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Impact of water demand pattern on calibration process.

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Abstract: Mathematical models are the basic tool that simulates the operation of the Water Distribution System (WDS). Building such a tool is a complex task that requires as much detail as possible. The information needed to build a model can be divided into two categories: network data and WDSs operating data. The first group includes pipes and nodes attributes, like pipe length, pipe diameter, pipe roughness, junction elevation, and junction demand. The second category includes data specifying network performance such as pump characteristics, water demand patterns, and controls. The quality of these data will reflect the quality (compatibility) of the model.

In WDSs modeling, especially dynamic modeling, water demand patterns will have a significant impact on model accuracy. The appearance of each patterns may be different, it depends on the type of consumption (domestic, industrial) or analyzed period. Consumption patterns defining the WDSs operational work. Changes in water demand patterns may affect the accuracy of the model calibration. The real WDS model were used in this paper. The three simulations were analyzed, each for another period: one year, six months, and one month. Junction demand and water demand patterns were generated from a GIS (Geographic Information System) and SCADA (Supervisory Control And Data Acquisition) database.

Key words: hydraulic model, calibration, water demand pattern

1. Introduction.

Mathematical models are basic tool using by water supply companies to support decision-making. The purpose of Water Distribution System (WDS) modeling is to reflect operational work of network. The most important task is to achieve the highest possible accuracy of WDS model, independently of chosen period or occurred failure, which are analyzed. For this purpose the model is calibrated. Calibration is a process during which is determining physical and operational data of the WDS, as a result, a coincident model of the WDS is obtained [1]. During modeling, all data that represent network graph and WDS performance are verified. According to Walski [2] the highest uncertainty of data are related to pipe roughness and water demand. These two data are verified in final stage of calibration - micro-calibration [2, 3]. Pipe roughness dependent to the pipe diameter, material, age and water quality, which can be defined by mathematical function or systemized. Water demand is a force determining type of network operational work.

Water demand is related with water consumption patterns and placement of consumption point [4]. Data used to create of hydraulic model are mostly based on GIS database (Geographic Information System), billing databases and SCADA systems (Supervisory Control And Data Acquisition). The location of the customers points is obtained from the first database, which assigns water demand to the nearest node. While water demand (average, maximal or minimal value) and water consumption patterns are exported from two other database. According to modeling algorithm, water consumption pattern is determined by formula below [5]:

$$d_i(k)=d_{base_i}\cdot pattern(k) \tag{1}$$

where:

- $d_i(k)$ – i junction water consumption at any time k
- d_{basei} – i water consumption (value from billing databases)
- pattern(k) – water consumption pattern exported from SCADA database

The sum of momentary water consumptions should equate total daily water consumption in node:

$$\sum_i d_i\,(k) = d_{total}\,(k) \tag{2}$$

Water consumption patterns vary from each other depending on the type of customer. There are four basic types of recipients: domestic, industry (factory), business and service (restaurant). Domestic and service areas are characterized by two maximum water demands per day, for domestic it is morning and evening and for service two in evening. Industry water consumption patterns are determined by customers character of work, the maximum water demand may occur in the afternoon and at night, while business is characterized by equal water intake during the day (Fig. 1).

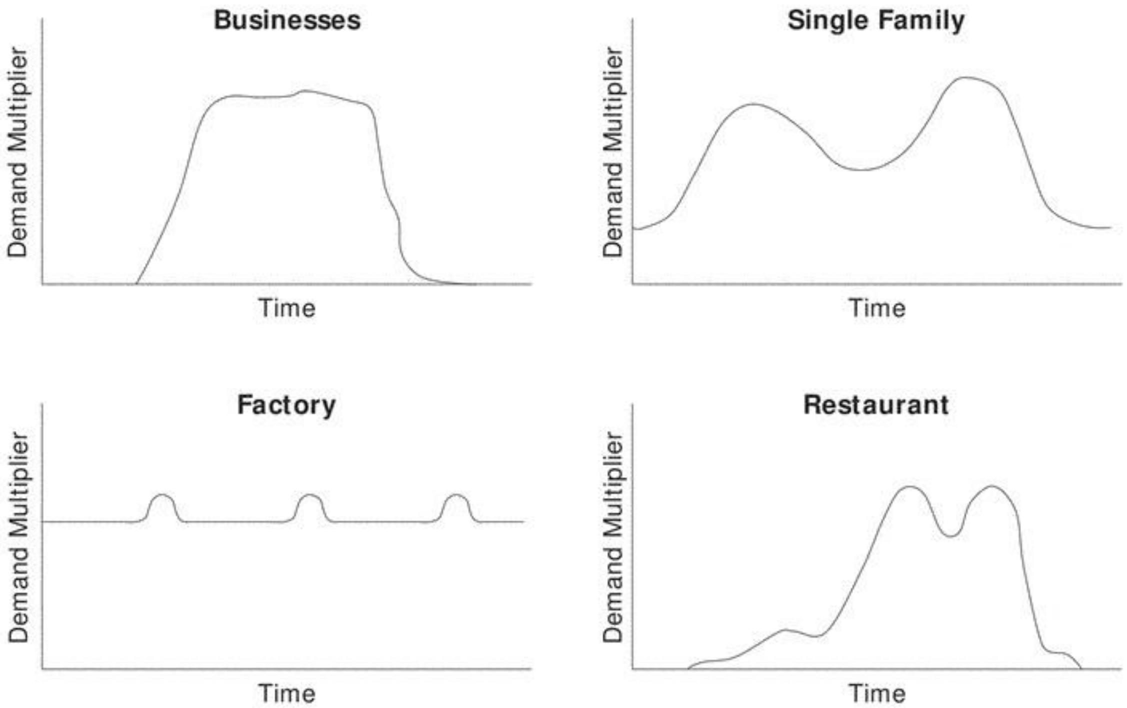

Fig. 1. Water consumption pattern for different type of areas [4].

