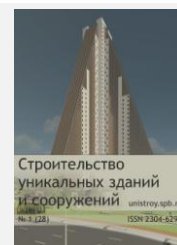




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The pressure-boosting pumping stations in modernization of water supply systems

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ABSTRACT

Based on the acknowledged theoretical proofs and experiences in the modernization of water supply systems, it can be concluded that out of the range of available measures to reduce leakages, the regulation and/or reduction of operating pressures is being recommended as the most efficient method thereto. The known proof-theoretical papers on water supply system leakage and the corresponding operating pressure losses advocate thesis on possibility to reduce the level of operating pressures to the range of 3.5- 2.5 bars, in all parts of the network where applicable, which is evidenced to be a sufficient level enabling the uninterrupted operations of the large percent of the users. The justification of the previously stated attitude can be proved by means of simple schemes of supply line which correspond to the possible states that can occur in actual operating modes of the water supply system. An analysis was performed with focus on the location and role of the pressure-boosting pumping stations used to increase the pressure in achieving the new low-pressure state and their respective influence on techno-economic parameters upon which a decision is made on economic viability of the solution concerned.

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Introduction

Previous papers by several authors [1, 7, 8] prove that the pressure reduction in water-supply systems results in the leakage reduction in those systems. Moreover, it appears that the most convenient formula [8] for a simple analysis and forecast of the leakage (L) – pressure (P) ratio, irrelevant of the point of analysis is the following:

$$L_1 / L_0 = (P_1 / P_0)^{N1}$$

where exponent N1 varies within a range between 0.5 and 2.5, depending on the pipe material, e.g. a type of crack. Based on the formula above, for an adopted level of leakage in a pipeline at high pressures, the expected percent of loss savings can be calculated for a pipeline with reduced pressures. An interval from 25% to 70% has been adopted as an actual and currently generally present range of the leakage levels (for the conditions pertaining to the water supply systems in Montenegro (former Yugoslavia)). Evidently, for different values of N1, the percent of savings e.g. leakages will differ for low pressures. The tables below show ratio of changes to introduced values of N1.

N1 = 0.5

$$L_{60} = L_{35} \left(\frac{60}{35} \right)^{0.5}$$

$$L_{35} = \frac{L_{60}}{1.30}$$

Leakages at pressure 60 mvs (%)	70	60	50	40	30	25
Leakages at pressure 35 (%)	53	46	38	30	23	19

N1 = 1.5

$$L_{60} = L_{35} \left(\frac{60}{35} \right)^{1.5}$$

$$L_{35} = \frac{L_{60}}{2.24}$$

Leakages at pressure 60 mvs (%)	70	60	50	40	30	25
Leakages at pressure 35 mvs (%)	31	26	22	18	13.5	11

The determined “high” pressure of 60 mvs is the most common value of pressure in the existing systems, while the proposed maximum pressure of 35 mvs, in the “reduced” option is sufficient enough to meet demand of all users, as implied by theoretical analysis (3).

In order to assess viability of the proposed states of pressure it is necessary to test both states, using a real model, under conditions which correspond to actual conditions that may occur in the water supply systems. For such purpose, two supply pipelines of common configuration, connecting the pump site and a reservoir, are selected. The analysis used a modeling software package EPANET, which enables modeling of hypothetical conditions of different pressures, leakages and solutions of supply lines (introduction of pressure booster pumps, swages etc.). The analysis gave consideration to the cases of water supply over a relatively flat terrain with a tank located at the specified elevation point and water supply over a terrain inclined in direction from the pump to the reservoir [1-20].

Example of the network modernization

Advantages achievable by the proposed modernization of the water supply systems in line with the regulation of pressure at low levels can be further confirmed on the example of the water supply network representing a single system or its part thereof. The figure 1 illustrates the “frame” of the medium-sized water supply system with elements which commonly appear in the real life situations. The assumption is that the water supply to the community is provided by a pumping station (PS1), which in addition to meeting the consumption demand and required level of pressure, provides water to reservoirs beyond the community area, thus serving demand of other parts of the community or some other system. Due to the elevation of the reservoir, it is required to boost water once more beyond the community area, by means of the pump PS2.

Given there is no reservoir area in the community, the pumps perform constant operations. By default, the purpose of these systems is to maintain the minimum required pressure at the critical consumption node, in this particular case being the node 15 which is located at the highest elevation point of the network. Based on the previous experience, the minimum value of this pressure does not drop below 35 mvs. Consequently, the remaining parts of the network are exposed to a pressure which varies in the range between 50mvs and 60 mvs, for most of the day.

1. Description of the States of the System

1.1. High pressure state

The water supply system concerned is a combined system, generally the ring type pipeline with a few peripheral branches. The system layout indicates pump sites, nodes, pipes, pumps and reservoirs, while the corresponding input data are shown in the tables. The assumption is that the total consumption is evenly distributed among all the consumers; hence the adopted consumption node values are equal for all nodes. The terrain configuration is adopted to ensure that the difference between minimum and maximum elevations of nodes enables the assumed profile of pressures.

