Rehabilitation of a sewage system for the municipality of Otaré in Norte de Santander, Colombia

Rehabilitación de un sistema de alcantarillado para el municipio de Otaré en Norte de Santander, Colombia

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Resumen

Este artículo presenta una propuesta de rehabilitación destinada a optimizar el sistema actual de alcantarillado sanitario en Otaré, Municipio de Ocaña, Norte de Santander. Actualmente, dicho sistema enfrenta deficiencias operativas debido a la incorporación de nuevos usuarios sin las mejoras adecuadas, lo que ha provocado fallos en su funcionamiento. Además, la comunidad ha manifestado su preocupación por la contaminación generada tanto por los vertimientos a cielo abierto del alcantarillado como por las descargas ilegales de usuarios no conectados a la red matriz. El sistema de alcantarillado cubre aproximadamente 3 km, beneficiando a casi toda la población del casco urbano de Otaré. En este contexto, la investigación llevó a cabo un diagnóstico del estado actual del sistema, seguido de su optimización mediante simulaciones hidráulicas utilizando el software SWMM-5Ve. Para ello, se elaboró un manual de procedimientos que detalla el proceso de simulación. Finalmente, se desarrolló el presupuesto de obra necesario para implementar las mejoras requeridas, garantizando un funcionamiento más eficiente del sistema de alcantarillado.

Palabras clave: Agua residual, Alcantarillado, Rehabilitación, Sistema hidráulico, Normas Colombianas.

Abstract

This article presents a rehabilitation proposal aimed to optimize the current sanitary sewer system in Otaré, Municipality of Ocaña, Norte de Santander. Actuallt, the system faces operational deficiencies due to the incorporation of new users without proper upgrades, leading to malfunctions. Additionally, the community has expressed concerns about the pollution caused by both open-air sewer discharges and illegal discharges from users not connected to the main sewer network. The sewer system spans approximately 3 km, benefiting almost the entire urban population of Otaré. In this context, the research conducted a diagnostic assessment of the system's current condition, followed by its optimization through hydraulic simulations using SWMM-5Ve software. A procedural manual was developed to detail the simulation process. Finally, a budget was prepared for the necessary improvements to ensure a more efficient operation of the existing sewer system.

Keywords: Residual water, Sewerage, Rehabilitation, Hydraulic system, Colombian Standards.

I. INTRODUCTION

Water is one of the aspects by which human beings ensure and guarantee their existence. In this way, the government is responsible for providing the minimum conditions for quality of life, such as the right to water and basic sanitation [1]. The use of water obtained from water sources brings with it the problem of evacuating wastewater due to the contamination it generates, becoming a harmful factor for health since it helps the spread of diseases that are generated by said contamination. The development of society leads to population growth which, among other cases, generates an increase in contaminant loads resulting from wastewater, for which today there are systems for collecting and transporting wastewater called sewage systems [2].

A sanitary sewer is a set of hydraulic structures to collect and transport wastewater to its final disposal, having a sewage system and wastewater treatment is an essential factor in the population's health and quality of life since the right to enjoy a healthy environment is part of the basic needs the state must satisfy. In Colombia, the provision of public sewerage services in municipalities and districts is deficient, considering that in 3 of 4 Colombian municipalities, sewerage coverage is less than 50%. Only 8% of the municipalities have coverage over 75% [3]. The priority of public service companies concerning rural areas, corregimientos, and municipalities. Exposing lies in preference to carry out investments that favor public health and its environment. For this reason, they are more concerned with providing vital drinking water service for life and not with its collection system, transportation, and final disposal of wastewater.

In Colombia, sewerage systems differ according to the type of population settlement since in urban areas; liquid waste is collected in sewerage networks and transported to final disposal, while in scattered rural areas, it is common to find individual final disposals systems, such as latrines or septic tanks. Due to the geographical situation of the country and the difficulty in guaranteeing all Colombians the service of drinking water and basic sanitation, the state, through legal means, grants territorial entities the authority to oversee, regulate, controlling, and guarantee the provision of these services.

PNUD, 2022 [4] mentions that it is expected to reduce the proportion of people without sustainable access to drinking water and basic sanitation services, guaranteeing safe access to safe drinking water and sanitation as a fundamental human right for the full enjoyment of life and all other human rights. In the case of water supply and sanitation services for each person, they must be continuous and sufficient for personal and domestic use. These uses typically include drinking water, personal sanitation, laundry, food preparation, personal hygiene, and household cleaning. According to the World Health Organization (WHO), between 50 and 100 liters of water per person per day are needed to meet basic needs, and major health threats do not arise [5].

Different authors from diverse countries have focused their studies on designing and redesigning sewage systems and wastewater management to mitigate the environmental impact generated by these systems. Likewise, the different investigations have used the evaluation, redesign, and redesign of sewage systems, considering as an initial part of the investigation topographic studies and inspection of each section's pipes and sewage systems. As in the case of Ecuador, the work developed by [6] and [7]. In Peru, the work developed by [8] and [9]. The work developed by Peña et al., 2013 on the treatment of wastewater in Mexico, the coverage situation, and its evolution over the years with some investment projects in this area. Finally, in the case of Colombia, the investigations were carried out by [10],[11] and [12].

According to the above, a good redesign of the sewage system is proposed to improve the current sanitary conditions of Otaré as established in the technical regulation of the drinking water and basic sanitation sector RAS-2000 [13]. First, the investigation will be carried out through a field visit verifying the physical state of the existing infrastructure using tools such as visual descriptions. Then, with the help of a GPS, the relevant geo-location of each of the points of the sewage system object of intervention will be obtained, applying the free SWMM-5vE simulation software. The necessary simulations that must be developed in the software facilitate the knowledge of the current operating conditions and, in this way, establish the causes of its malfunction and project a new sewage system where the necessary collectors are included to cover the areas that still do not have this service, managing to increase the coverage of the sewage system that currently provides the wastewater collection service in the urban area of Otaré. It is essential to mention that this research is based on fieldwork to know the existing hydraulic works and subsequently propose a redesign that leads to the improvement of the sewage system, supplying the needs that currently afflict the community by making use of specialized software that aid to understand better and optimize these systems of great importance in civil engineering as well as for the environment.

On the other hand, it is important to mention that in the current open literature, insufficient research was found to elucidate the relevance of improving this kind of sewage system. However, the integration of predictive models and data analysis: The article could present the development of predictive models and the use of data analysis to optimize the redesigning of the sewerage system. This involves the collection and analysis of large volumes of data related to hydraulic performance, water quality, usage patterns, and other relevant factors, with the goal of improving decision-making and future planning of the system.

II. MEHODOLOGY

For the realization of this project, the type of descriptive research was used, because, through this modality, it was possible to obtain pertinent and necessary information to identify the characteristics and components that make up the sewage system and the existing shortcomings by which it is proposed the redesign that leads to its improvement according to the current conditions found.

2.1. Geographic information.

El Otaré is located to the northwest of the municipality of Ocaña and southwest of Convención, it also comprises an extension of 0.062 km2, equivalent to 9.88% of the municipal territory, it is made up of the paths Cerro Monte Negro, Guadual, Patiecitos, Salobritos, Carpintero, Cerro las Casas, Piedecuesta, San Antonio, El Silencio, Pueblo Viejo, Vijagual and El Oso. The geographical location of the populated center of Otaré is 8°25'00" latitude and 73°26'00" longitude at 1545 meters above sea level, and its average temperature is 17 °C. On the other hand, the urban area of Otaré has a population of 479 inhabitants, not including the villages that are part of the corregimiento. Its geography is very varied and rugged since it is located in a mountainous area. Figure 1 shows the spatial location of Otaré obtained using the Google Earth computer tool [14]. It is important to mention that Otaré, belongs to the municipality of Ocaña. Likewise, it is characterized by being one of the largest population centers at the rural level, which has an obsolete sewage system that has lately been generating discomfort among the inhabitants of the area because the environmental authorities are in favor of the development of the region, despite the great efforts they make, have not mitigated the environmental impact generated by contamination and deterioration due to the mismanagement of the existing sewage system in Otaré.

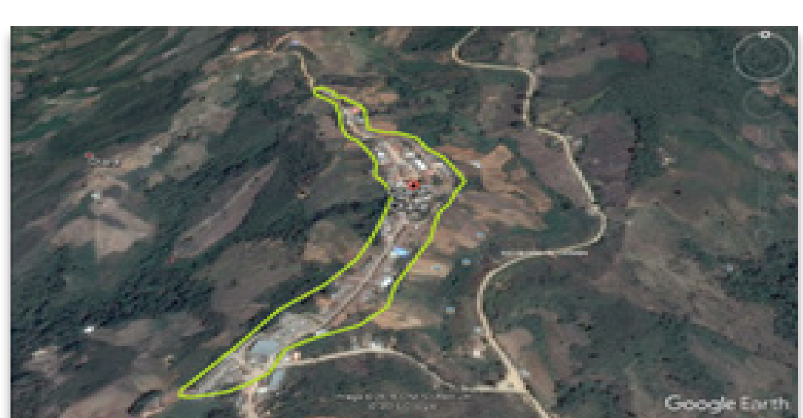

Figure 1. Geographical location of the Otaré.
Source: [14].

