwegian water infrastructure is currently ageing, and consequently faces an increasingrenewal and rehabilitation need (RIF, 2021). Budgets for renewal of ageing pipes represents the lion's share of the expected future costs in Norwegian water systems. Water managers are furthermore expected to transition towards a more sustainable management of their systems, e.g., byusing rehabilitation techniques with lower carbon footprints. At the same time their systems are subject to increasing demands in terms of level of service (capacity, reliability etc.), exasperating the need for continuous system upgrade. Effective technologies for renewing pipe infrastructure are therefore paramount for achieving a sustainable management of urban water systems.

Trenchless technologies can in many cases be a highly effective means for renewing pipes,in terms of cost, environmental impact and time needed for planning and execution (Jakobsen et al. 2010). Trenchless solutions can also contribute to minimize service disruption (of e.g., traffic, public transport), because of the reduced trench volume and quicker execution time, compared to traditional open-trench solutions. Trenchless technologies can be particularly beneficial in cold climates (e.g., Norway), since pipes often are buried deep (> 2 m) to avoid frost problems, and opentrenches consequently need to be deep and wide (implying large volume displacement). Yet, the experience is that the uptake of trenchless technologies is limited in the Norwegian water sector, and its market share is still low. Approximately 12 % of the water distribution and 20 % of the wastewater network is currently renewed using trenchless technologies in Norway, and only 25 %of the municipalities report that they apply trenchless technology (Krogh & Rostad, 2020). The aim of this paper is to investigate why the market share of trenchless technologies is at the current level and identify factors enabling and hindering its uptake in the Norwegian water market.

METHODOLOGY

To answer the research questions (in Table 1) and establish an overview of the current perception of obstacles and opportunities for the uptake of trenchless technologies in the Norwegian water industry, a series of interviews with the three most important stakeholder groups was performed:

1. The municipalities (utilities), who own and manage the pipe systems,
2. The consultants, who are hired by the utilities to plan the rehabilitation projects,
3. The contractors, who execute the rehabilitation projects planned by the consultants

The interviews were executed using a semi-structured interview guide, containing a set of complete questions, all written down before the actual interviews were performed, see Table 1. The written interview questions were sent by email to the interviewees beforehand, thus allowing the interviewees to prepare their answers. The interviews were all performed in Norwegian (the mother tongue of all interviewers and interviewees), allowing the participants to be precise in their answers and argumentation, with minimal language barriers and hinderances of translation.

The interviewees have been kept anonymous, ensuring that the interviewees "speaking their minds" when answering the questions, without risking negative reactions from other stakeholders who may disagree with their opinions. Due to the COVID-19 outbreak, the interviews were carried out as teleconferences, all of which were recorded with the permission of the interviewees. The interviews were transcribed and sent to the interviewees for corrections afterwards.

Table 1: Research questions and their respective interview questions

RQ1: How do the different actors choose the appropriate renewal method in water and wastewater renewal projects,and which criteria are most important for them to consider?
What is your current employment/position and professional function, and what is your professional experience? What experience do you have with trenchless technologies, and how familiar are you with the differenttrenchless technology solutions? Who, in your opinion, decides how much the four criteria *economy* (costs), *technical suitability/viability,environmental impact* and *social impact* is emphasised/weighted in projects with which you have been involved, and how much influence do you have on deciding the influence of these factors? How would you rank the importance of these four criteria (from most to least important) in the rehabilitationprojects with which you have been involved? Which evaluation criteria are usually included in projects with which you work, and how are they weighted? Do you have suggestions to changes in how the abovementioned criteria should be prioritised?
RQ2: How can the choice of Project Delivery Method (PDM) and contract type affect the prevalence of trenchlesstechnology application?
Which factors influence the choice of project delivery method? What are your thoughts about these choices? How are responsibilities and risks distributed in the rehabilitation projects, and why? Are the different criteria (price, technical solution, environmental impact and social costs) considered whenchoosing the project delivery method? If yes, how? What pros and cons do you see with the way you choose PDMs today? What do you think should be changed with regards to PDM and contract types in rehabilitation projects? Do you have experience with partnering contracts, and do you think they are relevant in the water industry? What can be gained from using partnering contracts in the Norwegian water industry? Why are partnering contracts seldomly used in the Norwegian water industry? Should partnering contracts be used more? If yes, how?

RQ3: How can the available trenchless technology solutions increase their market share in the water industry?
Do you always consider trenchless solutions as a possibility in your projects? What percentage of the projectsyou are involved in are carried out using trenchless technology? What are the causes for trenchless technologies not being used more extensively in your organisation? Whichchanges would have to happen for you to employ trenchless technologies more? Should the trenchless technology market share be larger in Norway? Why/why not? In your opinion, what are the causes for trenchless technologies not being used more in Norway? What changesshould be made to facilitate trenchless technology adaptation?

RESULTS AND DISCUSSION

All interviews were transcribed verbatim in Norwegian. For brevity, only key findings elicited from the interview answers are presented in this extended abstract. Factors hindering the uptake of trenchless technologies in the Norwegian market identified are:

- Market conservativism, both with regards to application of novel technologies as well as project organisation, is mentioned by several respondents. The Norwegian utilities seldomly have anything to gain from taking a risk. The risk of underinvesting is low for the stakeholders involved, because of the long timespan before the consequences of underinvestment become apparent, the utilities neither have profits nor losses because their budgets are constrained by full-cost recovery, and the pressure for innovative solutions to increase efficiency is consequently low as well.
- Several interviewees expressed that there is a lack of trust in the market. On the one side, thecontractors are reluctant to invest in new equipment necessary to enable implementation of more trenchless technology projects, because they fear that the utilities will not tender projects requiring said equipment to a degree sufficient to justify their investments. On the other side, the utilities are discouraged by the lack of innovation from the contractors and their experience that the contractors' main goal is profit. In a conservative market with a lowlevel of trust, the consultants tend to suggest only tried-and-tested solutions, avoiding innovative technologies that may leave the exposed to litigation in case of project failure. Another perspective is that there is possible friction between technology providing contractors who are "overselling" to a conservative market, implying that their solutions are suitable in "all" projects, when the market experience is that they are not.
- The distribution of (economic) risk. By default, the proprietor carries the economic risk of unforeseen circumstances in the construction phase. Uncertainty about soil conditions is considered the biggest risk when applying trenchless solutions. During the interviews, it became clear that some contractors are interested in carrying the risk of the soil conditions. However, this usually entails a significant price increase (uncertainty premium). This situation tends to emerge in markets where the contractors have a strong price competition with diminishing profit margins – accepting to carry the risk of soil conditions entails a potential for a significant monetary gain (unless there actually are problems with the soil conditions). Moving the soil condition risk to the contractor will usually be costly for the utility. The utilities usually have a superior economic solvency compared to the contractors – transitioning the risk of soil conditions to the contractors should therefore be considered with care, as it may also lead to bankruptcy of the contractor.
- Missing knowledge and resources in the utilities. The 337 of the 356 municipalities in Norway have less than 50 000 inhabitants; the water utility managers in the smaller municipalities usually must be "jacks of all trades", with limited capacity to specialise themselves in e.g., novel rehabilitation techniques. It is difficult to enable innovation and novel technologies to system proprietors which are not up to date. Larger municipalities can specialise more, which is reflected in their relatively advanced uptake of novel technologies.

Factors identified that can potentially enable the uptake of trenchless technologies are:

- Several respondents highlighted the important role of the consultants that are hired to make the plans for rehabilitation projects. A knowledgeable consultant is considered a key prerequisite for choosing the appropriate rehabilitation technique when the plans are being made, especially when working for the smaller utilities which have limited knowledge on the subject themselves. Under ideal conditions, the consultant also acts as a knowledge bridge between the contractors and the utilities. However, the knowledge about trenchless technologies is varied within the Norwegian consultancy market, and highly dependent on the experience of the personnel at each specific consultancy office. There is also a regional aspect to this, as the consultants in the larger cities usually have more experience with trenchless technology, compared to the smalltown consultancy offices. Knowledge acquisition and distribution among the consultancy offices is therefore identified as a key enabling factor for trenchless technology uptake.
- The project delivery method (enterprise form) and choices made in the tendering process arestated to have a high impact on the outcome of a rehabilitation project, and the choice of the technologies applied. Several interviewees stated that traditional project delivery methods (e.g., design-build or design-bid-build contracts) can hinder the exchange of ideas because of the lack of interaction between the stakeholders. Oftentimes the consultant may suggest a technology in the design phase that the contractor later advises against (due to technical or economic considerations) in the building phase. This lack of interaction leads to a suboptimal utilisation of each stakeholder's expertise, and can lead to inappropriate design solutions. The use of alternative project delivery methods, such as partnering contracts, are viewed as a potential means for achieving more flexible planning and execution of projects, enabling the appropriate choice of technology for each specific project.
- Issues with the tendering process itself were also raised. The experience of the interviewees is that the project cost criterion often overshadows other criteria (e.g., quality, experience of contractor etc.) when traditional scoring methods are applied, even if project cost is only moderately weighted, because the bids often have a high range in the cost criterion.

CONCLUSIONS

Through a series of interviews with central stakeholders, important factors influencing the uptake of trenchless technologies in the Norwegian water market have been identified. The factors have been categorised as either hindering or enabling, according to the interviewees' perception of the status quo. This categorisation is not static, and may change, depending on how the market evolves in the future. For instance, if the issue of trust were resolved, it would of course be changed from a hindering to an enabling factor. Based on the identified factors, a set of recommendations for improving the market conditions for trenchless technologies may be suggested:

- The issues of conservativism and lack of trust may be resolved by stakeholder-independent trade organisations. An active role from a trade organisation, stimulating a balanced dialogue, could help resolve the friction between the stakeholders, and at the same time raiseawareness about the consequences of underinvestment
- Knowledge creation and maintenance among utilities and consultants can partly be undertaken by trade organisations, but cooperation between smaller, rural utilities is recommended, to allow them to pool resources, thereby enabling them to specialise more
- The utilities must increase their focus on careful design of the award criteria and evaluation method, ensuring that the tendering process reflects the requirements of their project, and that the price criterion does not disproportionately overshadow other criteria. This, in combination with choosing the correct project delivery method are regarded as key success factors for a pipe rehabilitation project. Best practices/industry standards on how to distribute risk among stakeholders should be made and followed.

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Assets management from the point of view of the operator: implementation, practical results and day-to-day use

AM through the vision of a public water utility

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Abstract
The water utilities of the City of Lausanne in Switzerland developed an assets management method for its drinking water network in the 2000s, in collaboration with former Cemagref (actual INRAE) and within the framework of the European Care-W project. Due to the positive experience found while using asset management on the drinking water network, Lausanne decided in 2017 to implement a similar method for its sewage network.

We present the methodology used to develop a new asset management tool as wellas the challenges and difficulties found while implementing a new method, from the point of view of its end user: a city utility. We also present how the AM of the drinking water network, applied and adjusted since 2007, has progressively becomea real decision-making tool, the difficulties encountered as a user and the impact onthe effective management of the network.

Eventually, we will conclude about the perspectives it gives for a city utility to manage the whole urban water cycle and to apply asset management tools for bothdrinking water and sewage network.

Keywords
Water utility, Asset Management, practical application, worksite coordination, multi-fluid asset management

INTRODUCTION

The water utilities of the City of Lausanne in Switzerland started the development of an assets management method with the Cemagref (INRAE) in 2000. Thanksto the parallel development of a new database system, the method became operational in 2011 and is updated regularly ever since. The *Service de l'Eau de la Ville de Lausanne* manages more than 920 km of drinking water pipes and 360 km of sewage pipes, covering the needs of 250'000 inhabitants. Both our networks present the advantage of having a highaccuracy of digitalization, helping through the process of implementing and operating effective asset management methods. Moreover, we, as a public entity, act within the contextof the Swiss decentralized governance system, where each region has its own set of laws for water management.

METHODOLOGY

The AM method for the drinking water network of Lausanne, named MEDIREL, is composed of two steps:

1) Calculation of a failure index for each pipe section, using the characteristics of the pipes and the leakage history (~20 years of leakage coverage)
2) Application of the multicriteria method ELECTRE-TRI in order to prioritize the renewal ofthe network. The criteria and thresholds of this method have been adapted over the years.

The outcome is a map of the network that is used on a daily basis by the worksite organizers to target renewal opportunities (Figure 1).

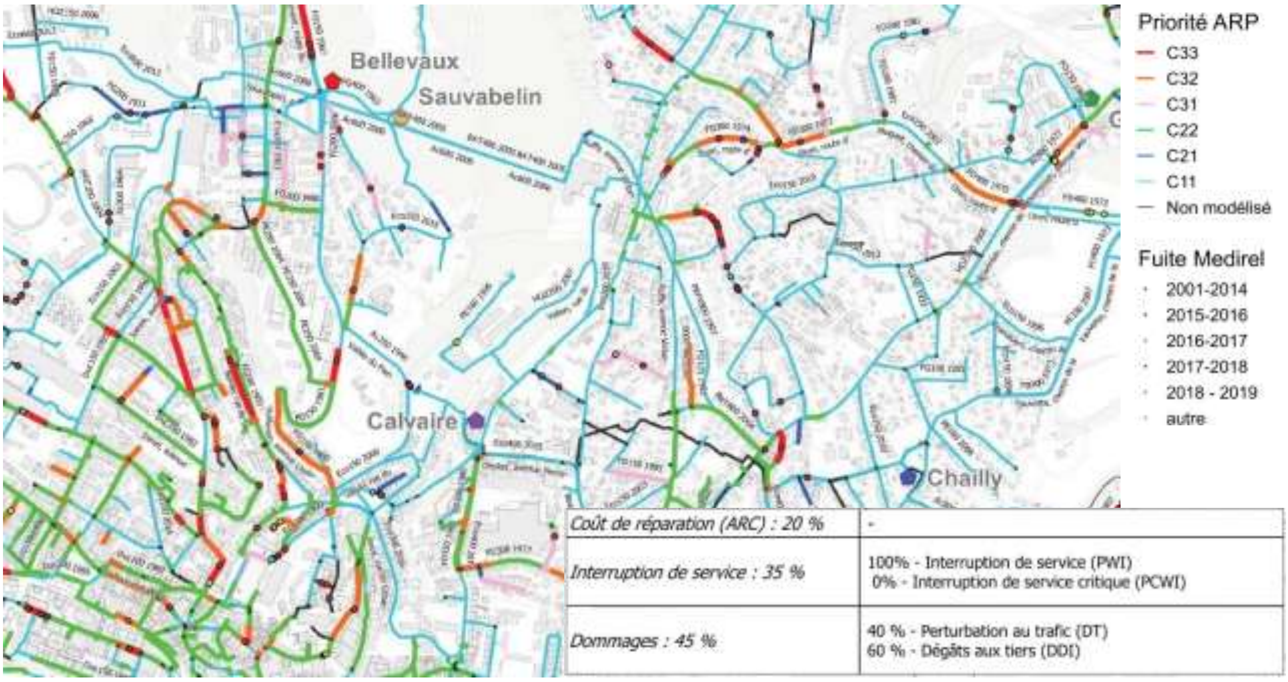

Figure 1: Results of the application of the AM method “MEDIREL”

Regarding the sewage network, the AM tool, called “MEDIREV”, is under development. The method to be implemented has already been identified and is strongly inspired by MEDIREL. It is also composed of two steps:

1) Evaluation of the state of each pipe of the network (both wastewater and rainwater)
2) Prioritization of the renewal and rehabilitation using the ELECTRE-TRI method.

Each pipe being inspected every 10 years, a statistical deterioration model must take place in order to evaluate the actual state of the pipes that either haven’t been inspected yet or have been inspected several years ago. The deterioration model is calibrated with the latest inspections and its result are used in the programming of the future inspections by identifying the pipes presenting the higher risks.

Once each pipe has its own evaluation, the application of the same multicriteria method ELECTRE-TRI as the one in MEDIREL is used in order to prioritize the renewal or rehabilitation of pipes. The criteria and threshold still have to be defined. Figure 2 presents an overview of the methodology.

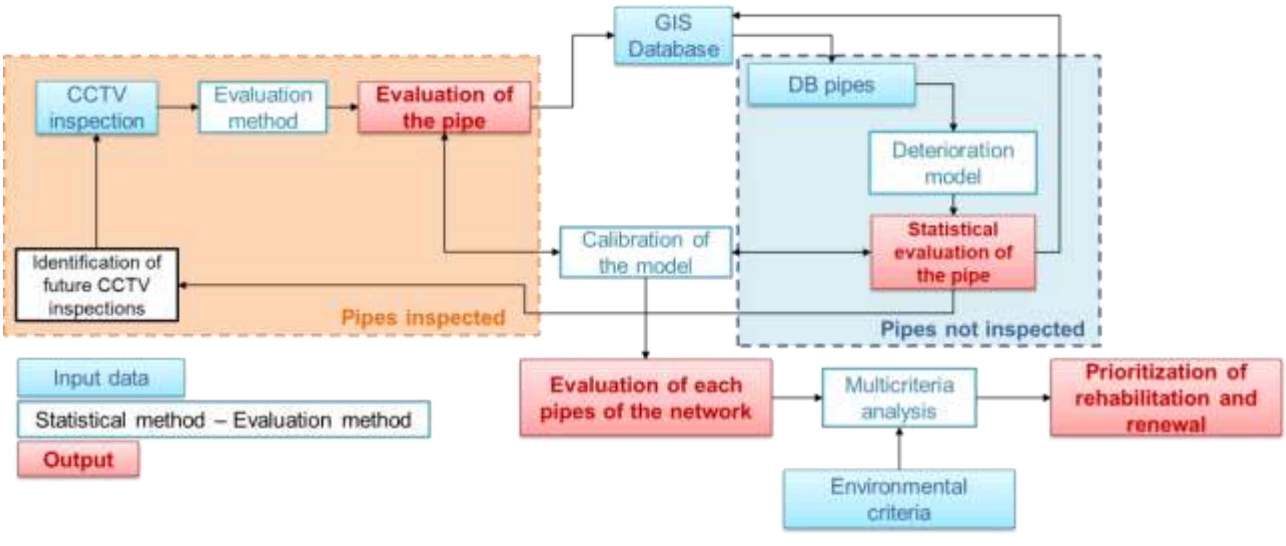

Figure 2: Methodology to implement for the future asset management tool MEDIREV

RESULTS AND DISCUSSION

Developing a new asset management methodology, implementing it and using its output present challenges at all levels of development for a public water utility. *Le Service de l'eau de la Ville de Lausanne* is currently facing those diverse challenges: a new asset management tool for its sewer network is being developed, and another fully implemented AM tool is regularly used for its drinking water network.

