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Hill Dam Design to Improve Water Use in Rural Areas—Case Study: Sacachún, Santa Elena

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Abstract: The Sacachún commune in Ecuador currently faces a lack of water for its agricultural development; this reduces its possibilities of socio-economic development and causes migration to urban areas. This research proposes a *presa colinar* (hill dam) design that uses ancestral knowledge and classic engineering techniques to promote water use during the dry season in semi-arid regions. The methodology consisted of: (i) a systematic compilation of the ancestral structures used for water planting and harvesting in Ibero-American; (ii) selecting an appropriate place to build the hill dam; (iii) the dam's body design; (iv) and creating a proposal for agricultural water use. The results helped define a good location for the hill dam implementation. In addition, a 10 m high and 40 m wide earthen dam was designed, with a storage capacity of 114,341 m^3, extending agriculture to 7.5 ha through a polyculture system of six different plants. The embankment has a cofferdam located downstream, which provides stability in static and pseudo-static conditions. In addition, the dam slopes have a 2:1 ratio, and a spillway channel and filter drain were dimensioned to protect the dam.

Keywords: dam; water collection; water management; ancestral knowledge; rural communities; nature-based solutions

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1. Introduction

Water is an essential resource that can guide a country or community toward sustainable development [1]. In 2015, the National Union established the sixth objective within the already existing sustainable objectives to "guarantee the availability and sustainable management of water and sanitation for everyone" [2]. However, despite the efforts of governmental entities to guarantee access to water sources, there is an evident contrast between rural areas or small settlements that experience constant water insecurity, in comparison to urban areas [3].

Physical water scarcity is defined as an issue presented when there are insufficient water resources to meet a territory's demand [4]. Economic water scarcity, on the other hand, is defined as the absence of investment, technical personnel, and institutions to manage the available renewable resources [5]. The ravages of physical water scarcity are evident in arid and semi-arid areas, where precipitation occurs in short periods throughout the year, causing food insecurity, child malnutrition, agricultural losses, and threatening the social and economic growth of the regions [6–8].

In developing cultures, agriculture serves as a shield against poverty by creating employment and social development [9]. Sadly, the agricultural sector is the most affected by droughts and water scarcity, given its dependence on water availability and soil humidity [10]. Drought periods can affect crop growth, photosynthesis, and carbon metabolism, reducing crop performance and as a result affecting the economic stability of the region [11]. The limited availability of either surface or underground water resources makes it necessary to find new water sources and use them optimally [12,13]. Sustainable agricultural development relies upon developing new technologies and practices to avoid adverse effects on goods and the environment, while improving food productivity [14,15].

Rainwater harvesting is an alternative that increases the water supply for different human activities [16]. It consists of retaining rainwater and storing it to be used in the future as either a principal or secondary water source [17]. Rainwater is the most accessible and transient water source for arid or semi-arid areas, as a result, its storage and exploitation are of great importance [18]. Rainwater can be stored in the earth, in dams, or containers, or it can be redirected to recharge aquifers, which in turn have productive uses as drinking water, cattle water and irrigation water [19].

Rural communities worldwide have used and encouraged the use of ancient techniques to increase water supply without compromising the natural environment [20]. On the Ecuadorian coast, the areas with difficult access to water use hydraulic structures that create artificial wetlands by storing rain. These constructions are known as "albarradas" (closed structures with permanently stagnant water) [21]. Albarradas are constructions made of earthen walls, that for centuries have allowed ancestral communities to obtain and use hydric resources equitably and sustainably [22]. Its construction and operation are based on traditional knowledge and ancestral practices, based on the natural processes of the environment, which makes it a nature-based solution (NBS) [23].

NBS are strategies developed to confront water scarcity, while prioritizing the conservation of the local ecosystems [24,25]. NBSs divide into three types: (i) none or minimal ecosystem intervention; (ii) managed intervention of an ecosystem in search of sustainability; and (iii) creating or profoundly modifying ecosystems to create green or blue solutions [26]. In addition, a NBS in water management can be adapted to mitigate the ravages of extreme events such as floods or droughts [27,28].

The presa colinar (hill dam) is a concept that merges ancestral knowledge with the use of NBSs in a specific location with the intention of obtaining small reservoirs with a greater capacity [29,30]. The hill dam is an earth structure that stores rain. Globally and nationally, a great variety of earth made dams have been built. For example, in Ethiopia, over the last 20 years, around 92 dams and micro-dams have been built to supply the water demand of its agricultural sector [31]. A small-scale dam construction program was implemented in Ghana in 2016 to provide water for human consumption and agricultural demand [32]. In Ecuador, 150 albarradas have been built in Santa Elena, and another 252 in Manabí and Guayas, with the main objective of mitigating the negative effects of the dry season [33].

This research proposes a presa colinar (hill dam) design in semi-arid regions. The design uses ancestral knowledge regarding water planting and harvesting and adapts it into a modern design incorporating classic engineering technics. In addition, the design seeks to promote water use for the development of local agriculture through the context of Nature Based Solutions (NBS).

The study is divided into four phases. The first phase focuses on reviewing hydraulic structures for water planting and harvesting that use ancestral techniques to store and increase water reserves through Nature-Based Solutions (NBS). The second stage corresponds to the selection of the site where the hill dam will be implemented; this includes the topographic survey and the supply basin delimitation. The third phase focuses on adapting ancestral technologies to modern engineering designs by including hydrological studies and soil tests using on-site materials as part of the NBS. The fourth and final stage proposes sustainable water use for resilient agricultural production.

Study Area

Located in the coastal area of Ecuador, south of the Santa Elena province, in the Simón Bolívar parish, is the Sacachún commune with an extension of 12,822.68 hectares (Figure 1). The predominant vegetation in the region is typical of tropical dry forests. Only a small extension of land is used for agricultural purposes due to limited access to water sources. Nevertheless, the commune is rich in cultural resources representing the history of the Manteño - Huancavilca culture and its heritage; an example is the San Biritute monolith, a 2.35 m high pre-Hispanic sculpture associated with rain and fertility, carved in a marine conglomerate [34].

