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Sanitary Sewerage Master Plan for the Sustainable Use of Wastewater on a University Campus

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Abstract: Wastewater collection, transport, and treatment systems are essential to ensure human and environmental well-being. The Escuela Superior Politécnica del Litoral (ESPOL), has been implementing various sanitary sewerage systems; however, population growth has given rise to discussion on the installed capacity versus the necessary capacity for the future population in the sustainable management of water resources. Therefore, this study aimed to develop a sanitary sewerage master plan by analysing the existing situation and applying technical criteria for the sustainable use of wastewater on a university campus. The methodology consisted of (i) evaluation and diagnosis of the area studied through data collection and processing, (ii) design of the sanitary sewerage system considering area-expansion zones, and (iii) SWOT analysis of a proposal to enhance wastewater transport and treatment systems. The proposal contemplates designing a sanitary sewer system that will manage the collection, transport, and treatment of wastewater over 15 years for 5667 inhabitants located in three expansion zones with occupation periods of 5, 10, and 15 years. The sewerage system comprises a pipe network 1.19 km long and 200 mm in diameter, transporting 12.37 L/s of wastewater generated to two treatment systems that guarantee efficient depuration and subsequent reuse. This design was complemented by a SWOT analysis of the existing sanitation system developed by experts in the area, which included optimising existing treatment systems and reusing wastewater for irrigation of green areas as tertiary treatment within the circular economy. The methodology used in the study allows us to offer a tool for efficiently managing wastewater on a university campus, guaranteeing human well-being, and promoting the circular economy of water.

Keywords: treatment; sustainability; social responsibility; expansion areas; resource recovery; circular economy

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1. Introduction

Approximately 70% of the Earth's surface is covered by water. However, less than 3% is freshwater [1]. As a result, domestic, industrial, and agricultural use of freshwater generates significant amounts of liquid waste, also called residual water, black water, or sewage [2], of which more than 80% is discharged into rivers or the sea without having been purified [3].

Raw wastewater comprises organic and inorganic matter: the remains of vegetables, animals, fats, oils, and small or large solids, such as fabrics, plastics, chemicals, and sand [4], which can be categorised as physical, chemical, and biological. To characterise these, some parameters have been defined, such as suspended and dissolved solids, biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), and coliforms, among others, which represent worrying contamination agents [5]. The discharge of these contaminants into water bodies prevents the necessary conditions for the development of aquatic life, which in turn impacts the economic growth and well-being of nearby communities [6,7]. In general, municipalities or city councils are the institutions in charge of drinking water and wastewater-treatment systems, whose management is carried out directly or indirectly through specialised companies in various regions of the world [8–14].

At the urban level, wastewater is returned to the sanitary sewerage system with a contaminant load that must be purified before being discharged into a body of water or used again for other activities [15]. The treated wastewater can be used for potable or non-potable purposes [16]. However, depending on the severity of the treatment, the processing cost will be higher [17–20].

The sanitary sewerage system is essential for urban development, because it is responsible for transporting sewage or residual water through a network of underground pipes to the facilities accountable for purifying it [21]. First, however, it must be ensured that this piping system is in good condition and of good design. Otherwise, problems may arise, such as leaks that contaminate the soil or nearby water sources [22–25].

Water is a scarce and valuable resource that is affected by contamination from anthropogenic activities. Therefore, it must be managed sustainably, i.e., to satisfy the needs of the present without compromising future needs [26,27]. In this context, social responsibility is vital, and the industry is gradually becoming more aware of it. Additionally, it is necessary to continue making efforts to raise awareness among the population to mitigate the impact of human activities [28–30]. Therefore, it is essential to understand that the excessive or improper use of water generates a state of water stress, which promotes water scarcity worldwide [31,32].

At the domestic level, several measures are implemented to save water. Some examples include using high-efficiency toilets that use less water, reuse of grey water, a rainwater-harvesting system for watering plants or cleaning, and the use of soaker hoses or a drip irrigation system for gardens, among other measures [33–35]. In addition, in agriculture, where water consumption is approximately 70%, treated wastewater could be used due to its nutrient content, which serves as fertiliser for crop soils [36,37].

Under this scenario, a management model based on the circular economy is essential, since it seeks to regenerate or reuse the waste produced [38]. However, this requires a change in the culture and consumption habits of the population [39]. In sewerage works, adequate planning is necessary to avoid future problems. A master plan is a comprehensive set of strategies that contemplate a series of actions, such as analysis of the situation, declaration of objectives, evaluation of alternatives, implementation, and follow-up, all of this to solve a problem in the short, medium, and long term [40–43].

The Escuela Superior Politécnica del Litoral (ESPOL) has a sewerage network that transports its wastewater to the points where it is purified for reuse. In addition, the institution has a membrane biological reactor wastewater treatment plant (WWTP-MBR), a dissolved air flotation system (WWTP-DAF), stabilisation ponds, septic tanks, and a WWTP for sludge activated by oxidation total.

ESPOL university has been implementing various sanitary sewerage systems; however, population growth has called into question the installed capacity versus the necessary capacity for the future population to sustain water resources.

This situation has motivated the institution to contemplate expansion areas that satisfy the growing student demand. Therefore, this study aimed to develop a sanitary sewerage master plan by analysing the existing situation and applying technical criteria for sustainable wastewater management on the university campus.

2. Materials and Methods

The methodology consists of three phases: (i) evaluation and diagnosis of the area studied through data collection and processing, (ii) design of the sanitary sewerage system considering area-expansion zones, and (iii) SWOT analysis of a proposal that enhances wastewater transport and treatment systems (Figure 1).

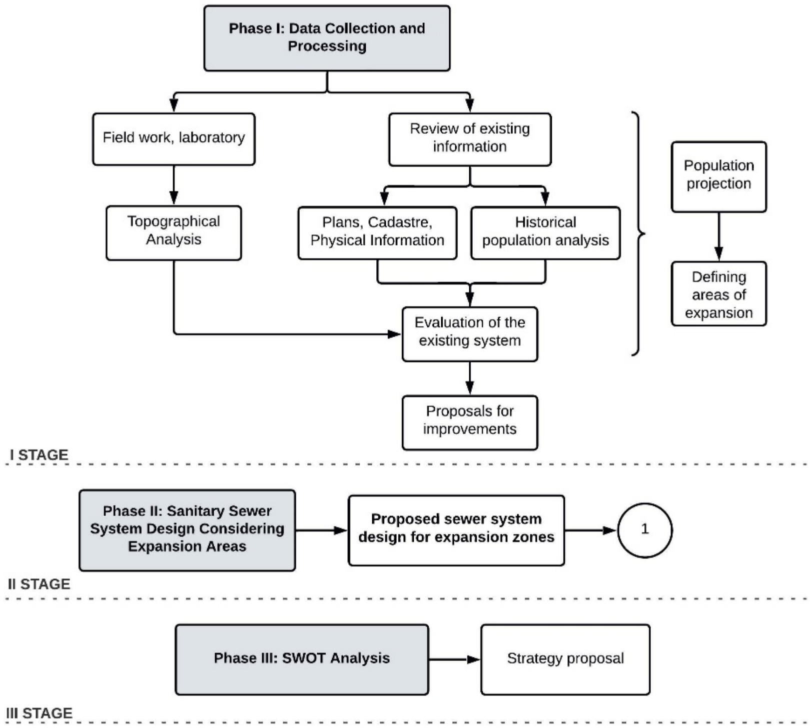

Figure 1. General scheme of the applied method.

