OPTIMIZATION OF PARAMETER SETTINGS IN PRESSURE MEASUREMENT USING ASTACUS TECHNOLOGY TO ACHIEVE STATISTICALLY REPRESENTATIVE ESTIMATION OF PRESSURE RATIOS IN THE WATER SUPPLY NETWORK

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Abstract

Reliable operation of public water supply systems requires a detailed understanding of pressure conditions within the network. Accurate pressure assessment involves extensive in situ measurements followed by statistical analysis. Key questions arise about the duration, location, methods, equipment, and frequency of such measurements. Since water pressure fluctuates due to flow dynamics and reservoir levels, this study analyses large datasets from various campaigns across multiple water networks.

Keywords

Water supply network, Pressure conditions, In situ measurement, Statistical analysis, Astacus technology

1 INTRODUCTION

Ensuring optimum pressure ratios in drinking water supply systems is key to proper functioning and minimizing the costs of operating water supply networks. In the conditions of the Czech Republic, the pressure ratios in the public water supply network are regulated by Decree No. 428/2001 Coll., which implements Act No. 274/2001 Coll., on water supply and sewerage for public use. This Decree lays down the technical requirements for the construction of water supply systems, including specifications relating to the pressure ratios in the network. The maximum overpressure at the lowest points of the water supply network in each pressure zone must not exceed 0.6 MPa. In justified cases it may be increased to 0.7 MPa. For developments of up to two storeys, the hydrodynamic overpressure in the distribution network shall be at least 0.15 MPa at the point of connection of the water supply connection. For buildings over two storeys, at least 0.25 MPa [1]. The optimum value in the distribution network is then usually considered to be between 0.35 and 0.45 MPa, unless special requirements are placed on the site to ensure higher pressures, e.g., for the supply of tall buildings. If the water supply network is also used for fire water supply, the Czech technical standard ČSN 73 0873 enters this issue, which prescribes that a static overpressure of at least 0.2 MPa must be ensured at the most unfavourably located hydrant for fire water supply [2].

Optimizing the pressure in the pipeline is a key prerequisite for reducing water losses caused by leaks [3]. It has also been shown in studies of real water networks that networks with lower pressure have lower failure rates [4]. On the other hand, to ensure sufficient hydraulic capacity of the water supply network and to reach the limits prescribed by legislation, it is necessary to maintain a certain required overpressure. Improperly regulated pressure ratios can lead to serious damage to the pipelines, which further increases maintenance costs and limits the functionality of the network [5]. Modern technologies, such as pressure control valves and IoT monitoring systems, not only reduce leakage but also increase the energy efficiency of the network [6]. Therefore, operational practices are increasingly incorporating advanced pressure control methods that combine automation with advanced algorithms to predict and control pressure ratios in real time [7].

Mathematical modelling of water supply networks is a key tool for analysing and optimising their operation. It allows the simulation of the hydraulic behaviour of the network, identifying potential problem areas and designing effective solutions to ensure a reliable water supply. To achieve accurate results, model calibration is necessary,

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which consists of adjusting selected parameters based on real measurements of pressures and flows in the network. This process involves conducting hydrant tests to measure pressure losses and flows in different parts of the network, allowing the model to be accurately adjusted to match actual operating conditions.

The calibration of the water network simulation model can preferably be done by using flow and pressure data measured in situ during hydrant tests and controlled flushing of the pipelines. Metering campaigns are a relatively costly activity if they are carried out specifically to measure hydraulic quantities on the network. Therefore, we see a significant advantage in obtaining this data free of charge as a side benefit during normal pipeline cleaning by controlled flushing, as offered by Astacus technology, which allows continuous measurement of pressure, flow and temperature of the discharged water during flushing. Pipe flushing is a specific hydraulic loading condition that replaces the dynamic hydrant test that is usually performed to obtain calibration data. It could therefore be used to obtain pressure and flow measurements of sufficient quality to be used for model calibration. The present study presents a more detailed analysis and reflection on how the data should be measured during the flushing process and subsequently processed to be most usable. The study presents a proposed methodology to enable the calibration of a mathematical model of the water supply network using data from Astacus technology.

2 METHODOLOGY

Measurement

For this study, a measurement campaign was selected to obtain detailed information on the pressure conditions in the water supply network, which was used to calibrate the mathematical model of pressure changes and optimize the operation of the water supply network. The pressure sensor is normally fitted to an underground hydrant. After seating and tightening, the hydrant gate valve must be opened to the maximum possible extent.