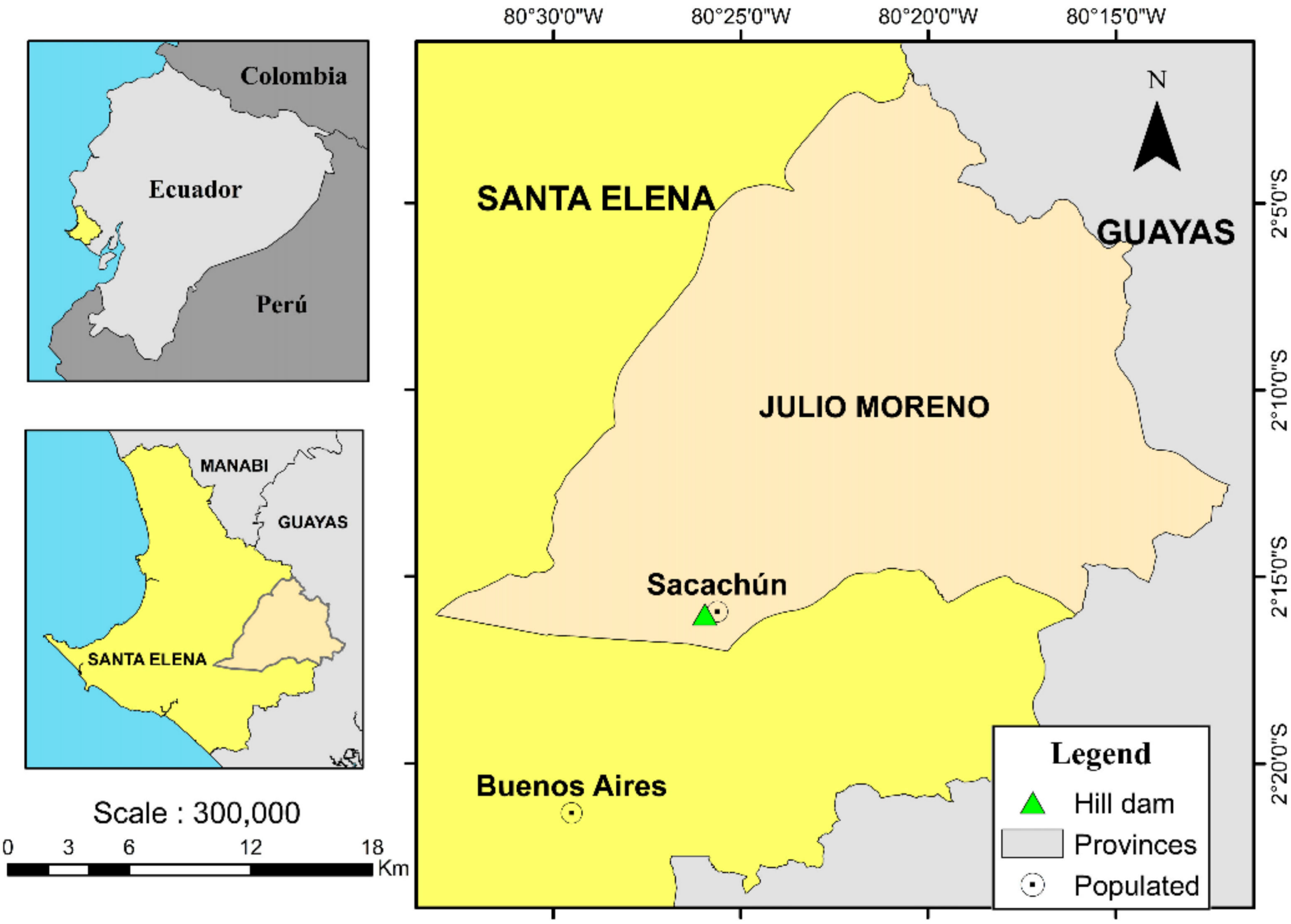


Figure 1. Location map of the Sacachún commune, province of Santa Elena.

From a geological point of view, the study area soil is composed of volcanic materials (Piñón Formation) and sedimentary volcano materials (Cayo Formation). On top of these materials there are cretaceous and tertiary sedimentary materials [35–39]. The study area's relief is made up of plains and undulating hills, with medium to gentle slope [40]. In terms of the site's hydrography, Santa Elena has 12 units of different stream order born in the Chongón-Colonche mountain range; one of these is the Zapotal River. The watershed and ravines found in Sacachún are made up of intermittent rivers, that is, rivers without runoff or water flow in the dry month of the year, which generates an arid ecosystem [41].

According to Köppen classification, the region's prevailing climate is hot and semi-arid [42]. Similarly, the study area has a dry, mega-thermal or hot climate [43]. There are two seasons: the wet season from December to May, with maximum temperatures of 28 °C; and the dry season, from June to November, with low temperatures of up to 23 °C. Rain occurs in short periods of the year, with an annual precipitation of less than 500 mm [44]. The lack of accessible natural water sources, and the long periods of drought, make agricultural production impossible, especially when water is restricted to human and animal consumption, limiting its use in agriculture. In the present day, the Sacachún commune lacks water for their agricultural development, which generates poverty, and population migration to urban areas.

The Sacachún commune opted for the construction of underground wells to obtain water during the dry seasons. However, this source does not cover the demand, and as a result, water must be transported from the Buenos Aires commune and used only for human and animal consumption [45]. The low availability of surface water motivated the inhabitants to build an artisanal embankment to dispose of water in the dry months. However, these structures tend to collapse during the winter season as a result of the dam's overflow, erosion, and poor construction practices [46].

2. Materials and Methods

This article presents the proposed design of hydraulic dams intended for water use. Figure 2 organizes the four phases and its corresponding activities. Subsequently, a detailed description of phase 3 used for the design of the hill dam is presented in Figure 3.

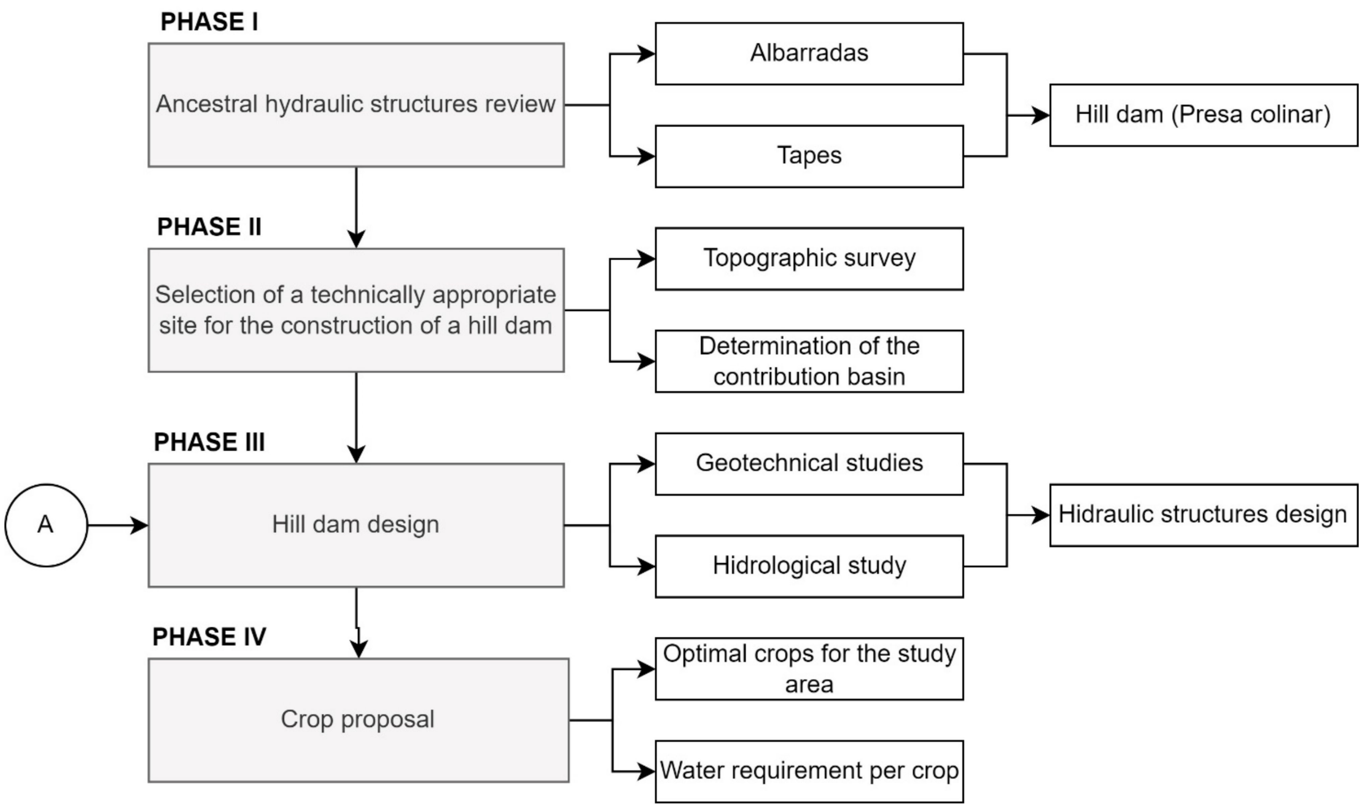


Figure 2. Applied methodology for the hydrological and hydraulic small dam design.

2.1. Ancestral Hydraulic Structures Review

During this review, a search for information pertaining to the ancestral storage structures that are still used in Spanish and Latin American towns, as a result of their semi-arid conditions, was carried out.