2.1. Study Area

The study area is located Guayaquil, Guayas al Oeste, Ecuador (Figure 2), with elevations from 25–380 m above sea level (m.a.s.l.). The lithology of the area corresponds to agglomerates, shale, and sandstone belonging to the Cayo Formation. The existing soils correspond to clayey sand and silty clay. The university campus has a primary and secondary forest called La Prosperina, which includes a diversity of flora (ceibo, carob, pechiches, among others) and fauna (birds, iguanas, squirrels, sloths, among others) [44]. The area has an average temperature of 26 °C, with two seasons: summer (June to December) and winter (January to May), with less than 2000 mm annual rainfall [45].

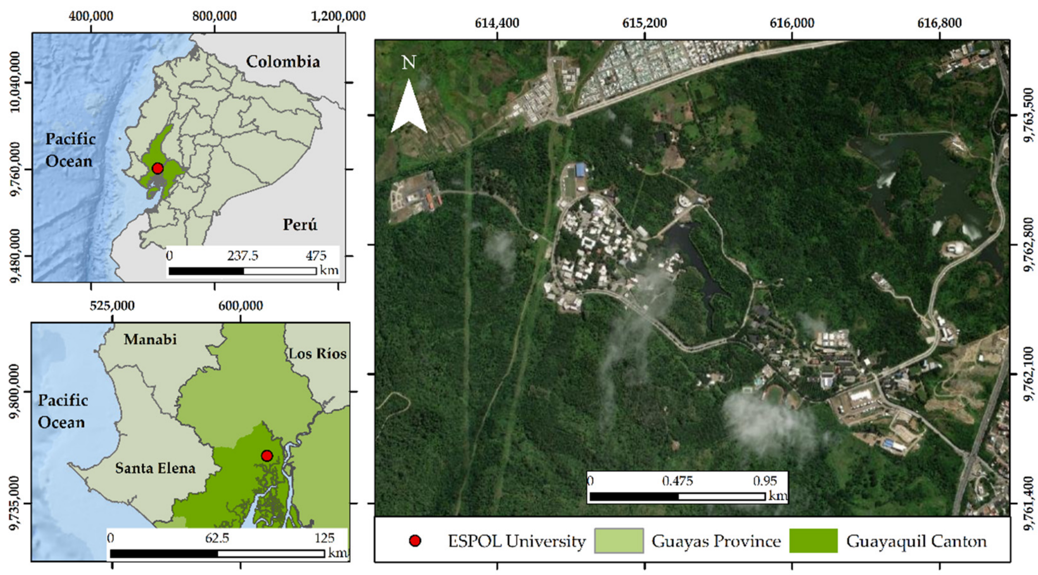

Figure 2. Study area.

2.2. Stage I: Data Collection and Processing

The work began with the topographical analysis of the study area. In this case, such programs as Google Earth (7.3.4.8642 version), ArcGIS (10.5 version), and Global Mapper (23 version) were used to obtain contour lines every 5 m and generate a topographic map. Subsequently, the historical population of the university was reviewed from 2002 to 2020 to analyse the population's behaviour from 2021 for 15 years. According to INEN 5:9:1 regulations [46], at least three population-projection methods must be used. This study used four: arithmetic, simple interest, geometric, and exponential. The objective of the analysis was to determine the population behaviour of the university campus to define the potential location of expansion zones that supply the population for the analysed design period. For the site of these areas, it was necessary to review the plans, record the characteristics of the existing sewerage system, project restrictions due to its location within a protected area, and combine it with the population analysis.

Finally, through limited field trips, given the health situation due to COVID-19, the current state of the sanitary sewer system was inspected. Likewise, the existing treatment systems were reviewed according to the type of treatment they carry out, the contribution areas they satisfy, and the flow they receive. The objective of this evaluation was to determine if the existing system can purify the additional flow that future expansion zones will generate in accordance with the regulations of book six of the Unified Text of the Secondary Legislation of the Ministry of Environment (TULSMA) [47].

2.3. Stage II: Technical Proposal Design

The results of Phase I formed the basis for designing the new sewerage network in the proposed expansion areas. From the projected population to 2035, the number of inhabitants occupying the expansion zones in the next 15 years was selected. For calculating the volume of wastewater collected by the sewerage network and due to the nature of the project (a set of buildings for educational purposes), the study considered the endowment values proposed by chapter 16 of the Norma Hidrosanitaria NHE-AGUA [48]. Through hydraulic relations, the system was designed to meet the minimum requirements of slopes, diameters, and speeds. Furthermore, the network design that supplies the expansion zones verified that the existing sewerage network that continues after the wells where one system will be connected to another could satisfy current and future demand. For this, the flow generated by the expansion zones was added to the flow proposed by studies [49,50], and similarly the minimum requirements were verified. These minimum considerations follow the recommendations of the INEN 5:9:1 standard INEN 5:9:1 [46] and the *Manual de Diseño de Redes de Alcantarillado* of the drinking water and sewerage concession company of Guayaquil Interagua [51] (Figure 3).

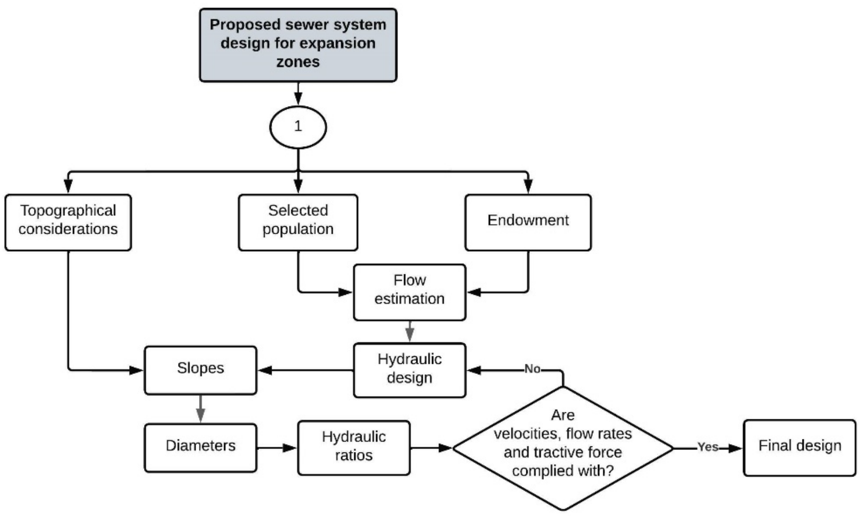

Figure 3. Methodological scheme for the design of sewerage in the expansion zones.

2.4. Stage III: SWOT Analysis

The study ended with a strength, weakness, opportunity, and threat (SWOT) analysis [52] of the existing sewer system and proposed system for expansion zones. This analysis will make it possible to define strategies to guarantee the proper functioning of wastewater transport and treatment systems in present and future scenarios, considering the social, environmental, and economic axis. Three focus groups carried out the analysis: (i) experts in wastewater management (civil and chemical engineers), (ii) authorities of the institution, and (iii) the study authors.

3. Results

The results of this study are shown through maps, figures, and tables detailing the topography, protection zones, existing and projected sewerage network for the expansion areas, historical and future population, and current status of sewage treatment systems, among others.

3.1. Existing Information

The campus is in an area with an irregular morphology that includes elevations between 25 and 450 m above sea level (Figure 4) and maximum slopes of 45°. This allows the formation of a series of natural drainage systems that preserve the protected forest and flow through a storm drainage system that avoids flooding problems on campus. The main buildings, where most of the university's activities occur, are mainly in the light-green zone.

