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DIMENSIONING OF UNDERGROUND PIPE NETWORKS OF IRRIGATION PLOTS. CASE STUDY - FÂNTÂNELE-SAGU IRRIGATION PLOT, ARAD COUNTY

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Abstract

To ensure the realization and efficient technical and economic operation of an irrigation system, it is important that, from the design, a correct dimensioning of the network of underground sprinkler irrigation pipes and, respectively, of the pressure station to ensure the necessary flow and pressure on all sections of the network, starting from the calculation of the irrigation regime, is ensured. The paper presents a calculation model for the correct dimensioning of the network of underground pipes within an irrigation plot, applied to the case study of the Fântânele - Sagu plot, Arad County, which takes into account the determination of the diameter of the main, secondary pipes and the antennas in such a way as to ensure the transport of the necessary water flow in each point of the plot and respectively to ensure the pressure necessary for the operation of the mobile watering equipment at all existing hydrants on this network. In the case study, the project for the modernization and retechnology of the secondary irrigation infrastructure is presented of the SPP Fântânele - Sagu plot.

***Key words**: antennas, hydrants, irrigation, pipe network.*

INTRODUCTION

Droughts, floods and other climate change-related threats have a significant impact on the stability of agricultural production and food security, and the lack of adequate infrastructure contributes to limiting opportunities for economic development despite the existence of potential in agriculture.

In order to adapt to the effects of climate change, for environmental protection and for reasons of competitiveness, it is necessary to modernize irrigation plots, which ensure the efficient use of water, through the correct technical and economic sizing of underground pipe networks, pressure pumping stations, by using new technologies that lead to a reduction in water and energy consumption at the level of investment.

This is proposed to be carried out within the National Strategic Program 2023-2027 - a program funded by the European Union and the Government of Romania through measures DR-25 (addressed to the OUAI for the rehabilitation and modernization of existing irrigation plots) and DR-26 (addressed to farmers for the realization of new local irrigation arrangements) - Modernization of irrigation infrastructure (AFIR, 2024).

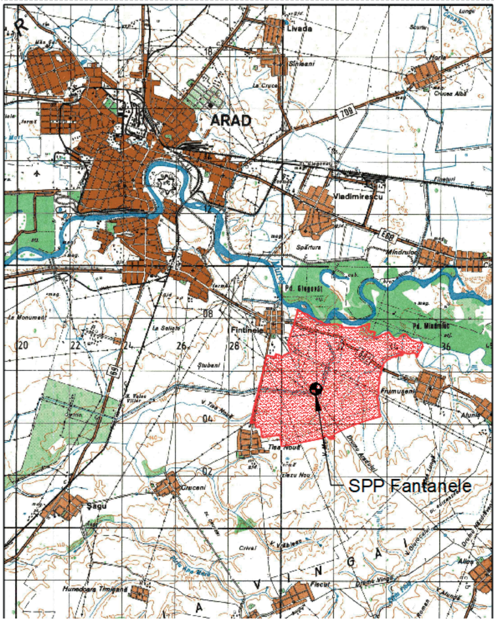

Figure 1. Map of SPP Fântânele, Arad County, Romania

In the process of carrying out these works, it is currently necessary to propose solutions for achieving intelligent irrigation using modern mobile irrigation equipment, as far as possible with automated operation and remote control (from the computer or even from the phone) (Cetin et al., 2023).

Currently worldwide (Biali et al., 2022) there are numerous pieces of equipment that, implemented in projects for the realization of new irrigation arrangements both by sprinkling and by dripping, or for the rehabilitation/modernization of old arrangements degraded over time, lead to important benefits of labor, water and energy saving. The studied location is located on the administrative territory of Fântânele, Arad County (Figure 1). The plot of SPP Fântânele Sagu is part of the Irrigation Arrangement Sagu Fântânele Arad (Figure 2).

The design of the irrigation system was carried out between 1966 and 1968 on an area of 7154 ha, the entire area being connected to the unique hydrotechnical scheme for this system, with the connection to the Mureş river and served by the adduction channel. The irrigated area is served by means of a floating pumping station, SP floating, located on the left bank of the Mureş River, upstream from Fântânele (ANIF, 2024).