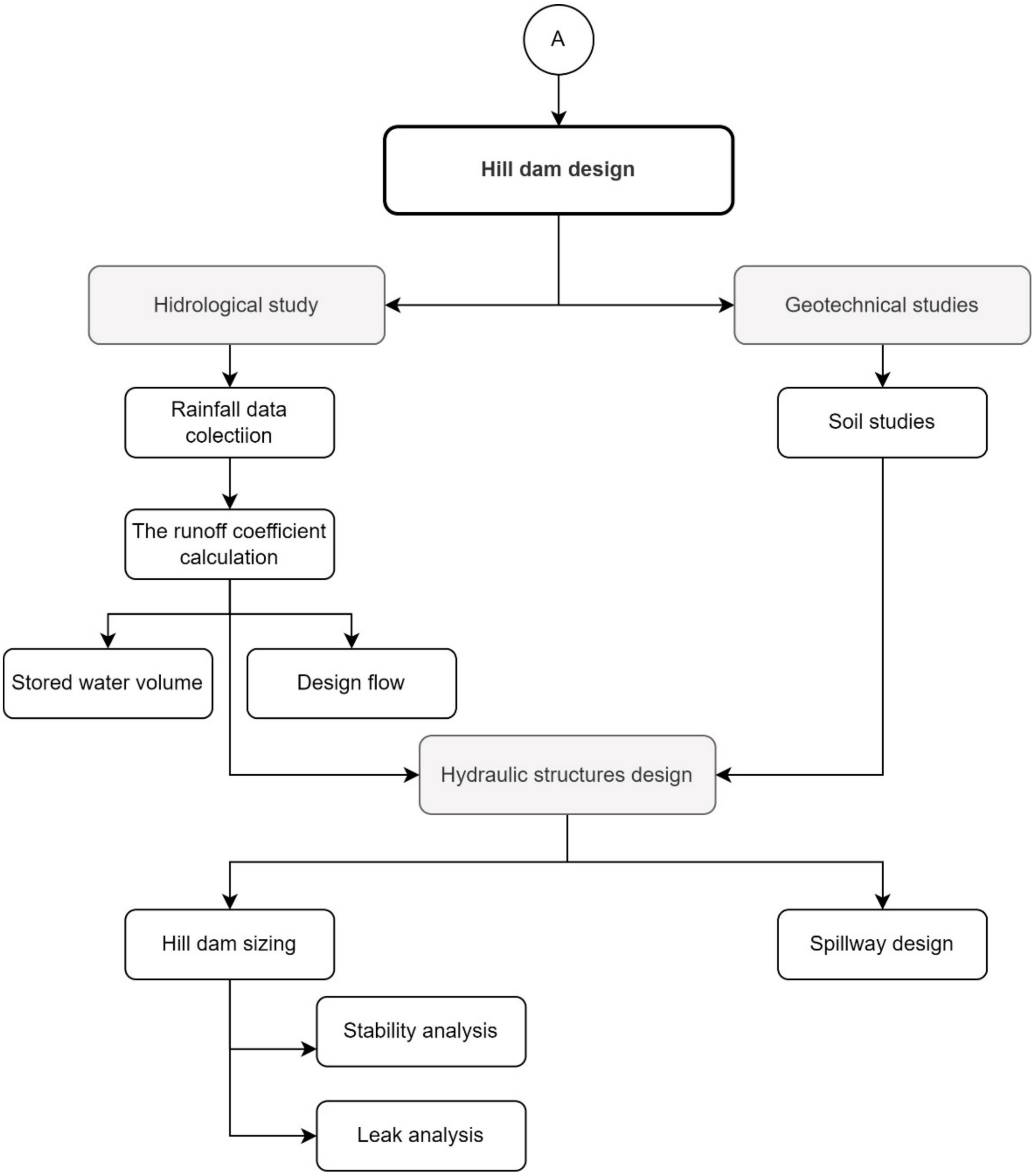


Figure 3. Phase III of the hill dam design.

2.2. Selection of the Technically Appropriate Site for a Hill Dam

The first phase consisted of field visits and laboratory tests to determine the environmental and geotechnical characteristics of the construction area. The fieldwork included the visual inspection of the dam site, a topographical survey, and digging one-meter-deep pits to take soil samples.

The topographical survey used a GPS-RTK (Real-Time Kinematic) to obtain relief information of the dam basin. GPS-RTK is a high-precision differential measurement system for real-time observation, consisting of a reference station and a mobile station [47]. The GPS-RTS took two hundred points distributed every 20 m to obtain a detailed representation of the slope variation of the land in the study area. Subsequently, a Civil3D project generated the contour lines of the surface and determined the volume of the reservoir.

The Digital Elevation Model (DEM) of ALOS-PALSAR (Advanced Land Observing Satellite- Phased Array L-band Synthesize Aperture Radar) by the Alaska Satellite Facility

(ASF), with a spatial resolution of 12.5 m, helped determine the inflow basin and its characteristics. In addition, the ArcGIS plugin ArcHydro [48,49] identified the drainage lines of the study area by defining the flow lines using the DEMs [50].

Finally, geotechnical studies took place to determine the resistance and characteristics of the material in the area. The specific studies were: particle-size analysis of soils; modified proctor compaction test; measurement of hydraulic conductivity of saturated porous materials using a flexible wall permeameter; and a direct shear test of soils under consolidated drained conditions.

2.3. Hydrological Study

The hydrological study considered 19 years of data interpretation provided by the National Institute of Meteorology and Hydrology (INAMHI), from 1995 to 2013 [51]. The data came from the El Azúcar weather station, the station with the most significant influence on the basin, which provided a more specific interpretation. Probabilistic methods predicted the behavior of annual rainfall (e.g., Gumbel type I distribution, which uses data on the maximum monthly precipitation for each year). This method made it possible to determine the maximum probable daily precipitation for different return periods. According to Weiss 1964, the real precipitation differs from the calculated, as a result the obtained values were readjusted by multiplying them by 1.13. Equation (1) determined the intensity, where P is the amount of water and T is the duration of the rain. Next, the coefficients proposed by Campos [52] were used to redistribute daily rainfall by hours. Finally, the Intensity-Duration-Frequency (IDF) curves were plotted:

$$I = P/T, \tag{1}$$

The rational method formula determined the estimation of the design flow by associating the runoff coefficient (C), the rainfall intensity (I), and the area of the drainage basin (A) (Equation (2)):

$$Q = C \times I \times A/3.6, \tag{2}$$

The method known as curve number (Equation (3)) obtained the runoff coefficient (C), which requires data on the runoff threshold (Po), which depends on the potential retention (S) (Equations (4) and (5)). The curve numbers (CN) obtained come from the combinations of the water group and the land use to which the area belongs; these values are extracted from tables [53]:

$$C = [(Pd - Po) \times (Pd + 23 \times Po)]/(Pd + 11 \times P0)^2, \tag{3}$$

$$S = [25{,}400/(CN(I)] - 254, \tag{4}$$

$$Po = 0.2 \times S, \tag{5}$$

The probable water volume of the dam was calculated using annual rainfall records. These records were listed and ordered in descending order. Subsequently, the calculus of its probability of occurrence P(%) took place using Equation (6), where m represents the order number and N, the total number of observations [54]. The data obtained helped establish a trend curve and choose precipitation with an exceedance probability that guarantees the water supply. Finally, the calculation of the probable volume to be stored took place by multiplying the basin area by the rainfall:

$$P(\%) = [(m - 0.375)/(N + 0.25)] \times 100, \tag{6}$$

2.4. Geotechnical Study

Geotechnical studies were conducted to determine the resistance and characterize the local material of the area. Studies such as particle size analysis, modified proctor test, variable head permeability test of soil, and direct shear test of soils, were carried out.

2.5. Hydraulic Structures Design

The reservoir design followed the parameters established by the United States Bureau of Reclamation (USBR), which considered the climate, geography, and soil, among other aspects. Additionally, technical-economic criteria helped analyze the most viable design while using the material extracted from the area.

The dimension of the embankment's crown considered several factors such as the level of importance of the construction, the geomechanically properties of the materials, the minimum filtration distance, and the possibility of an access road on the embankment (USBR) [55]. Based on these factors, formula 7 was used. The formula was obtained from the USBR book for the design of small dams, where Z represents the height of the dam in meters and W is the crown width:

$$W = (Z/5) + 3, \quad (7)$$

The GALENA software guaranteed the stability of the slopes by using the SPENCER-WRIGHT analysis method [56] for circular and non-circular failure surfaces, and the Sarma method in cases where vertical cuts were not required [57]. The analysis established two load states: static and pseudo-static. The input parameters entered were: angle of friction; cohesion; the volumetric weight of the material; geometry of the dam body; maximum reservoir level; and saturation line. The pseudo-static analysis required the maximum ground acceleration of the study area, established in the national seismic zoning map of the Ecuadorian Construction Standard [58]. Given that the Sacachún commune is an area of highhigh seismic hazard, a maximum ground acceleration (PGA) of 0.6 g was used.

The flow method, which consists of two orthogonal solutions of the fundamental water flow equation, determined the seepage analysis in the dam's body (Laplace's equation) [59]. Subsequently, the GeoStudio software [60] performed a computational filtration analysis.

Darcy's Law (Equation (8)) helped analyze the infiltration rate. Equation (8) transforms into two-dimensional modelling Equation (9). Where k corresponds to the permeability coefficient, H the head loss inflow, Nf the number of flow lines, and Nd, the number of equipotential lines [61]:

$$Q = k \times i \times A, \quad (8)$$

$$Q/L = k \times H \times (Nf/Nd), \quad (9)$$

The water must evacuate quickly to avoid filtration failures. Therefore, this study proposes the implementation of a gravel-sand filter to minimize the risk of failure. In addition, the saturation line must be located within the face of the slope downstream, and the flow of water must not remove any particles, avoiding internal erosion [62].