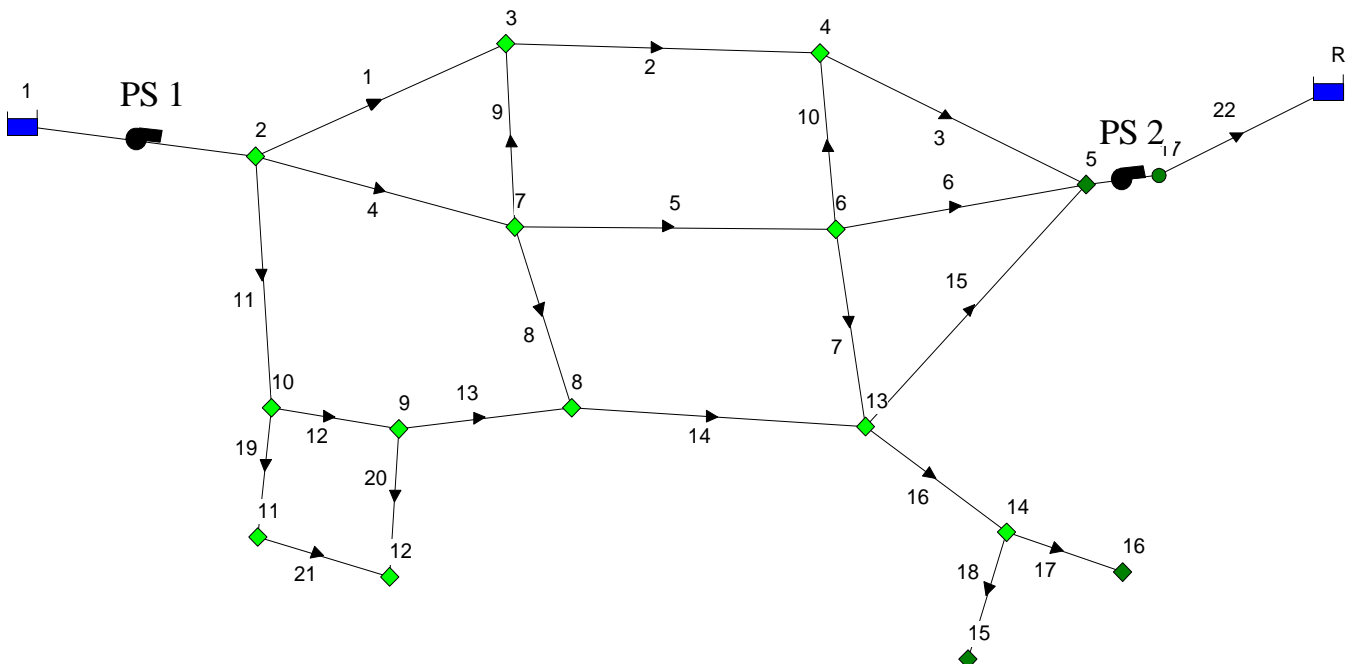


Figure1. Layout of the water supply network – marks of nodes, pumps and pipes

Table 1. System Data

Pipe Data				Consumption nodes Data		
No	From-to	L (m)	D (mm)	No	H (mnm)	Q (l/s)
1	2 – 3	350	250	1	0.00	/
2	3 – 4	500	250	2	20.0	10.0
3	4 – 5	500	250	3	30.0	10.0
4	2 – 7	400	500	4	25.0	10.0
5	7 – 6	500	400	5	30.0	10.0
6	6 – 5	350	300	6	30.0	10.0
7	6 – 13	350	250	7	25.0	10.0
8	7 – 8	350	250	8	30.0	10.0
9	7 – 3	250	250	9	25.0	10.0
10	6 – 4	300	250	10	30.0	10.0
11	2 – 10	350	300	11	25.0	10.0
12	10- 9	250	250	12	35.0	10.0
13	9 – 8	300	250	13	25.0	10.0
14	8 – 13	400	250	14	30.0	10.0
15	13 – 5	600	250	15	40.0	10.0
16	13 – 14	500	250	16	35.0	10.0
17	14 – 16	150	150	17	30.0	0.00
18	14 – 15	150	150	R	50	/
19	10 – 11	200	150			
20	9 – 12	200	200			
21	11 – 12	200	150			
22	17-R	500	350			

A usual daily chart for consumption is assumed with coefficients varying in the range between 0.5 and 1.8, with the curve shape as illustrated in Figure below.