Fântânele pumping station (SPP Fântânele) is located at the downstream end of the Aducțiune I with a length of 2,984 m. It has an installed flow Q=1.45 mc/s and a head of H=70 m with water, necessary for the water supply of the SPP Fântânele plot arranged in the area of 1,914 ha.

Through the technical expertise carried out, it is necessary to replace the pump + drive motors assemblies and the electrical components for control, protection and automation, which present great wear, both physical and moral, due to the more than 50 years from the date of commissioning and non-operation of the irrigation system.

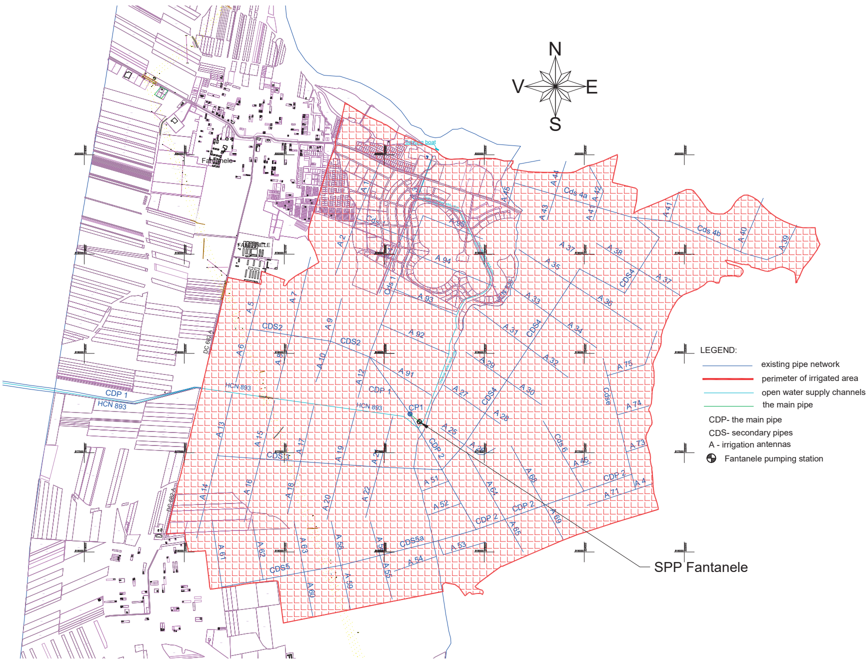

Figure 2. Map of existing irrigation system SPP Fântânele

MATERIALS AND METHODS

The elements of the irrigation regime include: Watering norm (m); Irrigation norm (Ni); Interval between waterings (T); Watering scheme; Irrigation hydromodule and uncoordinated and coordinated watering schedule chart. With these elements, the flow required for irrigation or the flow to be provided by the SPP (necessary to establish the time and number of pumping units) is calculated (Damian et al., 2022). The calculation relationships of these elements are:

- Irrigation norm is calculated using:

$$m = \frac{N}{\sum n} \quad \left(m^3 / ha\right)$$

where:
N - irrigation norm in (m^3/ha);
n - number of waterings.

- Interval between waterings (or time to recover $T_{i,j}$) is determined using:

$$T_{i,j} = \frac{m}{Epz(luna)} \quad \left(m^3 / ha / day\right)$$

Epz - daily potential evapotranspiration (average water consumption of crops)

- Calculus of watering scheme requires external humidity values W_{min} and W_{max}

$$W_{\min} = 100 \cdot \gamma_v \cdot H \cdot P_{\min}$$

$$W_{\max} = 100 \cdot \gamma_v \cdot H \cdot C_c$$

where:
γ - volumetric weight of soil;
C_c - field capacity (m^3/ha);
P_{min} - minimum humidity ceiling;
H - depth of the active soil layer (m).

- The hydromodulus of irrigation for a rotation is determined with:

$$q_0 = \frac{n_i \cdot m_i}{3.6 \cdot T \cdot t} \quad (l / s \times ha)$$

where:
n_i, m_i - the number of waterings, respectively the watering norm for the month of maximum consumption of the crop irrigation season (crop rotation) on the entire surface area (S_{pl});
T - 30 days the duration of surface watering the entire area with the maximum monthly irrigation norm;
T - 20 hours.
The required water flow rate is calculated with the ratio:

$$Q_i = q_i \times S_i \quad \left(l / s\right)$$

where:
q_i - irrigation hydromodule (l/s/ha);
m_i - watering norm required by i crop;
T (8-10 days) - total watering time of crop;
t - 20 hours daily watering time;
S_i - i crop occupied area.

