Hydraulic Modelling, GIS and Leakage Management

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ABSTRACT

Demand management representing leak detection, location and repair, rehabilitation (replacement and relining), metering and pressure reduction has become a major concern in the water supply and water distribution industry.

Linking the hydraulic model to GIS and telemetry systems allowing the modeling of hydraulic, water quality and economical parameters is of a growing interest nowadays. The integrated model monitors the pressure and flow conditions in the network; the economical parameters are evaluated in a parallel and their optimization is enabled. Such model also assists the practitioner to determine the most appropriate response to unusual operating conditions and is used for planning of the future pressure zone development states.

The systematic approach to the demand management is illustrated on the pressure zone 405 Vypich, one of 160 pressure zones within the Prague water distribution network. The complete network data and the billing data is stored in the geographical information and customer information systems. Continuous leakage monitoring was undertaken and the complete information was entered into the hydraulic model. The results of the analysis were used in the process of leak reduction and pressure zone optimization.

INTRODUCTION

Leakage has become a major concern and the industry has reviewed all its methodologies and procedures in order to produce realistic estimates on which to base major investment decisions. Water supply and distribution network of Prague with nearly 1.3 millions of inhabitants is a complicated large-scale network. It is divided into 160 separate pressure zones, Fig.1. The database model of the network includes all network elements such as main pipes, valves, gate valves, air valves, hydrants and service branch pipes. Data is stored in GIS system, operational data in SCADA system and the data link to MIKE NET is the key premise for a pipe network hydraulic modelling.

Hydraulic modelling of water supply and water distribution network is used for planning linking-up consumers to the network and evaluating the remaining capacity of the network, planning of network's breakdown and miscellaneous loading states such as fire flow analysis and their impact on water supply system, reconstruction of existing and planning of new pipes, pressure zone evaluating and in comparing measured and simulated data.

Most critical parts of the distribution network are being reconstructed, hydraulic modelling is already seen as a necessary step in the planning process. A conceptual model with all important water tanks, pumping stations and water sources is being developed for the whole Prague water supply system. Such a model will greatly assist in formulating and answering supply strategies and providing high reliability of the system.

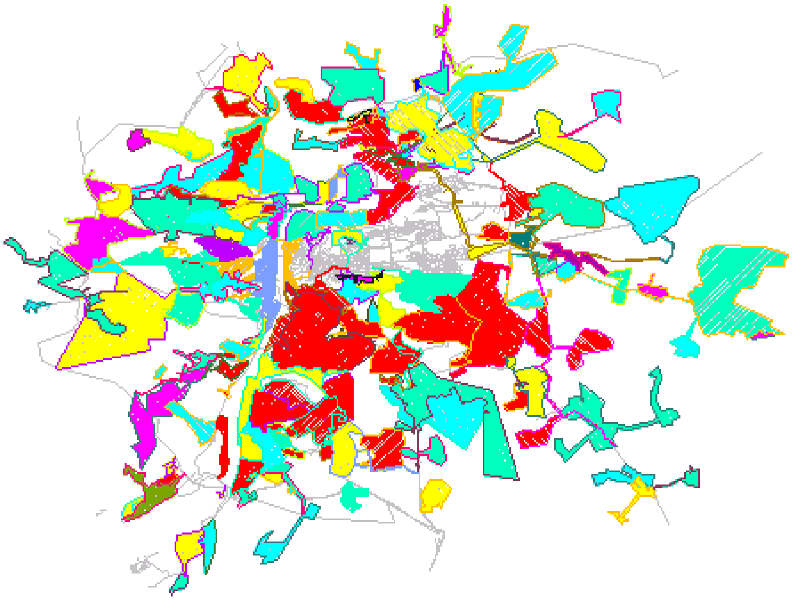


Figure 1 Prague water distribution system

Description of the Pressure Zone Vypich

Vypich Pressure zone is one of the zones with the highest surface elevation in Prague and it serves as a water source for Břevnova, Strahova, Střešovic, Liboce a Petřin districts. The residential type within the zone consists of housing estates, family houses and detached houses. The pumping station Vypich supplies the zone by the water from three different sources: Želivka 50%, Káraný 30%, Podolí 20%.

