Conceptual strategy for minimizing leakages in water supply systems

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Abstract: Operational and infrastructure problems in water supply systems are usually closely dependent on each-other. This paper presents two case study results where a complex strategy was applied in the form of water supply system master plans for optimization of the water supply systems, reducing leakage, securing capacity for future development, reconstruction plans, etc. The mathematical model applied was based on extensive in-situ measurements and used to closely monitor existing problems in the water supply system with detailed solutions. The applied approach resulted in great technical outputs and financial savings such as:

i) Leakage detection activities resulted in quick leakage reduction by 30%. As result, more than 50% return of the Master plan cost was achieved just during the project period by this particular task.

ii) The future urban development causes increased consumption by 20-25%. Due to this, the existing reserves in water sources capacity would be spent in 10-20 years. Therefore the leakage reduction strategy was set as fundamental principal for keeping water balance in the cities and keeping reasonable reserve of water sources.

iii) A lot of small but very important investments such as new pressure reduction and flow measurement sites, short interconnections, local pumping stations etc. were proposed in order to combine solution of several tasks: a) Pressure optimization taking into account the resulting pressure above the roofs – reduction of pressure by 0.1-0.3 MPa in critical zones b) Optimization of system of measurement, supply zones and DMAs – The average length of DMA size dropped from 15 km to 9 km c) High standard and security of water supply for new development areas and existing customers under standard as well as exceptional situations. d) Solving of the water quality problems caused by instability of flow conditions in some parts of the system. e) Reconstruction plan of water distribution system based on multi-criteria analysis, where leakage and pipe burst reduction plays fundamental part

Key words: water supply, master planning; water losses, financial optimization; economic level of leakage.

1. INTRODUCTION

Operational and infrastructural problems in water supply systems are usually closely dependent on each-other. As for example, low capacity of water sources depend on leakage level, leakage level is dependent on pressure conditions, DMAs, measurement conditions and technical conditions of the network. Pressure optimization and establishment of DMAs must take in account future urban development, actual operational problems etc. Occasional water quality problems mainly represented by high turbidity in the water distribution network are very often caused by unstable flow conditions. Suggestions for a successful remedy are usually interconnected with all other proposed measures.

There are usually common technical measures for solving most of the problems such as separating the main trunk pipes from reticulation pipelines and establishing regular supply zones of appropriate size and borders with inflow measurement and pressure reduction. But usually the task is not simple. In many cases water is transported to elevated areas of the terrain across the lowest part of the WSS, pressure has to be maintained at high level due to few high buildings etc.

The complexity of the solution is increased by future urban development which has to be taken into account during the pressure optimization process. Pressure reduction and closing pipes for establishing DMAs decreases the capacity of water distribution system. It has to be proven that applied optimization measures will not limit the system for future urban development.

This paper illustrates the methodology and results of two Case Studies of Water supply system Master plans for the Cities of Usti nad Labem and Teplice, where the NRW tasks played the key role.
2. CASE STUDIES – BASIC INFORMATION

The Cities of Usti nad Labem with 100 thousand inhabitants and Teplice with 50 thousand inhabitants are typical mid-sized municipalities in the northern part of the Czech republic. As the water source for both cities serve the North Bohemian regional water transmission system. The reserve in system capacity for both cities is approximately 25% of the maximal daily demand. The network is separated into many supply zones due to uneven terrain; however the existing size and other conditions are not optimal. Despite the extensive use of modern leakage detection methods, the leakage level for both cities was approximately 35%. The projection of the consumption due to future urban development is 20-25% of the existing demand.

The WSS Master Plan was provided for both Cities in years 2008 – 2010. Contributors of the project were SVS a.s (owner of the infrastructure) together with SCVK a.s. (WSS operator).

3. MAIN CHARACTERISTICS OF THE MASTER PLAN

The methodology applied for the Master plan is based on the following key parts.

3.1 Building and usage of the mathematical models

A combination of measurements and mathematical modelling application was applied in order to describe in detail the processes in the distribution network. The calibrated mathematical model is used for evaluation of the existing water supply system and identification of system bottlenecks and their reasons. The model is a basic tool for optimization of future system and for evaluation of efficiency of all proposed solutions.

3.2 Basic measurement campaign

The measurement campaign was divided into two phases. The basic measurement campaign was applied for the whole water supply system. The SCADA flow and pressure measurements were supplemented by temporary flow and pressure measurements. Ultrasonic flow meters were installed in key manholes in order to observe main flow directions, measure inflow in smaller areas of the network and for measurement of consumption time pattern of big customers. Registration pressure loggers were installed at fire hydrants.

