DRINKING WATER MASTER PLAN FOR THE MANAGEMENT OF WATER RESOURCES ON A UNIVERSITY CAMPUS

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ABSTRACT

Drinking water is an indispensable resource for human activities and health; therefore, it must be appropriately managed. The university campus of the Escuela Superior Politécnica del Litoral (ESPOL), since it was inaugurated in 1991, has been implementing various drinking water distribution systems that not being subject to a master plan, have led to present problems to the point of requiring a redesign. This study aims to elaborate the drinking water master plan by analyzing the existing situation and applying technical-sustainable criteria to efficiently manage the current and future water resources of a university campus. The methodology consists of: (i) data collection and processing for assessment and diagnosis, (ii) design of technical proposal, (iii) preparation of environmental analysis and reference budget. The proposal contemplates the supply for 5,667 inhabitants over 15 years in a strategically selected area, which includes the management of a model based on the circular economy. Therefore, the project was environmentally and economically viable for campus expansion purposes.

Keywords: water resources, circular economy, water supply, reservoir, water management.

1 INTRODUCTION

Freshwater represents only 2.5% of the available water on the planet [1] and is considered a priority resource due to its importance for life. However, in recent years, population growth and climate change have generated a shortage of this resource in various world regions [2]. Likewise, inadequate water management has contributed to water stress scenarios [3]. Faced with these conditions, efficient water resource management strategies must face current and future challenges [4], [5]. The provision of water resources for the growing population of urban areas has been a significant challenge in recent years [6], [7]. The world's urban population is projected to grow from 3.4 billion in 2009 to 6.3 billion people in 2050 [8]. Due to the population increase new urban areas with a greater water demand will appear, and the need to optimize the infrastructures of the urban water cycle for better use of water resources is essential [9]–[11].

The urban water cycle (UWC) comprises different stages, from collecting water to its discharge into the environment after use [12]. Firstly, the water is extracted from the surface or underground and transported to the drinking water treatment plant (DWTP), where it is treated to reach the necessary quality to be suitable for consumption [12]. Then, it is transported through the leading system (transportation) and the secondary system (distribution) to the points of consumption in the urban area [13]. Once in the urban area, the water is used for consumption, domestic uses, and various activities (for example, industry, services). Finally, after use, the water is collected and transported to the wastewater treatment plant, reaching the necessary quality to be released back into nature [14].

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Transportation and distribution systems guarantee water reaches consumers with adequate quality and pressure. However, the contamination of freshwater sources by human activities affects the effectiveness of these types of systems (e.g., toxic waste, organic and inorganic) [15], causing water quality failures of transport and distribution systems (e.g., biofilms, microorganisms, chemical leaching, among others) [16]. On the other hand, climate change poses many risks to human health, among which the supply of safe drinking water (DW) is a global problem [17]. The Intergovernmental Panel on Climate Change (IPCC) notes that drought, increased precipitation, higher temperatures, and more frequent natural hazards will affect the availability and quality of DW [18]. All these factors affect water supplies and have consequences on treatment conditions, production and distribution of DW [19].

The effects produced by anthropic activity and climate change compromise the quality and safety of DW, increasing costs in DW treatment plants. According to Heberling et al. [20], municipalities and DW treatment plants are faced with the need for DW treatment cost-saving approaches to meet consumption standards. On the other hand, a considerable part of the DW is wasted without any use due to water losses, categorized as bottom losses, overflows and leaks [21]. Given these scenarios, finding new resources or expanding the existing system is an alternative that generally implies a physical and economic burden.

In addition to these alternatives, studies aim to improve the management of water supply and distribution systems. The basis for this type of management is a master plan, defined as a comprehensive set of strategies that contemplate a series of actions (e.g., analysis of the situation, declaration of objectives, evaluation of alternatives, implementation, and follow-up) to give a solution to a problem in the short, medium and long term [22]. Just as municipalities require adequate planning to supply water to their population, universities must supply drinking water to their community and adapt their facilities to be sustainable over time so that water resource management is efficient. Therefore, implementing a master plan is ideal [23], [24].

Escuela Superior Politécnica del Litoral (ESPOL) in Ecuador has an approximate area of 658 ha and a population of 19,032 inhabitants in 2019. Currently, ESPOL has a DW system that includes five 200 m^3 reservoirs in the low reserve, 1,000 m^3 in the high reserve, approximately 12.30 km of pipes in the distribution system, and 1.7 km in the discharge line. However, considering the increased demand for water due to the constant increase in the student population, the need arises to implement a master plan that allows for improving, optimizing, and innovating the institution's DW systems, guaranteeing safe expansion in the medium and long term.

This study aims to prepare the DW master plan through the analysis of the existing situation and the application of technical-sustainable criteria, which allows the identification and mitigation of possible problems in the current system, as well as sustainable and affordable strategies that improve the efficient management of current and future water resources on the university campus.

2 MATERIALS AND METHODS

The methodology consists of three work phases: (i) data collection and interpretation, (ii) technical proposal design and (iii) environmental analysis and reference budget (Fig. 1).

