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Hydraulic Modelling And Calibration Of The Upper Silesian Waterworks In Poland

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PRELIMINARY RESULTS OF HYDRAULIC MODELLING AND CALIBRATION OF THE UPPER SILESIAN WATERWORKS IN POLAND

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Our paper presents the approach and preliminary results of hydraulic modelling and calibration of the complex water transfer and distribution system of the Upper Silesian Waterworks PLC (USW) in Poland. The USW network comprises some 880 km of main pipes and supports a population of approximately 3 million in the Silesian Metropolis. In this case study a concept of integrated ICT system will be presented.

THE UPPER SILESIAN WATERWORKS

The Upper Silesian Waterworks PLC (USW) is the largest water company in Poland and one of the biggest in Europe delivering water to over 3 million customers in the Silesian Metropolis. It covers an area of about 4.3 thousand square kilometres and the main water network is over 880 km long. The general topography of the water supply area is very hilly, with elevation differences of up to 120 m. This water distribution system incorporates the central and western sub-regions of Silesia (Silesian Metropolis) supplying water totalling about 350 000 cubic meters per day (2013). From an operational point of view, the Upper Silesian Waterworks water distribution system is divided into eight major networks. The USW water transportation system uses a combination of pressure and gravity mains (with diameters ranging between 300 mm and 1800 mm) conveying the water to several local (municipal) distribution systems and bulk buyers (industrial). The USW system is composed of 11 water treatment plants, 19 pumping stations and 9 complexes of storage tanks and reservoirs with a total capacity of 343 000 m^3. This capacity represents about 84% of the total water consumed in a day.

A key role in the water supply system is played by the storage tanks in Mikołów, with a total capacity of 100 000 m^3. These tanks are supplied from three major water treatment plants: Goczałkowice, Kobiernice and Dziećkowice. Their convenient location allows gravity transport to the northern and western parts of the system. About 138 000 m^3 is stored in three tanks: Czarny Las, Góra Wyzwolenia and Murcki (Fig. 1).

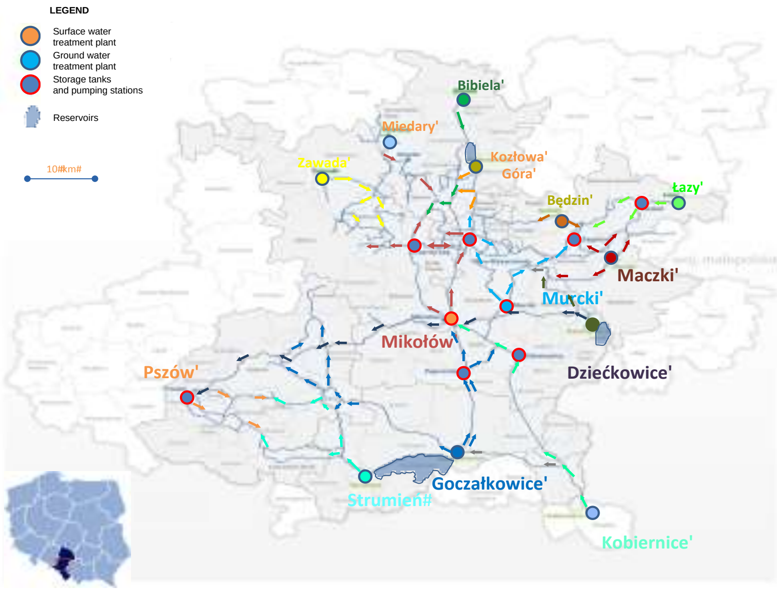

Figure 1. General overview of the USW main water distribution system and directions of water transport (during normal operation)

Pipelines in the water supply system with a diameter less than DN 500 comprise only 12.8% of the total length. The core of the main distribution system is composed of pipelines DN 1000 and larger, which makes up nearly 50% of the total length of the network (Fig. 2).

