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Stormwater Sewerage Masterplan for Flood Control Applied to a University Campus

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Abstract: Floods generated by rain cause significant economic and human losses. The campus of the Escuela Superior Politécnica del Litoral (ESPOL) has a drainage system that conducts stormwater to two discharge points outside the campus. The system works effectively at the macro-drainage level. However, a very crowded area is deficient at the micro-drainage level, which has registered flooding and the proliferation of vectors that affect people's health. This work aimed to design a masterplan for stormwater sewerage by analyzing the existing situation and applying technical criteria that allow the establishment of solutions and strategies to control floods at the university campus. The methodology consisted of: (i) data collection and processing for the stormwater drainage system diagnosis; (ii) a design proposal for micro-drainage and (iii) a SWOT analysis to propose improvement strategies in water management. The resulting flows for return periods of 5 years, 10 years, and 25 years are 9.67 m^3/s, 11.85 m^3/s, and 15.85 m^3/s, respectively. In the latter, as the most critical area (presence of flooding), the implementation of a trapezoidal channel 80.20 m long, with a capacity of 1.00 m^3/s, for a return period of 25 years was proposed. The stormwater masterplan will contribute to the execution of activities within the campus and prevent accidents and the proliferation of diseases, constituting a water-management model that can be replicated locally, regionally, and internationally.

Keywords: drainage channels; sustainability; social responsibility; resource recovery; circular economy

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1. Introduction

A hydrographic watershed is an area on the earth's surface that constitutes a natural drainage system for water captured by precipitation towards the same exit or gauging point [1]. These can be divided into sub-watersheds and micro-watersheds to make a more detailed analysis of the flow that enters and leaves [2]. One of the methods to assess the availability of water resources in a watershed is through the water balance, which analyzes the hydrological cycle by estimating the inflow of water through precipitation and its output process, which includes evapotranspiration, runoff, and infiltration [3].

In urban areas, the water cycle has another approach because it comprises of a series of stages. It begins with collecting and treating water that is supplied to the population and used in different activities that generate wastewater. Next, the generated wastewater is collected and transported through a systems of pipes to the treatment plants, to finally be returned to an effluent where it will have the effect of dilution by volume and does not deteriorate in quality [4].

The evapotranspiration, runoff and infiltration parameters will depend on the permeability of the soil, and in an urban watershed, this is a factor to consider. By 2030, it is estimated that the world population will reach 9.7 billion inhabitants [5], assuming continuous population growth. As a result, the need arises to occupy new areas in cities that require expansion. Furthermore, this will cause changes in the water cycle since part of urban development involves the construction of paved roads, asphalt roads, buildings, the removal of vegetation, and so on [6,7]. All this translates into the waterproofing of the soil, which modifies flow routes, increases runoff speed, generates higher flows and increases the frequency of flooding [8,9].

Floods are overflows of water that generate serious economic and human losses [10–12]. Causes of these events include extreme rainfall, river flow, the appearance of groundwater, astronomical tides, or storm surges. In addition, floods can occur due to unnatural reasons such as hydraulic failures in dams or dikes, collapses in stormwater or sanitary sewer systems, and soil erosion, which causes the soil to become more permeable [13].

Floods, regardless of how they originate, create ideal aquatic habitats for the development and proliferation of vectors, which are living organisms such as mosquitoes, which are transmitters of diseases such as dengue, malaria, Zika, and Chikungunya [14–16].

Climate change and urban growth significantly affect flood risk [17–19]. Therefore, adequate urban planning allows for reducing these risks because it implies a set of protection strategies at the engineering level, such as dikes or sewage systems, and at the social level through educational programs that raise awareness among the population to take preventive measures before these events [20–23].

A stormwater sewerage system comprises a systems of pipes, channels and other structures that drain rainwater that falls into urban areas and deposit it in bodies of water [24]. In addition, there are sewerage systems that combine wastewater with stormwater. However, it is currently a practice not recommended due to the pollution it generates when discharged without being treated, as well as to reduce the demand on treatment plants [25].

Sustainable urban drainage systems are those that mitigate their influence on the natural water cycle and incorporate some techniques that favor storage and infiltration, such as retention watersheds, permeable surfaces, bio-retention zones, filter strips, green ditches, seepage deposits, wetlands and others [26,27].

Due to the existing scarcity of water in some regions of the world (e.g., [28–33]), water is a resource that must be managed responsibly. Rainwater represents an alternative source of water that can be stored and collected for its uses, such as crop irrigation in dry seasons and certain domestic activities [34–36]. For this reason, more and more countries are aiming at adequate stormwater management at the urban level to avoid problems generated by irresponsible practices while implementing drainage infrastructures (e.g., [37–46]).

Stormwater sewerage works require proper planning to avoid future problems. A masterplan is a comprehensive set of strategies that contemplate a series of actions that start from the analysis of the existing situation, proposal of alternatives, implementation, and follow-up to solve a problem in the short, medium, and long term [47–50].

The study area corresponds to the Gustavo Galindo Campus of the Escuela Superior Politécnica del Litoral (ESPOL), located in the southwest of the coastal region of Ecuador, specifically in the city of Guayaquil, Guayas province. The university campus has an approximate area of 630.16 ha, of which 49% of its extension represents environmental protection forests called Bosque Protector Prosperina [51,52] (Figure 1). From the morphological point of view, the study area includes rugged terrain with slopes exceeding 40% and relatively flat areas with slopes of less than 15%, which contain the most buildings.

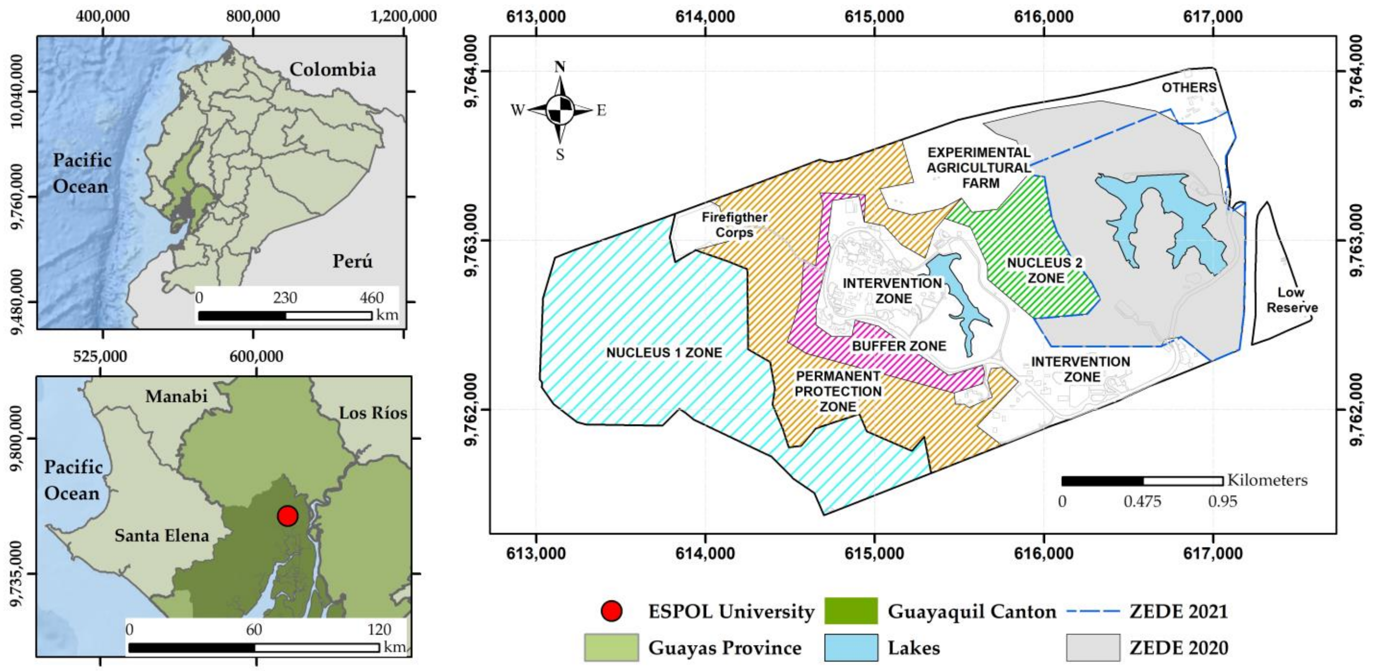

Figure 1. Study zone. ZEDE: Zona Especial de Desarrollo Económico (in Spanish).