Finally, a hydraulic system designed to regulate the flow inside the dam will protect the structure from possible overflows. However, given the small drainage sub-basin characteristics, it is estimated that the spillway would only work occasionally. Therefore, this study proposes using the region's materials and elements to save resources. The spillway design is a shallow earth channel with vegetation cover. Thus, the spillway dimensions calculated to withstand extreme events had to be less than and equal to the design flow. For this purpose, the Manning equation (Equation (10)) and the geometric properties of the hydraulic structure were applied. For an optimal design, the water depth was half the width of the bottom of the channel:

$$Q = (1/n) \times A \times Rh^{2/3} \times S^{1/2}, \quad (10)$$

2.6. Crop Proposal

This phase of the study proposes agricultural activities considering the water resource availability. The existing bibliography and the consultation of personnel specialized in the subject were used to estimate the arable hectares, the product to be cultivated, define the optimal types of crops in the area, the form of irrigation, and the water needs for crop development.

3. Results

3.1. Ancestral Hydraulic Structures Review

The information regarding six countries and 10 ancestral structures, used since pre-columbine times for an effective use of water, was found during phase I. The details are presented in Table 1.

Table 1. Ancestral hydraulic structures.

Country	Ancestral Hydraulic Structure	Structure's description	Function
Ecuador	Albarrada	Structures made of earth walls	Wetland formation Aquifer recharge
	Tape (artisanal dam)	Accumulation of rocks and sediments in a section of a river.	Aquifer recharge
Colombia	Agricultural Camellones	Land platforms surrounded by wide water channels.	Maintain moisture in the fields during droughts
Peru	Amunas	Canals built with impermeable Stone on permeable ground	Artificial aquifer recharge
	Acequias	Canals that capture water even in permeable areas	Artificial aquifer recharge
	Qochas	Dug wells connected by small canals	Artificial aquifer recharge
Spain	Acequias de careo	Canals dug into the ground to collect water from melting ice	Artificial aquifer recharge
Mexico	Terrazas (terraces)	Canals and aqueducts	Retain moisture and reduce crop's soil erosion
	Qanats	Underground Aqueducts	Artificial aquifer recharge
Chile	Capta niebla	Takes advantage of the water droplets present in fog	Capable of producing around 10,000 L in 8 h

Towns suffering from droughts find ways to implement small easy-to-build structures capable of storing water during the rainy season to use said water during the dry season. In this context, the presa colinar (hill dam) is a first term introduced in another research paper [28] to refer to a special type of containment system based on ancestral hydraulic structures (Albarradas Towns suffering from droughts, tape) that also apply technical and specialized construction techniques. As a result, the presa colinar has a greater storage capacity than tapes and albarradas, and given the implementation of technical designs, it has a greater guarantee of stability and safety. Hill dams also have low construction costs compared to traditional structures made of concrete, and their implementation and maintenance do not require specialized personnel.

3.2. Selection of the Technically Appropriate Site for the Construction of the Hill Dam

The hill dam will be located next to the Sacachún commune, in a ravine that forms an intermittent river. The topographic survey determined the location of the dam axis. Therefore, the chosen site has the shortest length (119.18 m), allowing considerable material savings. In addition, this site presents the best geomechanically and topographical characteristics for an embedment. The study area's selected location and contour lines are shown in Figure 4.

Sacachún's hill dam supply basin is estimated to be 38 hectares (Figure 5). The basin also has a perimeter of 3850 m and a maximum channel length of 1229 m. Its compactness index is 1.72. Additionally, the form factor reaches 0.25, and the average slope is 16.64%.

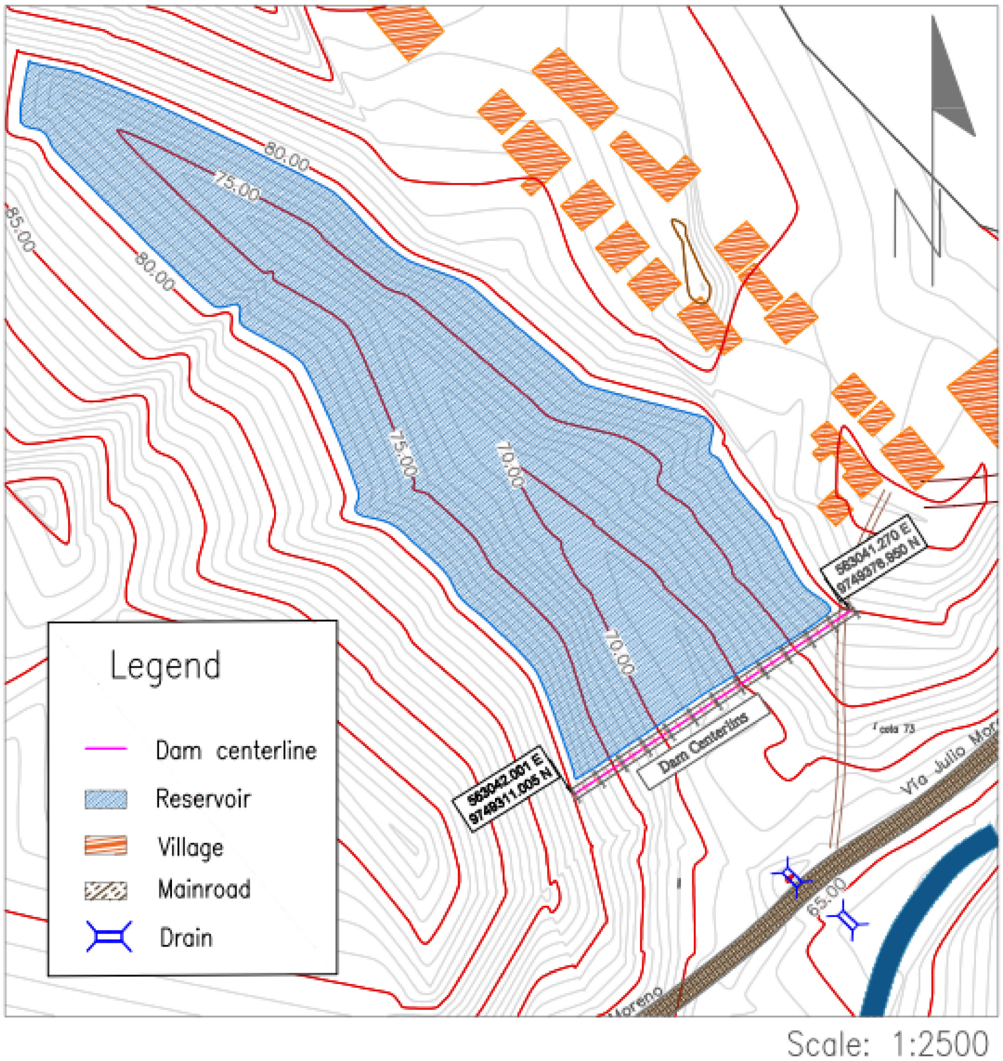


Figure 4. Relief and location of the dam body.

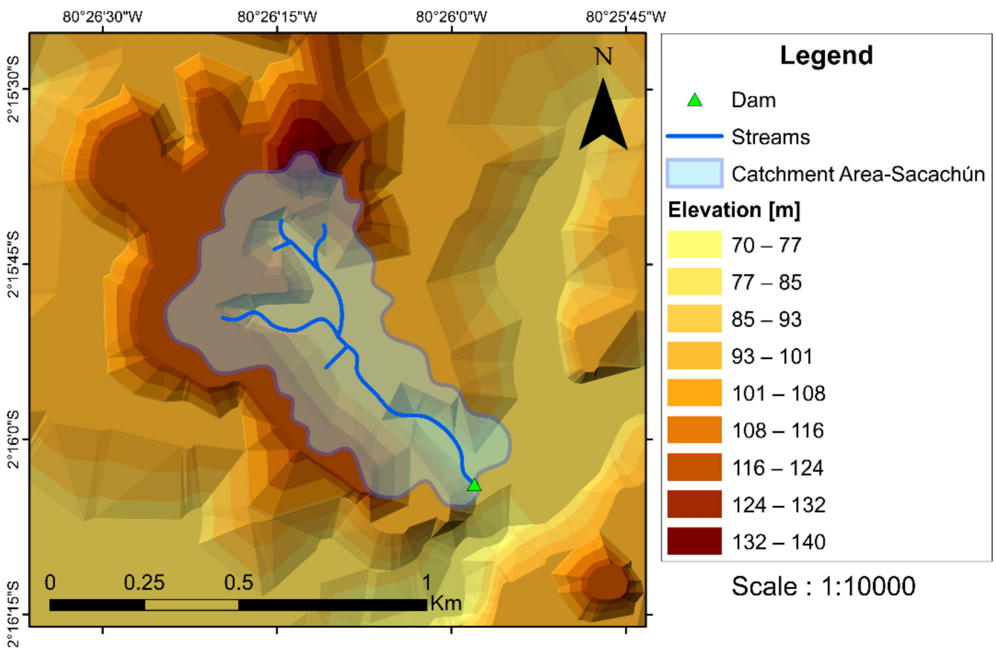


Figure 5. Drainage basin-Sacachún dam.

