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W-NET4.0 – INTEGRATED PLATFORM FOR SMALL AND MEDIUM SIZED WATER SUPPLY UTILITIES

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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, measurement data is usually not collected systematically. In addition, the companies often have neither a sufficiently well-maintained database of the water network nor geoinformation systems (GIS), 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). Large water suppliers are often better equipped technically, but the data is often not used in an efficient manner.

The objective of the W-Net 4.0 research project (www.wnet40.de) was to develop 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. The high degree of usability and accessibility of the platform supports the daily work of planning engineers, and network operators. The paper includes a detailed description of the platform and use cases. It also emphasizes the training program tailored for small and medium sized utilities.

Keywords
Integration, platform, GIS, simulation, digital twin, monitoring, dashboard, training, e-learning.

1 INTRODUCTION

Successful management of drinking water supply systems depends highly on the availability and quality of data describing the system and its operation. During the last decades sophisticated software tools for hydraulic network simulation, planning and management have been developed and are widely used by researchers and practitioners. However, the successful application of these models to solve real world systems requires sufficient information and data from the real system, which is often not available. The creation of a hydraulic simulation model is very often a tedious and time-consuming task with several remaining open questions at the end of the process. In this paper a holistic approach will be presented that places an emphasis on data acquisition, data management and sharing of data between different processes and that is tailored to the specific needs of small and medium sized water supply utilities.

One of the main problems in data collection and processing, especially for small water utilities, is that they do not know the actual condition of their water distribution systems [1,2]. The lack of data collection or the inadequate documentation are the result of the following deficiencies:

- The documentation within a pipeline network cadastre (GIS) and a regular data updating often do not take place. In the case of small water utilities, digital information about the pipe system (location, material, year of installation) is often missing and network maps, if available, only exist as analogous print outs from the time the network was built.
- Pipeline damages and maintenance measures are often not documented, so that failure statistics (necessary for forecasting rehabilitation measures as part of a modern asset management) cannot be kept.
- The amount and development of water losses are often not known, so that a water balance cannot be drawn up.
- After a significant change in the water consumption (e.g. after the expansion of the network or the connection of new large-scale consumers), the hydraulic capacity of the water distribution system is usually not verified.
- If available, operational data recorded using SCADA systems is usually not visualized and analysed adequately for achieving a better understanding of the real system behaviour.

Another decisive factor for a successful water system management are the human resources. Especially small and medium sized water suppliers are facing difficulties in acquiring adequate staff. As an example, the analysis of the small water utilities in Bavaria, Germany, revealed that the main challenge for the water utilities rely mainly on the lack of qualified personnel [3].

For improving the situation, the SchwarzwaldWASSER e.V. Cooperation Association was founded in 2008 in the southwest of Germany, the region of the Black Forest. It has roughly 60 members and serves as a strategic partner for small and medium sized communal water supply utilities. It bundles different kind of technical and commercial services for its members including lab testing for ensuring drinking water quality and engineering consultancy. SchwarzwaldWASSER e.V. also provides a platform for exchange of experience and knowledge, for example by regular meetings. In recent years, one technological focus has been on the digitization in water supply.

In this context, the R&D project W-Net 4.0 was initiated with the objective of making digitization and industry 4.0 technologies available also to small and medium sized water supply utilities. The idea is to provide a common central platform to the members so that they can share not only their knowledge but also hardware and specialized software tools that are tailored to their specific needs. Using the same digital platform instead of implementing individual solutions reduces cost and supports a lively exchange between the members. The project consortium of the R&D project W-Net 4.0 consists, besides SchwarzwaldWASSER, of the two SMEs (COS Geoinformatik: GIS software and services and 3S Consult: hydraulic simulation software and services), the Fraunhofer Research Institute ISOB and four end-users as associate partners.

Within the project, an integrated digital platform for improving the documentation and operational processes in water utilities was developed and implemented. It combines system documentation and mobile maintenance apps with hydraulic simulation and analysis tools for measurement data [4]. It can be understood as a first step towards the implementation of a digital twin of the water distribution system keeping in mind that there exist numerous definitions for a digital twin. In the context of W-Net 4.0, the platform contains a virtual model of the real physical system with all its properties that are necessary for network maintenance and operation. So far, the data flow is mostly one way from the physical system to the model, so that also the term Digital

Shadow may be used. However, in future development steps also interactions from the virtual to the real world are foreseen. That is why the term Digital Twin is used. For a detailed discussion about the differences between the two concepts see for example [5, 6].

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 of the project is to provide a tool that is simple in its application and can assist the network operators on their daily work on site.

The W-Net4.0 platform includes:

- a compact and user-friendly User Interface (UI)
- a complete definition of the standard processes
- efficient interfaces for model integration (GIS, hydraulic simulation, and sensor data analysis).

The project aims at increasing the attractivity of the jobs in water supply utilities by introducing modern digital tools that simplify the work of the operators and continuously improve the data base and documentation capabilities of the utility. Examples include the mobile apps for documentation and for the implementation of digital failure statistics.

