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Modernization and Rehabilitation of Irrigation Infrastructure through Hydraulic and Energy Upgrading of Pumping Stations and Pressurized Pipe Networks – A Technical Case Study in Romania

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ABSTRACT

The modernization of irrigation infrastructure is a critical requirement for enhancing water use efficiency, operational reliability, and agricultural resilience in regions increasingly affected by climate variability and aging hydraulic systems. This paper presents a comprehensive technical study on the rehabilitation and upgrading of an existing irrigation system in Romania, focusing on the modernization of a pumping station and its associated pressurized buried pipeline network serving an extensive agricultural area.

The study is based on detailed technical documentation and hydraulic calculations developed within a technical execution framework, aiming to restore and improve the functional performance of irrigation infrastructure supplying approximately 664 ha of irrigated land. The proposed modernization measures include the upgrading of pumping equipment, the replacement and extension of main and secondary pressurized pipelines, and the optimization of hydraulic and energy parameters in accordance with crop water demand and modern irrigation requirements.

Key design parameters such as flow rate, total pumping head, installed power, and network configuration were determined using hydromodule-based irrigation demand and technical specifications of the proposed equipment. The technical solution ensures adequate water conveyance capacity, improved pressure stability, and enhanced operational reliability for the integration of modern irrigation technologies, including mobile pivot systems. Additionally, the rehabilitation strategy contributes to reduced hydraulic losses, improved energy efficiency, and increased flexibility in system operation.

The results demonstrate that systematic rehabilitation of irrigation infrastructure represents a viable and effective approach for improving the performance and sustainability of agricultural water management systems. The findings of this study provide a replicable technical framework applicable to similar irrigation modernization projects in Romania and other regions with comparable agro-climatic and hydraulic conditions.

Keywords: Irrigation Infrastructure; Pumping Station Rehabilitation; Hydraulic Modernization; Pressurized Pipeline Networks; Energy Efficiency; Agricultural Water Management; Irrigation System; Water Management; Energy; Pipeline.

1. Introduction

Irrigation infrastructure plays a fundamental role in ensuring agricultural productivity, food security, and efficient water resource management, particularly in regions characterized by increasing climatic variability and recurrent drought periods. In many agricultural systems across Europe, including Romania, a significant proportion of irrigation facilities were developed several decades ago and are currently operating beyond their originally designed service life. As a result, these systems are often affected by reduced hydraulic performance, high energy consumption, operational unreliability, and limited compatibility with modern irrigation technologies.

The degradation of pumping stations and pressurized pipe networks represents one of the main technical challenges in the operation of large-scale irrigation schemes. Aging pumping equipment, undersized or deteriorated pipelines, and obsolete control systems contribute to excessive hydraulic losses, unstable operating pressures, and inefficient water delivery. These deficiencies not only increase operational costs but also limit the ability of irrigation systems to respond effectively to variable crop water demands and contemporary agricultural practices.

In the context of climate change and growing pressure on water resources, the modernization of irrigation infrastructure has become a strategic priority. Technical rehabilitation measures aimed at improving hydraulic efficiency, optimizing energy consumption, and enhancing operational flexibility are essential for ensuring the long-term sustainability of irrigated agriculture. Modernization efforts typically involve the replacement or upgrading of pumping aggregates, the redesign of pressurized pipe networks, and the integration of automation and control systems capable of adapting to dynamic operating conditions.

Romania possesses extensive irrigation infrastructure developed primarily during the second half of the twentieth century, much of which requires systematic rehabilitation to meet current performance and efficiency standards. While substantial investments have been directed toward infrastructure renewal in recent years, there remains a need for detailed technical studies that demonstrate practical modernization solutions based on real operating conditions and engineering design principles. Such studies provide valuable insight into the technical feasibility, performance improvement potential, and replicability of rehabilitation strategies for similar irrigation systems.

This paper addresses these challenges by presenting a technical case study focused on the rehabilitation and modernization of an existing irrigation system in Romania. The study emphasizes the hydraulic and energy upgrading of a pumping station and its associated pressurized pipeline network, with the objective of improving water conveyance capacity, pressure stability, and overall system efficiency. The proposed approach is grounded in detailed hydraulic calculations, equipment selection criteria, and irrigation demand analysis, reflecting the practical requirements of contemporary agricultural water management. By documenting the applied methodology and discussing the resulting technical performance improvements, this study aims to contribute to the body of knowledge on irrigation infrastructure modernization. The findings offer a structured and transferable framework that can support decision-making processes for similar rehabilitation projects in regions facing comparable hydraulic, climatic, and operational constraints.