- Calculation ratio of the volume of water (V) required for each watering is given by:

$$V = \frac{m \cdot S}{1000 \cdot \eta} \quad \left(\text{k m}^3\right)$$

where:
m - watering norm (m^3/ha);
S - irrigated surface (ha);
η - (watering yield in the field) = (0.85 - 0.90).
The determination of the sizing flow rate of underground pipe networks is based on the theoretical calculation of pressure drops, where in general, Chezy's formulas are used:

$$V = C\sqrt{Ri}$$

Associating the continuity equation is obtained for the flow rate:

$$Q = VS = SC\sqrt{Ri}$$

The hydraulic radius is explained by $R = \frac{S}{P}$ and we obtain:

$$Q = SC\sqrt{\frac{S}{P}i} = \frac{S^{\frac{3}{2}}}{P}C\sqrt{i}$$

Associating the Chezy formula we obtain the flow rate:

$$Q = SC\sqrt{Ri} = S\frac{1}{n}R^y\sqrt{Ri} = S\frac{1}{n}R^{y+\frac{1}{2}}\sqrt{i} =$$

$$= S\frac{1}{n}\frac{S^{y+\frac{1}{2}}}{P^{y+\frac{1}{2}}}\sqrt{i} = \frac{1}{n}\frac{S^{y+\frac{3}{2}}}{P^{y+\frac{1}{2}}}\sqrt{i}$$

in other words:

$$Q = \frac{1}{n}\frac{S^{1,5+y}}{P^{0,5+y}}\sqrt{i}$$

by substituting with the Manning relation, we obtain:

$$Q = \frac{1}{n}\frac{S^{\frac{5}{3}}}{P^{\frac{2}{3}}}\sqrt{i}$$

For circular pipes we have:

$$Q = \frac{1}{n}\frac{\left(\frac{\pi D^2}{4}\right)^{\frac{5}{3}}}{(\pi D)^{\frac{2}{3}}}\sqrt{i} = \frac{\pi D^{\frac{8}{3}}}{n 4^{\frac{5}{3}}}\sqrt{i}$$

flow module is noted:

$$K = \frac{\pi}{n}\frac{D^{\frac{8}{3}}}{4^{\frac{5}{3}}}$$

hydraulic resistance:

$$M = \frac{l}{K^2}$$

hence head loss is:

$$h_r = MQ^2$$

The study method is based on the use of Mike Urban software for hydraulic modeling of the underground irrigation pipeline network and the use of new / modern sprinkler irrigation equipment (DHI, 2024).

RESULTS AND DISCUSSIONS

The solution involves the rehabilitation of the pumping station building, with the replacement of the old pumping equipment with new ones with superior functional parameters, the rehabilitation of the underground network of transmission and distribution pipes with new HDPE pipes. The metering of consumption will be done entirely at the level of the pumping station, fencing (Figure 3)

Irrigation regime - was calculated for corn and wheat crop rotation. In Table 1 we find the calculation of the flow rate and the volume of water needed for sprinkler irrigation of 1857 ha during the vegetation period of one year (dry year). The entire area being cultivated with corn crop.