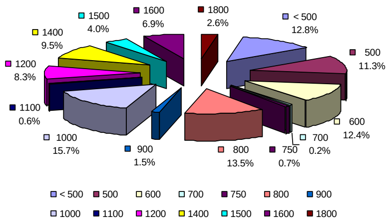

Figure 2. Pipeline diameter distribution in the USW water supply system (2013)

The area of the system is characterised by a great diversity of terrain altitude, heavy concentration of industry and extensive mining damages. This dynamic environment requires the constant updating of water distribution network (WDN) topology and real-time water demand from wholesale customers including towns and cities, coal mines as well as the steel, energy, automotive, machinery and chemical industries.

Water distribution systems are designed to satisfy the water requirements for a combination of domestic, commercial, industrial, and fire fighting purposes. The hydraulic analysis of a water distribution system is an essential step towards understanding the behaviour of the water supply and distribution system which includes the flow, pressure head, velocity, head loss in each pipeline, duty point and efficiency of pumps. The information obtained from the hydraulic model simulation of a water distribution system assists in management planning for maintenance and the replacement of system and plant equipment (i.e., pumps, valves, pipes, etc.) as well as assessing the performance of tanks and reservoirs.

The problems associated with the management of the USW lie in its size, the large number of sources with varying levels of water quality, the large number of wholesale customers (e.g. steel industry, coal mines), determining the flows of water in the water supply, the large diversity in the age and material of pipes, and in the significant dispersion of critical facilities over the entire water supply system. The USW system was first developed 130 years and originally its main purpose was to deliver water to industrial customers. The maximum capacity of the water distribution network was reached in the 1980's when the daily production of water was at about 1.6 million m^3/day and water consumption reached almost 1 million m^3/day. In the early 1990's due to political and economical changes in Poland, the maximum capacity of the system was constantly decreasing, reaching 0.9 million m^3/day in 2013 with an average water consumption of about 350 000 m^3/day. The production reserve of the water system is at about 60%.

Current works are in the framework of developing the ICT system for the management and control of the large water supply system [4]. This will have an impact on the progressive elimination of the weaknesses of the USW which include its oversized production capacity in relation to the current water demand, the need for maintenance and repair of approximately 60% of the pipelines (mostly due to old, failing steel pipes – cf. Figure 3), the periodic changes in the water quality and limited flexibility in the market activities. Furthermore, almost half of area covered by the USW system is under the strong influence of mining. The way to improve the weaknesses in the system is to keep the infrastructure facilities and the water treatment plants in good working order by optimizing the structure of sources, optimizing the process of water distribution and by maintaining the distribution network in proper technical conditions through optimal management of emergency repairs, renovations and upgrades.

The average age of the pipelines is about 38 years (between 28 and 62 years) with an average failure rate of 0.35, in the range between 0.23 and 0.65 (failures per km/year). Only 20% of the pipelines (approx. 170 km) have been lined with cement-mortar, PU or PE to protect against corrosion, tuberculation and water quality problems.

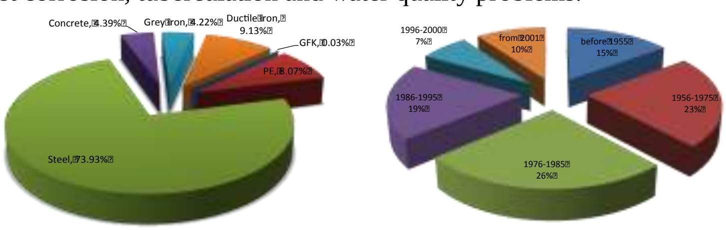

Figure 3. Pipeline material (left) and age distribution (right) in the USW water supply system (2013)

CONCEPT OF THE ICT SYSTEM FOR THE USW WATER NETWORK

The ICT system under development for the Upper Silesian Waterworks consists of three key elements: GIS system for maintaining and generating the topology of the water network, SCADA or telemetry system for measuring and recording the main hydraulic and water quality parameters (e.g. flow rate, pressure, chlorine residual, turbidity and the water consumption of the end users). The last building block of this system is the custom hydraulic model with the optimization or computational module with several algorithms and subprograms responsible for the computer aided solutions of the typical water network management tasks.

Among the programs incorporated in the optimization module, the hydraulic model of the water network plays the key role. This model calculates the water flows and pressures in the network and is also used by all the other programs in solving many different simulation and optimization tasks connected with the management of the water network.

