WISdoM: An Information System for Water Management

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Abstract In the future, equal and universal access to drinking water will become more critical. In this context, collecting, processing, and analysing data is a central part of the strategic decision-making process for water utilities. However, there is a lack of water management information systems that are specifically adapted to the requirements and use cases of water utilities. Therefore, this work presents a prototypically implemented water management information system. The three use cases long-term water demand forecasts, groundwater data management, and precipitation data management were implemented according to the requirements of the water utility Oldenburgisch-Ostfriesischer Wasserverband. This work provides a first software architecture design for a water management information system considering three specific use cases.

Keywords Water management information system · Long-term water demand forecast · Groundwater data management · Precipitation data management

1 Introduction

The climate change and growing exploitation of natural resources calls for an even more responsible and sustainable approach to use non-substitutable water resources [13]. Water utilities provide drinking water for industry and society. Each water utility needs to know about the water quality and quantity in the coming decades, not only
because of sustainable reasons but also due to economic reasons [7]. Knowledge about water quality and quantity is the most important strategic information for various decisions in water management. Information and data about water quality and quantity is used to make investment decisions for the construction of water supply plants [2], to develop adaptation strategies for the effects of climate change [3] and to identify conflicts between stakeholders [24].

However, the management of data and information about water quality and quantity confronts water utilities with challenges [27]: a multitude of influencing factors and interdependencies [24] have to be determined. The spatial transferability of influencing factors is not always possible [6, 27]. Also, the general availability of information is not always given [33]. This leads to the fact that each water utility has established individual processes to monitor and analyse data about the water quality and quantity [15].

The current changes in the availability of government data [21], provides new opportunities for water utilities in different use cases [6]. The current changes enable a critical as well as scientific examination of the technological, process-oriented and methodological possibilities, which may make use of these open data sources to provide new descriptive, diagnostic and predictive data-centered methods [34]. Above all, the integration of heterogeneous external semi and unstructured data into existing structured databases and data warehouses with company-owned data is a challenge [4, 5]. Also, there is a discrepancy between methods that have been tested theoretically and methods that were used in practice [26]. Water utilities often do not have the resources (time and employees) [19] to establish new methods. This leads to workarounds as well as application of inaccurate methods [24].

Therefore, this work describes a software architecture and core functionalities for a water management information system, that primary supports three water management use cases. In the water management information system the three use cases long-term water demand forecasts, groundwater data management, and precipitation data management, are implemented. Data sources of water utility companies (internal) and open data (external) are used to implement the use cases. The water management information system was iteratively developed together with the water utility Oldenburgisch-Ostfriesischer Wasserverband (OOWV) in the WISdoM project over one year. In the first step, workshops with experts were conducted for each use case. In the second step, a use case independent and extensible software architecture was designed and the use cases were prototypically implemented.

In the following, the state of digitalisation of water utilities (Sect. 2), the selection of the use cases (section 3), the software architecture (Sect. 4) and a description of the implemented use cases (Sects. 4.1, 4.2 and 4.3) are described. Finally, an evaluation of the implemented requirements (Sect. 4.4), a conclusion and a outlook is given (Sect. 5).


2 Digitalisation of Water Utilities

Digitalisation potential in the water sector could be summarised under different terms. At the European level, the term "digital water actions" [8] is used. The German Federal Environment Agency uses the terms "water management 4.0" and "water 4.0" [31]. Various research and industry projects (e.g. ICT4Water [9], SWAN [17], and more projects in [31]) focus on the use of digital water technologies. They consider the potentials with regard to the increasing complexity of decision-making. The research in the field covers several technical dimensions like data, methods, use cases and systems.

Wybrands [34] gives an overview of use cases, technologies, and data sources in the context of water management in smart cities. Eggimann et al. [6] and Song et al. [29] discussing opportunities and risks of data-centered concepts based on different data sources. Souza et al. [30] and Sapp et al. [26] presenting the opportunities and risks based on the currently researched methods for linking, processing, and analysing data in water management.