3.3. Hydrological Study

The selection of precipitation with a duration of 5 min and a return period of 50 years for the hydrological studies resulted in intensity of 177.8 mm/h (Figure 6). The runoff coefficient and the design flow results are in Table 2.

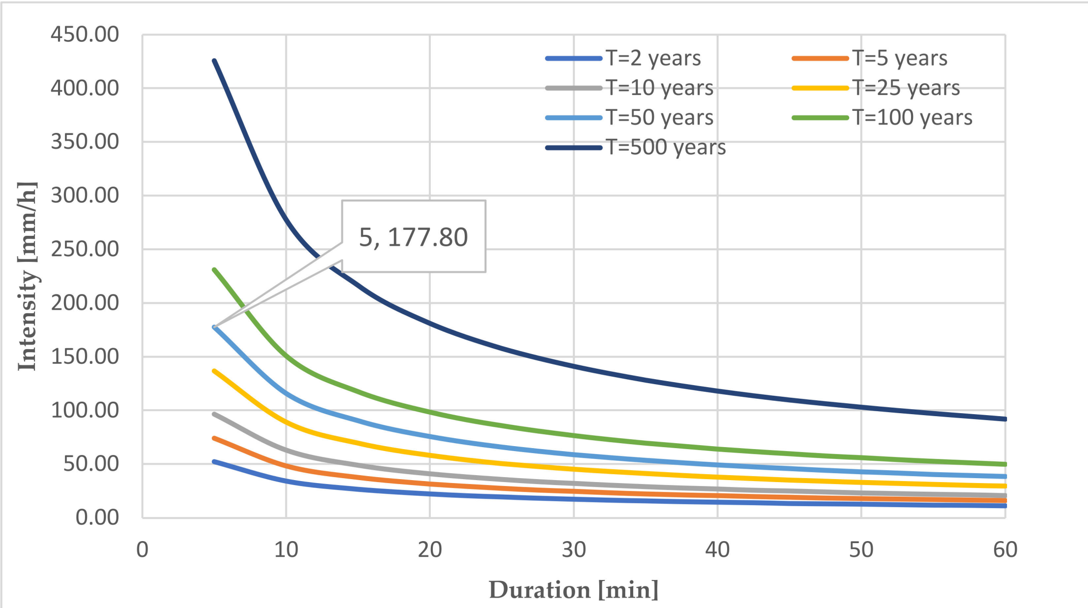


Figure 6. Results of statistical studies, IDF curves.

Table 2. Data from the calculation of the runoff coefficient, for the determination of the design flow by the rational method.

Runoff Coefficient		
Curve number (CN)	Hydro group C Land destined for forests	70
Potential retention (S)	259.19 mm	
Runoff threshold (Po)	51.84mm	
Probable Maximum Precipitation (P)	145.44 mm	
Runoff coefficient (C)	0.24	
Design flow		
Contribution basin area (A)	380,000 km^2	
Rain intensity (I); T = 50 years	177.8 mm/h	
Runoff coefficient (C)	0.24	
Design flow (Q)	4.5 m^3/s	

Precipitation with a recurrence probability of 75%, which corresponds to 124.84 mm, was selected to guarantee an adequate water supply. This precipitation, combined with the drainage basin area, resulted in a minimum annual volume of 47,440 m^3.

3.4. Geotechnical Study

According to the geotechnical study, the Sacachún commune contains silty sand, as established by the Unified Soil Classification System (USCS) [63]. The predominant soil in the area has a thinness of less than 40% (Figure 7). It has a liquid limit of 40.96% and a plastic limit of 26.07%; therefore, its plasticity index is 14.05%, which shows that the soil is plastic and compacts satisfactorily. The material is poorly permeable, with a hydraulic conductivity of 3.11×10^{-7} m/s. The maximum dry density is 1751.42 kg/m^3, with the optimum moisture content of 11.97%. The sample with the desired moisture content obtained an internal friction angle and cohesion values of 33 and 4.83 kPa. These values determined that the soil has a low shear resistance.

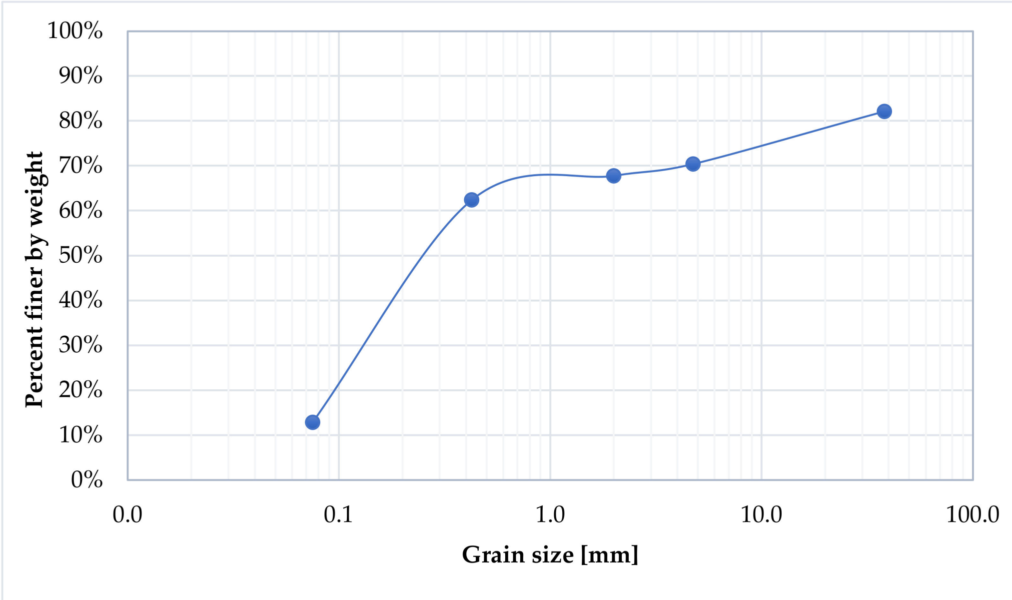


Figure 7. Characteristic granulometric curve of the dam vessel material.

3.5. Hydraulic Structures Design

The proposed dam's height, selected based on the location and fieldwork, is 10 m, measured from the foundation to the crown. In addition, a 1 m free edge was defined to avoid overflow on the crown. The crown of the dam locates at 80 m above sea level, and the maximum standard level of operation of the presa colinar is 79 m above sea level. Therefore, the width of the crown is equal to 4 m.

The selected ratio was 2H:1V for the upstream and downstream slopes. Additionally, the dam will have a 22 m embankment reinforcement at the foot of the slope, located 73 m above sea level. The slope ratio of 2H:1V is maintained, as shown in Figure 8. The embankment implementation is a reinforcement technique that counteract the low resistance of the material that forms the dam's body. Without the addition of this reinforcement element, the dam would be unstable and could fall in the face of seismic movements. As a result, this embankment increases the safety factor (SF).

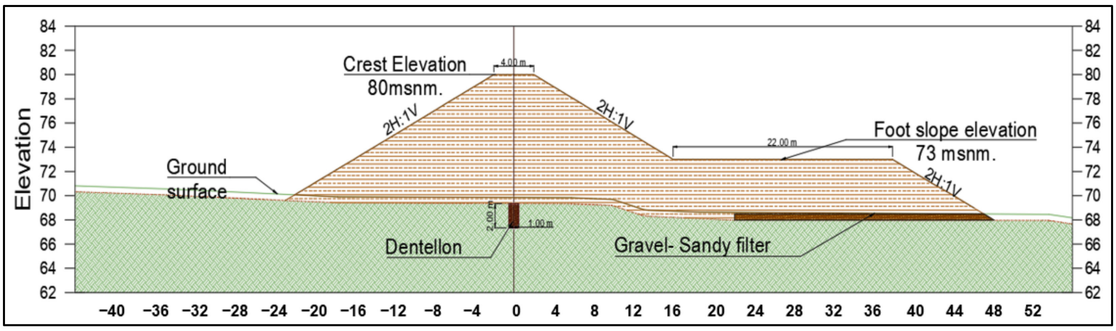


Figure 8. Cross section of the dam body.