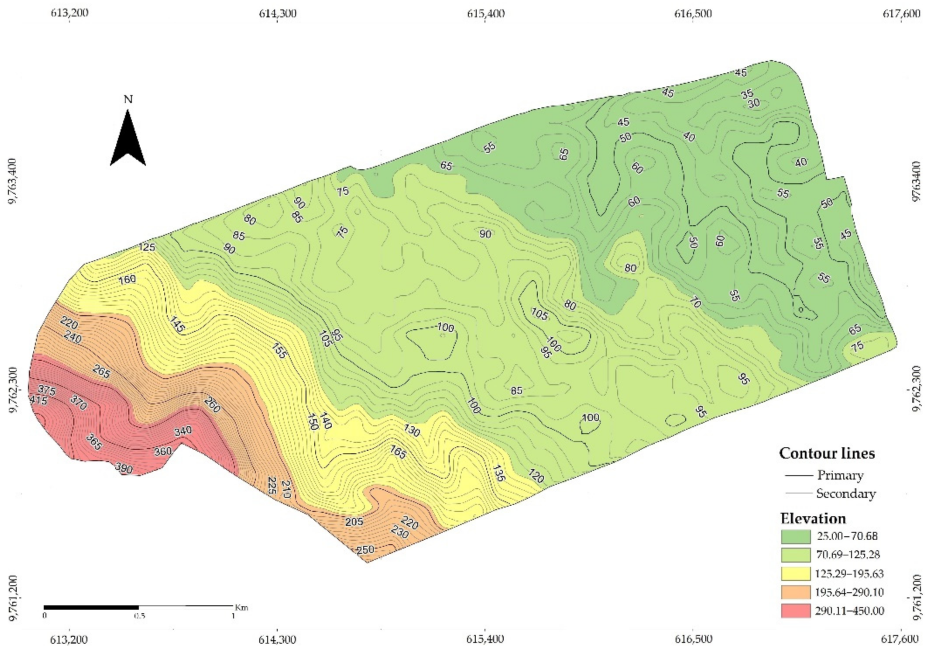

Figure 4. Topographic map of the ESPOL property.

For management and planning purposes, the ESPOL property is divided into 14 zones, excluding the low reserve property of 17.36 ha on the other side of Perimeter Road. Zones Z1 and Z8, with an area of 200 and 186.39 ha, respectively, occupy the most space. Most of the Z4, Z8, and Z10 zones belong to the Prosperina protected forest (Figure 5).

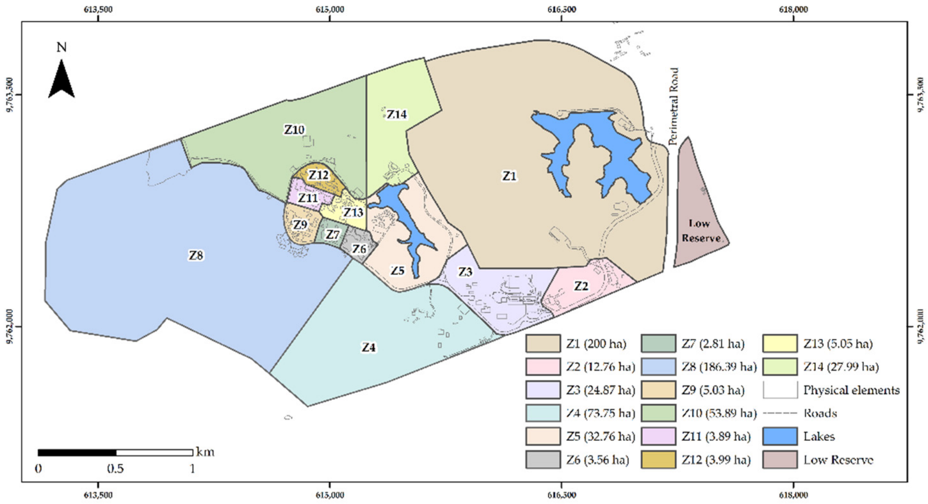

Figure 5. Zoning of ESPOL property.

Zone 1 has the smallest population, despite having the most significant area. According to the data analysed, zones 2, 3, 8, 9, 11, and 12 contain most of the population (Table 1).

Table 1. Population of the 14 ESPOL zones in 2019 [53].

Zone	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12	Z13	Z14
Population	93	2430	2335	59	619	144	31	2997	2911	33	2640	2761	1205	774

From the map of protection zones, we can distinguish between the intervention zone map, with an area of 325.69 ha (existence of infrastructure), and the zones where intervention is not allowed for forest-preservation purposes. These zones include core zone 1, core zone 2, the permanent protection zone and the buffer zone, which cover an area of 332.30 ha, not including the area generated by the right of way of the polyduct (17.76 ha) that crosses the property (Figure 6).

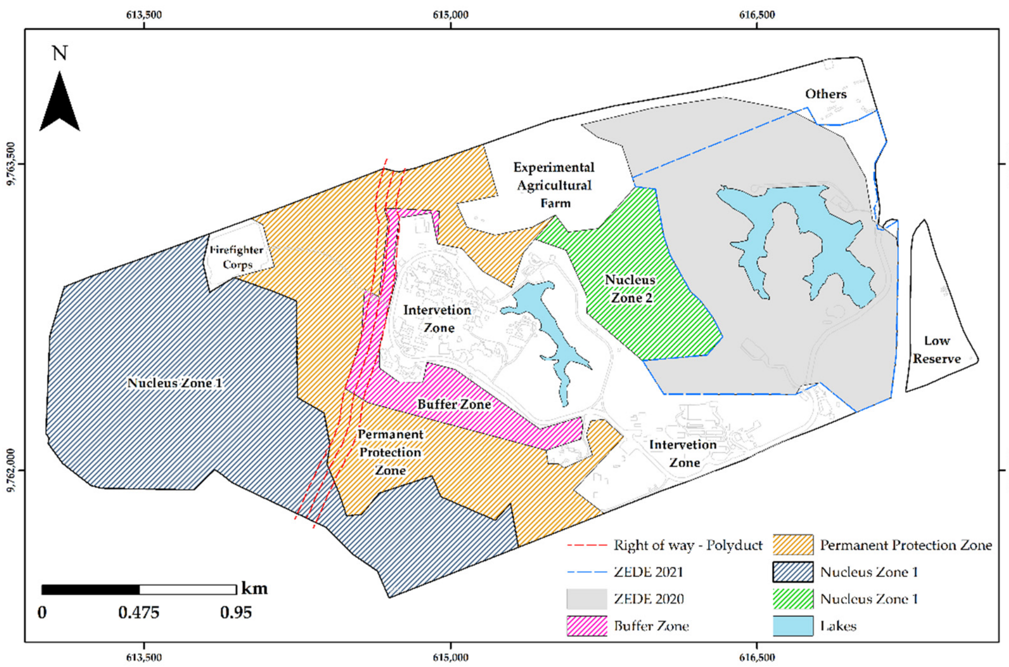

Figure 6. Map of protection zones of the ESPOL property.

According to the historical record of the population of the ESPOL campus, without taking into account the population of the Special Economic Development Zone (ZEDE) (because the population growth of this zone is not relevant to the study), irregular behaviour could be seen during the period 2009 to 2020. Between 2002 and 2016, the campus population showed a constant growth trend, with a peak of 21,779 inhabitants in 2016. However, from 2016 onwards, the population decreased until reaching 19,032 inhabitants in 2019 (the year of registration of the last population census of the campus) (Figure 7).