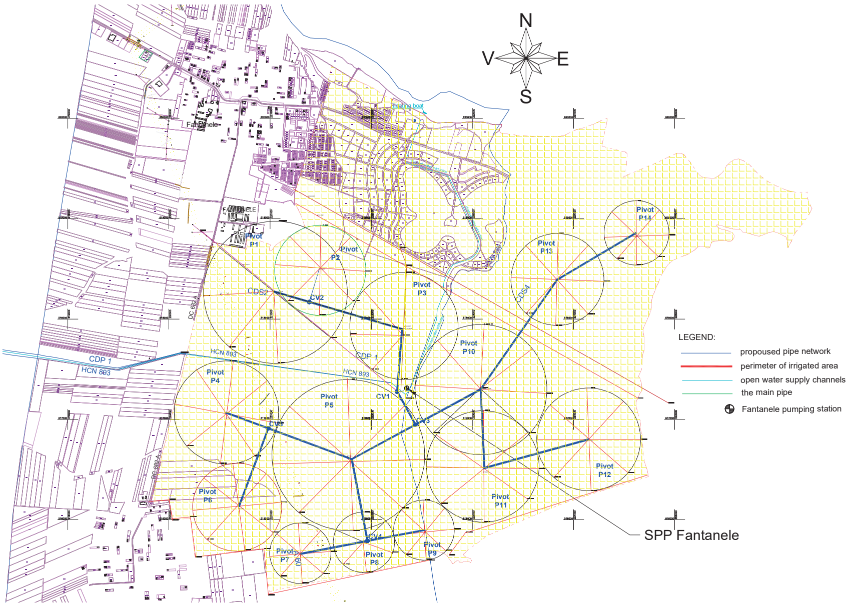

Figure 3. Map of proposed irrigation system SPP Fântânele

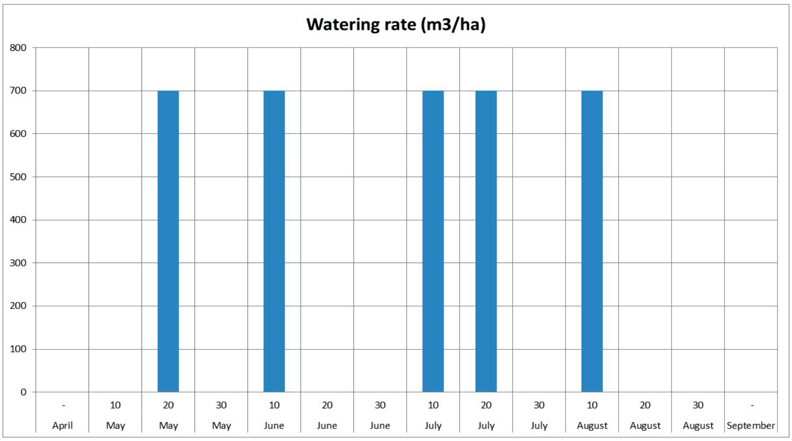

Figure 4. The annual and decadal watering charts

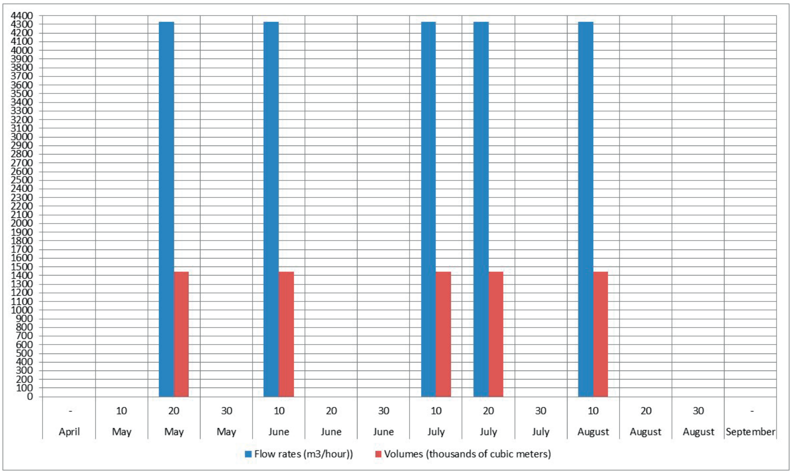

Figure 5. Uncoordinated watering schedule for a dry year

Figure 5 shows the water needs (flows and volumes) for decades, months and, the reference period (V-VIII) that the beneficiary must have a reference for watering.

To perform the modeling, the simulation model was developed by inputting coordinates in the Stereo 70 system, defining network nodes, and inserting pipe segments with specified materials and diameters. This process resulted in the layout plan illustrated in Figure 6. The SP Fântânele pumping station, which is supplied from the ANIF channel and has an installed flow capacity of 3991.9 m³/h, was integrated into the system. After calibrating and running the model, we obtained data on flow (Figure 7), velocity (Figure 8), headloss (Figure 9), and pressure (Figure 10) across all pipes and nodes, which were represented in corresponding diagrams.

Consequently, we were able to generate diagrams showing pressure, velocity, and headloss across all sections, specifically in the directions SP – A01 and SPP15 – P14, as shown in Figures 10 and 11.

