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ANALYSIS AND OPTIMIZATION OF THE WATER SUPPLY SYSTEM "BELO BLATO"

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Abstract: This paper deals with the analysis and optimization of the water supply system in the settlement of Belo Blato, with the aim of improving reliability and efficiency in water distribution. A hydraulic calculation was used to evaluate the average and maximum flow rates, pressure losses in pipelines, total head, and required pump power under different operating scenarios. Special emphasis was placed on the summer season, when water consumption increases by about 30%, as well as on the impact of adding a third well to the system's performance. The results show that the existing system does not meet demand during periods of increased consumption, while the installation of an additional well and the enhancement of pump capacity enable stable and reliable water supply. Based on the obtained results, guidelines were defined for improving system performance, which can contribute to reducing pressure losses and increasing the quality of service to consumers.
Key words: Water Supply, Hydraulic Calculation, Pressure Losses, Flow Rate, Pumps.

INTRODUCTION

Water supply systems represent vital infrastructure for any settlement, enabling the provision of clean and safe drinking water to the population for domestic, sanitary, and other daily needs. At the beginning of the twentieth century, the purpose of water distribution networks (WDNs) was to support economic and industrial development and to provide fire protection. The objective of modeling studies was to establish criteria for the hydraulic verification of WDN projects in relation to the water demand of different categories of users. Supplying consumers with uncontaminated drinking water is of essential importance for human life, and the water distribution system represents a key infrastructure for meeting this need [1,2].
Urban water distribution systems are facing increasing challenges due to energy inefficiencies caused by hydraulic anomalies, such as pipe aging, breakages, consumption variability, and the suboptimal operation of pumps and valves [3]. Effective planning, analysis, and optimization of these systems are crucial for ensuring stable and reliable water supply, particularly under conditions of variable demand and seasonal load. Water pumps are devices designed for transporting liquids, primarily water, and are most commonly used in smaller capacities, as they are more efficient for increasing flow velocity. Management of the water distribution system is an integral part of the water supply industry. It is necessary to ensure that systems operate efficiently while maintaining high service quality at the lowest possible cost [4,5].
Energy costs for pump operation represent the dominant share of the operational expenses of a water supply system [6]. Pump operation is constrained by pressure levels relative to the actual electrical power required to drive them, while pump efficiency is reflected in head and flow rate. The efficiency of water network optimization, when observed in terms of computational effort, depends on the speed of the hydraulic calculation; nevertheless, it is also necessary to account for factors such as pump type, head, flow variability, and the transition from laminar to turbulent flow caused by laminar instability. Flow transitions can be influenced by various factors, including wall roughness, head, pressure, and temperature [7-10]. The settlement of Belo Blato faces challenges in optimizing its water supply system to meet the population's needs, especially during the summer season when water consumption significantly increases. This paper addresses the analysis and optimization of the Belo Blato water supply system, focusing on hydraulic calculation, evaluation of pressure losses, total head, and required pump power. The steps for calculating nominal flow rates will be

presented, as well as system adjustments for increased loads during the summer season. Additionally, scenarios involving an additional water source (well) will be considered to demonstrate its impact on the overall system and its efficiency.
Methodological approaches for obtaining approximate solutions can broadly be classified into three groups: empirical methods, theoretical-analytical methods, and simulation methods. Since this study focuses on the optimization of an existing facility, in collaboration with engineers, certain coefficients were excluded from the calculations. Accordingly, the method applied in this paper belongs to the group of empirical–scientific methods, which are based both on the experience of engineers or project teams and on Nikuradze’s experiments and the Moody diagram [11,12].
The objective of this paper is to provide guidelines for improving the Belo Blato water supply system through hydraulic calculations, optimizing its operation, and reducing pressure losses, thereby contributing to better service quality and increased consumer satisfaction. In this hydraulic analysis, several key aspects related to the existing water distribution system in the settlement of Belo Blato will be examined.

