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# OPTIMIZATION OF HIGH PREASURE PIPELINE IN THE PRESSURE PIPE OF WATER SUPPLY

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SUMMARY

The water supply system is a set of facilities related to a functional unit with the primary aim of ensuring sufficient quantities of quality water by the most economical way. Design and implementation of such systems requires extensive previous research and analysis aimed at finding the optimal solution of water supply system.

This paper presents an analysis of the pressure pipeline of the water supply system in which discussed several alternatives with different input parameters. It is shown the influence of the position and the number of tanks in the system on the basic parameters such as a pressure in the pipeline, power of pump units and so on. It's analyzed the impact of changes in diameter of the pipe to the hydraulic parameters, and also to the initial and operating costs of the system. The main aim of the complete analysis is to establish a uniform depending of the analyzed elements in the system and finding the optimal parameters and their relationship that provide the most appropriate solution from the technical and economic aspects.

Keywords: pressure pipeline, pressure, pump station, water, water supply, reservoir

## INTRODUCTION

Among the many areas of modern technology aimed at raising of living standards, urbanization of settlement and development of the industry, water supply has a significant place. Supplying the population with clean and quality water has a significant hygienic importance because it protects people from various diseases that are transmitted by water. The insurance and bringing enough water in the stream is raising general living standards of people and arrangement of environment. Water consumption is even greater if the water is easily accessible. To meet the needs of modern multimillion cities it requires significant amounts of water that are daily measures by the millions of cubic meters [1].

In order to ensure the necessary amount of water, as well as high health (sanitary) quality of drinking water, special attention is paid to the choice of natural water sources, their protection from contamination and the possible need to improve water quality (water treatment) to the water supply devices. Today, in the world of healthy and clean water less, mainly due to continuous pollution. On the other hand, there is increasing demand and consumption of new water resources, due to the increase in population and the capacity of industry, agriculture, energy and others. To define the required amount of water is necessary as complete consideration of all potential consumers (and even the very water loss from water supply network), which consume water for various purposes. To ensure enough water to supply the population, the same need to draw from natural sources, and adequately transported to the consumer. Selection of water sources (water intake) to a large extent depends on the natural conditions of the location, and the available amount on the area under consideration.

In accordance with the characteristics of the water intake is selected and the appropriate water supply system of the village, or a way to transport water to the consumer.

If you take into account that the construction of a water supply system requires a significant investment, and very often their own operating costs can be quite large (eg. with the propellant system), select the optimal water supply system represents a significant step in the realization of such projects. Therefore, it is necessary to conduct a detailed prior research and extensive analysis to arrive variant solution with minimal initial investment and operating costs gives a technically satisfactory solution.

This paper analyzes the pressure pipe water supply system, in which water is transported from the intake to the reservoir. The aim is to reach an optimal solution that will meet all pre-specified parameters thereby taking into account a number of influencing factors characteristic for a given location and selected water supply system

## ANALYSIS OF WATER SUPPLY SYSTEM

In the planning and design of water supply system of the village special attention should be paid to the choice of the optimal position and characteristics of individual objects within the system. For this purpose, have been analyzed two variants of the water system of the same village. The first variation involves the abstraction of water from the water intake and transport thereof by the three-stage pumping water to the reservoirs $R_1$, $R_2$ and $R_3$ that are used in the water supply by gravity settlement.
The second option is similar, except that it treats the two-stage pump water to the reservoirs $R_1$ and $R_2$, which means that in this version omitted a one reservoir. Below is an analysis of both the variant solution, and comparative analysis of those varieties with a focus on pressure pipeline system.
As a basis for the analysis is selected water supply system of the village Sjenina and Sjenina Rijeka, which is located about 10 km northeast of the town of Doboj, on the right side of the river Bosna. For the analysis were adopted the following input parameters [2]:

- population that is planned to supply water is 3000 or 750 households
- planning period is 30 years
- rate of population growth is 1%
- specific consumption of the thresholds is between 150-180 l / capita / day
- coefficient of daily unevenness: $k_d$ = 1.50
- coefficient hour unevenness: $k_h$ = 2.00
- fire water $Q_f$ = 10,00 l/s for 2 hours for the fire (industrial applications)
- fire water $Q_f$ = 5,00 l/s for 2 hours for the fire (other purposes)
- equalization for the reservoir area k=0.35x$Q_{max,day}$; reservoir area plan about the same for all three or two zones.