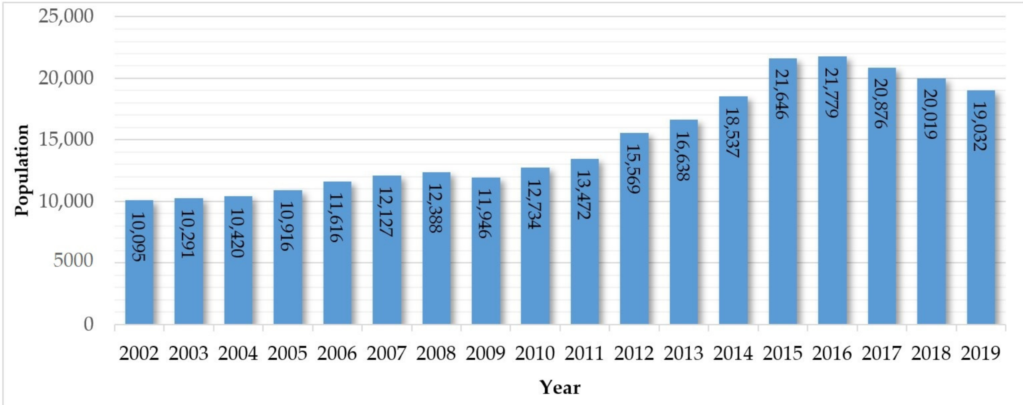

Figure 7. ESPOL historical population registry [53].

3.2. Sewerage and Treatment System

The campus has a sewer system that conveys the wastewater discharge of the current population. The system is connected to infrastructure that performs storage and treatment functions, comprising a WWTP-MBR, a WWTP-DAF, an activated sludge plant, two stabilisation ponds, and 16 septic tanks (Figures 8 and 9).

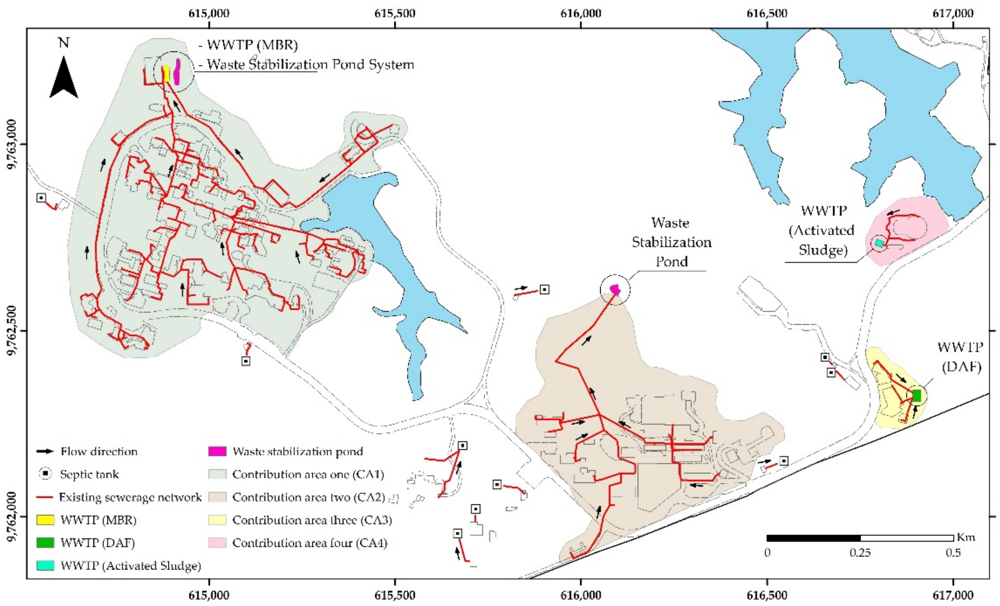

Figure 8. Existing sewerage system and final wastewater disposal.

According to the layout of the networks, there are four contributing areas. In contribution area one (CA1), most of the population is concentrated and includes the engineering faculties, administrative buildings, and sports and green areas. In contrast, contribution area two (CA2) is the second-most populated area because it contains the university's research centres, sports areas, public companies, and an educational institution belonging to ESPOL. On the outskirts of the campus is contribution area three (CA3), where the admissions building is located, with a considerable population because it receives those students who are taking a levelling period for access to the university. Finally, the fourth contribution area (CA4) corresponds to the Information Technology Centre—ITC, with a smaller population (Figure 8).

Figure 9. Existing on-campus wastewater treatment systems. (**a**) Membrane biological reactor wastewater treatment plant (WWTP-MBR), (**b**) engineering area stabilisation pond, (**c**–**e**) dissolved air flotation system (WWTP-DAF), (**f**) activated sludge wastewater treatment plant, (**g**) technology area stabilisation pond.

Based on the fieldwork and the information available on the operation of the wastewater treatment systems, it was determined that the MBR plant corresponded to the system with the largest capacity on campus, while the septic tanks represented the systems with the smallest treatment capacity based on their size (Table 2). In general, all systems require maintenance, improvements, and upgrades.

Table 2. Description of existing scrubber systems.

Area	Type of Treatment System	Description
CA1	Membrane biological reactor wastewater treatment plant (WWTP-MBR)	(a) It consists of 3 MBR units that operate 24 h a day. The incoming water is pumped from a double-chamber tank that supplies the lagoon system. The operating time is 6 h with a nominal capacity of 500 m^3/day. (b) The plant operates at 12% of its capacity. As a result, the system offers high percentages of total suspended solids (TSS), chemical oxygen demand (COD), and biochemical oxygen demand (BOD_5) removal. (c) In general, the plant requires maintenance. (d) The water treated by the plant complies with the maximum contaminant limits established by the TULSMA for discharge into freshwater bodies.
	Pond systems	(a) It consists of a maturation lagoon and a facultative lagoon that operate as a series system. The estimated volume of the facultative lagoon is 637.10 m^3, and of the maturation, the lagoon is 812.90 m^3. It is in a condition to continue operating with the appropriate improvements. (b) The lagoons' volume is generally insufficient to ensure hydraulic retention times for pollutant load removal. (c) During the rainy season, treated water from the MBR plant is discharged into the lagoon system, which decreases the retention time of the system and slows down its treatment process. (d) The system has specific overflow areas that do not comply with the maximum BOD_5 limit for discharge to freshwater bodies. (e) A lack of preliminary treatment to remove coarse solids hinders the treatment process.
CA2	Stabilisation ponds	(a) It has a low water level. (b) Dimensions of 20 × 25 m and a depth of 1.20 m. (c) Type of anaerobic lagoon with no preliminary treatment. (d) It requires an installation for taking samples and technical cleaning that allows observing the effluent outflow currently lost to vegetation. (e) Removal of vegetation in the centre of the lagoon. (f) It does not have a preliminary treatment system for removing coarse solids that slow down the treatment process.
CA3	Dissolved air flotation wastewater treatment plant (WWTP-DAF)	(a) It is operational and can increase the production of purified water. (b) The effluent presents favourable conditions for discharge to freshwater bodies.
CA4	WWTP—total oxidation activated sludge	Currently not operational.
The entire campus	Septic tank	They require cleaning and maintenance.

According to the analysis performed in the Avalos and Guerrero study [49], the concentration of TSS, COD, and BOD_5 of wastewater samples from CA1 was able to be estimated (Table 3).

Table 3. Characterization of wastewater samples from CA1.

Parameter	Unity	Concentration at the Entrance (Domestic Wastewater)	Outlet Concentration (Purified Effluent)	Current Use
TSS	mg/L	236	14	Lawn irrigation
COD	mgO_2/L	594	70	
BOD_5	mgO_2/L	350	60	

Based on previous studies, a set of technical proposals for improving and optimising treatment systems has been proposed (Table 4).

Table 4. Proposals for improvement of existing treatment systems.