The W-Net4.0 approach also includes a comprehensive training for the operators based on a self-learning program, which includes theoretical background, the application of technical rules (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. For the training, a digital water distribution system model was created using data of a real water network. The model servers as training simulator and is available online.

In the following chapter the central platform is introduced, and its three main components are briefly summarized: 1) documentation and GIS; 2) GIS-integrated hydraulic simulation, 3) data analysis, with a clear focus on 2). Then, in the next chapter, the use cases defined by the end users of the project are briefly described followed by the final chapter on the developed training concept and services.

2 W-NET 4.0 CENTRAL PLATFORM

2.1 Overview

The W-Net 4.0 platform consists of the three main applications GIS, data analysis and hydraulic simulation. The data is stored in a central database that relates to the GIS construction tools and the web-based information system. The latter presents the most recent secured state of the data model. The web service component integrates the API (Application Programming Interface) of the hydraulic simulation engine and the data analysis tools for network monitoring and dashboard visualization of sensor data (see Figure 1).

In the following subsection the GIS is briefly outlined followed by a more detailed description of the GIS-integrated hydraulic simulation which is accessible by the web-based information system through the browser running on a personal computer or mobile devices such as tablets or smart phones. Also accessible via the web is the data analysis section of the platform that is presented in the subsequent subsection.

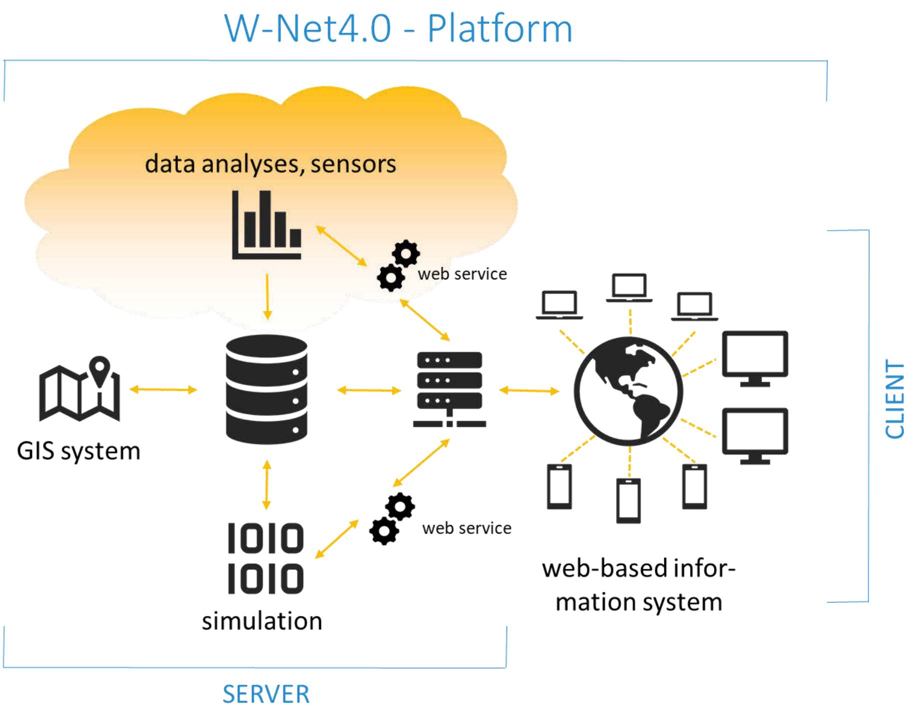

Figure 1. Components of the W-Net 4.0 digital platform

2.2 Geographic Information System

The GIS system that is used in the project provides numerous specialist modules, e.g., for water, gas, electricity, district heating and telecommunication networks. The data is stored in a central database server (Oracle). As an open and flexibly configurable system it enables to dynamically connect data from third-party databases, for example the consumption data or real time data from the SCADA system.

The presentation, visualization and evaluation of the entire database takes place in a web-based information system (see Figure 2). Here, authorized users can evaluate also the effects of operations by playing through scenarios that are interlinked with the hydraulic simulation module; for example, 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 via the web to the data server including for example the documentation of maintenance measures, valve manipulations etc.

Data collection via app with mobile devices is integrated into the data flow of the W-Net4.0 platform, from the water system on site to the simulation. The information flows automatically into the databases of the W-Net 4.0 platform, where it is processed further. The water utility's staff can handle a variety of tasks with these easy-to-use apps, such as recording maintenance measures for the plants and transmitting newly detected leaks, damages, valve position changes that are important for the simulation and much more.

As part of the W-Net 4.0 project, the integration of the GIS software COSVega with the simulation platform SIR 3S® and the data analysis tools developed by Fraunhofer IOSB has been realized.