The first challenge in developing a new asset management tool is in the definition of the method corresponding to utilities' needs.

The quantity of commercial software existing on the market and the lack of transparency about the methodology applied makes it hard to find the right tool corresponding to the needs of the utility.

The collaboration between public entities and research centres is, from our point of view and experience, an interesting and productive way to develop an AM methodology. Indeed, the needs of the end-user help to guide the research and the involvement of the water utility in the process allows the operator to develop skills in the AM field. This implication of the end-user is crucial since it is the one who needs to be convinced by the efficiency of the method in order to use it. The updating and maintenance of the tool in the long-term requires that the specific skills remain in-house, which is more difficult with a complex – although precise - method. This type of collaboration has been used for MEDIREL and has shown its strengths as this methodology has been used ever since by our department.

The second challenge to face in developing a new AM method is the availability and accuracy of data regarding the network. Indeed, having enough reliable data is mandatory to deploy an efficient asset management strategy. This requires, for the public entity, to dedicate resources and means to maintain and develop the geographic information system and its database. For example, in the city of Lausanne, a team of 5 people is dedicated to this task and many others are involved.

An asset management tool being developed, its implementation should be user-friendly so that the operators actually use it, and its impact measurable. Working on a GIS interface with the prioritization shown on a map (Figure 1) allows them to have a quick overview of the results of AM. Integrating the results of AM in the GIS database also makes it possible to get statistics on the impacts of AM like, for example, the rates of renewal categorized in high priority per year.

Finally, the day-to-day use of the outputs of AM is also confronted with other challenges. The MEDIREL tool, for example, is today widely used to initiate targeted worksites, and for the coordination with other utilities. But we have learned from our decade of experience that the human component in AM should not be underestimated and is the main challenge in applying AM tools.

First, the change of habits, by introducing a new tool, requires time and persuasion. Second, the reality of inter-utilities coordination and negotiations implies that the results of prioritization can only be partially applied.

CONCLUSIONS

Public utilities that want to develop, implement and then use an asset management strategy face a lot of challenges.

First of all, defining the needs can be a difficult task, especially for public utilities having no experience in that field. Being accompanied in this approach either by a research centre or a private company selling an AM software can be a good strategy. Having tested both, we would however recommend partnership with research centres in order to be more implicated and develop the required skills to be able to maintain and develop the AM tool afterwards.

The implementation of the tool must be discussed with the worksite coordinator. Indeed, he must feel comfortable with and convinced by the AM output in order to use it while programming the construction sites of the year. The city of Lausanne works with maps as output, integrated in a GIS interface. This allows not only the coordinator to quickly identify the priorities but also the AM team to be able to draw some performance indicators of AM based on the datasets of the pipes. The complexity of the method should be adapted to the end-user needs and capabilities, and the measure of the AM impact should be defined early enough.

Finally, one of the most challenging part of applying AM tools in the programming of construction site is the coordination with other utilities often forcing the coordinator to engage in sites where no priorities was identified by the AM method. In order to counteract this, the city of Lausanne decided to further develop its AM method, in partnership with INRAE, and include a long-term decision tool which analyses the influence of the renewal rate and the coordination rate on the network performance.

To finish, in order to have a stronger position in the coordination with other utilities, a global AM for water supply and evacuation will be necessary. Moreover, we shall continuously adapt our AM tools to new issues such as global warming, and to new technologies.

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Influence of input data uncertainty on sewer deterioration models

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Abstract
Visual inspection is currently the industry standard for assessing sewer and stormwater pipelines – a method prone to uncertainties as shown by previous studies. The data gathered from the visual inspection procedures is the main information base on which rehabilitation and replacement strategies are founded in current practice. Consequently, this study evaluates the quality of visual inspection data by quantifying the uncertainty and assessing its impact on the output of a deterioration model. The study was carried out by re-classifying pipe condition classes using the same video footage and transferring differences in the classifications into a distribution that was used as a measure of input data uncertainty. This quantified uncertainty was then propagated into a deterioration model using a Monte Carlo approach to assess its impact on the model behaviour. Results show that there is a considerable uncertainty in condition classes coded according to the Norwegian standard, and that it is comparable to uncertainties estimated in other studies using various European coding systems. The uncertainty assessment showed that the uncertainties have a considerable impact on the model predictions, which in consequence demonstrates that the uncertainty in the visual inspection methodology can heavily influence the decisions for rehabilitation and replacement strategies.

Keywords
Asset management, condition assessment, deterioration modelling, inspection, sewer, uncertainties

INTRODUCTION

Sewer and stormwater infrastructure provide a critical service to ensure public health and safety, as well as urban flooding prevention, and provide pollution control of the natural aquatic environment (EN 752, 2008). It is therefore important that the sewer system is kept in a condition that assures that these required services are upheld. Decisions on rehabilitation and replacement strategies amount to significant investments, for example, the sewer network in the European Union has an overall length of 2.5 million kilometres and a replacement value of 2.5 trillion € (Brüggemann, 2017). These cost-intensive decisions are often based either on visual inspection using Closed-Circuit Television (CCTV) or on models derived from those inspections. The data in this context refers to a condition class in the form of an integer, ranging from 1 to 5 in the Norwegian coding protocol (Norsk Vann Rapport 235, 2018), that describes the sewer pipe's condition, where 1 is the best condition and 5 is the worst. These data are often used without questioning their quality and the uncertainties they entail. There do not exist any studies that directly addresses the quality of these visual inspection data in Norway, and only a few internationally (Dirksen et al., 2013). This work therefore evaluates the quality of these visual inspection data to contribute to knowledge in this area. To do so this study seeks to quantify the uncertainty that exists within the CCTV sewer inspection data, and furthermore to assess how this uncertainty can influence the deterioration model used to make decisions for rehabilitation and replacement strategies for the sewer system.

METHODOLOGY

To evaluate the uncertainty, a subset of visual inspections has been re-assessed and coded (by another person), and the deviation in outcome of this re-assessment of the same data is used quantify the uncertainty of the process. The impact of this uncertainty is evaluated using a Monte Carlo approach to propagate 4 uncertainty distribution scenarios through the calibration process of an often-used deterioration model (Le Gat, 2008) in Norway.

RESULTS AND DISCUSSION

Results show that there is a probability of 37,5 % to classify the condition classes in a higher condition class when this case study attempt to classify the pipes, while there is a 10 % probability to classify it in a lower condition class. It is thus a 52,5 % probability to reproduce the CCTV sewer inspection data of the pipes in the sample for this case study. The uncertainty analysis using Monte Carlo assessments shows that the uncertainty is larger for the older pipes than for the younger pipes, which is probably because the dataset used to calibrate the deterioration model had fewer inspected old pipes. It also shows that the model seems to overestimate the condition of pipes below 60 years if uncertainty is not accounted for.

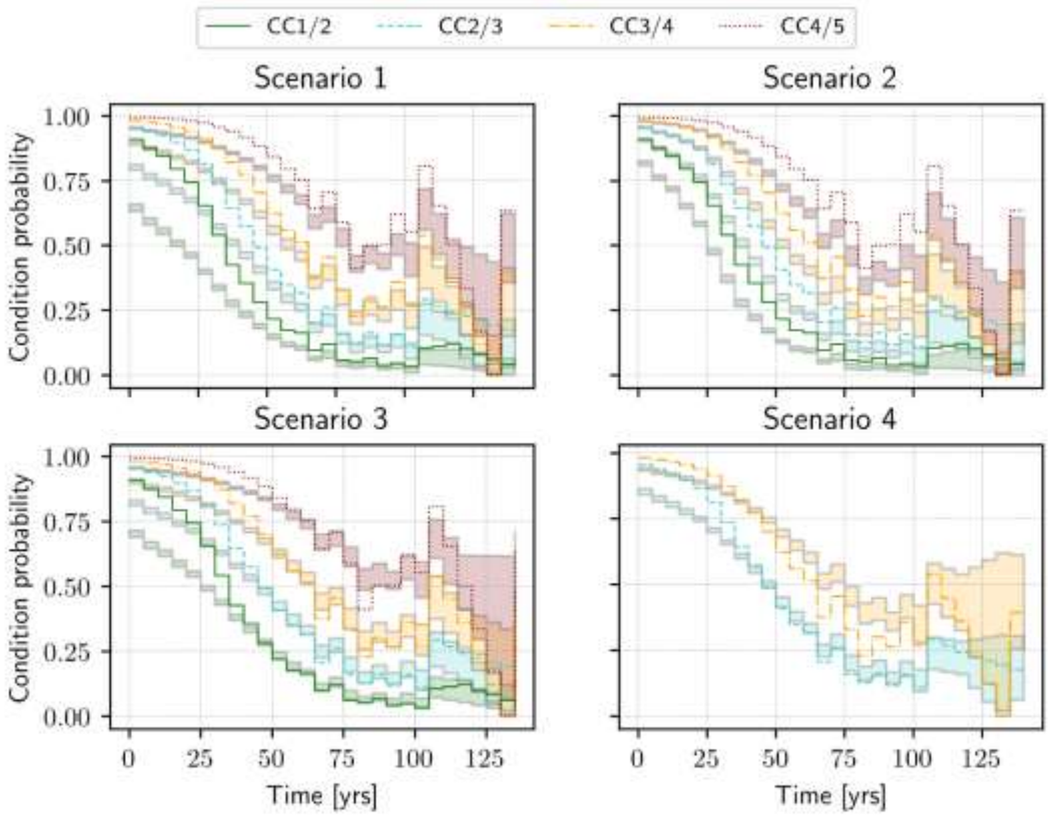

Figure 1: Condition probabilities of the calibrated GompitZ model and the corresponding uncertainty bands for the four defined scenarios

CONCLUSIONS

The results from this study shows that the uncertainty in the CCTV inspection data can influence the reliability of the output from the deterioration model and thereby affect the decision-making process regarding the renewal of sewer networks. It shows that the uncertainty is substantial, which in consequence influence both the model outputs and the decisions derived from the model analyses.

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Urban drainage asset management – now and future

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Abstract

Urban drainage asset management gained momentum and importance in recent years because of economic considerations, low levels of services and evidence of the poor condition of many infrastructure components. Maintenance and rehabilitation activities are capital intensive and resources are limited. Physical urban water infrastructure has life expectancies of up to 100 years, while decisions taken in sewer asset management will have long-lasting impact on the functionality and quality of future services provided. These decisions can be supported by different approaches based on multiple sources of information, from various inspection techniques, deterioration models to assess the probability of failure, or technical service life, to sophisticated decision support systems crossing boundaries to other urban infrastructure. This abstract briefly presents sewer asset management in its manifold facets spanning a wide field of research and highlights existing research gaps while giving an outlook on future developments and research areas.

Keywords

Condition assessment, data management, decision support, deterioration modelling, sewer inspection

INTRODUCTION

Management of urban drainage systems faces major challenges in fulfilling expectations on levels of service and their long-term functionality. The focus is shifting from network expansion to asset management and rethinking existing solutions. Sewer asset management can be defined as managing infrastructure capital assets to minimize the total cost of owning and operating them, while delivering the service level customer desire. The management of these assets represents an important share of municipal budgets. Sewer infrastructure is extremely capital intensive and fixed costs amount to 80% of total costs for a utility (Hukka and Katko, 2015). The estimation of investment levels for wastewater infrastructure is challenging because of the assets' characteristics: long life span, cumbersome condition assessment, differences between accountancy and real economic value and difficulty of assessing costs of deferred investments (CICA, 2007). This work aims to present sewer asset management in its manifold facets while highlighting views of future developments and research areas.

METHODOLOGY

This paper (Tscheikner-Gratl et al., 2019) is based on the diversity of experiences of the working group on Urban Drainage Asset Management (UDAM - https://udam.home.blog/) of the IWA and IAHR Joint Committee on Urban Drainage.

RESULTS AND DISCUSSION

In many data-intensive disciplines (e.g., bioinformatics), technical advancements in data collection, storage, transfer, and analysis have revolutionised their workflow, creating new opportunities for learning and finding solutions. In comparison, the value of data for underground urban drainage infrastructure management has not yet been fully realised (Sarni et al., 2019). These data could be used for a range of applications, from identification of sewer failures, prioritising inspection programs, supporting predictive maintenance to forecasting outcomes of investments. Good examples are the applications to condition assessment of system components. For example, machine learning has proven to be a useful tool to identify critical pipes, while survival analysis provides assessment on the influence of rehabilitation scenarios on the overall network condition. However, the impact of condition assessment uncertainties on such modelling work has not yet been investigated. Work is needed to quantify each source of uncertainty (Caradot et al., 2018), better assess their cumulative propagation in the models (Fugledalen et al., 2021) and find practical solutions to investigate their relevance and mitigate their impact on asset management outcomes. Visual inspection is applied as an industry standard for sewer system inspection for structural performance evaluation, remaining the primary source of information, despite identified limitations. This leads to over-reliance on these data without consideration of their limitations, which is conducive to weak assessment with high levels of uncertainty. The potential of modern inspection techniques to overcome these limitations is substantial. It is expected that within 5-10 years, the currently developed technologies (e.g., Lepot et al., 2017) will mature and be ready for practical applications. Such a revolution also has the potential for breaking down professional "silos" within water utilities and among various stakeholders. Broader approaches to urban drainage asset management (e.g., Cardoso et al., 2016) need to be further developed. Further research should also focus on a more holistic urban drainage asset management approach, allowing exploration of multi-utility asset management possibilities. Few existing approaches have shown promising results (e.g., Kielhauser, 2018), which often use simplistic assumptions about the cost-effectiveness of collaboration. But they do not fully explore potential the holistic benefits to these services and serviced areas. An integrated view of these approaches, including further knowledge about internal and external costs or an interdisciplinary multi-utility and multi-functionality life cycle assessment of urban drainage infrastructure, can be a step forward. Furthermore, the multi-dimensional complexity of this field can benefit from the use of multi-criteria decision analysis and cost and benefit analyses (direct and indirect) considering the utility's organisational structure and preferences of all stakeholders involved.

CONCLUSIONS

Despite its limitations, application of asset management principles to urban water systems is growing. Several areas require further development, others need to be operationalised by utilities, including the incorporation of new technologies and integration of nature-based solutions. Another common limitation is the insufficient consideration of tools to support decision processes: considering the complexity of these multi-criteria decision-making and stakeholders' preferences are crucial for successful decisions and another promising area of research in sewer asset management.

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Knowledge management and performance in water utilities, a balance between human resources and digital maturity – the case of AGS

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Abstract
Digitalisation and knowledge management in the water sector – and its impact on performance – greatly depends on two factors: human capacity and digital maturity.To understand the link between performance, human capacity, and digital maturity,six of AGS water retail utilities, were compared with all Portuguese utilities using Portuguese benchmark data (2011-2019). AGS utilities show better results, including system profile indices, which are assumed to be surrogates for digital maturity. These indices were also found to correlate positively with better performance. In fact, AGS utilities show levels of non-revenue water (NRW) (< 25%), below the national median (30-40%) with network replacement valuessimilar to the national median (< 0.5%). These results seem to imply that higher digital maturity can keep lower network replacement levels whilst guaranteeing lower NRW levels. Furthermore, regarding Personnel Aging Index and digital maturity – two internally developed indices – there was an increase in digital maturity and ageing of the staff which, again, raises questions about long-term sustainability. The growing performance and the slight increase in digital maturitycan be attributed to group-wide capacity building and digitalisation programs that bring together staff from all AGS utilities in year-long activities.

Keywords
Water utilities, performance, knowledge management, digital maturity

INTRODUCTION
Water utilities worldwide already make extensive use of digital services and the implementation of these tools has been shown to increase a utility's performance (Cassidy et al., 2021). However, data quality is an issue (Castro-Gama et al., 2020), only a fraction of the data collected is used and this data is not shared in corporate systems greatly limiting deeper understanding (Mounce, 2020).

However, there is very limited information regarding metrics to assess a utility's digitisation and digitalisation, and staff seniority. Regarding digitisation and digitalisation, IWA proposed a qualitative framework to qualitatively assess water utilities (Sarni et al., 2019), which is parametrized in this article. Furthermore, water utilities managers must keep a balance between the systematization of tacit knowledge, the deployment of new and innovative tools and the hiring of younger and highly skilled staff that will complement the existing staff. Regarding staff management, there are performance indicators for water utilities that deal with the number of staff allocated to specific tasks in the utilities, such as the breakdown of utilities' staff or outsourced staff(ERSAR, 2021). However, these indicators do not indicate the staff's maturity. As such, to complement this information, an index entitled Personnel Aging Index (PAI) was developed (Feliciano et al., 2016) and has been used in the past years. In this article, to the knowledge of the authors, it is the first time that a quantitative link between digital maturity, staff maturity level and utility performance/sustainability is studied using nation-wide benchmark data (Feliciano et al., 2021).

METHODOLOGY
This article analyses the performance of six AGS water supply retail utilities. To qualitatively evaluate the impact of digitalisation and the deployment of innovative management tools, the performance of these utilities was compared to the performance of all Portuguese water supply retail utilities using public data made available by ERSAR. Afterwards, AGS's utilities were analysed further in terms of its human resources age distribution and its digital maturity. The digital maturity of each water utility, was evaluated at seven different levels, ranked by increasedcomplexity. Each level is divided in several sub levels which are evaluated in terms of both availability and usability. More detail will be given in the final presentation.

RESULTS AND DISCUSSION

AGS's utilities have performed better than most of the utilities benchmarked by ERSAR (Figure 1), with levels below average for NRW and slightly higher levels for network rehabilitation. This indicates that even though the rehabilitation rates are below the optimal range defined by ERSAR (>2%), AGS utilities present lower NRW losses which can be hypothesized as being the result from optimized operational programs using systematized methodologies and software, often developed in-house.