2.2. Geology and soils.

Otaré presents the following geological characteristics: The soil at the head of the corregimiento is made up entirely of metamorphic rocks formed in the geological periods: Devonian and Permian [15], as shown in Figure 2.

Figure 2. Soil lithology of the municipality of Ocaña Norte de Santander.
Source: [15].

2.3. Relief and topography.

Norte de Santander territory is made up of very broken terrain, in which medium altitudes predominate, with great heights with paramount vegetation to the south and west. According to the study of soil and land zoning of Otaré, a large part of its territory comprises a mountainous system. This relief is part of the Andean system of the eastern mountain range that extends east to the Mérida Mountain range (Venezuela), and the north ends in the Serranía del Perijá (Cesar). On the other hand, Otaré is made up of reed-like metamorphic rocks, which are formed in Ocaña and reach Convencion, their bottoms being characteristically cut by erosion into enormous blades of whitish edges surrounded by relief, which stagger their reddish ridges like if it were the result of a general erosion in geological times, in which the massif was less enhanced [16].

2.4. Hydrology and climatology.

The orography of Otaré is watered to the north by the El Páramo creek, to the northwest by the San Francisco creek, in the central part, by the Otaré, and to the southwest by the El Tigre creek. The Map expert system and the Climate Change Adaptation Fund determined that the Otaré area has an average monthly rainfall of 1,100 – 1,300 mm of water [17].

The water resource available to the peasant community belonging to Otaré corresponds to the El Carmen creek micro-basin. According to [18], establishes that: The Quebrada el Carmen micro-basin is located to the north of the municipality of Carmen, occupying a large part of the Otaré, which supplies the basic needs of the corregimiento, such as human consumption, crop irrigation, and animal watering points. The surface area of the micro-basin is 401.70 km2, equivalent to 40170.851 hectares and a perimeter of 117.47075 km. It belongs to the Middle Magdalena Basin, its micro-basin code is 2321-001, and the Colombian water zone 02, Magdalena – Cauca water zone. In the case of Otaré, the surface area of the micro-basin is 3932.58 hectares, equivalent to 39.32 km2, which in percentage terms is equivalent to 55.81% of the total area of Otaré, as shown in Figure 3. On the other hand, the Quebrada el Carmen micro-basin has a scarcity index of over 50%, indicating that water demand is high and that the water cycle balance is strongly threatened. The expansion of the agricultural frontier affects the quality and amount of water resources, and the inhabitants of the geographical area under the influence of the Quebrada El Carmen micro-basin in Otaré are not prepared to face climatic anomalies of water scarcity such as those of the El Niño phenomenon.

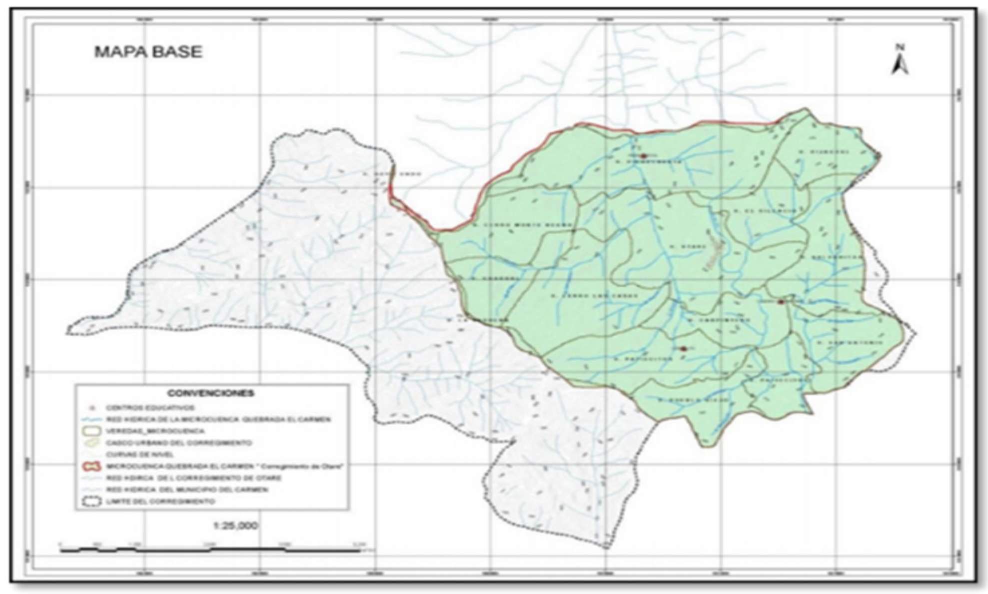

Figure 3. Morphometric characteristics of the El Carmen creek micro-basin.
Source: [18].

2.5. Information Collection

Otaré currently has a sewage system. However, to date, it cannot be ensured that this system is efficient in collecting the wastewater generated by the houses of the corregimiento in its urban sector, according to its inhabitants, in recent years. Otaré has been subjected to aggressive odors, which come from the inspection wells that make up the sewage system and also show some subsidence in some streets as a result of infiltration generated by the deterioration of the pipes, taking into account that this system was mainly built with stoneware tubes and some drop chambers do not comply with the provisions of the RAS-2000 and Res 0330 de 2017. Additionally good construction processes were not handled in the construction of inspection wells. In addition, Otaré does not have the technical information on the capacity and how these were built, which does not allow the establishment the failures of the existing system. Similarly, it should be noted that the current sewage system had a replacement in 2014 by the municipal government of Ocaña, changing the stoneware pipes to a total of 430 linear meters and the home sewers to a total of 424 linear meters, as well as some inspection wells. However, it does not cover the wastewater drainage solution of the entire community of the urban area of Otaré, for which the essential purposes that the state enshrines in its political constitution are not fulfilled, and that is the efficient provision of public services, likewise, the social welfare of the community.

The information collection was carried out considering the methodological considerations and the main methods described below.

2.5.1 The observation. Direct observation in the field to collect information on the current physical state of the sewage system, the hydraulic plans of the system were also studied. Through the modality of interviews with the leaders of the community action board, the necessary information will be managed to learn about the operation of the sewage system.

2.5.2 The interview. Direct dialogue with the competent environmental entities, the representatives, president, and vice president of Otaré, and the affected inhabitants and those dissatisfied with the present environmental situation due to the lack of control.

2.6. Specialized software for redesign.

The Stormwater Management Model "SWMM-5vE" (water management model), is free software developed by the EPA (Environmental Protection Agency of the United States), it is a dynamic simulation model that can be used for a single event or to perform a continuous simulation over an extended period. The program allows simulation of the quantity and quality of the water evacuated, especially in urban sewers. [19]. The SWMM-5vE software corresponds to the fifth version of the program, which was developed for the first time in 1971, and having experienced various improvements since then. The current version provides an integrated environment that allows entering input data for the drainage area, simulating hydraulic behavior, estimating water quality, and outputting the results in various formats. SWMM-5vE works by incorporating modules that are: the atmospheric module, ground surface module, groundwater module, and transport module, which determine a redesigned model for a sanitary, storm, or combined sewer network; it is not necessary to incorporate all the modules because if we speak in terms of a sanitary sewer, we would only take into account the transport module and the necessary data and elements for its simulation.

The classification to establish the redesign period according to the RAS technical standard defines it as part of developing wastewater and/or rainwater collection and evacuation systems. At a minimum, the wastewater and/or rainwater collection and evacuation systems must be projected for 30 years in the case of systems with a high level of complexity and 25 years in the other systems. According to the previously established level of complexity, a low level corresponded to arithmetic, geometric and exponential, as shown in Table 1. The documents are those recommended by the RAS, in numeral B.2.2.4, classified for each level of complexity.

TABLE 1. CALCULATION METHOD FOR PROJECTIONS ACCORDING TO THE LEVEL OF COMPLEXITY

Used method	Level			
	Low	Medium	Medium High	High
Arithmetic, geometric and exponential	X	X	-	-
Arithmetic, geometric, exponential, and others	-	-	X	X
By components (demographer)	-	-	X	X
Detail by zones and detail densities	-	-	X	X
Graphic Method	X	X	-	-

Note. Methods allowed according to the level of complexity of the system to project the population according to the redesign period.
Source: [20].

2.7. Methods to calculate the different sewage systems.

The calculation procedure to project the population according to the low complexity level, taking into account the allowed arithmetic, geometric and exponential methods, is described below where: = Future Population, = Last census population, = Initial census population, = Future time, = Last census time, = Initial census time and = Growth rate.

Arithmetic method

$$P_f = P_{\mathrm{UC}} + r(T_f - T_{\mathrm{UC}})$$

$$r = \frac{P_{\mathrm{UC}} - P_{\mathrm{Ci}}}{T_{\mathrm{UC}} - T_{\mathrm{Ci}}}$$

Geometric method

$$P_f = P_{\mathrm{UC}}(1 + r)^{T_f - T_{\mathrm{UC}}}$$

$$r = \left(\frac{P_{\mathrm{UC}}}{P_{\mathrm{Ci}}}\right)^{\frac{1}{T_{\mathrm{UC}} - T_{\mathrm{Ci}}}} - 1$$

Exponential method

$$P_f = P_{\mathrm{Ci}} e^{r(T_f - T_{\mathrm{Ci}})}$$

$$r = \frac{\ln P_{\mathrm{UC}} - \ln P_{\mathrm{Ci}}}{T_{\mathrm{UC}} - T_{\mathrm{Ci}}}$$

To determine the growth rate, the existing historical censuses of the study area are used, which correspond to those established in Table 2 for the three methods mentioned above. Subsequently, the population projection calculation by the different methods is shown in Table 3.