REPORT ON THE SPRING SITE INSPECTION

Water demand is determined based on the specific water consumption and the number of inhabitants. Specific water consumption (*qsp*) is defined as the amount of water consumed per capita per day. It is determined primarily on the basis of experience, although in some countries legal regulations exist in accordance with settlement size and the level of household sanitary equipment. In Serbia, it ranges from about 75–200 l/capita/day for villages and around 250 l/capita/day for towns.
The number of inhabitants (*Mk*) depends on local and general socio-economic factors and is not constant over time. It is based on the adopted spatial plan for the designated design period (20–50 years). The average daily water consumption *Qav,d* (l/day) for the population is determined using the following expression [12]:

$$Q_{av,d} = qsp \cdot Mk \tag{1}$$

For the hydraulic dimensioning of water intake structures, the following water quantities are relevant. The maximum daily consumption *Qmax,dn* (l/s) is obtained as the product of the average daily consumption and the daily peak factor [13]:

$$Q_{max,d} = Kd \cdot Q_{av,dn} \tag{2}$$

The maximum hourly consumption *Qmax,h* (l/s), in relation to *Qmax,dn*, is expressed using the hourly peak factor [13]:

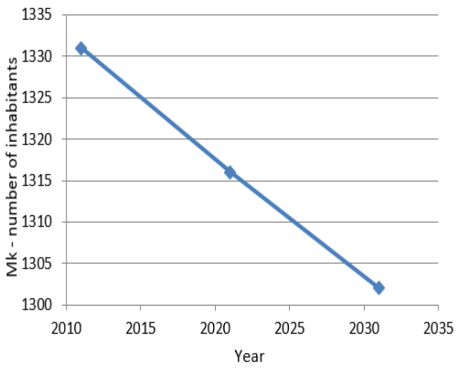
$$Q_{max,h} = (Kh \cdot Q_{max,d})/86.400 \tag{3}$$

Table 1. presents the calculated required instantaneous water demand for this settlement.

Table 1. *Calculated required instantaneous water demand [12]*

qk	Mk	$Q_{av,d}$ *[l/day]*	Q_{av} *[l/s]*	$Q_{max,d}$ *[l/s]*	$Q_{max,h}$ *[l/s]*	$Q_{min,d}$ *[l/s]*	$Q_{min,h}$ *[l/s]*
180	1331	239.580	2,77	4,44	8,87	1,22	0,12

For further analysis, we considered a period of 20 years. Figure 1 (left) shows the projected population for this 20-year period. Based on the graph, it can be concluded that in the coming years a natural population decrease of 11% is expected, followed by an additional decline after 2021. At the same time, water demand has increased, as reflected in the maximum daily water requirement for this settlement due to more frequent droughts and the growing need for larger water volumes. After 2021, a slight decrease in maximum water demand occurred, as shown in Figure 1 (right) [12].



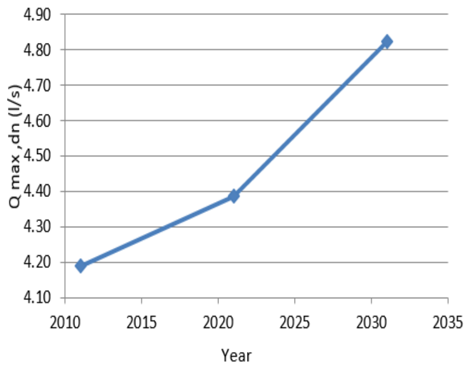


Fig. 1. *Population forecast for the upcoming period (left),Forecast of max. daily water demand (right) [12]*

It is important to note that this calculation was carried out empirically, which means that, in addition to the considerations mentioned in the introduction, the invoiced water quantity for this settlement was not taken into account, and small deviations are therefore possible. Consequently, the actual consumption may be slightly lower during the winter period and somewhat higher than projected during the summer period, when water is used irrationally for lawn, orchard, and garden irrigation.