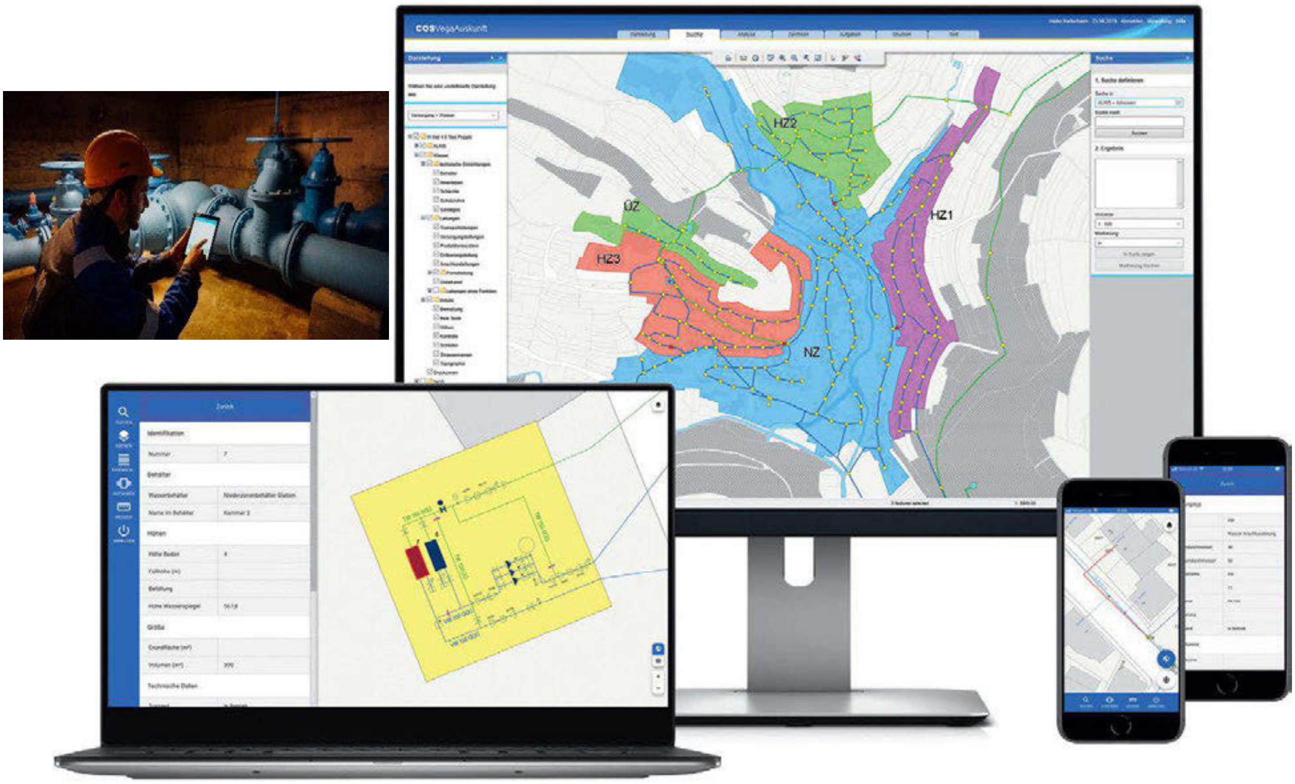

Figure 2: Web-based GIS platform with mobile maintenance apps and integrated hydraulic simulation

2.3 GIS-Integrated Hydraulic Simulation (HS)

The web-platform also provides modules for the hydraulic simulation of the water distribution system. The traditional way of creating a hydraulic simulation model is to collect data from different sources (GIS, Consumption billing, Digital Elevation Model, …) and to compile it into a consistent model. To enhance this process different interfaces have been developed by the provider of hydraulic simulation software. With their help data can be automatically imported in the simulation model. However, this process is one way in nature, without any automatic feedback to the GIS data source about the quality of the data. In most cases the data that is imported is insufficient for hydraulic network calculations because of incompleteness, topological errors, data errors, missing data, wrong data types etc.

In W-Net 4.0 the import of data is replaced by so-called model data integration of GIS and hydraulic simulation. There is a continuous connection between the two data models while each of them maintaining its individual structure. This allows data exchange in two directions. From both sides, GIS and HS, an agreement was made on the properties of an exchange database that includes the most important properties of the network and its operation. The exchange database is the minimal compromise of data that are relevant for hydraulic modelling. For implementation of the two-directional data integration with the exchange database both sides, GIS and HS, had to develop their individual interpreters (see Figure 3).

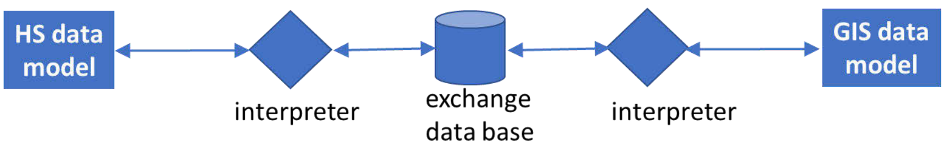

Figure 3: Model data integration of GIS data with Hydraulic Simulation data

The GIS data model includes all the information required for running steady-state calculations. Since pipe systems of public water supply utilities are dynamic systems, the properties of their components are continuously changing. The changes may be caused by construction work, new consumer connections, pipe removal or rehabilitation, valve operations etc. To maintain the integrity of the model a defined state is frozen and disconnected from the construction platform. When the constructions are closed and have reached another defined state, the frozen model is replaced by an updated version. This continuous process guarantees, on the one hand, that always a calculable model is available in the web information system. On the other hand, the intervals for model updates are short enough to represent the physical system adequately enough in the hydraulic simulation model.