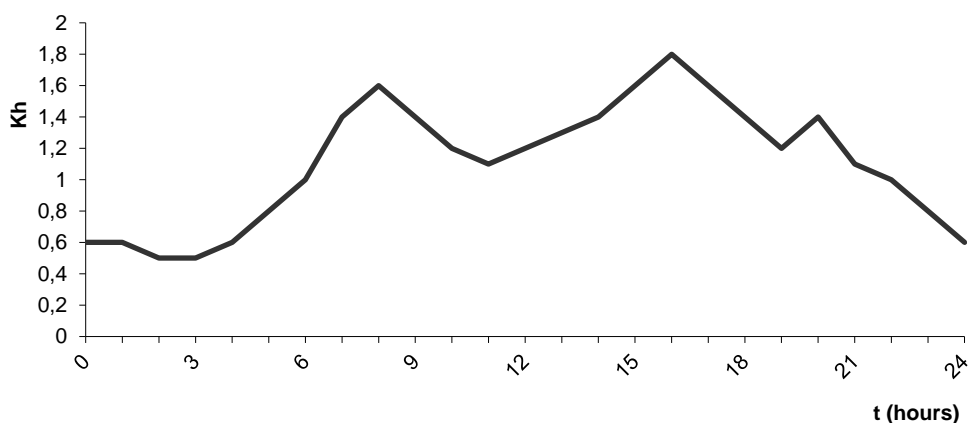


Figure 2. Daily chart showing changes in consumption in the water supply system

As previously mentioned, the purpose of the described water supply systems is to maintain the minimum required pressure of approximately 3.5bar throughout all day at all consumption nodes. Due to topography of the network, the node number 15 is identified as critical. As a result of maintaining pressure at this node, the pressure at other nodes ranges up to approximately 6.0bar. The pump installed at the pump site is in compliance with the previously mentioned requirements relating to the pressure; therefore the pump performance curve has the shape as illustrated in figure below.

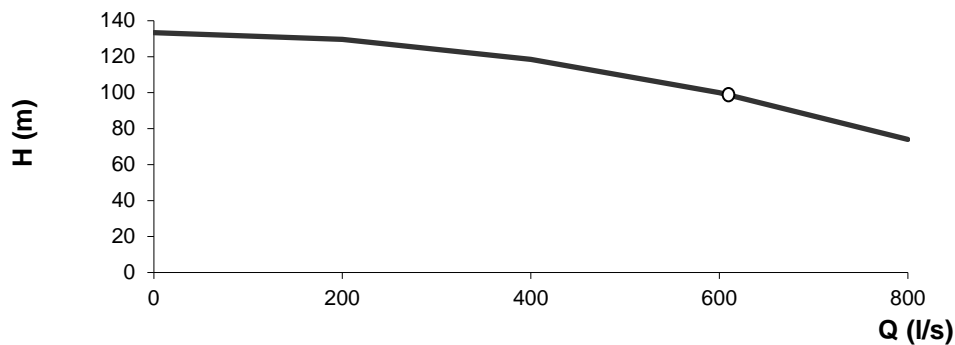


Figure 3. pump performance curve

Simulation of flow in the adopted system, with previously selected elements, results in the flow rate of the system being within the range of optimal flow rates

1.2. State of modernized system – reduced pressures

Based on the thesis (10) advocating useful effect of the pressure reduction in the modernization of the water supply system, the previous system can be converted into a new scheme which shall meet the following requirements:

- A new main supply pipeline is selected, separated from the remaining part of the system;
- Pressure in the main supply line is reduced to the minimum level, as the main supply line is relieved from the former consumption (the consumers are directed to other sources of water supply) and it becomes a transit line to the reservoir.
- System is divided in several smaller consumption zones which are defined by certain modifications such as capping, transferring, activation of the pressure booster pump;
- Each newly formed zone can operate independently, with one access point to the zone and possibility of the pressure regulation. The pressure in the zones is maintained by means of the pressure booster pumps which are directly connected to the pipelines;
- Modifications made to the main water supply line enable adjustments of the pump at the pump site, and/or reduction in pump effort. This results in the already mentioned need for water boosting at the entry points of the newly formed zone.

All the previously mentioned assumptions lead to establishment of a new scheme of the same system which is consisted of three independent zones, with the pressure booster pumps installed before the zones' entry points to maintain the required pressure level. The Node 15 remained critical in case of this new scheme as well, hence the same pressure requirements shall be provided as in the previous case.

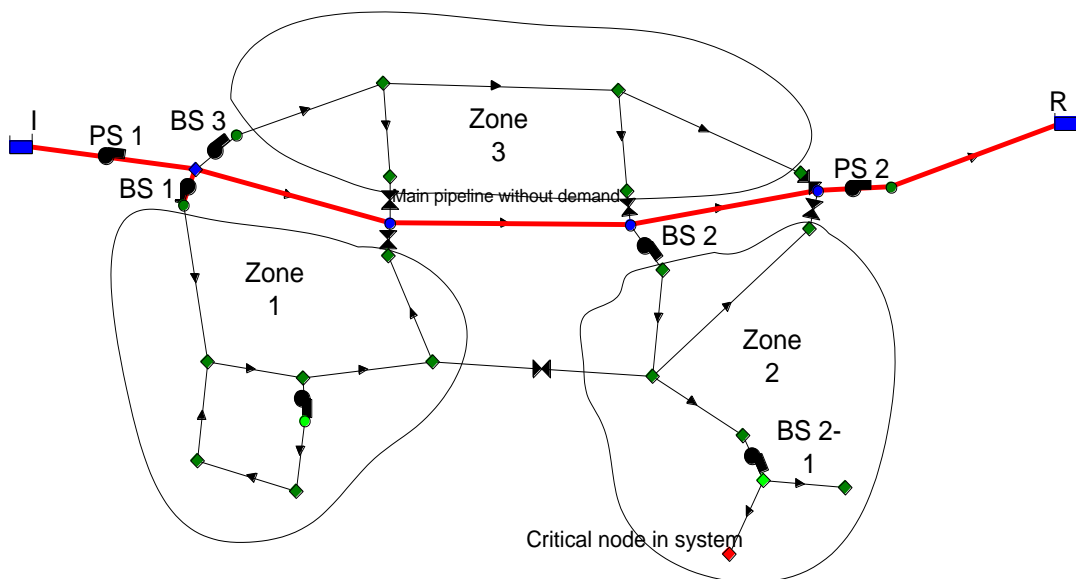


Figure 4. Layout of the modified water supply network – provided state of the low pressures

