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REVIEW

Optimization of the drinking water treatment system in Bochalema: a technical and operational proposal

Optimización del sistema de tratamiento de agua potable en Bochalema: una propuesta técnica y operativa

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ABSTRACT

Introduction: this study addressed the development of an operation and maintenance manual for the El Topacio Drinking Water Treatment Plant in the municipality of Bochalema, Norte de Santander. The importance of drinking water as a fundamental right was recognized, and it was noted that the plant faced technical and operational problems that compromised the quality of the water supplied.
Development: to develop the manual, we began with a review of the Technical Regulations for the Drinking Water and Basic Sanitation Sector (RAS) and similar studies conducted in other municipalities in the country. Key concepts such as raw water, residual chlorine, preventive maintenance, and water quality were integrated. In addition, relevant background information was analyzed, showing successful experiences in improving treatment plants through technical diagnostics and maintenance strategies. The geographical, demographic, and environmental situation of the municipality was studied, identifying key aspects such as the main water resource (the Aguablanca stream) and the sources of pollution present in the area.
Conclusions: the manual proved to be a technical and training tool for improving plant efficiency, standardizing procedures, and strengthening decision-making. It was adapted to the specific conditions of the territory and proposed as a basis for training operational personnel. Its correct implementation would guarantee service continuity, preserve infrastructure, and ensure sustainable access to drinking water for the population of Bochalema.

Keywords: Drinking Water; Operation; Maintenance; Aqueduct; Treatment.

RESUMEN

Introducción: el presente estudio abordó la elaboración de un manual de operación y mantenimiento para la Planta de Tratamiento de Agua Potable “El Topacio” del municipio de Bochalema, Norte de Santander. Se reconoció la importancia del agua potable como derecho fundamental y se señaló que la planta enfrentaba problemas técnicos y operativos que comprometían la calidad del agua suministrada.
Desarrollo: para desarrollar el manual, se partió de una revisión bibliográfica del Reglamento Técnico del Sector de Agua Potable y Saneamiento Básico (RAS) y de estudios similares realizados en otros municipios del país. Se integraron conceptos clave como agua cruda, cloro residual, mantenimiento preventivo y calidad del agua. Además, se analizaron antecedentes relevantes que mostraron experiencias exitosas en la mejora de plantas de tratamiento mediante diagnósticos técnicos y estrategias de mantenimiento. Se estudió la situación geográfica, demográfica y ambiental del municipio, identificando aspectos clave como el recurso hídrico principal (la quebrada Aguablanca) y las fuentes de contaminación presentes en la zona.
Conclusiones: el manual resultó ser una herramienta técnica y formativa para mejorar la eficiencia de la planta, estandarizar procedimientos y fortalecer la toma de decisiones. Se adaptó a las condiciones

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específicas del territorio y se propuso como base para la capacitación del personal operativo. Su correcta implementación permitiría garantizar la continuidad del servicio, preservar la infraestructura y asegurar el acceso sostenible al agua potable para la población de Bochalema.

Palabras clave: Agua Potable; Operación; Mantenimiento; Acueducto; Tratamiento.

INTRODUCTION

Access to drinking water is a fundamental right that guarantees the minimum conditions of health, well-being, and development for communities. In this context, the proper operation and maintenance of water treatment systems play a key role in ensuring the quality of water for human consumption. In Colombia, drinking water regulations are defined by Decree 1575 of 2007 and Resolution 2115 of the same year, which establish quality parameters, monitoring systems, and requirements for service providers. These provisions aim to mitigate the health risks associated with consuming contaminated water by promoting the adoption of efficient and sustainable treatment processes.

The municipality of Bochalema, located in the department of Norte de Santander, has a conventional drinking water treatment plant (PTAP) called “El Topacio”. This facility is responsible for collecting, treating, and distributing water to approximately 4000 inhabitants of the urban area. However, as in many municipalities across the country, the plant faces challenges related to equipment maintenance, training of operating personnel, supply availability, and technical management of the system. These factors can affect the quality of the water supplied and compromise compliance with the standards established by national legislation.