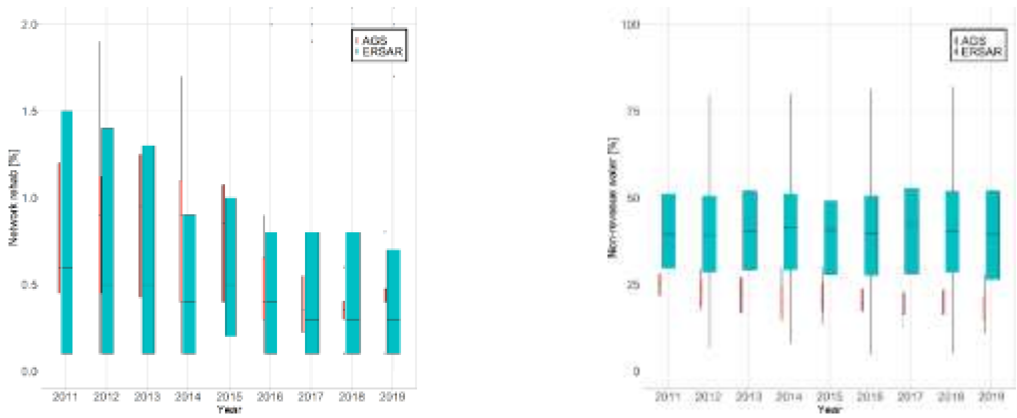

Figure 1: Box-whisker plots depicting distribution of data points in the period of 2011 to 2019. Left: Percentage of network rehabilitated per year. Right: Non-revenue water.

For Flow measuring index (FMI) and Infrastructure knowledge index (IKI), AGS utilities also present higher levels (Figure 2). The level of detail, and scope of the two indices (ERSAR, 2021), mean that to perform well in these indices, utilities are expected to have deployed, and make extensive use of digital tools. In other words: better system knowledge.

Additionally, there is a negative correlation between NRW and both FMI (correlation index = -0.5) and IKI (correlation index = -0.5), which means that more network knowledge can be translated into lower NRW, i.e., better service performance. This performance can only be maintained through maintaining a stable workforce and by deploying digital tools, i.e., increasing the utility's digital maturity.

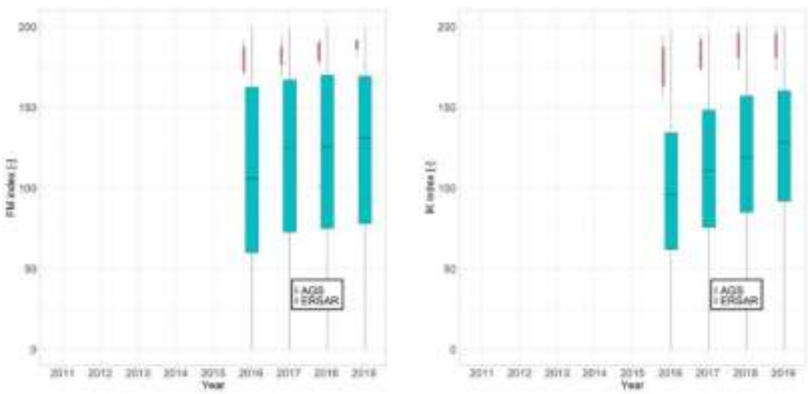

Figure 2: Box plots depicting distribution of data points in the period of 2016 to 2019. Left: Flowmeasuring index. Right: Infrastructure knowledge index.

To be able to further optimize the medium- and long-term planning and to understand and evaluate knowledge creation, transfer, and retention, AGS has created two maturity indices. These indices measure digital maturity and human resources and were calculated for the six AGS utilities surveyed in this article (Figure 3). PAI (ideally 0.4-0.6) decreased for three utilities, remained stable for two and increased slightly for one. A lower PAI indicates that, in general, staff is closer to retirement age, and that the natural ageing of the staff was not offset by the hiring of younger staff (Feliciano et al., 2016). The greatest threat to maintaining a stable PAI with knowledge retention is to compensate staff retirement with the utility's ability to attract younger employees (Sandelin et al.,2019). In some utilities, this process is hindered by the decrease in active population either due to aging or dislocation to other municipalities and particularly from rural areas to cities (INE, 2021).

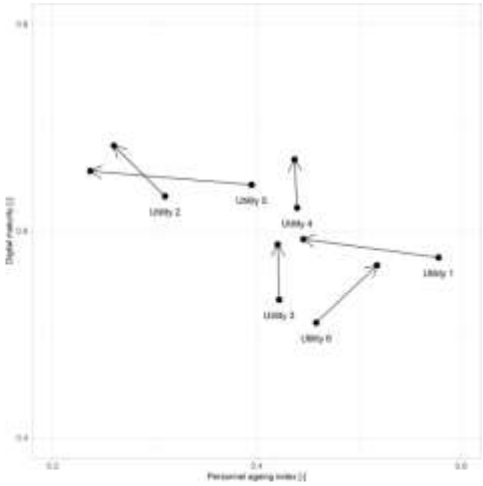

Figure 3: Digital maturity (0-1) versus Personnel ageing index (0-1) for the six AGS utilities.

The arrows indicate the progression from 2016 (beginning of the arrow) until 2019 (end of the arrow). As such, utilities must, in parallel, make use of other tools to guarantee knowledge management and to maintain the provision of the best service to their customers. For the six AGS utilities, the increase in digital maturity has been the chosen strategy and each utility presents different levels of digital maturity due to the specific characteristic of each utility. Digital maturity increased for the six AGS utilities in the period of 2016-2021 (Figure 3) and simultaneously, the performance of all utilities also increased. This seems to indicate that a balance between PAI and digital maturity leads to increased performance. However, due to the absence of a control group – utilities for which we can quantify digital maturity that are not part of AGS – it is not possible to prove causality but solely correlation.

CONCLUSIONS

AGS's performance increased in the analysed period and was higher than ERSAR's average. Regarding network rehabilitation, AGS performance was in-line with that of ERSAR's evaluated utilities, below ideal levels (> 2% per year), which poses serious questions regarding service performance in the coming years and decades. Nevertheless, it can also by hypothesized that that higher rehabilitation rates are not necessarily linked to low NRW and that low rehabilitation rates can be compensated by raising digitalisation and data-driven decision support. Furthermore, regarding PAI and digital maturity – two internally developed indices – there was an increase in digital maturity and ageing of the staff which, again, raises questions about long-term sustainability. The growing performance and the slight increase in digital maturity can be attributed to group-wide capacity building and digitalisation programs that brings together staff from all AGS utilities in year-long activities. In fact, by implementing collaborative projects within AGS' utilities, the knowledge management with a systematization of methodologies and supported increase in digital maturity has resulted in a sustained and continuous operation and provision of water services.

This article shows that both PAI and the Digital Maturity Index are strong tools for internal analysis that allow identifying and highlighting frailties, at utility level, that can support knowledge management and the roadmap towards digitalisation.

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Effect of water temperature on water main failures, the SEDIF (Syndicat des Eaux d'Ile de France) case study

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Abstract
The Syndicat des eaux d'Île-de-France (SEDIF) supplies 4.6 million customers in the Île-de-France region with 790,000 m³ of water per day through a water distribution network of 8,000 km. Noting an increase in the number of breaks on cast iron pipes in its network in winter, the Syndicat des eaux d'Île-de-France (SEDIF) wanted to analyse in detail the impact of water temperature on the dynamics of breaks. Altereo analysed 314,824 pipe objects: 4,137 failure records and water temperature readings from 207 "in-flow" sensors over 4 years. A specific survival analysis shows a strong impact of the survival probability of pipes subjected to very cold (0-6°C) and cold (6-12°C) water temperature. It also shows a potentially higher risk for a specific cohort of grey cast iron pipes laid between 1930 and 1940 when subjected to very high-water temperatures (24-30°C). Climate change induces a reduction in the frequency of cold waves, which is favourable to the reduction of the failure rate on the network. Because of their importance, the management of drinking water networks must however take into account the monthly variations of the risk of failure during the year in order to optimise the inherent costs of network operation.

Keywords
Asset management, climate change, drinking water network, infrastructure, pipe failure hazard, temperature

INTRODUCTION

The Syndicat des Eaux d'Île-de-France (SEDIF) supplies water to 4.6 million customers in the Île-de-France region (approximately 790,000 m³ of water per day) through a distribution network of approximately 8,000 km. Observing an increase in the rate of leaks from its pipes in winter, the SEDIF is considering whether it would be useful to take this phenomenon into account when identifying the pipes to be replaced as a priority. As the temperature of the water distributed varies greatly during the year and the monthly variation in the number of breaks is significant, especially for cast iron pipes (Wengstöm 1993), the aim here is to highlight the evolution of the risk of failure, the importance of the evolution of the risk induced by the temperature of the distributed water and the difference in risk depending on the material and the date of installation.

In a context of global warming and increasing average temperatures (IPCC 2018), the variation of the risk according to the variation of the temperature can be an important factor to take into account and to anticipate within the framework of the construction of replacement plans for drinking water pipes.

MATERIALS AND METHODOLOGY

Data used

The work undertaken concerns the cast iron pipes of the SEDIF network over a limited period of just over 4 years (2014-2018). The SEDIF network is equipped with 217 Kapta probes which measure the levels of chlorine, temperature and conductivity of the water in the distribution network. The history of the temperatures recorded by these probes and used in this work begins at the end of 2014 and ends at the end of 2018. The position of the Kapta sensors is accurately known via a geographic layer.

The 314,824 pipe objects studied are grey cast iron and ductile cast iron pipes, representing respectively 46% and 54% of the linear distribution of these two materials (80% of the total linear distribution of the drinking water network). 6% of the total length of pipes taken into account corresponds to removed pipes which are also used to enrich the analysis.

The failures used are distributed between 24 September 2014 and 31 December 2018. The number of failures is 4,137. Both databases are available as geographical layers.

Methods used

The methods used were the following: construction of pipe classes, development of temperature classes, survival analysis and adaptation to time variables.

RESULTS AND DISCUSSION

Does temperature variation affect the risk of failure?

First, a stratification by temperature class is performed to plot the survival curves of pipes exposed to different water temperature classes (Figure 1).

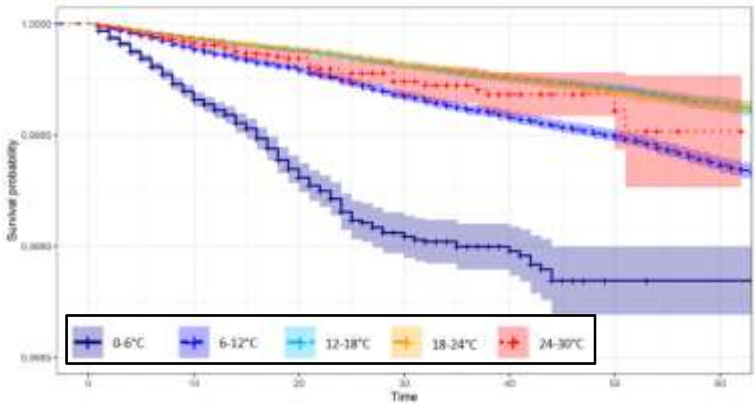

Figure 1: Survival curves by temperature class (time in days)

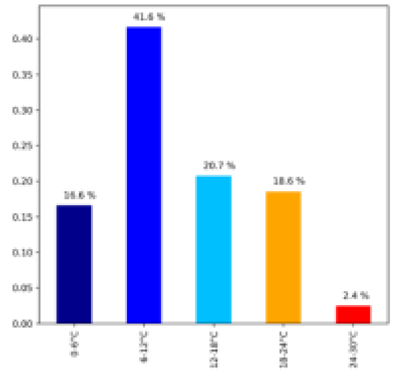

Figure 2: Failure distribution according to temperature classes

It is clear that low water temperatures (0-6°C and 6-12°C) significantly increase the risk. These survival behaviours are significantly different because the confidence intervals of the survival curve for the 0-6°C and 6-12°C temperature classes do not overlap with the other survival curves for 12-18°C and 18-24°C.

An analysis of the frequency of the temperature classes and the distribution of breaks per temperature class (Figure 2) shows that:

- The 0-6°C temperature class concentrates 17% of the breaks for a frequency of 5% of the time.
- The temperature class 6-12°C concentrates 42% of the breaks for a frequency of 34% of the time.
- For the other temperature classes, there is no differentiated survival behaviour for the 12-18°C, 18-24°C and 24-30°C temperature classes. This last temperature class concentrates 2.4% of the failures for a frequency of 2.6% of the time.

For each temperature class, which pipe class characterised by a material/laying period pair is the most or least sensitive?

Using the Cox proportional model, a relative risk can be estimated between a reference risk defined by the survival probability of a reference pipe class and the risk represented by the other pipe classes. The reference pipe class to be taken into account is the predominant pipe class, i.e. the class of grey cast iron pipes laid between 1940 and 1970.

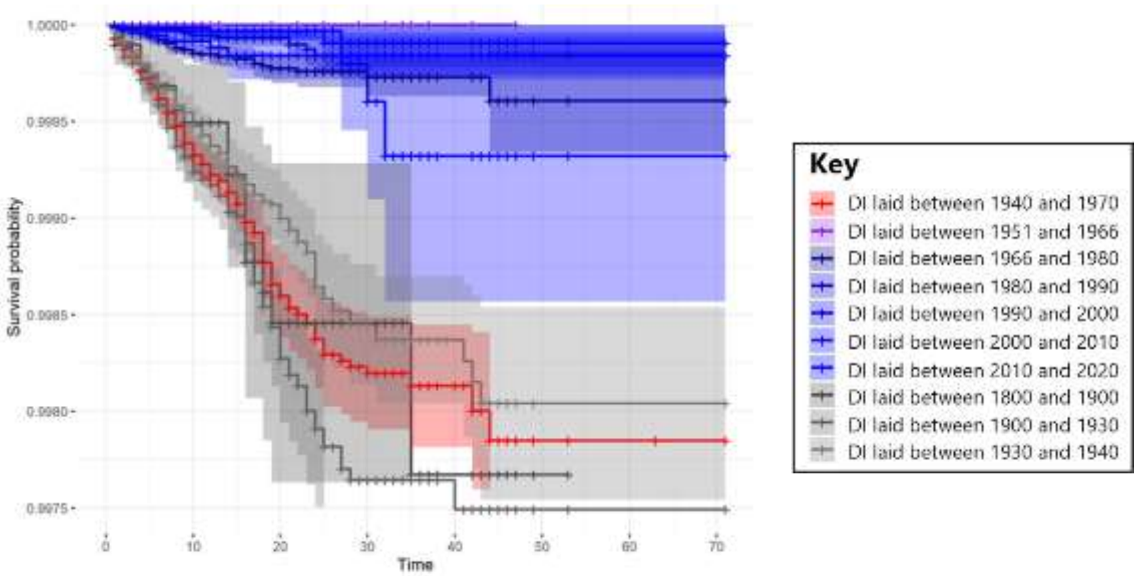

Figure 3: Survival curves for the temperature range 0-6°C

The different survival behaviours for the temperature class 0-6°C (Figure 3) then show different survival probabilities between the grey cast iron pipe classes (grey and red colour) and the ductile iron pipe classes (blue colour). As the survival curves for grey cast iron pipes and their confidence intervals overlap with each other, the associated risk of failure of all grey cast iron pipes can then be considered to be undifferentiated, irrespective of the laying period. Thus, grey cast iron pipes are subject to a greater relative risk than ductile iron pipes over this temperature class.

For each class of pipe characterised by a material/laying period pair, which temperature class increases or reduces the risk the most?

In order to answer this question, the same analysis as above is performed using the Cox model. The reference class is a temperature class corresponding to the class with the median temperature (13°C), i.e. the temperature class 12-18°C.

The survival curves for each temperature class on the class of grey cast iron pipes laid between 1940 and 1970 are plotted (Figure 4).

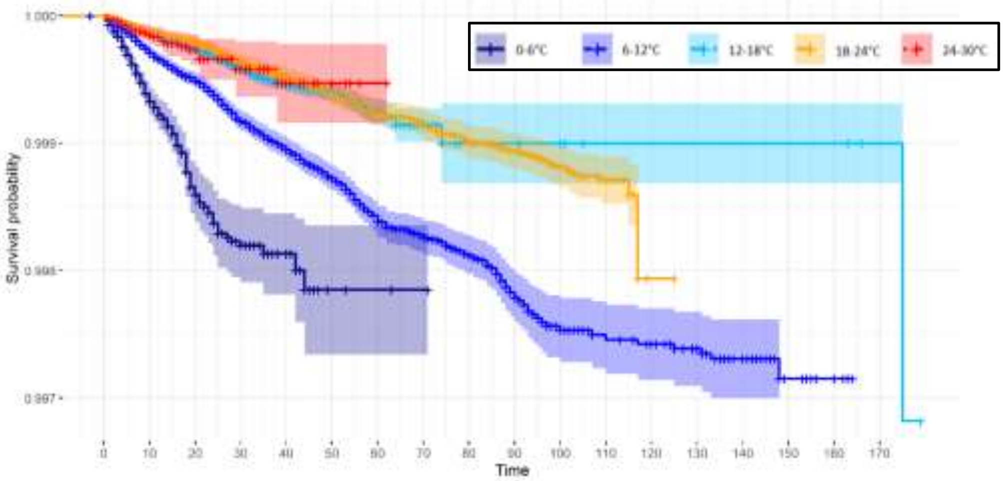

Figure 4: Survival curves on the class of grey cast iron pipes laid between 1940 and 1970.

The 0-6°C temperature class has lower survival probabilities than the other temperature classes (6-12°C, 12-18°C, 18-24°C and 24-30°C). Similarly, the 6-12°C temperature class has lower survival probabilities than the higher temperature classes. Finally, the temperature classes 12-18°C, 18-24°C and 24-30°C have similar survival probabilities, their risk of failure can be considered as undifferentiated as the confidence intervals are merged for these three classes.

An increased risk of failure is also observed for the class of grey cast iron pipes laid between 1930 and 1940 when the water temperature is between 24 and 30°C and which constitutes a significant part of the SEDIF's assets.