DATA FOR CALCULATION OF THE EXISTING CONDITION

Water density:

$$\rho \approx 1000\,\frac{kg}{m^3}$$

Gravity:

$$g = 9{,}81\,\frac{m}{s^2}$$

Pump efficiency:

$$\eta = 0{,}75 = 75\%$$

The pipe lengths and diameters are as follows: for ACC Ø100 mm, length 208 m, made of galvanized steel, with an adopted friction factor of f = *0.02*. The second pipe, ACC Ø150 mm, length 45 m, also made of galvanized steel, has a friction factor of f = *0.018*.
Figure 2 shows the Moody diagram, which presents the flow characteristics. The transitional, or critical, zone is in the range of 2320 < Re < 4000, representing the shift from laminar to turbulent flow and vice versa. Experiments conducted within the transitional zone are considered unreliable [11,12,16].

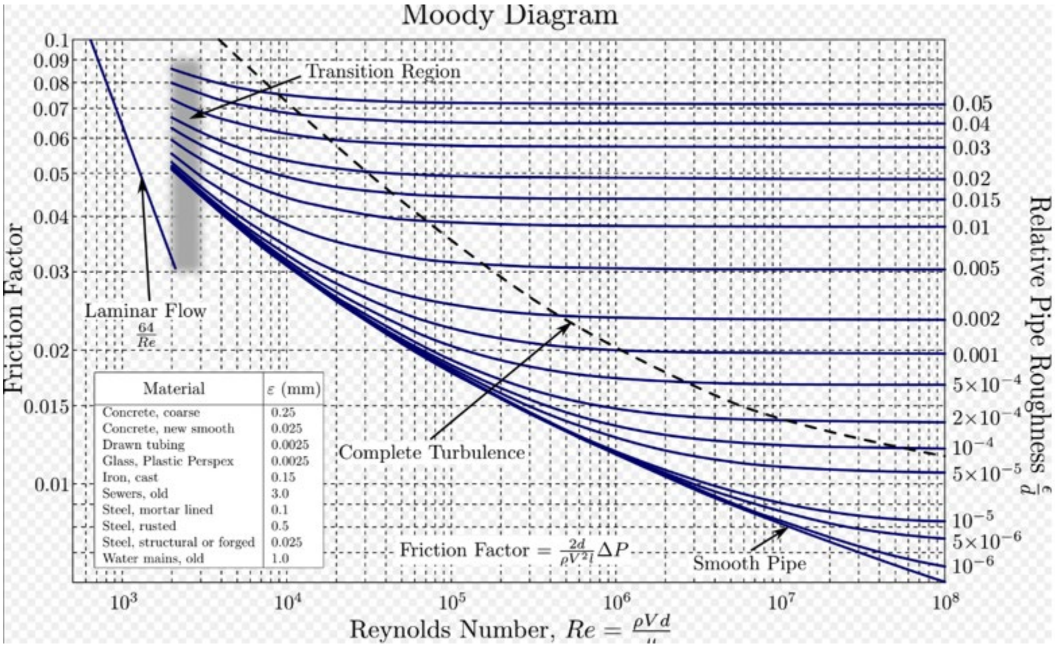


Fig 2. *Moody's diagram [11,6]*

Table 2 presents the characteristics of both pumps, which are centrifugal, underground, and submersible, powered by three-phase current, and operating at pressures ranging from 2.2 bar to 3 bar.

Table 2. *Pump specification [12]*

Pump 1: AP6-F6	**Pump 2: AP6-D9**
Power: 5,5kW	Power: 5,5kW
Voltage: 380V	Voltage: 380V
Current: 14,5A	Current: 14,5A
RPM: 2850min^{-1}	RPM: 2850min^{-1}

CALCULATION OF THE REQUIRED PUMP POWER

Average flow rate: P – pump power [5500W]; H – pumping head [24m].

$$Q = \frac{P \cdot \eta}{\rho \cdot g \cdot H} \tag{4}$$

Losses in ACC Ø150mm pipe through pressure drop: L – pipe lenght [45m]; D – pipe diameter [0,15m]

$$\Delta P = f \cdot \frac{L}{D} \cdot \frac{\rho \cdot v^2}{2} \tag{5}$$

$$v_{150} = \frac{Q}{A_{150}} \rightarrow v_{150} = \frac{Q}{\frac{d_{150}^2 \cdot \pi}{4}} \tag{6}$$

Losses in ACC Ø100mm pipe through pressure drop: L – [208m]; D – [0,1m]

$$v_{100} = \frac{Q}{A_{100}} \rightarrow v_{100} = \frac{Q}{\frac{d_{100}^2 \cdot \pi}{4}} \tag{7}$$

Total pumping head:

$$H_{total} = H + \frac{\Delta P_{150} + \Delta P_{100}}{\rho \cdot g} \tag{8}$$

Required pump power:

$$P_{req} = \frac{\rho \cdot g \cdot Q \cdot H_{ukupno}}{\eta} \tag{9}$$

The obtained values from the previous calculation are presented in Table 3.