In light of this situation, preparing an operation and maintenance manual is a crucial tool for optimizing the operation of the WTP. This document aims to provide clear and standardized guidelines on technical procedures, infrastructure management, and water quality control protocols. It also seeks to enhance the competencies of personnel in charge, facilitate informed decision-making, and ensure the long-term sustainability of the system.

This work is based on a documentary review of the Technical Regulations of the Drinking Water and Basic Sanitation Sector (RAS), as well as other manuals and studies applied in similar contexts, such as those developed in the municipalities of Toledo, San Francisco de Sales, and Río de Oro. Based on these references and the specific conditions of the city of Bochalema, a manual was constructed that is adapted to the physical, social, and operational characteristics of the territory. This document aims to contribute to the improvement of local water resource management, promoting a safe and efficient aqueduct service that complies with current regulations.

DEVELOPMENT

Conceptual framework

To interpret and apply this Manual, the following definitions will be considered, which are taken from the technical regulations of the drinking water and basic sanitation sector (RAS)- Titles B and C, as well as other documents referenced throughout the work.

- Raw water: this is the water that has not been subjected to any treatment process.
- Drinking Water: water suitable for consumption, due to its physical, chemical, and bacteriological characteristics. It does not affect human health, does not produce rejection, and does not cause damage to pipes and other materials.
- Water quality refers to the set of physical, chemical, and microbiological characteristics that must be met for the water supplied to be safe for the population.
- Colloids: finely divided (non-dissolving) solids that remain dispersed in a liquid for a long time due to their smaller diameter and the presence of an electrical charge on their surface.
- Water contamination: alteration of its organoleptic, physical, chemical, radioactive, and microbiological characteristics, as a result of human activities or natural processes, which produce or may produce rejection, illness, or death to the consumer.
- Clarification: process of separation of solids from water by the action of gravity.[1]
- Free Residual Chlorine: that portion remaining in the water after a defined contact period, which reacts chemically and biologically as hypochlorous acid or as hypochlorite ion.[2]
- Jar Test: these tests simulate the coagulation-flocculation process in beakers or jars that will occur in the treatment plant, evaluating different parameters during or at the end of the tests to characterize its operation.
- Operator: qualified person responsible for the operation and Maintenance of the drinking water treatment system facilities.[3]

- Population Served: the number of people supplied by a water supply system.[2]
- Distribution Network: set of pipes, accessories, and structures that carry water from the storage tank or treatment plant to the points of consumption (RAS TITLE B).
- Maintenance: refers to the set of actions that are executed in the treatment plant facilities on a permanent and scheduled basis to ensure the good operating condition of each of the components, in other words, the actions that must be performed on the structures and equipment to prevent or repair damage.[4]
- Corrective Maintenance: actions carried out to repair damage caused by deterioration or malfunction of a system that could not be avoided with preventive Maintenance.[5]
- Preventive Maintenance: actions that are carried out periodically in the supply system to prevent service failures and deterioration of equipment and facilities.[5]

State of the art

Given the great importance of water supply in a population and the quality it should have for human consumption, it has been necessary to optimize the water purification process in the municipality of Bochalema, to provide a liquid suitable for consumption.

Drinking water treatment plants do not always have all the required treatment processes and the potabilization of water can be affected because they do not have properly qualified workers, they are not supplied with the necessary supplies for their proper operation, they are not provided with the required Maintenance, and they do not have an adequate laboratory to control and guarantee the quality of the water they treat.[6]

In the project entitled Plan to improve the operation and Maintenance of the drinking water treatment plant (PTAP) in the Tacuí and Cuní camps, located near the town of El Valle, municipality of Toledo, in northeastern Antioquia, developed by Laura Marín, focused on improving the drinking water treatment plant based on the analysis of the information obtained and technical and operational inspections, allowing to establish the needs and priorities of the PTAP, with an operating flow of approximately 9 l/s, benefiting about 3700 people.