It can be noticed that the proposed modifications affect the hydraulic characteristics of the system and may also result in the reduced quality of water in the vicinity of the installed caps as there are no water flows; somewhat reduced throughput of the main supply line to the another pump or reservoir, given that water now inflows through the main supply line only, while consumers which are accustomed to high pressures can protest against the incurred reductions. Therefore it should be confirmed that the effects of this procedure are sufficiently positive so that any eventually inconvenient consequence would not affect its implementation.

2. Simulation of different states of leakage

The primary purpose of the system modernization and pressure reduction is to reduce the present level of system leakages. For this reason, it is necessary to analyze several states of the system with the present leakages within the wide range from 70% to 25%. Effects of the modernization of the system performance and in particular the pressure reduction as the measure of modernization process are reflected in the reduced level of present leakages and consequently in the savings of the system operational costs (2).

As in previous cases, the testing of all effects of reorganisation and pressure reduction, inclusive of activation of the pressure booster pumps, is conducted by simulation of the system state using the EPANET software package. The “emitter” option in EPANET software package, which features among attributes of the nodes description, enables quite accurate simulation of leakages in pipes between two consumption nodes. The “emitters” represent the model tool connected to the network nodes which is used to *model the flow through a nozzle or orifice that discharges to the atmosphere*. This flow through is a pressure function expressed as:

$$Q = cP^x$$

where Q = flow rate, P = pressure, c = discharge coefficient and x = pressure exponent. By variation of the discharge coefficient values, it is possible to simulate change of the leakage percent at consumption nodes for the known pressure and pressure exponents (adopted value 0.5).

The state of water supply systems in Montenegro is such that a real assumption e.g. measured results suggest that for the pressure levels of approximately 60mvs, the percent of leakage amounts even up to 70%, while it is considered that the water supply system operates relatively good if the percent of leakage is 25%. For this reason the range of leakages between 70% and 25% is in high pressure systems is analysed and the effects of modernization of the modified systems are monitored.

3. Computation results

Results of changed pressures levels, consumption and leakages at the level of the selected consumption nodes suggest the following:

Pressures in the newly formed consumption zones are reduced to the assumed level (max up to 35 m) which is proved to meet all demands of final users. Only critical Node 15 which is located in the newly formed zone 2 shall have the same pressure change curve as this is the assumed requirement for the high pressure systems which needs to be retained upon the system modernization. The selected charts refer to the simulation cases where the percent of leakage is 70%, yet the validity of change is the same for other cases as well.

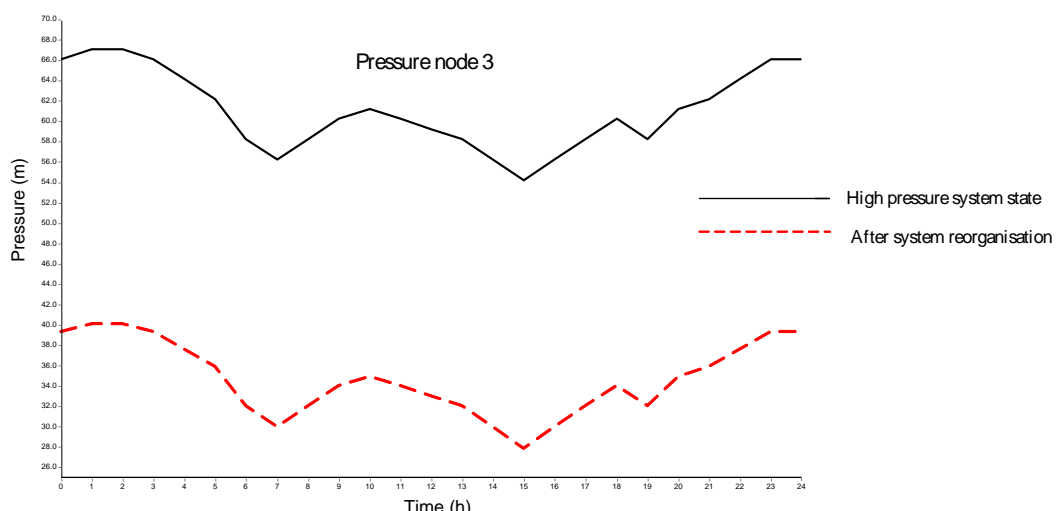


Figure 5. Changes of pressure levels at Node 3 (Zone 3) before and after system reorganization (high and low pressure states)