Table 3. *Calculated values for required pump power*

The parameters	Values
Q – Average flow (l/s)	17,5
v_{150} – Flow velocity Ø150 (m/s)	0,990
v_{100} – Flow velocity Ø100 (m/s)	2,23
ΔP_{150} – Pressure drop Ø150 (kPa)	2,64
ΔP_{100} – Pressure drop Ø100 (kPa)	103,4
H_{total} – Total head (m)	34,82
P_{req} – Recuired power (kW)	7,97

CALCULATION OF THE REQUIRED PUMP POWER DURING THE SUMMER SEASON

The same parameters as in the previous calculation were processed, except that a 30% higher load was applied due to summer conditions, when temperatures are significantly higher and water is consumed in a considerably more irrational manner. The obtained data are presented in Table 4.

$$Q_{summer} = 1{,}3 \cdot Q \tag{10}$$

Table 4. *Calculated values for required pump power in the summer season*

The parameters	Values
Q_{summer} – Average flow (l/s)	22,75
$v_{150,summer}$ – Flow velocity Ø150 (m/s)	1,29
$v_{100\ ,summer}$ – Flow velocity Ø100 (m/s)	2,9
$\Delta P_{150,summer}$ – Pressure drop Ø150 (kPa)	4,493
$\Delta P_{100,summer}$ – Pressure drop Ø100 (kPa)	174,928
$H_{total,summer}$ – Total head (m)	42,29
$P_{req,summer}$ – Recuired power (kW)	12,584

CALCULATION OF PUMP POWER WITH THREE PUMP„B-3“

In the next step, the parameters were calculated in order to determine the operation of the system in the case of adding another identical well, i.e., an additional identical pump. The obtained results are presented in Table 5.

The total nominal flow rate for a single pump:

$$Q_1 = \frac{Q}{2} \tag{11}$$

The total nominal flow rate for a three pump:

$$Q_3 = Q_1 \cdot 3 \tag{12}$$

Table 5. *Calculated values for required power using three pump*

The parameters	Values
Q_1 – Average flow for single pump (l/s)	8,75
Q_3 – Average flow for three pump (l/s)	26,25
$v_{150,3}$ – Flow velocity Ø150 (m/s)	1,49
$v_{100\,,3}$ – Flow velocity Ø100 (m/s)	3,35
$\Delta P_{150,3}$ – Pressure drop Ø150 (kPa)	5,994
$\Delta P_{100,3}$ – Pressure drop Ø100 (kPa)	233,45
$H_{total,3}$ – Total head (m)	48,4
$P_{rec,3}$ – Recuired power (kW)	16,62

CONCLUSION

An analysis of the existing water supply system for the settlement *Belo Blato* was carried out, leading to the conclusion that the required pump power is 7.97 kW during the non-summer period. After performing calculations for the system under increased demand of 30% during the summer season, when water consumption becomes significantly less rational, the required pump power amounts to 12.584 kW, which cannot be provided by two wells. The specific problems that arise in this case are reflected in pressure drops and insufficient flow.
The actual pumping head of the wells is 24 meters. Based on the calculation with three wells, it was concluded that the required pump power would amount to 16.62 kW, which is sufficient to ensure the water supply of the settlement *Belo Blato* throughout the entire year and under varying weather conditions.
It is important to emphasize that the data used were obtained from the private archives of the company. Furthermore, the invoiced water consumption for this settlement was not taken into account, which may result in slight deviations. Specifically, the actual consumption may be somewhat lower during the winter period or slightly higher than the forecast during the summer period.

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