Through this project, water quality was improved by applying the following methodology: diagnosis, evaluation of processes and water quality and identification of faults, in which it was detected that there were high levels of turbidity, and therefore the existing structure was not able to meet the quality levels required by the regulations, which merited the inclusion of a new one, which would contribute to the reduction of 80 % NTU of Nephelometric Turbidity Units (Nephelometric Turbidity Units).[7]

We also found the manual proposed by Diana Garzón and David Piraquive, (2017) of the aqueduct system of the municipal head of San Francisco de Sales-Cundinamarca, the description of the aqueduct system is presented, in which the potabilization processes typical of a conventional plant are carried out, processing a flow of 17 l/s for a population of 9872 inhabitants (2017), the operation and maintenance activities recommended to ensure proper operation are described, with the development of this manual a positive impact is expected both in the community, as well as the entity providing the aqueduct service, since it will be a basis to train better new plumbers who take on the work of operation and Maintenance of the aqueduct.

Manuals have been developed in different municipal aqueducts to guide operators in the proper operation of the plants, as is the case of the aqueduct of the municipality of Rio de Oro, located in the Department of Cesar, which borders to the north with the city of Gonzalez and the Department of Norte de Santander; to the south with San Martin, to the east with Ocaña and the west with Aguachica. A manual was implemented for an aqueduct with a capacity of 13,5 liters per second to supply 6133 inhabitants in the urban area benefiting from the aqueduct, located at an altitude of 1150 meters above sea level. In this study, Castillo Armenta makes a diagnosis that specifies the operating conditions of the plant, taking into account the necessary guidelines for water quality, and also presents a series of recommendations regarding equipment maintenance. Additionally, he emphasizes the importance of acquiring the required equipment for water quality diagnosis.

To prepare an operation and maintenance manual for an aqueduct system, information must be available concerning the system components, where instructions are given to the operators so that the work is carried out as efficiently as possible and as a result the objective of an aqueduct system, which is to supply quality water to a population, is achieved (Pan-American Center for Sanitary Engineering and Environmental Sciences - CEPIS, 2006). For the elaboration of this manual, a bibliographic review was conducted, examining documents such as the RAS, manuals, and articles on water quality, potabilization, diagnosis, Maintenance, and infrastructure.

The review of the manuals showed that they have a content that, according to the RAS, should provide at least an introduction, an operational description of the treatment plant for each of its components, water intake, measurement of influent flow, dosing of chemicals (coagulants, alkalinizers and disinfectants), rapid mixing, flocculation, sedimentation, filtration, chlorination tank, storage tank, measurement of effluent flow, instrumentation, and a flow diagram of the entire plant. It is necessary to attach all the manufacturers' catalogs, duly classified and organized.

Consequently, the purpose of this manual was to provide a decision-making tool based on instructions and

knowledge of the processes carried out in a conventional water treatment plant. This manual offers operators with expertise regarding the infrastructure, operation, and Maintenance of the water treatment process in the municipality of Bochalema. The proposed manual builds upon previous ones in the socialization and training of operating personnel.

The proposed manual contributes to previous ones in the socialization and training of operating personnel, providing technical knowledge, and serves as a foundation for operators in the water treatment field.

For this reason it has been necessary to have essential aspects such as the description of the infrastructure, Maintenance and operation of the plant in greater depth, which together provide an overview for decision making, recommending the importance of adequately maintaining the structures so that they can fulfill the function for which they have been established in the process.

