Evaluation of urban water networks - Case study

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Abstract. The subject of the paper is the elaboration of the topic of modeling and optimization of the reliability of systems for drinking water supply in the town of Hlucín and the adjacent villages Bobrovniky and Darkovicky. The paper points out modern ways of management and maintenance of these buildings, eg in the form of passportization, unification of various types of documentation, records of failures and accidents, etc. The aim is to point out possible ways to optimize these buildings and overall evaluation of the water supply network, including the suitable renewal schedule design. These practices are essential for the efficient operation of water supply networks, especially nowadays, when there is a shortage of water and it is necessary to promote sustainable urban development through its economical management.

1. Introduction
Sustainable development of the state or the city as a whole is conditioned mainly by the sustainable development of its individual parts, including the drinking water supply system. We must not forget that it is important for water infrastructure to be as reliable as possible at all times with the lowest possible risk of failure, because these disorders have a negative impact on the functioning of the city not only in terms of quality of life, but also affect public health, hygiene, safety, protection of landscape, and environment. However, these requirements are unthinkable without a quality project, professional construction, use of state-of-the-art materials, and procedures go hand in hand with state-of-the-art technical equipment ensuring their quality management, maintenance, and renewal of fixed assets. Well-executed, managed and maintained water management infrastructure then forms one of the basic segments of every urbanized area. [1,2]

The aim of the paper is to assess and optimize the drinking water supply system in the town of Hlucín and the adjacent villages Bobrovniky and Darkovicky. The purpose is to unify the documentation, passportization of individual elements of the water supply system and failures and accidents on this water supply line. Water is an essential component of life and it is undeniable that the drinking water supply system is one of the most important components for the functioning of the city. Without this system the territory could not be functional and is fully in line with sustainable development to make this system work as best as possible, ie. effectively, with as few failures and accidents as possible, so that the operation is economically manageable, including easy maintenance, and in view of the growing problem of water scarcity in recent years, its management is as economical as possible. Drinking water is important for the lives of people, animals, as well as for businesses and our quality of life and activities are directly dependent on it. [2,3,4]

The municipality of Hlucín and its task is to supply 14.5 thousand inhabitants with drinking water and operate approximately 73 km of water supply networks. The water supply system has been built in the territory since 1935 and it is evident that during its existence, the administrator of this network had to
deal with a number of failures and problems. Now the water supply system is managed by the city-based organization VaK Hlucín, s.r.o. (VaK means Water supply and Sewerage), which is gradually renewing the water supply network, however, there are still places, especially in the village of Bobrovniky, which are still problematic. The purpose of optimization will be a detailed analysis of the current situation with the identification of risk areas and design of new routes with respect to all limits and problems in the area, passportization of existing facilities, evaluation of pressure conditions with respect to buildable areas, and economic evaluation of the design. The work will also include a description of the maintenance and operation of the system with a proposal for modifications and recommendations. The basis for the elaboration was spatial planning documentation, materials provided by the waterworks administrator - topography with a description, annual reports, as well as the real estate cadastral, maps, professional literature and valid legislative regulations.

2. Current state and characteristics of drinking water supply system
98% of the population living in Hlucín is supplied by the water supply system. The system for drinking water supply (DWS) consists of three separate integrated units in each of the cadastral areas and are operated in one pressure zone with local automatic pressure stations. The Hlucín and Bobrovniky water mains have been built since the middle of the 20th century; in Darkovicky, the water supply network was put into operation since the 1990s.

Table 1. General information about drinking water supply system in 2018.

| Parameter                               | Value               |
|-----------------------------------------|---------------------|
| Number of supplied inhabitants          | 14 192              |
| Length of water supply network          | 73.1 km             |
| Number of water connections             | 2 823 pcs           |
| Number of installed water meters        | 2 807 pcs           |
| Number of water treatment plants        | 1 pcs               |
| Number of operated reservoirs           | 3 pcs               |
| The reservoirs volume                   | 1 900 m³            |
| Number of pumping station               | 2 pcs               |
| Drinking water consumption              | 108.3 l/inhabitant/day |

The system for DWS Hlucín is connected to several sources and feeders. The Hlucín district is connected to three supply lines. In the western part of the village, the water supply system is connected to the supply line from the Dolní Benešov DN 300 reservoir, from the east to the DN 300 reservoir from the Malánky reservoir. In the area called Rovniny, there is a collection area, which is connected to the system by the DN 100 series. The flow rate of this source is approximately 11.1 l/s. Bobrovniky are connected to the Ostrava regional water supply system by the DN 900 Krásné Pole - Karviná feeder, which supplies the local water reservoir, which brings water to the DN 150 series of appliances. Water is supplied to the appliances via reservoir in Darkovice in the DN 200 series, this reservoir is no longer in the solved system.