In the case of long-term water demand forecasts, Rinaudo [24], Ghalekhondaibi et al. [14] and Singh et al. [28] give an overview of methods to forecast the water demand and Liehr et al. [20] describe a process-oriented methodology for long-term water demand forecasting on the example of the water utility Hamburg Wasser. Wybrands and Marx Gómez [33] describing a web-based software prototype that enables water utilities to visualise information about their supply regions. Rueppel et al. [25] present a system for the management of groundwater data and the industrial products AquaInfo of GeoConcept-Systeme GbR and KISTERS Groundwater are specialised in the management of groundwater data. Friese et al. [12] show the current state of research and industry in processing and analysing precipitation data for water utilities.

The research project W-Net 4.0 [10] develops a simulation and data analysing platform, and the project DynaWater 4.0 [10] researches the potential of digital twins in water management. Dmitriyev et al. [5] discussing a software architecture to manage sensor data in water management.

A comprehensive overview of the challenges in German water management is given by the Federal Environment Agency [31]. For classification purposes, Oelmann et al. [23] developed a maturity model for digitisation in water management and applied it to the largest water supply utilities in Germany. Both the Federal Environment Agency [31] and Oelmann et al. [23] conclude that there is a need for practical action for digitisation in water management. In their conclusion, the Federal Environment Agency [31] calls for further development of data generation, storage, and use of data in water management information systems.
3 Selection of Use Cases

The selection of the use cases was carried out in a three-step selection process. Before the project started, the project partner OOWV limited the selection to water supply processes that consider the qualitative and quantitative aspects of drinking water. Business processes related to procurement, controlling, finance, maintenance, or project management were not considered. The area of wastewater treatment was also not considered. The five use cases laboratory (qualitative analyses of drinking water), environmental information act, groundwater data management, precipitation data management, and long-term water demand forecasts were identified.

In a second step, expert interviews, according to [22] were planned and carried out. Within the scope of these initial expert interviews, the processes were recorded and analysed. The persons, existing data sources and improvement potentials of the existing processes are identified. The expert interviews aimed to gain a comprehensive understanding of the processes. A total of five interviews with experts in the field of long-term water demand forecasts, groundwater data management, precipitation data management, environmental information act, and laboratory (qualitative analyses of drinking water) were conducted.

In the third step, the results of the expert interviews were processed and discussed. The central part of the preparation was the creation of Business Process Model and Notation diagrams to visualize the considered processes. Personas were created to represent the experts. With these diagrams, the processes of the individual use cases could be compared consistently, which was a useful basis for decision-making when selecting the use cases.

It was decided that the use case environmental information act is not suitable as a first use case. Environmental information requests are too complex due to the persons involved, approval processes, departments, data sources, data formats, and return media. The same applies to the laboratory use case (qualitative analyses of drinking water). The use cases groundwater data management, precipitation data management, and long-term water demand forecasts could be recorded entirely and were classified as suitable in the discussion. Another deciding aspect was the transferability to other water management processes and the existing processes improvement potentials.

4 Water Management Information System: WISdoM

To address and solve the challenges of water management, a prototype of a water management information system was developed. The water management information system uses a microservice architecture. Figure 1 shows the water management information system architecture and core services. Each use case involves a set of specific microservices that interact and complement each other. Beside the microservices there are six core services (message broker core service, API gateway core
service, authentication core service, load balancer core service, service discovery core service and web client core service) that implements management functionalities of the water management information system.

The message broker core service provides an integration and communication channel. It is implemented by RabbitMQ. The message broker core service ensures that the microservices and core services can communicate with each other.

The API gateway core service is the central access point to all core and microservices. The API gateway core service is implemented by Netflix Zuul. The API gateway core service is supported by a load balancer core service, an authentication core service, and a service discovery core service. The load balancer core service and service discovery core service are implemented by Netflix Eureka and the authentication core service is implemented by OAuth2.0.

The load balancer core service is responsible for load distribution if several instances of a particular microservice are initialised or required. When the API gateway core service receives a request, it queries the service discovery core service to determine a microservice instance. The request is then forwarded to the microservice.