TABLE 2. GROWTH RATE ACCORDING TO THE DIFFERENT METHODS

				Arithmetic Growth	Geometric Growth	Exponential growth
468	456	2013	2007	2.00	0.00433863	0.004329248
479	456	2015	2007	2.875	0.00616993	0.006150973
479	468	2015	2013	5.5	0.01168388	0.011616151
Average				3.458333	0.00739748	0.007365457

According to the results obtained in Table 3, the redesigned population to be used corresponds to the arithmetic method since it is the one recommended by the RAS-2000 for small populations that generally have linear growth, and the floating population is almost nil.

TABLE 3. POPULATION PROJECTIONS, ACCORDING TO THE REDESIGN PERIOD, FOR A LOW LEVEL OF COMPLEXITY.

Year	Arithmetic	Geometric	Exponential
2017	486	486	491
2018	489	490	494
2019	493	493	498
2020	496	497	502
2021	500	501	506
2022	503	504	509
2023	507	508	513
2024	510	512	517
2025	514	516	521
2026	517	519	524
2027	521	523	528
2028	524	527	532
2029	527	531	536
2030	531	535	540
2031	534	539	544
2032	538	543	548
2033	541	547	552
2034	545	551	556
2035	548	555	560
2036	552	559	565
2037	555	563	569
2038	559	567	573
2039	562	572	577
2040	566	576	581
2041	569	580	586

2.8. Contributions or contributions of residual waters. Corresponds to the volume of wastewater supplied to a collection and evacuation system comprising domestic, industrial, commercial, and institutional wastewater. Other contributions are also considered due to poor connections of rainwater and downspouts from the roofs to the sanitary sewer system and connections due to soil infiltration. Since it is one of the two existing sanitary sewers in Otaré, only domestic contributions are considered due to wrong connections and infiltration.

2.8.1. Domestic contributions (Q_D). The domestic contributions correspond to the flow for each section that makes up the wastewater sewerage network, for which it is of vital importance to know the demand for drinking water since it is considered that 100% of the demand for water per inhabitant, the 20% is consumed by the human body. The remaining 80% is returned to the water tributaries, but with a contaminant load; in the same way concerning the redesign in this project, it is considered that the pipe must be able to satisfy 100% of the demand for the evacuation, transport, and final disposal of wastewater. Following the guidelines of [21], where three types of equations are specified that depend on the knowledge that exists in the area about the population's demand for drinking water so that, in this case, there is no existing information on the demand for drinking water and the value of losses in the system, Equation 1:

$$Q_D = \frac{C_R \cdot P \cdot D_{\text{NETA}}}{86400} \text{ Eq 1}$$

Where: Q_D = Domestic wastewater flow (L/s), C_R = Return coefficient (dimensionless), P = Number of inhabitants projected for the redesign period (inhab), D_{NETA} = Projected net drinking water demand per inhabitant (L/inhab/day). Considering the above, tables 4 and 5 must be considered for the flow analysis.

TABLE 4. DOMESTIC WASTEWATER RETURNS COEFFICIENTS

System Complexity Level	Return coefficient
Low and Medium	0.80
Medium High and High	0.85

TABLE 5. ENDOWMENT PER INHABITANTS ACCORDING TO THE LEVEL OF COMPLEXITY.

System Complexity Level	Net endowment (L/inhab×day) temperate and cold climates	Net endowment (L/inhab×day) warm climate
Low	90	100
Medium	115	125
Medium High	125	135
High	140	150

Note. Net endowment according to the level of complexity and the warm, temperate and cold climate.
Source: [21]

To obtain the number of inhabitants projected for the redesign period (P), the population to be used in each pipeline section must correspond to the area of said section. Therefore, it is necessary to find the population density using the area of the urban area of Otaré obtained from the basic land use plan of Ocaña. The total population projected according to the calculated redesign period to subsequently multiply this density value with the corresponding area to each bracket and obtain the number of inhabitants by brackets for domestic contributions, considering the following: Total area of the populated center of Otaré = 5,874 hectares, the projected population according to the redesign period = 569 inhabitants and a population density that is calculated using Equation 2, obtaining a value of 96.87 inhabitants/ha.

$$D = \frac{\text{Projected population}}{\text{Otaré Area}} \quad \text{Eq. 2}$$

It should be noted that within the study area where the redesign for the optimization of the sewerage system is carried out, commercial, institutional, and industrial contributions are not taken into account due to the existence of two sewerage systems in the Otaré. Because it is an area of rural influence, the few consumptions by commercial, institutional, or industrial activity are located within the area of operation of the new sewer system.

2.8.2. Contributions for wrong connections (Q_{CE}). They are the contributions of rainwater that must be considered to the wastewater sewage system, coming from poor roof connections and patio downspouts, since it depends on the control measures used in the quality of home connections. The flow due to incorrect connections must be calculated using the average daily flow of wastewater with prior justification for having a high percentage of rainwater wastewater, proposing an independent system only for rainwater. For the calculation of contributions for faulty connections for the improvement of the old sewage system, information was not used by the public service provider company because it does not exist in the area, for which, by recommendation of the standard technical RAS-2000 [21], when there is no storm sewer system, a value of 2 L/s×inha is used, for all cases of complexity level.

2.8.3. Infiltration Contributions (Q_{INF}). It corresponds to the infiltration of sub-surface waters into the residual sewage system networks, mainly due to the water table, fissures in the pipes, at the junction of pipes with inspection chambers, and other structures when they are not completely impermeable. Estimating this value depends on the ground-level conditions, its permeability, topographic conditions, and the water table variation, among other aspects that must be considered. Therefore, given the difficulty in determining this value, which requires in-depth study, the contribution can be obtained based on the values in Table 6. It should be noted that the RAS-2000 technical standard [21] recommends application equations to determine infiltration in existing sewage networks depending on their age, both for wells and pipe sections; For the calculation of the contribution of infiltration in the project, the values of table 6, considering that when applying the recommended formulas the values turn out to be lower, to have a more significant margin for infiltration.

TABLE 6. INFILTRATION CONTRIBUTIONS

System complexity level	High infiltration (L/s×inh)	Medium infiltration (L/s×inh)	Infiltration (L/s×inh)
Low and Medium	0.15 – 0.4	0.1 – 0.3	0.05 – 0.2
Medium High and High	0.15 – 0.4	0.1 – 0.3	0.05 – 0.2

Note. Input values used when there is no information to determine the infiltration rate.
Source: [21].

2.8.4. Average daily flow (Q_{MD}). The average daily flow of wastewater is determined for each section of pipe between well and well, depending on domestic, commercial, institutional, and industrial contributions. In the case of the Otaré, only domestic contributions will be considered as average daily flow. ($Q_{MD} = Q_D$).

2.8.5. Maximum hourly flow (Q_{MH}). The maximum hourly flow corresponds to the average daily flow multiplied by an increase factor. The increase factor takes into account variations in water consumption by the population. The value of the factor decreases as the number of inhabitants considered increases. When it is not possible to determine the factor by direct methods, the proposed formulas recommended by the RAS-2000 technical standard can be used, which in its latest update called "RAS", it can be calculated using the empirical equation of Angeles where F is calculated based on the average daily flow, in liters per second, the formula must be applied for average flows between 0.28 L/s and 4250 L/s; therefore, Equation 3 of the angels' theory is used.

$$F = \frac{3.53}{{Q_{\mathrm{MD}}}^{0.0914}} \text{ Eq. 3}$$

Where: F = Magnification factor (dimensionless) and Q_{MD} = Average daily flow of wastewater (L/s). In this way, Equation 4 is used:

$$Q_{\mathrm{MH}} = F \cdot Q_{\mathrm{MD}} \text{ Eq. 4}$$

The increase factor F must be calculated for each pipe section and must be greater than or equal to 1.4 and according to the RAS technical standard (in its last update), the maximum value of the increase factor must be limited according to the size of the pipe population served, (although this new norm is not yet in force), as shown in Table 7:

TABLE 7. MAXIMUM INCREASE FACTOR ACCORDING TO THE POPULATION SERVED

Population served in number of inhabitants	Maximum increase factor
< 20.000	3.00
20.000 – 50.000	2.50
50.001 – 750.000	2.25
> 750.000	2.00

Source: [21].