Water demand depends also on seasonal changes, like spring (gardening) and summer changes. Select the simulation period should be preceded by precise analysis of the network operational work and water consumption, so that it reflects the normal operating work of the WDS.

2. Research subject - selected area of the WDS.

The subject of the study is the selected water supply area of the large WDS. The subsystem consists of four Water Treatment Plants (WTP A, WTP B, WTP C and WTP D) with a total daily average production of 55,000 m^3 and four complexes of tanks (TANKS E, F, G and H) with a total capacity of 162,000 m^3 (Figure 2). Tanks E are additionally supplied from a pumping station (PUMPING STATION I) located outside the considered area of subsystem, in an average daily amount of 60,000 m^3. The average daily amount of supplied water in this area is 115,000 m^3. Daily water demand for this area is 102,000 m^3. Considered WDS is an wide network with a total length of 256 km. The water supply infrastructure is characterized by high variability of material and diameters from 55 mm to 1600 mm. The WDS is mainly made of steel (73%) and polyethylene PE-SDR17 (10.6%), with a small share of ductile iron (Table 1). The oldest pipelines that build this distribution subsystem come from 1929 (steel wires) and the latest from 2016 (PE-SDR17).

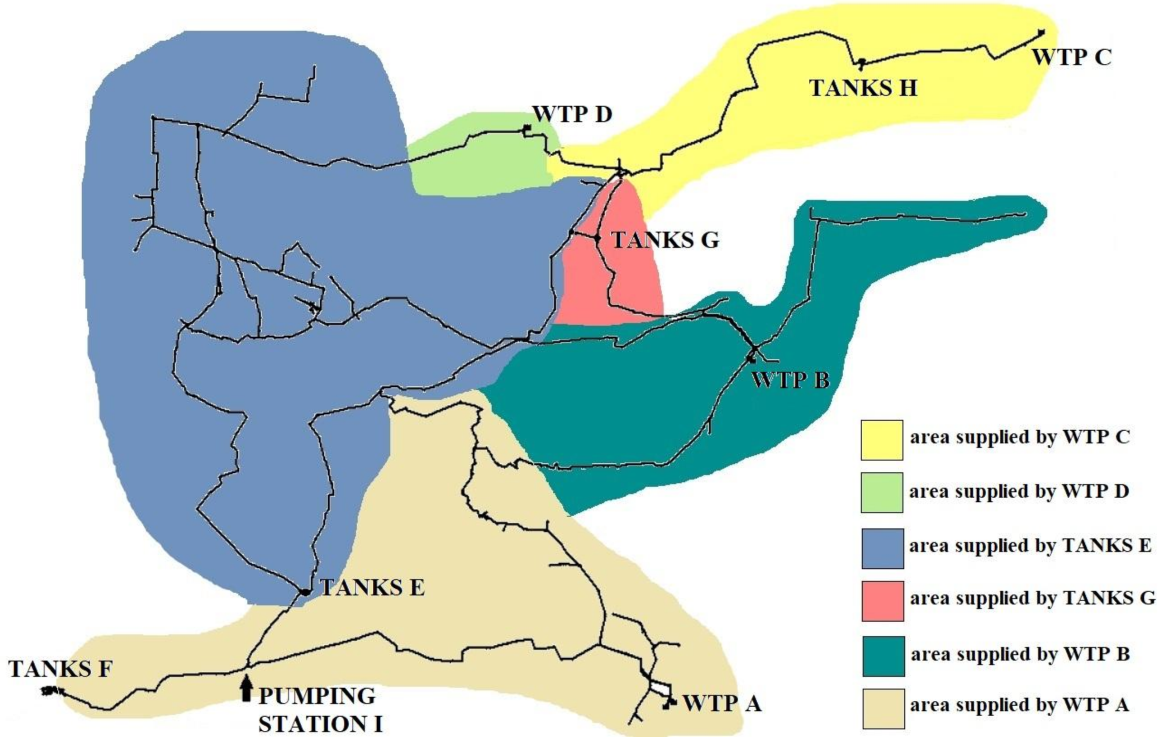

Fig.2. Structure of WDS with water supply areas.

The central point of the subsystem is the storage tanks E, which is supplied from two directions (WTP A and PUMPING STATION I) and supplies water to the largest number of customers, representing nearly 50% (Fig.2 color blue). Tanks F are the boundaries of the subsystem and in the simulations under consideration are the water receivers (normally supplied water in five directions). Storage tanks G supplied the smallest area due to pipes failures occurred in considered period. WTP D works periodically, in situations of increased water consumption (summer time) (Fig. 2).