The structure of the proposed ICT system [2] for the USW water supply system is shown in Figure 4.

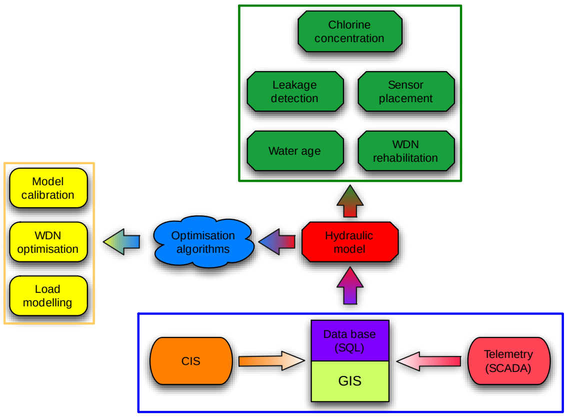

Figure 4. Overview of the ICT system

The programs in the optimization module are divided into two groups. The first group of programs use only a hydraulic model and its simulation solves management tasks such as sensor placement planning or water age calculation. The second group of programs solve more demanding tasks like the calibration and validation of the hydraulic model or water network optimization. This type of programs uses additional algorithms of optimization [6].

The following paragraphs characterize the main elements of the ICT system developed for the USW main water distribution system.

GIS SYSTEM

The GIS system is based on the Intergraph G/Water. The SQL database containing information from the telemetry system, CIS and hydraulic model will be integrated with GIS. The necessary information and results of analyses will be available to the end-user through the G/Water graphical interface. Information about the structure, topology, water consumption data and key elements of the water network will be directly linked to the hydraulic model. This link will allow for a periodical, fully automated update of the hydraulic model.

The massive work to update and validate the existing GIS database has been undertaken. Due to the long history of the system, there are serious information shortages (e.g. due to lost or destroyed documentation) and only by time-consuming, extensive surveys the lost data can be retrieved. Another challenge was posed by mining damages. Mining-induced surface subsidence in the region of the Upper Silesia cannot be neglected. Not only are pipelines affected, but also the elevation of water in the storage tanks is constantly changing, influencing the hydraulic state of the whole system which in part operates by gravity. Surface subsidence in the area is dynamic too - in the last 35 years the elevation of water in the Murcki storage tank (Fig. 2) has changed by 6 meters and recent measurements have proven that the subsidence rate in the storage tank area has increased (mainly due to continuing mining activity).

TELEMETRY SYSTEM AND DATA COLLECTION FOR CALIBRATION

The collection of field data provides an opportunity to understand the operation of the system at a specified number of locations and times [1]. For the calibration and validation of the hydraulic model we used the extensive telemetry system (available online by web service or accessed by SQL database links) composed of 180 monitoring stations (including wholesale customers meters, reservoirs, tanks, pumping stations etc.). This online data acquisition system contains over 500 sensors measuring flow rate, pressure head, water levels, turbidity and chlorine residual. Some structures also include local SCADA systems (not included in online service) where data must be collected manually.

The field measurement campaign will be conducted in order to supplement data for the final calibration and validation of the hydraulic model. The existing database of measurements will be temporarily supported by mobile measurement points used for the identification of hydraulic properties of selected groups of pipelines [3, 5].

MODELLING AND PRELIMINARY CALIBRATION OF THE MAIN WATER NETWORK

The specifics of the USW system and planned usage in the integrated ICT system require a low level of model skeletonization. To deal with the complexity of the USW water network, the development of the hydraulic model was divided into three major stages. In the first stage a preliminary, simplified hydraulic simulation model of the water-distribution network was built. This model has a rather low level of detail (about 320 nodes – Figure 5), although it captures all of the key elements in the system and the transport routes of water. After the initial calibration (using data from the telemetry system), this preliminary (steady-state) model was used for expanding studies of the monitoring system and for verifying the calibration and validation campaigns. With a computer model of the water supply system, the functioning of a complete hydraulic system can be simulated and analysed in terms of spatial and temporal characteristics.