2.1 Stage I: Data collection and interpretation

The first stage of the study addresses the collection and review of existing information (e.g., reports, theses, plans) related to topics such as: drinking water distribution, topography, soil

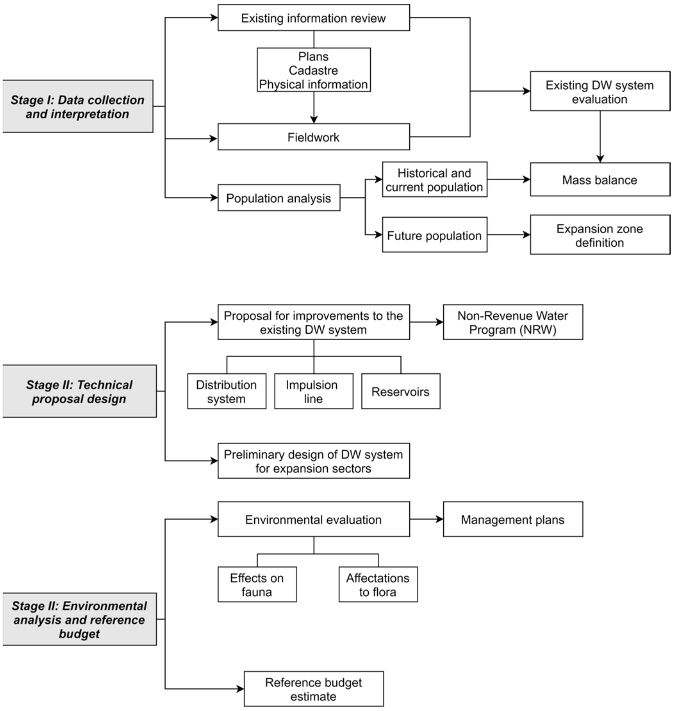


Figure 1: General method of the study.

type, climate, flora, and fauna of the studied area. The development of fieldwork together with the information collected allows determining the main characteristics of the current drinking water system, for example: reservoirs number and capacity; characteristics of the design and condition of the water transport-distribution pipes, pressure pipe, and characteristics of the medium through which the pipes pass; among others.

This phase also contemplates a mass balance analysis in which water consumption has been compared in a known range of years (2017–2020), considering 262 campus working days. This analysis compares a specific provision for this type of consumer against the volume of water consumed by the population in the same period, which allows for quantifying the system's losses.

To complement this information, the projection of the future population (design population) of the university campus was carried out through four methods (geometric, arithmetic, exponential, and simple interest) that will allow knowing the behaviour of the population that will be supplied with drinking water for the established design period (15 years). The method that best represents the historical behaviour of the growth of the studied population was selected. Finally, the new expansion areas and their location are proposed, considering the projection of the selected population growth, water consumption, and natural protection zones.

2.2 Stage II: Technical proposal design

For this phase, local regulations have been considered, represented by the Código de Práctica Ecuatoriana del Instituto Ecuatoriano de Normalización (CPE INEN 005-9-1) [25], plus the application of sustainability criteria. Different proposals focused on distribution systems, pressure pipe and reservoirs are proposed to improve the DW system with short-, medium- and long-term actions. In addition, the preliminary design of the DW system for the expansion sectors of the campus is also carried out. The population analysis of phase one, a design period of 15 years, is used in such a way as to ensure the efficiency of the system and endowment, among others (Fig. 2). For the water system design, the WaterCAD program was used, with which the optimal diameters were obtained, and it was verified that there is adequate pressure at all points of the system to provide an excellent service to users.

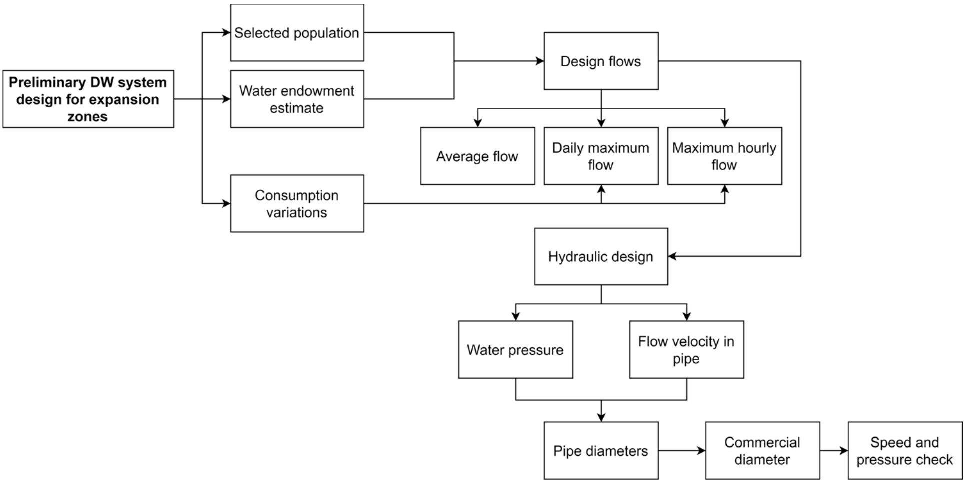


Figure 2: Parameters considered for the design of the DW system.