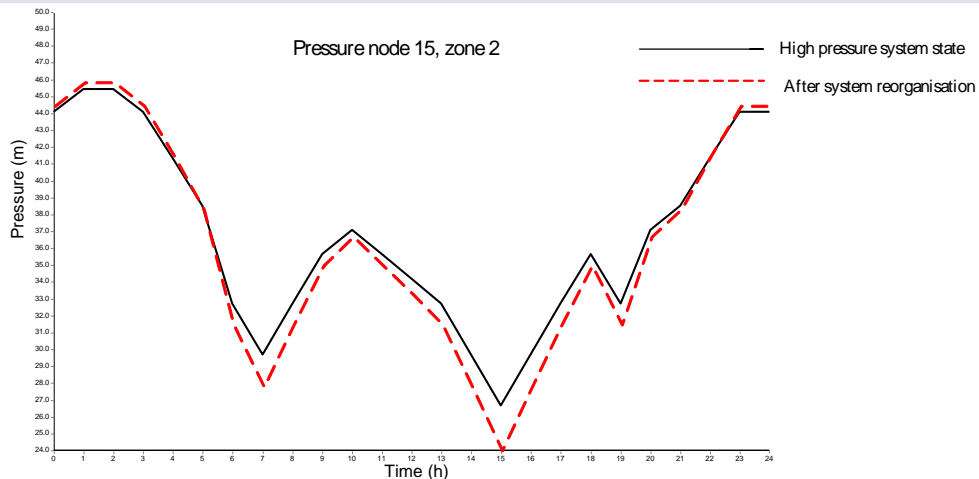


Figure 6. Changes of pressure levels at Node 15 (Zone 2) before and after system reorganization (high and low pressure states)

Based on the adopted methodology of modelling of leakage, these are contained in the node consumption and the results of simulation indicate the consumption inclusive of the leakage. Modernised system with reduced pressures and several pressure booster pumps results in the reduced consumption at nodes. If the change of consumption (inclusive of leakage) was to be considered independently, a wrong conclusion could be made about the leakage and pressures, meaning the effects of the proposed measures. The consumption partially depends on the operating pressure, however this dependence is not sufficiently expressed and there is not enough supporting data to be found in the available literature. The question whether and how to relate the effects of pressure on consumption is still disputable and should be solved above all based on the in-situ measurement data (6). Doubtlessly, based on the obtained consumption results a conclusion can be drawn that the pressure reduction, affects reduction in night consumption at the largest extent, while the changes of maximum consumption are smaller. However, if the leakages were to be considered independently, then based on the validity of their daily change, it is evident that these are not dependent on consumption but are proportional to the local pressure at the consumption node, hence the pressure is higher over the night than during the day and the leakages are changed in the similar way.

Moreover, it is evident that in line with the system modernisation and pressure reduction, the leakages at the consumption node level are reduced. This is further confirmed by example of the critical Node 15, where no change of pressure is recorded; hence there is no change of consumption and naturally no leakages.

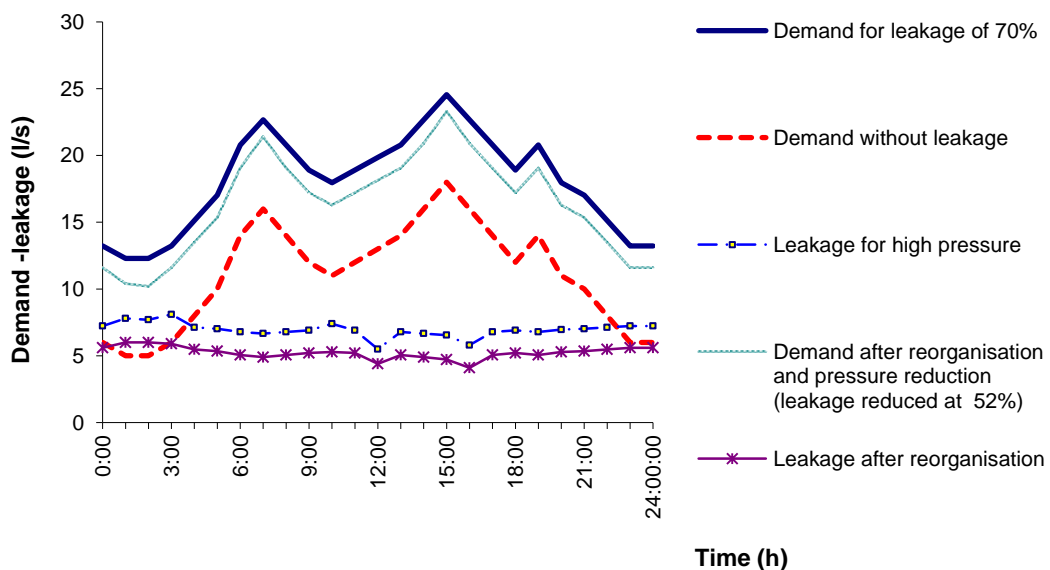


Figure 7. Change of consumption and leakage at Node 3 for the state of high and reduced pressures for the assumed leakage percent of 70% at high pressures