The WDS is supplying an urban-industrial area with a high prevalence of urban areas (93.8%). Domestic water consumption patterns are characterized by the standard regularity of the occurrence of two peaks in water consumption in the morning and in the evening (Figure 3).

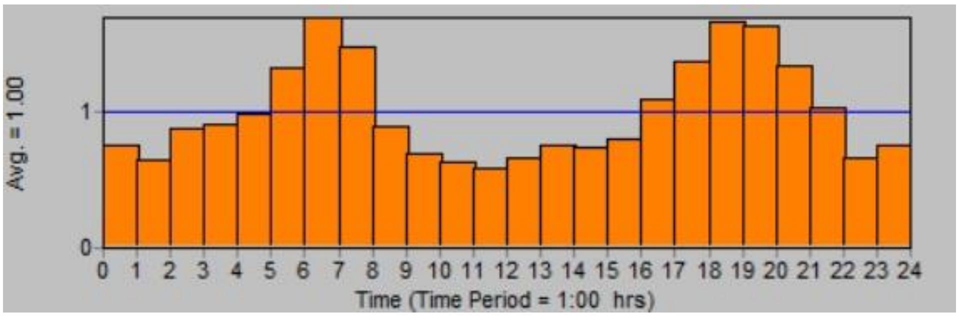

Fig.3. Daily water consumption pattern for selected domestic customer.

Industrial consumers often collect water irregularly or periodically, contributing to the maintenance of high network pressures around the clock at 75-100 m H2O. Figures 4 and 5 show exemplary water consumption patterns for industry that show irregular water consumption. Figure 4 shows a customer receive water for 13 hours, and figure 5 shows the customer characterized by a certain regularity of water intake from morning to night.

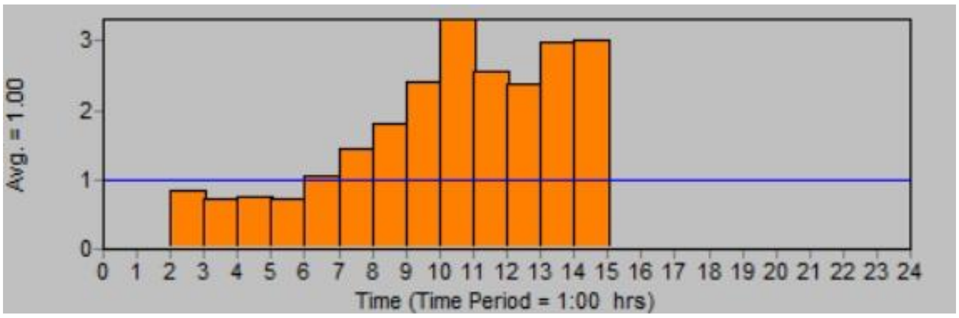

Fig.4. Daily water consumption pattern for selected industrial customer.

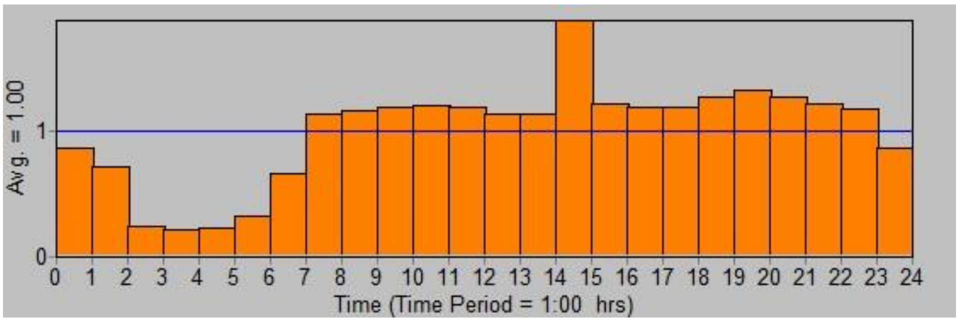

Fig.5. Daily water consumption pattern for selected industrial customer.

3. Assumptions simulation and result discussion.

The calibrated model was used in the study. EPANET 2.0 was used for the simulation. The network graph was exported from the GIS database, while the water demand data, from the one year period (2016), was exported from the available billing databases. Daily water consumption patterns were created from the SCADA telemetry system. Model is built from 1488 pipes and 1989 nodes, 524 valves, 22 pumps, 4 tanks and 4 reservoirs. The calibration was performed for data from one month data (October 2016), while model validation covered a period of three days (17, 18, 19 October). Correlation of simulation results and actual measurements for flows is 98,5% and for pressure is 99,2%.

In the study model was simulated for three scenarios. For each scenario, data (average water demand and water consumption patterns) was retrieved from other period:

1.Scenario I - simulation for one month (October). The period for which the model has been calibrated. In the simulation there are 267 nodes with a total average water demand 105 500 m^3/day. Compatibility of the simulation result with actual measurements: for flows is 98.5%, and for pressures 99.2%.

2. Scenario II - simulation for the period of 6 months (second half of 2016). In the simulation there are 275 nodal water demands with a total average water demand of 104 500 m^3/day. Compatibility of simulation result and actual measurements: for flow is 98.7%, and for pressures 99.3%.