The measured data were used for the model calibration, leakage distribution in the supply zones and sub-zones and for indication of the operational problems.

3.3 Detailed leakage survey

The high leakage contributed to approximately 35% and this was one of the main problems of
the water supply system. Even though the operator has used modern leakage detection methods, the leakage detection actions in some areas were not satisfactory as many small leaks were detected but the major leaks remained.

![Image of temporal pressure and flow measurement equipment and fire hydrant tests](image)

**Figure 2. Example of temporal pressure and flow measurement equipment and fire hydrant tests**

The detailed leakage detection using the method of night measurement by ultrasonic flow meters of inflow in small separated districts and consumption of big customers was applied. A very complex survey was done in the City of Teplice. Based on the basic measurement campaign results, 58% of total network length with almost 95% of total leakage was inspected.

The survey indicated about 20% of pipelines with the highest leakage. As a result, reduction of leakage level by more than 20% in Usti nad Labem and more than 30% in Teplice was achieved during the project period (1 year).

![Image of detailed leakage survey – Thematic map of network areas by leak in l/s. The major repaired leaks are indicated by red circles (Teplice)](image)

**Figure 3. Results of detailed leakage survey – Thematic map of network areas by leak in l/s. The major repaired leaks are indicated by red circles (Teplice)**

The results of used method indicated indicate a great potential for the method used. The achieved savings of leakage was 31 l/s, i.e. reduction of the leakage by 43%. Financially the water saved corresponds to 180 000 Euro per year.

### 3.4 Implementation of Leakage Monitor – a technology for technical and economical optimization of the leakage

Dividing the water supply network in the DMAs is usually the most efficient long-term approach to the leakage reduction. However, the success depends on right sizing and prioritizing of districts as well as appropriate approach to collection, validation and evaluation of obtained data as well as good interpretation and usage of gained results.

Leakage Monitor is a software and implementation for complex data collection and tasks solution connected with leakage evaluation, technical and economical optimization working as utility information system.
Leakage monitor runs all analysis and prepares all outputs automatically at chosen time (i.e. 5 AM). Evaluation of leakage in DMAs is based on analyses of measurement data by the SCADA system as well as from GSM and GPRS devices. Data are processed and stored in a central database. The results of the evaluation can be checked by the Leakage Monitor user interface from any place in utility intranet. Leakage monitor also generates daily reports and provides water supply operator with the actual data analyses via intranet.

Figure 4. Data collection and result distribution working scheme of Leakage Monitor

The night inflow is summarized from all inflow/outflow sensors and used for evaluation of leakage. The consumption of big night customers is considered and night consumption of other customer can be either calculated or manually entered. The second supported method of NRW volume evaluation is comparison of inflow in a DMA after invoiced and self-consumption. All analyses are done automatically.

Figure 5. Automate evaluation of leakage (black line) from night inflow in a supply zone
Leakage Monitor evaluates and stores all important changes of leakage in a DMA. The operator can easily obtain information about historical leakages in a DMA.

The Economical level of leakage in a supply zone is calculated based on balance between possible cost savings on leaking water and costs of leakage reduction works. The evaluation of the possible cost savings on leaking water considers:
- actual level of leakage in a supply zone
- level of leakage that is possible to receive after leakage reduction actions
- price of leaking water
- dynamics of the leakage creation

The costs of leakage reduction works is calculated based on evaluation of unit price of the typical leakage detection actions and extent of such actions needed in a supply zone. Some of the inputs must be estimated based on operator’s experience at the beginning. However the system can be adapted very soon to the real and representative data.

The main economic indicators evaluated for each supply zone are:
- Return period of the costs of leakage reduction works in months
  It indicates supply zones, where will be leakage detection works most efficient
- Economical leakage level for selected return period in l/s
  It indicates difference of the actual leakage from the level that is worth to solve from economical point of view.
- Time to reach the economical leakage level

All economic indicators are presented in complex but simple outputs and serve for effective planning of leakage detection works.

Leakage monitor is usually used as a part of NRW reduction project, however it can be implemented as independent tool immediately whereas the implementation period is few months.

The Leakage monitor system can be administrated by water utility but also remote administration and supervision can be provided by DHI.

### 3.5 Infrastructure rehabilitation plans

The infrastructure rehabilitation plans include both, the system structures (i.e. water tanks, pumping stations) and distribution pipelines. The rehabilitation plan of the distribution system is based on a tool that is a part of the modelling software. This simplifies the data processing and allows the transfer of simulation results data as inputs for the rehabilitation plan. The rehabilitation results are sent back to the model. The results of the rehabilitation planning are used for the proposal of new investment in the model.