The authentication core service is responsible for authenticating incoming requests. It is possible to use different authentication strategies (e.g. local, OAuth, LDAP, Active Directory, OpenID). The implementation takes place using a token-based bearer authorisation using OAuth 2.0. The authentication core service uses the Resource Owner Password Credentials Grant, where the user passes his credentials directly to the application [16]. All other microservices and the web client core ser-
vice request the **authentication core service** to check the permissions of a user who wants to use the water management information system. In the following paragraphs, the technical core functionalities of the water management information system are described and the two core functionalities **metadata management** and **versioning** are discussed in detail. Maven modules were implemented to reduce complexity and allow faster development of new microservices. The modules provide different core functionalities like **REST-APIs**, **database connections** to relational databases or Cassandra, **versioning**, **metadata management**, **personalisable dashboards** and **AMQP-messaging**. Each microservice can add dependencies and use these functionalities in a standardised matter.

**Metadata management** is one of the technical core functionalities of the water management information system. The aim of having metadata is to attach additional descriptive information to data to ensure transparency of data modifications, processes and analyses. In this context, metadata is descriptive information about individual records. Some examples are the data source, the format of the raw data, etc. The water management information system can add, edit, delete, and retrieve metadata for single rows or even whole data tables. The metadata is saved in an instance of Apache Cassandra due to possible high amounts of metadata. **Metadata management** is implemented in a separate maven module to allow fast implementation in other microservices.

Another technical core functionality is **versioning**. The aim is to allow reproducibility for processes, forecasts, and analyses. Therefore, it is necessary to assign each correction a new version. Old versions still have to be accessible after a new version is created. To achieve this, a new data dimension time was introduced to the data model. The concrete data type is a timestamp. The dimension itself is represented by an extended primary key, that contains the new dimension time. Due to the primary key, each version of a row is now unique per timestamp. This allows querying for all recent data for a given maximum timestamp.

The water management information system uses several internal and external data sources. Internal data sources, for example, are **water consumption data**, **raw water flow rates**, or **precipitation data**. These were made available by the OOWV. An overview of all existing data sources is shown in table 1. Currently implemented external data sources are **population data** and **population trend data** and **weather data** from Germany’s National Meteorological Service (Deutscher Wetterdienst (DWD)). Each data source is wrapped by a microservice which allows querying for the wanted data. The data sources can be combined by using the **message broker core service** to receive data from different sources.

A client can access the microservices by sending requests to the **API gateway core service**. The **API gateway core service** queries the **service discovery core service** to get the information on which microservice is accessible on each port. Several microservices are exposing an API. For example, there are analysis and management microservices like **per-capita-prognosis service** or **water-demand-linear-prognosis service**. These need to have access to data sources. Therefore, data is exposed by data microservices, like **water-consumption-data service**, **raw-water-flow-rate-data service**, **water-rights-data service** or **regional-information-data service**. All microser-
Table 1  Overview of available data in the water management information system

| Data source                                | Description                                                                 | # of rows |
|--------------------------------------------|-----------------------------------------------------------------------------|-----------|
| Precipitation data                         | Live data from measuring stations of the OOWV                               | ~770.000  |
| Water consumption data                     | Water consumption on the basis of individual grid connections and at municipal level (both annual) | ~6.500.000 |
| Population data and population trend data  | Population figures per municipality, aggregated over one year. Contains forecasts and is based on values by GENESIS Online | ~1.700.000 |
| Raw water flow rates                       | Information about waterworks and their raw water extraction. Aggregated over one year | ~600      |
| Regional information                       | Structure of the OOWV supply areas with allocation of the waterworks        | ~600      |
| Weather data                               | Based on data from the Open Data Portal of the DWD                         | ~400.000  |
| Groundwater measuring points               | Measured data from groundwater measuring points                             | ~6.000    |
| Water rights                               | Legally permitted groundwater extraction capacity for waterworks per year    | ~300      |

vices can communicate implementing the Advanced Message Queuing Protocol (AMQP).

The user is able to create own dashboards in the web client. He can choose between different data sources. The data can be displayed in graphical form, such as a table or a diagram. In the dashboard, a query builder allows users to perform filtering and aggregation operations without any knowledge of SQL. With this functionality, the water management information system offers a high degree of flexibility in analysis, even for non-technical users.