At the macro level, the existing drainage system works adequately; however, when zones carry out the analysis, it can be identified that, at the micro-drainage level, one of them works inefficiently because a civil structure (building) is in the natural drainage area. In this area, which is very busy, significant flooding has been recorded in the winter season, resulting in damage and impacts to the well-being of the university community. Following this problem, components should be considered that are crucial in the masterplan of a university campus that allow for flood and decrease the risk of vector proliferation, as well as the proposal of short, medium, and long-term interventions, and works that will improve the well-being of the campus community.

ESPOL constantly seeks to optimize the management of the drinking water, sanitary sewerage and stormwater sewerage systems to guarantee safe expansion in the short, medium and long term [53,54]. That is why, through analyzing the existing situation and applying technical criteria, this study proposed a masterplan as a comprehensive management model for flood control on campus, which will provide solutions that are viable on the economic level as well as sustainable. Furthermore, adequate flood control will mitigate the proliferation of vectors responsible for diseases and health effects.

2. Materials and Methods

ESPOL is considered the first green university in Ecuador, and according to the UI Green Metric World University Ranking, it is among the greenest universities in the world [55]. In addition, the campus has academic and administrative infrastructure areas and important areas declared as environmental protection areas.

Considering the morphology of the terrain and the meteorological conditions that condition the hydrographic system of the study area, it is important to develop stormwater-management projects that evaluate the behavior of the existing sewage infrastructure on campus and in populated peripheral zones. Furthermore, the hydrological analysis of watersheds and micro-watersheds is a fundamental tool in stormwater management in occupied areas with future expansion plans. In this case, to mitigate flooding problems within a university campus, work phases have been contemplated that include: (i) data collection and processing for the stormwater drainage system diagnosis; (ii) a design proposal for micro-drainage; and (iii) a SWOT analysis to propose improvement strategies in water management (Figure 2).

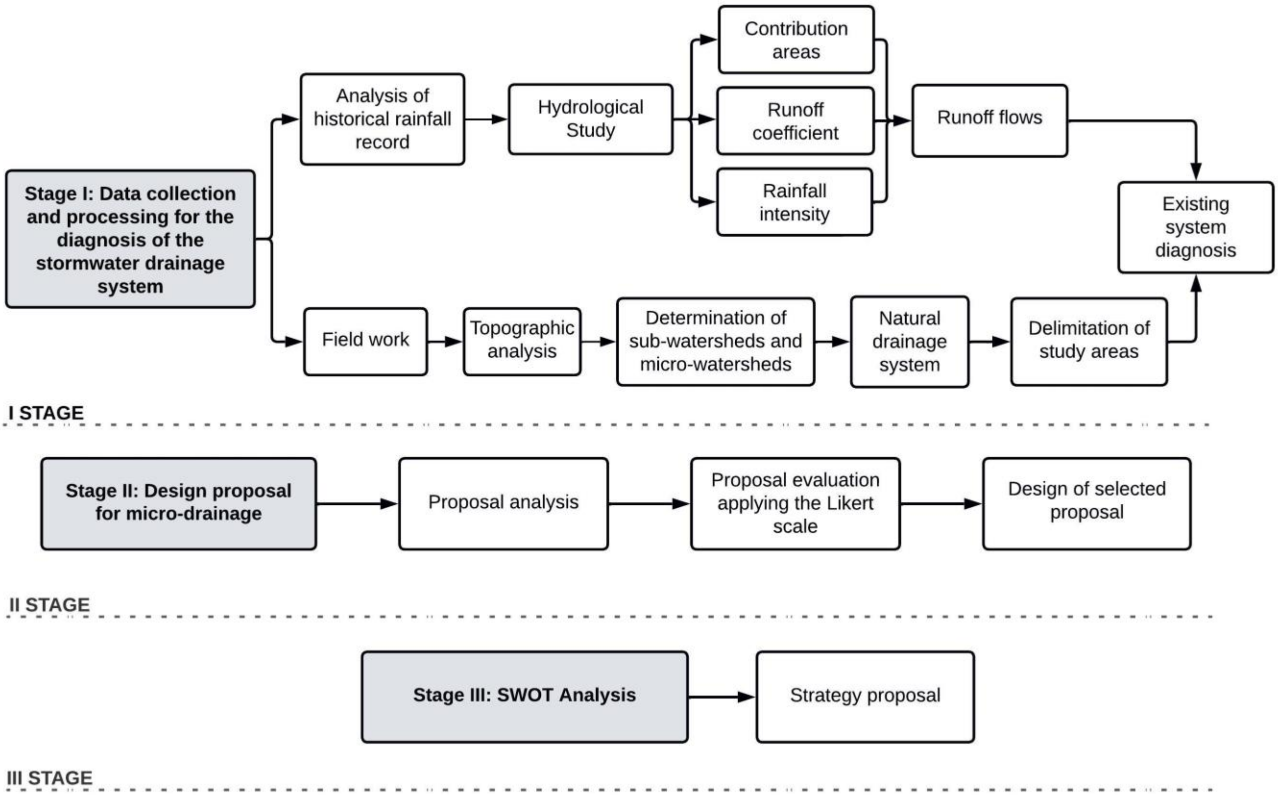

Figure 2. General methodological scheme.

2.1. *Stage I: Data Collection and Processing for the Stormwater Drainage System Diagnosis*

The study began with collecting and processing data from the area that included: topography, population data, previous projects of the stormwater sewerage system, and meteorology, among others. Then, computer software such as Google Earth, CivilCAD, and ArcGIS made it possible to obtain the topography.

With the land's topography, we proceeded to delimit the sub-watershed and micro-watersheds through the ArcGIS software using the Flow Direction and Flow Accumulation tools to determine the drainage areas of the micro-watersheds. The average between the results obtained from the Kirpich (Equation (1)) [56] and California (Equation (2)) [57] equation allowed us to determine the concentration time (t). The two methods are similar and useful in watersheds of medium size, have considerable slope, have soils dedicated to cultivation (mango planting in experimentation), and are widely used in the environment. For Equation (1), Lo is the length of the channel upstream to the outlet point, and S is the average slope of the basin; while for Equation (2), L is the length of the longest watercourse and H is the difference between the watershed and the outlet.

$$t = 0.006628 \cdot \frac{Lo^{0.77}}{S^{0.385}} \quad (1)$$

$$t = \left(\frac{0.871 \cdot L^{0.3}}{H} \right)^{0.385} \quad (2)$$

The analysis of different factors to determine the design flow of rainwater (Q) included: values of intensity (I), duration and frequency of average precipitation from the nearest meteorological station (M0056) based on the data provided by the National Institute of Meteorology and Hydrology (INAMHI, acronym in Spanish) [58] (Table 1). This analysis aimed to determine the values of maximum precipitation intensities for a given return period T (2 years, 5 years, 10 years, 25 years, 50 years, 100 years). Subsequently, the determination of the runoff coefficient (C) depended on the surface characteristics in developed areas (e.g., asphalt, concrete, gardens, parks, among others) and undeveloped areas (e.g., crop areas, pastures, forests), making use of the Chow matrix [59] (Table 2).

Table 1. Guayaquil airport station records (INAMHI, 2015).

Station		Time Intervals (Minutes)	Equations	R	R^2
Code	**Name**				
M0056	Guayaquil Airport	5 < 30	$I = 135.778 \times T^{0.2169} \times t^{-0.30063}$	0.9840	0.9683
		30 < 120	$I = 203.0259 \times T^{0.2169} \times t^{-0.417068}$	0.9944	0.9889
		120 < 1440	$I = 1113.4537 \times T^{0.2169} \times t^{-0.7779}$	0.9992	0.9984

Table 2. Runoff coefficients [59].