1.1. Study Objectives

The general objective of this study is to evaluate the technical feasibility and performance benefits of modernizing aging irrigation infrastructure through hydraulic and energy upgrading of pumping stations and pressurized pipeline networks, using a representative large-scale irrigation system in Romania as a case study. In line with recent research emphasizing the role of infrastructure rehabilitation in improving water and energy efficiency under climate change conditions the specific objectives of this study are as follows:

1. To assess the current hydraulic and energy performance of an existing irrigation pumping station and pressurized pipe network, identifying the main technical limitations associated with aging infrastructure, including excessive head losses, reduced operational flexibility, and increased energy consumption, as highlighted in recent irrigation modernization studies.

2. To develop a technically optimized modernization for the pumping station, based on updated hydraulic calculations, improved pump selection, and adaptive operating conditions, with the aim of ensuring reliable water delivery and enhanced pressure stability under variable irrigation demand.

3. To redesign and dimension the pressurized pipeline network, minimizing hydraulic losses and ensuring uniform pressure distribution at downstream irrigation equipment, in accordance with contemporary design recommendations for pressurized irrigation systems.

4. To evaluate the potential energy efficiency improvements resulting from infrastructure rehabilitation, including the impact of modern pumping equipment and improved system configuration on overall energy consumption and operational costs.

5. To demonstrate the applicability of a structured technical rehabilitation methodology that can be replicated in similar large-scale irrigation systems facing comparable hydraulic, climatic, and operational challenges in Eastern Europe and other regions with aging irrigation infrastructure.

6. To contribute to the current body of knowledge on irrigation infrastructure modernization, providing a practical engineering framework that supports sustainable agricultural water management and aligns with recent international research trends in irrigation efficiency and energy optimization.

2. Study Area and Existing Irrigation Infrastructure

The analyzed irrigation system is part of a large-scale agricultural water management scheme developed to supply irrigation water to an extensive cultivated area in Romania. The system was originally designed to support irrigated agriculture under specific hydraulic and agronomic conditions prevalent at the time of construction. Over the years, changes in crop patterns, irrigation technologies, and operational requirements have imposed additional demands on the existing infrastructure, highlighting the need for technical rehabilitation and modernization.

The irrigation scheme is supplied from a surface water source, which ensures the availability of water for agricultural use during the irrigation season. Water abstraction and conveyance are performed through a centralized pumping station responsible for delivering pressurized flow into a buried pipeline network. The infrastructure serves a net irrigated area of approximately 664 ha, characterized by relatively uniform topography, which is favorable for pressurized irrigation systems but requires stable hydraulic operating conditions.

2.1. Existing Pumping Station

The pumping station represents the core hydraulic component of the irrigation system, providing the necessary discharge and pressure to ensure water distribution across the network. Prior to modernization, the station was equipped with a limited number of pumping aggregates designed for operating conditions that no longer correspond to current irrigation demand. The existing configuration resulted in insufficient flexibility during peak demand periods and reduced overall system efficiency.

The original pumping equipment was characterized by constrained operating ranges and limited adaptability to variable flow requirements. Additionally, the absence of advanced control and automation systems restricted the ability to optimize pump operation according to real-time irrigation needs. These factors contributed to increased energy consumption and reduced operational reliability, particularly under partial load conditions.

2.2. Pressurized Pipeline Network

The irrigation network consists of buried pressurized pipelines arranged in a hierarchical configuration, including a main conveyance pipeline, secondary distribution pipelines, and terminal connections supplying irrigation equipment. The original network layout was designed to accommodate a specific irrigation technology and flow distribution pattern, which has since evolved due to the introduction of modern irrigation systems, such as mobile pivot installations.

Field inspections and technical assessments revealed that portions of the existing pipeline network exhibit inadequate hydraulic capacity, leading to elevated head losses and non-uniform pressure distribution. Variations in pipe diameters, material aging, and localized bottlenecks further exacerbate these issues, limiting the effective performance of the irrigation system during simultaneous operation of multiple irrigation units.

2.3. Energy Supply and Control Systems

Electrical energy required for pump operation is supplied through a dedicated power connection designed to meet the installed capacity of the pumping station. However, the original electrical configuration was not optimized for energy-efficient operation under variable demand scenarios. The lack of frequency control devices and modern automation limited the capacity for adaptive pump operation, resulting in suboptimal energy performance.