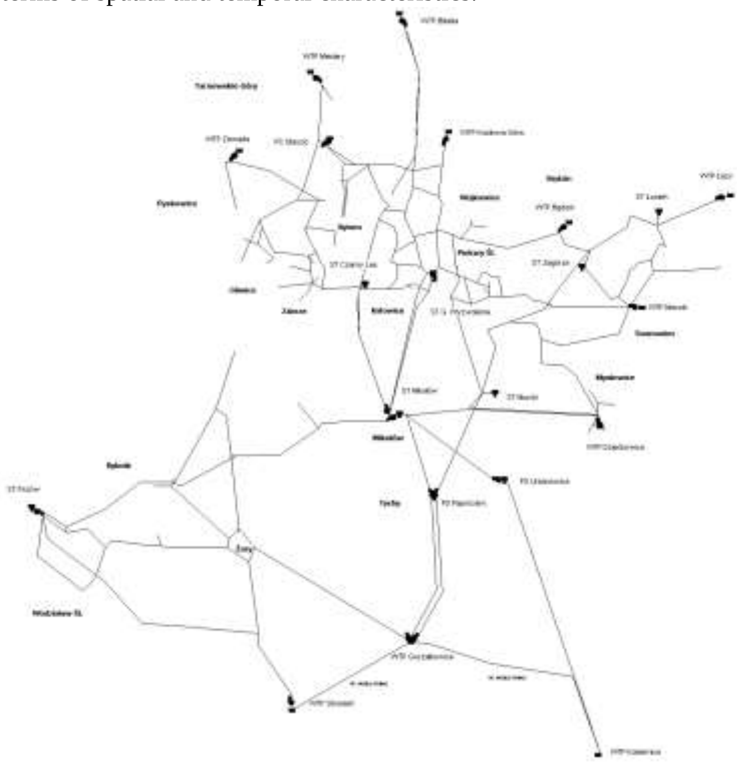

Figure 5. Preliminary hydraulic simulation model of the USW main water distribution system (abbr. used in this figure: WTP – water treatment plant, PS – pumping station, ST – storage tank; major cities served by the system are given in bold)

The second step is devoted to the preparation of detailed models for all the major elements in the system. The USW system is composed of 11 water treatment plants (water sources, surface and groundwater), 4 major pumping stations and 5 complexes of storage tanks (usually with pumping stations). The detailed models were prepared and verified using data from the online data acquisition system.

In the final step a complete network of main distribution pipelines (above DN 300) will be connected with detailed models of network structures (prepared in step two) to obtain a complete hydraulic model for extended period simulations. In the detailed model the spatial location of all water demands will be included. This model will be calibrated and validated using the data collected by the telemetry system (SCADA) and during field measurement campaigns. In field measurements, the hydraulic resistance will be field tested for selected groups of pipelines in order to determine the values of the pipe roughness coefficient. The results of stages two and three will be reported in upcoming papers.

Model calibration involves adjusting model parameter values until an acceptable match is achieved between measured (field) data and model predicted values. For general calibration of the simplified preliminary model, the traditional method of trial-and-error has been used. The main parameters adjusted during the calibration process were pipe roughness coefficients, nodal demands, pump curves and operation regime (control algorithms and settings of variable speed drive) and initial water tank levels. Calibration runs were finished when the model output agreed with field data according to predefined requirements. Since the USW water distribution system operates as a whole (only the Zawada sub-network is isolated) the calibration was done simultaneously for the entire network.

For the calibration and validation of the final (stage three) network model, a combination of traditional and advanced methods (genetic algorithms) will be adopted. The planning of field tests will be based on network sensitivity analyses made with the use of the preliminary hydraulic model (prepared in stage one).

The initialization of the hydraulic model for water transfer and the distribution system of USW by EPANET will be constructed from data needed for the simulation of the quasi-steady hydraulic state of a real system. This approach allows for estimating the average output parameters of cooperating pumping stations and reservoirs within the water network and finally for the customers connected to the points of sale.