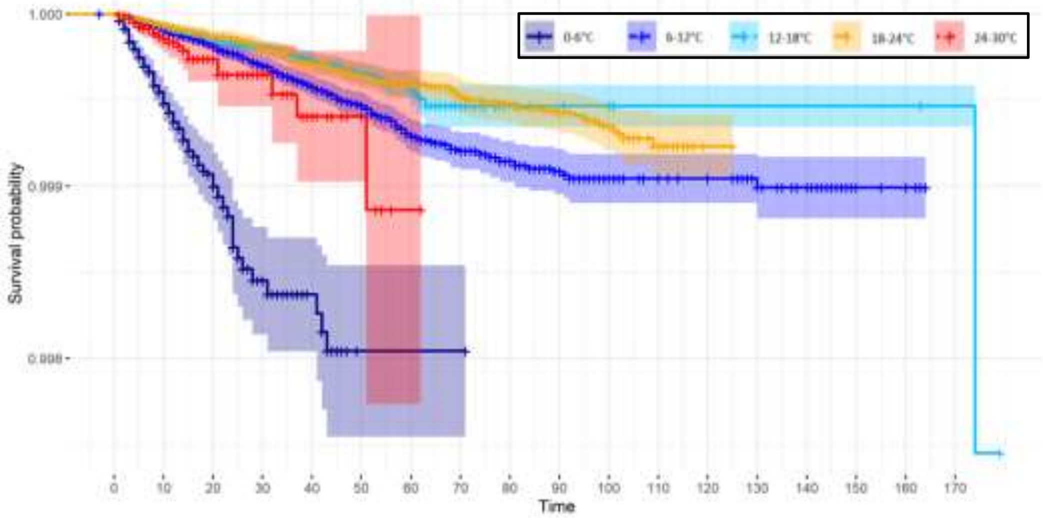

Figure 5: Survival curves on the class of grey cast iron pipes laid between 1930 and 1940.

The survival curves for the class of grey cast iron pipes laid between 1930 and 1940 are plotted by temperature class (Figure 5). Thus, the 24-30°C temperature class has a survival probability that decreases faster than the 6-12°C temperature class for this specific class of pipes, while remaining higher in terms of survival probability than the 0-6°C temperature class, which represents a much greater relative risk.

CONCLUSIONS

The reduction of the risk of failure is one of the priorities of local authorities in the framework of asset management policy materialised by multiannual replacement plans. The variation of the failure rate associated with the variation of the water temperature imposes a smaller risk management scale (monthly or seasonal). The monthly increase in the number of breaks is accompanied by an increased number of interventions on the network, where the availability of intervention teams may be limited.

The length of pipes subject to monthly variations in the risk of failure is very significant, representing almost half of the total length of the network in place. Despite an average replacement rate for drinking water networks that is well above the national average, with rates exceeding 1% in 2018 and 2019 (SEDIF), this specific risk cannot be reduced on a short time scale. The management of this specific risk is nevertheless possible in the replacement policy implemented by integrating a specific sensitivity criterion. This would allow the replacement of pipes to take into account the effects of climate change by targeting the most sensitive pipes to this risk.

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Asset Management advisory services to water utilities in Albania

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Abstract
Water Utilities (WU) in Albania are facing difficulties and significant challenges in managing of their assets. The WU still struggle to collect and record reliable and complete data of their assets while the asset management procedures are almost inexistent or very poor.

In this context, the Water Supply and Sewerage Association of Albania (SHUKALB) has been implementing since March 2019, a Project of Asset Management (AM) for Water Utilities in Albania. 18 small, medium and big size WU, covering almost 70% of the population in Albania with water services, are part of the project and are applying procedures of data capturing and registering, digitalization and maintenance management based on the use of suitable AM software. Furthermore, SHUKALB is supporting the participating WU with building technical capacities of their staff through trainings and advisory services.

This presentation aims providing an overview of the project implementation including identification of various challenges that the WUs have faced finding the right approach and tools on asset management, coordination between departments in the WU in having the same access to key asset data, identifying the conditions and performance of their assets and moreover allocating funds to replace or rehabilitate appropriate assets at an appropriate time.

Keywords
Asset management, data capturing, data registering, maintenance management, SHUKALB, water utilities

INTRODUCTION

Generally, the situation with water and wastewater services in Albania is not in its optimal level, even though over the years there have been significant investments. The statistics shows that, on average, 77.5% of the population in Albania has access to water supply services network, while the situation with sewerage has not much advanced, with an overall coverage, at the national level, of only 52.4%. Only 13.8% of the population is covered with wastewater treatment.

Furthermore, most of Albania's water utilities are financially unsustainable and unable to cover their operating costs due to several factors, such as low billing and collection rates, high levels of NRW, high operating and maintenance costs etc. Only 9 out to 57 WU can manage to cover 100% of their operating and maintenance costs, 25 WUs perform at the levels of 71 % - 100 %, and 23 WUs below the level of 70%.

Along with this situation it is a clear understand that the Water Utilities in Albania are facing significant challenges in managing their assets, as the assets lose their value over time, the system ages and deteriorate. Also, it becomes more difficult for the Utility to deliver the services to the customers. Operation and maintenance costs increase with the aging of assets, leading the company to excessive costs that it can no longer be afforded, and access to funding proves becomes more and more difficult.

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Figure 1: Albanian Water Utilities participating in the program

To address the situation and face the challenges, best AM practices were introduced through the Asset Management Advisory Services to Water Utilities in Albania project, implemented in the framework of the of Asset Management Advisory Services to Water Utilities in South-Eastern Europe Program. The project started implementing in March 2019, through the expert hubs in this case through the Water Supply and Sewerage Association of Albania, in corporation with the technical partner Hydro-Comp Enterprise and the support of GIZ – ORF.

The first year of the project, started with the participation of 12 WUs, coming up with 18 WUs in the third year, which covers almost 70 % of the total population in Albania. The aim was to provide consultancy and direct technical assistance to WUs based on the software solutions called EDAMS and through best practice methodologies.

Hub experts (SHUKALB) support the WUs according to their needs and special requirements, offer their expertise and experience to accompany the participating utilities with each step along the whole program.

These solutions are introduced through three stages, as follow:
Silver Stage – Network Data Management constitutes a comprehensive asset register for the utility networks. It provides a geographical network database with proper functionality for the capturing, structuring, maintenance and management of all existing assets. This stage results consist in a systematic mapping of all assets with factual and reliable data and geographical reference; Consistent, consolidated and validated data repository allows easy network assessment and applicability of all functions to business processes.

Gold Stage – Maintenance Management for the improvement of productivity and efficiency of the maintenance function and the improvement of service delivery (less breakdown time) through the implementation of proper business procedures and workflows. This stage provides a systematic condition assessment of the whole network, an integrated workflows and business procedures, efficient sustainment of infrastructure and cost control for maintenance as biggest cost centre.

Platinum Stage – Asset Management and Distribution, Non-Revenue Water Management enable advanced Integrated Asset Management functions namely such as, Commercial Data Management, Water Quality Management, Distribution/ NRW Management, Rehabilitation/ Maintenance Planning and Business Planning. This stage provides maintenance and rehabilitation plans to minimize cost of asset ownership, distribution Management and Control of NRW as well as network rehabilitation planning.

METHODOLOGY

The work methodology is based on three stages, such as Silver, Gold and Platinum. The purpose is to support the WUs individually with tailored advice and comprehensive capacity development that enables WUs to perform a full range of asset management solutions. Initially, several trainings were provided and delivered to the WUs staff, on regular basis addressing all aspects of asset management as well as the use of EDAMS software. Additionally, WUs are continuously assisted in data collection/evaluation and processing, and in the conversion and uploading in EDAMS software.

Respectively, 1 WU is following the Silver Stage (Tirana), 7 WUs are in Gold Stage (such as Gjirokastër, Kamza, Kruja, Kukes, Lushnjë, Maliq, Pogradec), and 10 WUs are in Platinum Stage (such as Berat, Cërrik, Elbasan, Gramsh, Himarë, Korcë, Peqin, Sarandë, Shkodër, Vlorë).

At the initial stage (Silver), each WU goes through the process of creating and maintaining a valid geographic network database and creating an asset register following the below steps:

1. *Collection of the existing data* by the WUs staff. These data could be water supply networks, reservoirs, valves, hydrants etc, in different format such an AutoCAD files, GIS maps, hardcopy maps, or any previous projects that contain technical data, orthophoto, cadastral maps, spreadsheet in excel, etc.
2. *Evaluation and processing of the existing data* – which consists of georeferencing, digitalization of the data, performed by the assistance of the hub experts. So, that all the collected materials must be processed and converted into GIS shapefile system adapted according to the rules required by the EDAMS software, as the software in which the AM is based.
3. *Conversion and uploading to EDAMS software* – after preparing the materials in GIS shapefile, the next steps is the conversion in EDAMS, done by hub and Hydro-Comp Enterprise experts. EDAMS program by itself does the control of the existing data and generates graphical errors of water supply system. Errors should be corrected by the WUs staff with the assistance of the Hub.
4. *Collection and verification of data in the field* – during this stage, WU staff should correct the complete the data, by verifying those in the field or collect those from any other department or source within the utility. This is done by the staff of the utility with the assistance of hub experts.

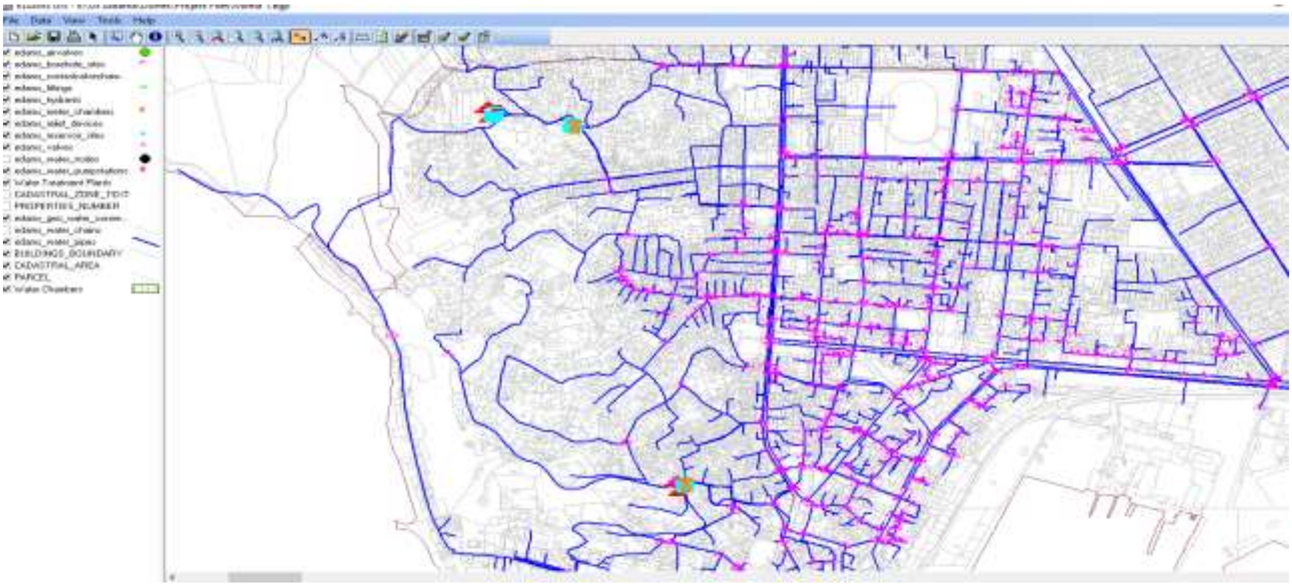

Figure 2: Example of the water supply network shown in EDAMS software

5. *Filling in the missing data in EDAMS software* – Once the missing data is collected and verified, should be reflected in EDAMS. This is an ongoing process that continuous during the whole work with the program.

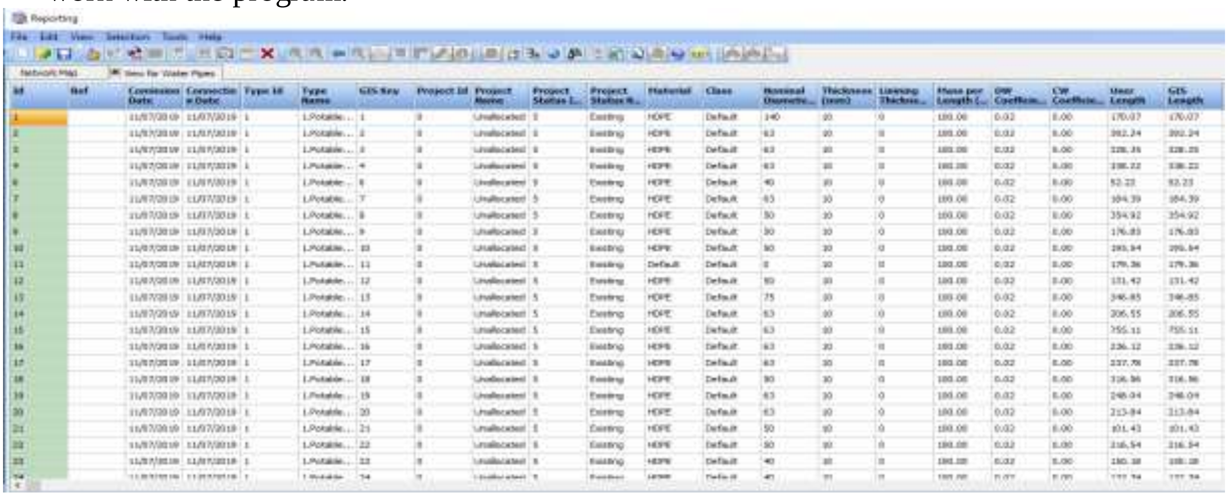

Figure 3: Example of attribute table shown in EDAMS software

Second stage (Gold) on Maintenance Management consists in improving the efficiency of maintenance and service delivery as well as registering maintenance problems. The EDAMS Maintenance Management system gives the opportunity to WUs to create a database for all defects, maintenance activities through issuing job cards. Each WU was assisted through the following steps:

1. *Completion of technical-economic data* – WUs staff has to gather and fill the basic necessary data which require technical-economic information for the utility such as, asset inventory, list of the materials usable for resolving defects, maintenance activities, data for the types of defects, etc.
2. *Data Processing and Evaluation* – In case the data are not filled in properly by the WU staff, additional assistance is provided for the evaluation and processing, in order for the data to be converted in EDAMS.
3. *Conversion and uploading to EDAMS software* – Includes the final steps the conversion in the EDAMS system and start the work with maintenance.
4. *Opening of the accounts for each WU and start working on Maintenance Management*

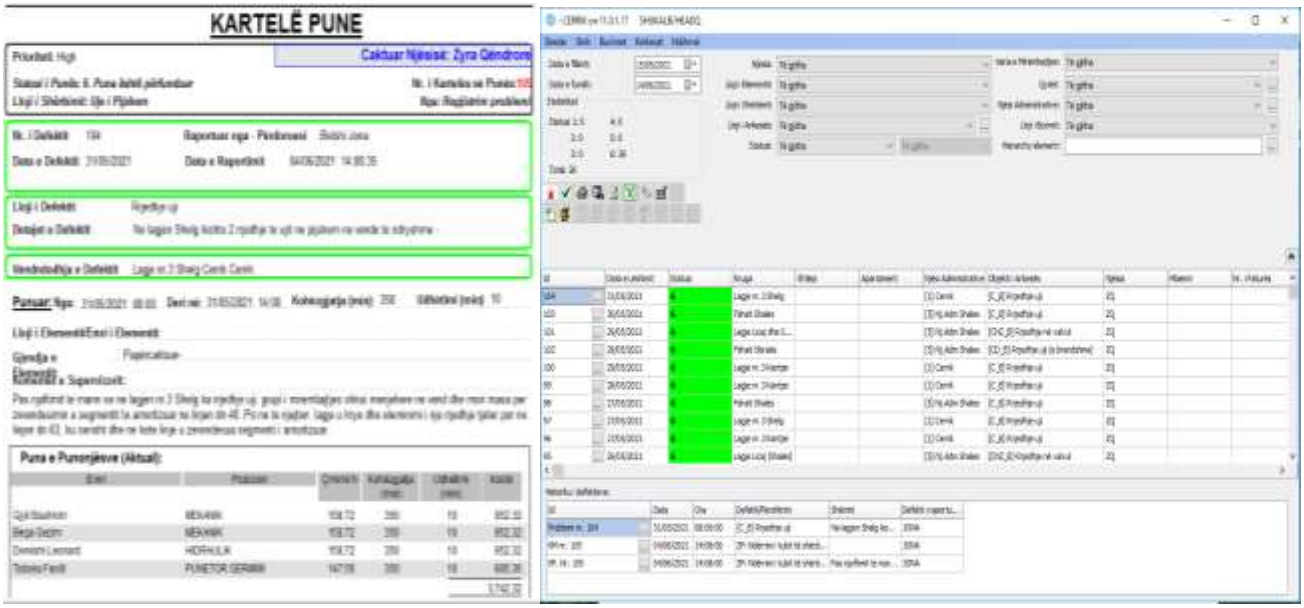

Figure 4: Job card issued from the system

In continuation and parallel to the maintenance activities several WUs are in the *third stage (Platinum Stage)* which consists in activating advanced Integrated Asset Management functions and is aimed for those WUs that have established a validated asset register and want to embark on the more advanced Asset Management activities. These WUs have already gone through the necessary trainings and are in the process of collecting data.

CHALLENGES

Several challenges have been identified along the three years of the implementation of the project. Given that WUs rather than improving work practices, were focus only on keeping their distribution network running, and had poor or not at all maintenance procedures, it was found a lack of data recording and most of the WUs possessed reduced technical data information, or no data at all. Also, the majority of WUs proactive maintenance activities were almost non-existence, WU are dealing only with reactive maintenance.

Furthermore, there were utility cases where the data/information provided was not in electronic format or in software such as AutoCAD or GIS convenient to be converted in AM system. Materials and data were found in hard copy documents and therefore an intensive work has been done in cooperation with hub experts to register and capture the data and ensure a georeferenced and reliable data.

In addition, lack of human resources and staff shortages or replacement were the most significant challenges during the project implementation. Also, there were no adequate and trained staffs to run these innovative systems. Certainly, some WUs are more advance than the others, but still the majority are not able to perform full asset management practices.

CONCLUSIONS

Asset management is impossible without the support of good asset records, as asset register or asset database. Therefore, going through the above explained stages, WUs have ensured a comprehensive database for the existing assets and a systematic mapping of all assets with factual and reliable data and geographical references.