The rehabilitation plan is based on the evaluation of several technical parameters (material, age, failure rate, leakage). The tool simulates deterioration of the distribution network and process of its rehabilitation in the next period of 30 years. Based on the results the future development of network age, leakage, number of failures and corresponding operational costs can be evaluated. The results
are different for methodologies implemented in the tool for the simulation. The variants of the distribution system rehabilitation are compared regarding the economical evaluation of both investment costs and operational costs and finally, the most effective variant is selected.

**Figure 7. Comparison of leakage reduction works costs (blue columns) with possible cost savings on leaking water (green columns) and return period index**

**Figure 8. Evaluation of leakage results in map**
3.6 Conceptual solution of the WSS development

Detailed evaluation of the existing hydraulic and water quality conditions indicated several operational problems, especially high and oscillating pressures, occasional turbidity problems and locally low pressures. The size of some supply zones and the flow measurement is not appropriate for efficient leakage evaluation. Several parts of the water supply system are in danger under exceptional situations such as flooding and failures of main pipelines.

The Urban master plan indicated huge urban development in some areas. Total increase of the water demand due to planned urban development achieved approximately 25%. The leakage reduction has been indicated as a main proceeding for keeping sufficient reserve in water sources. As a result high attention was paid to optimization of the existing WSS.

3.7 Investment plan

The proposed investment targeted the following objectives:
- Secure sufficient water resources by keeping sufficient reserve for urban development of the city
- Avoid risks during exceptional situations
- Establish sufficient conditions for sustainable and efficient system operation
  - Elimination of existing operational restrictions
  - Pressure optimization
  - Separation of distribution system in efficient supply zones and DMAs
  - Upgrade monitoring system for efficient evaluation of night flows and leakage
Most of the proposed investment represent small local investment actions such as new manholes with new PRV and flow meter, supply existing manholes with flow measurement with data transmission, new valves etc.

Figure 10. Examples of evaluation of the water supply conditions in proposed future system and evaluation of the water balance.

Figure 11. Example of proposed Investment plan - individual actions by priority (Usti nad Labem)

4. CONCLUSION

The applied Master plans of WSS solved the following tasks and achieved the following results:

- Leakage detection activities that conducted the fast leakage reduction by 20, resp. 30%. As result, more than 50% return of the Master plan cost was achieved just during the project period by this particular task.

- The future urban development causes increased consumption by 20-25%. Due to this, the existing reserve in water sources capacity would be spent in 10-20 years. Therefore the
leakage reduction strategy was set as the fundamental principal for keeping water balance in the cities and keeping reasonable reserve of water sources.

- A lot of small but very important investments such as new pressure reduction and flow measurement sites, short interconnections, local pumping stations etc. were proposed in order to combine solution in several tasks:
  - Pressure optimization taking in account the resulting pressure above the roofs – reduction of pressure by 0.1-0.3 MPa in critical zones
  - Optimization of system of measurement, supply zones and DMAs – The average length of DMA size dropped from 15 km to 9 km
  - High standard and the security of water supply for new development areas and existing customers under standard as well as exceptional situations.
  - Solving of the water quality problems caused by the instability of flow conditions in some parts of the system.
  - Reconstruction plan of water distribution system based on multi-criteria analysis, where leakage and pipe burst reduction plays a fundamental part

Combining solved tasks is important for the financial optimization of the planned investment. The mathematical model proved that the proposed investment will achieve the desired high water supply standard for existing and future water supply system under cost reduction.

Necessity of interconnection of pressure- and other operational optimization with planned urban development was proved in many places. Proposal of pressure optimization and division of the water distribution system in DMAs without a conceptual system design can easily create an incorrect technical concept resulting in an uneconomical investment.

Complex solving of interconnected operational and conceptual problems leads to high investment and operational savings. Extensive collaboration with the infrastructure operator is essential for the success of the measurement campaigns and immediate leakage reduction. The data analysis brings new information that can be specific for different locations. The applied methodology has to reflect new findings and has to be modified in the process of the project building. The active involvement of the infrastructure owner in the project processing is unavoidable.

The Leakage monitor was implemented and is systematically used by the Water utility. It provides immediate overview of the actual situation in leakage and serves for prompt planning of leakage detection based on economic indicators. The tool helped decreasing leakage and after that is used for managing leakage at low and economically optimal level.