The population at the end of the planning period or after n-years is defined by [3]:

$$S_b = S_p\left(1+\frac{k_p}{100}\right)^n$$

*$S_p$ - population at the beginning of the planning period*
*$k_p$ - rate of population growth (1.0%)*
*n - number of years of the planning period*

Average daily water consumption is calculated according to the formula:

$$Q_{sr} = q_{sp} \cdot N$$

*$q_{sp}$ - specific water consumption (liters/resident/day)*
*$N$ - population*

Maximum daily consumption:

$$Q_{\max,\,day} = Q_{sr} \cdot k_d$$

*$k_d$ - coefficient of daily unevenness*

Maximum hourly consumption:

$$Q_{\max,\,h} = Q_{sr} \cdot k_d \cdot k_h$$

*$k_h$ - coefficient hour unevenness*

Table 1 shows the required amount of water for water supply of settlements, for the planning period of 30 years, presenting the the basic input parameter for sizing and analysis of the water supply system.

Table 1: The necessary quantities of water for consider planning period

| **Planning period** | **Number of resident** | **Spec. consumpt. $q_{spec}$ *(l/resident/day)*** | **$Q_{sr}$ *(l/s)*** | $Q_{\max,\,day}$ ***(l/s)*** | **$Q_{max,h}$ *(l/s)*** | **$Q_f$ *(l/s)*** |
|---|---|---|---|---|---|---|
| Begining | 3000 | 150,00 | 5,21 | 7,81 | 15,62 | 10,00 |
| After 10 years | 3314 | 160,00 | 6,14 | 9,21 | 18,40 | 10,00 |
| After 20 years | 3660 | 170,00 | 7,20 | 10,80 | 21,60 | 10,00 |
| After 30 years | 4044 | 180,00 | 8,43 | 12,65 | 25,30 | 10,00 |

PRESSURE PIPELINE WITH THREE-STAGES PUMPING WATER

The first alternative solution represents a pressure pipe with three-stage pumping water to higher levels (figure 1). Water abstraction is carried out in the existing reservoir volume V=500,00 m³ belonging pipework neighboring village, located at an altitude of 196.5 meters above sea level. As part of the cover member chamber of the reservoir it is built pump station $PS_1$ that deliver water to the reservoir $R_1$, located at an altitude of 262.60 m above sea level (maximum water level in the tank). The length of the pipeline from $PS_1$ to $R_1$ is 4 455,00 m. As part of the cover member chamber of the reservoir $R_1$ it is located pump station $PS_2$ that deliver water from the tank $R_1$, by pressure pipeline length of 622.00 m, further to the reservoir $R_2$ with maximum water level at an altitude of 312,.50 meters above sea level. From the reservoir $R_2$ via a pumping station $PS_3$, water is transported to the reservoir $R_3$ via pressure pipeline length of 365.22 m. The water level in the reservoir $R_3$ is 367,00 meters above sea level.

Water supply of the settlementis is carried out from the tank $R_1$, $R_2$ and $R_3$, by gravity, through the distribution network. Considering the position of the tank settlement it is divided into three distribution altitude zone. The lower zone (I) are supplied with water from the reservoir $R_1$, central zone (II) is supplied with water by gravity from the reservoir $R_2$, while the upper zone (zone III) supplied with water from the reservoir $R_3$. One part of the zone III is supplied with water by gravity, while the second part (at higher altitudes) supplied with water through the booster station (UPP) located in the reservoir $R_3$.

The main pipeline from the pumping station $PS_1$ to the reservoir $R_1/PS_2$ should be sized to flow $Q_{max,day}$ = 12,65 l/s.

Fire consumption for this type of settlement is $Q_f$ = 2x2,5=5,00 l/s for residential premises. But in the same area there is a gas station and other commercial facilities that reuires the amount of fire water $Q_f$=2x5,00=10,00 l/s in the lower zone, while middle and upper zone, according to the type of settlement, should be covered with smaller diameter hydrants [4].