4.1 Long-Term Water Demand Forecasts

In general, water demand could be defined as the consumption of water measured by the various customers of water utility [24]. Water demand forecasting is a central task of water utilities and pursues several objectives. In addition to operational processes such as short-term expenditure planning [24], they can also support strategic decisions such as infrastructure expansion or adaptation of strategies for the effects
of climate change [2, 3]. Furthermore, water utilities are obliged to provide certain stakeholders with the information resulting from the water demand forecasts [1].

However, the preparation of long-term water demand forecasts for the next 30 years poses great challenges for water utilities. On the one hand, long-term water demand forecasting is a highly interdisciplinary field that has to take into account a multitude of different data sources. Ghalekhondaibi et al. [14] name historic consumption volumes, climatic variables and socio-economic variables such as population growth rates and economic parameters as relevant variables. On the other hand, these variables are subject to great uncertainty [24]. Besides temporal extrapolation models such as ARIMA, multivariate statistical models, and scenario approaches are mentioned to counter the uncertainties [14, 24].

Moreover, several techniques like artificial neural networks or support vector machines are frequently used for demand forecasting, although they seem to work better for short-term forecasts than for long-term water demand forecasting [14]. According to these results, no single method can be considered the best one for long-term water demand forecasting. Instead, a hybrid approach could represent a promising option. Besides the selection of suitable forecast models, the integration of significant variables plays an important role as well in improving prediction accuracy. Singh et al. [28] have investigated in further studies that models that only consider proven effective factors perform better than models using all available data. Regarding Ghalekhondaibi et al. [14], water demand forecasting for different types of consumers and small spatial units such as communes could be a promising approach, where the inclusion of additional variables could lead to more applicable and reliable models.

The research findings are very well aligned with the requirements determined during a workshop with experts from OOWV. Within this creative workshop, a total of 59 requirements, including 123 acceptance criteria, were identified and recorded as story cards. This set of core use case functionalities are summarised in Table 2.

Concerning the research findings, the focus in realising the requirements and core use case functionalities was less on providing a single, perfectly adapted forecast microservice for the OOWV association area. Instead, the use case functionality should be developed, which is going to be flexible and expandable, offering the user various options. The foundation for this flexibility and expandability is the software architecture of the water management information system that is primarily based on microservices. Various additional data sources and forecast microservices can be added to the water management information system. In this manner, the water-consumption-data service, raw-water-flow-rate-data service, and water-rights-data service were implemented to make the required internal data sources available for demand forecasting. See Table 1 for data source details.

Furthermore, the integration of external data was illustrated by the development of one additional microservice to provide open access to data sources. Demographic developments received by Genesis Online were encapsulated in a separate microservice that provides historic population censuses as well as different population trend scenarios. These various population trends enable the required implementation of scenario-based approaches considering miscellaneous per capita consumptions. The
Table 2  Overview of the core functionalities for the use case long-term water demand forecasts

| Core functionality                              | Description                                                                                                                                 |
|-------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Integration of internal and external data sources| Not only internal data sources such as historic water consumption data, raw water water flow rates and water rights, but also freely accessible external data sources such as population data or weather data should be integrated |
| Deployment of various forecast services          | The water management information system should provide the selection between different forecast microservices. Besides simple mathematical microservices, scenario-based microservices should be available |
| Selection of spatial units and consumer types    | The integrated data as well as the executed long-term water demand forecasts should be matched to different selectable consumer types and spatial units such as communes or counties automatically |
| Expandability                                    | The water management information system should be expandable with further data sources and forecast microservices |

Fig. 2  Water demand prognosis settings

regional-information-data service took on a central role, to overcome the requirement of selecting different spatial units for long-term water demand forecasting. For the calculation, the integrated variables must first be converted to the selected spatial unit, such as communes, counties, or waterworks, which is done automatically by an additional microservice.

Also, two exemplary prognosis microservices for executing the actual long-term water demand forecasts were implemented. The water-demand-linear-prognosis ser-
vice is a simple regression microservice, which allows a linear as well as a polynomial or logarithmic regression. The per-capita-prognosis service is a scenario-based approach, which calculates long-term water demand forecasts based on various population trends in conjunction with automatically calculated or transferred per capita consumptions (see Figs. 2 and 3). According to the implemented microservice architecture, the integrated internal and external data sources, as well as the forecast microservices, could easily be replaced or extended by further microservices to meet more extensive or different requirements.