3. Analysis of the drinking water supply system failures
In total, approximately 73 km of water supply network is operated in the Hlucín area, of which 52 km is in the cadastral area of Hlucín, 11 km in Bobrovniky and 10 km in Darkovičky. In 2018, a total of 565,426 m³ of drinking water was distributed to the final consumer throughout this system.

The analysis and statistics of the operation of the system for drinking water supply in Hlucín is processed on the basis of fault sheets of the company VaK Hlucín s.r.o., see Fig. 1 where a photocopy of one fault sheet is shown. Failure lists were introduced by the operator in 2005, so the statistics are based on data from years between 2005-2018. During the monitored period, a total of 221 failures were recorded in the water supply network in Hlucín, Bobrovniky and Darkovičky. Fault leaves were also kept for the sewer lines and were not distinguished from the water supply system. Often the fault sheets are only
partially filled in, they do not contain all the important information, therefore some data may be distorted or idealized for better registration. [5,6,7]

Figure 1. Fault sheets of the drinking water supply system operator; Source: Water supply and sewerage Hlučín, s.r.o.

4. Failures
Faults and accidents have occurred on almost all types of equipment, parts, profiles and materials over the past 13 years. There are also several types of disorders that have been caused by various factors.

4.1. Types of failure pipelines
Water supply and sewerage Hlučín, s.r.o. manages and ensures operation on all types of DWS system equipment. In the network for DWS there are distribution, storage or supply lines, but also connections. The operator also performs and records faults on the house parts of the connections, although they are not owned by itself. However, most faults were reflected in the classic distribution line, then in the public parts of the connections, as well as in the supply line, see Fig. 2. A number of faults have occurred, when a fault in the oven on the distribution line has also damaged the connection or vice versa. In such cases, a primary failure has been reported on the part that caused the failure.

Figure 2. Number of faults according to the type of device.
4.2. Broken parts
There are a huge number of objects in the whole system, but mainly fittings on which faults can occur, see Fig. 3. However, the largest volume of material is contained in the pipes of the water supply system, so it is nothing surprising that the most common failures happened on them. Another problematic element in the network are the individual pipe connections, where various stresses and shut-off valves occur. Mudguards and aerators have proven to be a very reliable element of the water supply system. This type of part has not failed for 13 years. Occasional failures, however, can be noted in hydrants, and quite exceptionally, a failure in the reservoirs. A total of 17 failures out of a total of 221 faulty parts were not recorded, it was marked as “other” or “other arm fittings”.

![Figure 3](image)

**Figure 3.** Number of faults according to broken part.

The most frequently damaged parts are made of classic gray cast iron without lining (112 defects). However, during its lifetime, a large part of the water supply network was reconstructed and replaced with pipes made of plastic materials. Linear polyethylene and steel also have a significant presence in statistics.

4.3. Type of faults
The disorder can manifest itself in a variety of ways and occur due to a number of factors. In the monitored period from 2005 to 2018, the most accidents occurred due to the transverse fracture of the pipeline, see Fig. 4. Leakage in the joints of individual pipes also appear to be problematic, another significant type is a hole, a tear or a crack.

![Figure 4](image)

**Figure 4.** Number of faults according their type.
It is impossible to unambiguously determine the main cause of a water supply failure, often several causes appear in the records at once. The resulting failure is caused by the interaction of several factors and causes. The most numerous cause of faults is the movement of the soil, which is, however, caused by poor laying of the pipeline. An indispensable cause is corrosion, which in turn occurs due to the age of the pipeline, see Fig. 5.

5. Summary and analysis evaluation
A total of 221 disorders occurred during the monitored periods. Most faults occurred in the cadastral area of Hlučín, which is understandable due to its size. There were a total of 173 failures in Hlučín, 42 in Bobrovníky and 6 failures occurred in Darkovičky, where the water supply system has been in operation for only 23 years. In Fig. 6 the number of faults per 1 km of water supply system can be monitored, and in Fig. 7 then the total number of faults on individual DWS systems are shown.

A total of 52 km of water supply network is operated in Hlučín, 11 km in Bobrovníky and 10 km in Darkovičky. From the recalculation of faults per 1 km of the network in individual cadastral areas, it is evident that most faults occurred in Bobrovníky. Darkovičky can be described as an almost problem-free area. It should be mentioned that over the years there was a gradual reconstruction of the water supply network, especially in the Hlučín district, and so it is now possible to declare the Bobrovníky area more problematic.