Surface Characteristics	Return Period (Years)						
	2	**5**	**10**	**25**	**50**	**100**	**1000**
Developed areas							
Asphalt	0.73	0.77	0.81	0.86	0.90	0.95	1.00
Concrete/roof	0.75	0.80	0.83	0.88	0.92	0.97	1.00
Green zones (gardens, parks, etc.)							
Poor condition (less than 50 % grass cover of the area)							
Plain, 0–2%	0.32	0.34	0.37	0.40	0.44	0.47	0.58
Average slope, 2–7%	0.37	0.40	0.43	0.46	0.49	0.53	0.61
Slope over 7%	0.40	0.43	0.45	0.49	0.52	0.55	0.62
Average condition (50% to 75% grass cover of area)							
Plain, 0–2%	0.25	0.28	0.30	0.34	0.37	0.41	0.53
Average slope, 2–7%	0.33	0.36	0.38	0.42	0.45	0.49	0.58
Slope over 7%	0.37	0.40	0.42	0.46	0.49	0.53	0.60
Good condition (greater than 75% of the area covered with grass)							
Plain, 0–2%	0.21	0.23	0.25	0.29	0.32	0.36	0.49
Average slope, 2–7%	0.29	0.32	0.35	0.39	0.42	0.46	0.56
Slope over 7%	0.34	0.37	0.40	0.44	0.47	0.51	0.58
Andeveloped areas							
Crop areas							
Plain, 0–2%	0.31	0.34	0.36	0.40	0.43	0.47	0.57
Average slope, 2–7%	0.35	0.38	0.41	0.44	0.48	0.511	0.60
Slope over 7%	0.39	0.42	0.44	0.48	0.51	0.54	0.61
Grasslands							
Plain, 0–2%	0.25	0.38	0.30	0.34	0.37	0.41	0.53
Average slope, 2–7%	0.33	0.36	0.38	0.42	0.45	0.49	0.58
Slope over 7%	0.37	0.40	0.42	0.46	0.49	0.53	0.60
Forests							
Plain, 0–2%	0.22	0.25	0.28	0.31	0.35	0.39	0.48
Average slope, 2–7%	0.31	0.34	0.36	0.40	0.43	0.47	0.56
Slope over 7%	0.35	0.39	0.41	0.45	0.48	0.52	0.58

On the other hand, with the data on runoff coefficient (C), rainfall intensity (I), and estimated areas of the micro-watersheds (A), the calculation of the maximum runoff flows was carried out using the rational method (Equation (3)) [60], for different return times for micro-drainage (5 years, 10 years, and 15 years).

$$Q = CIA \tag{3}$$

Finally, the diagnosis of the existing system included the identification of the sewers and channels that the university campus has for the transport of rainwater, with the respective information on diameters, sections, dimensions, and current conditions. For this, based on the measurements made, in the case of channels, the depth was estimated (Equation (4)), where H is the total height of the channel, which is the sum of the deep (y) and the free edge (FE), the FE being between 5% and 30% of the tightness [59,61]. Therefore, it was considered that pipes work at 75% of their capacity [62].

$$H = y + FE \tag{4}$$

The study determined the capacity of the existing channel and pipe, using the depth of the water flow through the formula developed by Robert Manning [63], in which the estimated flow depends on parameters such as roughness coefficient (n), the hydraulic radius (R_h), longitudinal slope (S), and cross-sectional area (A) of the existing systems analyzed (Equation (5)). The value of n was taken from [63] and as the specialized literature on this subject indicates, this value depends on the type of material in which the channel or pipe is constructed (e.g., closed conduit, lined channel, natural flow, excavated) and the lining material.

$$Q = \frac{1}{n} \cdot A \cdot R_h^{2/3} \cdot S^{1/2} \tag{5}$$

2.2. Stage II: Design Proposal for Micro-Drainage

2.2.1. Analysis Zones

Based on the flows that each of the micro-watersheds generates, the study evaluated the capacity of the existing channels, defining four main discharge sites (SD) (two that correspond to the macro drainage and two based on the problems identified in the site). For the proposed SDs, the capacity evaluation considered a return period of 50 years, which made it possible to define the venting areas that present flooding problems and the increase in infrastructure capacity and propose the respective solutions based on conditions in each site.

2.2.2. Constraint Analysis

The approach of alternatives that solve the problems identified in the area considered the already established constructions and the environmental conservation areas (protective forest and green areas). Similarly, it is important to consider technical criteria such as location, slope, and sector of influence. Therefore, the alternatives considered technical criteria (natural slope, location, area, previous studies, connection points) to guarantee the operation of the gravity system and avoid high operation and maintenance costs due to energy expenses when installing pumping stations. Additionally, the analysis considered sustainability criteria, including social (e.g., population growth, health emergency, road development), economic (e.g., construction costs, machinery costs, maintenance costs) and environmental (e.g., impact on forests, green areas) criteria.

Finally, these criteria take on values through an adaptation of the Likert scale [64], a semiquantitative methodology in which the assigned score depends on the opinion of the evaluators and the level of compliance with the parameter in the alternatives analyzed. The scores within this methodology include evaluations between 1 to 5 considering: (i) one is "totally unfavorable", (ii) two is "certainly unfavorable", (iii) three is "neutral or indifferent", (iv) four is "certainly favorable", and (v) five is "totally favorable" (Table 3). In addition, this study will analyze the alternative that obtains a higher score.

Table 3. Criteria, parameters, and scores used for the evaluation through Likert scale.

Criteria	Parameters	Score
Technical considerations	Natural slope Location and area Preliminary studies	1–5
Social considerations	Sanitary emergency Population growth	
Economic considerations	Building costs Machinery and equipment costs Maintenance costs	
Environmental considerations	Impact on flora and fauna Affectation of protection areas Changing the natural course of water	

The hydraulic design of the pipes and channels took into account the considerations established in the Ecuadorian Code of Practice of the Ecuadorian Standards Institute (CPE INEN) 5:9:1 [65].

2.3. Stage III: SWOT Analysis

The study ended with an analysis of the main strengths, weaknesses, opportunities, and threats (SWOT) [66] of the campus storm sewer system, which allows the proposal of improvement strategies that guarantee the management of rainwater in the short, medium, and long term. This analysis contemplated a comprehensive approach that involved the participation of ESPOL campus authorities related to sustainable water management, civil engineers, and authors of the work.

3. Results and Discussion

3.1. Study Area Diagnosis

The campus has an irregular morphology that includes elevations between 25 and 450 m above sea level (Figure 3) and maximum slopes of 45°. This condition allows the formation of a series of natural drainages that preserve the protective 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.

According to the topographic data of the study area and the hydrological analysis performed in ArcGIS software, two sub-watersheds of 401.90 ha and 228.26 ha were delimited for sub-watershed one and two, respectively (Figure 4). Sub-watershed 1 encompasses 90% of the campus infrastructure (target area for flood event analysis) and protective forest. On the other hand, sub-watershed two comprises an area designated for economic and sustainable development that includes experimental farms and part of the protective forest.

In the specific analysis, ten drainage micro-watersheds were determined (Figure 5), with micro-watershed four occupying the largest area, with maximum slopes; on the other hand, micro-watershed two is the smallest area and has the lowest slopes (Table 4). The drainage system obtained from the elevation and slope data reflects main and secondary channels that converge at two main water dump points (WDP) or outflow points to the north of the study area (Figure 5). WDP1 collects the flow generated by sub-watershed one, while WDP2 collects the discharge from sub-watershed two.