The connection between the GIS information system and the hydraulic simulation software is realized by the integration of a newly developed API. In addition to the interpreter for model data integration, the API includes a model edit interface for inserting, updating, and deleting single network components. The model edit interface is used for scenario calculations. A scenario consists of the base model (current published frozen state of the GIS model) and a collection of selected data changes. The advantage of this approach is that the base model must be loaded only once at the beginning of the session. The scenario calculations require minimal data manipulations that are executed using the mode edit interface.

The management of the scenarios is part of the web information system. Any number of scenarios can be created by the user. Each scenario includes a list of actions that distinguish it from the base model. For the hydraulic calculation the scenarios can be combined with four predefined load cases: peak hour demand, fire flow calculation, average demand, and stagnation. Figure 4 shows a fire flow calculation scenario with the corresponding load case selected (ComboBox 1). The text box 2 includes a brief description of the measures (changes compared to the base model): hydrant opened, and valve closed. By pushing button 3 the hydraulic calculation is launched.

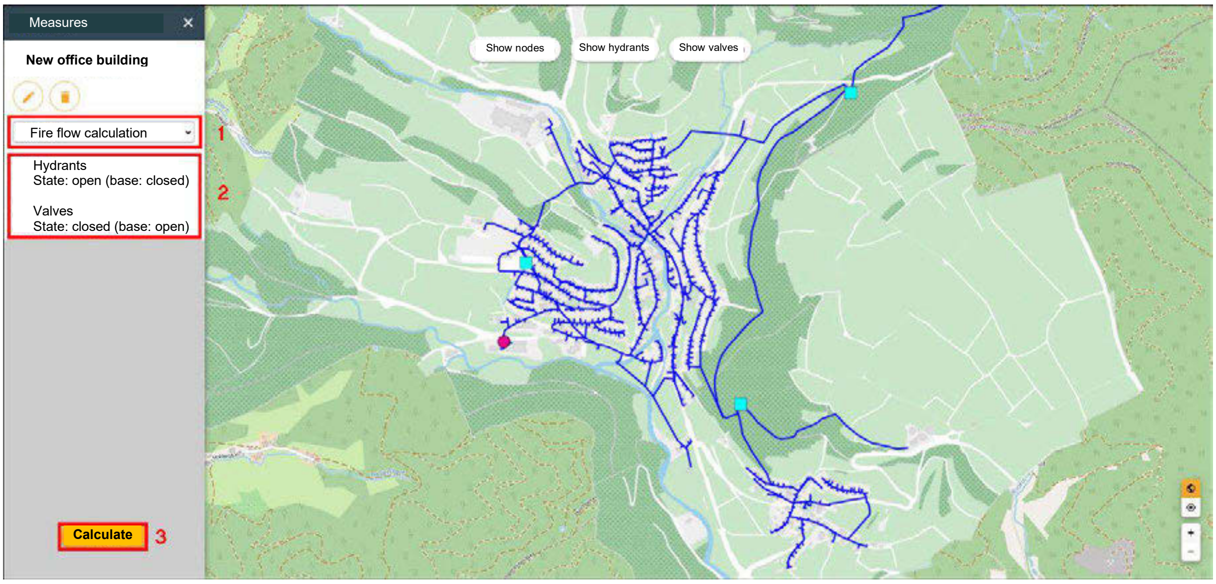

Figure 4: Web-based GIS platform with fire flow calculation scenario

The underlying GIS model distinguishes from other GIS in the fact that all the interior of pumping stations, storage tanks, valve chambers etc are also included in the model. Conventional GIS normally include the pipe system, end at the wall of buildings and exclude the interior of operational stations. In the W-Net 4.0 approach the GIS includes all data that is necessary for calcualting the hydraulic steatdy-state of the base model. No further adaptation is required in the hydraulic simulation engine. Figure 5 shows as an example the model of a storage tank with two chambers (1). The tank is supplied by the transport pipe on top (2). The inflow is controlled by a pressure sustaining valve (3) in order to maintain sufficient pressure in the upstream network. From the storage tank the water flows into the low pressure zone (4) and part of it is pumped to a high pressure zone (5). The pumping station consists of three parallel branches of series of valve (6), pump (7), check valve (8) and valve (9).