3. Scenario III - Simulation for one year (2016). In the simulation there are 281 nodal water demands with a total average demand of 123 900 m^3/day. Compatibility of the model with actual measurements for flows is 97.5%, and for pressures 98.7% .

For each scenario, was received a different number of nodes with water demands, and a different value of water consumption. This can be cause by periodic water intake from some water consumption points or devices failure. In relation to Scenario I, water demand for Scenario II was 1% lower, while for Scenario III was 15% higher. This indicates that the length of the period, from which the data was exported, has a great influence on the specifics of the model.

Due to the size of supplying area, a detailed analysis was conducted for Tanks E (Fig. 1, color blue). Figures 6-11 shows simulations results for two flows from Tanks E - west and east directions.

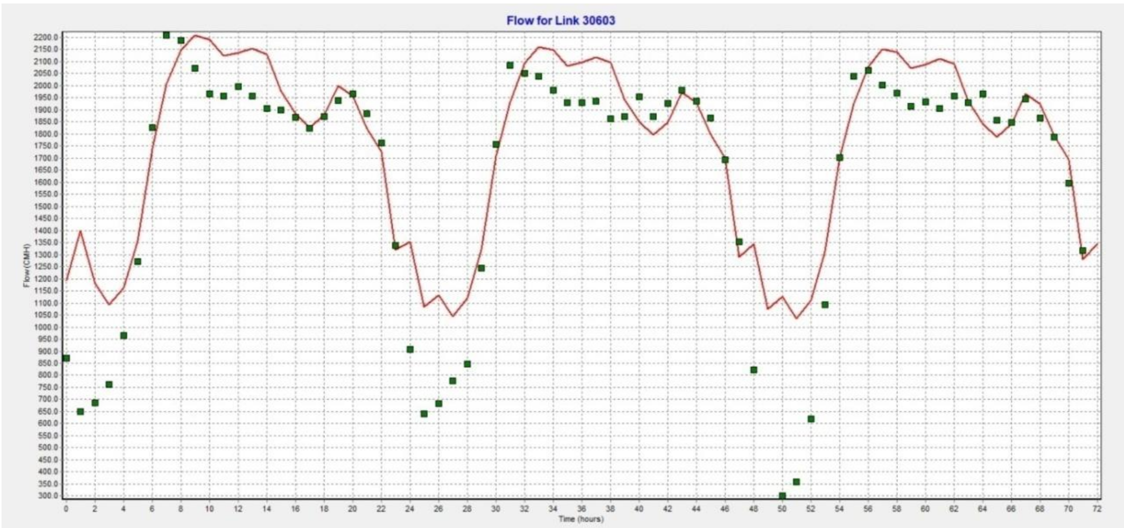

Figure 6. Results of Simulation I for Tanks E, east direction.

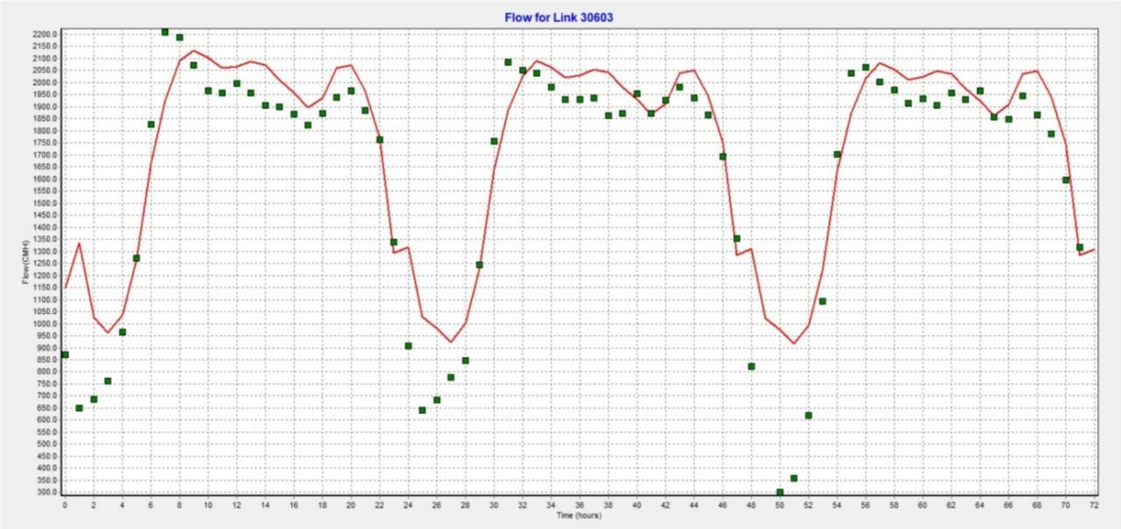

Fig.7. Results of Scenario II for Tanks E, east direction.