4.2 Groundwater Monitoring Management

The management of groundwater data illustrates the interaction between the individual use cases and the various data sources of water utilities. This relationship between long-term water demand forecasts respectively, the resulting raw water flow rates, precipitation data, and groundwater measuring points are particularly evident in the water cycle.

The European Directive 2000/60/EC describes groundwater as all water, that is below the surface of the ground in the saturation zone and has direct contact with the ground or subsoil. A key objective of the European Directive 2000/60/EC is the establishment of a framework for the protection of groundwater to address both unsustainable water use and water pollution. As a result, European Directive 2000/60/EC requires member states to continuously monitor the quality and quantity of groundwater. Besides chemical pollutants from agriculture and industry, excessive water extraction also represents major environmental pollution [7]. In this context, the quantitative status of groundwater resources must be continually assessed. According to European Directive 2000/60/EC, the status is considered good if the development of groundwater levels shows that long-term groundwater abstraction does not exceed the available groundwater supply.
In Germany, the implementation of this groundwater monitoring is the responsibility of local water utilities. To ensure this, the OOWV has installed about 2,500 groundwater monitoring points in its extraction areas. Most of the measurements are read manually by employees. These and further challenges were identified in a Google Design Sprint [18] with three experts as 55 requirements and 150 acceptance criteria that can essentially be condensed into three use case core functionalities (see Table 3).

Similar to the use case, *long-term water demand forecasts*, the various use case core functionalities for displaying (see Fig. 4) and editing monitoring point data were implemented in form of individual microservices. Further microservices for reporting and managing damaged measuring points were added as well. A central problem with the previous administration and controlling of the hydrographs was the required handling of SQL statements. A generic query builder was developed, which enables the user to generate detailed queries with only limited knowledge and skill in SQL. This query builder allows the employee to create queries without having knowledge of the underlying database structure. The user can select the required operators and variables on the client-side from automatically prepared lists. Furthermore, this fea-

| Core functionalities                      | Description                                                                 |
|-------------------------------------------|-----------------------------------------------------------------------------|
| Overview of the measuring points          | All measuring points should be displayed on a map and selectable by the user within this map |
| Display and adjustment of data            | The master data and the groundwater measurements of selected points should be editable. Furthermore, groundwater measurements should be presented as hydrographs which graphically illustrate the observed values over time |
| Notifications of damage                   | Damaged or defective measuring points should be reported and managed within the water management information system |

**Table 3** Overview of the core functionalities for the use case long-term water demand forecasts

![Fig. 4](image-url) Overview of groundwater measuring points
ture enables aggregates such as sums, averages, or maximum values of considered variables. Later, this query builder component was adapted and applied in further use cases and data sources.

4.3 Precipitation Data Management

Water utilities require precipitation data for drainage modeling and planning of sewer networks [12]. The relevance of this data is continuously increasing due to the growing number of heavy rainfall events [11]. The public’s interest in information is growing. The usage of such data could be helpful for decreasing amount of property damage caused by heavy rainfall event. Therefore, a proper precipitation data management is required to process, analyse, and archive the data. The data is also essential for internal planning, as support for operational purposes and communication with the public. A classification of heavy rain events takes place via the specially developed heavy rainfall index (Fig. 5) [12].

In a workshop with two technical experts from the water utility OOWV, 47 functional requirements with a total of 124 acceptance criteria were identified. These

![Image of data and graph]