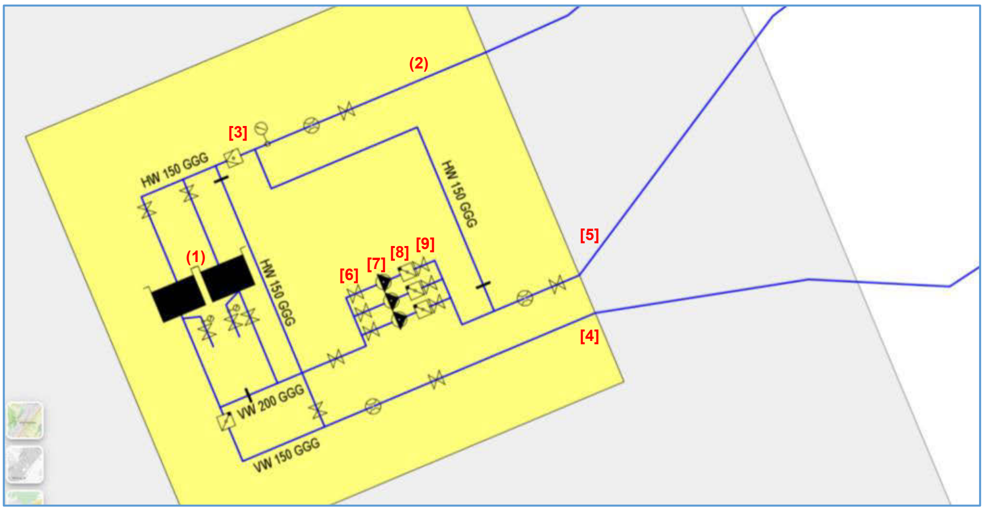

Figure 5: Interior of storage tank with two chambers, pressure sustaining valve and pumping station

After the hydraulic calculation the results are provided by the API of the simulation module through a memory data set that is accessible by the web information system. The results are presented by individual tool tips for the network components (nodes, pipes, valves, etc.) and by coloration of nodes and pipes (see Figure 6).

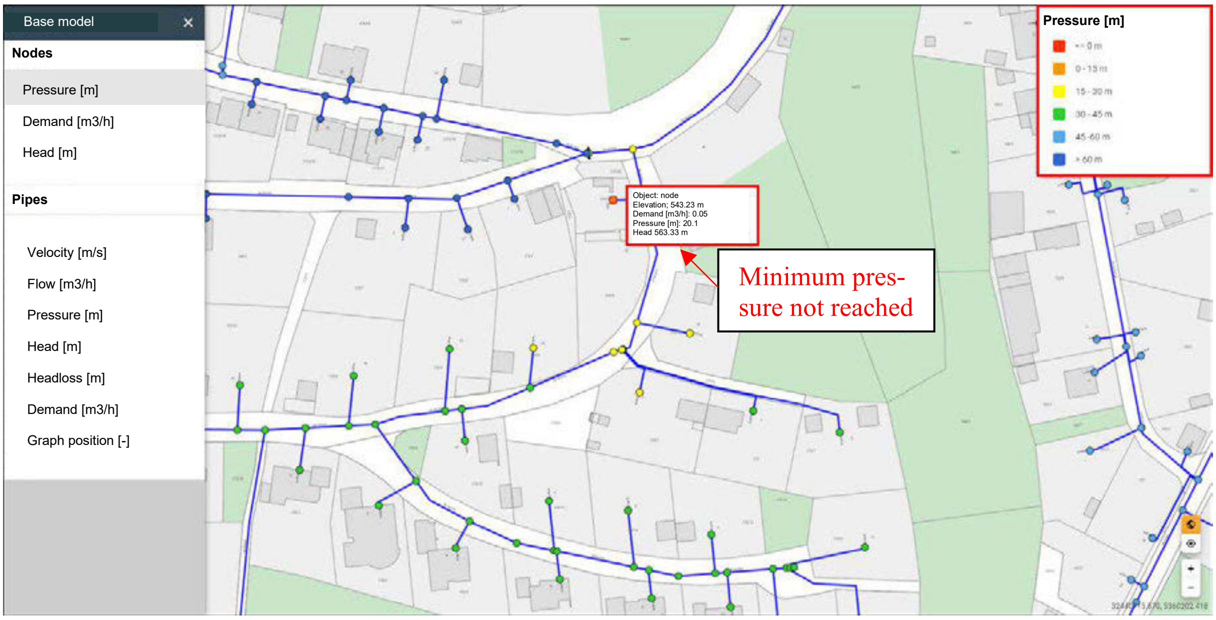

Figure 6: Calculation results for nodal pressures of fire flow calculation with violation of minimum pressure requirement of 1.5 bar at elevated demand node (DVGW W 405 [7])

For getting realistic simulation results that reflect the real system's behaviour, it is very important that the topology of the network is modelled correctly. In the simulation mode also the results of the decomposition of the network graph into looped blocks, bridges and forest [8] can be visualized. In Figure 7 the pipes at position 1 and 2 visually seem to be part of the looped network. Although they are signed as forest links. A more careful investigation shows that the pipes are disconnected (see Figure 8). The reason for the disconnection should be clarified: is it intentional and does it reflect the real system or is it a possible data error?