2.8.6. Redesign Flow (Q_{DT}). It corresponds to the redesign flow of each section of the pipe network; it is obtained by adding the maximum hourly flow with the contributions due to infiltration and wrong connections, where we use Equation 5.

$$Q_{\mathrm{DT}} = Q_{\mathrm{MH}} + Q_{\mathrm{INF}} + Q_{\mathrm{CE}} \text{ Eq. 5}$$

2.9. Uniform Flow Equations for Redesign of Flowing Partially Filled Pipes. The SWMM software uses the Manning equation to establish the relationship between the flow that circulates through the conduit as a function of its section or wetted area, the hydraulic radius, the slope, and Manning's roughness coefficient. However, Manning's equation is applicable only for the case of hydraulically rough, turbulent uniform flow and the original expression considered in terms of velocity is Equation 6:

$$v = \frac{1}{n} \cdot R^{\frac{2}{3}} \cdot {S_o}^{\frac{1}{2}} \text{ Eq. 6}$$

Expressed in terms of flow, Equation 7 is obtained:

$$Q = \frac{1}{n} \cdot A \cdot R^{\frac{2}{3}} \cdot {S_o}^{\frac{1}{2}} \text{ Eq. 7}$$

Where: V = Mean flow velocity, n = Manning's roughness coefficient, Q = Flow rate, R = Hydraulic radius, A = Transverse wetted area. and So = Longitudinal slope of the pipe.

2.10. Equation for calculating shear stress. In sewer pipes, it must be guaranteed that the sediments that enter the system can be moved by the action of the flow downstream of the pipes. For this, minimum shear stress must be guaranteed, which is established by the RAS 2000 technical standard in its Title D. literal D.3.2.7 [21], establishing that the value of the average shear stress must be greater than or equal to 1.5 N/m2 (0.15 kg/ m2) and in those cases in which, due to the present topographic conditions, it is not possible to reach the minimum speed, it must be verified that the shear stress is greater than 1.2 N/m2 (0.12 kg/ m2) to ensure self-cleaning behavior of the flow. The mean shear stress is given by Equation 8.

$$\tau = \gamma \cdot R \cdot S_o \text{ Eq. 8}$$

Where: τ = Mean shear stress, γ = Residual water specific weight, R = Hydraulic radius of the section and S_o = Pipe slope.

2.11. Flow regime. The uniform flow in a pipe or duct of a sewage system can be critical, subcritical, or supercritical, which own choice is governed by the value obtained from Froude's Equation 10:

$$\text{Fr} = \frac{v}{\sqrt{g \cdot D}} \text{ Eq. 10}$$

Where: Fr= Froude number (dimensionless), g = Acceleration of gravity (m/s^2), D= Hydraulic depth (m), and v= Flow velocity (m/s).

The values of the Froude number to determine the following intervals determine the flow regime: Fr=1.0, Fr<0.9, and Fr>1.1. When the Froude number equals 1, the flow regime is said to be in critical conditions, less than 0.9 subcritical, and greater than 1.1 supercritical. According to a study conducted by [22] in a monograph, it says that, when the flow is critical and quasi-critical, that is, when the Froude number is between 0.7 and 1.5 approximately, it is characterized by its instability and variability of the flow depth around the critical flow depth. Therefore, avoiding those flow rates that imply a Froude number in this interval is advisable. If the flow regime is supercritical, the design must focus on the possible generation of translational waves in the pipes. The generation of annoying noises in the sewage pipes and possible undermining problems in the chambers or inspection wells downstream accompanies this type of wave.

III. RESULTS AND DISCUSSIONS

Diagnosing the existing sewage system of the Otaré, was necessary to go to the study area in a series of visits made to collect information. In the first visit, some general characteristics of the corregimiento were established and socialized with the community and with the communal representatives of the corregimiento to listen to their concerns and discomforts due to the deterioration of the existing sewage system. In subsequent visits, the current conditions of the sewerage level and the respective inspection wells were recorded, including the conditions of its cover and the state of the pipes.

It is important to clarify that Otaré has two sanitary sewer systems that operate independently, including its discharge point. Taking into account that one of the existing sewage systems, which covers a large part of the population, was restored in 2018, for this study, for the quantification of the information, reference is made to the new sewer system as one that is in good condition and does not require detailed analysis, the unrestored sewage system is mentioned in the old sewer document like the one with the greatest age and shortcomings in its system, so the redesign for the improvement of the Otaré sewer system focuses more on the old sewer system.

3.1. Initial aspects for the redesign.

Next, all the necessary aspects that were considered for the knowledge of the current conditions of the sewage system are presented.

3.1.1. Inspection wells. To recognize the inspection wells' current conditions, the parameters considered in Table 3, used in previous studies on evaluations of current sewage systems in the municipalities of Costa Atlántica, were used as background for the visual qualification. The characteristics that were identified for each of the wells to make it easier to interpret and manage the information are: the depth of the well, the diameter of the well, the type of cover, the material of the cover, the material of the well, the type of well and subsequently the qualification of the current state of the well, for the old sewer with a total of 14 wells and the new sewer with a total of 9 wells.

3.1.2. Pipe sections. The pipe sections are those collectors that collect the wastewater, taking it to the inspection wells until its final disposal. The measurement was made with a tape to know the distances between each collector and its level, taking into account that for the hydraulic evaluation, reference coordinates were taken by adjusting the sections of collectors with measured in the field. The results are summarized in Table 8:

TABLE 8. INSPECTION SECTIONS OF OLD SEWAGE RESIDUAL PIPES

Section between wells	Length (m)	Flush
1-2	54.48	Rigid concrete with stone attached
2-3	17.87	Unpaved ground
3-4	28.86	Unpaved ground
4-5	24.68	Concrete in glued stone
5-6	26.7	Concrete in glued stone
6-7	26.27	Rigid concrete
7-8	63.25	Rigid concrete
7-9	35.87	Rigid concrete
9-10	24.52	Rigid concrete
10-11	36.45	Unpaved ground
11-12	36.74	Unpaved ground
12-13	45.83	Rigid concrete with stone attached
13-14	96.44	Rigid concrete with stone attached
14-4	67.06	Rigid concrete with stone attached

Note. Existing lengths between inspection wells and the conditions present in their grade.

For the identification and evaluation of the new sewer system, the information provided by the technical report of the audit carried out during the execution of the project, provided by the municipal mayor's office of Ocaña, was used, in which the actual final measurements of the said new sewer system is shown in Table 9:

TABLE 9. INSPECTION OF NEW SEWAGE RESIDUAL PIPE SECTIONS

Sections between wells	Height (m)	Length (m)
initial well -1	1.85	51.80
1-2	2.0	55.84
2-3	1.90	72.9
3-4	1.85	32.5
4-5	1.85	86.0
5-6	1.85	6.0
6-7	1.85	60.0
7- end well	1.85	15.5
8- end well	2.02	18.56
8-9	1.99	41.83

Note. Lengths of collectors between wells of the new sewage system, as well as the state of the grade of rigid concrete with stuck stone.

About the state of the wells, it was possible to show the poor state that this present concerning the old sewage system because during the revisions carried out, when trying to lift one of the covers to inspect the current conditions carefully, it was similar to a piece of bread was broken in half, as shown in the left image of Figure 4. Moreover, when observing the interior state of well 3 with the broken cover, the deterioration of the structure is notorious, which still has the construction forms of the well with an inferior thickness of the concrete to support the support ring on which the cover remains, showing a fragile structure.

Figure 4. Broken inspection of the well cover and internal state of the well.

Considering that the material of the maintenance hole covers is iron. On the other hand, of the 14 wells that make up the old sewage system, it was recorded that well 12 has a depth less than the minimum depth established by the RAS-2000 technical standard, which can be seen in Figure 5, where the diameter of the pipe is shown, which in this case corresponds to 6", and it does not have a gutter, which causes some sediments to remain stagnant at the bottom of the well, the height of the well is observed to be 35 cm, and it is that at a maximum flow is easily flooded.

Figure 5. Inspection well in poor condition.

In the technical report of the comptroller, in compliance with the parties, both the contractor and the comptroller specify that: the existing Otaré sewerage network has depths greater than 3.0 m, so it was convenient to reduce these depths to less than 2.0 m, which guarantees an adequate hydraulic behavior, implying the inclusion of the construction of inspection wells in reinforced concrete. Furthermore, within the hydraulic analysis, it is observed that the established diameter exceeds the true need of the hydraulic demand. With a smaller diameter, it satisfactorily meets said requirement, for which the NOVAFORT corrugated PVC replacement pipe with a diameter of D = 250 mm (10") was made for your convenience with a diameter D = 200 mm (8"), changing a total of 430 linear meters of the existing pipe, in addition, the household connections were made with a diameter D = 160 mm (6") in a total of 424 linear meters with their respective home boxes.

In Figure 6, it was observed that some sections of pipes or collectors at the entrance to the inspection wells, due to the topography, have their elevation of more than 0.75 m measured from the bottom of well 5, considering according to the standard RAS- 2000 technique, as a fall chamber, which does not have a water cushion, nor an established reed, which leads over time to the deterioration of the structure of the well as a result of the abrasion generated by the blow of the falling water when it comes into contact with the structure.

Figure 6. Interior condition of the old sewer inspection wells.

3.1.3. Homes without sewerage. When starting the old sewage system, a total of 7 houses do not have a home connection to the sewage system. In addition, it does not have pavement, but it does have public water and electricity services, as can be seen in Figure 7.

Figure 7. Homes without sewage collection.

In Figure 8, the areas corresponding to the houses without sewer service are indicated in red; it should be noted that the area indicated in the lower part with red corresponds to the entrance of the populated center of Otaré and the one indicated in the upper part corresponds to the Otaré exit. This road leads to the municipality of Carmen.