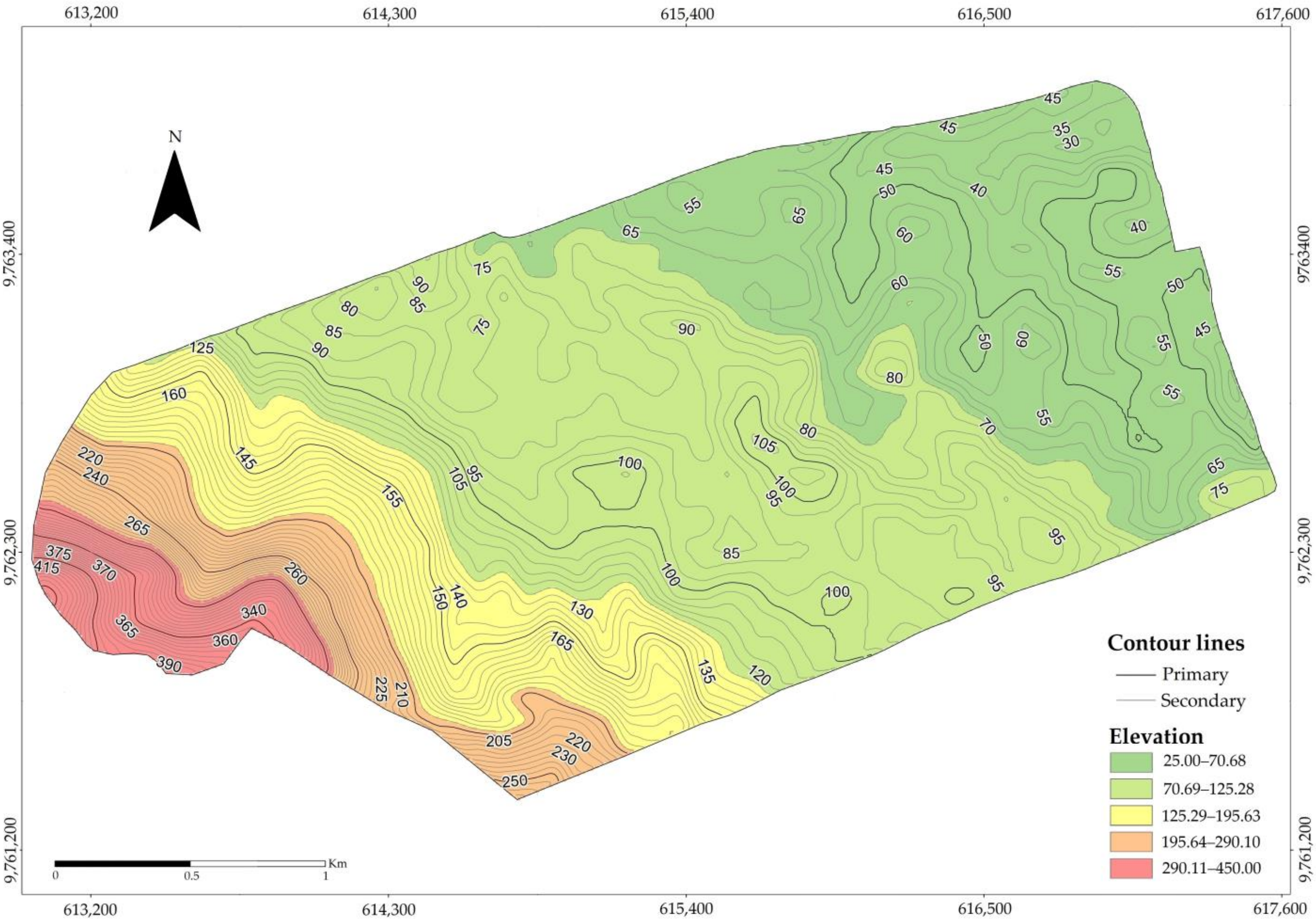

Figure 3. Topographic map of the ESPOL property.

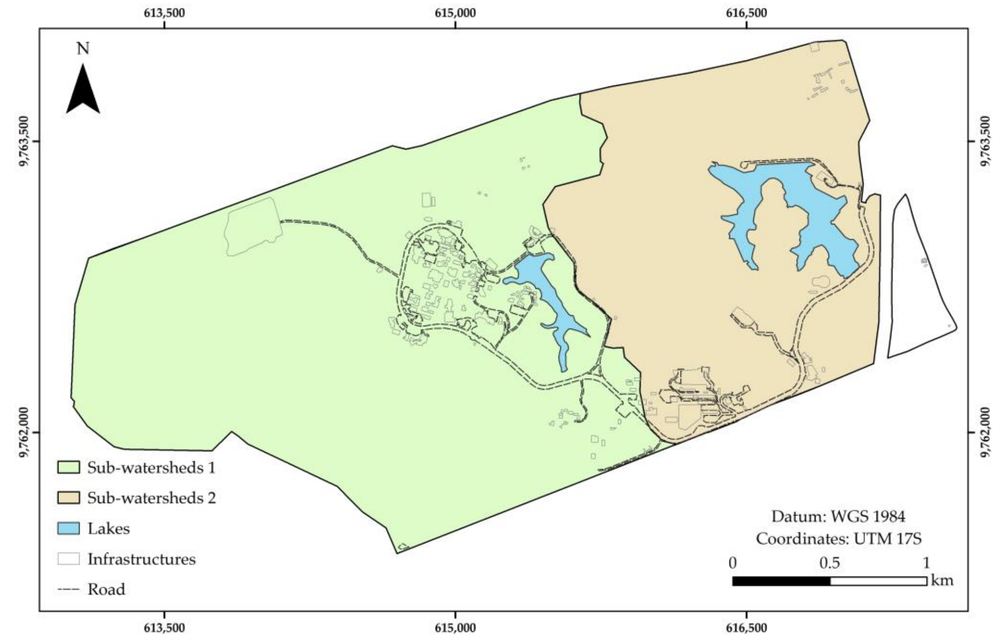

Figure 4. Delimitation of drainage sub-watersheds.

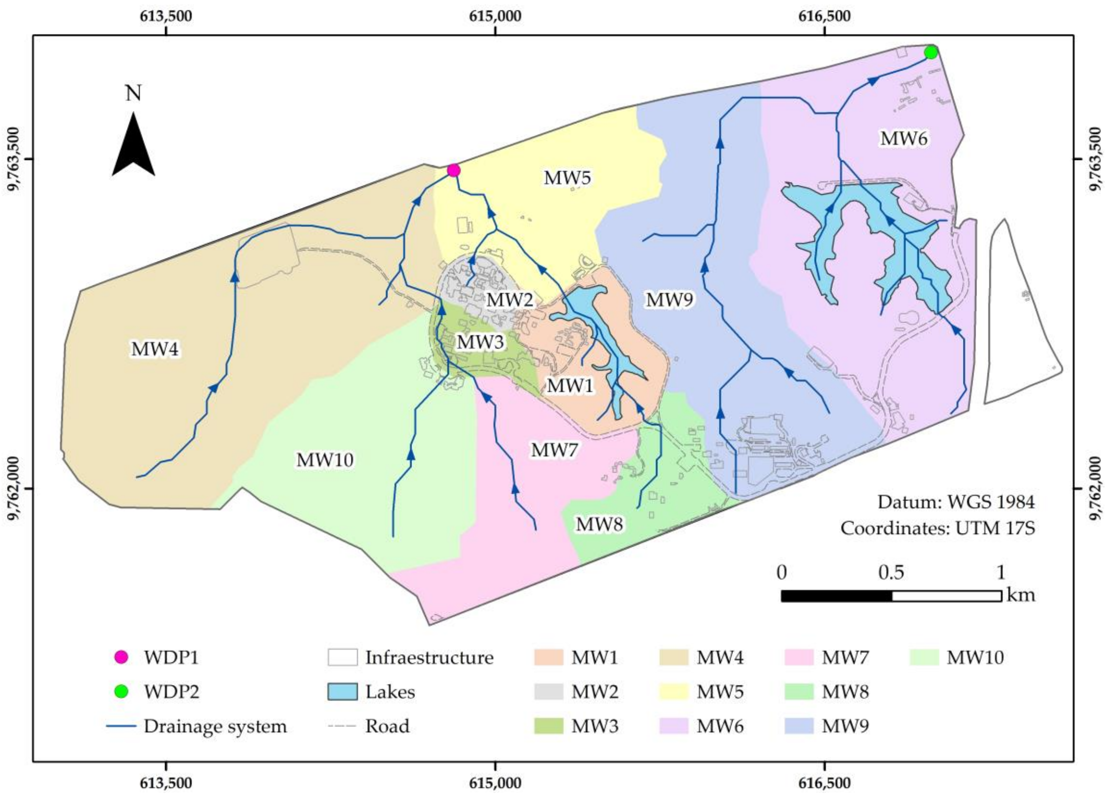

Figure 5. Identification of Micro Watershed (MW) and Water Dump Points (WDP).

Table 4. Values taken from ArcGIS modeling.

Micro-Watershed	Area (ha)	Length (km)	Max. Elevation (m)	Min. Elevation (m)	Slope (S)	Height (m)
1	35.15	0.76	87	80	0.01	7
2	8.60	0.26	81	79	0.01	2
3	12.26	0.36	90	81	0.03	9
4	138.80	2.11	350	70	0.13	280
5	56.13	0.80	79	66	0.02	13
6	110.29	1.57	70	35	0.02	35
7	49.86	1.16	190	92.5	0.08	97.5
8	27.94	0.69	120	87	0.05	33
9	118.35	2.01	90	40	0.02	50
10	72.78	0.97	210	90	0.12	120
Total Area	630.16	0	0	0		0

The water flow coming from WDP1 goes through an unlined channel that conveys the water to the outside of the campus (Figure 6a), to the sector called "Socio-Vivienda" (Figure 6b), passing through two pipes of Ø500 and Ø800 mm (Figure 6c). The flow of WDP2 discharges to the drainage system of a perimeter road (first-order highway).

Figure 6. Identification of water dump points: (**a**) channel coming from the university, (**b**,**c**) connection pipes that allow the flow of water between the university and the sector called Socio-Vivienda.

3.2. Hydrological Study

The average values obtained from the Kirpich and California equations show a maximum concentration time (t) of 28.29 min corresponding to micro-watershed nine and a minimum of 7.40 min corresponding to micro-watershed three (Table 5).

Table 5. Concentration time by Kirpich and California equations.