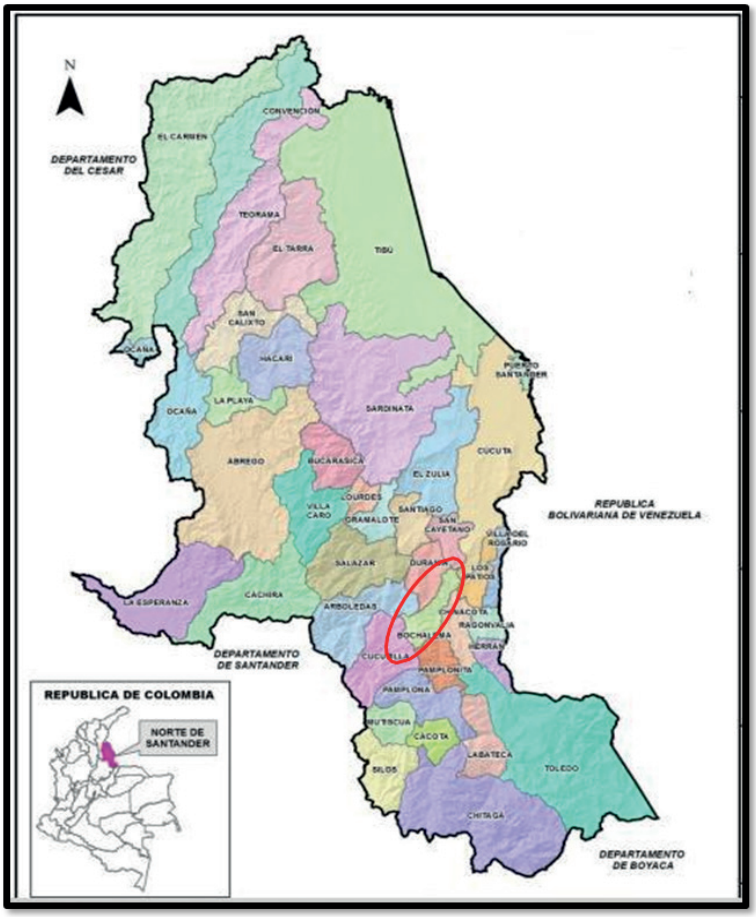

Figure 1. General Location in Colombia and in Norte de Santander of the Municipality of Bochalema

Figure 2. Geographic boundaries of the municipality of Bochalema, Norte de Santander

General information about the municipality

The following is a summary of the characteristics and physical and economic aspects of the municipality of Bochalema.

Hydrography

In the municipal capital, the most important water resources are the Aguablanca Creek, El Chorrerón Stream, and La Chiracoca Creek. In Don Quixote, the Pamplonita River and the Aguanegra, Quebraditas, Los Caños, La Nicolasa, and Cote Creeks are also significant.

Bochalema's hydrographic network is part of the Great Catatumbo River Basin. Within it, in descending hierarchical order, are the Greater Zulia River Basin and the Pamplonita and Zulia River Basins, which are sectors of the latter. 86,65 % of the municipal territory belongs to the Pamplonita River, and the remaining 13,35 % of the municipality's territory belongs to the Zulia River Basin.[9] Figure 3 shows the hydrological map of the municipality of Bochalema, Norte de Santander, with its watersheds.

Bochalema, Norte de Santander, in which the Aguablanca stream micro-watershed is selected, for better visualization purposes, the legend of this is shown in figure 4.