Area	Type of Treatment System	Description
CA1	WWTP-MBR	(a) Repair and replacement of blowers and suction and recirculation pumps. (b) Complete replacement of all the membranes of the three bioreactors, including piping and fittings. (c) The metal tanks of the bioreactors show high corrosion and require a review of the thickness of the metal plates at different points of the system, with the corresponding repair or replacement recommendations [49].
	Pond systems	(a) Survey the dimensions of the stabilisation ponds to know the real volume of sewage that can be stored to determine the maximum influent that must be received to achieve sufficient retention times and acceptable pollutant load removal percentages. (b) Design of desander to protect the performance of the pumps and the treatment system. (c) Diversion of the MBR plant is treated water discharge, currently discharged into the lagoon system to a natural drainage point [49].
CA2	Stabilisation ponds	(a) Optimising the existing system, transforming it into a horizontal sub-surface flow wetland with the exact dimensions to comply with secondary treatment processes, where it was estimated that 80% of TSS and 31% of BOD_5 would be removed, complying with the parameters established in the standard. (b) Design a desander 4.40 m long, 1 m wide, and 2 m deep as a preliminary treatment so that 25% of TSS and 20% of BOD_5 will be removed, complying with the parameters established in the standard [54].
The entire campus	Septic tank	(a) Design a wastewater collection system to carry the water stored in the wells to the stabilisation pond located in CA2 (Figure 8). (b) Due to the new flow, an additional lagoon of dimensions 16 × 20 m with a depth of 1.20 m was designed (Figure 8) [50].

3.3. Population Projection

Due to the population decrease as of 2015, the trend of the projection methods used was compared with the population growth from 2002 to 2014. Based on the results obtained, the arithmetic and simple interest methods were the ones that best matched the historical growth. Through these methods, the average of both methods was equal to 24,698 inhabitants for 2035 (Figure 10), which corresponds to the design population.

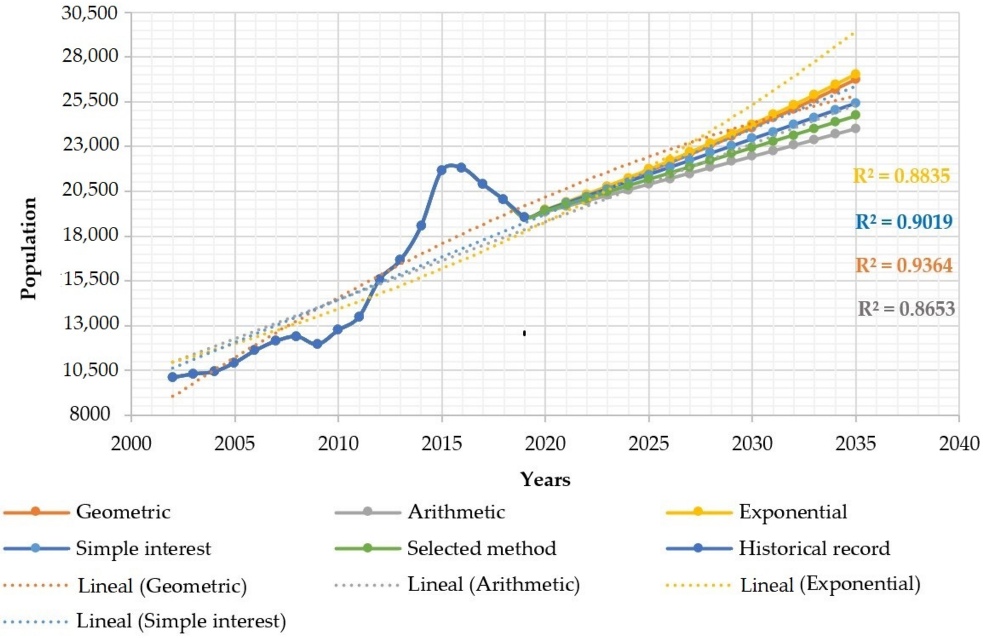

Figure 10. Population projection curve.

3.4. Definition of Expansion Areas

Not including the ZEDE zone, in 2019 the populated area was 14.80 ha, with a density of 28.92 person/ha, while for 2035 it was estimated to be 25.36 ha, with a density of 39.84 person/ha. Therefore, the required expansion area, obtained from the difference between the populated area of both years, was equal to 10.56 ha (Table 5).

Table 5. This is a table. Tables should be placed in the main text near the first time they are cited.

Zone	Year 2019				Year 2035			
	Population	Delimited Area [ha]	Populated Area [ha]	Green Area [ha]	Population	Delimited Area [ha]	Populated Area [ha]	Green Area [ha]
Total ZEDE	93	133	2.57	130.43	1517	133	46	87
Total ESPOL	18,935	524.99	14.80	510.19	24,699	524.99	25.36	499.63
Total	19,028	657.99	17.37	640.62	26,216	657.99	71.36	586.63
Density [people/ha]	28.92				39.84			

Considering the limitations of the protected areas, topography, proximity to access roads, and the availability of essential services, three expansion zones of 7.04, 2.56, and 1.07 ha were located, corresponding to expansion zones 1, 2, and 3 (EA1, EA2, EA3), respectively (Figure 11). The three zones total 10.61 ha, and their occupation is proposed in 5, 10, and 15 years.

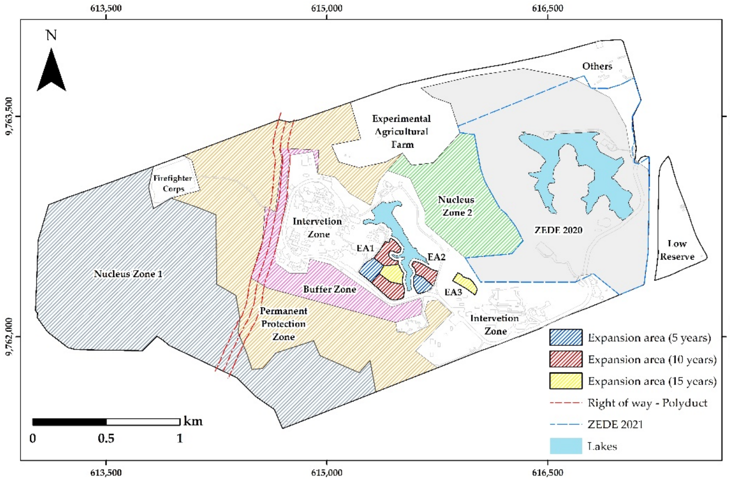

Figure 11. Location of expansion areas restricted by protected zones.

3.5. Sewerage Design in Expansion Areas

With an initial endowment of 50 L/inhab·day, it was considered that for each year of the design period (15 years), the endowment increases at a rate of 1.5%. Finally, the projected endowment resulted in 62.5 L/inhab·day for 2035 (Table 6).

Table 6. Parameters for the calculation of design flow rates.

Expansion Zone	Endowment	Coefficient of Return (CR)	Population	Area	Coefficient of Manning (n)
1	62.5	0.8	3760	7.04	0.013
2–3	62.5	0.8	1914	3.57	0.013

The design flow rates for EA1 were calculated based on the endowment values in Table 6, obtaining a maximum flow rate equal to 0.0124 m^3/s (Table 7). The hydraulic design of the network was checked through the parameters of minimum slope (S), which fluctuates between 0.015 and 0.030 m/m, flow velocity (v), with a range between 0.72 and 0.94 m/s, and the tractive force (τ) between 5.44 and 6.67 N/m^2. Diameters of Ø200 mm were obtained for both systems (Table 8).

Table 7. Design flow rates for expansion zone 1.