Micro-Watershed	Kirpich (min)	California (min)	Average Kirpich/California (min)
1	19.44	19.47	19.46
2	9.25	9.26	9.26
3	7.39	7.40	7.40
4	15.39	15.41	15.40
5	16.46	16.48	16.47
6	24.42	24.44	24.43
7	11.53	11.55	11.54
8	9.61	9.63	9.62
9	28.28	28.31	28.29
10	8.69	8.71	8.70

According to the times of concentration (Table 5), the rainfall intensity values reflect maximum values of 171.84 mm/hour in the return period T of 50 years for micro-watershed three. On the other hand, micro-watershed nine with an intensity of 69.15 mm/hour for a T of five years corresponds to the minimum intensity value in the study (Table 6).

Table 6. Rainfall intensity values (mm/hour) for the different return periods (T).

Micro-Watershed	5 Years	10 Years	15 Years	20 Years	25 Years	30 Years	50 Years
1	77.55	90.13	98.42	104.75	109.95	114.38	127.79
2	97.36	113.16	123.56	131.52	138.04	143.61	160.43
3	104.28	121.20	132.34	140.87	147.85	153.81	171.84
4	83.31	96.83	105.73	112.54	118.12	122.88	137.28
5	81.61	94.85	103.57	110.24	115.71	120.37	134.48
6	72.33	84.06	91.79	97.70	102.54	106.68	119.18
7	91.00	105.77	115.49	122.92	129.02	134.22	149.95
8	96.23	111.84	122.12	129.98	136.43	141.93	158.56
9	69.15	80.37	87.75	93.40	98.04	101.99	113.94
10	99.23	115.33	125.93	134.04	140.69	146.36	163.51

According to the classifications proposed by [59] and the slopes calculated for each micro-watershed, 70% of the area analyzed corresponds to pitches between 0 and 7% with maximum runoff coefficients of 0.92 at a T of 50 years. In contrast, 30% of the zone (micro-watersheds 4, 7, and 10) with slopes greater than 7% reflect maximum runoff coefficients of 0.48 for a 50-year (T).

Although the ESPOL campus has many green surfaces that allow water filtration, micro-watersheds two and three have the highest runoff coefficient; this is because both areas contain most of the campus infrastructure, and due to the presence of concrete, the soil is less permeable, so rainwater runs off more easily (Table 7). Similarly, when reviewing other case studies, it can be seen how the runoff coefficient is higher in urbanized areas [67–69].

Table 7. Application of runoff coefficients in micro-watershed for the different return periods (T).

Micro-Watershed	5 Years	10 Years	15 Years	20 Years	25 Years	30 Years	50 Years
1	0.40	0.43	0.44	0.45	0.46	0.47	0.49
2	0.80	0.83	0.85	0.86	0.88	0.90	0.92
3	0.80	0.83	0.85	0.86	0.88	0.90	0.92
4	0.39	0.41	0.42	0.44	0.45	0.47	0.48
5	0.36	0.38	0.39	0.41	0.42	0.44	0.45
6	0.34	0.36	0.37	0.39	0.40	0.42	0.43
7	0.34	0.36	0.37	0.39	0.40	0.42	0.43
8	0.36	0.38	0.39	0.41	0.42	0.44	0.45
9	0.39	0.41	0.42	0.43	0.45	0.47	0.48
10	0.39	0.41	0.42	0.43	0.45	0.47	0.48

For a return period of 50 years, the micro-watershed presents a maximum flow equal to 4.30 m^3/s (Table 8). The rational method allowed for estimating the average flow of the micro-watersheds with areas smaller than 139 Ha, which according to [70] the application of this method is ideal for watersheds smaller than 25 Km^2 (2500 Ha), demonstrated its efficiency in different studies [71–73].

Table 8. Runoff Flow Values for the different return periods (T).

WDP *	Micro-Watershed	5 Years	10 Years	15 Years	20 Years	25 Years	30 Years	50 Years
WDP1	1	0.51	0.64	0.72	0.78	0.84	0.89	1.03
	2	0.32	0.38	0.42	0.46	0.49	0.52	0.60
	3	0.48	0.58	0.65	0.70	0.75	0.80	0.91
	4	2.12	2.59	2.9	3.23	3.47	3.77	4.30
	5	0.78	0.95	1.07	1.19	1.28	1.40	1.60
	7	0.73	0.89	1.00	1.12	1.21	1.32	1.51
	8	0.46	0.56	0.63	0.70	0.75	0.82	0.94
	10	1.33	1.62	1.81	1.97	2.17	2.36	2.69
	Subtotal 1	6.73	8.21	9.20	10.15	10.96	11.88	13.58
WDP2	6	1.46	1.80	2.02	2.26	2.44	2.66	3.04
	9	1.5	1.83	2.05	2.24	2.46	2.67	3.04
	Subtotal 2	2.96	3.63	4.07	4.5	4.9	5.33	6.08
	Total	9.69	11.84	13.27	14.65	15.86	17.21	19.66

* WDP: Water Dump Points.

3.3. Existing System Evaluation

The study considered four analysis points: (i) point A, where a large part of the flows generated by the different areas where many of the campus activities take place to converge; (ii) points B and C, which are the outlets for the entire ESPOL storm drainage system; and (iii) point D, characterized by being the busiest zone on campus, locating a cafeteria and other classroom buildings are located; the latter has local flooding problems. Figure 7 shows the location and slope value corresponding to the sections of each point.

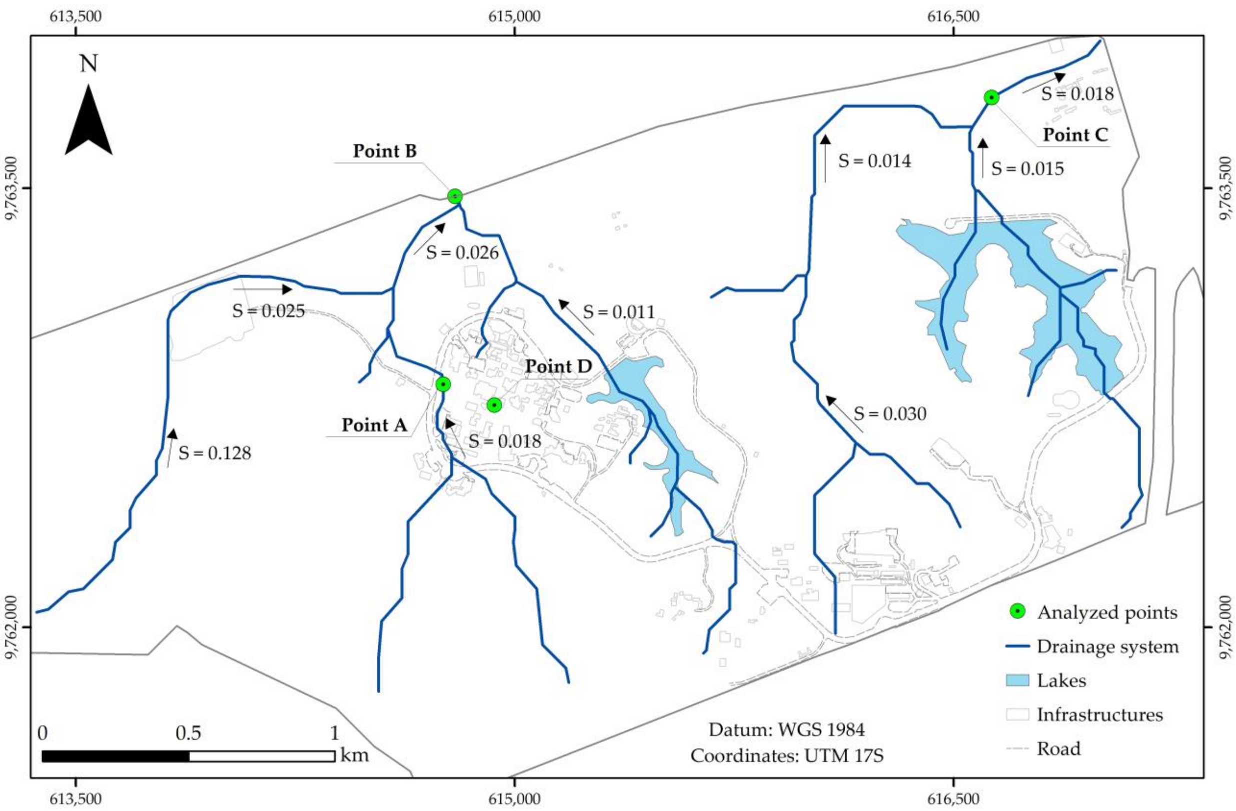

Figure 7. Pluvial system analysis.