**Fig. 5** Visualisation of data gathered by weather stations
Table 4  Overview of the core functionalities for the use case long-term water demand forecasts

| Core functionalities | Description                                                                                                                                 |
|----------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Station data         | The user should be able to get an overview of existing precipitation stations (DWD and OOWV), including metadata available to them. The different weather stations (DWD and OOWV) should be visible on a map, and both historical precipitation data and incoming data should be available in minute intervals |
| Plausibility         | The user should have the possibility to create precipitation forecasts based on existing data                                               |
| Precipitation forecasts | To be able to evaluate existing data in a meaningful way, it should be possible to adjust the resolution the data is displayed. Heavy rainfall events are automatically determined based on selected periods. It should also be possible to compare the data of individual stations |
| Evaluation           | It should be possible to adjust the resolution the data is displayed. Heavy rainfall events are automatically determined based on selected periods. It should also be possible to compare the data of individual stations directly |

requirements were described in user stories with a descriptive text, acceptance criteria, and prioritisation. These user stories were then again reviewed by the experts in a second feedback loop. In summary, these 47 requirements can be represented by four use case core functionalities (see Table 4). The data used in the use case are generated from one of the 27 weather stations that measure precipitation and other types of measurements in the OOWV region. Especially the water and sewage plants are equipped with their monitoring stations.

4.4 Evaluation

In order to validate the applicability of the presented approach, a two-stage evaluation was planned in cooperation with the OOWV. First, the usability of the water management information system should be tested by a cognitive walkthrough [32] with expert users. For this purpose, five defined scenarios should be executed by different experts on the water management information system. The comparison of the actual processes with the defined target processes should identify possible improvement potentials. In the second stage, the functionality of the software was to be tested by evaluating the initial requirements in expert interviews with regard to their degree of fulfilment.
Although the flowcharts for the target processes of the cognitive walkthrough as well as the guidelines for the expert interviews have already been prepared, the planned evaluation could not be carried out due to the comprehensive measures in the context of the COVID-19 pandemic in spring 2020. Instead, an internal evaluation was carried out in which all acceptance criteria were assessed on a scale from 1 (not fulfilled) to 4 (requirement exceeded). Of the total of 397 acceptance criteria surveyed, about 46% could not be implemented within the year. However, this high proportion must be put into perspective by two factors. Firstly, the requirements were defined at the beginning of the project without restrictively considering the time frame. Secondly, some requirements of the different use cases were quite similar. These requirements were primarily dealt with in the first use case. In the use case of long-term water demand forecasts, therefore, considerably more acceptance criteria could be positively evaluated (62%).

5 Conclusion and Future Work

In this work, a prototypically implementation of a water management information system is presented. The three use cases of precipitation data management, groundwater data management, and long-term water demand forecasts are implemented using a scalable microservice architecture. The microservice architecture enables the integration of external and internal data sources into processes and generates added value for business users. The water management information system can be flexibly adapted to new use cases through core functionalities REST-APIs, database connections to relational databases or Cassandra, versioning, metadata management, personalisable dashboards and AMQP-messaging. By deliberately focusing on only three use cases, a solid software architecture has been developed that provides a foundation for further research in the field of digitisation in water management and water management information systems. The water management information system is currently being extended by the following functionalities:

The plausibility check of incoming groundwater measurement data is currently carried out over a value corridor. This will be automated by an anomaly detection using autoencoder. Master and measurement data of assets (water supply plants, sewage treatment plants, pumping stations, etc.) are to be integrated into the water management information system. In the first step, pumping stations with related maintenance processes will be analysed. The long-term water demand forecasts are currently using simple regressions. The process of long-term water demand forecasting will be extended by new techniques to obtain an even more accurate estimation of future long-term water demand. Extension of the precipitation data management to include forecasts provided by the DWD.

Also, some use case core functionalities currently have an idea status, but no practical research is in progress: In addition to quantitative data use cases like groundwater data management, long-term water demand forecasts, and precipitation data management, laboratory (qualitative analyses of drinking water) is a high priority use...
case. These can be integrated into the water management information system. Also, the water management information system can be used to handle complex requests for environmental information act requests and to provide corresponding data for citizens. Due to the complexity of the requests for environmental information, it is not possible to limit the requests to particular data sources. The linking of an open data portal to provide information is another idea. In combination with the requests for environmental information as well as the obligatory analyses for waterworks resulting from the national Drinking Water Regulation (TrinkwV), new questions and practical possibilities for research arise. Another idea is the documentation of water rights cases. A water rights case can be lasting several years with different reports, emails, and analyses. Due to the lack of water management information system, the transfer of the water management information system into an (open source) software product was discussed.

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