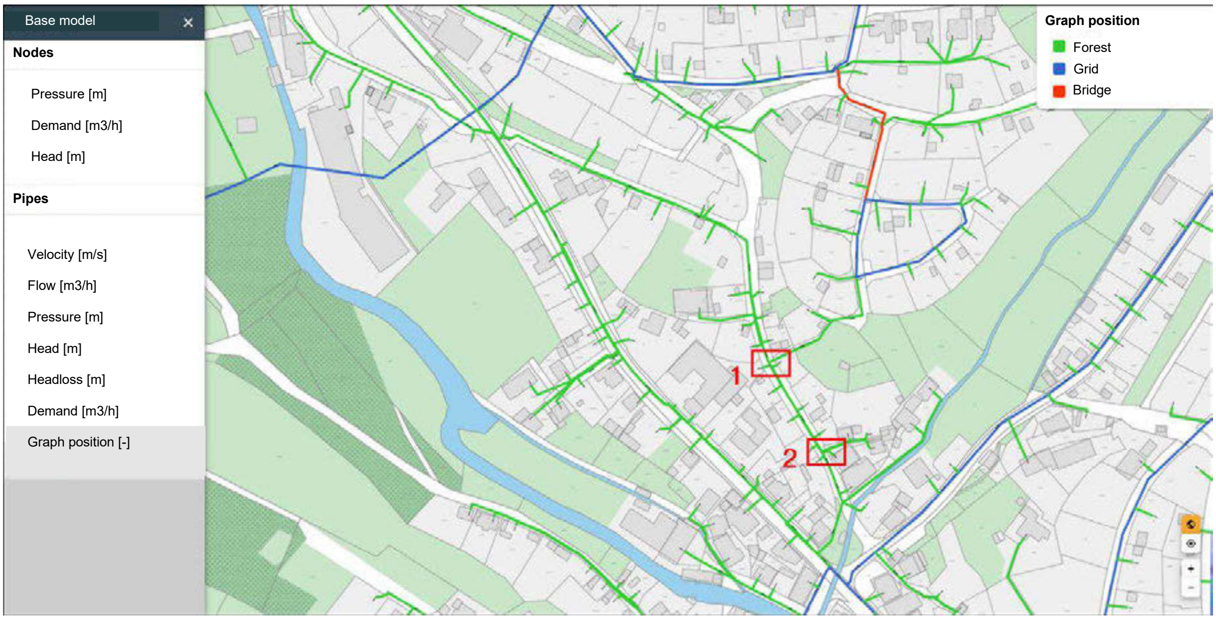

Figure 7: Graph decomposition with looped blocks (blue), bridges (red), forest (green)

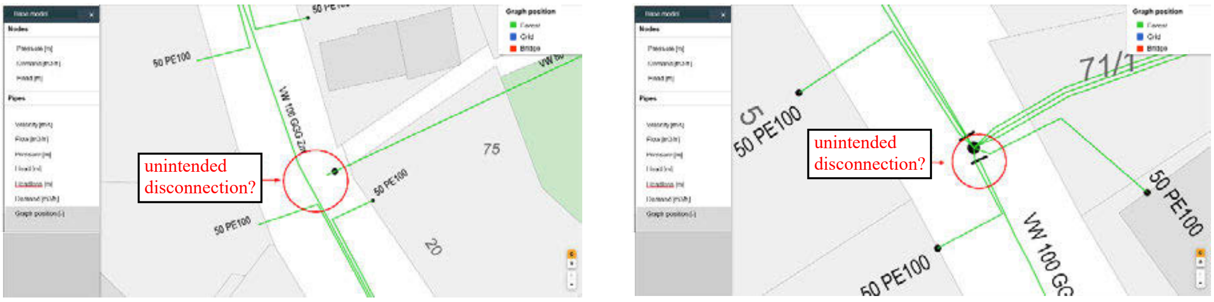

Figure 8: Possible sources of disconnection: distant node (left), valve closure (right)

2.4 Data analysis tools

High-quality data analysis tools have been offered for several years, both as commercial and as freely available software. However, small and medium-sized water utilities use them only to a very limited extent due to insufficient data collection. At large utilities, data platforms with sufficient measurement data are often available. However, there is a lack of specialized personnel to use analysis tools. Therefore, easy-to-use data analysis tools were developed in W-Net 4.0. The structure of the data analysis platform is shown in Figure 9. The individual areas are described briefly below (according to Figure 9 from left to right):

a) <u>Data transmission of the sensors/meters:</u> The sensors/meters installed in the network (or at the waterworks) usually transmit their measured data to a control system. Direct connection to a control system is often difficult. Therefore, the export of this data is often done by means of a cyclic filing (e.g., every 10 minutes) in a CSV (Column Separated Value) file on an FTPS (FTP over TLS or File Transfer Protocol over Transport Layer Security) sever or a cloud-based file repository. Data from retrofitted sensors is often stored in cloud solutions. From there, they can be retrieved via REST (Representational State Transfer) or MQTT (Message Queuing Telemetry Transport).