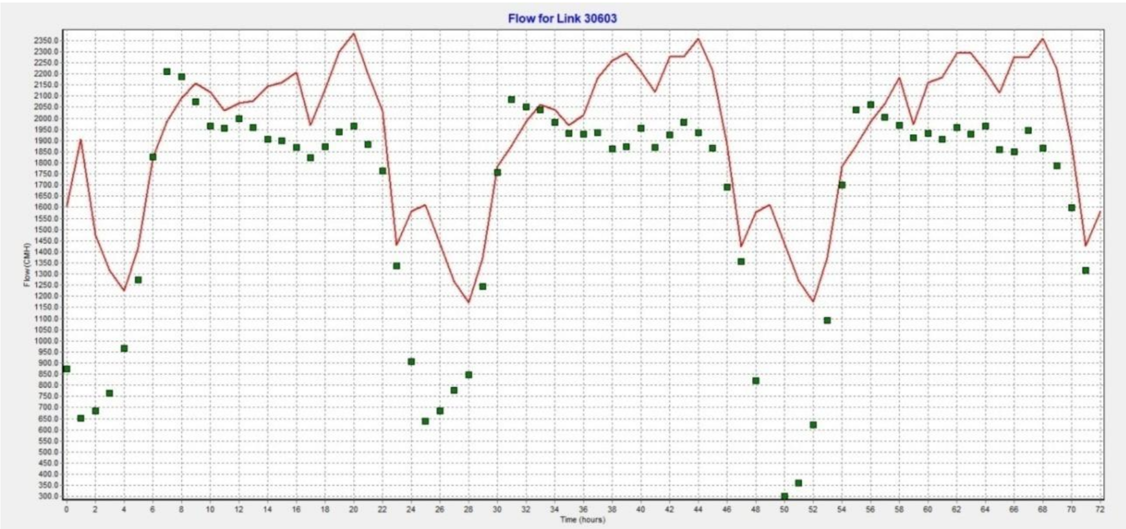

Fig.8. Results of Scenario III for Tanks E, east direction.

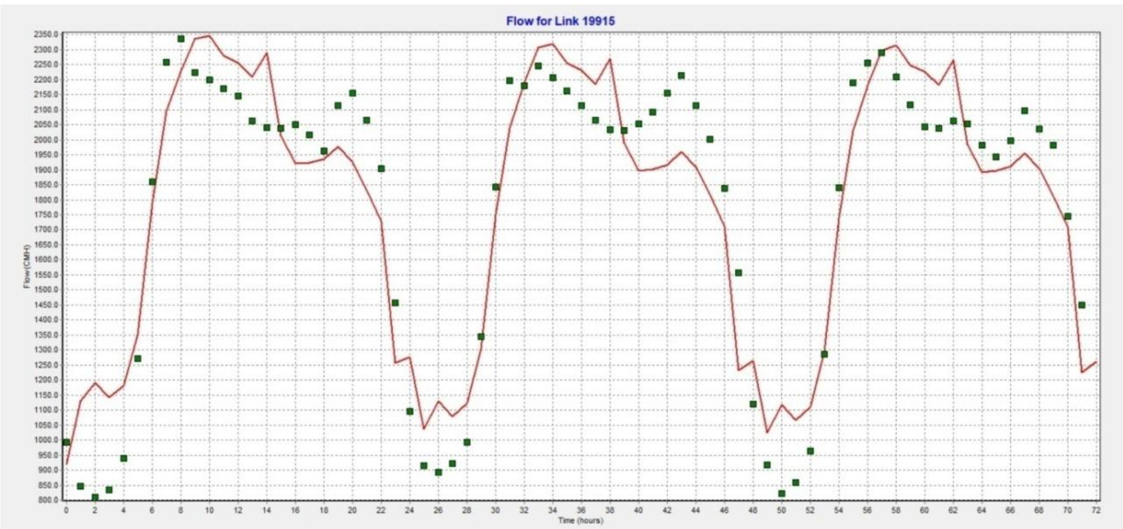

Fig.9. Results of Scenario I for Tanks E, west direction.

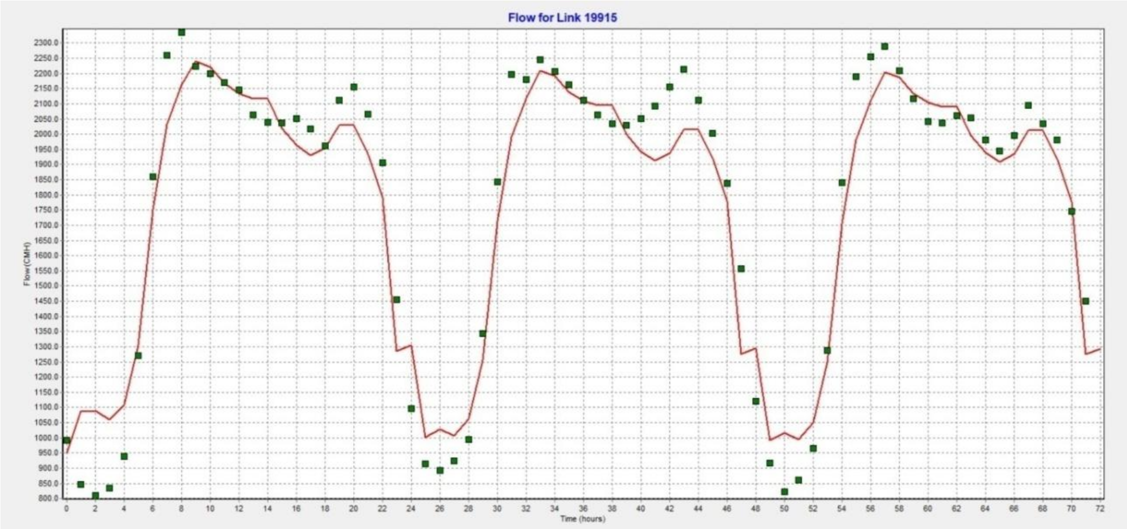

Fig.10. Results of Scenario II for Tanks E, west direction.