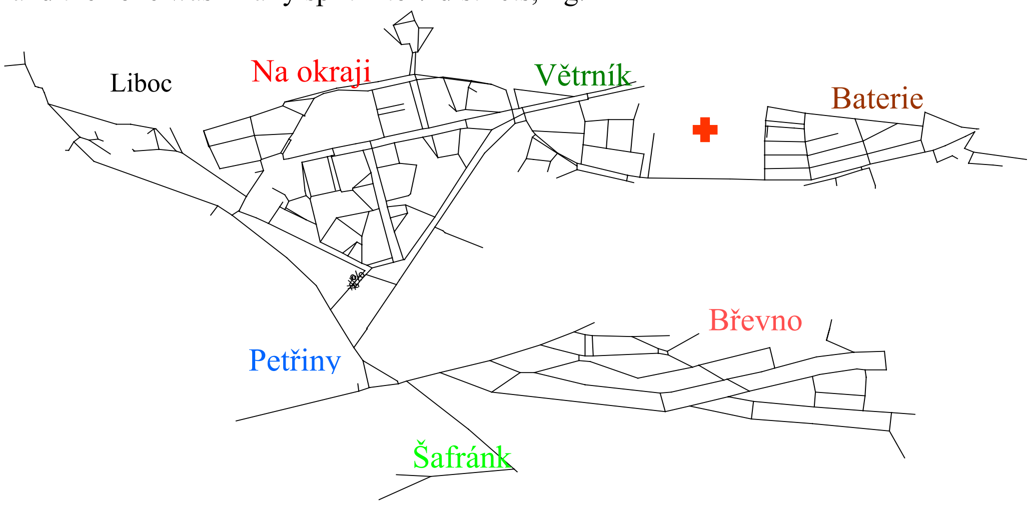
The minimum zone node elevation is 315.0 m, maximum is 370.0 m, the elevation difference is app. 55 m, while the ideal elevation difference would be 20-30 m [2]. The pipeline system was built up in 1930, with some of the pipes from 1910. The total pipe length is 43 km, the equivalent pipe length is 41.5 km.

Remark: the equivalent pipe length is equal to the pipe length of pipe diameter of 150mm, which has the same perimeter as the original pipe. The equivalent pipe length is used widely in order to compare the leakage from different zones.

There is one large water consumer – Military Hospital Střešovice within the zone, with the average demand of 14,78 $l.s^{-1}$.

The water distribution network has a high level of breakdowns and it is therefore systematically observed since 1994 when the zone boundaries were fixed by the means of zone valves. The zone inflow as well as the minimum flow during the night hours is carefully monitored and compared to the invoiced water quarterly.

The first flow measurements were conducted in 1993, when the first zone districts were isolated during the night hours and the zone inflow was observed. The leakage rate in the whole pressure zone was estimated based on these observations. Another problem was caused by the old and non-functioning zone valves; all these valves were replaced by the ***Fig. 2*** Scheme of the pressure zone Vypich new ones and the zone was finally split into 7 districts, fig.2



Figiure 2

With respect to the well permeable sub-soil (unstable cracked arenaceous marls), most of the breakdowns are not visible on the surface but rather hidden. The breakdown evolution is significantly higher than in other cities, as it is shown in the Table 1, [4].

Table 1 Breakdown statistics in the selected European cities

City	Breakdowns Count/Km/Year
Gent	0.15
Mnichov	0.15
Antverpen	0.15
Copenhagen	0.16
Helsinky	0.17
Stockholm	0.18
London	0.20
Budapest	0.25
Zurych	0.30
Oslo	0.30
Milan	0.35
Amsterdam	0.70
Vienna	0.90
Hamburg	0.90
Prague	1.32
Pressure Zone Vypich	**1.86**

The detailed and up-to date hydraulic model was developed as part of the systematic approach to the leakage control and reduction of the zone. The hydraulic model, combined with the reduction of the unaccounted demands, and replacement of the over-sized water meters helps to locate the leakage, open pipe culverts and closed pipe interconnections and to optimise the pressure and flow distribution.

The Hydraulic Model

The hydraulic and water quality analysis was performed by MIKE NET. MIKE NET, DHI Water and Environment is the professional engineering software package for the simulation of flows, pressure distributions and water quality of pressurised water distribution systems. MIKE NET can be used in order to perform steady state analysis, extended period analysis and water quality analysis on any size of water distribution and water supply networks. Worldwide accepted industry standard numerical engine EPANET 2.0, EPA, Cincinnati, USA is included.

MIKE NET provides you with a wide range of tools enabling easy and both directional linkage to GIS systems such as FRAMME, SMALWORLD, ArcView, MapInfo. Any sort of ODBC (Open Database Connectivity) compliant database systems such as ORACLE, SYSBASE, INFORMIX, Microsoft Access, Dbase can be accessed. Multiple geocoding routines are used in order to import, export, update and maintain external data including complex manipulation of billing records from the customer information systems.

Unique SCADA interface allows you to link MIKE NET to SCADA (Supervisory Control and Data Acquisition Systems) and to perform on-line modeling in the infinite loop. This greatly assists you in the process of auto-validation and auto-calibration of the pipeline system and allows you to model hydraulic, water quality and economic parameters in the real time.