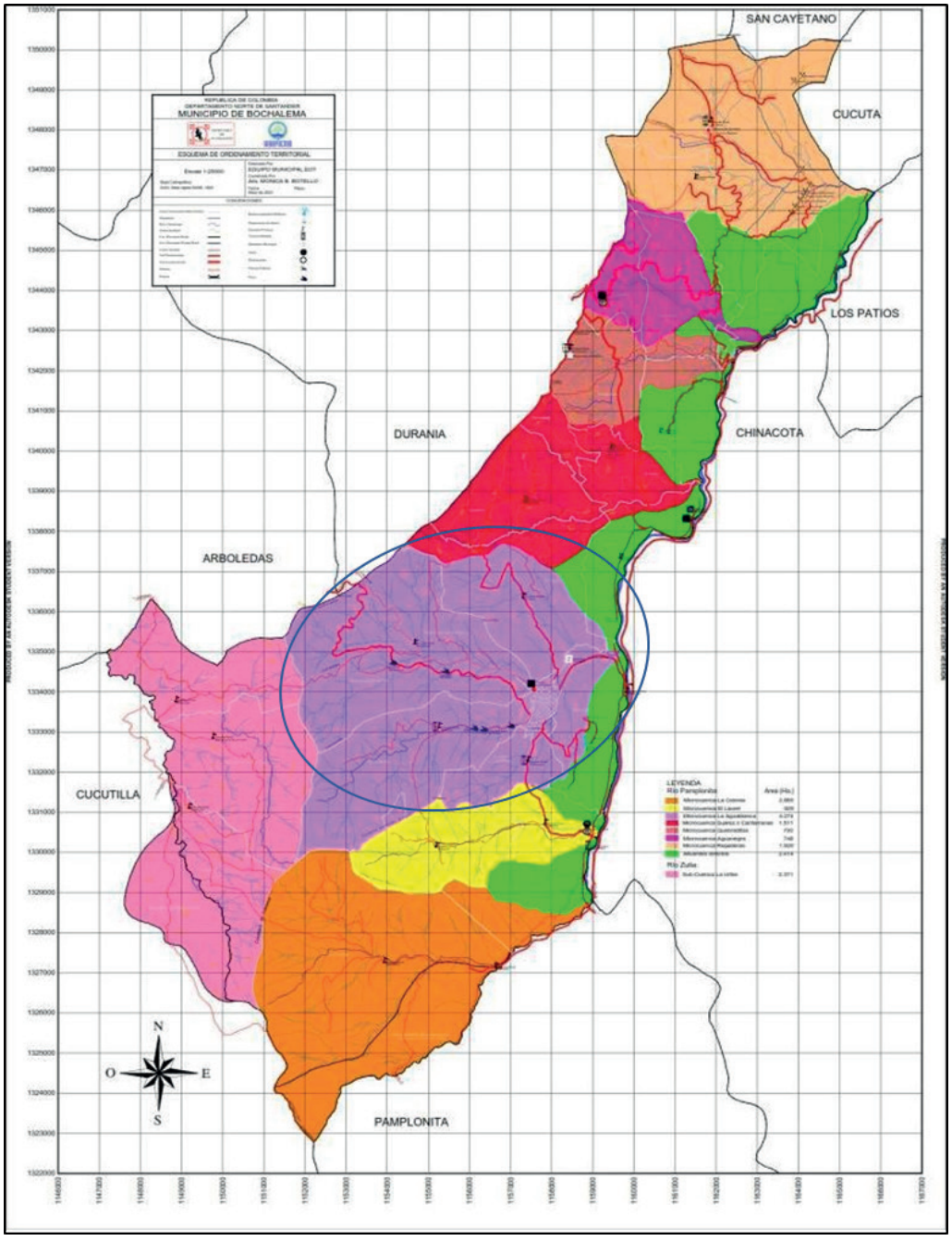

Figure 3. Hydrological Map of the Municipality of Bochalema

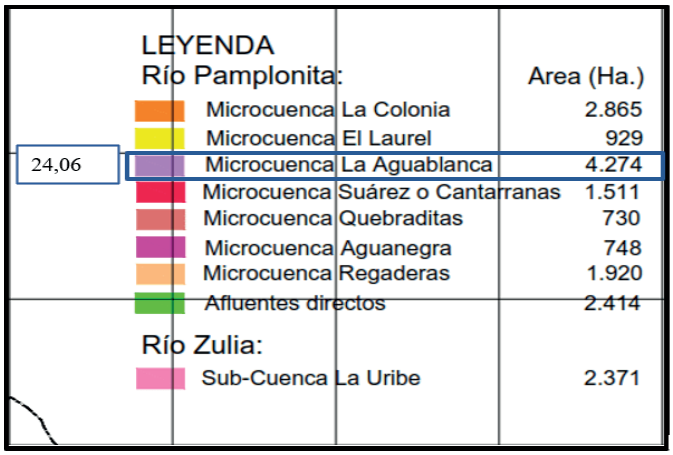

Figure 4. Legend of Figure 3 Hydrological Map of the Municipality of Bochalema

Location and geographical limits

Bochalema is a municipality in the Department of Norte de Santander, located in the southeastern subregion. The urban center of the city is 45 km from the capital of the Department and 33 km from the city of Pamplona. Figure 1 illustrates the location of the Department of Norte de Santander at the national level, providing a general outline of the Department and highlighting the municipality, which is marked in red.