2.3 Stage III: Technical design and reference budget

The study concludes with the environmental analysis and the estimation of the referential budget. The environmental analysis considers environmental factors, the physical environment (climate, geomorphology, and altitude), the biotic environment (flora and fauna), and the socioeconomic and cultural environment (current population and future population); to identify the possible impacts generated due to the different activities contemplated by the execution of the project. Once the impacts generated have been identified, the project uses the del Sistema Único de Planificación Ambiental (SUIA) to propose mitigation plans based on preventive and corrective measures, whose objective is to preserve the protection zones and the intervened zone.

Likewise, a unit price analysis (UPA) is carried out based on the costs provided by the campus and those proposed in the magazine of the Cámara de la Construcción de Guayaquil [26]. For labour costs, the salaries proposed by the Contraloría General del Estado (CGE) [27] have been considered, and the yield values for each item were obtained from the web platform of the Servicio Nacional de Contratación Pública (SERCOP). These costs were grouped into two types: direct (labour, materials and equipment used) and indirect (control payment, utilities, administrative expenses, among others).

Finally, the budget calculated for the execution of the project included the expenses required for the prevention and mitigation measures of the environmental impact, obtaining a total referential budget.

3 RESULTS

3.1 Existing DW system evaluation and population analysis

The area is located on the Cordillera Chongón-Colonche, with elevations from 25–380 meters 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” protective forest, which includes a diversity of flora (ceibo, carob, pechiches, among others) and fauna (birds, iguanas, squirrels, sloths, among others) [28]. The area has an average temperature of 26°C, with two seasons: summer (June to December) and winter (January to May), with less than 2,000 mm annual rainfall [29]. The study area in the intervened zone has high and low sectors, which allow the pressurization of the system to take advantage of the potential energy given by the difference in elevations.

The existing drinking water system is made up of a Ø200 mm pressure pipe that transports water from the low reserve, made up of five tanks with capacities of 200 m^3 located outside the campus, to the 1000 m^3 elevated tank located inside the campus. Gustavo Galindo Campus by pumping. Additionally, the system has a main or conduction line, with diameters that vary from Ø25 to Ø400 mm, distributing the water from the elevated tank to the system using gravity. However, this line does not supply the admissions area. The pressures of the existing system vary from 13 meters of water column (m.w.c.) to 114 m.c.a., which averages a pressure of 42.2 m.w.c., while the flow speed varies from 0.003 m/s to 1.14 m/s, which average a speed of 0.25 m/s.

The study carried out by López Alaña and Zambrano Figueroa [29] evaluated the existing system, determining excessive pressures at specific system points. Local regulations establish that valves must be placed to control the pressure in those points of the pressure system higher than 50 m.w.c. The highest pressures occurred at those points of connection with the mainline.

From the execution of educational policies in 2009, irregular growth of the student population was evidenced until 2020 (Fig. 3). Therefore, for the population projection methods carried out until 2035, the growth trend of the period 2002 to 2009 was compared. Based on the results obtained, the arithmetic and simple interest methods are the ones that best fit the historical growth. Therefore, the final population projection resulted from the average between the two selected methods, with a design population of 24,698 inhabitants (Fig. 3).

Subsequently, water consumption was analyzed from 2017 to 2020, where it was found that the average consumption in that period was 37%, compared to a loss percentage of 63%. (Table 1).

Table 2 considers all populated sites in 2019 and their projection to 2035. In 2019, the populated area was 14.80 ha without including ZEDE, with a density of 28.92 hab/ha. In 2035 the required expansion area is 10.56 ha, which results in 25.36 ha with a population density of 39.84 hab/ha.

Three expansion zones were located within the Gustavo Galindo campus based on the required area, covering 10.61 ha. The location of the zones was defined within the intervened zone (area with existing infrastructures) to promote the conservation of the zones corresponding to the protective forest of the university campus. Additionally, work was done to estimate the occupation of the areas for 5, 10 and 15 years (Fig. 4).