Various optimization techniques can be used in order to optimize the pressure and flow distribution, leakage reduction and energy costs distribution within the pressure zone models. Modeling tool for breakdown simulation, planned infrastructure development, fire flow analysis, leakage reduction is the most important in the process of network maintenance and manipulation.

The geometrical and descriptive data were taken from the GIS system and the detailed mathematical model was developed. The node elevations were interpolated from the digital model of terrain – constructed by digitising the contour maps.
The water consumption data was taken from the existing billing database. The average demand was calculated for the time period of the last 3 years. These averaged consumptions were compared to the actual ones as part the network calibration.

The impact of the large water consumer – the military hospital is shown in the Fig 3, its demand is almost 7x higher than the second largest demand.

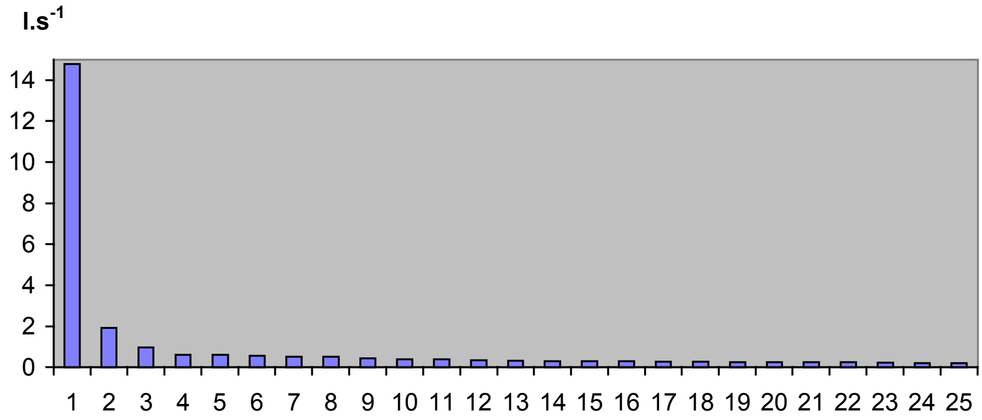


Figure 3 The large water consumers in the pressure zone ČS Vypich

The results from the night hours observations were carefully implemented into the model. These are especially the extents and locations of the leaks within the zone districts.

The fictive nodes – corresponding to the leak spots were introduced into the model and modelled as a time dependent demands with their own diurnal curve. As the pumping station pressure was lowered automatically during the night hours (12 am-5 am) the leak diurnal curve was supposed to be constant during the simulation period, Fig.4.

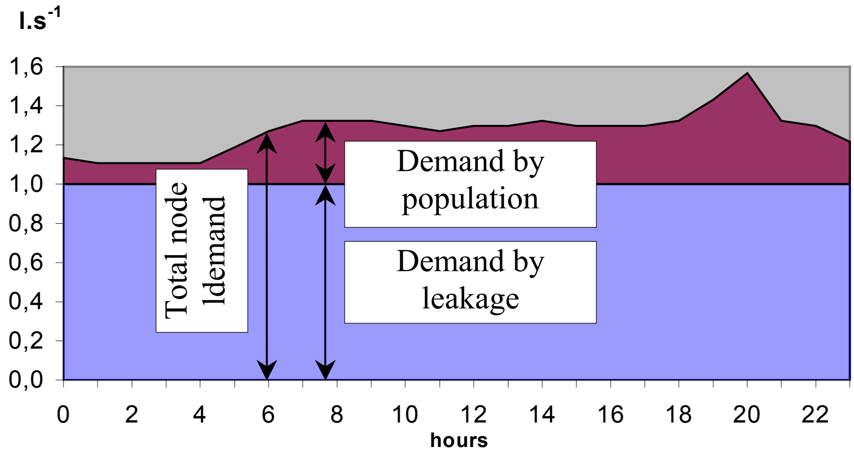


Figure 4 Water consumption and the leakage distribution

The model calibration was performed in two steps, macro-level calibration and micro-level calibration. The pressure sensors and flow meters were installed over the zone in order to get the calibration data. The pressure sensors recorded the pressure distribution within the 30 second intervals during the whole day, the flow was recored within the time step of 6 minutes.