Segment		Population	Q_{avg} (L/s)	F	Q_{max} (L/s)	Q_{inf} (L/s)	Q_{illi} (L/s)	Q_{des} (L/s)	Q_{des} (m^3/s)
MN-1	MN-2	518	0.45	3.97	1.78	0.097	0.097	1.98	0.0020
MN-2	MN-3	940	0.82	3.82	3.11	0.176	0.176	3.47	0.0035
MN-3	MN-4	1597	1.39	3.66	5.07	0.299	0.299	5.67	0.0057
MN-4	MN-5	2142	1.86	3.56	6.62	0.401	0.401	7.43	0.0074
MN-5	MN-6	2729	2.37	3.48	8.24	0.511	0.511	9.26	0.0093
MN-6	MN-7	3263	2.83	3.41	9.66	0.611	0.611	10.88	0.0109
MN-7	MN-8	3760	3.26	3.36	10.96	0.704	0.704	12.37	0.0124

MN, manhole; Q_{avg}, average flow; Q_{max}, maximum flow (considers a major factor); Q_{inf}, infiltration flow; Q_{illi}, illicit flow; Q_{design}, design flow.

Table 8. Design of the sewerage system in expansion zone 1.

Segment		Length (m)	Q_{des} (m^3/s)	S (m/m)	$Ø_{des}$ (m)	$Ø_{ext}$ (m)	$Ø_{int}$ (m)	v (m/s)	τ (N/m^2)	Auto Cleaning $v_{min} \geq 0.6$	Auto Cleaning $τ \geq 1.2$	Non Erosion $v_{max} \leq 2.5$
MN-1	MN-2	97.38	0.0020	0.030	0.06	0.24	0.2	0.72	5.44			
MN-2	MN-3	94.78	0.0035	0.019	0.08	0.24	0.2	0.73	4.94			
MN-3	MN-4	94.23	0.0057	0.020	0.09	0.24	0.2	0.84	6.18			
MN-4	MN-5	104.56	0.0074	0.010	0.11	0.24	0.2	0.71	3.97	OK	OK	OK
MN-5	MN-6	58.02	0.0093	0.015	0.12	0.24	0.2	0.86	5.75			
MN-6	MN-7	58.02	0.0109	0.011	0.13	0.24	0.2	0.81	4.96			
MN-7	MN-8	64.02	0.0124	0.015	0.13	0.24	0.2	0.94	6.67			

$Ø_{des}$, design diameter; $Ø_{ext}$, external diameter; $Ø_{int}$, internal diameter.

The capacity of the existing sewer network that continues from manhole MN-8 (the existing connection well that receives the discharge from EA1) to WWTP-MBR was verified. As a result, the diameter required to supply the current and future demand fluctuates between 130 to 147.4 mm (Table 9). On the other hand, the diameter of the pipes downstream of MN-8 is Ø200 mm and was verified by fieldwork. Additionally, the hydraulic design of the system was reviewed according to the values of slope, velocity, and tractive force (Table 10).

Table 9. Capacity of the pipeline connecting to the sewerage network of EA1.

Segment		$Q_{existing}$ (L/s)	$Q_{additonial}$ (L/s)	Q_{Total} (L/s)	$Ø_{calculated}$ (mm)	$Ø_{existing}$ (mm)	Complies	$Ø_{adopted}$ (mm)
MN-8	MN-9	1.65	12.98	14.63	130.0			
MN-9	MN-10	3.14	12.98	16.12	146.9			
MN-10	MN-11	3.15	12.98	16.13	147.0	200	OK	200
MN-11	MN-12	3.20	12.98	16.18	147.1			
MN-12	MN-13	3.28	12.98	16.26	147.4			

Table 10. Hydraulic parameters of the pipeline connecting to the sewerage system of EA1.

Segment		S (m/m)	v (m/s)	τ (N/m^2)	Auto Cleaning $v_{min} \geq 0.6$	Auto Cleaning $τ \geq 1.2$	Non Erosion $v_{max} \leq 2.5$
MN-8	MN-9	0.0095	1.09	4.28			
MN-9	MN-10	0.006	0.95	3.05			
MN-10	MN-11	0.006	0.95	3.05	OK	OK	OK
MN-11	MN-12	0.006	0.95	3.05			
MN-12	MN-13	0.006	0.95	3.05			

The same procedure was followed for designing the sewerage network in EA2-3. First, based on Table 6, the design flow rates were calculated, obtaining a maximum flow rate of 0.0067 m^3/s (Table 11). Then, with the parameters of the slope, velocity, and tractive force, whose values fluctuate between 0.009 to 0.001 m/m, 0.63 to 0.69 m/s, and 3.36 to 3.77 N/m^2, the hydraulic design of the system was carried out (Table 12).

Table 11. Design flow rates for expansion zones 2 and 3.

Segment		Population	Q_{avg} (L/s)	F	Q_{max} (L/s)	Q_{inf} (L/s)	Q_{illi}(L/s)	Q_{des} (L/s)	Q_{des} (m^3/s)
MN-14	MN-15	1340	1.16	3.71	4.32	0.25	0.25	4.82	0.0048
MN-15	MN-16	1340	1.16	3.71	4.32	0.25	0.25	4.82	0.0048
MN-16	MN-17	1914	1.66	3.60	5.98	0.36	0.36	6.70	0.0067
MN-17	MN-18	1914	1.66	3.60	5.98	0.36	0.36	6.70	0.0067

Table 12. Design of the sewerage network in expansion zones 2 and 3.

Segment		Length (m)	Q_{des} (m^3/s)	S (m/m)	$Ø_{des}$ (m)	$Ø_{ext}$ (m)	$Ø_{int}$ (m)	v (m/s)	τ (N/m^2)	Auto Cleaning $v_{min} \geq 0.6$	Auto Cleaning $\tau \geq 1.2$	Non Erosion $v_{max} \leq 2.5$
MN-14	MN-15	94.1	0.0048	0.01	0.097	0.22	0.2	0.63	3.36	OK	OK	OK
MN-15	MN-16	95.03	0.0048	0.01	0.097	0.22	0.2	0.63	3.36			
MN-16	MN-17	98.29	0.0067	0.009	0.112	0.22	0.2	0.66	3.44			
MN-17	MN-18	75.24	0.0067	0.01	0.110	0.22	0.2	0.69	3.77			

Likewise, the capacity of the existing sewerage network from manhole MN-18 (the existing connection well that receives the discharge from EA2-3) to the CA2 stabilisation pond was reviewed. The diameter required to supply the current and future demand ranges from 153.9 to 200 mm (Table 13). Finally, the hydraulic design was reviewed through slope, velocity, and tractive force (Table 14).

Table 13. Capacity of the pipeline connecting to the sewerage network of EA2-3.

Segment		$Q_{existing}$ (L/s)	$Q_{additonial}$ (L/s)	Q_{Total} (L/s)	$Ø_{calculated}$ (mm)	$Ø_{existing}$ (mm)	Complies	$Ø_{adopted}$ (mm)
MN-18	MN-19	19.10	6.70	25.8	200	200	OK	200
MN-19	MN-20	19.10	6.70	25.8	162.4			
MN-20	MN-21	19.10	6.70	25.8	162.4			
MN-21	MN-22	19.10	6.70	25.8	153.9			
MN-22	MN-23	19.10	6.70	25.8	153.9			

Table 14. Hydraulic parameters of the pipeline connecting to the sewerage system of EA2-3.