In point D, there are infrastructures where concrete covers a large part of the soil. Unlike the natural ground, concrete does not allow water loss by infiltration, favoring the flow transit [74], making the area vulnerable to flooding due to the abovementioned conditions [75,76].

Point A currently has a trapezoidal section channel, while in point B and C, there is a natural channel with a rectangular section. Finally, the drainage system in point D consists of a Ø500 mm diameter pipe (Figure 8). The capacity evaluation used Equation (5).

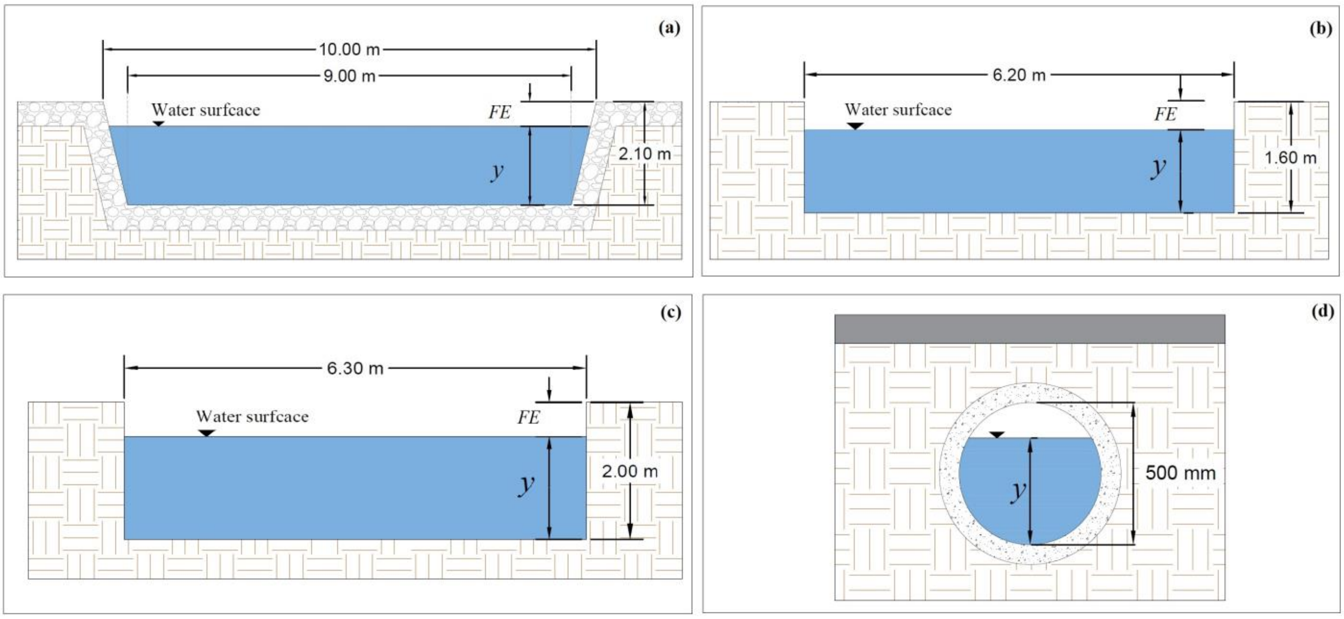

Figure 8. Existing channels. (**a**) Point A drainage system, (**b**) Point B drainage system, (**c**) Point C drainage system, (**d**) Point D drainage system.

Initially, the study considered a FE of 30% of the depth for the capacity analysis of the channels of points A, B and C. However, for point D, as it is a pipeline, it was considered that it works at 70% of its capacity, as indicated in the standard. Therefore, for point A, the analyzes carried out considered a depth of 1.60 m and a roughness coefficient (n) equal to 0.017 to calculate the existing system capacity. The results indicate that for a return period of 50 years, the canal works at 10% of its capacity, with the canal's capacity equal to 55.25 m^3/s, compared to a runoff flow of 5.41 m^3/s (Table 9).

Table 9. Current vs. future capacity ratio—Point A.

Trapezoidal Channel Analysis Point A			
Return Period (Years)	**Runoff (m^3/s)**	**Capacity Current Q (m^3/s)**	**Capacity Ratio (%)**
5	2.69	55.25	5%
10	3.28	55.25	6%
15	3.67	55.25	7%
20	4.03	55.25	7%
25	4.37	55.25	8%
50	5.41	55.25	10%

In point B, for a discharge of 1.20 m and a n = 0.03, the calculated flow was 12.33 m^3/s, so the channel would work at 110% for a return period of 50 years, representing problems in its hydraulic operation (Table 10).

Table 10. Current vs. future capacity ratio—Point B.

Rectangular Channel Analysis Point B			
Return Period (Years)	**Runoff (m^3/s)**	**Capacity Current Q (m^3/s)**	**Capacity Ratio (%)**
5	6.71	12.33	54%
10	8.21	12.33	67%
15	9.20	12.33	75%
20	10.15	12.33	82%
25	10.96	12.33	89%
50	13.58	12.33	110%

However, considering a free edge of 15% of the depth, the channel can drain 15.47 m^3/s; therefore, for a return period of 50 years, the canal would be working at 87% of its capacity without overflow problems.

For the channel in point C, with n = 0.03, the depth obtained was 1.50 m. Therefore, for a return period of 50 years, the flow would work at 35% of its capacity, so it would not present any problems in its operation either (Table 11).

Table 11. Current vs. future capacity ratio—Point C.

Rectangular Channel Analysis Point C			
Return Period (Years)	**Runoff (m^3/s)**	**Capacity Current Q (m^3/s)**	**Capacity Ratio (%)**
5	2.96	17.44	17%
10	3.63	17.44	21%
15	4.07	17.44	23%
20	4.50	17.44	26%
25	4.90	17.44	28%
50	6.08	17.44	35%

In point D, with n = 0.014 for a minimum return period of five years, the corresponding flow would be 0.64 m^3/s, which represents a problem because the pipe capacity is only 0.17 m^3/s (Table 12).

Table 12. Current vs. future capacity ratio—Point D.

Pipeline Analysis Point D			
Return Period (Years)	**Runoff (m^3/s)**	**Capacity Current Q (m^3/s)**	**Capacity Ratio (%)**
5	0.64	0.17	376%
10	0.77	0.17	453%
15	0.86	0.17	506%
20	0.93	0.17	547%
25	1.00	0.17	588%

Finally, the map in Figure 9 shows the drainage system implemented on the campus, which consists of a canals system and pipes that transport rainwater to the natural drainage systems. The piping that presents capacity problems and would cause flooding during rainy seasons can be seen (Figure 10).