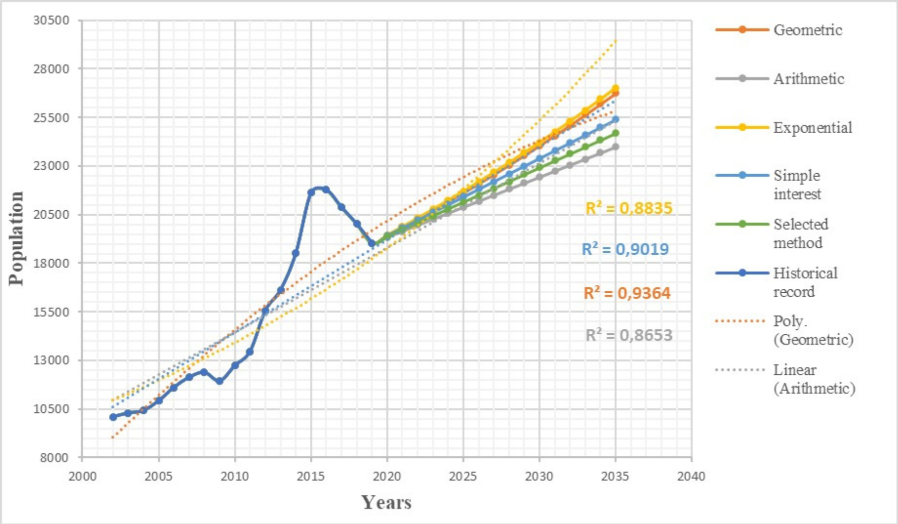


Figure 3: Population projection curve.

Table 1: Mass balance.

Year	Population	ESPOL annual consumption (m^3)	Consumption by endowment (l/hab*day)		Losses (wrong use)	
2017	20,876	272,140	104,943	39%	167,196	61%
2018	20,046	338,849	100,265	30%	238,584	70%
2019	19,032	278,899	97,061	35%	181,837	65%
2020	18,207	215,564	94,293	44%	121,270	56%
Average		276,363	99,141	37%	177,222	63%

Table 2: ESPOL population and populated area.

		Year 2019				Year 2035			
Zone	Sector	Pop.	Delimited area (ha)	Populated area (ha)	Green area (ha)	Pop.	Delimited area (ha)	Populated area (ha)	Green area (ha)
Total ZEDE		93	133	2.57	130.43	1,517	133	46	87
Total ESPOL		18,935	524.99	14.8	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 (hab/ha)		28.92				39.84			

3.2 DW system design for expansion areas

For the proposed expansion zones 1E, 2E, and 3E, a drinking water system was designed with Ø50, Ø32, and Ø25 mm pipes, respectively (Fig. 4). The total length of the pipe system that will supply the three expansion zones is 1,254.67 m. The parameters obtained for flow, consumption, velocities, diameters, and pressures are detailed in Table 3. A consumption coefficient of 1.40 and 2.00 was used to calculate maximum daily and maximum hourly flows.

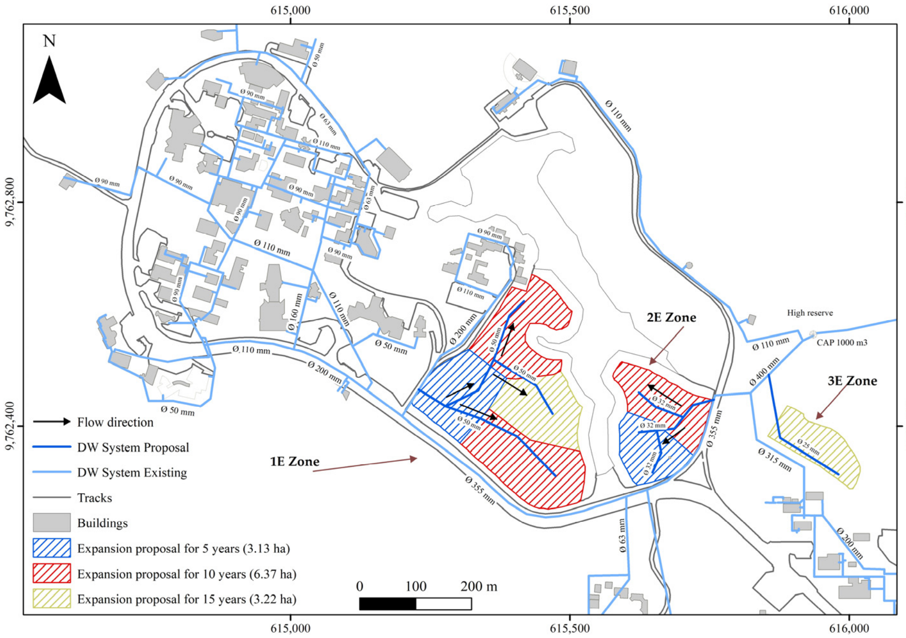


Figure 4: Map of existing DW system and proposed system for expansion areas.

Table 3: Parameters calculated for the design of the drinking water system.

Z	A (ha)	P	De	Q_{med} (l/s)	Q_{md} (l/s)	Q_{mh} (l/s)	Cd(mm)	Pr (mca)	Id (mm)	L (m)	Speed range (m/s)			RC
											V_{min}	V_{med}	V_{max}	
1E	7.04	3,760	62.5	2.72	3.81	5.44	50	63	47.4	688.7	1.54	2.16	3.08	OK
2E	2.50	1,335	62.5	0.97	1.35	1.93	32	80	29.8	328.07	1.38	1.94	2.77	OK
3E	1.07	572	62.5	0.41	0.58	0.83	25	100	22.8	237.9	1.01	1.42	2.03	OK
Total	10.61	5,667												

(*) Z = zone, A = area, P = population, De = design endowment, Q = flow rate, Cd = commercial diameter, Pr = pressure, Di = internal diameter, L = length, RC = regulations check.