Also, asset register based on the use of the software ensures that there will not be loss of information due to the staff replacement or shortages, as one of the main concerns and problems faced in the WUs.

Moreover, well coordination and knowledge sharing of the same information between different departments in some WU it is achieved.

At this phase of the work, 7 WUs out of 19 have register almost in the range of 90% - 95 % of the water supply network, 8 WUs in the rage of 50% - 75 %, and 3 WUs have register less than 30% of the total water supply network.

Figure 5: Percentage of water supply network registered for each Water Utility

Frequent trainings have been delivered and technical assistance has been provided through hub experts for the staff of each WU. Furthermore, depending on the need of the utilities, additional consultation and assistance for the capacity building of the staff has been given through the years.

According to the maintenance management activities, few WU are practicing the procedures and benefiting from the program. The others are still in the process of data registering assisted by the hub.

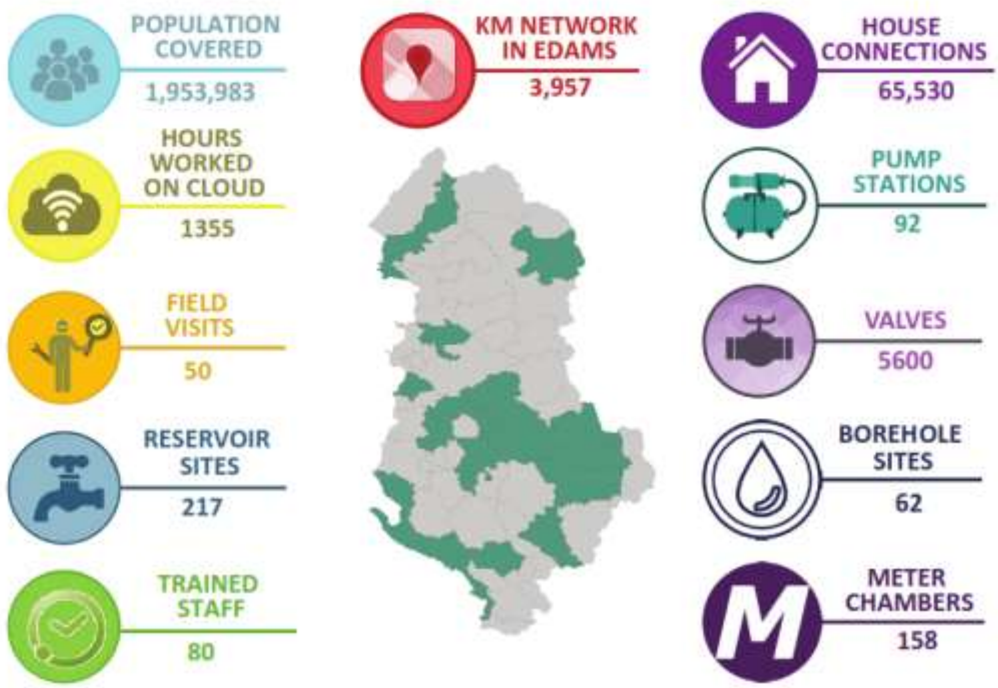

Figure 6: Results achieved and asset registered in 18 WUs

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Managing strategic assets in desertic conditions, a Jordanian experience

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Keywords: EAM (Enterprise Asset Management), desertic conditions, deep wells, drinking water, workforce management

BACKGROUND

Jordan is the second most arid country in the world regarding water availability for the population. A significant part of the drinking water supply of the capital Amman relies on a complex system of 55 deep wells and water conveyance from the southern desert and 365km throughout the country. The tight management of this critical infrastructure faces multiple challenges such as operation and maintenance of more than 11,000 assets, the long distances and the tough nature of some of the areas, workforce management and safety practices that can be ineffective with traditional approaches.

APPROACH AND SOLUTIONS

To succeed in the day-to-day operation and maintenance, as well as the long term uninterrupted of water supply, the team formed by the Operator and partners had to put in place and sustain a high-maturity level of asset management framed by multi certifications in ISO 55001, 14001, 9001 and 45001.

In addition, the EAM (Enterprise Asset Management) has been customized into a real-time monitoring integrated system for the management of the O&M on-site activities across the desert and remote areas, from the wellfield area till Amman in Jordan. Valuable enhancement of the asset management has been reached thanks to features such as remote activation of work permits, and geolocation system even in areas where telephone networks are not available, workforce allocation optimization, on site- request, and high level of digitalization of work orders history (videos, photos and documents), instantaneous access to the technical database and real-time dashboards.

RESULTS AND CONCLUSIONS

To date, the operator and partners have performed an outstanding level service to the population while successfully mitigating the risk of remote accident, reducing maintenance, and facilitating business continuity plan during the COVID-19 pandemic.

In a context of water resources limitations, extensive and desertic conditions on assets and activities, and financial constraints, Jordanian skilled team combines high maturity level in strategic asset management with local innovations and demonstrates the resilience of their water supply.

Asset Management journey for Samra Wastewater Treatment Plant

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Keywords: EAM (Enterprise Asset Management), Asset Management Golden Rules

BACKGROUND

In a rapidly growing population and limited rainfall, Jordan understands the value of water reuse. Samra Wastewater Treatment Plant, a state-of-the-art facility with capacity to treat 365,000 cubic meters of wastewater daily, serves a population of some 3.5 million people in the capital city Amman and the neighbouring city of Zarqa. Phase 1 was constructed in 2008 and phase 2 in 2015 under a 25-year BOT (Built Operate Transfer) contract.

Samra Plant was one of the first in the world to reclaim renewable energy from hydraulicturbines powered by the flow of raw water and biogas generators, resulted in achieving 90% of electrical power recovery. 100% of the treated water is re-used for farming irrigation in theJordan valley, putting the plant at the forefront of the government's sustainability ambitions.

Samra's operation relies on hundreds of thousands of diverse assets, from long transmission pipelines, electromechanical equipment to the energy generation systems, site buildings, and moveable equipment, which are worth hundreds of million dollars.

Samra has been certified for ISO 55001 since 2016. An Asset management system can be understood from standards and references as all actions and implementation of policies or procedures within an organization which help in managing asset value through its lifecycle more effectively. It is the art of making balance between Risk, Cost and Performance in a way that keep alignment with organization global objectives and good integration with all entities. This realization and following scientific approach through many years made Asset management at Samra a success story.

ASSET MANAGEMENT GOLDEN RULES

With the experience of Asset management in a wastewater treatment plant for almost 12 years at Samra, the journey can be described as mining works because it is needed to dig more to get better results. So, either for building a new or sustaining an existing Asset Management system that will grow among years to achieve work excellence, it is recommended to adopt below summarized golden rules and each of them can be expanded during the implementation:

1 Know the project boundaries, prepare good Asset register, know all requirements(legal, contractual, etc.)
2 Use a Strategic Management Plan which to be dynamic, simple, comprehensive aspossible, with aligned and balanced approaches to manage asset practices.
3 Build Sufficient Maintenance Facility & Tools. Prepare workshop, special tools, monitoring systems, etc.
4 Select and utilize an Asset Management (EAM) system Computerized Maintenance Management System (CMMS) that fits the project needs. It is essential and important for large and complicated projects to automate Work-Order Cycle and its outcomes.
5 Prepare and keep sufficient spare parts stock for regular and strategic use. Without good stock inventory management, works planning will be interrupted frequently.
6 Build and sustain a team competent to execute works and supervise outsourced works.

People are the most valuable asset.

7 Experience and look after QHSE (Quality, Health, Safety & Environment) on daily basis.
8 Maintain effective Work planning, prioritization, Risk management, and using new technologies in balance with other Inputs like Cost Management, Reliability, and Flexibility.
9 Define and execute the best Assets life cycle management approach. Do necessary preventive, corrective and modification works. Poorly maintained assets will result in many process interruptions.
10 Have an evaluation and performance review systems in place, like Key Performance Indicators, Key Risk Indicators & Key Control Indicators, Maintenance Dashboard, reports, management reviews.

RESULTS AND CONCLUSIONS

In the Journey of Asset Management, there is no definite right or wrong, it's the experience to achieve organization main objectives. Drawbacks should be managed to make the system more robust.

Change is the only constant, so above golden rules are always expanding, and it was easily integrated to ISO 55001 Asset Management Standards

Through the past eleven years, many evidences of effective AMS were foreseen, like Satisfaction of our Stakeholders, winning the AFNOR OR'NORMES (France) Trophy in 2018 for good AMS implementation, Infor Excellence in Action Awards winner in the category of Operational Excellence for best utilization of CMMS in 2016, and permanent representation in SUEZ Asset Management Committee.

How to move from floodway management to floodway integrated stormwater management

Applying Infrastructure Asset Management principles to stormwater management

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Abstract
Due to climate change and rapid urbanization, many Norwegian cities and urban areas suffer from pluvial flooding caused by intense rainfall exceeding the capacityof the stormwater management system, resulting in increased runoff, volumes, andpeak flows in the drainage network. As a response to these challenges, the authors propose a framework developed to help policy makers make informed decisions for floodway management. The framework is expanded to consider the entire stormwater system, highlighting the difference of IAM principles applied to a partof a stormwater system as opposed to the entire stormwater management system.

Keywords
Urban flooding, Floodways, Infrastructure Asset Management, Stormwater

INTRODUCTION

Rapid urbanisation and climate change impacts have resulted in frequent and severeurban flooding events in cities worldwide (Feng et al., 2020). As extreme precipitation events become more frequent and more severe, cities will need to rapidly transform their stormwater drainage and interdependent systems, in addition to the knowledge systems that guide their infrastructure decisions and policy (Rosenzweig et al., 2019). Traditional drainage subsurface solutions have been questioned by many scholars as they lack sufficient flexibility, and more importantly, for their inability to adapt to critical circumstances (Kourtis and Tsihrintzis, 2021).

Applying surface solutions and evolving the drainage systems are essential steps for the reductionof flood impacts and utilizing urban surface areas as integrated parts of the drainage system (Sörensen et al., 2016). Upsizing the existing drainage system to relieve the increasing pressure from climate change and urbanisation has proved to be costly, impractical, and unsustainable, especially for urbanised areas (Qin et al., 2013).

In Norway, the Stormwater 3-Step Approach (S3SA) is widely accepted as industry standard for climate adapted stormwater management: infiltration for light rainfall, detention and retention for moderate rainfall and convey stormwater in safe floodways for heavy rainfall (Lindholm et al., 2008). Previous research has so far been focused on the first two steps, and there is a need for moreresearch on the safe conveyance of stormwater in safe floodways. Urbanization and challenges withurban flooding have led to an increased focus and investment in designing and implementing urban floodways that activates when the precipitation intensity or volume exceed design criteria or at function failure for step 2. There has been less focus on how to manage urban floodways as assets. Asset management in the context of urban flooding has been limited to how urban flooding affects assets, not considering flooding as an asset itself. By implementing the S3SA, Norwegian municipalities are introducing floodways as infrastructure assets to the urban environment, with the following need for management or maintenance (Skrede et al., 2021). To address this, a floodway management framework was developed for municipalities to make informed decisions and manage urban floodways (Skrede et al., 2021). The framework was developed to aid municipalities to map, identify and manage floodways as infrastructure assets, by separating urban floodways from other types of urban flooding, while highlighting the hazard potential unknown flood paths are representing, with the associated risk and cost of not actively managing them (Skrede et al., 2021).

However, as floodways are one component of the S3SA, there is a need to expand the framework for floodway management to a stormwater management strategy by including IAM principles for the S3SA as a system. Reassuring that the S3SA provide a sustainable service over an indefinite lifespan, and balances performance, risk, and cost dimensions (Alegre et al., 2013). The stormwatersystem should not be optimized just for floodways, but in alignment with the utilities long term strategic objectives. The measures and steps in the S3SA have often been designed as independent units rather than integrated systems. In addition, the application of the S3SA have often been implemented on property scale and optimized based on cost, area use, and to reduce discharge to subsurface drainage network. There is a need to align the steps and consider the S3SA as a system on city scale. This study investigates the following: (1) How to move from floodway management to floodway integrated stormwater system management on city scale; and (2) How to expand the framework by applying IAM to the S3SA, not just step 3.

METHODOLOGY

A framework for floodway management (Figure 1) was developed to identify differenttypes of urban flooding and its potential to function as floodways. The development of the framework was based upon the steps of the ISO 31000:2018 Risk Management guideline and presented at ICUD 2021(Skrede et al., 2020).

The floodway management framework was initially developed with an iterative process to fulfil the following objectives (Skrede et al., 2021); (1) differentiate between floodway management and flood risk mapping; (2) deterministic and transparent; (3) adaptable to users with different computational maturity and available data; (4) adaptable for different strategic goals and values ; (5) determine if a floodway is safe, at implementation and during the life-cycle; (6) consider floodways as a system and components; (7) evaluate changes in existing floodways; (8) promote continuous updating and evaluation of the floodway network; and (9) identify which assets should need to be managed, by whom. However, the floodway management framework presented at ICUD 2021 (Skrede et al., 2021), does not consider the step 1 and step 2, and the interaction between the steps. The Plan, Do, Check, Act (PDCA) principles were included to ensure full alignment between the strategic objectives and targets, for all steps of the S3SA.

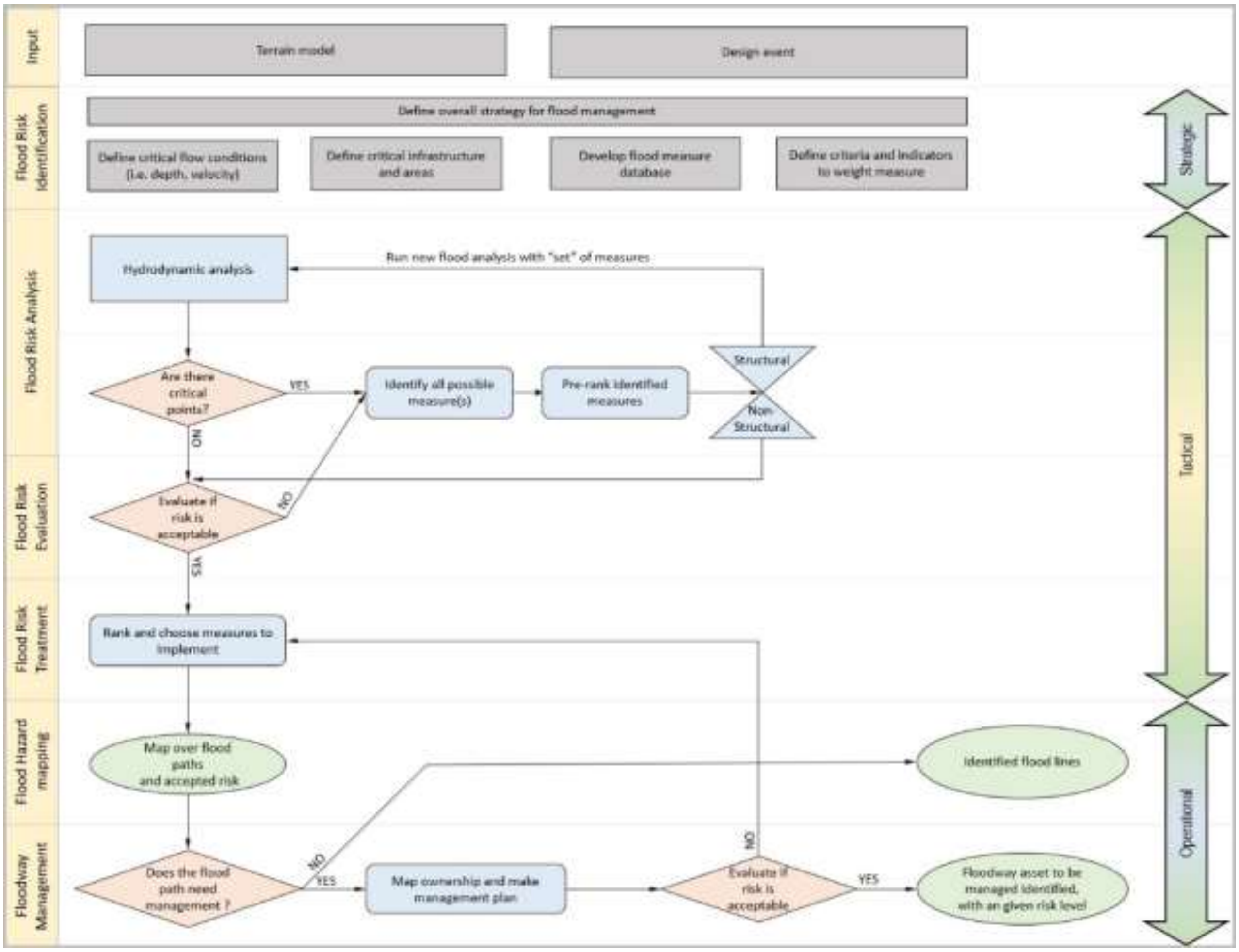

Figure 1: Floodway management framework

The following questions (Alegre and Coelho, 2012) were compared to floodway management, and then adapted to a stormwater management perspective:

1. Who are we at present, and what service do we deliver?
2. What do we own in terms of infrastructures?
3. Where do we want to be in the long-term?
4. How do we get there?

RESULTS AND DISCUSSION

For floodway management the focus is on finding the flood paths system and identifying assets that should be managed as a part of the stormwater system. The traditional IAM-questions focuses on the level of service the managed infrastructure provides. The result fromadapting the IAM-questions from the method when applied to a floodway perspective, is presented in Table 1, corresponding to the framework presented in Figure 1.

Table 1: Proposed IAM questions compared to a Floodway IAM context

Traditional IAM context	Floodway IAM context
Who are we at present?	What are the overall flood management strategy?
What service do we deliver	What are the assessment criteria?
What do we own in terms of infrastructures?	What are the available measures?
How do we get there?	What assets do we have?
Where do we want to be in the long-term?	How to priorities actions?
	What is the associated risk?

To move from a floodway management perspective to a floodway integrated stormwater system management, defining level of service for the stormwater management system is crucial. There is a need for an objective process to evaluate the current stormwater system, where we want it to perform to be in the future, and if the cost of improvement is higher than the cost of doing nothing. In the perspective of Stormwater management, municipalities need to define their goals, then diagnose where they are now, and asses the gap between expected service today and the future. A lack of system thinking and alignment between the strategic long-term objectives, and independent design criteria for each step will not contribute to achieving the full potential of the S3SA. Definingthe overall strategic objectives for the system, then break it down to which part each step should have in achieving the long-term goal. Viewing the steps as measures to achieve the overall goal andreducing the practice of optimizing each step based on their function and local conditions.