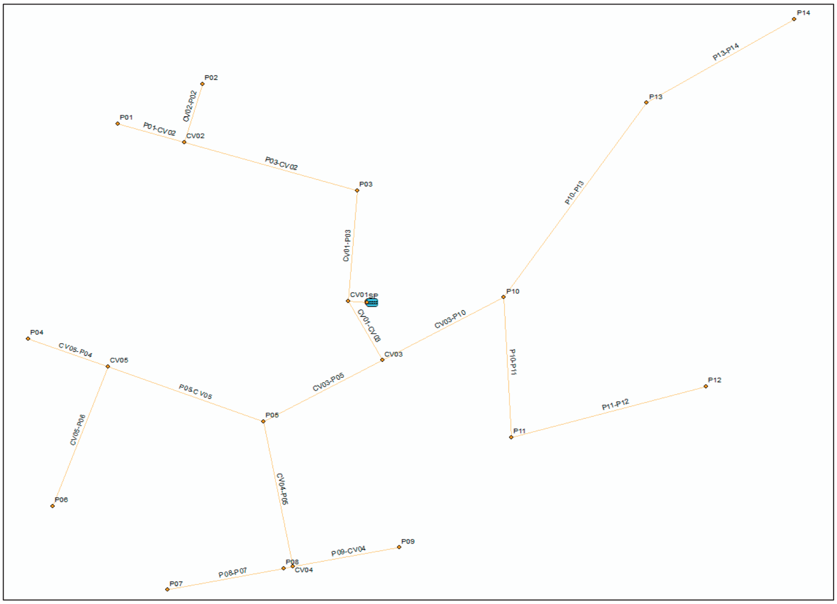

Figure 6. Plan view model

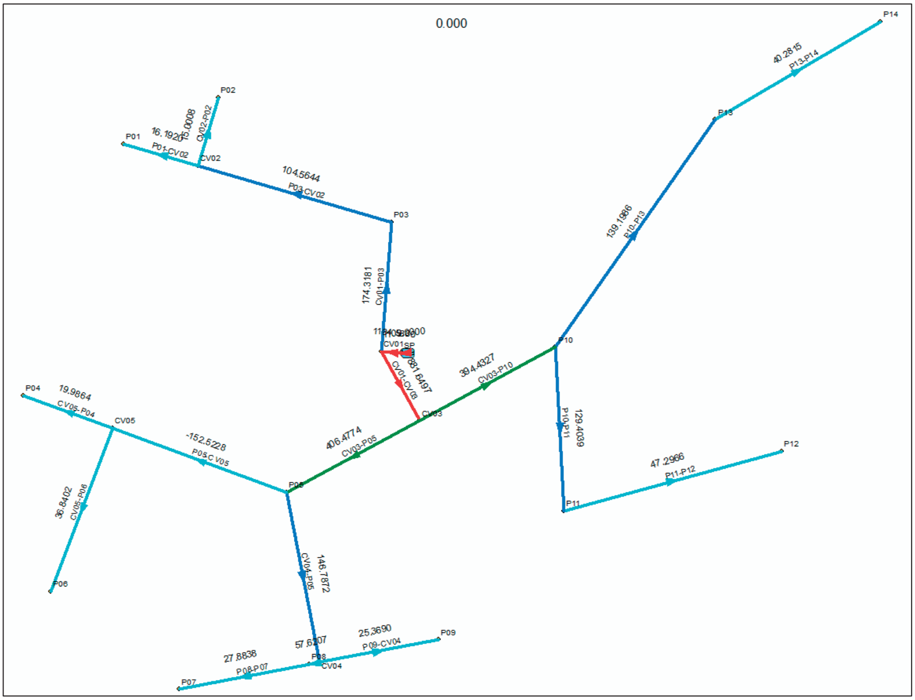

Figure 7. Pipe flows (l/s)