The hydraulic model alternatives:

- Optimum flow distribution within the zone
- Alternative supply of the Liboc district from another pressure zone
- Pumping station Vypich reconstruction based on the pumps equipped by the frequency regulation
- Pressure zone split into the two separate zones with respect to the residential type and zone elevation distribution
- Overall pipe reconstructions within the zone
- Fire flow analysis
- Water age analysis

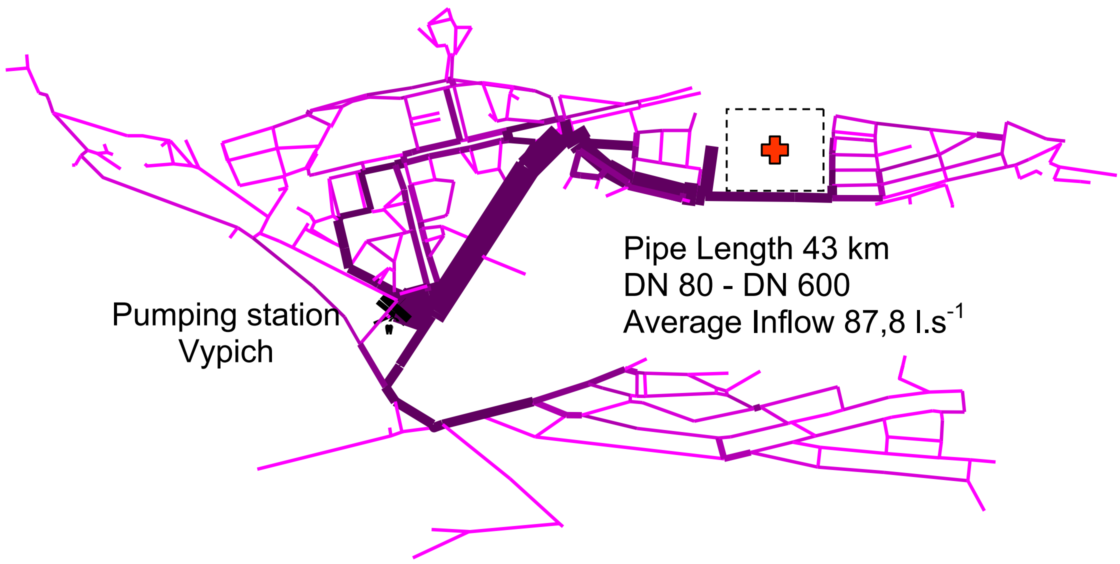


Figure 5 The flow distribution

THE CONCLUSION

The hydraulic model results shown that the water distribution network is over-sized and that the pumping station operation schedule is not the optimum one. With respects to the terrain configuration and/or unfortunate residential type, the present water supply scheme is not suitable. The maximum pressure criterion is one of the main objectives; the pressure one of the lowest parts of the pressure zone is exceeding 105 m. Also, the model calibration and verification raised up the assumption of closed valves in the zone and/or the presence of the highly incrusted pipe segments, Fig. 6. However, with regards to the poor network state and not functioning valves it was not possible to prove it fully.

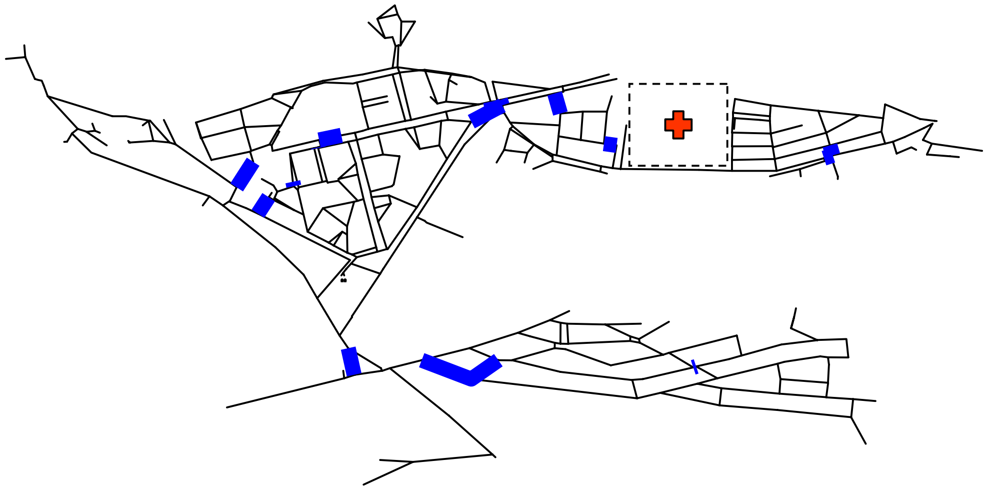


Figure 6 Possibly closed valves and/or high pipeline incrustation

The following steps were made in order to improve the zone operation:

- Split the zone into two separate parts with respect to the residential type and the terrain elevation
- Renovate the pumping station Vypich by the pumps equipped with the frequency regulation
- Supply the Liboc district from another zone
- Check all places where the closed valves are expected
- Replace the selected over-sized water meters
- Continue the systematic approach of leakage detection within the zone

The overall pipe network renovation will be conducted as part of the "Systematic Network Program Rehabilitation". One of the project alternatives was therefore focused on the pressure and flow distribution after the overall pipe replacements. The pipe roughness reduction, hidden leakage elimination, and elimination of the possible closed valves are the main issues in the case.

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