Statistics show that during the monitored years there was a gradual decrease in the number of failures, mainly in Hlučín. The turning point was the year 2008. Now we can observe an almost seven-fold decrease in failures compared to 2005. The years 2012 and 2015 were exceptional, where there were significantly more failures, probably due to severe winters, which were characterized by holofrosts.

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**Figure 5.** Number of faults according their cause.

**Figure 6.** Number of faults per 1 km of water supply network.
In general, it can be said that most of the failures that occurred on the water supply network were caused by the transverse fracture of the old cast iron pipes, mainly due to the movement of the soil caused by poor deposition. The network administrator most often has dealt with this problem with a repair bracket. The water supply network in Hlučín was old and prone to failures, due to maintenance and gradual reconstruction, the number of failures was minimized to a sustainable level. Due to the quality work of the network operator, water losses are minimal, the company can be proud of the lowest water leaks in the entire Czech Republic.

5.1. **SWOT analysis of water supply network**

SWOT analysis can be used to evaluate the water supply network, see Tab. 2. The task of the SWOT analysis is to draw attention to all strengths, weaknesses, threats and opportunities of the solved system for drinking water supply in Hlučín and adjacent municipalities.

| STRENGTHS                                                                 | WEAKNESSES                                                                 |
|---------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Almost 98% of the population is connected to the water supply              | Unbalanced pressure conditions in the network                             |
| Minimal water losses (< 4%)                                               | Insufficient water accumulation for the Hlučín district                    |
| Water quality all hygienic requirements with reserve fulfilling           | Sometimes only temporary or cheap troubleshooting                         |
| Several water sources and feeders                                         | The reservoir supplying Darkovičky is not owned by the water supply operator|
| Own collection area                                                       |                                                                           |
| Sufficient capacity with regard to the development areas of the municipality|                                                                           |
| Relatively low failure rate                                               |                                                                           |
| The operator's effort to gradually reconstruct the water supply lines     |                                                                           |

| OPPORTUNITIES | THREATS |
|---------------|---------|
| Replacement of old cast iron and metal pipes with plastic ones           | Oversize of the network due to population decline                         |
| Construction of a reservoir to increase water accumulation and balance the pressure in the network | Insufficient amount of fire water in crisis situations                     |
| Introduction of quality records of failures and prediction of the need for reconstruction of individual water mains | Lowered water quality due to smaller abstractions                          |
| Introduction of predictive maintenance of water supply                   | Increased water loss                                                       |
| Increasing the number of people taking drinking water                     | Gradual reduction of yield of groundwater sources                          |
| Improving water quality                                                   | Possibility of water contamination caused by water supply failure or its leakage |

![Figure 7. Number of failures in years 2005–2018.](image)

**Table 2. SWOT analysis.**
Bad registration and documentation of the water supply network

The analysis proves that the solved water supply network has quite a few strengths, but there is much place for improvement. It is necessary to eliminate a relatively large number of threats and part of the weaknesses that the solved system for DWS undoubtedly has.

6. Optimization, adjustment, and building proposal
In this case, optimization is understood as a step to improve the operation of the system for drinking water supply in Hlučín, improve its maintenance, minimize its failures and the resulting costs. So far, failures have been recorded only on paper, using ie. fault sheets. The faults recorded on these sheets were subsequently scanned into electronic forms and apparently the faults were also recorded in the geoinformation system. [8,9,10]

![Figure 8. Representation of critical places on the water supply network of the town of Hlučín.](image)

6.1. Failure accident record sheet design
Existing fault sheets of VaK Hlučín s.r.o. they had certain shortcomings in the form of missing and defined fields of some information. A new record sheet for a water main accident was designed, which is inspired by the existing fault sheet, but is extended by some fields of important information and the fields for notes and situational drawings of the fault are newly defined in it. In the header of the sheet, the fields are defined for basic data to identify the failure. The first data is the registration number of the accident, followed by data on the location of the fault with GPS coordinates, time steps of reporting the fault, the start and end of its repair and information on whether the water was closed or the method of alternative water supply. In the main part, there are check boxes that indicate who reported the failure, the severity of the accident, the type of damaged equipment, the damaged part, the primary type of failure, material and DN of the profile, profile storage, primary and accompanying causes of failure and repair method. The fields are predefined and, if the given type of information is not in the lists, it is possible to use listing fields with the name “other” or a space for notes. In the footer of the sheet there is information about which technicians participated in the repair, who managed the repair, who filled in the record sheet and which person focused and drew the repair.