Figure 8. Location of areas without sewerage in the populated center of Otaré.
Source: [14].

3.1.4. Dwellings with direct discharges. The number of dwellings with direct discharges that are part of the Otaré is nine dwellings. Figure 8 shows a series of houses that have been built for a short time, which are not included in the wastewater collection system, for which they are forced to generate direct discharges; these houses are on the road that leads to the entrance of the populated center of Otaré.

3.1.5. Sewage discharges to the tributary. The existing sewage systems in Otaré have their discharge point separately, but they flow into the same water tributary, poorly known as La Cagona; it is broken as it has a small flow. The physical state of the water shows a dark color which gives an understanding of the high contaminant load resulting from the wastewater discharged without any treatment (see Figure 9).

Figure 9. Stream that receives discharges from the sewage system and direct discharges.

3.1.6. Summary status of the sewer wells. Knowing the problems of Otaré because the new sewage system is in good condition,Table 10 represents the state of the wells only of the old sewer system, which deserves its restoration, showing 28.6% of the wells in poor condition.

TABLE 10. STATE OF THE OLD SEWER WELLS

Qualification	Number of wells	%
Excellent condition	0	0.0
Good condition	6	42.8
Fair state	4	28.6
Disrepair	4	28.6
TOTAL	14	100

Note. Number of wells according to their status and the percentage value of each one.

3.1.7. New sewer. Although the new sewer system has only been in use for a short time, its shortcomings do not correspond to a poor hydraulic redesign or construction process but rather to the inclusion of a wrong connection without the pertinent siphon that prevents the passage of harmful gases produced by the collectors, since by reference to the last inspection well that receives all the wastewater from the new sewage system is the point of most significant contamination to which a pipe that comes from the platform of a house is connected, affecting all the inhabitants of the sector. On the other hand, the sports center that Otaré has a hydraulic structure for its pluvial drainage in poor condition since it was observed that it had the gutters and downspouts of the roof in poor condition, causing stagnation at the time of precipitation.

3.2. Redesign of sewerage system components using SWMM 5vE modeling software.

3.2.1 Calculation parameters for the hydraulic redesign. For the elaboration of the hydraulic evaluation of the sewerage network, it is necessary to know all the parameters that the simulation requires in the software since the model to be used by the software is the dynamic wave model, and the contributions of flows that it generates must be known. The population of Otaré to check if the existing network can cover the demand of all the inhabitants of the corregimiento, considering the simultaneity that it can generate since a flow of greater conditions to the existing operating capacity in the network would lead to a malfunction. It must be taken into account that due to the current conditions in the previous objective, we speak of a conventional sewage system where some inspection wells are also falling chambers.

3.2.2. Population estimation and level of complexity of the system. The existing population in the Otaré for the current year is obtained through the information collected by the censuses carried out by the public entity for a rural extension by the municipal mayor of Ocaña, called the Basic Unit of Attention (UBA) to Otaré, where they are represented by Table 11:

TABLE 11. POPULATION RECORDS IN OTARÉ

Year	Population
2007	456
2013	468
2015	479

Because the censuses are not updated for the current year, a population projection must be carried out to know the current and future estimates, depending on the redesign period, considering the complexity level. To determine the level of complexity, resolution 1096 of 2000 is used, in which four levels are established for the assignment, which is shown in Table 12. To calculate the level of complexity, it is necessary to know the population of the center town and have an estimate of its economic capacity. According to the economic characterization of the population using the methodologies allowed by the RAS, in Title A.3.2, the average salaries of the corregimiento correspond to strata 1 and 2, which are decisive for a low level of complexity since more than 50% of the populated center of Otaré falls within this classification.

After establishing the level of complexity, taking into account that in our case, we are talking about a small population, it is not necessary to carry out a deep analysis for the projection of the population, such as a sensitivity analysis, carrying out an analysis of assigning the level of complexity as shown in Table 12.

TABLE 12. COMPLEXITY LEVEL ASSIGNMENT

Complexity level	Population in the urban area (inhabitants)	Economic capacity of users
Low	< 2500	Low
Medium	2501 a 12500	Low
Medium High	12501 a 60000	Medium
High	> 60000	High

Note. Range of inhabitants to determine the allocation of the level of complexity of the system.
Source: [21].

3.2.3. Simulation hydraulic model options in Swmm 5vE. The SWMM software is a simulation model that in its formulation, uses the equations for the conservation of mass, energy, and momentum for both gradually varied flow and transient flow (that is, Saint Saint's equations). For this simulation, there are three hydraulic transport models:

Uniform flow model. It represents the simplest form of water behavior inside the ducts. However, this type of hydraulic model cannot consider the storage of water in the conduits, the phenomena of a hydraulic jump, the losses at the entrance and exit of the maintenance holes, the reverse flow, or the phenomena of pressurized flow.

Kinematic wave model. The kinematic wave model allows the flow rate and the area to vary spatially and temporally inside the duct. However, this transport model cannot consider effects such as hydraulic jump, losses at well inlets or outlets, reverse flow, or pressurized flow, and its application is restricted only to branched networks.

Dynamic wave model. The dynamic wave model solves the complete one-dimensional Saint Venant equations and theoretically generates the most accurate results. This model can consider effects such as pipe storage, hydraulic jumps, inlet and outlet losses in wells, reverse flow, and pressurized flow.

The hydraulic model used both for modeling the existing sewer system and for the design of the new sewer system corresponds to the dynamic wave model because it presents a better behavior in recognizing the variables to be considered.

3.3. Hydraulic evaluation of existing sewer.

The evaluation of the existing sewage system to simplify all the information necessary for modeling in the SWMM software is shown in Table 13, considering the collection of information previously obtained.

TABLE 13. PARAMETERS FOR HYDRAULIC MODELING

Section between wells		Area (inh)	Length (m)	Diameter (mm)	Domestic Q (LPS)	Increase factor
From the well	towards the well					
1	2	0.1249000	54.48	152.4	0.0100823	5.442443988
8	7	0.0991790	63.25	152.4	0.00800602	5.569397806
10	9	0.0910200	24.52	152.4	0.00734744	5.617412656
9	7	0.0484750	35.87	152.4	0.01126048	5.382626151
7	6	0.0811971	26.27	152.4	0.02582098	4.953961813
6	5	0.0394447	26.7	152.4	0.02900507	4.896689089
5	4	0.0147635	24.68	152.4	0.03019682	4.877011678
10	11	0.0500345	36.45	152.4	0.00403893	5.963802538
11	12	0.0340506	36.74	152.4	0.0067876	5.662110067
12	13	0.0897479	45.83	152.4	0.01403232	5.26546799
13	14	0.1366624	96.44	152.4	0.02506411	4.968721829
14	4	0.0205297	67.06	152.4	0.02672133	4.93701116
4	3	0.0309788	28.86	152.4	0.05941886	4.557823343
3	2	0.0097738	17.87	152.4	0.06020783	4.551815176
2	Final	0.0000000	30.5	152.4	0.07029013	4.48188268

Because the SWMM software does not record the consumption of the tributary areas for sanitary sewers, it was necessary to determine the redesign flow of each section to later enter them into the software as direct contributions in each connection or inspection well. The contributions presented by the SWMM modeling software, according to their classification, as shown in Table 14.

TABLE 14. INPUT PARAMETERS FOR HYDRAULIC SIMULATION

Section between wells		QMH L/S	QCE L/S	QINF L/s	QDT L/S	QDTadopt L/S
From the well	Toward the well					
1	2	0.054176243	0.24980000	0.03747000	0.34144624	1.5
8	7	0.043935868	0.19835800	0.02975370	0.27204756	1.5
10	9	0.04063926	0.18204084	0.02730613	0.24998928	1.5
9	7	0.059898979	0.27899084	0.04184863	0.38072092	1.5
7	6	0.127318953	0.63974304	0.09596146	0.86306742	1.5
6	5	0.141507185	0.71863244	0.10779487	0.96794251	1.5
5	4	0.146780205	0.74815944	0.11222392	1.00717382	1.5
10	11	0.023595467	0.10006900	0.01501035	0.13869615	1.5
11	12	0.037815685	0.16817020	0.02522553	0.23125852	1.5
12	13	0.073157104	0.34766610	0.05214992	0.47291297	1.5
13	14	0.123923503	0.62099096	0.09314864	0.83803195	1.5
14	4	0.131346342	0.66205036	0.09930755	0.89272191	1.9
4	3	0.271495314	1.47216752	0.22082513	1.96444923	2.0
3	2	0.274768805	1.49171522	0.22375728	1.99024960	2.3
2	Final	0.316273583	1.74151522	0.26122728	2.31901290	2.2

The values used to determine the area of the contributions that subsequently generate the contributions for each section were determined using the ground plan of the geospatial location of the urban area of Otaré taken from the basic plan of the territorial ordering of Ocaña, where due to the visual inspection made, many of these delimitations obtained from the plan had to be adjusted through the use of Google Earth since the houses built corresponded to smaller areas than those considered in the totality of the properties according to the plan. Therefore, in Figure 10, the actual areas used for modeling the old sewer system are shown, where the information of each area segment was exported from Google Earth to AutoCAD through the CAD-Earth application.