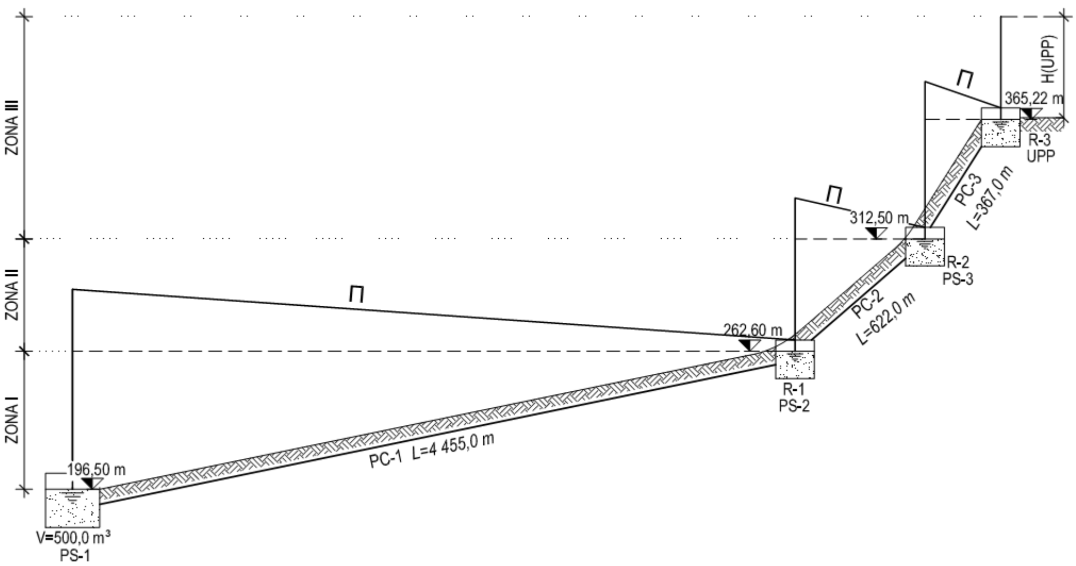


Figure 1: Hydraulic scheme of the three-stage pressure pipeline

Since the water supply system formed in three altitude zones, it is estimated that the lower zone (zone I) belongs 35% of $Q_{max,day}$ and 35% of $Q_{max,h}$, central zone (zone II) 30% $Q_{max,day}$ and 30% $Q_{max,h}$ and the upper zone (zone III) 35% $Q_{max,dax}$ and 35% $Q_{max,h}$.

Table 2 shows consumption of water by individual altitude zones for the planning period of 30 years.

Table 2: Distribution of water consumption by hypsometric zones

| **Hypsometric zones** | ***$Q_{max,day}$* (l/s)** | **(%)** | **Cons. by zones *$Q_{max,day}$* (l/s)** | ***$Q_{max,h}$* (l/s)** | **(%)** | **Cons. by zones *$Q_{max,h}$* (l/s)** | **Fire *$Q_f$* (l/s)** |
|---|---|---|---|---|---|---|---|
| **(zone I)** | 12,65 | 35 | 4,43 | 25,30 | 35 | 8,86 | 10,00 |
| **(zone II)** | 12,65 | 30 | 3,80 | 25,30 | 30 | 7,60 | 5,00 |
| **(zone III)** | 12,65 | 35 | 4,43 | 25,30 | 35 | 8,86 | 5,00 |

PRESSURE PIPELINE WITH TWO-STAGES PUMPING WATER

The second variety of water suply is a two-stage water supply. Water is pumping by pipeline to the reservoirs $R_1$ and $R_2$, from where the water is transported to the settlement by gravity (figure 2). Since the water supply system was established in the two height zones, with about the same population, it is estimated that both zones belongs to the 50% of $Q_{max,day}$ and 50% of $Q_{max,h}$. Table 3 shows consumption of water by individual hypsometric zones for the planning period of 30 years.

Table 3: Distribution of water consumption by hypsometric zones

| **Hypsometric zones** | ***$Q_{max,day}$* (l/s)** | **(%)** | **Cons. by zones *$Q_{max,day}$* (l/s)** | ***$Q_{max,h}$* (l/s)** | **(%)** | **Cons. by zones *$Q_{max,h}$* (l/s)** | **Fire *$Q_f$* (l/s)** |
|---|---|---|---|---|---|---|---|
| **(zona I)** | 12,65 | 50 | 6,33 | 25,30 | 50 | 12,65 | 10,00 |
| **(zona II)** | 12,65 | 50 | 6,33 | 25,30 | 50 | 12,65 | 5,00 |

Figure 2 shows the hydraulic scheme of water supply system with specified an elementary hydraulic parameters.