6.2. Division of the water supply network into rows
For better clarity and management of the water supply network, the system was divided into individual lines. The division is based on the location of the slides and the closability of individual branches or circuits. Each part that can be closed from both sides is considered as a separate series. If a row can be closed only from one side, i.e., there is a free-terminating branch, and is connected to a separate row, this branch is considered as a secondary row. The series that is then based on this series is secondary series.
Each cadastral area was divided separately, in the database there are series of designations HL as Hlučín, DR as Darkovičky and BR as Bobrovníky. Each individual row was assigned a letter of the alphabet. In the case of Hlučín, the alphabet was insufficient in its scope, so the letters two were used - AA, AB, … Continuing rows are then marked with a separate letter with a hyphen and a number. Sub-rows are marked with a letter of the alphabet with a hyphen, a number, another hyphen and a Roman numeral, see Fig. 9.

7. Conclusion
The city of Hlučín was selected for its specific position in the maintenance and management of drinkable water supply network. The municipality is the main owner and the main administrator of this technical infrastructure. For this reason, the availability of fault records, maintenance methods and other data is easier to get than those recorded by private companies. According to the analysis a total of 221 disorders occurred during the monitored periods. Most faults occurred in the cadastral area of Hlučín, which is understandable due to its size. Most failures, specifically 103 failures, were evaluated on the mainline. Cast iron pipes were identified as the most problematic, which were gradually transformed into plastic pipes in the last few years. Among the most common disorders the transverse fracture and leakage of joints appeared. The largest number of failures was recorded between years 2005 and 2008. Thanks to the high-quality database and the responsible approach of the network administrator, the administration gradually focused on a proactive form of management. The change in the approach led to a reduction in water losses in the network system from the original 9% to 4.5%. For this reason, it is obvious that the optimization of the water supply network could be assessed as very effective.

The fact that the water supply network supplies almost 14,000 inhabitants of the town of Hlučín was the impetus for the creation of this work. Drinking water is a basic human need and it is in the interest of all of us that its distribution be ensured in a high level of quality and should be treated in accordance with the sustainable development of the environment. Optimization ensures trouble-free operation of this system, points out problems and offers solutions. A passport of the existing drinking water supply system was prepared, including a description of its operation and maintenance system. A detailed analysis of faults recorded over the last 15 years has helped to identify the most problematic places in the network, pointed out the shortcomings of the existing fault recording and also the factors that cause these faults. Although the operation of the water supply network is affected by several factors, even those that cannot be influenced by human activity, its operation is still primarily dependent on it. Optimization depends on the consistent, high-quality and knowledgeable operation of the water supply network by its administrator. Insufficient funding could be the biggest obstacle to achieve the proposed optimization. The approximate calculation of investment costs for the replacement of pipes in the western part of Hlučín set the price of the proposed solutions at almost two million crowns. However, the costs do not include recommendations related to network monitoring, purchase of new equipment, training and staffing. These theoretical recommendations, if implemented, could reach investment costs in the order of tens of millions of crowns. One can only hope that there will be as few obstacles as possible to optimizing the drinking water supply system in Hlučín. Already such quality management can be improved by predictive maintenance, some of the lowest water losses in the country can be sustained, resulting in economic, environmental and high quality operation of the network, which provides life for about 98% of the population, including their fire safety. [13,14,15]
Acknowledgment
This work was supported by the means of conceptual development of science, research and innovation allocated to VŠB-TUO by the Ministry of Education, Youth and Sports of the Czech Republic.

References

[1] Christodoulou S E, Fragiadakis, M 2015 Vulnerability Assessment of Water Distribution Networks Considering Performance Data J. Infrastruct. Syst. doi 10.1061/(ASCE)IS.1943-555X.0000224
[2] Tichý T, Brož J, Bělinová Z and Pirník R 2021 Analysis of Predictive Maintenance for Tunnel Systems Sustainability 13 (7) p 3977 https://doi.org/10.3390/su13073977
[3] Tůhovcak L, Rucka J and Pirník R 2021 Analysis of Predictive Maintenance for Tunnel Systems Sustainability 13 (7) p 3977 https://doi.org/10.3390/su13073977
[4] Tichý T, Brož J, Bělinová Z and Pirník R 2021 Prediktivní využití diagnostiky pro údržbu telematických systémů Smart City Symposium (Praha IEEE Press New York NY USA) doi: 10.1109 / SCS249987.2020.9133818
[5] Beran V, Teichmann M, Kuda F, Zdarilova R 2020 Dynamics of Regional Development in Regional and Municipal Economy Sustainability 12 9234 doi: 10.3390/su12219234