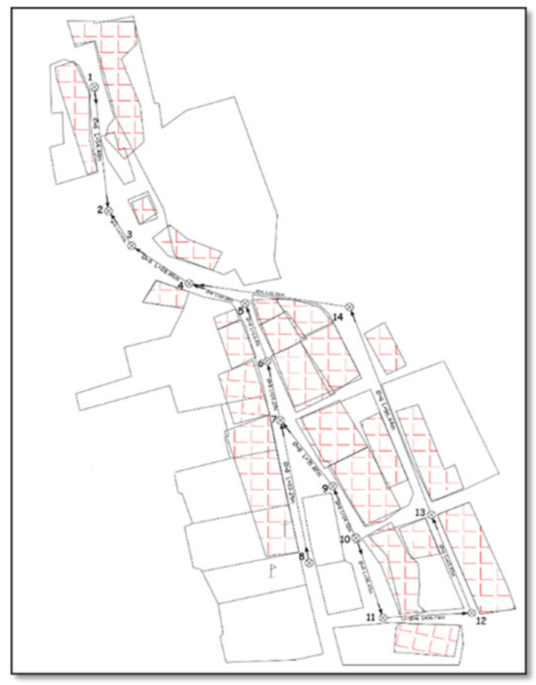

Figure 10. Floor plan with areas of domestic contributions old sewer.

3.4. Analysis and modeling results.

To carry out the modeling, considering the aforementioned conditions concerning the calculated diameter for each pipe section, a 6" diameter was used, corresponding to the current diameter of the existing pipes in the old Otaré sewerage network, as summarized in Table 15.

TABLE 15. RESULTS OF MODELING PIPE SECTIONS

Line	Flow (LPS)	Level (m)	Velocity (m/s)	Froude No.	Capacity
Section 8-7	1.50	0.04	0.47	0.96	0.23
Section 10-9	1.02	0.02	0.87	2.53	0.12
Section 9-7	2.52	0.04	0.78	1.58	0.23
Section 7-6	5.52	0.05	1.10	1.87	0.32
Section 6-5	7.02	0.05	1.28	2.11	0.34
Section 5-4	8.52	0.06	1.15	1.66	0.42
Section 10-11	0.61	0.02	0.52	1.52	0.12
Section 11-12	2.11	0.03	0.68	1.39	0.23
Section 12-13	3.61	0.04	0.99	1.90	0.25
Section 13-14	5.07	0.07	0.57	0.75	0.49
Section 14-4	6.55	0.05	1.20	1.97	0.34
Section 4-3	16.94	0.09	1.58	1.90	0.57
Section 3-2	18.82	0.09	1.78	2.14	0.56
Section 2-Final	22.53	0.08	2.16	2.62	0.56

Due to the conditions of the flow regime obtained from Table 15, according to the Froude number, some pipe sections work at critical flow, so to perform any optimization, it is necessary to improve the slopes of the pipe to solve this problem. Regarding speeds, all pipe sections comply with the minimum speed established by the standard, which should not be less than 0.45 m/s [10], obtaining the results shown in Tables 16 and 17.

TABLE 16. SUMMARY RESULT OF LINES

Name	Initial Knot	Final Knot	Length	% Slope.	Rugosity
Section 1-2	1	2	54.5	4.4096	0.0130
Section 8-7	8	7	63.2	1.5812	0.0130
Section 7-6	7	6	26.3	1.9037	0.0130
Section 6-5	6	5	26.7	1.8730	0.0130
Section 5-4	5	4	24.7	6.0891	0.0130
Section 4-3	4	3	28.9	1.7328	0.0130
Section 3-2	3	2	17.9	2.2389	0.0130

Section 2-Final	2	15	60.0	3.3352	0.0130
Section 10-9	10	9	24.5	3.0602	0.0130
Section 9-7	9	7	35.9	1.0594	0.0130
Section 10-11	10	11	36.5	1.0975	0.0130
Section 11-12	11	12	36.7	1.3610	0.0130
Section 12-13	12	13	45.8	1.5276	0.0130
Section 13-14	13	14	96.4	0.2074	0.0130
Section 14-4	14	4	67.1	1.6405	0.0130

TABLE 17. SUMMARY OF CROSS SECTIONS

Conduit	Full Flow
Section 1-2	43.37
Section 8-7	25.97
Section 7-6	28.50
Section 6-5	28.27
Section 5-4	50.97
Section 4-3	27.19
Section 3-2	30.91
Section 2-Final	37.72
Section 10-9	36.13
Section 9-7	21.26
Section 10-11	21.64
Section 11-12	24.10
Section 12-13	25.53
Section 13-14	9.41
Section 14-4	26.46

Note. Summary of the hydraulic properties according to the modeling carried out in SWMM, for a single section, circular geometric shape, filling level of 0.15, filling sand of 0.02, the hydraulic radius of 0.04, and a maximum width of 0.15.

Considering the above, Figures 11, 12, and 13 of the simulations of the sewerage profile for the different dumping grounds were obtained.

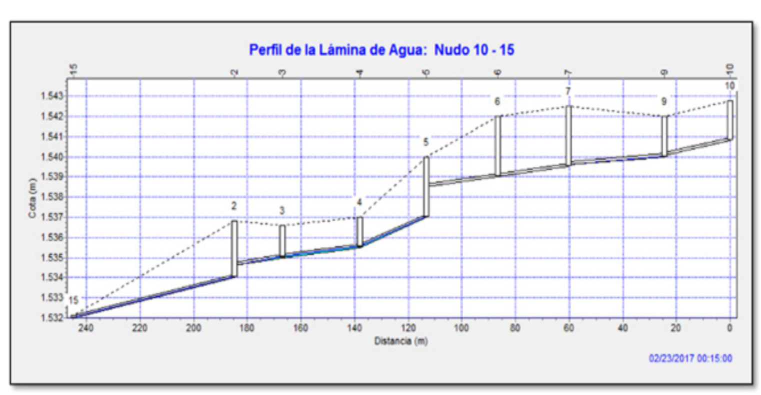

Figure 11. Old sewer profile from well 10 to the point of discharge.

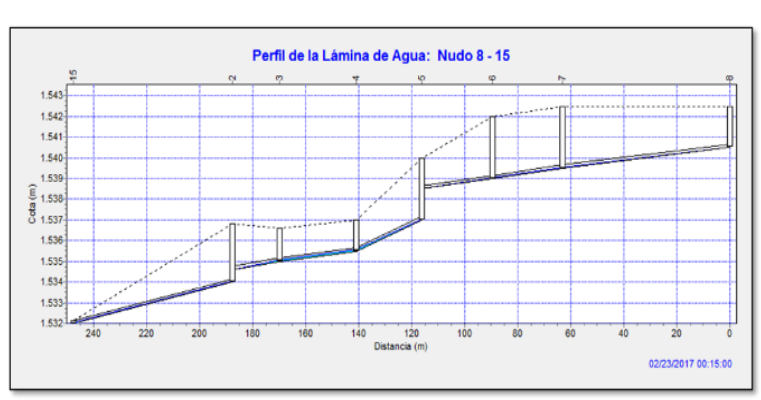

Figure 12. Old sewer profile from well 8 to the point of discharge.

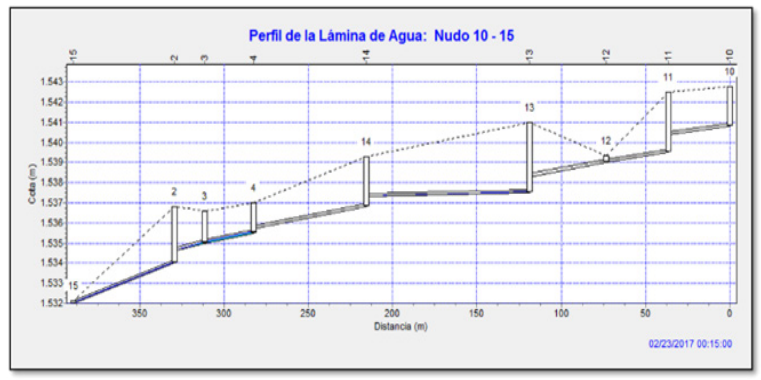

Figure 13. Old sewer profile from well 10 to the point of discharge.