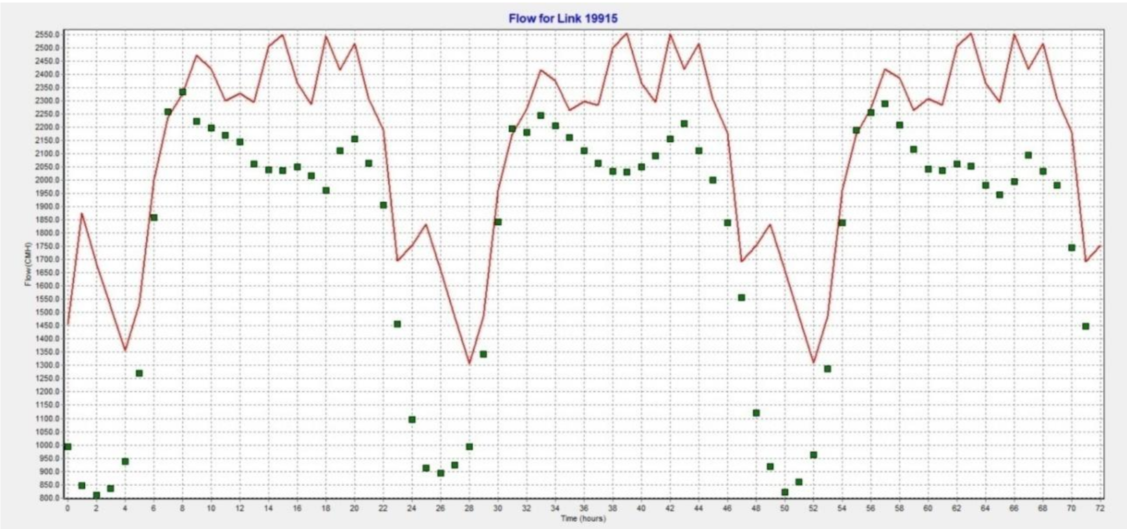

Fig.11. Results of Scenario III for Tanks E, west direction.

The best results were obtained for the scenario II (data from six months) and the worst for Scenario III (data form one year). Compatibility of simulation results for these two directions for mean flow values is as follows:

Simulation I: east direction 92,8% , west direction 99,6%

Simulation II: east direction 94,0% , west direction 98,6%

Simulation III: east direction 84,8% , west direction 83,8%

Figures 12-14 shows charts of comparison of mean value created in EPANET 2.0.

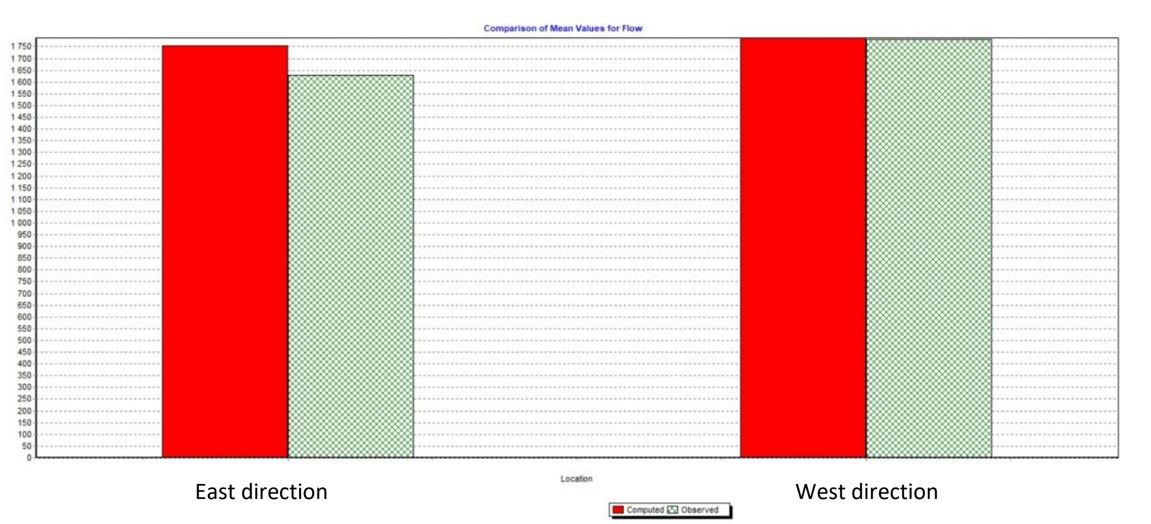

Fig.12. Simulation results of Scenario I.