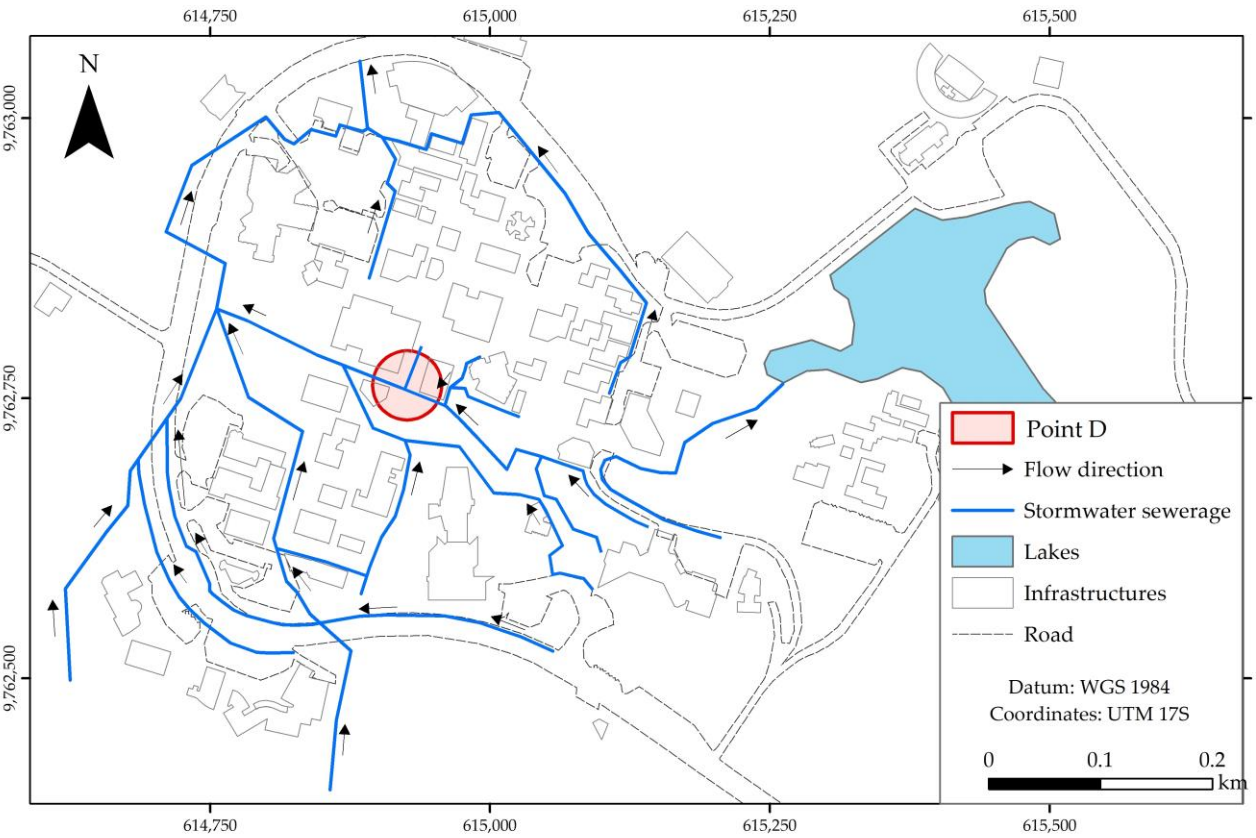

Figure 9. Drainage system implemented within the campus.

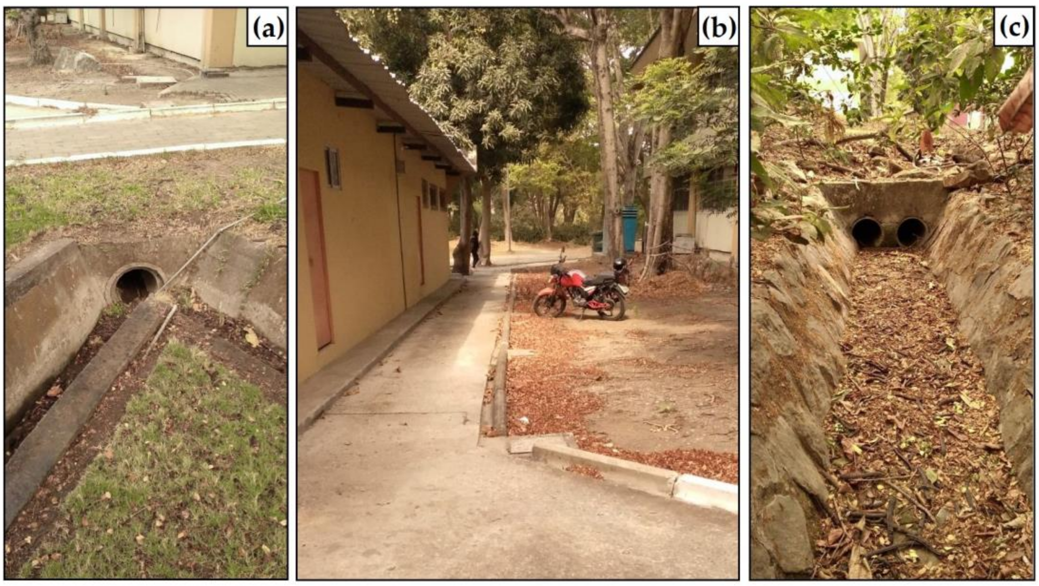

Figure 10. Point D analyzed: (**a**) pipe discharge into the canal; (**b**) stormwater inlet at point D; and (**c**) route of the stormwater collector.

3.4. Evaluation of Alternatives Using a Likert Scale

Based on the problems encountered in Point D, the alternatives for the solution are as follows:

- Alternative 1: Implementation of new channels and change of diameters in receiving pipes;

- Alternative 2: Implementation of green and blue solutions, creation of flood zones, green roofs, and use of permeable concrete.

The selected alternative that best fits the evaluated conditions considered the results obtained from the Likert scale, in which alternative one obtained a score of 36. For example, in the case of the slope, a value of one was considered for pitches against the direction of flow, two for slopes equal to zero, three for slopes between 0% and 2%, four for slopes between 2% and 7%, and five for slopes between 7% and 15%. Similarly, the assessment of the other conditions was carried out (Table 13). The Likert scale assessment method allows the measurement of the conditions presented by different scenarios in a qualitative or semi-quantitative manner. Therefore, this study assessed two alternatives regarding technical, social, economic and environmental factors, as has been done in other studies [12,77,78].

Table 13. Evaluation of alternatives by Likert scale.

Pluvial System	**Scores**	
	Alternative 1	**Alternative 2**
Technical considerations		
Natural Slope	4	4
Location and area	4	3
Preliminary studies	4	3
Social considerations		
Health Emergency	3	3
Population Growth	4	4
Economic considerations		
Construction costs	4	3
Equipment and machinery costs	3	3
Maintenance costs	3	3
Environmental considerations		
Impact on flora and fauna	4	4
Impact on protected areas	4	5
Change of natural watercourse	3	3
Total	36	35

3.5. Desing of Selected Proposal

The hydraulic performance of the selected alternatives contemplated a maximum return period of 25 years. The flow velocity for the proposed trapezoidal channel fluctuates between 1.50 m/s to 1.65 m/s, within the permissible range (Table 14). The results indicate that the existing pipe needs to be replaced by another one with a diameter equal to Ø1.10 m, resulting in a flow velocity of 1.65 m/s, complying with the minimum diameter and velocity requirements (Table 15). For the design of both solutions, the slope is equal to 0.003 m/m, which allows for obtaining a flow velocity within the range established by local regulations.

Table 14. Analysis of the proposed channel for different runoff flows.

Proposal 1: Trapezoidal Channel Design								
Return Period (Years)	**Flow Point D Q (m^3/s)**	**Sill (m)**	**Estimated Flow Depth (m)**	**Hydraulic Area (m^2)**	**Perimeter (m)**	**Water Surface (m)**	**Velocity (m/s)**	**Range of Permissible Velocities (m/s)**
5	0.64	0.50	0.62	0.43	1.80	0.87	1.50	
10	0.77	0.50	0.70	0.49	1.95	0.92	1.56	
15	0.86	0.50	0.74	0.54	2.05	0.95	1.60	0.60–4.00
20	0.93	0.50	0.78	0.57	2.13	0.97	1.63	
25	1.00	0.50	0.81	0.60	2.20	0.99	1.65	

Table 15. Diameter of the concrete pipe for the different return period (T).

Proposal 2: Concrete Pipe Design					
Return Period (Years)	**Runoff Flow (m^3/s)**	**Diameter Required (m)**	**Velocity (m/s)**	**Minimum Diameter (m)**	**Range of Permissible Velocities (m/s)**
5	0.64	0.88	1.50		
10	0.77	0.97	1.50		
15	0.86	1.03	1.50	0.25	0.75–5.00
20	0.93	1.06	1.50		
25	1.00	1.10	1.50		

The proposed channel and the pipe contemplate a length of 80.20 m, and because point D is a busy sector, the channel must be closed in certain sections. Therefore, the design of the proposed pipe considered that it should work at 80% of its capacity. The lining material of the channel, as well as that of the piping, is concrete (Figure 11).

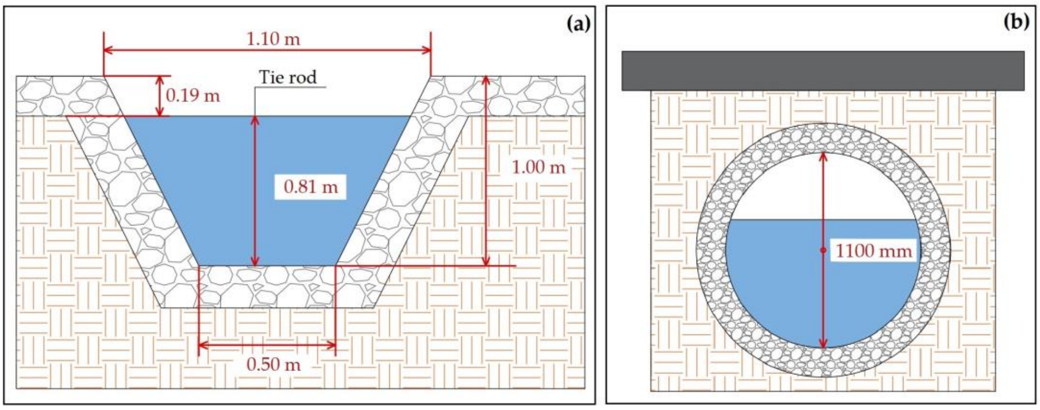

Figure 11. Proposed solutions: (**a**) trapezoidal channel design; and (**b**) concrete pipe design.