3.5. Hydraulic evaluation of projected sewer.

For the improvement of the existing old sewage system in the Otaré, an increase in the diameter of the pipe is proposed, which currently corresponds to 6”, and the inclusion of five new pipe sections to the existing network, considering that the projected sewage system has in its totality with the redesign of each of the elements that are part of the sewage system. As with the modeling of the old sewer system, for the projected sewer system, the calculation was also carried out to determine the redesign flow for each section of the pipe, taking into account the new sections that complement the sewer system, which correspond to Tables 18 and 19:

TABLE 18. PARAMETERS FOR HYDRAULIC MODELING

Section between wells		Area (Inha)	Length (m)	QDomestic	Increase factor
From the well	Toward the well			LPS	
1+	2+	0.12113926	75.24	0.00977872	5.38843851
2+	1	0.03971431	35.87	0.01298458	5.25058152
1	2	0.20207534	54.48	0.02929670	4.87424642
8	7	0.20926639	63.25	0.01689260	5.12581868
10	9	0.03358562	24.52	0.00271113	6.05877402
9	7	0.03525949	35.87	0.00555738	5.67405539
7	6	0.09022186	26.27	0.02973296	4.86766565
6	5	0.10717040	26.70	0.03838407	4.75535891
5	4	0.03653987	24.68	0.04133368	4.72328896
10	11	0.03957853	36.45	0.00319490	5.96852970
4+	11	0.03719666	23.76	0.00300262	6.00248539
11	12	0.03405060	36.74	0.00894619	5.43244077
12	13	0.18235590	45.83	0.02366649	4.97025722
10	13	0.03456712	32.65	0.00279036	6.04284363
13	3+	0.16101439	59.76	0.03945441	4.74341988
7	3+	0.04953319	41.85	0.00399847	5.84738448
3+	14	0.08751281	35.70	0.05051717	4.63746216
14	4	0.05780944	67.06	0.05518372	4.60016260
4	3	0.06224113	28.86	0.10154169	4.35078287
3	2	0.02379831	17.87	0.10346276	4.34333616
2	Final	0.00000000	30.50	0.13275945	4.2454773

For registering the new pipeline Sections, it was also necessary to project the location of four new inspection wells with which the new pipeline sections will be connected. However, it should be clarified that the new sewerage redesign will keep the same location of the inspection wells, and an inspection of the old sewage system, but not the same existing structures as these are in deplorable condition.

TABLE 19. INPUT PARAMETERS FOR HYDRAULIC SIMULATION

Sections between the wells		QMH L/S	QCE L/S	QINF L/S	QDT L/S	QDTadopt L/S
From the well	Toward the well					
1+	2+	0.05263616	0.24227852	0.03634178	0.33135646	1.5
2+	1	0.06815373	0.32170714	0.04825607	0.43811694	1.5
1	2	0.14279009	0.72585782	0.10887867	0.97752658	1.5
8	7	0.08657781	0.41853278	0.06277992	0.56790905	1.5
10	9	0.01643339	0.06717124	0.01007569	0.09367032	1.5
9	7	0.03157214	0.13769022	0.02065353	0.18987159	1.5
7	6	0.14479888	0.73666672	0.11050001	0.99186561	1.5
6	5	0.18255221	0.95100752	0.14265113	1.27611086	1.5
5	4	0.19520103	1.02408726	0.15361309	1.37290138	1.5
10	11	0.01908469	0.07915706	0.01187356	0.11001531	1.5
4+	11	0.01800787	0.07439332	0.011159	0.10356019	1.5
11	12	0.04853856	0.22165158	0.03324774	0.30343787	1.5
12	13	0.11769948	0.58636338	0.08795451	0.79191737	1.5
10	13	0.01687108	0.06913424	0.01037014	0.09637546	1.5
13	3+	0.18716324	0.9775264	0.14662896	1.31130186	1.5
7	3+	0.02338954	0.09906638	0.01485996	0.13730173	1.5
3+	14	0.23423151	1.2516184	0.18774276	1.67361267	1.67
14	4	0.25385116	1.36723728	0.20508559	1.82617403	1.83
4	3	0.44172506	2.5158068	0.37737102	3.33490288	3.33
3	2	0.44938827	2.56340342	0.38451051	3.39728022	3.40
2	Final	0.56367835	3.28926124	0.49338919	4.34627878	4.35

To accommodate a more significant number of users, considering that the Otaré, over the years, will lead to a population growth represented in new constructions, to calculate the redesign flow, some tributary areas that are currently Free zones for the construction of houses and development of the urban area of Otaré, as shown in Figure 14.

Figure 14. Floor plan of the projected old sewer.

3.6. Analysis and modeling results.

The modeling of the projected sewer system uses the same order and numbering as the old sewer system, taking into account that the numbering of the projected inspection wells is followed by the "+" sign, as detailed in the modeling in lines of Table 20.

TABLE 20. SUMMARY OF MODELING IN LINES

Line	Flow (LPS)	Level (m)	Velocity (m/s)	Froude No.	Capacity
Section 1+-2+	1.5	0.3	0.62	1.11	0.17
Section 2+-1	3.0	0.3	0.87	1.79	0.19
Section 1-2	4.50	0.03	1.41	2.97	0.18
Section 8-7	1.50	0.03	0.58	1.33	0.15
Section 10-9	1.63	0.02	0.92	2.39	0.12
Section 9-7	3.13	0.04	0.76	1.47	0.21
Section 7-6	6.13	0.05	1.18	2.09	0.25
Section 6-5	7.63	0.04	1.55	2.79	0.24
Section 5-4	9.13	0.04	1.84	3.31	0.25
Section 10-11	1.50	0.03	0.62	1.46	0.15
Section 4+-11	1.50	0.03	0.49	1.06	0.17
Section 11-12	4.50	0.04	1.05	1.98	0.22
Section 12-13	6.00	0.06	0.83	1.28	0.32
Section 10-13	1.50	0.04	0.31	0.55	0.24
Section 13-3+	9.00	0.07	0.98	1.38	0.38
Section 7-3+	1.50	0.04	0.32	0.59	0.24
Section 3+-14	12.10	0.08	1.17	1.56	0.42
Section 14-4	13.80	0.09	1.15	1.43	0.47
Section 4-3	26.13	0.10	1.69	1.84	0.57
Section 3-2	29.43	0.11	1.88	2.03	0.58
Section 2-Final	38.13	0.11	2.28	2.37	0.61

According to the result of the modeling concerning the flow regime, as can be seen in Table 20, all the pipe sections comply with the supercritical regime, except the sections that go from well 10 to well 13 and the section that goes from well 7 to well 3+, where the flow regime is subcritical. Therefore, it is also observed that its speed is much lower than the minimum established by the standard corresponding to 0.45 m/s. In this case, an increase in the slope of these pipe sections is made to avoid failures in the hydraulic system. Finally, the summary of the lines is shown in Table 21, and the summary of the cross-sections is in Table 22.

TABLE 21. ABSTRACT LINES

Name	Initial Knot	Final Knot	Length	%Slope.
Section 1-2	Pozo1	2	54.5	4.4096
Section 8-7	8	7	63.2	1.1068
Section 7-6	7	6	26.3	1.9037
Section 6-5	6	5	26.7	3.7479
Section 5-4	5	4	24.7	5.2747
Section 4-3	4	3	28.9	1.7328
Section 3-2	3	2	17.9	2.7991
Section 2-Final	2	15	60.0	3.3352
Section 10-9	10	9	24.5	3.0602
Section 9-7	9	7	35.9	1.0594
Section 10-11	20	11	36.5	1.0975
Section 11-12	11	12	36.7	1.9056
Section 12-13	12	13	45.8	2.1825
Section 13-3+	13	16	59.8	0.8367
Section 14-4	14	4	67.1	1.0439
Section 3+-14	16	14	35.7	1.9612
Section 7-3+	22	16	41.9	4.7844
Section 10-13	21	13	32.6	8.6075
Section 1+-2+	18	17	75.2	1.3292
Section 2+-1	17	1	35.9	1.3941
Section 4+-11	19	11	23.8	2.1048

Note. Summary of the necessary values used in the modeling in SWMM, for a Conduit type and a Roughness of 0.0130.

TABLE 22. SUMMARY OF CROSS SECTIONS

Conduit	Full Flow
Section 1-2	63.30
Section 8-7	31.71
Section 7-6	41.59
Section 6-5	58.36
Section 5-4	69.23
Section 4-3	39.68
Section 3-2	50.43
Section 2-Final	55.05
Section 10-9	52.73
Section 9-7	31.03
Section 10-11	31.58
Section 11-12	41.61
Section 12-13	44.53
Section 13-3+	27.57
Section 14-4	30.80
Section 3+-14	42.21
Section 7-3+	65.94
Section 10-13	88.44
Section 1+-2+	34.75
Section 2+-1	35.59
Section 4+-11	43.73

Note. Results of the pipe sections' properties calculated in the SWMM modeling, for a single section, circular geometric shape, fill level of 0.18, fill sand of 0.03, hydraulic radius of 0.05, and a maximum width of 0.18.

The hydraulic behavior in the cross-section of each pipe section, where the level corresponding to 0.18 m is shown, for all the ducts since all the sections were worked. With the same diameter, the level filled also corresponds to the actual internal diameter of the pipe. As the area was filled in m2, the hydraulic radius and the maximum width given in m, since it is the same pipe diameter for the entire sanitary sewer system, the values in the table do not differ [11]. The last column of the table corresponding to the total flow varies due to the accumulated flow that each pipe section transports, depending on the previously established tributary areas.

Table 23 shows all the necessary information for the inspection wells in which the depth of the bottom represents the height of the pan for most of the Pipe Sections; node 15 is located at the end of the first column, represents the shedding point when working with the dynamic wave model, according to the SWMM software. It is necessary to establish a discharge point before the final outfall where the wastewater ends. The depth used for inspecting wells in the new sanitary sewer redesign corresponds to the maximum depth.