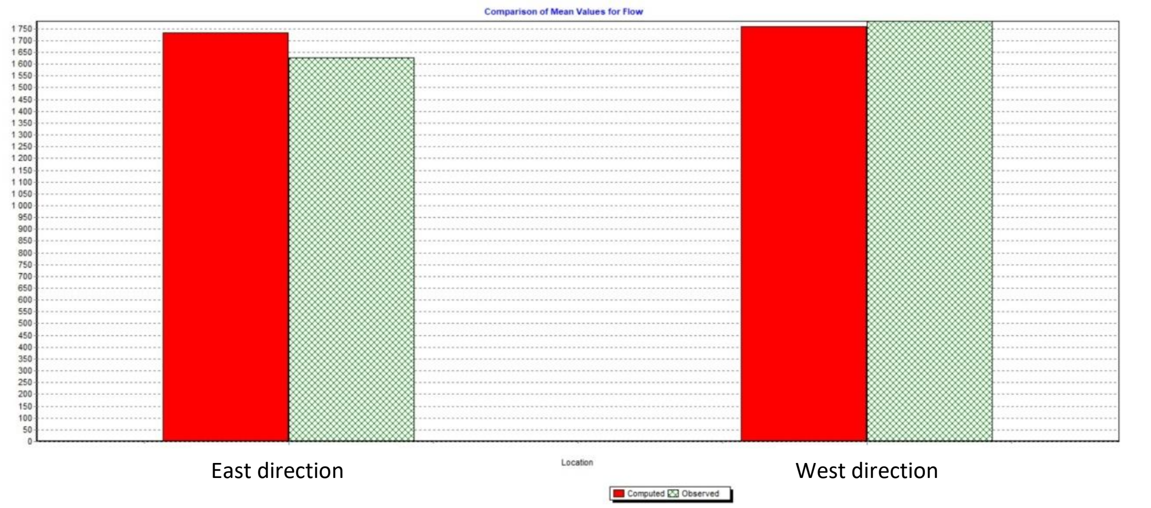

Figure 13. Simulation results of Scenario II.

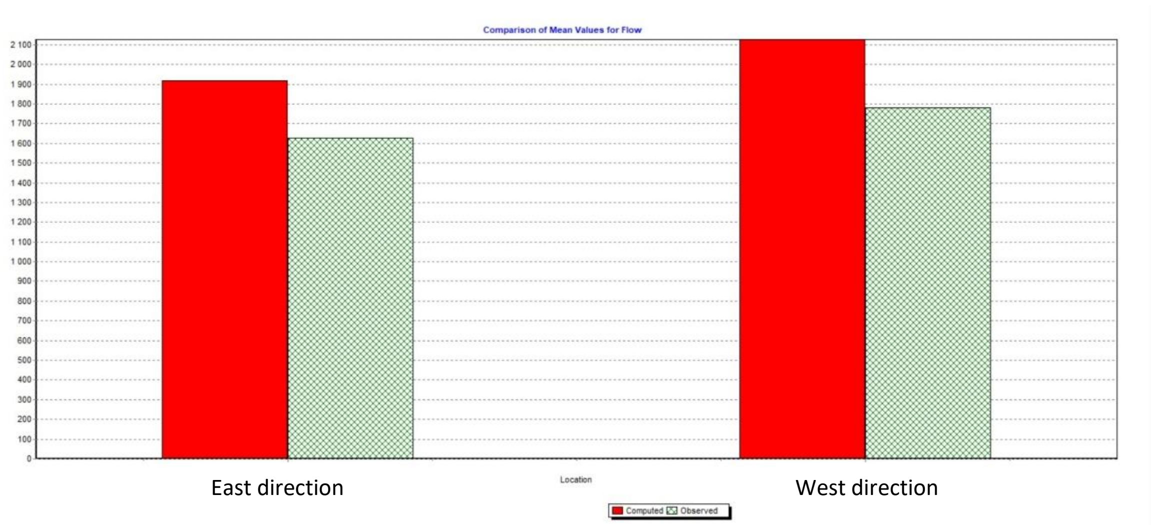

Figure 14. Simulation results of Scenario III.

Such results may be due to various events occurring in the given periods, which influenced the quality of the data. The one month period may seem appropriate because there are no seasonal fluctuations, but data from this period will be very sensitive to disturbances. In October, in this area, there were several pipe failures and several devices failures, which affected the data. In the period of six month and year, there were dozens of such failures, but these distortions were "lost" in the correct data. From the other hand the nodal demand values are calculated over the entire period that contains seasonal fluctuations. This means that the average value can be overestimated or underestimated. The figures below show daily water consumption patterns for selected water intake points from the area supplied by Tanks E. Figure 15 shows the variability of the water consumption pattern, depending on the time period, for domestic area, and Figure 16 for industry area. The graphs show that the longer period, from which patterns were created, the hourly demand values are closer to the daily average demand value (line = 1), this means that they are more stable.