Municipalities need to consider what do to expect from the stormwater system and how much they are willing to invest maintain an acceptable level of service. Also, they need to consider what the public consider acceptable level of service for the stormwater system. It is acceptable with activation of urban floodways every 5 or 100 years; Or is it not acceptable with any flooding; No damage to critical assets or infrastructure? As urban areas often are fully developed and the S3SA already have been applied on property scale for a decade, there is a need to not only assess which assets the municipality own, but which assets that contribute or function as part of the stormwater system. Critical assets might not be owned by the manager of the stormwater system. Highlighting the need to map assets and assets owners, that can have with different priorities and long terms goals as the owner of the stormwater system. These considerations are summarized in the questionsadapted for stormwater presented in Table 2.

Table 2: IAM in stormwater context

Traditional IAM context	Stormwater IAM context
Who are we at present?	What service do we deliver?
What service do we deliver	What performance do we want in the future?
What do we own in terms of infrastructures?	What is our system?
How do we get there?	What assets is a part of the system?
Where do we want to be in the long-term?	Where are our assets?
	Who owns the assets?
	How does it perform today?

However, these considerations emphasis on the decision process needed on a strategic level before implementing the S3SA. Further work is needed to incorporate continuous monitoring and updating as a part of the PDCA-loop.

CONCLUSIONS

The study has expanded the framework presented at ICUD2021 providing planning authorises with a framework to better identify natural flood paths as floodways. Further investigation of the challenges and consideration when integrating floodway management to stormwater management in a city scale were discussed. Then a new set of questions to integrate IAM into stormwater management is presented. Municipalities should decide the overall stormwatermanagement strategy before implementing the S3SA, highlighting the need for further preplanning. And the need to define the system, what service the system provides, requiring full alignment between strategic objectives, actual priorities, and the steps in the S3SA.

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Statistical detection of water main failures from flow monitoring

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Abstract
In addition to the financial burden to water utilities, water losses in water supply networks may represent substantial economic and environmental losses to society. In this context, water utilities need to detect failures on the operational management of their networks. Within this study, a simple new method is proposed to detect failures. The method is applied to a case study in Portugal, confirming that returns much less false positives than simple naïve methods, maintaining the same capability to detect failures.

Keywords
Flow monitoring, water loss, statistical, outlier detection, data scarcity, control window.

INTRODUCTION

In a context of population growth and climate changes, water is becoming an increasingly valuable resource. Consequently, reducing water losses is an attractive investment because alternatives (e.g., desalination, tapping of new sources) are usually more expensive both in financial and environmental terms (carbon emissions from energy consumption). Figure 1 presents the evolution of the total water abstracted for drinking water supply and the water losses in Portugal between 2011 and 2020. Over this period, an average of $188x10^6$ m^3 of drinking water were lost every year, which correspond to over $66x10^6$ kWh of energy consumed and more than $20x10^6$ kg of CO_2 emitted per year (assuming that electricity is the main source of energy involved in the production and transport).

Detecting leakages in water distribution pipes quickly and efficiently is vital to water utilities. Not only does it improve the reliability of their service, it also contributes decisively to limiting water losses.

METHODOLOGY

Analysing anomalous flow records from the networks monitoring systems is an efficient way to detect potential bursts on-line and virtually in real-time. This can be done using two categories of statistical approaches: i) naïve methods and ii) flow forecasting methods. The methods on the former category tend to be based on outlier detection, such as the Tukey method. The later includes traditional statistical tools (e.g., time series models) and artificial intelligence tools (e.g., artificial neural networks, support vector machines). Flow forecasting methods are potentially more accurate and can account for more factors, but they also have disadvantages. Notably, they are more complex and difficult to implement, have substantial data requirements, and can be computationally demanding. Moreover, artificial intelligence tools produce black-box models whose interpretation is not easy. In practice, numerous utilities implementing/developing methodologies for the detection of potential burst are resorting to naïve methods. A recent literature review on the topic can be found in Wu and Liu (2017).

This communication presents a performance comparison of different simple naïve methods applied to a case study in Portugal, discussing: i) the option of using absolute or normalized flow data; ii) the selection of the window of data to estimate the outlier limits; and iii) the method used to determine the outlier limits.

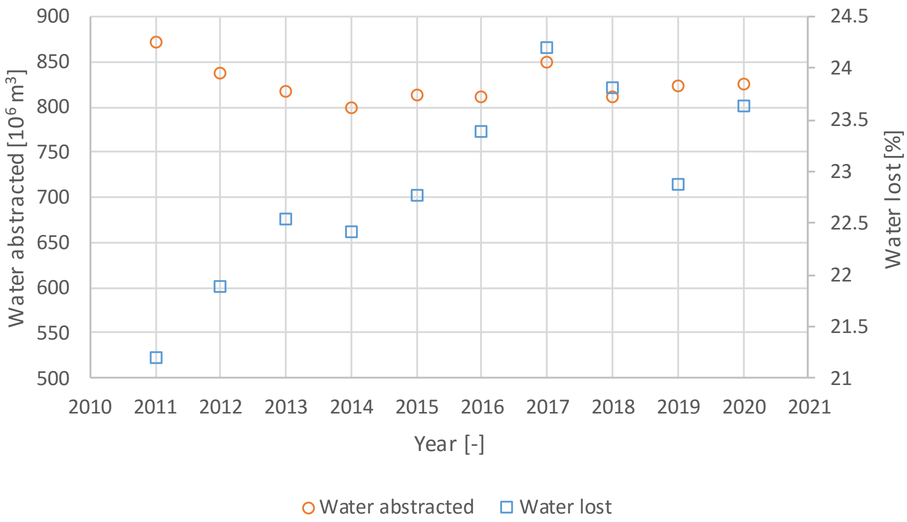

Figure 1: Evolution of the total water abstracted and the water losses in Portugal

RESULTS AND DISCUSSION

Naïve methods are prone to generate a large number of false positives, particularly in small metering and control areas with daily (weekdays versus weekends) and seasonal (winter versus summer) variations. The proposed alternative simple and general solution, based on a logical control window in alternative to single control point, minimizes this problem. In fact, this alternative dismisses the need for adjusting a threshold parameter for each case, which requires the knowledge of past bursts and corresponding flow record, such as proposed by Loureiro et al. (2016).

CONCLUSIONS

Simple naïve methods are less demanding in terms of input data and computational requirements than other more sophisticated methods. However, they tend to produce a large number of false positives. The proposed method returns much less false positives, having the same capability to detect failures.

ACKNOWLEDGEMENTS

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Anglian Water case study - investment planning for net zero

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Abstract
Decision Analytics empowers UK water utility to achieve carbon reduction targets and deliver greater value. Anglian Water is the largest water and water recycling company in England and Wales. Central to Anglian Water's Environmental, Social and Governance (ESG) strategy is the goal to achieve net zero by 2030 and ensure that greenhouse gas emissions (GHG) are lower or equal to mitigation activities. Through the implementation of a Decision Analytics Solution, Anglian Water can deliver low carbon, low-cost solutions.

Copperleaf has an important role to play in helping organisations plan for net-zero. We have been working at the forefront of asset management best practices for more than 20 years, delivering best-in-class decision analytics solutions to many of the world's largest and most respected utilities. At Copperleaf, we believe an organisation's value is the result of the decisions it makes and executes. We have seen that the best-performing organisations create a value-based culture of alignment, transparency, and trust—which delivers optimal outcomes and business agility.

This presentation will outline how the Copperleaf solution empowers our clients to optimise their investment portfolios to drive their strategic outcomes and minimise the impacts of climate change. We will feature a case study on our work with Anglian Water and will be joined by David Riley, Head of Carbon Neutrality at Anglian Water.

Keywords
Asset Management, Climate Change, ESG, Decisions Analytics, Investment Planning

INTRODUCTION

Anglian Water has made enormous progress since first setting carbon reduction targets in 2010. The company's determination to do the right thing by its communities and the environment has been codified in its purpose: "to bring environmental and social prosperity to the region we serve through our commitment to Love Every Drop". Anglian Water has driven the development of PAS 2080, the global standard for carbon management in infrastructure. PAS 2080 provides a common framework within the infrastructure sector and supply chain that helps companies reduce the volume of carbon used throughout a project. It encourages organisations to work collaboratively and more effectively by managing the whole lifecycle of carbon use, enabling a more sustainable way of working.

Anglian Water's net zero strategy sets out its goals to achieve net zero operational emissions by 2030 and to maintain this thereafter. In line with the broader industry Water UK Routemap, Anglian Water is applying good practice in its approach to decarbonisation by following the emissions reduction hierarchy of:

- Reducing/avoiding GHG emissions
- Using green electricity and investing in renewable energy systems
- Removing any residual and difficult to avoid/remove emissions through natural sequestration measures locally and/or credible offset credits.

In addition, Anglian Water has also set a 70% capital carbon reduction target by 2030 from a 2010 baseline.

METHODOLOGY

In 2015, Anglian Water recognised an opportunity to enhance its expenditure optimisation and planning capability in alignment with both ISO 55000 and PAS 2080. Copperleaf® partnered with Anglian Water to implement the Copperleaf Decision Analytics Solution as part of a continuous investment planning and management process that is adaptable to evolving strategic objectives, regulatory requirements, and changing technologies.

At the heart of this solution is the Copperleaf Value Framework—the basis for investment evaluation, scenario analysis, and portfolio optimisation. Anglian Water's unique value framework encompasses both economic and ESG metrics, and these empower the organisation to holistically evaluate investment projects and demonstrate progress against strategic objectives and ESG goals. For example, Anglian Water's value framework includes a measure that outputs the number of agricultural or open areas affected by flooding. Anglian Water then leverages Copperleaf Portfolio to model the impact of different asset investment plans and account for private and societal costs associated with flooding.

In addition, Anglian Water aligned its value framework with the six capitals of integrated reporting—with investment planners challenged to consider the natural, environmental, social, manufactured, intellectual, and financial impacts of proposed investments. These six capitals thinking helps Anglian Water ensure that its customers, communities, and the environment are top of mind when making business decisions. A set of metrics for each of the capitals is defined within Copperleaf Portfolio to provide insight into the impacts of different investment decisions. For example, the importance customers place on enhancing natural capital, such as biodiversity, is a key facet of the decision-making process, and alternative options are assessed that will add or subtract from the region's natural capital balance sheet.

Anglian Water prioritises interventions that have the most significant carbon reduction potential and the greatest co-benefits in the region in alignment with the six capitals approach. This ensures investment decisions strike the right balance between carbon reduction potential, cost, customer bill impacts, and the long-term resilience of its operations.

To support its ambitious carbon reduction targets, Anglian Water uses Copperleaf's Cost Estimation capability to model capital carbon and capture operational carbon associated with an asset's full lifecycle. The solution provides visibility of capital baselines in proposed investments from which performance against targets is measured.

Initially, all investments are created with an indicative design based upon the needs identified. As part of this process, capital carbon figures are calculated using over 1,300 carbon models that are combined to 'build up' the asset using the relevant model for each of the constituent parts. This process generates a 2010 capital carbon baseline, using capital carbon information relevant to 2010, and a capital carbon number based on more recent information. This capability ensures consistency with baselines, but also allows design teams to identify areas of high carbon and optioneer low carbon approaches. Design gateways are used to review capital carbon performance and iterate designs such that capital carbon reduction opportunities are maximised.

This provides an enterprise repository of all cost, carbon, and value information and ensures that every investment decision is based on a single source of the truth. At a strategic level, this provides greater transparency, visibility, and alignment with the company's purpose. The increased transparency and alignment between investment decisions and ESG factors has empowered Anglian Water's investment planners to establish a culture of value and innovation that delivers improved business outcomes.

RESULTS AND DISCUSSION

Through its work with multiple stakeholders, Anglian Water realised that the greatest reduction in carbon often occurs early in the design process. With Copperleaf Portfolio, each project can be reviewed, challenged, and iterated upon as it moves through different project milestones within an asset's full lifecycle. This enables investment planners to determine if there may be a better solution in terms of value, cost, and carbon impact. Cost estimates for each asset consider a wide range of factors, including:

- Asset Level Models: Each scope sheet is made up of multiple asset level models. These may be replacement/ refurbishments of existing assets or addition of new assets to support the proposed project. For example, the "flexible pipework" asset model requires length and diameter attributes.
- Capital Cost: The capital cost to build the asset(s), including additional location factors and oncosts. Models also include a forecast for repeat capex over the lifecycle of the asset (e.g. 50 years for Civils; 15 years for Mechanical and Electrical; and 7 years for Instrumentation and Control).
- Operating & Maintenance Costs: This is the change in lifecycle maintenance cost to operate the asset(s). These maintenance impacts can be positive or negative.
- Capital Carbon, Operational Carbon: The cost in terms of equivalent tonnes of carbon dioxide for both capital/embodied carbon and operational carbon.
- PR09 Carbon: This is the all-important baseline, using 2010 baseline models that allow Anglian to demonstrate carbon efficiency.
- Capital Water: In addition to calculating capital carbon, the estimation models also calculate the capital water – another important environmental resource.

By challenging the default use of traditional, high carbon assets, Anglian Water aims to reduce unnecessary material costs. In recent years, innovations include:

- The use of zero cement concrete to reduce carbon in the base slab of assets by 60%.
- Moving from 'open cut' to 'no dig' solutions for below ground infrastructure. Since 2005, Anglian has moved from using 95% open cut solutions, to 75% no dig solutions in 2018.
- A totex approach to prioritise reusing existing assets, using no-build solutions or building less and making use of standard products, and building on site.

This makes financial sense too. Analysis of the investment planning portfolio shows that a reduction in capital costs and a reduction in capital carbon go hand in hand. Evidence has been collated over a number of years illustrating the relationship between reducing carbon and reducing cost. As can be seen in Figure 5, most projects are concentrated in the reduced carbon and reduced cost quadrant.

CONCLUSIONS

Benefits include:

Enhanced portfolio and scenario capabilities

The scenario analysis capabilities of Copperleaf Portfolio have allowed Anglian Water to compare optimised plans under different constraints or climate scenarios, answering questions such as:

- How can we develop a 'deliverable' plan that meets resource constraints across our supply chain?
- How much do we have to spend to achieve environmental performance commitments while providing reliable service today?
- What is the forecast residual risk after different levels of investment?

The integrated system's optimisation capabilities have been demonstrated to develop deliverable plans that meet customers' needs. Anglian Water believes Copperleaf's optimisation approach will offer 1.5-2% greater customer value in terms of service risk mitigation and benefit realisation than existing plans. Over the Anglian Water investment portfolio, this enables productivity benefits worth up to £50 million over a 5-year period.

Productivity improvements

In one example, the improved plan for a particular portfolio was developed 80% faster than legacy planning procedures. These time savings on the strategic planning side allow for a higher quality regulatory submission. The time requirements on Anglian Water's senior management team have also been greatly reduced due to improved data visibility and enhanced confidence in planning processes.

Enhanced reporting and visualisation

Copperleaf's out of the box reporting supports strong corporate governance at Anglian Water by empowering planners to easily report on long-term risks, their potential impacts, and the company's mitigation efforts.

Achieving ESG commitments

The increased transparency and alignment between investment decisions and ESG factors challenges Anglian Water's investment planners to innovate to deliver greater value to the business. The company has exceeded its 2020 goals and driven down capital carbon by 61% against 2010 baselines. Looking forward, Anglian Water is on track to reach net zero by 2030 which requires a 70% reduction on 2010 baselines. Reducing carbon isn't just good for the planet, it's good for the business.

W-Net4.0 – a digital platform for management of small and medium sized water distribution systems

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Abstract
More than 5,800 companies ensure the supply of drinking water in Germany. The vast majority of these are small and medium-sized water supply companies. So far, they are using information and automation technology to a very limited extent. Therefore, measurement data is usually not collected systematically. In addition, the companies often have neither a sufficiently well-maintained database of the water network nor Geographical Information System (GIS), a simulation software or data analysis tools that can be used to plan and optimise interventions in the drinking water system (e.g. expansion of the network). Without this information and data, the elaboration of rehabilitation planning strategies as part of modern asset management is out of reach. Large water suppliers are often better equipped technically, but the data is rarely used in an efficient manner.

The R&D project W-Net4.0 aims at providing a software, including analysis tools and processes for the implementation of a digital data infrastructure (www.wnet40.de) for water supply utilities. The core component is a modular and scalable platform that combines GIS, simulation software and data analysis tools and meets high IT security standards. Combined with novel service concepts, value-added networks and training concepts, also small and medium-sized water utilities will be enabled to use these technologies and to benefit from digitization. The high degree of user friendliness and accessibility of the platform not only supports the daily work of planning engineers and network operators, but also assists technical staff of small utilities with system operation and maintenance.

Keywords
Digital platform, GIS, Rehabilitation, Maintenance, Simulation, Dashboard, Sensors

INTRODUCTION

The implementation of a successful asset management for drinking water supply systems highly depends on the availability and quality of data describing the system and its operation. Often, small utilities suffer from shortage of technical staff resulting in poor documentation of the systems and consequently fail also in maintaining a comprehensive asset data base. Usually, digital information about the pipe system is missing, network maps, if available, only exist as analogous print outs from the time when the network was built. This lack of data prevents the creation of digital models for deficit statistics, rehabilitation planning and strategy, which are common tools used in modern asset management. Due to the missing data also hydraulic simulation models, that are indispensable for system planning, rehabilitation and monitoring, are not applicable.

Also, operational data are important to get a better understanding of the real system behaviour under different load cases and operational states. Not only large utilities benefit from the installation of online sensor systems that provide continuous information about hydraulic data (such as pressure and flow, as well as water quality data). The information might be also useful for the daily operation of smaller utilities, which can be sometimes even more complex than larger utilities. This is the case of the Black Forest region in Germany, where the large differences in elevation result in the creation of multiple interconnected pressure zones.