Segment		S (m/m)	v (m/s)	τ (N/m^2)	Auto Cleaning $v_{min} \geq 0.6$	Auto Cleaning $\tau \geq 1.2$	Non Erosion $v_{max} \leq 2.5$
MN-18	MN-19	0.003	0.84	2.05	OK	OK	OK
MN-19	MN-20	0.009	1.27	4.97			
MN-20	MN-21	0.009	1.27	4.97			
MN-21	MN-22	0.012	1.40	6.35			
MN-22	MN-23	0.012	1.40	6.35			

Figure 12 shows the location of the proposed sewer networks for the expansion areas and the connection point to the existing sewer network.

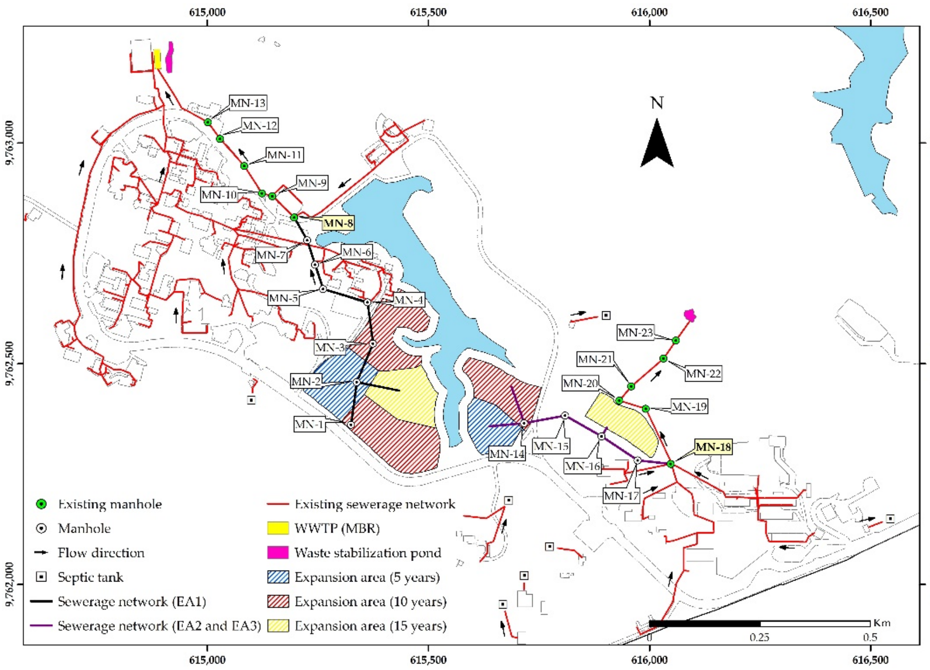

Figure 12. Sewerage networks for expansion zones 1, 2, and 3.

The capacity of the WWTP-MBR to meet the additional demand generated by the sewerage network proposed for EA1 was also analysed. For this purpose, two scenarios were considered:

- Scenario 1: EA1 average flow vs. plant capacity during 6 h of operation.
- Scenario 2: EA1 design flow vs. plant capacity during 6 h of operation.

Considering the endowment and return coefficient values in Table 6 and the fact that the campus maintains 16 h of activity, the values of average flow (from CA1) and design flow (from EA1) were calculated to analyse the proposed scenarios (Tables 15 and 16). However, for capacity analysis during the day, the WWTP-MBR, due to each pump's startup and shutdown processes, has a total operating time of 6 h per day; therefore, this net operating period was taken.

Table 15. CA1 input flow rate.

Endowment [L/hab·day]	CR	Population	Operating Time	Q_{med}	
				[L/s]	[m^3/h]
62.50	0.80	10254	16	8.90	32.04

Table 16. Contribution flows from the EA1 area.

Population	Operating Time [h]	Q_{med} (L/s)		F	Q_{max} (L/s)	Q_{inf} (L/s)	$Q_{ilicito}$ (L/s)	Q_{desing} (L/s)	Q_{desing} (m^3/s)
		[L/s]	[m^3/h]						
3760	16	3.26	11.74	3.36	10.95	0.704	0.704	12.36	44.50

Based on the future flow, the capacity at which the plant would be operating for both scenarios during its net operation period was determined, obtaining the highest capacity for scenario two (91.90%) (Table 17).

Table 17. MBR plant capacity.

Parameters	Scenario 1	Scenario 2
Average flow rate value of CA1 year 2019 [m^3/h]	0.80	10,254
Value of the average flow rate of EA1 [m^3/h]	11.74	-
Value of the design flow rate of EA1 [m^3/h]	-	44.50
Future flow rate [m^3/h]	43.78	76.54
WWTP-MBR Capacity [m^3/h]	83.30	83.30
Capacity at which the WWTP-MBR would operate	52.50%	91.90%
WWTP-MBR wasted capacity	47.50%	8.10%

In the case of the sewerage network for EA2-3, which connects to the CA2 lagoon, based on the estimates made by the studies of Arias Vivanco and Fernández Cuesta [50] and Quiñonez Zambrano and Vintimilla Peña [54] on the lagoon located in CA2, based on the hydraulic retention time, it was determined that it did not have sufficient capacity to meet current and future demand (Table 18).

Table 18. Hydraulic retention times of the stabilisation pond located in CA2.

Study	Situation	Flow [m^3/day]	Length [m]	Width [m]	Water Mirror Depth [m]	Volume [m^3]	Retention Time [Days]	Minimum Retention Time [Days]
Quiñonez & Vintimilla [54]	Existing	1215.24	25	20	1.20	600	0.5	1–5
Arias & Fernández [50]	Additional	1972.54	25	20	1.20	600	0.3	1–5
Case study	Expansion	2489.40	25	20	1.20	600	0.2	1–5

3.6. SWOT Analysis

The SWOT analysis used in this study made it possible to establish specific strategies for the existing sanitation system (Table 19) through the combination of internal and external characteristics that include management, design, environmental, financial, academic, and social aspects. As a result, the proposed strategies will make it possible to manage wastewater, minimising the environmental impact sustainably. Specifically, the analysis provided by the three focus groups establishes as the primary strategy the contribution of academia in projects to optimise the existing sanitation system, guaranteeing water reuse for irrigation.

Table 19. Strengths, weaknesses, opportunities, and threats (SWOT) matrix analysis of current and proposed sewer system. The SWOT combines the internal environment (strengths and weaknesses) identified by numbers 1 to 4 and the external environment (opportunities and threats) identified by letters (a) to (d).

Internal Environment / External Environment	Strengths	Weaknesses
	1. The current system contemplates sufficient infrastructure to supply the campus wastewater discharge. 2. There are various types of treatment systems. 3. Interaction of academia and research centres to optimise the current systems. 4. Environmental management plans.	1. Age of the transport and treatment infrastructures. 2. Poor maintenance. 3. Designs without considering future scenarios. 4. Overflow of treatment systems. 5. Limited budget for operation and maintenance.

Table 19. *Cont.*

Internal Environment / External Environment	Strengths	Weaknesses
Opportunities	**Strategies: Strengths + Opportunities**	**Strategies: Weaknesses + Opportunities**
a. Ability to redesign sewer networks for future scenarios. b. Undergraduate and graduate studies for the optimisation of treatment systems, c. Reuse of treated water. d. Models of liquid waste management replicable in other universities.	1.a. Redesign of pipelines in areas identified with hydraulic problems. 2.c. Design irrigation systems that use treated water. 3.a.b. Develop studies for the establishment of innovative and sustainable techniques in the transport and treatment of wastewater. 4.d. Develop wastewater management campaigns at the institutional and inter-institutional levels.	1.3.b. Repower treatment systems to meet current and future demand. 2.c. Propose effective operation and maintenance (OPEX) plans to reuse water safely. 5.a. Establish cooperative alliances for financing redesign and repowering projects.
Threats	**Strategies: Strengths-Threats**	**Strategies: Weaknesses-Threats**
a. Leaks in pipes or overflows in treatment systems. b. Environmental contamination due to possible leaks or infiltrations. c. Low percentage of removal in lagoons due to insufficient retention time. d. Degradation of pipe material due to lack of maintenance.	1.d. Use of appropriate materials for the fulfilment of the useful life of the project. 3.c. Carry out undergraduate projects that contemplate the evaluation of the capacity of the treatment systems. 4.c. Carry out periodic water quality analyses at the inlet and outlet of the systems.	2.b. Conduct evaluation studies of the lagoon isolation system to prevent infiltration. 3.b. Conduct workshops on the most common problems in sewerage systems due to a lack of user knowledge. 3.c. Implement tertiary treatment to limit the discharge of nutrients to water bodies, e.g., the use of green filters.