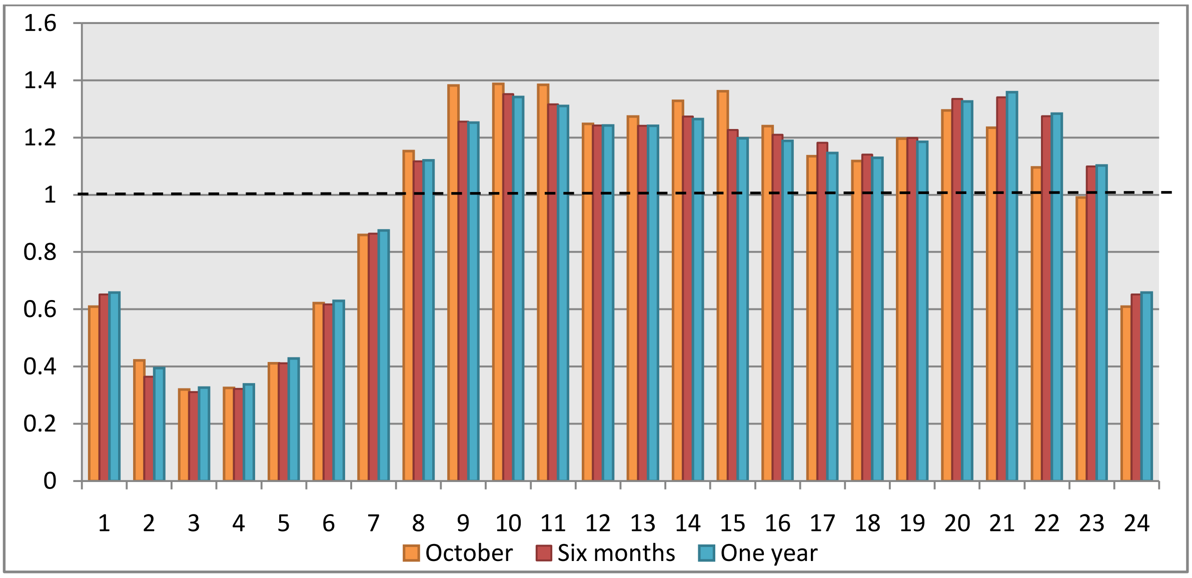

Figure 15. Simulation results of Scenario III.

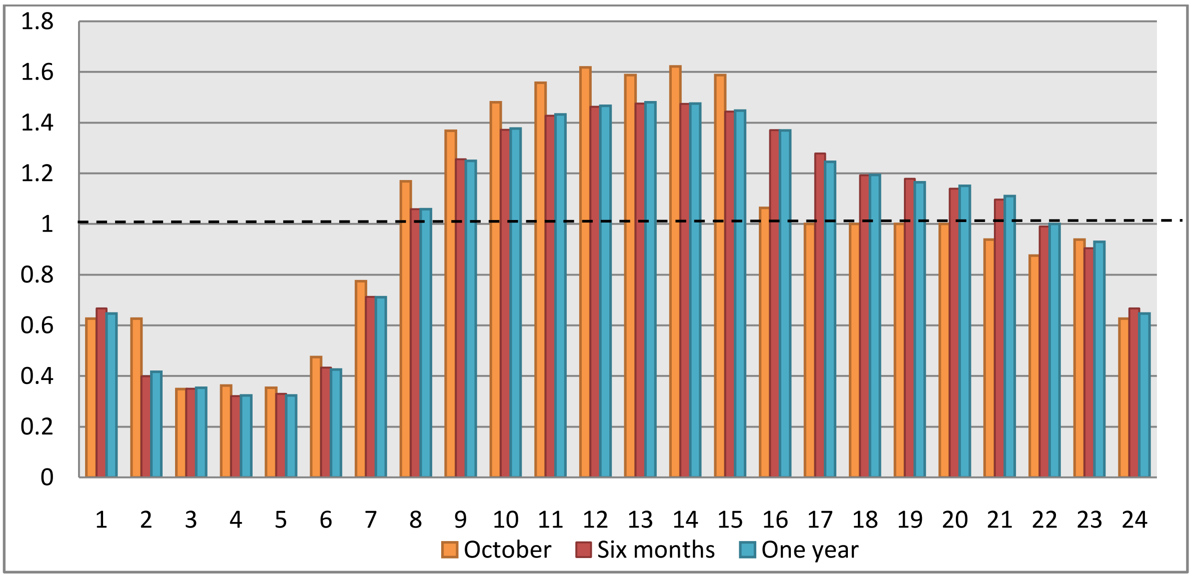

Figure 16. Simulation results of Scenario III.

4.Conslusion.

Calibration is a complex process that requires a lot of data analysis. Particular attention should be paid to water demand and water consumption patterns. These data are groups of information that are very sensitive to disturbances, which occurred during the considered period. Therefore, this period should not be too short or too long. In the short period the water demand values may be overestimated or underestimated due to disturbances. While in extended period, like one year, there are seasonal fluctuations which affect the data. Modelers should pay attention to the selected period, they specify unwanted events such as pipe and devices failures. During modeling it is important to choose a period that reflects the normal operation of the WDS.

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6.

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1. **Author Contributions:** A short paragraph specifying their individual contributions must be provided. The following statements should be used “Ewelina Bartkiewicz and Izabela Zimoch conceived and designed the experiments; Ewelina Bartkiewicz performed the experiments; Ewelina Bartkiewicz and Izabela Zimoch analyzed the data; Ewelina Bartkiewicz wrote the paper.” Authorship must be limited to those who have contributed substantially to the work reported.
2. **Conflicts of Interest:** Declare conflicts of interest or state “The authors declare no conflict of interest." “The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results”.