TABLE 23. SUMMARY OF LEVEL IN NODES

Knot	Type	Maximum level meters	Medium level meters	Maximum height meters	Instant Max Level days hr:min
1	JUNCTION	0.03	0.03	1536.53	00:11
2	JUNCTION	0.11	0.11	1534.11	08:55
3	JUNCTION	0.10	0.10	1534.60	18:33
4	JUNCTION	0.11	0.11	1535.11	13:24
5	JUNCTION	0.04	0.04	1536.54	02:10
6	JUNCTION	0.04	0.04	1538.04	19:32
7	JUNCTION	0.05	0.05	1538.55	19:11
8	JUNCTION	0.03	0.03	1539.23	00:19
9	JUNCTION	0.04	0.04	1539.04	15:31
10	JUNCTION	0.02	0.02	1539.82	01:34
11	JUNCTION	0.04	0.04	1539.04	03:09
12	JUNCTION	0.05	0.05	1538.05	03:09

13	JUNCTION	0.07	0.07	1537.07	00:09
14	JUNCTION	0.09	0.09	1535.89	06:24
16	JUNCTION	0.07	0.07	1536.57	00:12
17	JUNCTION	0.04	0.04	1537.04	00:07
18	JUNCTION	0.03	0.03	1538.03	00:21
19	JUNCTION	0.02	0.02	1539.52	00:19
20	JUNCTION	0.03	0.03	1539.83	00:57
21	JUNCTION	0.02	0.02	1539.82	00:05
22	JUNCTION	0.02	0.02	1538.52	00:08
15	OUTFALL	0.11	0.11	1532.11	07:55

Table 23 shows the levels reached by the water in the inspection wells during the hydraulic modeling at a certain instant of time; since the software gives us the option of establishing the time in which the simulation is carried out, for redesign purposes, a time of 23:00 h was used, where every 15 min the program automatically generates results. Finally, Table 24 shows all the contributions made to each of the inspection wells, where the maximum total contribution corresponds to the sum of the flows added to each section according to the upstream contributions.

TABLE 24. SUMMARY OF CONTRIBUTIONS IN NODES

Knot	Type	Maximum Lateral Contribution LPS	Maximum Total Contribution LPS	Instant Maximum Contribution days hr:min	Lateral Supply Volume 106 L	Volume Total Contribution 106 L
1	JUNCTION	3.20	4.50	00:08	0.124	0.372
2	JUNCTION	4.20	38.13	20:20	0.348	3.151
3	JUNCTION	3.30	29.43	16:41	0.273	2.432
4	JUNCTION	3.20	26.13	16:40	0.265	2.159
5	JUNCTION	1.50	9.13	12:29	0.124	0.755
6	JUNCTION	1.50	7.63	12:29	0.124	0.631
7	JUNCTION	1.50	6.13	01:09	0.124	0.507
8	JUNCTION	1.50	1.50	00:00	0.124	0.124
9	JUNCTION	1.50	3.29	00:00	0.124	0.259
10	JUNCTION	1.63	1.63	00:00	0.135	0.135
11	JUNCTION	1.50	4.50	00:23	0.124	0.372
12	JUNCTION	1.50	6.00	03:09	0.124	0.496
13	JUNCTION	1.50	9.00	00:29	0.124	0.745
14	JUNCTION	1.70	13.80	00:12	0.141	1.141
16	JUNCTION	1.60	12.10	00:10	0.132	1.000
17	JUNCTION	1.50	3.00	00:21	0.124	0.248
18	JUNCTION	1.50	1.50	00:00	0.124	0.124
19	JUNCTION	1.50	1.50	00:00	0.124	0.124
20	JUNCTION	1.50	1.50	00:00	0.124	0.124
21	JUNCTION	1.50	1.50	00:00	0.124	0.124
22	JUNCTION	1.50	1.50	00:00	0.124	0.124
15	OUTFALL	0.00	38.13	07:55	0.000	3.150

Considering the above Figures 15 of the simulations of the sewerage profile for the different dumping grounds were obtained. Unlike the profiles made for the old sewer system, in the new redesign, a better distribution can be observed in the slopes of the pipes and the inspection wells, considering that for the new design, it was not necessary to use drop chambers.

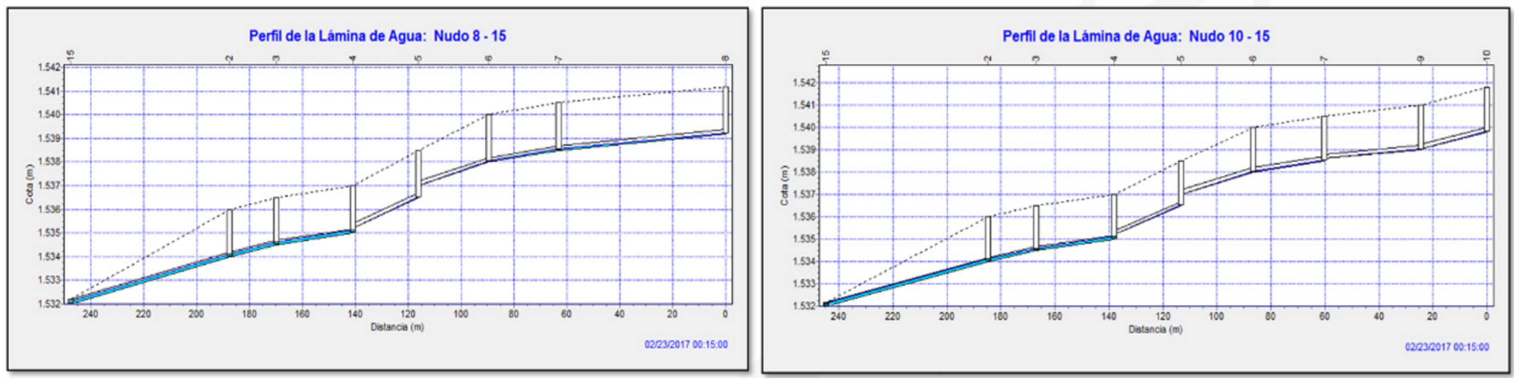

Figure 15. Water sheet profile from well a) 8 and b) 10 to the point of discharge.

3.7. Economic evaluation of the redesign

The total budget for the new redesign of the sewer system for the optimization of the existing Otaré system is hidden in Table 25, it should be noted that the analysis of unit prices due to its extension is attached to the general budget.

TABLE 25. OVERALL OPTIMIZATION BUDGET

Item N°	Description	Unit	Quantity	Unit value ($)	Total value ($)
1	Location and layout	m2	615.52	$ 1309.00	$ 805.716.00
1.1	preventive tape	ml	1647.82	$ 479.00	$ 788.811.00
2. Concrete demolition					
2.1	Roadcut	ml	632.09	$ 21.904.00	$ 13.845.047.00
2.2	Demolition road cut	m3	246.51	$ 74.112.00	$ 18.269.349.00
2.2	Demolition wells	m3	66.91	$ 74.112.00	$ 4.958.841.00
3. Excavation					
3.1	Pipeline	m3	2294.82	$ 86.352.00	$ 198.161.838.00
3.2	wells	m3	96.2	$ 86.352.00	$ 8.307.043.00
4	pipe removal	ml	647.19	$ 74.112.00	$ 47.964.610.00
5	pipe installation	ml	823.91	$ 156.822.00	$ 129.207.544.00
5.1	affirmation of the ground	m3	192.37	$ 132.252.00	$ 25.441.336.00
5.2	Installation of joints	und	138	$ 32.720.00	$ 4.515.346.00
6. Concrete					
6.1	Wells	m3	46.82	$ 593.226.00	$ 27.774.851.00
6.2	Road reconstruction	m3	189.63	$ 465.326.00	$ 88.239.807.00
7	Stuffed	m3	1572.88	$ 129.582.00	$ 203.816.228.00
8	Reinforcing steel wells	kg	3660.05	$ 13.790.00	$ 50.473.891.00
SUB-TOTAL VALUE OF WORKS					$ 822.570.258.00
A.I.U. (30%)					$ 246.771.077.00
TOTAL VALUE OF WORKS					$ 1.069.341.336.00

IV. CONCLUSIONS

The redesign of the sewage system for the optimization of the existing system increases 5 new Sections that did not exist and needed to meet the need for evacuation of wastewater from the community of the urban area of Otaré.

The redesign or rehabilitation of the sanitary sewer through the SWMM simulation software facilitates the calculation procedures to determine whether it meets the redesign criteria established by the RAS technical standard, showing good hydraulic behavior, using a 200 mm diameter NOVAFORT PVC pipe.

Regarding the manual, most of the functions available in the SWMM software apply to storm sewers. However, its use to simulate sanitary sewers is not prohibited since the hydraulic calculations are the same for any sewerage system.

The total cost to optimize the existing Otaré sewage system has a value of 1,069,341,336 million pesos, which includes all the demolition of the existing infrastructure and the construction of the elements of the new system, considering the paving of its grade in rigid concrete.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Marco Lanziano-Barrera: Conceptualization, Methodology, Research, Formal Analysis, Data Curation, Writing - Original Draft. **Byron Cuesta-Quintero:** Conceptualization, Methodology, Visualization. **Nelson Afanador-García:** Conceptualization, Methodology, Visualization. **Rafael López-Barrios:** Conceptualization, Methodology, Visualization.

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