Another important component of a successful drinking water distribution system management is the human factor. Especially, small and medium sized water suppliers are facing difficulties in acquiring adequate staff. The project W-Net4.0 aims also at increasing the attractivity of the jobs in water utilities by introducing digital tools that simplify the daily work of the operators and besides, continuously improve the data base and documentation capabilities of the utility. Examples are mobile apps for documentation of maintenance work and the implementation of digital deficit statistics. The project includes also a comprehensive training including theoretical background and technical rules (mainly provided by the DVGW – "Deutsche Verein des Gas- und Wasserfaches e.V", in English: "German Technical and Scientific Association for Gas and Water") and the usage of the integrated software platform.

Within the project W-Net4.0 (Bernard 2022) an integrated digital platform is implemented that combines system documentation and mobile maintenance apps with hydraulic simulation and analysis tools for measurement data. The software is tailored to small and medium sized utilities that usually do not have specialized academic staff for asset management and hydraulic system analysis. The objective is to provide a tool that is simple in its application and assists in the daily work of the network operators. This implies different challenges for the development:

- Compact and easy to use UI (User Interface)
- Definition of standard processes
- Efficient interfaces for model integration (hydraulic simulation with GIS and sensor data).

In the following chapter the four columns of the project, namely documentation and GIS, hydraulic simulation, data analysis and training, are briefly summarized.

METHODOLOGY

Central platform and GIS:

By mean of a GIS, information of objects with a geographic spatial reference are linked. This allows arbitrarily complex data structures to be clearly represented. Unfortunately, the digital database at water supply companies is often only inadequately maintained. Therefore, the potential of a GIS for documentation, monitoring, simulation, asset management and rehabilitation is often not exhausted. Mostly every division in a water utility uses different data systems tailored to different specific needs. These systems are usually maintained independently of each other, so that redundancies, gaps and inconsistencies are inevitable. The GIS system COSVega that is used in the project provides different modules, e.g., for water, gas, electricity, district heating and telecommunication networks. The data is stored in a central database server. As an open and flexibly configurable system, COSVega enables to dynamically connect from third-party databases, for example a link to the consumption data or to the SCADA system is possible. The presentation, visualization and evaluation of the entire database takes place in a web-based information system (see Figure 1). Here, authorized users can evaluate the effects of operations by playing through different scenarios that are interlinked with the hydraulic simulation module. For example, it can be visualized how pressures and flow velocities change, when closing certain shut-off valves. Central rights management regulates the access of the various user groups. Data can be sent on site by smartphone directly to the COSVega data server, including for example the documentation of maintenance measures, valve manipulations etc. As part of the W-Net 4.0 project, the integration of COSVega with the simulation platform SIR 3S® and the data analysis tools developed by Fraunhofer IOSB was realized.

Figure 1: Web based GIS platform with mobile maintenance apps and integrated hydraulic simulation

Hydraulic Simulation

Software products for hydraulic pipe network calculation are well known in drinking water utilities. The application ranges from simple steady-state calculations through extended period simulations to transient pressure surge calculations. If they are online connected with a SCADA system, simulation tools also allow the continuous monitoring of the entire pipe network, the detection and localization of leaks and operational optimization in near real-time.

The validity of the model calculations depends crucially on the quality of the underlying data – for planning, operation and asset management. So far, the data are transferred in a complex and time-consuming process from different data sources about the network (e.g. from GIS, NIS, analogue plans, ALKIS, consumption billing, digital elevation models) and other operational information (pumping stations, water storage facilities, etc). At the end of the process calibration and validation of the model is done, based on a carefully planned measurement program. Currently, one of the major problems is that the model requires regular updates as far as the network changes, a process that is time consuming and expensive. Particularly, smaller water suppliers can often not afford the initial creation and maintenance of a model.

As part of W-Net 4.0 a uniform database is created that is also the basis for the hydraulic simulations. Simulation model updates are therefore no longer required. Based on the continuously updated network, the quality of simulation calculations is highly increased since the model is always using actual data. Agreement with the real system is further secured, through constant comparison with real measurements.

The processing of hydraulic issues such as the evaluation of the effects of rehabilitation measures due to temporarily disruptions, or the connection of new network areas is thus immediately possible without further financial time and human effort for model creation or model update. Most of the functions can be operated directly from the GIS. Training in application of several user interfaces and software is thus no longer required. Simple calculations even can be done via mobile apps on field (e.g. to check the effects of valve closing). With a user friendly design interface also operators of smaller and medium-sized water supply companies can benefit from hydraulic simulations. In addition to being used as a planning and monitoring tool, the simulation model can also be used for training of staff at the water company.

Data analysis tools

High quality data analysis tools have been available for several years, both, as products (e.g. Matlab, SQL Data Analysis Tool) as well as freely available software (e.g. RapidMiner, Python libraries, Scilab). However, they have been used only to very small extend by small and medium water supply utilities. In W-Net 4.0 the data analysis tools are integrated with the GIS and presented by a comprehensive set of intuitive dash boards. The system checks also for violation of threshold values and, in case of, sends automatic warning messages by email. Once configured, the system is easy to handle for the water suppliers and does not require expert knowledge.

Training and services

The implementation of the digital platform is accompanied by a comprehensive framework for training and services. For this, a modular training concept has been developed. As a first step, a training analysis has been carried out for identifying the different prerequisites of the employees in the utilities. Based on the results, the modules for the theoretical and practical training content were designed.

It is important to mention that even staff with little IT skills can use the platform. Starting with the data acquisition and sensor technology used (e.g. pressure, flow rate, temperature, pH values, etc.) and ending with the simulation model, the aim of Water 4.0 is to make digitalisation in the water supply sector a reality, as it allows also small water utilities to participate.

The training modules consist of live seminars, where the trainees get a brief introduction in the theoretical background and the technical rules, followed by practical training using the platform. For a deeper knowledge, the platform includes an E-Learning module with more detailed explanations and practical exercises. The development of the platform and the training courses is almost finalized. First training courses already took place, and the feedback of the attendees has been used for modifications and improvements.

RESULTS AND DISCUSSION

Four use cases were defined in the W-Net 4.0 project as examples of small and medium-sized water suppliers: Bühl, Messkirch, Nagold and Glatten (all located in the south-west of Germany – Black Forest region).

Use Case 1: Provision of fire-fighting water. In case of a fire, water can be taken from the public drinking water supply network. Using the hydraulic model, a simulation shows the effects of withdrawing water from the network hydrants, answering the following questions:

- Is there enough firefighting water available?
- How much water can be taken from the hydrant by maintaining the minimum pressure requirement in the whole system?
- What is the effect of using multiple hydrants?

Appropriate measures can then be derived from the results; in addition, the capacity of the network for taking water for firefighting can be checked at any time. Building law requirements of the municipality can also be derived from the results (Ripl and Deuerlein 2017).

Use Case 2: Switching operations in the network. In the case of operational changes in the transport and distribution network, individual pipes or even larger supply areas may be shut off by closing gate valves. A simulation model can be used to simulate the effects of a planned measure. In addition, it can be checked whether or which consumers will be affected. The simulation also makes it possible to analyse necessary relocations due to construction measures.

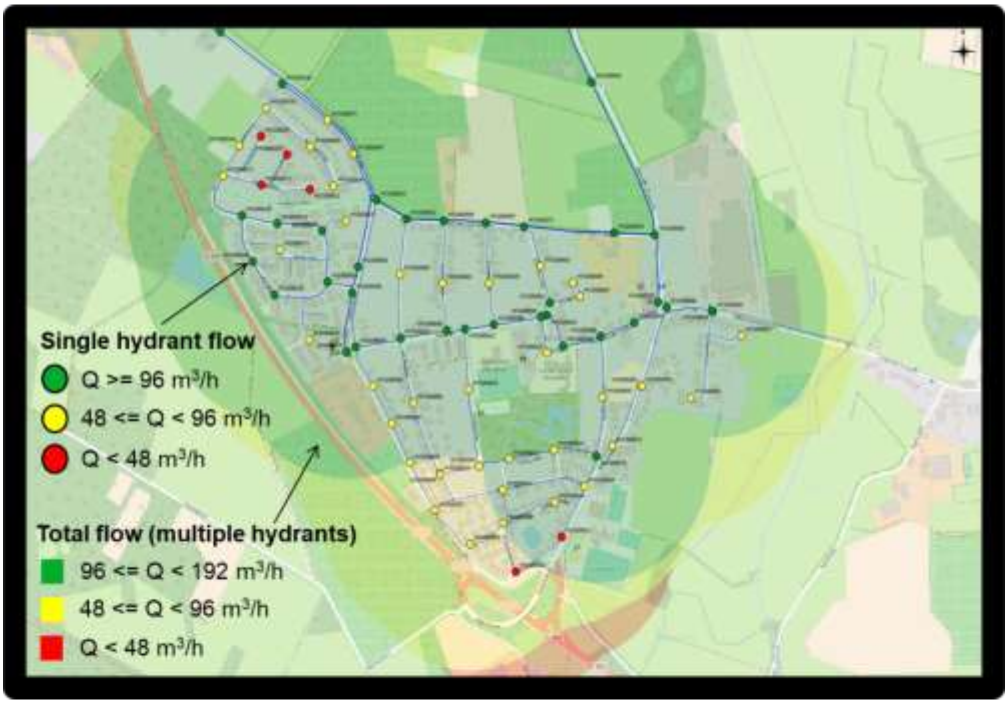

Figure 2: Result of fire flow calculation based on DVGW W 405 (2008)

Use Case 3: Expansion of the settlement area and development of commercial areas: Any type of new development, structural densification and changes in land use result in a change in the demand on the supply networks. By use of mathematical optimization (here: Linear Programming, Cembrowicz (1988)) the optimal design of pipe diameters by maintaining a defined minimum supply pressure can be calculated (see Figure 3). In addition, simulation can be used to quickly determine the impact of major measures in the network, such as enlargement or decommissioning of storage facilities. By means of the rehabilitation planning tool, it is possible to plan and to prioritise the corresponding investment measures and to evaluate their performance.

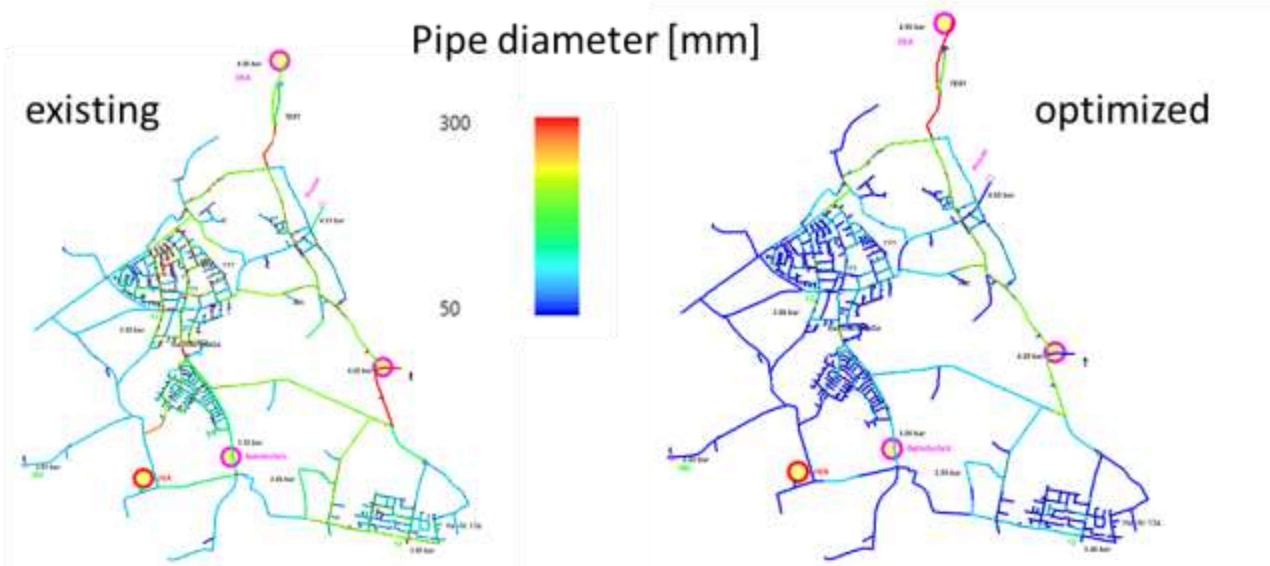

Figure 3: Result of diameter optimization using Linear Programming

Use Case 4: Water losses and leakages. To record water losses, the network is divided into district metered areas (DMAs). The DMAs are equipped with suitable measuring devices. By balancing the amount of water transported into the zone, the consumption and the amount of water flowing out of the zone, it can be calculated whether there is a leakage. Continuous leakage monitoring is to be investigated, i.e. software-supported loss monitoring with pressure and flow measurement in the pipe network (Steffelbauer et al. 2022).

CONCLUSIONS

The project has been applied and tested for four use case partners from the Black Forest region in Germany. The small to medium water utilities supply from 2.000 to 30.000 people and industry with drinking water.

The W-Net 4.0 platform will be commercialized after concluding the project by leadership of the SchwarzwaldWASSER Gmbh. The other partners (COS, 3S and FhG-IOSB) provide the required software tools and maintenance. In addition, the service includes a comprehensive package of IT- and engineering services that can be considered by the utilities on demand.

It is expected that with this platform and concept also the smaller utilities can achieve the necessary steps forward towards digitalization. One of the major economic benefits is that the users can share the cost for hardware and software. There is no need for server installations at the side of the clients. The central platform will be provided by the main contractor. In terms of technical innovations, the next step will be to connect the simulator with online data from the SCADA system for providing fully automatized real-time simulations of the current state of the system. The information gained from the system can be efficiently used for rehabilitation planning and next generation asset management.

ACKNOWLEDGEMENTS

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Enhanced mainstream anammox nitrogen removal by switching main flow with sidestream at extensively long time intervals

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Abstract
During more than 2 years, single- reactor mainstream wastewater (municipal wastewater at 16.5 °C) treatment was performed by switching wastewater flows after 8 weeks with side stream (reject water at >22 °C) to sustain anaerobic ammonium oxidation (anammox) biomass activity benefitting from side stream, as latter contains anammox bacteria and relatively low organic carbon/N ratio of 1.6/1. Experiments in a 20 L moving bed biofilm reactor (MBBR) and batch- scale were performed to evaluate the optimum concentrations of organic carbon on anammox process to perform the autotrophic nitrogen removal for the biomass enriched on ring- shaped biofilm carriers. Loss of anammox bacterial activity at lower temperatures and higher organic contents needs to be studied to perform mainstream anammox at extended cycles (8 weeks). Real side stream wastewater (biogas plant effluent) (≈1200 mg NH_4^+ -N L^{-1}) and synthetic mainstream (municipal wastewater-like source) (≈80 mg NH_4^+ -N L^{-1}) wastewater were used for reactor feeding. The highest total nitrogen removal rate (TNRR) of 530 g N m^{-3} d^{-1} (average TNRR 180 (±140) g N m^{-3} d^{-1}) was achieved with side stream at a low chemical oxygen demand (COD)/TN ratio of 1.1/1. COD/N ratio of 3.2/1 was maintained for mainstream. The maximum TNRR in a batch test was achieved at the COD concentration of 480 mg L^{-1}, showing a TNRR of ≈ 5 mg N g^{-1} TSS h^{-1}. With a highest COD concentration of 2600 mg L^{-1} (TOC/TN=8/1), TNRR decreased similarly in both feeds to 1.6 mg N g^{-1} TSS h^{-1}. Among anammox microorganism's genuses relative abundance, Candidatus Brocadia enrichment in deammonification biofilm reactor was elevated at mainstream feeding (constituting 7.6 % of all bacteria) compared with side stream feeding (<0.7 % out of all species). Planctomycetes abundance was slightly higher in side stream compared to mainstream feed (5% and 4%, respectively).

Keywords
Specific anammox activity; biofilm; reject water

INTRODUCTION
Ammonium-rich waste streams with a high biodegradable C to N ratio are produced in different industrial, landfilling and municipal waste handling systems (Van Hulle et al., 2010). In some of them, like anaerobic digestion tank, it contains high nitrogen and low organic carbon concentrations (COD/TN ratio ≤ 1) suitable for anaerobic ammonium oxidation (anammox) process. Various anammox process setups have been applied for treatment of side stream wastewater (Zekker et al., 2014), but the process application for municipal wastewater (mainstream) (COD/TN ratio > 1) treatment has not been applied often as the volumes that needs to be treated are 90% higher than for sidestream and process efficiencies are limited. Nitrogen removal rate drops from 0.465 kg N $m^{-3}d^{-1}$ at 29 ºC to 0.046 kg N $m^{-3}d^{-1}$ at 12.5 ºC in a system using domestic wastewater has been detected (Laureni et al., 2015).

Aims of current work are to find ways how overcome these issues is the periodic switching (8 weeks) of biomass between warmer side stream and colder mainstream reactors. The ways how anammox bacteria can have recuperation time in low TOC/TN ratios and high temperature side stream treatment phase were observed.

METHODOLOGY
A plexiglass reactor with a 20 L liquid volume, being equipped with a water jacket was used for the enrichment of anammox microorganisms at constant temperatures (24.0±0.5°C for side stream and 15.0±0.5°C for mainstream). Anammox biofilm was developed onto the surface of biofilm carriers made of polyethylene (Bioflow 9, Aquamyc, (RVT Process Equipment GmbH) Germany) by creating continuous flow-through conditions of anaerobic tank reject water ($NH4^+$ source). The carriers

(specific surface ≈800 m^2 m^{-3}) occupied about 50% of the liquid volume of the reactor (constituting a total surface area of 1.78 m2). Periods with mainstream feeding at low nutrients concentration of 80 mg $NH4^+$-N L^{-1} (mainstream) lasted 8 weeks, followed by 8 weeks at high nutrients concentration of ≈1200 mg $NH4^+$ -N L^{-1} from real reject water (side stream). Effluent pH in the system was in range 7.16 (±0.65) and 7.37 (±1.25) for the operation of mainstream and side stream, respectively. DO was controlled by DO controller at range up to 1.5 mg L^{-1}, after that value controller switched off aeration in aerobic phase (55 min aeration phase out of 60 min total cycle duration).