The results of simulation research conducted on a quasi-steady model enable the general quantitative verification of the system and for estimating the coverage and tracing individual supply sources. Moreover, comparison with directions of water flow and values of flow rates monitored on the real network will help identify errors in the network structure model as well as the occurrence of significant unaccounted local minor losses caused by the closure of valves, incrustation of pipelines, etc.

The quality and suitability of the constructed model depends on the accuracy of both the mapping of the real network structure and estimations of the hydraulic parameters of water pipes such as length, diameters and roughness coefficient. As for the USW system, extensive field research is planned in order to estimate the hydraulic resistance of individual classes of pipes differentiated by the diameter, type of material, time of exploitation and path expressed by water flow velocity depending on the pipe location in the network.

The inclusion of the latter criterion will require conducting simulation analyses with the use of the created hydraulic model of the USW. It is also to be used for the iterative calibration of water pipe resistance based on both local and entire system field surveys. While conducting the surveys covering the entire water distribution system it is necessary to provide the simultaneous registration of flow and pressure measurements on all checkpoints and then to compare these with replies of the model.

Primarily, the estimated weights of base demand assigned to the individual water recipients, who are defining the characteristics of the real system and its model, will be essential for the quality of constructed model and increase in its utility. The recipients of water sold and delivered through points of purchase of the municipal water distribution network of USW include cities located within USW area, urban districts, street divisions, wholesale customers (i.e. mines, production sites and service companies of different sizes, public services) and individual recipients.

The data used for the construction of the quasi-steady water consumption model were registered in the USW billing system in the year 2013 in 742 measurement points localized in points of purchase. The distribution of clients and average water consumption is shown in Figure 6.

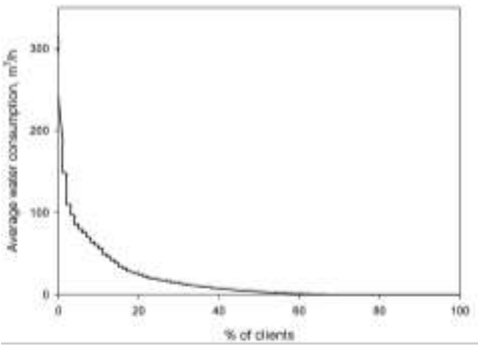

Figure 6. Average water consumption vs. clients

The weights of recipients were calculated based on the average hourly consumption collected in the year 2013. The year 2014 is the first common measurement period for the full range of recipients varied by the frequency and technique of water consumption measurements, from manual quarterly and monthly based surveys to real time, constant SCADA telemetric system registrations.

At the end of 2013 the telemetry (partial AMR) system consisted of 100 measurement points which registered approximately 38.8% of annual water consumption. In the year 2014 the data acquisition system is to be expanded by the next 190 biggest water recipients. With this investment, measurements by the telemetry system will cover 93% of total water consumption. The remaining 7% of water consumption, which represents 62% of water recipients, will be measured manually. Water use for these consumers will be estimated based on the annual average level modified by current consumption.

Notably, information about 93% of the recorded continuous measurements of water consumption allow the creation of aggregated hourly water demand patterns for any time horizon, including 24 hour distributions aggregated to the individual day of the week and any sequence of consecutive holidays. Moreover, hourly water consumption rates recorded in the telemetric system enable the creation of the distribution for the water consumption range in any hour taken from the mentioned aggregated water consumption patterns. These consumption models allow for simulating the functioning of the USW system on assumed confidence levels.

The final step in the creation and exploitation of the USW system model is the availability and use of real time water consumption data. This will allow for automatically verifying and calibrating both the structure and parameters of the systems and their elements.

CONCLUSIONS

In this research, the Upper Silesian Waterworks (USW) main water distribution system was studied. Current operational, economical and maintenance challenges necessitate the development of an integrated decision support tool for the aging USW water distribution network. The approach and assumptions for the development of an integrated ICT system was presented. The key elements of this system GIS, CIS, telemetry (SCADA) as well as tools for multi-criteria optimisation and forecasting have been examined. The GIS was used to manage and process input and output data from the model. Specific aspects of data collection, model calibration and simulation were discussed. Special focus was given to the hydraulic model of the vast and complicated USW water distribution system.

ACKNOWLEDGMENTS

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