The stability analysis determined that it has a safety factor (SF) value of 1.76 for static conditions in the stability analysis (see Figure 9).

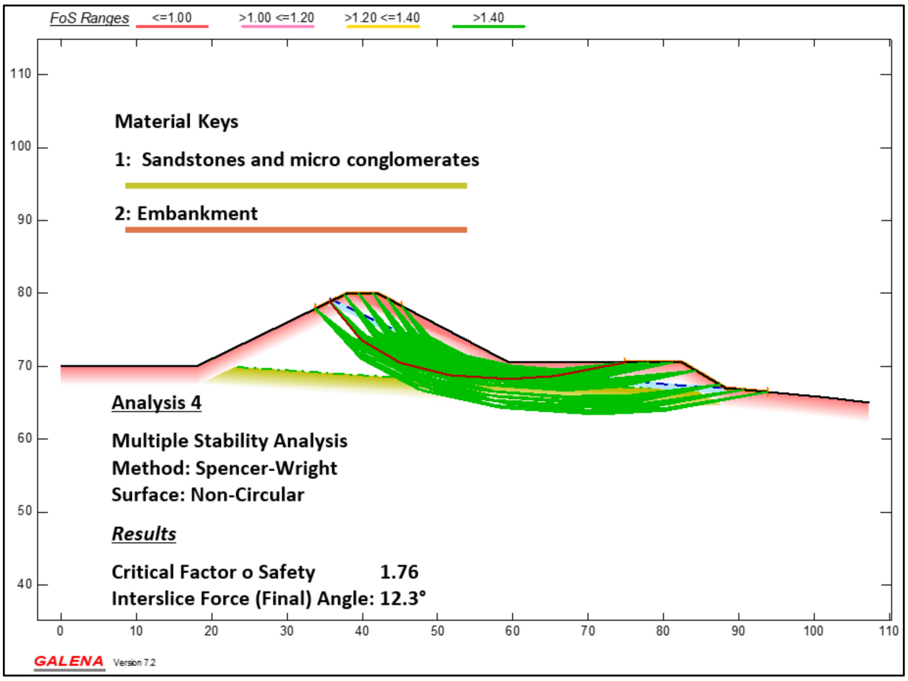
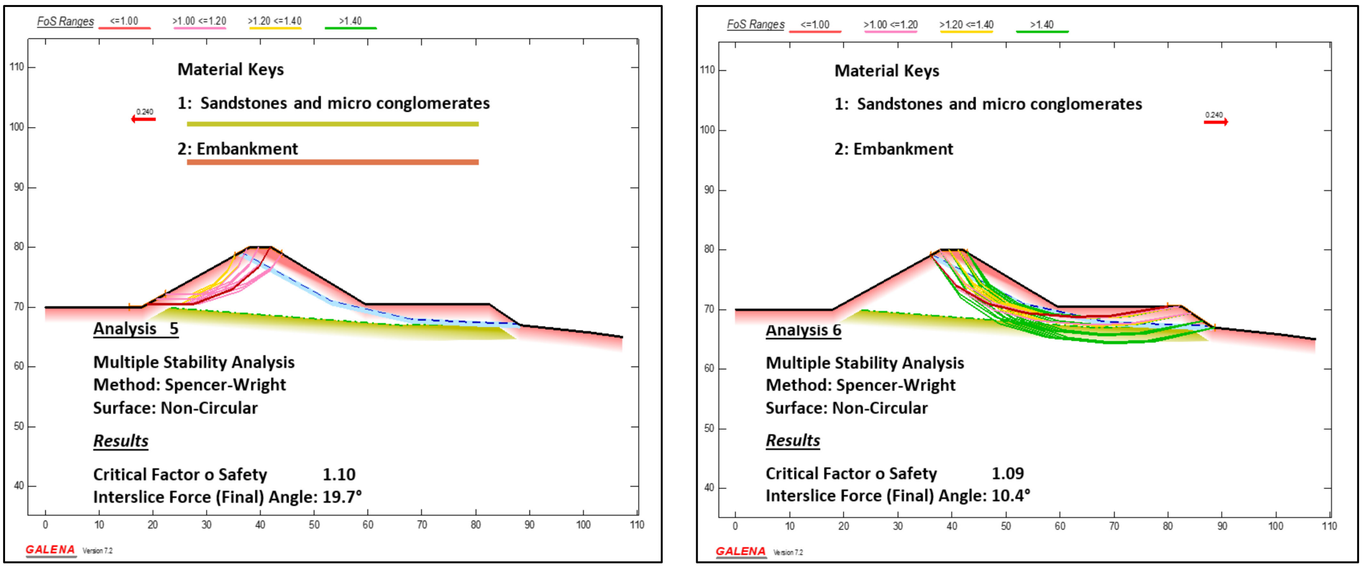


Figure 9. Dam stability analysis under static conditions y un SF = 1.76.

Figure 9 showcases the stability analysis for the *presa colinar* in static conditions using the Galena Software. The green lines represent the fault surface. According to the Ecuadorian Norms of Construction (NEC, Spanish acronym), the minimum-security factor value must be 1.05. This study's security factor was 1.76, indicating strong construction stability [58].

In addition, the pseudo-static analysis considered 40% of the maximum acceleration corresponding to the study area (NEC-SE-GC). The result is a seismic acceleration value of 0.24. The safety factor is 1.10 and 1.09 for upstream (Figure 10a) and downstream (Figure 10b), respectively. This indicates a decrease in the 1.76 value in static conditions by 37% compared with the pseudo-static analysis. However, in both cases, these values are higher than the minimum safety factor of 1.05 recommended by the NEC [58].



(**a**) (**b**)

Figure 10. Upstream slope's stability analysis in pseudo-static conditions SF = 1.10 (**a**), and downstream analysis in pseudo-static conditions SF = 1.09 (**b**).

The dam's leak analysis, done before and after incorporating the gravel-sand filter (Figures 11 and 12) is in Table 3.

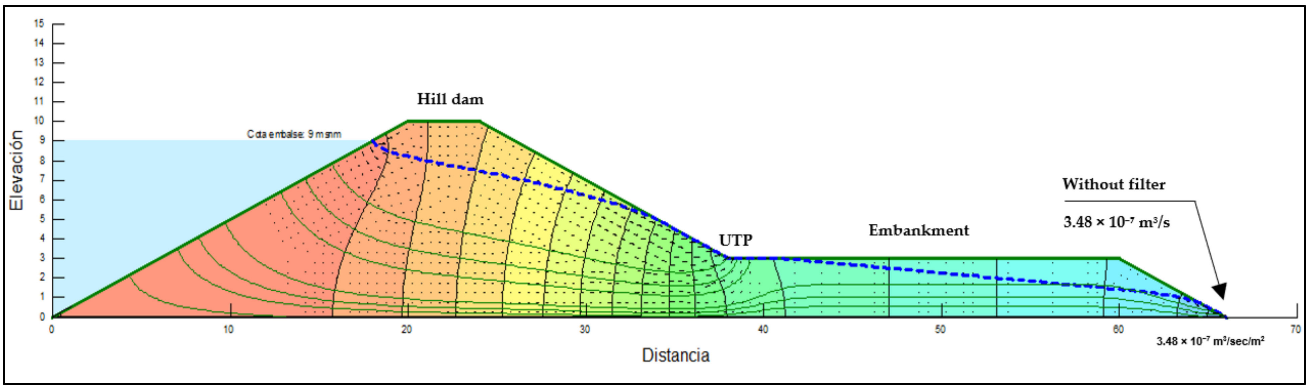


Figure 11. Flow networks in the body of the dam, without filter.