In total, measurements were taken at 15 locations covering key network nodes such as pressure zone inlets, reservoir outlets, and distribution branch end points. The locations were selected based on the dynamic characteristics of the network and the required accuracy of the model. The selection of the sites was based on an analysis of water consumption in the areas, considering high- and low-flow areas, which allowed for obtaining representative samples for different operational scenarios.

The measurements were carried out using Sebalog P-3-Mini precision digital pressure sensors with certified accuracy of <1% in the range of 0–25 Bar (Fig.1). The instruments were regularly calibrated. The length of the measurement campaign was set at 14 days, which allowed for capturing both daily and weekly cycles of pressure changes in the water supply network, including the effects of operational peaks and nighttime lulls.

Fig. 1 Location of the measuring device [8].

The pressure sensors were set to record four readings per minute, i.e., at 15-second intervals. This interval was chosen based on previous studies, which have shown that it provides sufficiently fine resolution of dynamic pressure changes without overtaxing the recording device capacity. The selected measurement frequency was able to capture rapid changes in network pressure, such as sudden shifts in consumption or water supply, while providing sufficient statistical representativeness for trend analysis.

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Preprocessing

All raw data was cleaned of gross errors, such as power failures, recording errors, or abnormal values before the analysis began. After data cleaning, the records were grouped into hourly intervals, allowing for subsequent visual assessment and detection of any anomalies. The hourly interval was selected based on specific water consumption requirements, and the hourly aggregation proved to provide a balanced view of pressure conditions without too much variance. These findings can be seen in Fig. 2.

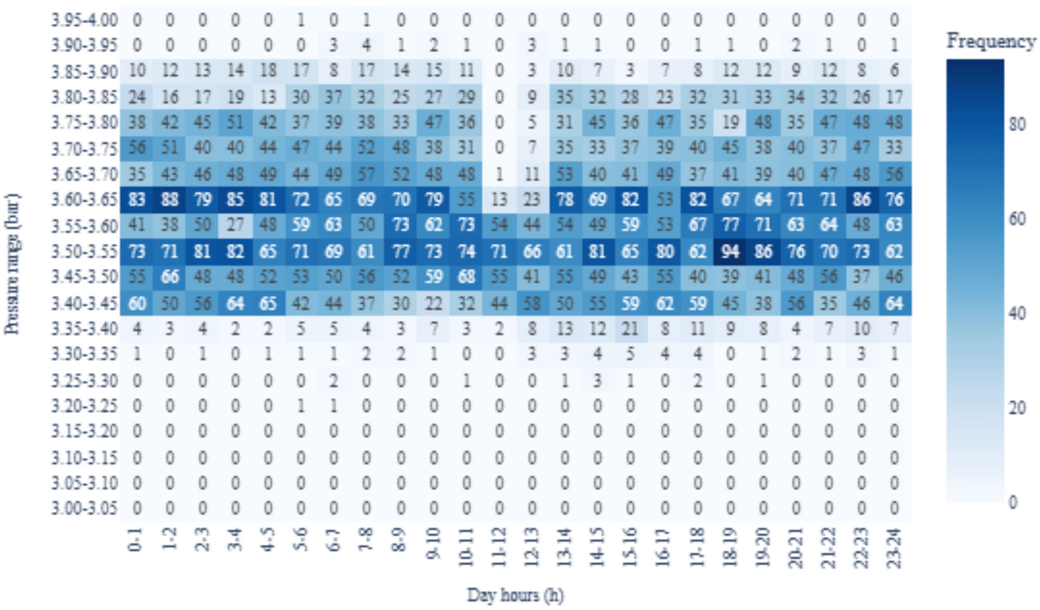

Fig. 2 Frequency of occurrence of pressure during the day APS.

The figure can be interpreted to show that in the range of 11–13 hours, we detect the smallest scatter in the measurements. On the other hand, between 7–9 hours, we can observe a balanced number of values for the interface pressures. There is a large variability of pressures and therefore a large dispersion.

Basic parameters such as mean, median, and standard deviation were used for statistical analysis, which provide a quick overview of the pressure behaviour in the network. These values also provide a basic statistical picture of the data and its validity for this study.

Processing

To reduce the number of measurements but maintain a high probability of finding a mean value for the hourly interval, it was necessary to choose a performance evaluation method. Again, visual inspection of the data was required for better orientation, with histograms for each hourly interval displayed (see Fig. 3).