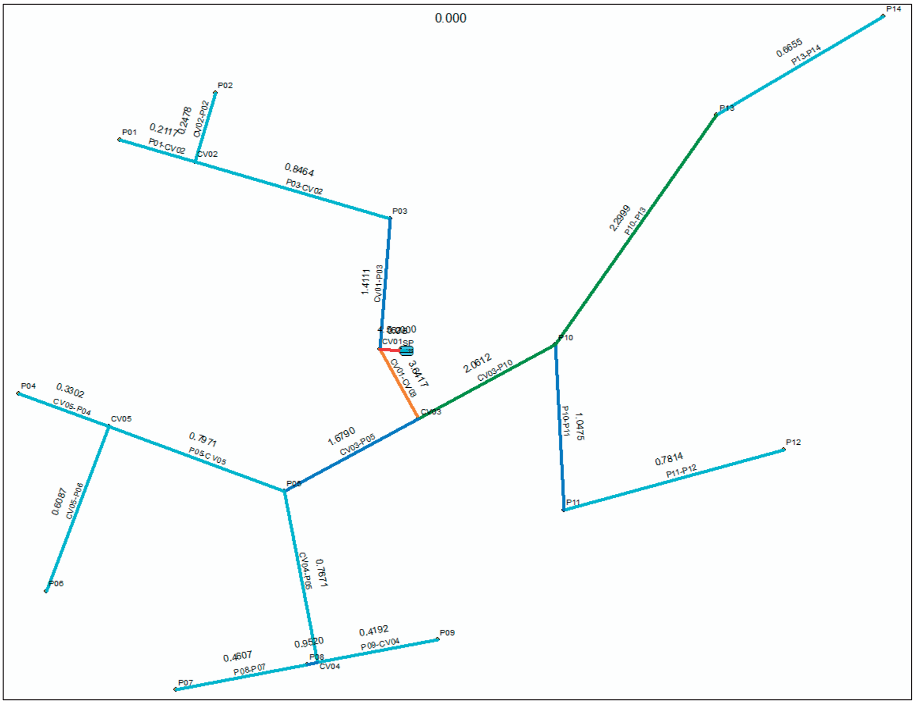

Figure 8. Pipe velocity (m/s)

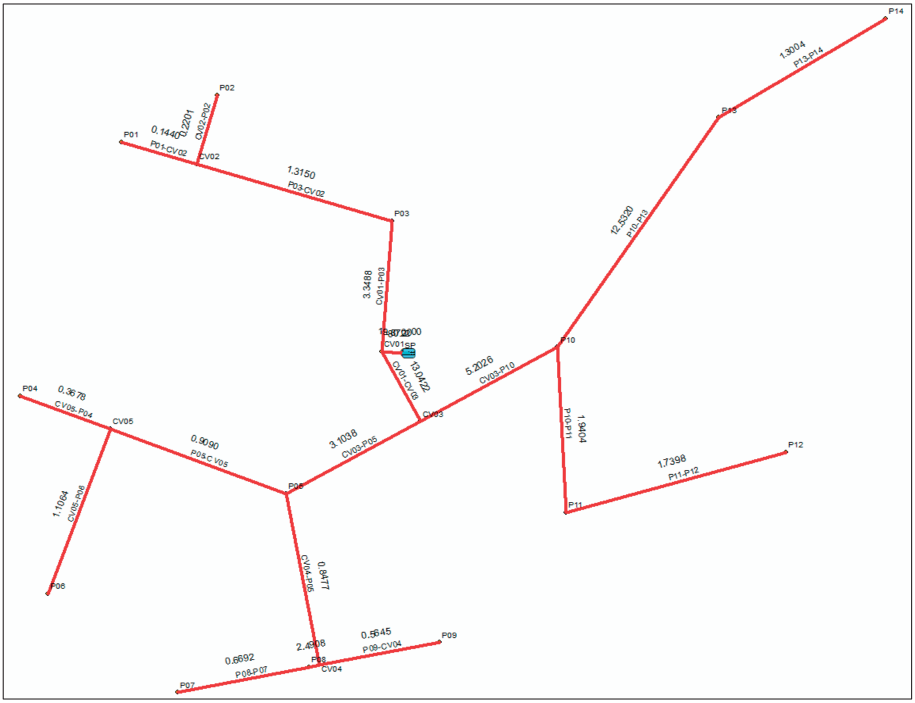

Figure 9. Pipe head-loss (m/km)