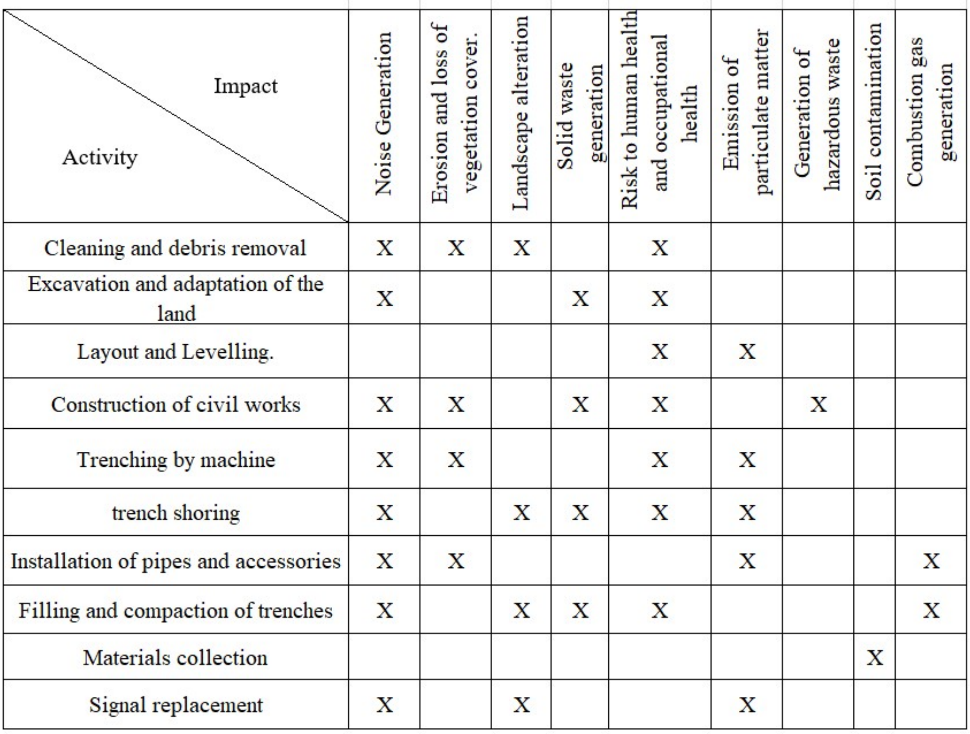
The new pipelines for the expansion zone connect to the old system without any problem. This is because they have enough transport capacity and what needs to be worked on is the issue of high and low reserves.

3.3 Reference budget and environmental evaluation

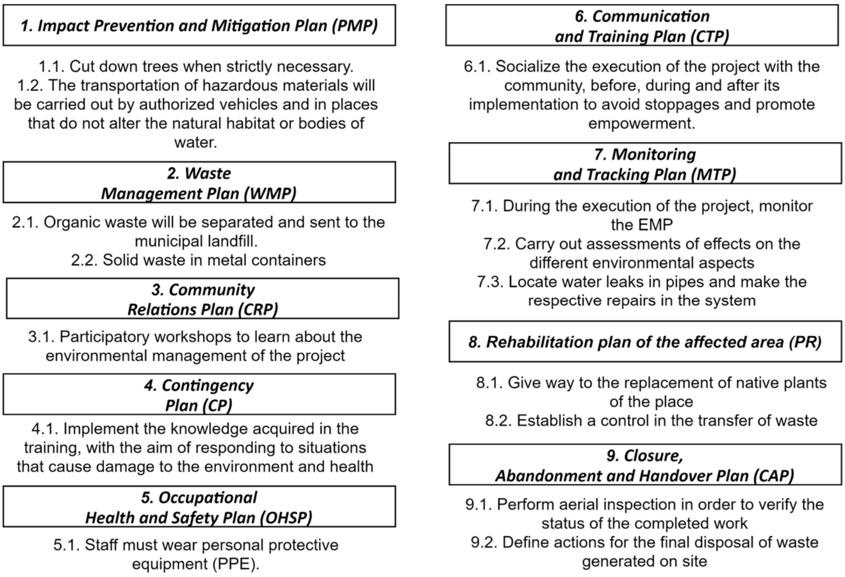
The estimated budget of the proposal was USD 297,543.06. The items were grouped into three categories: preliminary works (USD 205,834.00), drinking water system (USD 89,167.30), and functionality tests (USD 2,541.76).

For the environmental analysis, the SUIA platform was used, where the description of the leading environmental impacts was detailed in a technical file (Table 4), and the environmental management plan in the construction, operation, and maintenance stage (Fig. 5). The cost of the environmental management plan was equal to USD 11,771.73.

Table 4: Main environmental impacts.