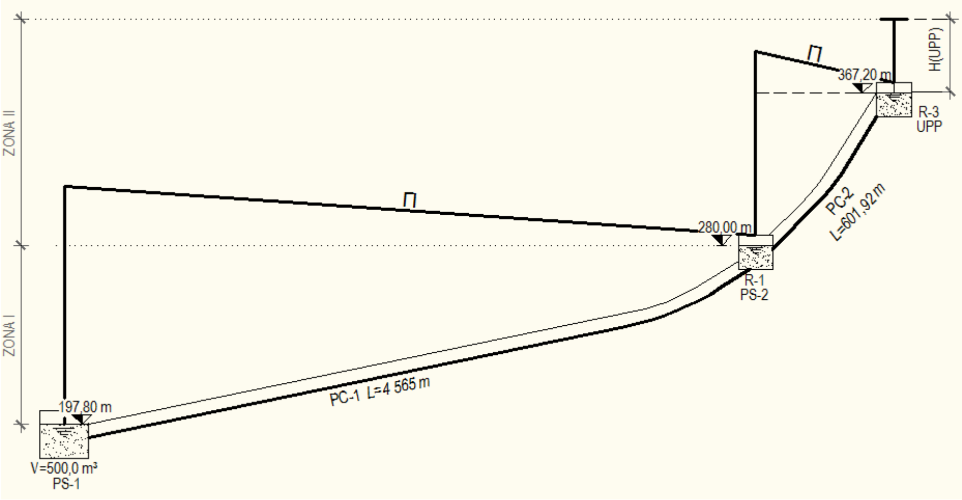


Figure 2: Hydraulic scheme of the two-stage pressure pipeline

ANALYSIS OF THE THE RESERVOIR VOLUME

In previous chapters, were analyzed for two alternative solutions of water supply system of the settlement. It was analyzed the necessary quantity of water, pipeline diameters, pressure losses in the pipeline and calculation of water hammer in order to get data of the maximum pressure in the pipeline as a result stationary and unstationary flow of water.

For the tree-level system of pressure pipeline takes three tanks with a total volume of reservoir space:

$$V_{tot} = 250 + 200 + 250 = 700{,}00 \ \ m^3$$

In the second version was dropped one reservoir, so that the total volume of useful reservoir space, in the two-level system, is:

$$V_{tot} = 330 + 300 = 630{,}00 \ \ m^3$$

It is evident that the second variant solution requires smaller storage space for 70 m³ compared to the first variant (figure 3), which represents savings both in initial construction costs of the system and in the maintenance of the system.

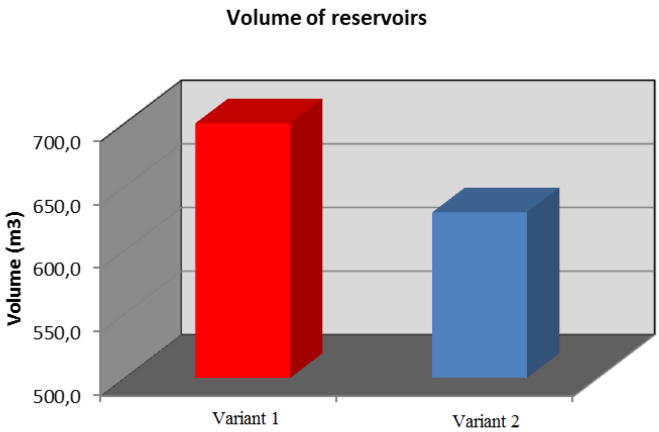


Figure 3: The required volume of the reservoir for the considered variants

OPTIMIZATION OF PRESSURE IN THE PRESSURE PIPELINE

In the stage of planning and designing of water supply system an important issue, which is necessary to consider, is analysis of the maximum and mnimalnih pressures in the pipeline. The pressure in the pipeline, for the stationary flow, is caused by geodetic height that must be overcome and the loss of pressure in the pipeline. Pattern of of pressure losses [5]:

$$\Delta H = \lambda \cdot \frac{L}{D} \cdot \frac{v^2}{2g} + \Sigma\xi \cdot \frac{v^2}{2g},$$

It is evident that the total losses depend on the type of pipe material (λ), the length of the pipeline (L), diameter pipe (D) and the speed of flow of water in pipes (v).