b) <u>Storage of all sensor/meter data in a common database</u>: The data is stored in a common time series database. In the project, InfluxDB has proven to be a very powerful time series database. Important here is the introduction of a suitable data model so that all essential properties of the measuring point are mapped (e. g. suitable location designation, measuring point name, physical quantity, physical unit).

c) Algorithm toolbox: By means of an algorithm toolbox, the data are suitably pre-processed (e. g. removal of outliers, resampling). Suitable key figures are calculated (e. g. minimum night flow value). Furthermore, based on the historical data, prognosis modules are learned, which allow a prediction of the flow in the network. An alarm tool allows to define simple threshold alarms as well as more complex alarms (e. g. linking of several measuring points; comparison of current sensor values with values from the past).

d) Transmission of results to the users: (1) Alarms: If an alarm occurs, the user is informed by e-mail. A meaningful plot of the measurement data and alarm threshold is sent along. The alarms are stored in an alarm database so that they can be subsequently evaluated at longer intervals. (2) Dashboards, Reports, Prediction Tools: The time series of the sensors/meters, the calculated metrics and predicted flows are visualized in clear browser-based dashboards. Monthly and annual reports are generated, which contain an overview of the most important sensors, key figures and alarms. (3) Coupling to GIS: The data analysis platform was linked to the GIS via a REST interface. The interface is used, for example, to transmit the alarms that have occurred to the GIS.

The realized data analysis platform was implemented and successfully tested in the project at three smaller water utilities.

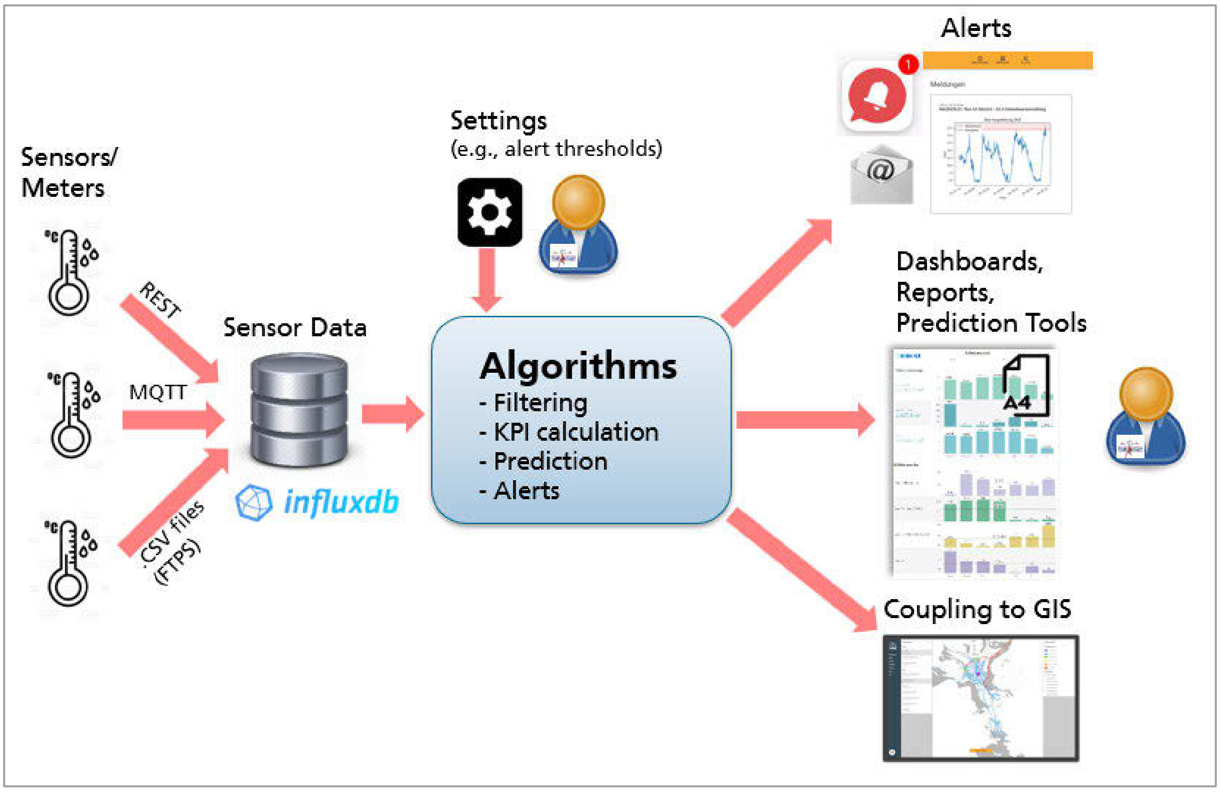

Figure 9: Structure of the data analysis platform

3 USE CASE APPLICATIONS

Five use cases have been defined by the end users, which are supposed to be the most relevant for small and medium sized water supply utilities. The integrated GIS and simulation platform was tailored to the use cases and specialized engineering services have been developed for assisting the utilities. As a general concept, simple calculations can be done by the operational staff using the information system's web services. The calculations can be carried out also in the field on tablet computers or mobile phones for supporting ad-hoc decisions. The solution of more complicated problems, comprehensive analysis and investigations are offered as engineering services. In contrast to conventional approaches where a simulation model must be built or at least updated in a time-consuming process, here, an up-to-date model always exists in the GIS, which is ready for instant use in the simulation software. The model that runs the steady-state calculations in the information system is the same that runs in the specialist software.