The flooding in point D is a consequence of inadequate planning, as it needs to consider the flow generated for a return period of 25 years following local regulations. In addition, the diameter of the existing pipe, despite being greater than the minimum recommended, needs more capacity to drain the water generated in this micro-watershed.

These floods generated cause material and health problems; therefore, implementing an adequate drainage system will prevent the stagnation of water, which is the means that allow organisms carrying diseases such as dengue or malaria, characteristic of tropical climates such as Ecuador, to proliferate [79].

Although the material damage present in the area does not reflect a significant severity, inefficient planning can lead to more serious consequences; such as the case of what happened on 31 January 2022 in the city of Quito, Ecuador, in the sector known as La Gasca, where a landslide, which consists of a flow of abundant water that drags with it loose material from a hillside or stream [80], occurred which left a total of 170 people affected, 28 dead, 41 houses affected, and seven houses destroyed. In addition to morphological conditions such as the presence of hillsides and ravines [81], inadequate management of the city's natural drainage, and poor territorial planning coupled with detonating events such as heavy rains or earthquakes, can increase vulnerability to flooding [82,83]. These events, under similar conditions, have also occurred in other areas of the world (e.g., [84–86]) affecting infrastructure and the safety of inhabitants.

3.6. SWOT Analysis

The strategies proposed in the SWOT analysis focus on optimizing the campus rainwater drainage system to avoid health problems and flooding. The analysis of external and internal aspects established strategies that promote the integral participation of authorities, teachers, students and ESPOL staff, as well as the application of sustainable techniques that allow the reuse and use of rainwater for different purposes and activities on campus (Table 16).

Table 16. Strengths, weaknesses, opportunities, and threats (SWOT) matrix analysis of current and proposed sewer system. The SWOT combining 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. Green areas for rainwater filtration. 2. Academic and logistical support for the improvement and implementation of solutions. 3. Independent pluvial and sanitary system. 4. Drainage plans and delimited basins with sufficient capacity. 5. As-built plans of the storm sewer system.	1. Lack of maintenance of the campus drainage system. 2. Natural habitat for vector proliferation. 3. Limited budget. 4. Lack of sufficient and trained personnel
Opportunities	Strategies: Strengths + Opportunities	Strategies: Weaknesses + Opportunities
a. Reuse rainwater for cleaning work on campus. b. Student learning in the development of degree thesis. c. Water sowing and harvesting through detention ponds (albarradas in Spanish). d. Recharge and replacement of water in ESPOL lakes.	2.3.b. Development of grade and postgrad studies for the evaluating the pluvial system considering climatic and infrastructure variations. 2.c. Permanent training for grade and postgrad students oriented to WS&H as NBS for the using rainwater. 3.4.d. Stormwater conduction system implementation that guarantees the water recharge from artificial lakes considering infiltration problems. 2.a.d. Conduct periodic studies of the quality and quantity of lake water for conservation and management.	1.4.a. Train personnel to maintain the pluvial system that guarantees the cleanliness and reuse of water. 2.a.b. Stormwater sewerage masterplan execution that solves flooding problems in the study area. 3.c.d. Design and implement WS&H techniques for storing and reusing stormwater as an ecological and economic solution. 3.b.c. Circular economy water project development with public and private interinstitutional collaboration for fundraising and NBS execution.
Threats	Strategies: Strengths–Threats	Strategies: Weaknesses–Threats
a. Health effects. b. Affectations to tangible goods and services. c. Climate emergency. d. Blockage of the drainage system due to the solid waste content	1.a. Stormwater distribution systems implementation to infiltrate green areas that prevent flooding and proliferation of vectors. 4.b. Strategic planning for the construction of future buildings considering drainage areas. 2.3.c. Research projects execution for effective water reuse in the conservation of endangered species located in the environmental protection zone of the campus.	1.2.a.b.d. Execute periodic maintenance and cleaning labours that prevent blocking of the pluvial system. 2.3.a.c. Environmental impact studies develop for future expansion projects. 3.c. Manage funds related to the climate emergency to strengthen the budget for sustainable water management.

In general, from the analysis, the importance of raising awareness among the population regarding water care through the application of nature-based solutions (NBS) is rescued. Among these, for flood control, there are green-blue infrastructures such as green roofs, retention, and detention ponds (albarradas in spanish), renaturalized rivers without sewers, ditches and 'bioswales', or rain gardens, generating a positive impact on social and environmental well-being [87–89]. However, the NBS should only sometimes be implemented as a solution since this will depend on the conditions of the problem and the environment where it develops, as has been done in other studies [90,91].

From the SWOT analysis, the recommendations mainly focused on the rescue of ancestral knowledge arise through the construction of albarradas for the natural storage of water, an NBS alternative that has little impact on the environment and whose effect on the hydrological cycle of water is minimal [92–94]. However, it is important to highlight that poor management would promote the proliferation of vector organisms such as rats, ticks, or mosquitoes [95].

Usually, the investment allocated for implementing these infrastructures is minimal due to a lack of knowledge or economic limitations, which translate into a cognitive bias [96,97]. Due to this, in the study area and general in the country, it is necessary to implement water policies that involve and promote NBS as efficient alternatives to technological solutions.

ESPOL has large extensions of green areas within the campus, in which implementing NBS would favor the ecosystem. However, point D represents a specific problem of strangulation of the drainage system due to the lack of capacity of the existing system. Therefore, as an immediate solution, it was proposed to increase the system's capacity using a trapezoidal channel or the replacement of the pipe with one with a larger diameter.

The proposed solution for the area with the flooding problems complements the study carried out [98], in which the implementation of NBS on the university campus was analyzed, such as rain gardens, infiltration fields, cisterns and permeable stone paving blocks. In his study, he considered the implementation of permeable stone paving blocks in an area containing point D. It was concluded that this solution has an efficiency of only 6.59% because it is a low point where other sub-watersheds are located. Therefore, implementing a technical solution through a trapezoidal channel or pipe replacement responds more effectively to adequate water transport and flood mitigation.

This study complements the masterplans proposed for the sanitary sewerage and drinking water systems [53,54], strengthening the management of water and sanitation on the ESPOL campus through technical, social, environmental, and economic criteria through specific technical solutions in areas with flooding problems. In addition, the masterplan contemplates NBS components that could be applied in the medium and long term in environmental protection, avoiding the disturbance of ecosystems by engineering works. Furthermore, implementing the designed proposals promotes and creates awareness in the ESPOL community about the circular economy of water and offers the appropriate environment for the different geotourism and geoeducation activities, considering the geological and biodiverse wealth of the campus [52].

The integration of technical solutions and NBS on the university campus represents a responsible and preventive water-management model before future scenarios, which can be replicated at the regional level as an alternative to mitigate climate change's effects [99,100] and contribute to fulfilling the fulfillment of Sustainable Development Goals (SDGs) of UNESCO [101,102].

4. Conclusions

The masterplan allowed for the global drainage evaluation, determining that the system does not present problems at the macro level. Three essential aspects stand out from the results obtained:

- The integration of technical-academic knowledge in the development of a stormwater masterplan for a university campus demonstrated the importance of water management in areas where, despite not being considered, poor planning generates damage to infrastructures and put the health of inhabitants at risk;
- The development of SWOT analysis in decision-making for managing water resources allows for the proposal of holistic strategies from the social, academic, and governmental points of view, which guarantee the functionality of sewerage systems and water reuse in the short, medium, and long term;

- Ancestral (traditional) knowledge is important through NBS for collecting and managing water, as 3E (Ecological, Economic, Effective) alternatives, and are replicable locally and regionally.

At the micro-drainage level, a punctual flooding problem exists in point D. This study allowed for the design of a solution in which technical, environmental, social, and economic criteria were considered through the implementation of a trapezoidal channel, with a capacity of 1.00 m^3, or a Ø1100 mm pipe diameter, adequate for a return period of 25 years.

Additionally, the authors recommend that, in the future, it will be important during the execution of study to evaluate of the capacity of the external sewage system in which the flow is managed on the campus and discharged. This will help to avoid flooding problems in peripheral areas (populated with little infrastructure).

Finally, this study raises the possibility of further research needed to evaluate the efficiency and implementation of NBS in different areas of the university campus in order to use the rainwater and avoid alterations in the water cycle.

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