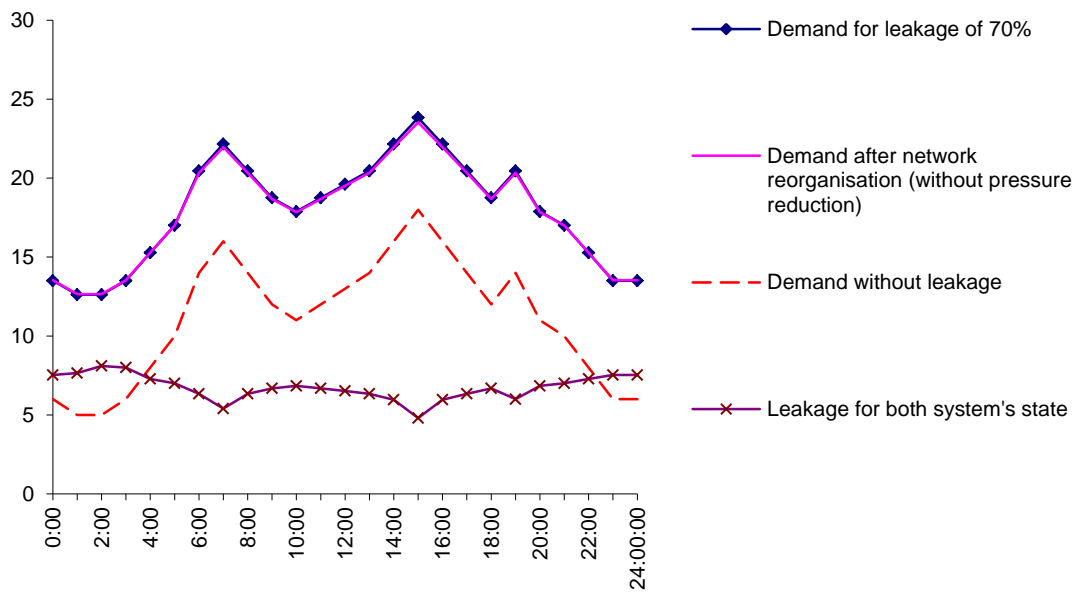


Figure 8. Change of consumption and leakage at Node 15 for the state of high and reduced pressures for the assumed leakage percent of 70% at high pressures

Additionally, charts of total daily production – demand of water of the system indicate major difference between the two states of the system, that is to say reduction in demand after the system modernization. The following figures illustrate charts of daily production – demand of water for both options of the system, reflecting the effects of the undertaken measures towards the demand reduction. The same color has been used to illustrate cases of leakage simulation, meaning leakage percent for the high pressure case and the achieved leakage percent for the same states after the system modernization.

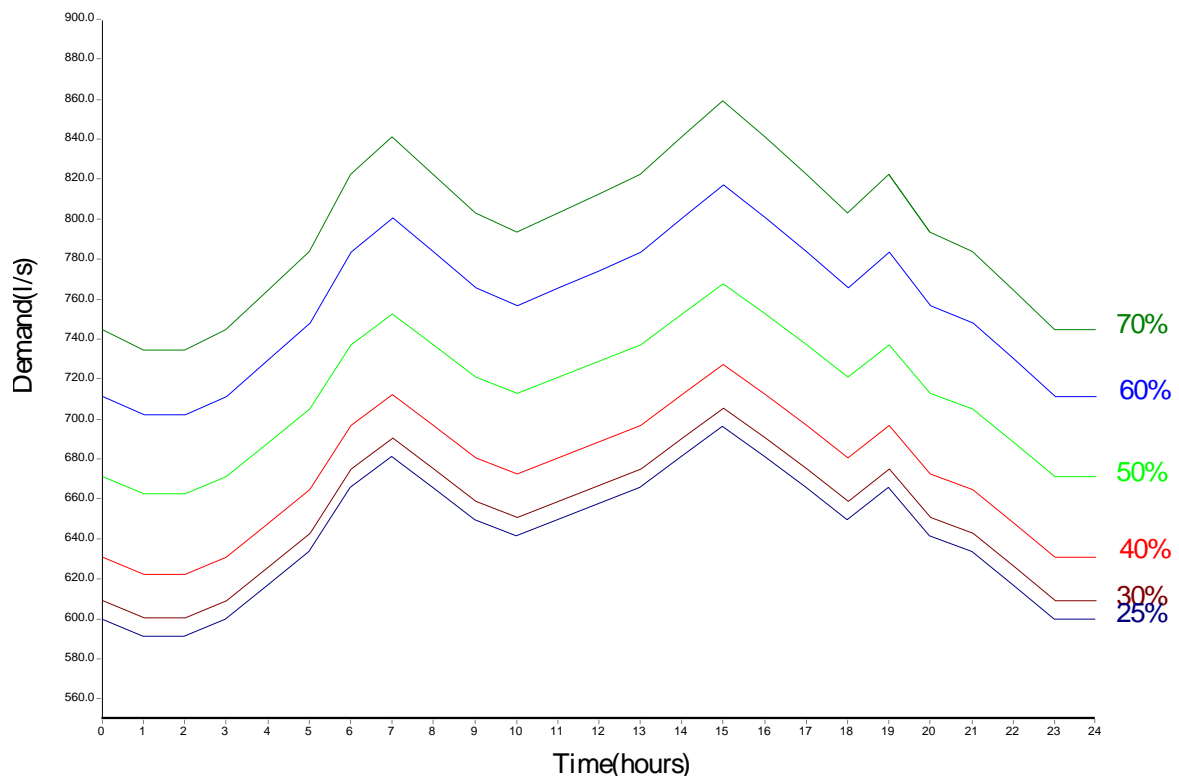


Figure 9. Chart of change of water production-demand for high pressure case for different simulations of the system leakage percent