Overall, the existing irrigation infrastructure reflects typical characteristics of aging large-scale irrigation systems, where hydraulic and energy inefficiencies accumulate over time. These deficiencies provided the technical motivation for the proposed rehabilitation and modernization strategy, which is addressed in the following sections of this paper.

3. Current Condition of the Pumping Station

The analysed pumping station represents the central hydraulic component of the irrigation system, being responsible for water abstraction from the surface source and pressurized delivery to the distribution pipeline network. The station was constructed as part of large-scale irrigation schemes developed during the second half of the twentieth century and was originally designed to operate under hydraulic and agronomic conditions characteristic of that period. These conditions were associated with traditional irrigation technologies and operational requirements that differ significantly from current demands.

From a structural and functional perspective, the pumping station is equipped with a limited number of pumping aggregates, dimensioned for relatively constant operating regimes and lacking the ability to efficiently adapt to variations in irrigation demand. This rigid configuration results in reduced operational flexibility, particularly during peak irrigation periods when water demand is high and highly variable.

The existing pumping equipment is characterized by narrow operating ranges and hydraulic efficiencies that are below current performance standards. The absence of variable speed control systems forces the pumps to operate under non-optimal conditions, leading to significant energy losses, especially under partial load operation. Without adaptive control of flow rate and pressure, the pumping station is unable to respond efficiently to the fluctuating requirements of downstream irrigation users.

From an energy supply perspective, electrical power is provided through a dedicated connection dimensioned to meet the originally installed capacity of the pumping station. However, the electrical configuration does not include modern automation and control equipment, such as variable frequency drives or real-time monitoring systems. This limitation restricts the potential for energy optimization and contributes to increased operational costs.

Furthermore, the overall aging condition of the mechanical and electrical components negatively affects the operational reliability of the pumping station. Frequent start-stop cycles, performed without advanced control strategies, impose additional mechanical and hydraulic stresses on both the pumping equipment and the pipeline network. These conditions increase the risk of failures and reduce the service life of critical infrastructure components.

Overall, the current condition of the pumping station reflects the typical limitations of aging irrigation infrastructure, characterized by low energy efficiency, limited operational flexibility, and reduced adaptability to modern irrigation requirements. These deficiencies provide a strong technical justification for the implementation of a comprehensive rehabilitation and modernization strategy, addressing hydraulic performance, energy efficiency and automation aspects, as further discussed in the following sections of this paper.

4. Technical Solution for Infrastructure Modernization

The proposed technical solution aims to restore and enhance the functional performance of the irrigation system through targeted rehabilitation of the pumping station and pressurized pipeline network.

4.1. Pumping Station Modernization

The rehabilitation strategy includes the installation of new high-efficiency pumping aggregates designed to meet the required discharge and pressure conditions. The proposed configuration ensures sufficient redundancy and operational flexibility to accommodate variable irrigation demand throughout the irrigation season.

To improve energy performance and control accuracy, the pumping station modernization incorporates frequency control devices and automated operation systems. These measures allow for adaptive pump operation, reducing energy consumption under partial load conditions and minimizing hydraulic stress within the network. The general configuration of the pumping station is illustrated in Figures 1 and 2.

Figure 1. General view of the irrigation pumping station supplying the analyzed agricultural area, highlighting the arrangement of pumping units and the main hydraulic components prior to rehabilitation.

Figure 2. Electrical pump starting and control system of the existing pumping station, illustrating the conventional configuration used before the implementation of energy-efficient automation and frequency control.

4.2. Pressurized Pipeline Network Rehabilitation

The pipeline network modernization focuses on replacing hydraulically inadequate sections and extending the network to improve water distribution uniformity. Pipe diameters were selected based on calculated flow rates and permissible head losses, ensuring stable pressure conditions at the terminal points supplying irrigation equipment.

The upgraded network configuration supports the integration of modern irrigation technologies, including mobile pivot systems, while reducing friction losses and improving overall system efficiency. Additional hydraulic protection elements were included to enhance operational safety and durability.

Figure 3. Schematic representation of the rehabilitated pressurized pipeline network, showing the main and secondary pipelines, flow direction, and improved hydraulic layout adopted to reduce head losses and ensure pressure stability.

5. Hydraulic Calculations and Design Parameters

Hydraulic design calculations were carried out to ensure that the proposed irrigation system operates reliably under peak demand conditions.