The reactor's TNLR and TNRR were calculated based on feed flow rate, influent and effluent ammonium, nitrite, and nitrate parameters, and carriers' total specific area/reactor volume present. Flow rate of the feed varied during reactor operation from 4.67 to 14.5 L d^{-1}. DO, TSS concentration, pH, and temperature were also registered. A set of batch assays were conducted to study the effect of various TOC concentrations effect on the specific anammox activity (SAA). Thermostated chamber maintained the temperature at 24 (±0.5°C).

RESULTS AND DISCUSSION

Performance of biofilm reactor with mainstream wastewater depending on influent TN/influent COD ratio at 16.5±3.5°C resulted in the maximum TNRR of 61 g N $m^{-3}d^{-1}$ (Fig. 1, Fig. 2). Average TNRR achieved for side stream wastewater treatment was 180 (±140) g N $m^{-3}d^{-1}$ and for mainstream 20 (±15) g N $m^{-3}d^{-1}$. The average COD/TN ratio for mainstream was more than twice higher than for side stream operation: 3.2/1 (±1.9/1) and 1.1/1 (±0.72/1), respectively.

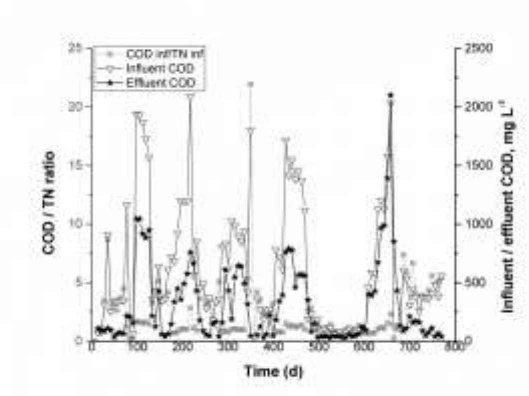

Figure 1: Influent COD/influent TN ratios, influent and effluent COD concentrations during mainstream and sidestream MBBR operation

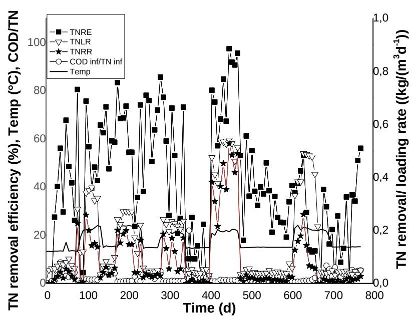

Figure 2: 8 week cycles of COD/influent TN ratios, TNREs, TNLRs TNRRs during mainstream and sidestream MBBR operation days depending on temperature

Most efficient specific TNRR in batch test was achieved for biomass taken during mainstream operation period at a low COD concentration of 480 mg L^{-1}, reflecting a specific TNRR of ≈ 4.9 mg N g^{-1} TSS h^{-1}. At higher COD concentrations, the results with mainstream period biofilm surpassed side stream TNRRs – the specific TNRRs achieved were 1.65 mg N g^{-1} TSS h^{-1} (COD concentration of ~2650 mg L^{-1}) and 0.7 mg N g^{-1} TSS h^{-1} (COD concentration of ~2550 mg L^{-1}), respectively.
Our results show that similarly to high COD/TN ratios, the TOC/TN ratios increased over 3/1 affect the TNRR negatively (Fig. 2). High COD concentration affected nutrient components utilization balance (Fig. 3) and moreover, a high COD/TN ratio held at long period (8 weeks), may enhance heterotrophic denitrifiers activity and results in a shift of the composition of microbial consortia towards decreasing anammox bacteria relative abundance (Fig. 4).

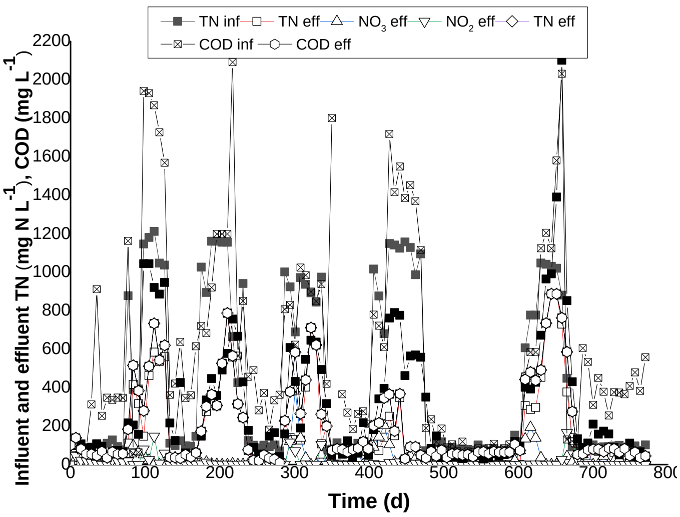

Figure 3: 8-week cycles of Influent and effluent TN and COD forms concentrations during mainstream and sidestream MBBR operation days.

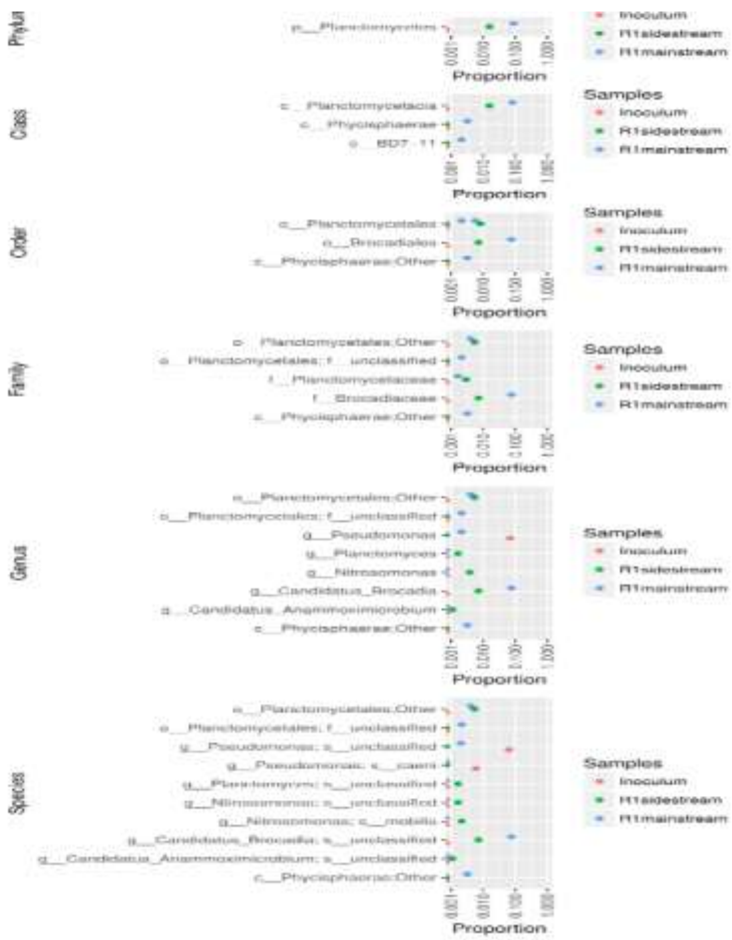

Figure 4: Relative bacterial abundances of Planctomycetes, denitrifiers and nitrifiers communities during mainstream and sidestream operation and in the *inoculum* (reject water).

But, according to microbial analyses, anammox quantities were determined to be higher in case of mainstream treatment as compared to side stream treatment (Fig. 4). Similarly, high specific TNRRs were achieved in the batch tests depending on the TOC/TN ratio: for the TOC/TN ratio 1/1 – 3/1, the specific TNRR was ≈ 5 mg N g^{-1} TSS h^{-1} for the biomass taken during mainstream and side stream period. When TOC/TN ratio was 4/1, specific TNRRs were ≈ 4 and 3 mg N g^{-1} TSS h^{-1}, for the biomass taken during side stream and mainstream, respectively.

CONCLUSIONS

The aim of the paper was to investigate how the biofilm reactors feed switching between mainstream and side stream at extended periods (8 weeks) affects autotrophic nitrogen removal. The results showed how low temperatures and low organic carbon diminished efficiency of the process, which was faster boosted once side stream conditions were re-sustained. Based on the performed experiments, it can be concluded that nitrogen removal occurs at the treatment of the mainstream, both through denitrification and the anammox process. The longer duration of the low loading at low temperature will start to affect the activity of anammox bacteria, which are becoming increasingly diminishing due to the low optimization temperature. The high organic matter content of the mainstream is much more suitable for denitrification bacteria, because heterotrophic bacteria can operate more efficiently in such an environment. The effects of organic carbon were examined on anammox biofilms in a MBBR system. Earlier detected Anammox bacterium clone P4 was closely (99%) related to "Candidatus Brocadia fulgida", in congruence with the Candidatus Kuenenia" strains and was detected from reactor samples in mainstream and side stream period.

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Chances and barriers of Building Information Modelling in sewer Asset Management

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Abstract
The advancing digitalisation is one of the great challenges of our times. Related activities also concern the (waste-)water sector. One emerging approach is building information modelling (BIM). The presented work investigates, to which extend BIM practices have already found their way to the sector, and what kind of benefits and constraints are incorporated. Information is collected by means of literature review and international expert surveys. Preliminary results indicate that several digital technics are already well established in sewer asset management. However, data management and interdisciplinary planning approaches still could be improved. Consequently, the (preliminary) assumption can be made, that the BIM approach could certainly play a supporting role in wastewater management.

Keywords
Data management, digitalisation, digital twin, geographic information system, integrated planning, sewer operation and maintenance

INTRODUCTION

Digital technologies and the related digitalisation of our life is on the advance worldwide. To cope with the upcoming challenges of digital transformation, the European Union has declared the current time horizon until 2030 as Europe's Digital Decade (European Commission, s. a.). The strategy evolves around four core aspects: government, business, skills, and infrastructures. In this context, the International Water Association has also launched a Digital Water Programme, which aims at supporting the water sector on the journey towards digital uptake and implementation (IWA, s. a.). In the field of building construction, the application of Building Information Modelling (BIM) has been evolving in recent years. The BIM concept is based on a continuous elaboration and utilisation of a digital representation of a specific building asset and aims at the integration of all relevant professions fields (actors) during the entire life span of the related construction (planning, construction, operation and maintenance, and demolition). Basically, the political will to further introduce this approach is apparent (EU BIM task group, s. a.), in certain countries around the world BIM application is even already mandatory, at least for public buildings. However, in regard to the underground infrastructure this methodological approach still seems not very common today, although, digital applications are not new to the concerned fields (application of geographic information system, hydraulic modelling, etc.). Also (continuous) data collection is already rather wide spread, addressing both, static and dynamic information (inventory and operation & maintenance).
To cast more light on this issue, the presented work investigates, (1) to which extend BIM-approaches might have already been introduced to the wastewater (sewer) sector (possibly under different terms), and (2) what chances and barriers are related to the practical implementation of the BIM approach in sewer asset management.

METHODS

Information in regard to the current distribution on BIM in sewer asset management will be collected in two ways: On the one hand, by means of literature review. On the other hand, by (national and international) expert surveys. The latter are based on already existing protocols from interviews with 5 Austrian national experts from different professions fields (civil engineers and utility operators) presented by Kammerlander and Ladinig (2018). In the current work, a content analysis of these protocols was made to derive core concerns in regard to BIM in wastewater management in general, and in sewer asset management in particular. In the following, the results of the content analysis are used to elaborate a new questionnaire serving as a guiding document for a second round of expert interviews. These surveys, which have just started, will be carried out in an international context. Finally, the outcomes (contents) of the new interrogations will be reconciled with the results of the ongoing literature review to derive conclusive information on the current state of BIM application in the field of wastewater (sewer asset) management and the related chances and barriers of practical implementation.

PRELIMINARY RESULTS AND DISCUSSION

First results already indicate, that certain aspects of the BIM approach have already found their way into modern sewer assets management. This concern, above all, the digital mapping/representation of sewer networks in database software and/or 3D-models (geographical information systems, hydraulic models), not only including the location of the different segments but also their specific constructional and even operational condition/characteristics. Consequently, this “as built” information provides an appropriate foundation for the elaboration of “digital twins” for sewer system management. However, improvement opportunities in regard to current data management practice might be found in the fact, that today’s data storage often takes place in “silos”, from where it is difficult to share with other disciplines and/or project partners. A continuous, database centred workflow (“one-stop-shop”) through the entire lifespan of the different assets still shows great optimisation potential. In regard to sewer cleaning and inspection activities this approach already seems more evolved compared to sewer rehabilitation planning.

The integrated and interdisciplinary working approach in terms of common data environments and collaboration formats can be considered as another core feature of the BIM approach. In this regard, interdisciplinary cooperation between the different stakeholders sharing their common underground space certainly can be improved as well.

So far, collected concerns and preconceptions in regard to practical BIM application primarily refer to an expected increase of workload and costs, possible interface malfunctions between established and new software products, the generation of “data graveyards”, as well as not seeing an obvious benefit in comparison with recent work practice. Furthermore, one of the main benefits in planning and construction of buildings, the preview and prevention of collisions of different working tasks in time and space seems not to play an important role in sewer construction but only for pumping stations and wastewater treatment plants. The reason might be found in the fact the latter involve different working/professional fields as for instance construction, mechanical, and electrical engineering. Concluding, the application of BIM at wastewater treatment plants and pumping stations is perceived more suitable than it appears for sewer systems, at least at the current stage of our research work.

CONCLUSIONS

Digitalisation is advancing in several fields, also concerning the water sector. In the context of building construction, the evolvement of the BIM approach, which involves the application of digital twins and interdisciplinary collaboration during the entire lifespan of a structure, is gaining in importance. The management of underground infrastructure, referring to sewer asset management in the context of this article, already applies different digital technologies and related approaches. Hereby, the question arises, whether the BIM approach could also be an option in this field. First investigations reveal, that certain BIM related aspects have already found their way to the current practice of sewer asset management (towards the application of digital twins). However, other points, as for instance the introduction of more collaborative working concepts, still would deserve further attention. Emerging approaches as for instance the smart city concept incorporate high(er) degrees of complexity, in regard to data management and interdisciplinary collaboration. The BIM approach could provide a solid basis for future (co-)working concepts. Although, the current practice of overground management would certainly require some adaption to the underground environment. Existing concerns and preconceptions appear comprehensible. They can be overcome with good/best practice examples as well as with stakeholder education and knowledge building. This includes additional research efforts in both fields, (sanitary) engineering and social sciences. This article shall contribute to this goal by stimulating additional research work in regard to BIM and sewer asset management.

ACKNOWLEDGMENT
This article is based on the (ongoing) master's thesis of the second author quoted as Franziskowsi (under preparation) in the References section below.

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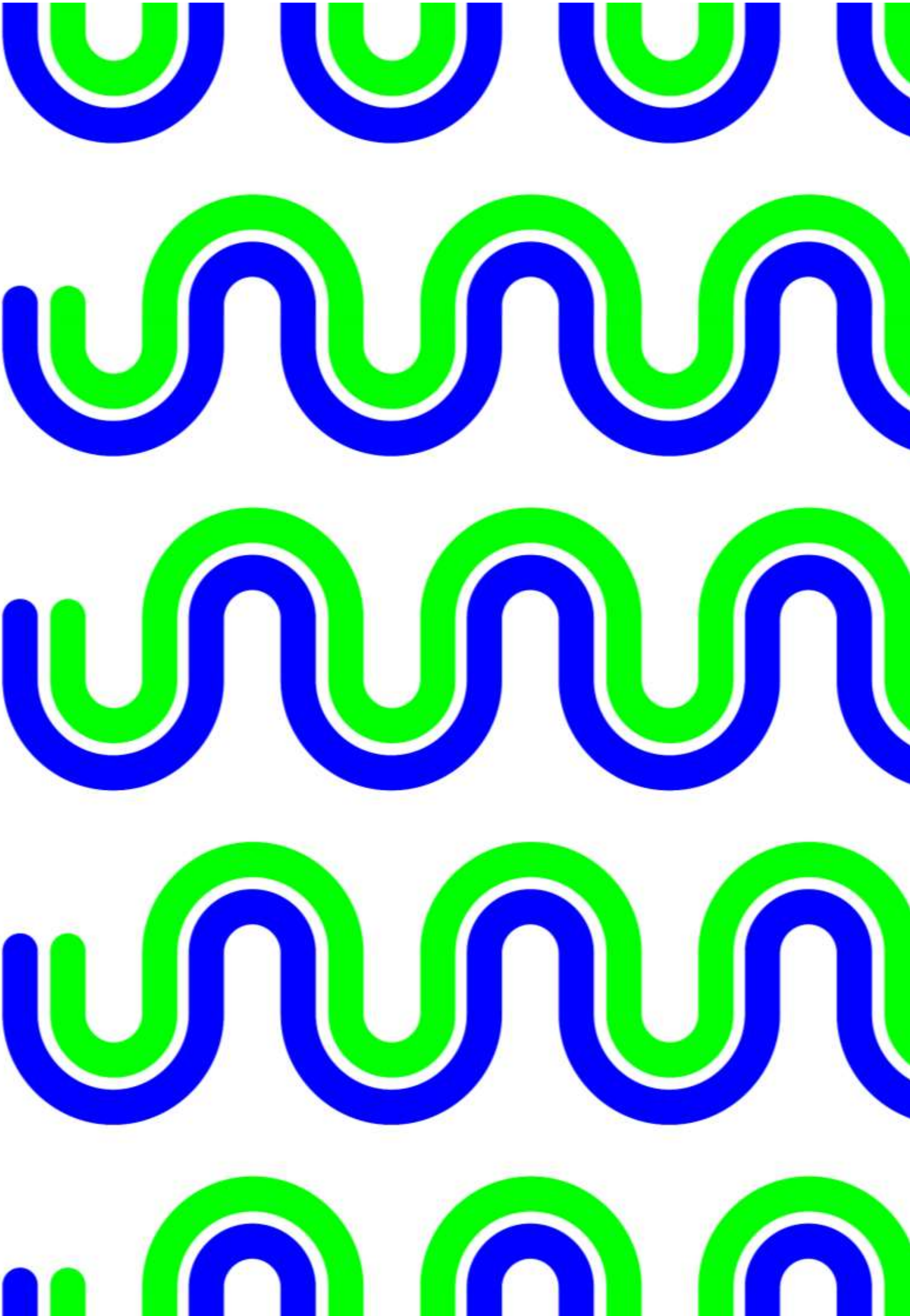

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