One of the main goals in the planning stage is, as much as possible, to reduce the loss of pressure, especially in the pressure pipe. This provides savings in operating costs of pumping water (less the manometer head), as well as lower the required nominal pressure of the pipeline (lower pipeline cost price). So, for the type of pipe material and given the length of the pipeline section, it is possible to reach the optimal pressure in the pipeline by variations in diameter pipes (therefore flow rate),. Therefore, the analysis is done for a relation between the diameter of pipes and pressures in the network, considering of water hammer. The results are shown in Table 4.

Table 4: Impact of change in diameter of to the hydraulic parameters of the pipeline

| Diamet. (mm) | $v_m$ (m/s) | Line losses ΔH (m) | Man. height $H_{man}$ (m) | Pow. of pump P (kW) | Hummer Δh (±m) | $H_{max}$ (m) | $H_{min}$ (m) |
|---|---|---|---|---|---|---|---|
| **DN 225** | 0,50 | 11,42 | 98,62 | 16,03 | 18,76 | 117,38 | 79,86 |
| **DN 200** | 0,62 | 21,20 | 108,40 | 17,62 | 23,25 | 131,65 | 85,15 |
| **DN 180** | 0,76 | 36,69 | 123,89 | 20,13 | 28,49 | 152,38 | 95,40 |
| **DN 160** | 0,97 | 68,24 | 155,44 | 25,26 | 36,73 | 191,87 | 119,01 |

According to the formula for pressure loss, flow rate is directly proportional to the value of line losses, it can be concluded that reducing the diameter of the pipeline causes an increase in line losses. The ratio of diameter pipes and line losses is shown in Table 4, a functional dependence of these parameters is shown in the graph (Figure 4).

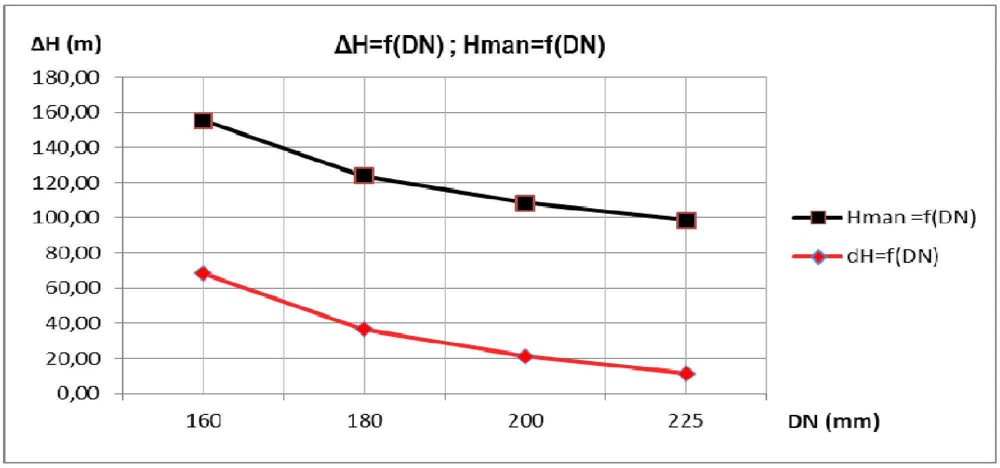


Figure 4: Dependence of line losses and manometer height of the pipeline diameter

The total manometer height is the sum of the geodetic head, the sum of all losses and the level in expired (in this case the height of a $H_i$=5,0 m).

Figure 4 shows the relationship of the manometer height and diameter of the pipeline, where it can be noted that reducing the diameter of the pipeline causes an increase in pressure, or, according manometer height.

As the manometer height directly related to the required pump power, and consideration the previously defined relations of manometer height and diameter of the pipe, it is clear that the required pump power is inversely proportional to the diameter of the pipeline [6]. So reduction in diameter causes an increase in losses (therefore manometer height), which results in an increase in the required pump power to overcome given height.

Figure 5 shows the functional dependence of the diameter of the pipe and the required pump power.