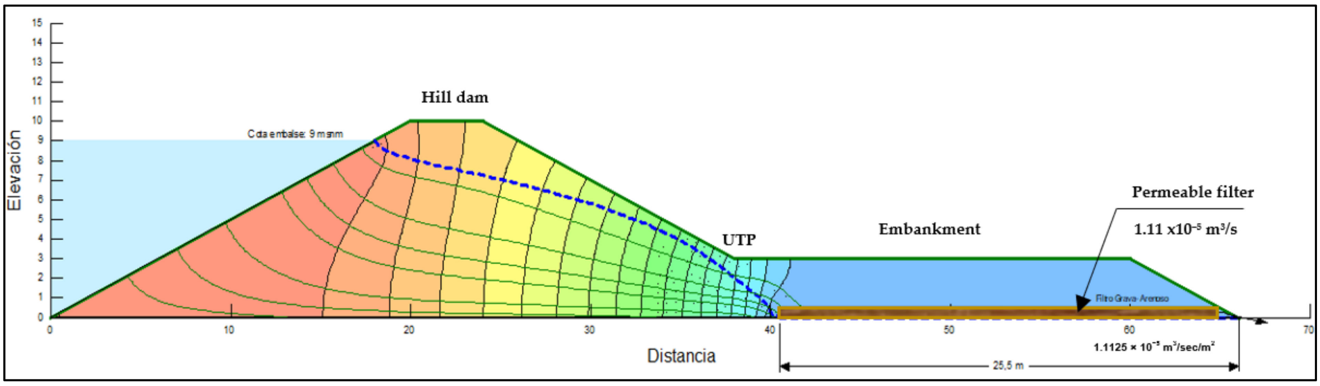


Figure 12. Convergence of the flow lines towards the permeable filter.

Table 3. Comparison of filtration in the earth dam.

Figure	Protection against Leaks	Convergence of the Saturation Lines	Infiltration Rate	Dam Status
11	Unfiltered	Convergence at 4.72 m from the heel of the dam.	3.48×10^{-7} m^3/s	Imminent failure
12	25.5 × 0.5 m horizontal permeable filter	Convergence towards the permeable filter	1.11×10^{-5} m^3/s	Stable dam

Figure 11 shows the flow lines -green lines- convergence which come out at the foot of the slope and before the embankment (junction of the embankment dam-UPT). This analysis indicates that the dam would fail; as a result, the problem must be fixed either by increasing the embankment's height or by implementing a filter that would change the flow lines configuration (as shown in Figure 12). Additionally, the saturation line -highlighted in blue- is visible from the maximum level of the reservoir to the slope downstream of the dam, which ends with an infiltration ratio of 3.48×10^{-7} m^3/s.

In Figure 12, when implementing the permeable filter as part of the embankment, the direction of the flow lines quickly changes towards the filter to drain the liquid, instead of going toward the dam and the embankment junction (UPT). In this case, the saturation line highlighted in blue converges towards the permeable filter with an infiltration rate of 1.11×10^{-5} m^3/s. Therefore, as it is evident, implementing a filter is vital to avoid the dam's collapse.

A trapezoidal cross-section was obtained for the spillway design, which provides greater stability to the walls. The channel design established a height of 1.2 m, a depth width of 1.50 and a water depth of 0.75 m. As a result, the slope of the embankment has a 1H:1V ratio (Figure 13).

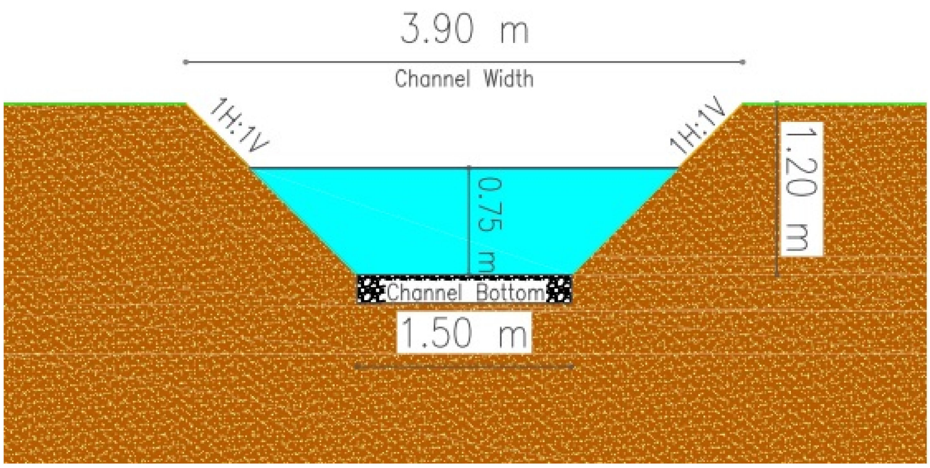


Figure 13. Cross section of the spillway design.

3.6. Crop Proposal

The surface drip method selected considered both the region's dry climate and the total capacity of the dam. Unlike traditional methods, such as furrow irrigation, the surface drip method increases the efficiency of the water resource, supplying the water directly to the root of the plant and avoiding evaporation, and reducing water losses by up to 90%.

In turn, a polyculture system would help avoid soil fatigue produced by monocultures and guarantee food security. A suggestion is to start with the plantation of corn, watermelon, melon, pearl onion, kidney tomato and pumpkin. The purpose of crop selection is to guarantee healthy and nutritious products for the commune's consumption, while only selling the surplus.

Table 4 presents the water needed for each type of plantation under the drip irrigation system.

Table 4. Average water needs of the proposed crops.

Plantation Type.	Water Needs for Drip	Production Time
Corn	5000–6000 m^3/ha [64]	100–125 day [65]
Watermelon	2000–3721 m^3/ha [66]	75–95 day [67]
Melon	3000–4000 m^3/ha [68]	90–120 day
Pearl onion	3500–4500 m^3/ha [69]	150–170 day [70]
Tomato	2000 m^3/ha	90–150 day [71]
Pumpkin	1000–1250 m^3/ha [72]	100–120 day [73]
Average	3160 m^3/ha	101–130 day

4. Discussion

This article presents a presa colinar (hill dam) design, elaborated through the use of ancestral construction knowledge and technical analysis, applying NBS. The dam implementation allows for an integral water management, while promoting the agricultural development of the area, even during dry months. With adequate water management, it is calculated that the cultivated area could extend to approximately 7.5 hectares, considering the most probable availability of 47,440 m^3 and the production time.

This design uses the ancestral knowledge of indigenous communities through the construction of dams and albarradas [74,75], imitating nature, to solve their water scarcity problems. Similar projects have been implemented in the coastal areas of Ecuador, such as in

Santa Elena [76]. These projects have generated water storage and recharged aquifers in the short and medium-term [76]; this is because the bottom of these structures is not completely impermeable, which leads to future groundwater exploitation through the drilling of wells [77]. In addition, the construction of these NBSs has allowed the sustainable growth of communities; a clear example is the Manglaralto commune in Santa Elena [78].

In this context, the term presa colinar (hill dam) is introduced to refer to a special contention system based on albarradas (earth dams) that involves more specialized and technical constructions. In this study, the hill dam is set to be built in intermittent rivers, or at the closing of small streams that do not form rivers or large estuaries. A presa colinar is a small minimally invasive structure 5 to 12 m high [79]. It takes advantage of the local topography, and the terrain elevation differences for its construction. In addition, it is built with local materials, such as silt, clay, or sand extracted from the bottom of the selected area, so it is even possible to increase the storage volume.

The limitations of this study are: (a) the absence of a meteorological station at the proposed site; (b) the insufficient number of meteorological stations present in the Santa Elena province, resulting in the lack of precipitation data not allowing the application of the Thiessen polygons, a method that gives a more approximate estimation of the real conditions in the area [80]. As a result, the data from previous studies carried out in Sacachún and the yearbooks of the meteorological station closest to the study area (meteorological station El Azúcar) had to be used; (c) the restricted period of pluviometric data collection that only reached 19 years; and d) the incomplete temperature record for the calculation of evaporation in the reservoir. However, it is important to mention that these solutions have already been implemented in similar areas of the sector [81] using structures based on ancestral knowledge [82,83], such as tapes or dikes. These structures have managed to rehabilitate ecosystems by obtaining a systematic recharge of aquifers and achieving a better use of the wells that serve as a source of water for human consumption.

The hydrological study estimated the volume of stored water using annual rainfall, considering a recurrence probability of 75% and the area of the input basin. However, other factors, such as evaporation and seepage losses, must be considered to obtain better results, as is indicated in the manual for the design and construction of small dams [80].