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The required pumping station discharge was determined based on the effective irrigated area and the adopted design hydromodule, representative for large-scale pressurized irrigation systems. The resulting design discharge for the analyzed system is:

$Q \approx 389$ l/s (0.389 m³/s) …(1)

The total dynamic head of the pumping station was calculated by summing the static lift, the pressure head required at the irrigation equipment and the hydraulic losses occurring along the pressurized pipeline network. The total head is expressed as:

$H_{tot} = H_{stat} + H_{req} + h_f + h_l$ …(2)

Where H_{stat} represents the static head, H_{req} the pressure requirement at the terminal irrigation equipment, and h_f and h_l the linear and local head losses, respectively.

Based on the hydraulic configuration of the system and the characteristics of the pipeline network, the resulting design total dynamic head is approximately:

$H_{tot} \approx 80$ m …(3)

The hydraulic power required to deliver the design discharge under the specified head conditions was determined using the classical power equation:

$P_h = \rho \cdot g \cdot Q \cdot H$ …(4)

Substituting the design values ($\rho = 1000$ kg/m³, $g = 9.81$ m/s², $Q = 0.389$ m³/s, $H = 80$ m), the hydraulic power requirement is:

$P_h \approx 305$ kW …(5)

To estimate the installed electrical power, pump and motor efficiencies were taken into account. Assuming representative efficiency values for modern pumping equipment ($\eta_{pump} = 0.78$, $\eta_{motor} = 0.95$), the required electrical power is:

$P_{el} = P_h / (\eta_{pump} \cdot \eta_{motor}) \approx 412$ kW …(6)

These calculated parameters formed the basis for pump selection and system configuration, ensuring sufficient capacity, pressure stability, and operational flexibility under varying irrigation demand scenarios.

6. Results and Discussion

The proposed modernization solution significantly improves the hydraulic and operational performance of the irrigation system. The upgraded pumping station configuration ensures stable delivery of the required discharge and pressure, even during peak irrigation periods.

Hydraulic losses within the pressurized network are substantially reduced due to optimized pipe diameters and improved network layout. This results in more uniform pressure distribution and enhanced compatibility with modern irrigation equipment.

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From an energy perspective, the integration of automated control and frequency regulation contributes to reduced energy consumption and improved operational efficiency. The rehabilitation strategy also increases system reliability and extends the service life of key infrastructure components.

The results demonstrate that systematic technical rehabilitation represents an effective approach for enhancing the performance of aging irrigation infrastructure in large-scale agricultural systems.

7. Advantages of the Proposed Modernization Strategy

The main advantages of the proposed solution include:

1) Improved hydraulic efficiency and pressure stability;
2) Reduced energy consumption through optimized pump operation;
3) Increased operational flexibility and reliability;
4) Compatibility with modern irrigation technologies;
5) Enhanced sustainability of agricultural water management.

8. Conclusion

This study presents a comprehensive technical approach to the modernization of large-scale irrigation infrastructure in Romania, focusing on the rehabilitation of a pumping station and its associated pressurized pipeline network. The proposed solution is based on detailed hydraulic analysis and practical engineering design principles.

The results confirm that targeted rehabilitation measures can significantly improve hydraulic performance, energy efficiency, and operational reliability. The methodology and technical framework presented in this paper are transferable and can be applied to similar irrigation systems facing comparable technical and operational challenges.

9. Future Research Directions

Extending the analysis to include real-time operational data obtained from instrumented pumping stations, in order to validate the proposed hydraulic and energy performance improvements under actual field operating conditions and seasonal irrigation demand variability.

Integrating advanced automation and control strategies, such as variable speed drives combined with smart irrigation scheduling algorithms, to further optimize pump operation and reduce energy consumption in large-scale pressurized irrigation systems.

Assessing the long-term economic and environmental impacts of irrigation infrastructure modernization, including life-cycle cost analysis and greenhouse gas emission reduction potential associated with improved energy efficiency.

Evaluating the performance of modernized irrigation systems under future climate change scenarios, focusing on the resilience of pumping stations and pipeline networks to increased water demand variability and extreme hydrological events.

Comparing different rehabilitation and modernization approaches for irrigation pumping stations and pressurized networks across multiple case studies, in order to identify best practices and transferable design solutions for regions with similar agro-climatic conditions.

Investigating the potential integration of renewable energy sources, such as photovoltaic systems or hybrid energy configurations, to supply irrigation pumping stations and further enhance the sustainability of agricultural water management systems.

Declarations

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Consent for publication

The author declares that he/she consented to the publication of this study.

Authors' contributions

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