Figure 2 shows the following geographical limits of the municipal territory: to the north with San Cayetano and Cúcuta, to the south with Cucutilla and Pamplonita, to the east with Los Patios and Chinácota, and the west with Arboledas and Durania.

Economic activity of the municipality

The municipality's primary economic activities include livestock farming, agriculture, and mining. Regarding livestock, the production of cattle, pigs, and poultry is notable; the agricultural sector accounts for 40 % of the municipality's productive areas. Coffee is the most important crop. There are also sugar cane, traditional corn, technified tomatoes, bananas, cassava, beans, lulo, and blackberry crops. On the mining side, notable mines include those for coal, feldspar, and limestone.[6]

It is essential to highlight that in recent years tourism has been part of the development of this municipality with different attractions, such as the swimming pools including Aguablanca, Chiracoca and villa luz, recreational centers such as the cordillera country club and points of contact with nature such as the ecological trail and the La Peronia waterfall, among others, which has generated an increase in visitors mainly on weekends, where hotels, restaurants and sales around the park and in areas of concurrence, have been benefited.[8]

Water supply source and contamination

The supply system of the Municipality of Bochalema is carried out through the Aguablanca Creek tributary of the Pamplonita River that are born north of the urban area in a rural area intervened by agricultural activities, which are intensified in the middle and lower parts of the basins, aggravating the deterioration of the resource with the discharge of much of the urban wastewater near its mouth on the Aguablanca stream, in addition to the environmental impact caused by the flow of tourists to the ecological trail, which is located on the banks of the water source. For this reason, campaigns aimed at protecting and caring for the environment have been encouraged.

Population

Bochalema is a municipality in Norte de Santander, with a population of approximately 8105 inhabitants. The municipality comprises the urban area, the population center of Don Juana, and the veredas. The urban area comprises 14 neighborhoods located in the municipal capital of Bochalema and 8 in Don Juana, while the rural area has 24 veredas.

According to information provided by the Public Utilities Unit, there are 1000 users in the urban area aqueduct system of the municipality (2021), with a population served of approximately 4000 inhabitants, of which 67 % of the treated water is sourced from the conventional plant.[9,10]

General description of the plant

The conventional drinking water treatment plant is called "El Topacio" and is located in the Agua Blanca hamlet, about 470 meters from the urban center, which collects raw water from the Aguablanca stream and has the following processes: coagulation, flocculation, sedimentation and filtration, then, disinfection is carried

out by applying granulated chlorine to eliminate pathogenic organisms present in the water, finally it goes to the storage tanks from where it is distributed to users through the aqueduct network, figure 5 shows a diagram with the processes that are carried out.[11,12]

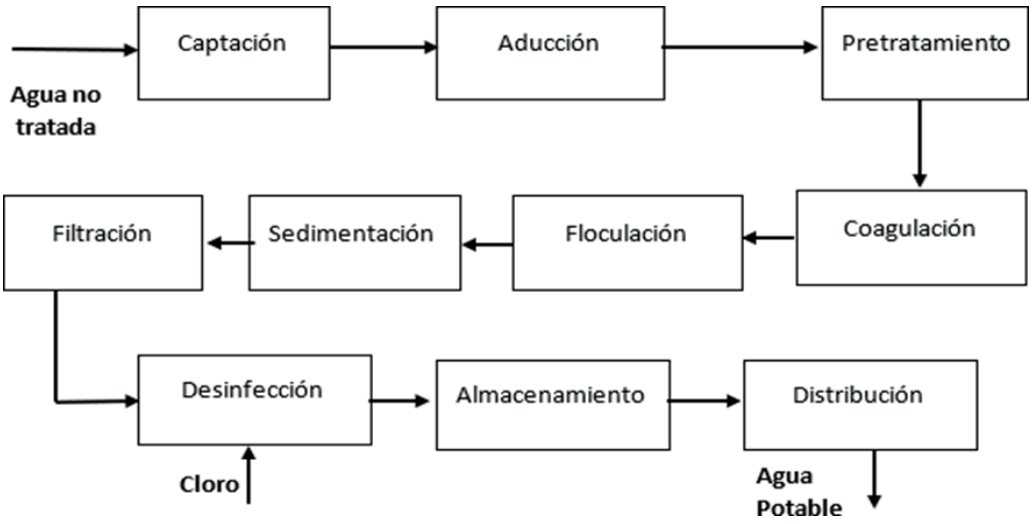

Figure 5. Block Diagram of Water Treatment Processes, Conventional Water Treatment Plant, Municipality of Bochalema