The benefits of the dual use approach are:

- no additional import or export of data is required for creation of the simulation model
- the GIS-web-application is not overloaded and tailored to the carefully identified needs of practitioners. It doesn't have to show up all the details and parameters that are required for in-depth investigations.
- Only few steps necessary for preparing the model for extended period, slow transient or water hammer calculations.
- Additional apps are available as plugins for the solution of use cases (fire flow app, diameter optimization app, supply reliability app). The plugin concept is designed for any additional extensions.

The five use cases defined in the project are summarized in the following table:

Table 1. W-Net 4.0 use cases and solutions provided by the new development

Use Case	**Web service (online modus)**	**Hydraulic Simulation (expert modus)**
1. Introduction to general network calculations	steady-state calculation	Steady-state and transient calculations
2. provision of firefighting water	capacity calculation for individual hydrants	App for automatized fire flow calculation of entire system
3. network operations	Steady-state behaviour of pumps, valves, control devices	Dynamic behaviour of pumps, valves, control devices
4. Expansion of the settlement area and new development of commercial areas	Manipulation of demands, what-if calculations	App for mathematical optimization of pipe diameters and pumps, reliability calculation, asset strategy
5. Water losses and leakage	Continuous monitoring of pressure and flows	Dual model: prototype for leak detection and isolation [9]

4 TRAINING AND SERVICES

The software development in the project is accompanied by a comprehensive training package and engineering services.

4.1 E-Learning Module and Training courses

The training is focussed on theoretical background, application of German technical rules and usage of the software. The content is guided by the five use cases of the previous chapter. There will be training courses for the end users as well as E-Learning modules that are designed for individual learning. The structure is the same for all modules and includes the sub-chapters:

- Introduction (why is the topic important for the target group of the training?).

- What do the rules and regulations say?

- Thematic content depending on the module

- Consolidation

- Learning test (2-3 questions per module)

- Literature, rules and regulations

The in-depth part of the module “network calculation” also includes the possibility of interactive pressure loss calculation for individual pipes. A JavaScript module for the calculation of frictional pressure losses in pipes based on the Darcy-Weisbach equation was implemented. The pressure loss calculation is a central component of the pipe network calculation. Often, however, only a rough estimation of the pressure loss in an isolated pipe is required.

The second block includes an introduction on how to work with the web platform, especially the simulation subsection. For this purpose, an anonymized training simulator model that is based on a real system is introduced. All training exercises are based on this model. The handling of the simulation platform is explained in detail followed by the interpretation of calculation results.

The third block contains exercises, both for working with the web platform and for self-studying and practical application of the theoretical basics. The exercises contain detailed solutions, which are initially invisible and can be displayed on demand.

4.2 Technical services

The holistic concept of W-Net 4.0 includes a close collaboration of the technical staff of the water supply utilities and external service engineers. The technical responsible at the utility can use the web information system for solving daily problems arising with network operation and management. If the problem is getting more complicated or time-consuming outsourcing is more efficient. SchwarzwaldWASSER in collaboration with the GIS, HS and IOSB partners provides a service package that covers all steps from data acquisition and creation of the initial GIS model over model calibration and field measurements up to specialized problems such as monitoring and data analyses, rehabilitation planning and restructuring, reliability calculations and water hammer analysis.

5 CONCLUSION

The aim of the project W-Net 4.0 is to enable small and medium sized water supply utilities to benefit from industry 4.0 technologies and digitization. A centralized digital platform has been developed whose core is a GIS database that is connected to offline applications for construction and model development and an online information system realized as web services. The GIS is interlinked with hydraulic simulation and data monitoring tools, each of them remaining individual applications. For the end-user it feels like one single application and all tools being integrated in the central platform. Keeping the tools separate has the big advantage of higher flexibility. For the provision of engineering services, the integrated models can also be loaded in specialist software.

The platform has been implemented and tested for the four associate partners of the project, each of them with different focus and prerequisites in terms of data availability, topographical characteristics of the supply area and size of the network. The intermediate results presentation to the utilities already created great interest and consent. It is planned that the results are also presented to a bigger audience in workshops and meetings of SchwarzwaldWASSER e.V. and beyond.

As next logical step of development the simulation model of the platform shall be extended to cyclic, automatic online calculations. The central platform already integrates all the necessary data: an updated GIS that includes all information for hydraulic calculation. And the data analysis tools that provide time series for all kind of process data coming from the SCADA system and from the sensors in the field.

More research has to be done for the definition of the best suited time intervals for updating the GIS data for hydraulic simulation. If constructions take place in the field, at least a state update of the isolation valves that are closed for the separation of the pipes under construction should be effectuated.

6 ACKNOWLEDGEMENT

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