Impact / Activity	Noise Generation	Erosion and loss of vegetation cover.	Landscape alteration	Solid waste generation	Risk to human health and occupational health	Emission of particulate matter	Generation of hazardous waste	Soil contamination	Combustion gas generation
Cleaning and debris removal	X	X	X		X				
Excavation and adaptation of the land	X			X	X				
Layout and Levelling.					X	X			
Construction of civil works	X	X		X	X		X		
Trenching by machine	X	X			X	X			
trench shoring	X		X	X	X	X			
Installation of pipes and accessories	X	X				X			X
Filling and compaction of trenches	X		X	X	X				X
Materials collection								X	
Signal replacement	X		X			X			



1. Impact Prevention and Mitigation Plan (PMP)

1.1. Cut down trees when strictly necessary.
1.2. The transportation of hazardous materials will be carried out by authorized vehicles and in places that do not alter the natural habitat or bodies of water.

2. Waste Management Plan (WMP)

2.1. Organic waste will be separated and sent to the municipal landfill.
2.2. Solid waste in metal containers

3. Community Relations Plan (CRP)

3.1. Participatory workshops to learn about the environmental management of the project

4. Contingency Plan (CP)

4.1. Implement the knowledge acquired in the training, with the aim of responding to situations that cause damage to the environment and health

5. Occupational Health and Safety Plan (OHSP)

5.1. Staff must wear personal protective equipment (PPE).

6. Communication and Training Plan (CTP)

6.1. Socialize the execution of the project with the community, before, during and after its implementation to avoid stoppages and promote empowerment.

7. Monitoring and Tracking Plan (MTP)

7.1. During the execution of the project, monitor the EMP
7.2. Carry out assessments of effects on the different environmental aspects
7.3. Locate water leaks in pipes and make the respective repairs in the system

8. Rehabilitation plan of the affected area (PR)

8.1. Give way to the replacement of native plants of the place
8.2. Establish a control in the transfer of waste

9. Closure, Abandonment and Handover Plan (CAP)

9.1. Perform aerial inspection in order to verify the status of the completed work
9.2. Define actions for the final disposal of waste generated on site

Figure 5: Environmental management plan (construction stage and operation and maintenance stage).

4 DISCUSSION OF RESULTS

The drinking water (DW) master plan designed in this study consists of a set of strategies so that, based on the evaluation and diagnosis, existing problems in ESPOL's DW system are determined, and actions are proposed for the short, medium long term. This methodology allowed proposing solutions based on the correct management of water in the face of problems in the current system and for increased demand due to the increase in population and infrastructure, thus ensuring the sustainability of the water resource. Furthermore, this evaluation was essential to determine the basic elements of the system, consumption, and condition of water resources management that ensure technical and economical solutions to the current system [30].

The mass balance reflected that the average consumption of the population between 2017 and 2020 was 99,140 m^3/year. In the same period, a value of 177,222 m^3/year of NRW was recorded, which would give a total of 276,363 m^3/year. Therefore, NRW could translate to pipe damage, leaks, misuse of water, excessive pressures at specific points in the system, and theft. On the other hand, the flow speeds are between 0.003 m/s and 1.44 m/s, with an average speed of 0.25 m/s, which does not comply with current regulations [29].

Based on the evaluation of the existing system, different alternatives were established to improve and optimize the current conditions of the current DW network on campus. These strategies focus on repairing and maintaining pipe networks, using the existing water in lakes and purified water for irrigation, and environmental awareness:

- Conduct an awareness program for students, faculty, staff and administrators on the proper use of potable water.
- Implement a change in sanitary devices, faucets, and others to regulate the improper use of water by students in the bathrooms of the institution.
- It is proposed to construct a building to serve as housing for students from other provinces on the Lower Reserve property to avoid future encroachment.
- Implement a pumping station with an elevated tank that stores water from the lake and distributes it to the green areas of the campus by gravity.
- Use the water treated by the wastewater treatment plant to irrigate green areas, as it is rich in nutrients needed by plants, to contribute to the circular economy.
- Make changes in valves and piping to correct existing deficiencies due to low velocities, high pressures, and lack of maintenance. high pressures and lack of maintenance.

Based on the population analysis, it was determined that the campus population would increase at 1.60% per year. However, considering that universities generally do not have uncontrolled population growth, the budget allocated by the state and the type of academic offer are the most influential factors in the increase or decrease of the university population (students, teachers, administrative staff, among others). Therefore, according to the analyzed population growth, it was decided to propose 10.61 ha of expansion distributed in three zones projected at 5, 10 and 15 years. A DW system was designed to meet the generated demand for the 5,667 inhabitants. The design consists of a pipes system with a minimum diameter of 25 mm for zone 3E and a maximum diameter of 50 mm for zone 1E (Fig. 4). The design complies with the speed limits and water pressures established in the country's regulations to avoid sedimentation and erosion problems (Table 3).

When considering universities as small cities, applying this type of study serves as a tool to achieve adequate water resources management in a given time through a master plan [31]. The application of master plan projects for water management is extensive in different countries (e.g., [32]–[34]).