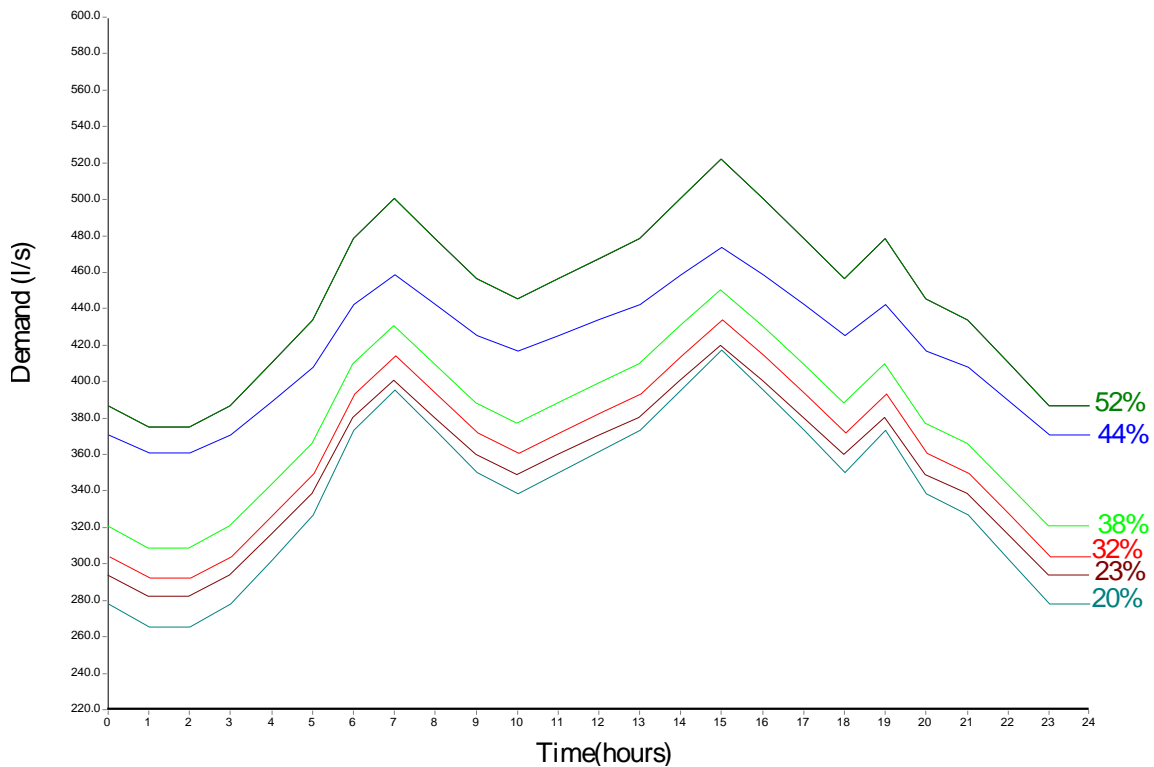


Figure 10. Chart of change of water production-demand for modernized system with pressure reduction – the leakage values are reduced after the system modernization

Results of simulation indicate that the leakage changes in relation to the change of pressures in fully analogous to the earlier reasoned theoretical validity (in this case, value of exponent N1 is 0.5)

Simulations of different states of leakages for case of high and/or reduced pressures confirm significant cost savings in the system energy consumption-pumping, given that lower leakage means smaller amount of water and consequently lower power of the pumping power units. Naturally, profile of change of pressures at consumption nodes remains the same during the day for all cases, meaning the pressure meets demand of final users and can be regulated by means of the pump located before the access point of the zone.

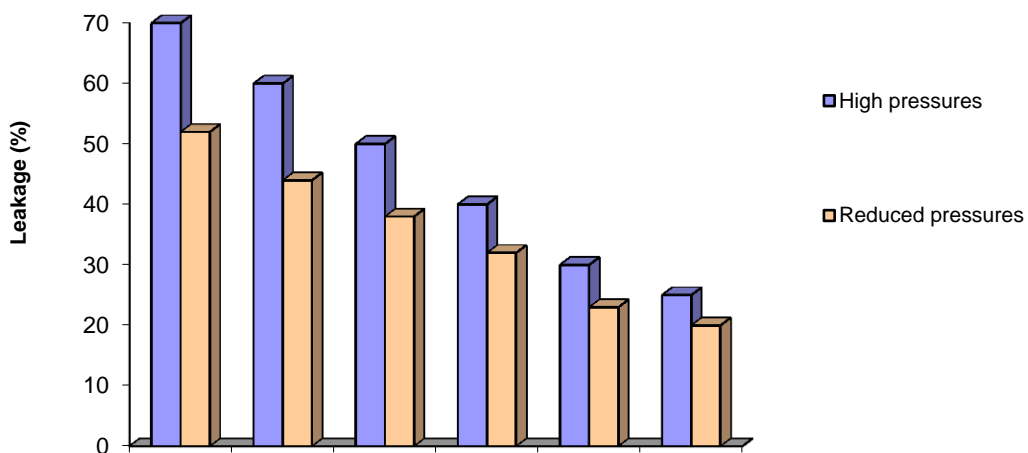


Figure 11. Change of the system leakage percent for the state of high and reduces pressures