On the graph, 24 subplots can be seen, which represent individual hourly intervals. For each subplot, it is possible to see a histogram showing the distribution of values. The X and Y axes of each subplot are consistent. It is therefore possible to observe pressure fluctuations, with histograms shifting more to the right at certain hours and to the left at others. This phenomenon is related to water abstraction and level movement in the water reservoir.

Each one-hour interval contained 240 records. These records were then divided into smaller datasets that were analysed based on the number of measurements, ranging from 20 to 240 samples of 20 measurements each. The mean and standard deviation were calculated for each block of data. This procedure was repeated for all hourly intervals.

Several methods were used to assess the representativeness of the data samples. One of the methods was evaluation using a Z-test, which is a statistical test suitable for datasets with enough samples (at least 30) and a known standard deviation. This test returns a p-value to assess whether the sample results are statistically significant. The

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disadvantage of the Z-test is that if the tested data blocks are asymmetric or show significant deviations from a normal distribution, inaccuracies in the assessment may occur.

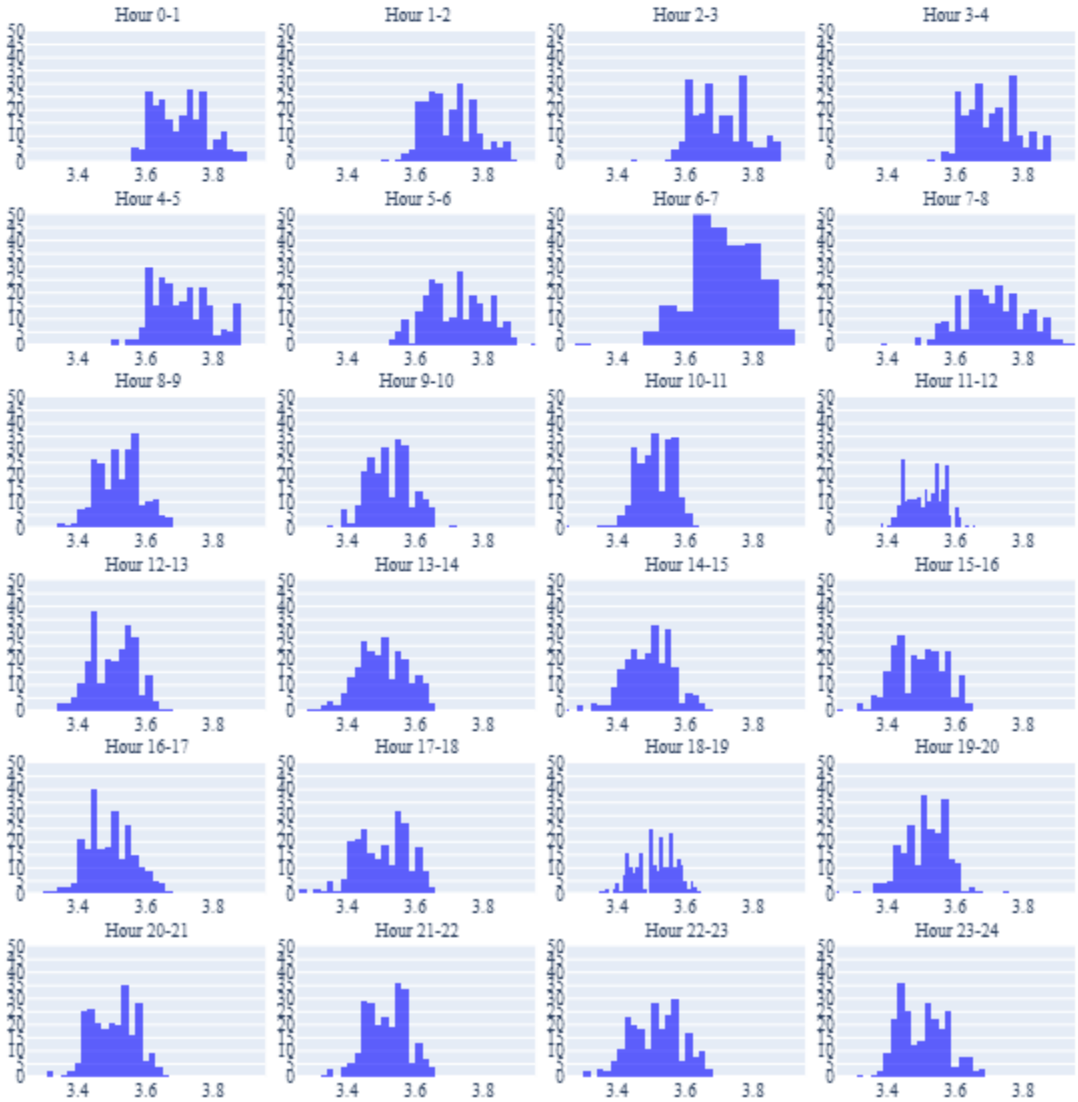

Fig. 3 Histograms of pressure for 2023-05-10.