This study can be replicated at the level of universities and cities in the country to integrate urban development projects, including land use and distribution plans and the respective urban underground space planning (UUS) [35]. The importance of planning the UUS lies in its services to the inhabitants, particularly the drinking water supply. However, the main limitations of the proposed study consist of: (i) economic aspects, the budget allocated for the proper management of water resources is a crucial factor for the implementation of master plans, which seek to solve existing systems and ensure future management of the water; and (ii) the level of education of the population regarding this type of studies, considering as a fundamental axis, their participation in all stages of the project from planning to management and monitoring, promoting the conservation and proper management of water.

5 CONCLUSIONS

Correctly planning surface and underground space is key to executing expansion plans focused on sustainable development. The work carried out offers a methodology for managing drinking water on a university campus, which solves current problems and ensures future demand.

The proposed system for the expansion zones (10.61 ha) considers the implementation of 1,254.67 m pipes with diameters between 25 mm and 50 mm, which allow the distribution of water for the future population (5,667 people) with speeds and pressures within the country's regulations. Likewise, proposals are established that allow solving possible existing problems in the current DW system. The proposals for improving the current system consist of: (i) installing control valves in areas with excessive pressure that would cause possible damage to the pipes, (ii) ensuring that the speed ranges established in the regulations, (iii) implementing a pumping station together with an elevated tank that stores water from the lake and distributes it to the green areas by gravity, and (iv) implementing campaigns/workshops for the participation of the university population to raise awareness about the proper water use. The detection of water leaks by different factors saves water, reduces the need for collection, purification, and distribution, achieving efficiency in the water cycle and greater availability of water resources.

Finally, this study can be complemented with future work focused on rainwater and wastewater management as a comprehensive strategic plan that makes possible the sustainable development of the campus through the circular economy of water.

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REFERENCES

[1] Maroušek, J., Maroušková, A., Zoubek, T. & Bartoš, P., Economic impacts of soil fertility degradation by traces of iron from drinking water treatment. *Environ. Dev. Sustain.*, 2021. DOI: 10.1007/s10668-021-01636-1.

[2] Ekwueme, B.N. & Agunwamba, J.C., Trend analysis and variability of air temperature and rainfall in regional river basins. *Civ. Eng. J.*, **7**(5), pp. 816–826, 2021. DOI: 10.28991/cej-2021-03091692.

[3] Pan, D. & Chen, H., Border pollution reduction in China: The role of livestock environmental regulations. *China Econ. Rev.*, **69**, 101681, 2021. DOI: 10.1016/j.chieco.2021.101681.

[4] Kadam, A.R.M., Umrikar, B., Bhagat, V., Wagh, V. & Sankua, R.N., Land suitability analysis for afforestation in semi-arid watershed of Western Ghat, India: A groundwater recharge perspective. *Geol. Ecol. Landscapes*, **5**(2), pp. 136–148, 2021. DOI: 10.1080/24749508.2020.1833643.

[5] Morante Carballo, F., Marcatoma Brito, L., Carrión Mero, P., Aguilar Aguilar, M. & Tumbaco Ramírez, J., Urban wastewater treatment through a system of green filters in the Montañita commune, Santa Elena, Ecuador. *WIT Trans. Ecol. Environ.*, vol. 239, WIT Press: Southampton and Boston, pp. 233–249, 2019. DOI: 10.2495/WS190211.

[6] Sharma, S.K. & Vairavamoorthy, K., Urban water demand management: prospects and challenges for the developing countries. *Water Environ. J.*, **23**(3), pp. 210–218, 2009. DOI: 10.1111/j.1747-6593.2008.00134.x.

[7] Herrera-Franco, G. et al., Communication methods on water care during the COVID-19 pandemic and its impact on the resilience of the rural community of "Libertador Bolívar", Ecuador. pp. 109–118, 2021. DOI: 10.2495/WRM210101.

[8] UNESCO, Managing water under uncertainty and risk, 2012.

[9] Sanjuan-Delmás, D. et al., Environmental assessment of different pipelines for drinking water transport and distribution network in small to medium cities: A case from Betanzos, Spain. *J. Clean. Prod.*, **66**, pp. 588–598, 2014. DOI: 10.1016/j.jclepro.2013.10.055.

[10] Merchán-Sanmartín, B. et al., Design of sewerage system and wastewater treatment in a rural sector: A case study. *Int. J. Sustain. Dev. Plan.*, **17**(1), pp. 51–61, 2022. DOI: 10.18280/ijsdp.170105.

[11] Merchan, B., Ullauri, P., Amaya, F., Dender, L., Carrión, P. & Berrezueta, E., Design of a sewage and wastewater treatment system for pollution mitigation in El Rosario, El Empalme, Ecuador. pp. 77–85, 2021. DOI: 10.2495/WS210081.

[12] Sun, C., Puig, V. & Cembrano, G., Real-time control of urban water cycle under cyber-physical systems framework. *Water*, 12(2), p. 406, 2020. DOI: 10.3390/w12020406.