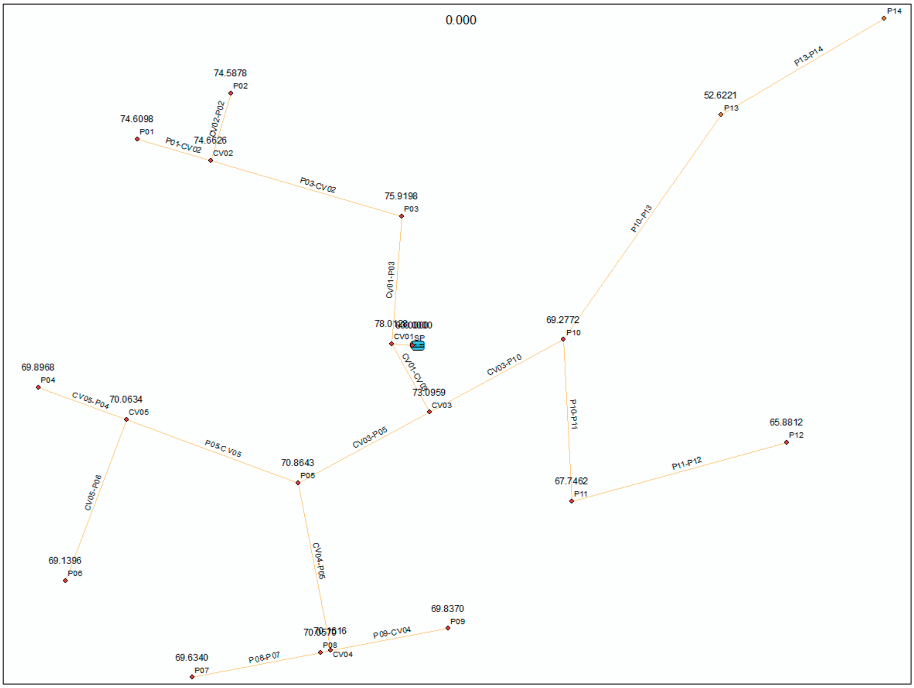

Figure 10. Node pressure (m)