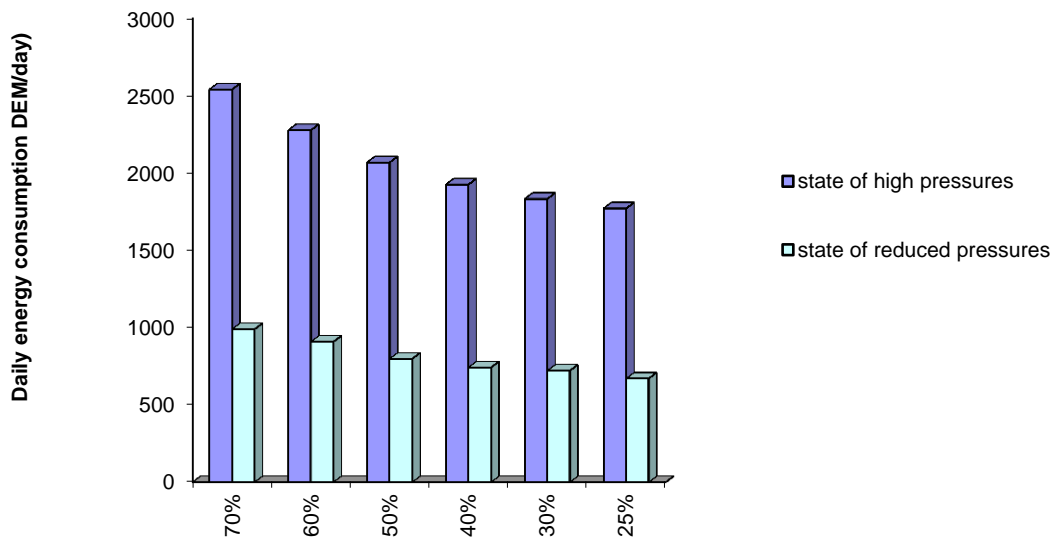


Figure12. Comparison of change in daily energy consumption for cases of high and reduced pressure cases at different system leakage percent

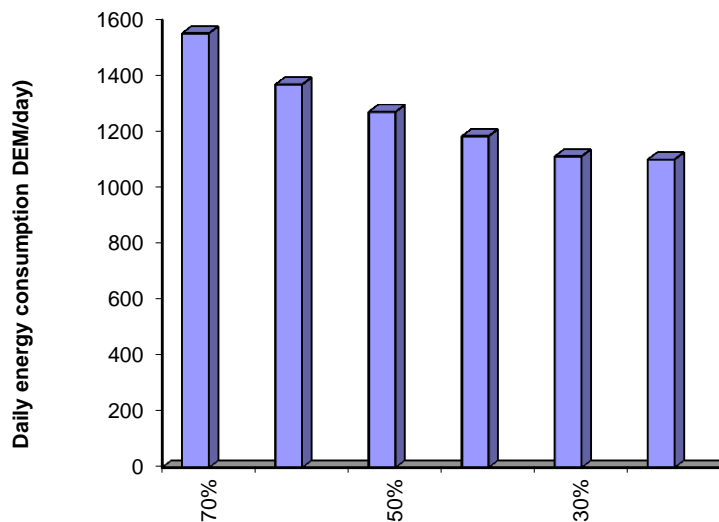


Figure 13. Change in daily energy consumption in case of high and reduced pressure cases for different leakage percent

Conclusion

Theoretically, any present system can be reorganised according to the previously mentioned principles. Certainly, in case of some systems, the reorganisation can be complicated and expensive and can result in some of the already mentioned consequences. The effects of system modernisation or pressure reduction is more evident in case of systems with originally high leakage percent, while the modernisation effects proportionally drop in line with the reduction of the leakage percent. Given that scale of investments in modernisation of the water supply networks vary for different systems and different states of the system leakages, the cost-benefit analysis should indicate to which level of the present leakage it will be cost-effective to apply the proposed measures.

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Повышающие давление насосные станции в модернизации систем водоснабжения

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АННОТАЦИЯ

На основании общеизвестных теоретических знаний и опытов в области модернизации систем водоснабжения, можно сделать вывод, что из диапазона доступных мер по сокращению утечек, регулирование и / или уменьшение рабочих давлений рекомендуется в качестве наиболее эффективного способа. В известных теоретических работах по утечкам в системе водоснабжения и соответственно потерям рабочего давления говорится о возможности снизить уровень рабочих давлений в диапазоне 3.5-2.5 бар во всех частях сети, где это применимо, с сохранением бесперебойной работы большого числа пользователей. Количественные показатели могут быть обоснованы с помощью простых схем питающей линии, которые соответствуют возможным состояниям, которые возникают в реальных условиях работы системы водоснабжения. В статье проведен анализ роли повышающих давление насосных станций во взаимосвязи с технико-экономическими показателями, на основании которых делается заключение об экономической целесообразности принятых решений.

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