[13] Peña-Guzmán, C.A., Melgarejo, J., Prats, D., Torres, A. & Martínez, S., Urban water cycle simulation/management models: A review. *Water*, **9**(4), p. 285, 2017. DOI: 10.3390/w9040285.

[14] Marsalek, J., Jiménez-Cisnero, B., Karamouz, M., Malmquist., P.-A., Goldenfum, J. & Chocat, B., *Urban Water Cycle Processes and Interactions: Urban Water Series – UNESCO-IHP*, Springer: Berlin, 2007.

[15] De Filippis, G. et al., Water quality assessment: A quali-quantitative method for evaluation of environmental pressures potentially impacting on groundwater, developed under the M.I.N.O.Re. project. *Int. J. Environ. Res. Public Health*, 17(6), p. 1835, 2020. DOI: 10.3390/ijerph17061835.

[16] Sadiq, R., Kleiner, Y. & Rajani, B., Water quality failures in distribution networks-risk analysis using fuzzy logic and evidential reasoning. *Risk Anal.*, **27**(5), pp. 1381–1394, 2007. DOI: 10.1111/j.1539-6924.2007.00972.x.

[17] Wheeler, T. & von Braun, J., Climate change impacts on global food security. *Science (80-)*, **341**(6145), pp. 508–513, 2013. DOI: 10.1126/science.1239402.

[18] Intergovernamental Panel on Climate Change, *Climate Change and Water*, IPCC Technical Paper VI, World Health Organization, 2008.

[19] Delpla, I., Jung, A.-V., Baures, E., Clement, M. & Thomas, O., Impacts of climate change on surface water quality in relation to drinking water production. *Environ. Int.*, **35**(8), pp. 1225–1233, 2009. DOI: 10.1016/j.envint.2009.07.001.

[20] Heberling, M.T. et al., Comparing drinking water treatment costs to source water protection costs using time series analysis. *Water Resour. Res.*, 51(11), pp. 8741–8756, 2015. DOI: 10.1002/2014WR016422.

[21] Farley, M. & Trow, S., *Losses in Water Distribution Networks: A Practitioner´s Guide to Assessment, Monitoring and Control*, IWA Publishing: London, 2003.

[22] Marques Arsénio, A., Câmara Salim, I., Hu, M., Pedro Matsinhe, N., Scheidegger, R. & Rietveld, L., Mitigation potential of sanitation infrastructure on groundwater contamination by nitrate in Maputo. *Sustainability*, **10**(3), p. 858, 2018. DOI: 10.3390/su10030858.

[23] Richter, B.D. et al., Assessing the sustainability of urban water supply systems. *J. Am. Water Works Assoc.*, **110**(2), pp. 40–47, 2018. DOI: 10.1002/awwa.1002.

[24] Rabêlo, V.G., Berchin, I.I., De León, M., de Toledo, J.H.D., da Silva, L.R. & de Andrade Guerra, J.B.S.O., University campuses as town-like institutions: Promoting Sustainable development in cities using the water-sensitive urban design approach. pp. 497–511, 2019.

[25] Instituto Ecuatoriano de Normalización, Norma para estudio y diseño de agua potable y disposición de agua residuales para poblaciones mayores a 1000 habitantes, Quito, 1992.

[26] Cámara de la Construcción de Guayaquil, Precios Unitarios: Rubros, Guayaquil, 2019.

[27] Contraloría General del Estado, Reajustes de precios: Salarios mínimos por ley, Quito, 2021.

[28] ESPOL, Bosque Protector "La Prosperina", 2019. http://www.bosqueprotector.espol.edu.ec/biodiversidad/.

[29] López Alaña. J. & Zambrano Figueroa, C., Análisis del Sistema Existente y Diseños de Optimización del Sistema Matriz de Agua Potable de la ESPOL, Escuela Superior Politécnica del Litoral, Guayaquil, 2021.

[30] Simonovic, S., Application of water resources systems concept to the formulation of a water master plan. *Water Int.*, 14(1), pp. 37–50, 1989. DOI: 10.1080/02508068908692032.

[31] Goodman, A.S., *Principles of Water Resources Planning*, 1984.

[32] Che, W., Zhao, Y., Yang, Z., Li, J. & Shi, M., Integral stormwater management master plan and design in an ecological community. *J. Environ. Sci.*, **26**(9), pp. 1818–1823, 2014. DOI: 10.1016/j.jes.2014.06.028.

[33] Choukr-Allah, R., Nghira, A., Hirich, A. & Bouchaou, L., Water resources master plan for sustainable development of the Souss-Massa River Basin. pp. 1–26, 2016.

[34] Kibiiy, J. & Kosgei, J.R., Long-term water planning: A review of Kenya National Water Master Plan 2030. pp. 193–208, 2018.

[35] Bobylev, N., Mainstreaming sustainable development into a city's master plan: A case of urban underground space use. *Land Use Policy*, **26**(4), pp. 1128–1137, 2009. DOI: 10.1016/j.landusepol.2009.02.003.