Post-processing

Data analysis in Python enabled efficient processing of large datasets. The output of this analysis was CSV files containing hourly means, medians, standard deviations, and p-values for each site. These data were then used to create graphical outputs showing the spatial distribution of pressures in each section of the water network. The graphs and tables provide a visual overview of network performance and assist in real-time pressure optimization decisions.

3 RESULTS

For the study, data were aggregated into hourly intervals. This interval was also chosen in relation to the mathematical modelling of water supply networks. Another factor was the connection to SCADA systems commonly used by water utilities.

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The Z-test was used to analyse the temporal variability of pressure changes. The Z-test is a statistical method used to test hypotheses about the population mean when the variance is known. This test is based on a standardized normal distribution. The Z-test formula used was as follows:

$$Z = \frac{\bar{X} - \mu}{\frac{\sigma}{\sqrt{n}}} \tag{1}$$

where: $\bar{X}$ is the arithmetic mean of the sample, μ is the hypothetical population mean (the value in the null hypothesis), σ is the standard deviation of the population, n is the sample size.

The Z-test was used to analyse the temporal variability of pressure changes (1). The results showed the following trends (Fig. 4):

- The time intervals between 7:00–9:00 and 19:00–20:00 show lower p-values, indicating higher variability in network pressure during these times.
- Intervals between 23:00–1:00 show high p-values (yellow colour in the heatmap), indicating more stable pressure conditions.

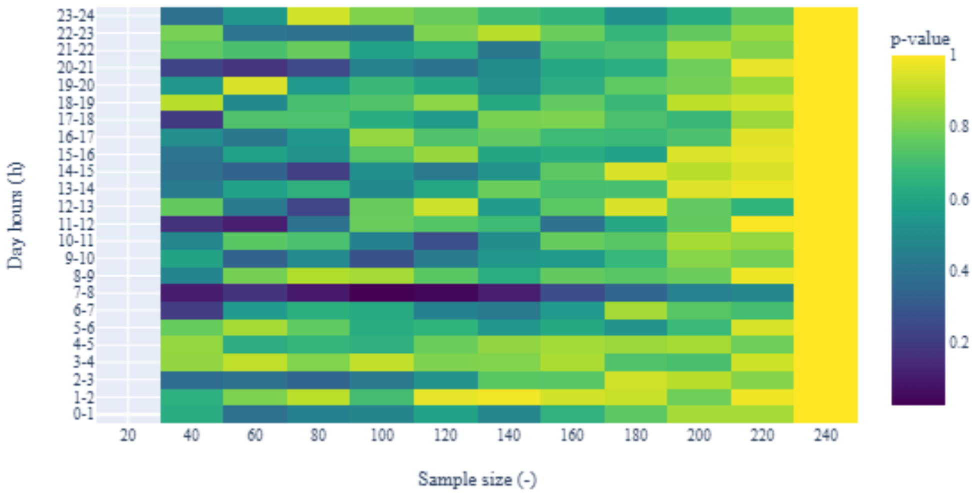

Fig. 4 Heatmap of p-values (Z-test).

It can also be observed from the figure that if there are less than 30 valid values, the Z-test is not performed (first column). On the other hand, if there are 240 values, one can expect 100% agreement with the standard deviation, as indicated by the last column coloured yellow. These findings are entirely consistent with the distribution of values, i.e., the variability of pressures.

After evaluating all statistical indicators, the ideal number of measurements appears to be 120 values. This value showed the best agreement with the complete dataset (240 values). Also, the standard deviation was optimal for 120 values.