4. Discussion

This study raises the possibility of achieving sustainable development by starting with the elaboration of a master plan that—based on an evaluation and diagnosis of the existing situation—foresees whether or not the current infrastructure will be able to meet the future demands of wastewater production and its treatment before being discharged into the environment. Better yet, it proposes that these effluents be used sustainably in the irrigation of gardens, for example, in the extensive green areas that the ESPOL campus has, promoting the circular economy of water.

According to the population projection, ESPOL will increase to 24,698 inhabitants in 2035. Therefore, the plan includes three expansion areas (EA1, EA2 and EA3), totalling 10.61 ha, corresponding to three development phases of 5, 10, and 15 years. For this, the design of the sewer network complies with the technical and regulatory criteria in terms of speed, slope, and tractive force to avoid sedimentation and erosion problems as stipulated in this design [55]. Likewise, these zones were in the sites with the most negligible impact on the protective forest environment, delimited by the buffer zones defined by the physical infrastructure management (GIF).

The MBR plant supplies the current and future capacity fully; however, it requires maintenance and equipment replacement to improve pollutant removal efficiency. In addition, the anaerobic lagoon (in design, but not in implementation) located in CA2, due to the low level of the water mirror, should be wholly redesigned as proposed by some initiatives that did not include the contribution of the EA3 [50,54]. Currently, these anaerobic systems are usually avoided for domestic wastewater because they do not have high levels of pollutant load [56–58]. On the other hand, these systems are very effective in industrial processes [59,60]. However, considering that the pollutant load of CA2 is very low, a viable alternative could include the implementation of a subsurface horizontal flow lagoon as proposed by [54]. Population projections in land design and planning studies do not always reflect the actual behaviour of urban development, resulting in inefficient designs with excess capacity and high operating costs [61–63]. Therefore, the construction of new treatment systems or the adaptation of existing systems, when developed in stages, would reduce operation and maintenance costs, in addition to guaranteeing operation in future scenarios [64–66].

The master plan of this study is reinforced by the SWOT analysis, which contemplated the proposal of corrective, preventive, and predictive strategies for the existing sanitation system's short, medium, and long term. Specifically, the analysis conducted by the three focus groups determined that the existing sanitation system requires optimisation activities for future scenarios and preventive maintenance of infrastructure. Of the proposals put forward, the following stand out:

- Conduct evaluation studies of the sewerage system and treatment systems for the establishment of sustainable techniques in the management of wastewater, which supply the current and future demand, promoting the sustainable development of the campus.
- Promote effective water reuse through tertiary treatment systems, which contemplate the installation of green filters for future irrigation plans and agricultural experimentation. Unconventional treatments, such as nature-based treatment systems, represent efficient tools in wastewater purification with low implementation, operation and maintenance costs, as well as limited energy use [67–69]. Within these systems, the vegetation filters and soil application system or commonly called green filters, allow reaching levels of purification suitable for the reuse of water [70,71], through mechanisms of absorption in the soil, biodegradation and absorption by plants, processes responsible for eliminating contaminants in the water [72,73].
- Develop educational workshops on sustainable water management at the institutional and inter-institutional levels.
- Establish academic–business cooperation alliances to promote research and financing for projects that seek to implement the circular water economy.
- It is proposed that treated wastewater be used for irrigation of green areas and for studying crops in the area of the university's Agricultural Experimental Farm due to its nutrients [74].
- Provide the opportunity for students and other professionals to research the consumption of products produced from treated wastewater [37,75–77].

This methodology can be replicated in other universities and at the urban level because it promotes wastewater management and seeks the alternative of more environmentally friendly treatment systems [78,79]. In addition, this is aesthetically appealing as it can boost recreational and academic activities [80,81]. This type of study is widely employed in such countries as Bali [82], Indonesia [83], the USA [84], Tanzania [85], China [86], Vietnam [87], and Ecuador [88].

The rural areas of Ecuador are characterised by the absence of sanitary systems that guarantee the transportation and purification of wastewater (e.g., [89–94]). In many cases, it is discharged directly into bodies of water, polluting the environment and compromising the health of the inhabitants and ecosystems. Few studies have focused on improving the country's sanitary system at the rural level (e.g., [55,95–97]). However, they serve as management models that can be executed at the municipal level with individual plans for prevention, mitigation, and correction of environmental impact. Considering that one of the productive axes of Ecuador is agriculture, future studies could include the implementation and optimization of purification systems that guarantee their use in irrigation systems for the productive sector, promoting the sustainability of water resources.

According to UI Green metric World University Ranking, ESPOL is among the green universities in the world, being the first at the national level [98], so the contribution of this research provides a management tool that promotes the sustainable use of water, opening the possibility of obtaining a higher ranking. On the other hand, considering that the university campus has sites of relevant geological interest that can be used in geo-education strategies [99], sustainable wastewater management will serve as a geoconservation strategy. Therefore, implementing the proposed design will minimise environmental contamination, avoid the degradation of geosites and sites of natural interest [100,101], and guarantee good conditions for geo-tourism and geo-educational activities.

Furthermore, this contributes to training young professionals who are more aware of sustainability [98,102]. Young people are the real drivers and architects of the change of paradigms on this planet and can effectively manage to protect a valuable and irreplaceable resource, such as water on Earth.

5. Conclusions

ESPOL, located in southwest Ecuador, is an example of a university campus that must strengthen its health system to supply future scenarios. This study developed a master plan that defines the location of future expansion zones complemented by the existing wastewater transportation system, as well as medium- and long-term improvement strategies that ensure the hydraulic performance of the sewer network and effective treatment processes.

As a result, the design and proposals established in this study highlight three main aspects:

(i) The sewerage system for the proposed EAs will be made up of 200 mm diameter pipes that will supply a maximum flow of 12.37 L/s for a design period of 15 years. The new discharge generated will be connected to two existing inspection wells, connected by pipes with adequate dimensions, guaranteeing the transport of residual water to the treatment systems.

(ii) From the existing treatment systems, the WWTP-MBR and the adjoining pond system in CA1, together with the stabilisation pond located in CA2, will receive the new discharge from the proposed systems. Therefore, the evaluation of these systems, together with the SWOT analysis, included preventive, corrective, and predictive strategies: (i) evaluation of the capacity of the treatment systems, (ii) permanent analysis of water quality that guarantees the required removal percentages, and (iii) implementation of tertiary treatment systems that contemplate the effective reuse of water.

(iii) The importance of the master plan is that it allows the identification of problems associated with poor management and improves it through a comprehensive management model that provides solutions based on technical and sustainable criteria, being the innovative part that opens the opportunity for studies carried out by the same students under the supervision of professionals; allowing to strengthen learning.

Finally, this study demonstrates that joint participation among academia, research, and authorities allows the efficient management of wastewater, promoting the circular economy in a context of sustainability.

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