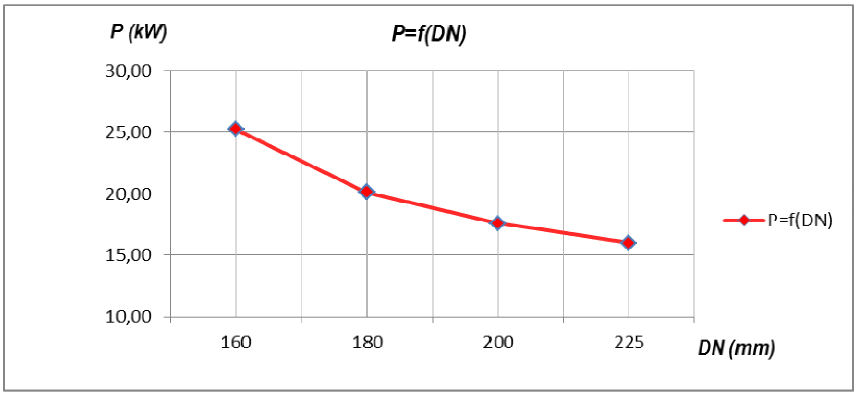


Figure 5: The ratio of pipeline diameter and the required pump power

In the previous section are defined and analyzed individual flow parameters for the steady flow of water in the pipes. But at the stage of putting into operation or in the sudden stop operation of pump (loss of electricity, etc.) comes to temporal changes of speed and pressure in the pipeline. This type of flow is described by a mathematical model of unstationary flow. In the case of sudden changes in the flow rate, it may cause a significant increase of pressure in the pipeline [7,8]. This phenomenon is called water hammer (figure 6).

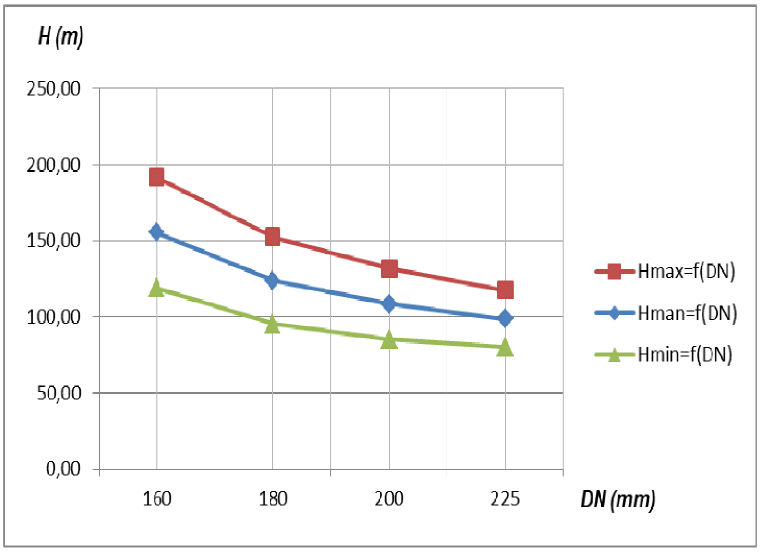


Figure 6: Pressure as a function of diameter pipes

The occurrence of water hammer is analyzed for all considered variants, and were defined the value of the maximum and minimum pressures. Obtained results are shown in Figure 6 for four analyzed variants of pressure pipe $PC_1$ (in variants of two-stage pumping).

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## CONCLUSIONS

The aim of the present study was to reach the optimal solution of the pressure pipeline and related facilities (reservoirs, pumping stations, pipelines and equipment etc.) by using a detailed analysis of all parameters. It was performed an analysis of several parameters that significantly affect to the technical and economic characteristics of a water suply system. By the analysis of required reservoir space can be concluded that the solution with two-level system is more favorable because it requires less storage capacity of the reservoir, which as the economic aspect brings savings of about 10% of investment in the construction of reservoirs in the system. It is also important to note that the maintenance costs is lower in second version, as it contains one reservoir less.

It's also analyzed the pressure in the pipes, in terms of adopted diameter pipelines and power of the pump units. If we take into account the price of certain diameter pipe with one hand, and the price of energy to run the pump units on the other hand, simply can be done and economic analysis of alternative solutions.

As for the operating costs of the system, it can be concluded that a system with two-stage pumping water requires a slightly higher power pump aggregates in relation to tree-level system. This means that the operating costs are higher for two-stage pump. However, if we have regard that each system has a constant inflow of financial resources during exploitation (collection from consumers), in certain circumstances, the initial cost of building the system is more important for analyze of justification for certain varieties of water supply system.

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