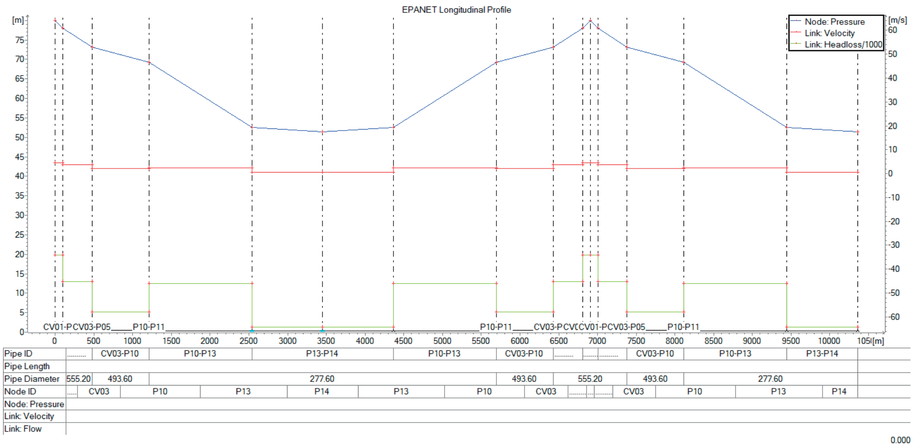

Figure 11. Section pressure diagram SP – P14

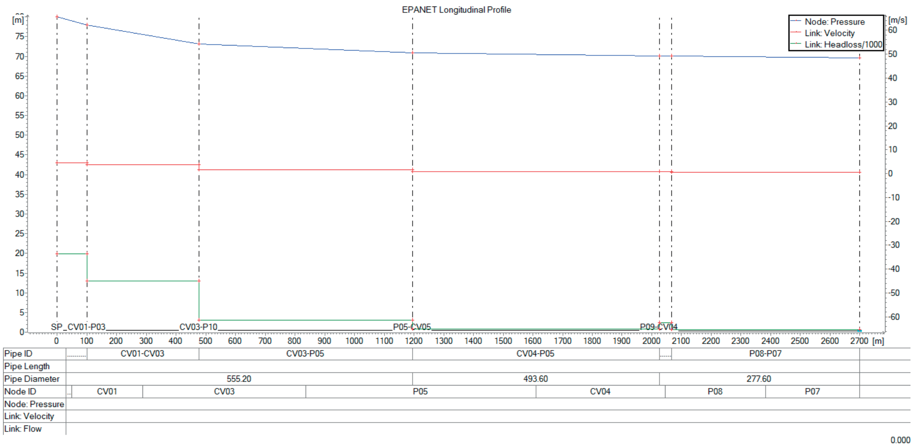

Figure 12. Section pressure diagram SP – P07

Without Project Scenario

Starting from the plant water requirement of 1600 m³/ha for 1198 ha, the total required volume is 1,916,800 m³. Assuming a field irrigation efficiency of 75%, the required volume at the hydrant is: 2,555,734 m³. To achieve this, with a pipeline network efficiency of 85%, the volume to be transported through the buried pipeline network must be 3,006,746 m³. Given the pump efficiency at the pressurization station is 65%, the volume to be extracted from the source (canal) is 4,625,763 m³.

Therefore, the water loss in the scenario WITHOUT the project is 2,708,963 m³.

With Project Scenario

Starting from the same plant water requirement of 1600 m³/ha for 1198 ha, the total needed volume remains 1,916,800 m³.

Assuming a field irrigation efficiency of 85% (due to new irrigation equipment acquired by the OUAI members), the required volume at the hydrant is 2,255,059 m³. To deliver this volume, with a modernized pipeline network efficiency of 95%, the volume to be transported is 2,373,746 m³.

With upgraded pumping units having an efficiency of 80%, the required intake from the source (canal) is 2,967,183 m³. Therefore, the water loss in the scenario WITH the project is 1,050,383 m³.

Water Loss Reduction

The reduction in water losses is calculated as the percentage difference between the losses in the "without project" and "with project" scenarios 61.22% Thus, the project implementation results in a 61.22% reduction in water losses.

The proposed technical solution ensures the functional safety of the entire irrigated area within the current irrigation system, starting from the distribution pipeline network required for water transport to the proper operation of the irrigation installations up to their terminal end.
The initial parameters of flow rate and discharge pressure are maintained to accommodate any crop plan with varying irrigation water requirements.
The new water distribution network, made of PE100 SDR17 PN10 polyethylene pipes, will lead to significant water savings.
Water losses in a pipeline network made of asbestos cement and pre-stressed concrete pipes older than 40 years, operating under a pressure regime of 6 bar, amount to approximately 25% of the volume of water pumped through the system. By replacing the old pipes with new HDPE (High-Density Polyethylene) pipes, these 25% losses can be eliminated.
In the case of the old hydrants, losses in the buried pipeline network are around 5% of the pumped water volume. Replacing the hydrants will eliminate this 5% loss as well.
For furrow and sprinkler irrigation methods, as originally designed for the buried pipeline system, the efficiency of this dual irrigation method is 0.8. By using new irrigation equipment such as boom and reel-type systems, irrigation efficiency increases to 0.9, thereby reducing water losses by approximately 10%.
Considering all three factors that influence water loss - replacement of the buried pipeline network with HDPE pipes, replacement of hydrants, and use of high-performance irrigation equipment - total water losses will be reduced by approximately 40%. Additionally, replacing the pumping units results in a further reduction of losses by around 15%, due to an increase in pump efficiency from 65% (old pumps) to 80% (new pumps).

CONCLUSIONS

The use of hydraulic modeling resulted in the pressure diagrams shown in Figures 11 and 12, which are essential for properly dimensioning the underground pipeline network used for irrigation. These diagrams ensure that both the pressure and flow rates are adequate for the efficient operation of sprinkler irrigation systems.
The proposed modernization scenarios focus primarily on optimizing the performance of the SP Fântânele pressure pumping station and the associated irrigation pipeline network responsible for delivering water to irrigated agricultural areas.
Installing new equipment to measure both water flow and volume distributed for irrigation will support transparent, contract-based operations between the water provider - ANIF Territorial Branch for Land Improvements Arad - and the beneficiary, OUAI Fântânele. This upgrade aims to prevent potential disputes arising from the absence of monitoring systems.
Additionally, the implementation of advanced automation technology is recommended to minimize staffing requirements at the pumping station during the system's operation period, thereby increasing operational efficiency.

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