Regulatory Framework

Colombian drinking water regulations are governed by a series of physicochemical and microbiological parameters that determine whether the water is suitable for human consumption, thereby preventing diseases that can cause health damage to the population. Colombia has a variety of regulations, including National Decree 1575 of 2007 and Resolution 2115 of the same year. The purpose of the decree is to establish a system for the protection and control of water quality for human consumption, in order to monitor, prevent, and control risks to human health associated with its consumption.[13,14]

Applying to those providers who supply or distribute water for human consumption,[14,15,16] the following is the resolution by which characteristics, basic instruments, and frequencies of the control and surveillance system for the quality of water for human consumption are indicated. This resolution establishes the maximum permissible values for physical, chemical, and microbiological parameters of water.[2]

The operation and maintenance manual requires orientation with current regulations to determine the guidelines to be followed in the aqueduct system.

CONCLUSIONS

The preparation of the operation and maintenance manual for the "El Topacio" Drinking Water Treatment Plant (DWTP) in the municipality of Bochalema is a fundamental technical tool to improve efficiency in the management of local water resources. Throughout the development of this document, essential aspects related to infrastructure, drinking water treatment processes, the regulatory framework, and the social and geographic conditions of the municipality were identified. This integration of elements allowed the construction of a contextualized manual, aligned with the real needs of the community and with the guidelines established by the Technical Regulations of the Drinking Water and Basic Sanitation Sector (RAS).

Among the most significant findings is the urgent need to strengthen the operation and maintenance of the plant, due to factors such as the shortage of trained personnel, inadequate supplies, limited access to quality control laboratories, and the progressive deterioration of specific infrastructure components. These shortcomings compromise the quality of the water supplied, making it essential to standardize technical procedures and reinforce preventive and corrective activities at the plant.

The analysis of previous experiences in other municipalities, such as Toledo, San Francisco de Sales, and Río de Oro, made it possible to identify successful practices in preparing manuals and processes for improving water supply systems. These cases served as a reference to structure a document that not only describes the components of the plant and its processes, but also proposes concrete actions to guarantee the continuity of service and water quality.

Likewise, the geographical, hydrological, and socioeconomic context of the municipality of Bochalema was a determining factor in adapting the manual's contents. The information related to the source of supply, environmental conditions, and population structure enabled the delimitation of the specific needs of the aqueduct system and the orientation of maintenance actions more effectively.

The manual serves not only as an operational guide but also as a training tool for current and future

operators, thereby contributing to institutional strengthening and the continuous improvement of the aqueduct system. Its proper implementation will reduce sanitary risks, prolong the useful life of the equipment, and ensure sustainable access to drinking water, thus promoting the well-being of the Bochalema population and compliance with current Colombian regulations.

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CONFLICT OF INTEREST
The authors declare that there is no conflict of interest.

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Formal analysis: Sara Esther Sanchez Carrillo, Ana María Rosso Cerón.
Research: Sara Esther Sanchez Carrillo, Ana María Rosso Cerón.
Methodology: Sara Esther Sanchez Carrillo, Ana María Rosso Cerón.
Project Management: Sara Esther Sanchez Carrillo, Ana María Rosso Cerón.
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Software: Sara Esther Sanchez Carrillo, Ana María Rosso Cerón.
Supervision: Sara Esther Sanchez Carrillo, Ana María Rosso Cerón.
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Writing - proofreading and editing: Sara Esther Sanchez Carrillo, Ana María Rosso Cerón.