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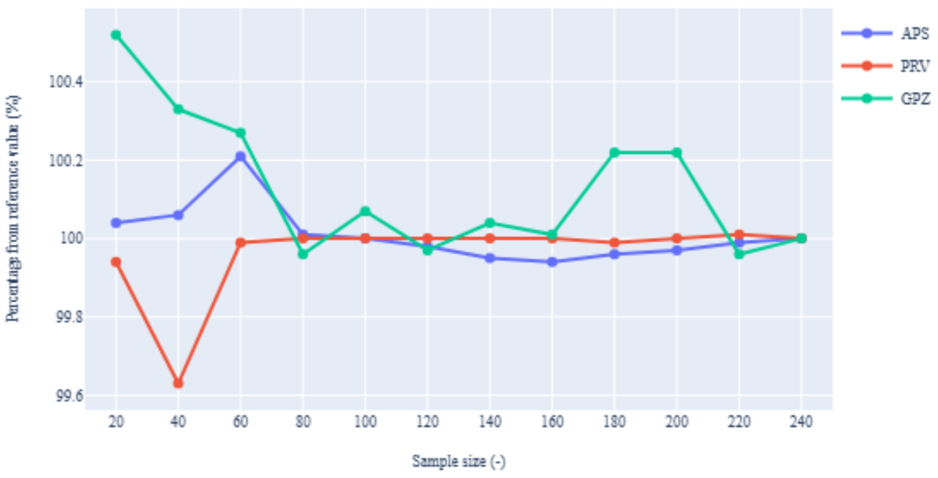

Fig. 5 Comparison of sample sizes.

In Fig. 5, it is possible to observe how the percentage of mean pressures was achieved when using a single number of values depending on the location.

Furthermore, an evaluation of 120 measurements between each measurement point versus time was made, and the relative standard deviation (RSE) was calculated for selected sites.

4 DISCUSSION

The results of the analysis show that the pressure ratios in the network are influenced by the measurement location, with smaller deviations in the areas downstream of the reservoir than at the end points of the network, where pressure differences are more pronounced. This is not surprising, as there are several known factors involved in the variability of network pressures. One factor is the roughness of the pipeline in question. These findings, however, confirm the need for an individual approach to data assessment in different parts of the network.

The interpretation of the time intervals between 7:00–9:00 and 19:00–20:00, which show lower p-values, suggests higher pressure variability at these times. This may be due to increased traffic or surge water withdrawals during the morning and evening peak hours. Conversely, higher p-values between 23:00–1:00 indicate more stable pressure conditions, which may be the result of lower withdrawals and reduced traffic during these hours.

These findings have a direct impact on the optimization of metering campaigns and can serve as a basis for a better understanding of the dynamics of the operation of a given water network. They can also help to optimise the management of pressure control elements and reduce water losses. Water losses are another direct factor influencing the pressure levels in the water network.

Identifying a minimum number of measurements that provides reliable results allows for flexible planning of measurement campaigns and ensures operational stability. It will be necessary to further validate these conclusions on a wider range of water supply networks and in different operational configurations to ensure their universality. This is precisely the limitation of this proposed method, so it will be necessary to analyse multiple networks with multiple specific locations, e.g., downstream of a pressure-reducing valve.

Cost reduction should be an aspiration for network operators. However, a metering campaign is a major financial burden, and rightly so, as it is a very specific task that is challenging in many ways. Astacus technology (Fig. 6) could be a way to make this process more efficient and cheaper. This technology combines a controlled network flushing device and a calibrated flow meter. In essence, this would be a typical water company activity with a broader context linked to network modelling. A suggestion for further research is to verify whether measuring 120 values with this technology will provide a sufficiently representative sample.

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Fig. 6 Astacus technology [9].

5 CONCLUSION

This study provided a detailed overview of the pressure conditions in the water supply network based on a measurement campaign with 15 locations, where pressure sensors were installed with an accuracy of ±0.05 MPa. A suitable measurement interval of 15 seconds was verified, allowing rapid pressure changes to be captured while still obtaining sufficiently representative samples. After data cleaning, the analysis was performed based on hourly aggregations, with one hourly interval containing up to 240 measurements. The observed standard deviation of the pressures ranged from 0.02–0.08 MPa depending on the location and time of day.

The statistical methods used, including the Z-test and the Bootstrap Confidence Interval (CI), showed that as few as 60 measurements were sufficient to achieve 99% agreement with the hourly mean in some intervals, while in other cases up to 120 samples had to be analysed. The results of this study serve as a basis for optimizing the operation of the water network and for setting the parameters of the Astacus technology. The next phase of the research will focus on practical verification of these findings and implementation into operational practice.

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