The supply basin has a compactness index of 1.72, indicating an elongated shape, as shown in Figure 5 [81]. The shape factor calculated revealed that the basin has a low tendency to flash floods and is less susceptible to erosion [82]. Additionally, based on the obtained slope of 16%, it was determined that the relief of the basin has a high potential for surface runoff production [83].

To make use of the local soil during the dam's construction, it was necessary to evaluate the soil's characteristics. As a result, a low permeability was determined (6.96×10^{-5} cm/s), demonstrating the optimal conditions of the reservoir and low filtration in the embankments. Budhu [59] corroborated these data in 2010. In his research, he concludes that fine sand has low hydraulic conductivity, with values between 1×10^{-3} cm/s and 1×10^{-5} cm/s. On the other hand, the direct shear test determined a low resistance, which means it is necessary to implement a reinforcement dam at the foot of the slope, to improve the safety factor against seismic movements.

Given the magnitude and importance of the construction, the design flow was estimated based on a return period of 50 years. This extreme event serves as a reference in the design of control structures to avoid water overflow on the crown, the leading cause of failure in earth dams, as Chanson indicates in his study [84].

The effects produced by filtrations in the body of the dam can be mitigated with the implementation of a horizontal filter drain, which displaces the saturation line of the face of the slope downstream, prevents internal erosion, increases the discharge of filtration, and reduces pore pressure within the dam (Figure 12). In addition, a recommendation is to implement an NT 1500 geotextile to minimize the migration of the fine material that makes up the dam's body towards the drain filter.

Worldwide, mega dams built on rivers have negative effects on local biodiversity as a result of the large flooded areas that destroy local ecosystems [85]. However, this problem does not occur with presas colinares. The presa colinar is a sustainable solution with a minimally invasive design that has a lower impact on the environment, preserves ecosystem services and allows the management of new habitats and ecosystems by taking advantage of rainwater and the development of life in the implemented sector. The hill dam has the disadvantage of forming a lentic ecosystem that can attract flora and fauna that could alter the existing ecosystem [86]. In this context, it is recommended to implement a management and prevention plan for invasive species, such as mosquitoes. One measure could be the application of microbial larvicides [87].

Finally, the hill dam design proposes a solution for water scarcity in the study area and other arid and semi-arid regions. It is important to recognize how ancestral techniques serve as an alternative to traditional engineering by offering a lower environmental impact solution, which can be reinforced with a technical design to guarantee the infrastructure efficiency and the user's safety [88,89]. The hill dam facilitates the channeling and storing of water from the winter (rainy season), thus guaranteeing water availability during the dry season. The solution is also more economical and viable than large hydraulic projects because it collects excess rainwater and takes advantage of local materials for constructing the dam's body. In addition, it does not require specialized personnel for its operation [90].

Moreover, the hill dam entails an adaptation process where the water storage will depend on the climatic conditions and the monitoring of the filling process for ecosystem changes to occur. Another benefit is that it allows the community to participate in the construction, operation, and maintenance of the hill dam [91]. Additionally, the hill dam will promote the restoration of degraded semi-arid spaces, allowing new ecosystems to form and improving food security and biodiversity [92,93].

5. Conclusions

This research presents the design of a presa colinar for a semi-arid area, that applies a NBS and uses ancestral knowledge and technical criteria for an integral water management system during the dry season. Due to climate change and potential social problems, humans must be resilient and adapt to create new solutions. Under this consideration, this study incorporated a solution based on nature for comprehensive irrigation water management. The proposed hill dam is set to take advantage of the topography of the area, placing the dam at the end of a shallow ravine with stable slopes. In addition, using the soil extracted from the area, it is possible to form an embankment 10 m high and 119 m long with slopes in a 2:1 ratio, seismically stable thanks to a foot of slope built downstream of the dam's body.

In general, the presa colinar contributes to: (i) mitigating the water scarcity problem in agricultural use in the Sacachún commune; (ii) maintaining the sector's biodiversity as it is a minimally invasive infrastructure; and (iii) being a natural attraction by maintaining a design similar to the ancestral albarradas used in the commune. This solution is efficient, sustainable, and profitable, by managing the demand for water in a rural area that is difficult to access. The infrastructure made with local materials works the same as a gray infrastructure for water storage. In addition, it has a lower cost and provides additional benefits to the area.

Recognizing that nature alone does not solve water scarcity problems, it is necessary to implement designs that adapt to the ecosystem and, at the same time, include nature. The hill dam and its intention to join the NBS concepts for water management in irrigation is a promising solution to guide the coastal communities of Ecuador towards more sustainable development.

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References

1. Aragonés, J.I.; Raposo, G.; Izurieta, C. The Dimensions of Sustainable Development in Social Discourse. *Stud. Psychol.* **2001**, *22*, 23–36. [CrossRef]
2. Naciones Unidas CEPAL La Agenda 2030 y Los Objetivos de Desarrollo Sostenible Una Oportunidad Para América Latina y El Caribe Gracias Por Su Interés En Esta Publicación de La CEPAL. 2018. Available online: https://repositorio.cepal.org/bitstream/handle/11362/40155/24/S1801141_es.pdf (accessed on 9 February 2022).
3. Hinojosa, L.; Villegas, W.G.; Muñoz, P.A. Exploring water security and water demand determinants in rural areas. The case of canton Cotacachi in Ecuador. *Water Resour. Rural Dev.* **2017**, *10*, 22–32. [CrossRef]
4. Vanham, D.; Hoekstra, A.Y.; Wada, Y.; Bouraoui, F.; de Roo, A.; Mekonnen, M.M.; van de Bund, W.J.; Batelaan, O.; Pavelic, P.; Bastiaanssen, W.G.M.; et al. Physical water scarcity metrics for monitoring progress towards SDG target 6.4: An evaluation of indicator 6.4.2 "Level of water stress". *Sci. Total Environ.* **2018**, *613-614*, 218–232. [CrossRef] [PubMed]
5. Rijsberman, F.R. Water scarcity: Fact or fiction? *Agric. Water Manag.* **2006**, *80*, 5–22. [CrossRef]
6. Sathler, D. Understanding human development, poverty and water scarcity patterns in the Brazilian Semi-arid through cluster analysis. *Environ. Sci. Policy* **2021**, *125*, 167–178. [CrossRef]
7. Herrera-Franco, G.; Alvarado, J.; Gordillo, P.; Veintimilla, L.; Merchan, B.; Carrión-Mero, P.; Berrezueta, E. Communication Methods on Water Care during the COVID-19 Pandemic and Its Impact on the Resilience of the Rural Community of "Libertador Bolívar", Ecuador. *WIT Trans. Ecol. Environ.* **2021**, *250*, 109–118. [CrossRef]
8. Zarei, Z.; Karami, E.; Keshavarz, M. Co-production of knowledge and adaptation to water scarcity in developing countries. *J. Environ. Manag.* **2020**, *262*, 110283. [CrossRef]
9. Molina, E. *La Agricultura en Países Subdesarrollados. Particularidades de Su Financiamiento*; CLACSO: Buenos Aires, Argentina, 2015; ISBN 2015090801053.
10. Narasimhan, B.; Srinivasan, R. Development and evaluation of Soil Moisture Deficit Index (SMDI) and Evapotranspiration Deficit Index (ETDI) for agricultural drought monitoring. *Agric. For. Meteorol.* **2005**, *133*, 69–88. [CrossRef]
11. Venancio, L.P.; Filgueiras, R.; Mantovani, E.C.; Do Amaral, C.H.; Da Cunha, F.F.; Dos Santos Silva, F.C.; Althoff, D.; Dos Santos, R.A.; Cavatte, P.C. Impact of drought associated with high temperatures on *Coffea canephora* plantations: A case study in Espírito Santo State, Brazil. *Sci. Rep.* **2020**, *10*, 19719. [CrossRef]
12. Panigrahi, B.; Panda, S.N. Optimal Sizing of On-Farm Reservoirs for Supplemental Irrigation. *J. Irrig. Drain. Eng.* **2003**, *129*, 117–128. [CrossRef]
13. Carrión-Mero, P.; Morante-Carballo, F.; Vargas-Ormaza, V.; Apolo-Masache, B.; Jaya-Montalvo, M. A Conceptual Socio-Hydrogeological Model Applied to Sustainable Water Management. Case Study of the Valdivia River Basin, Southwestern Ecuador. *Int. J. Sustain. Dev. Plan.* **2021**, *16*, 1275–1285. [CrossRef]
14. Pretty, J. Agricultural Sustainability: Concepts, Principles and Evidence. *Philos. Trans. R. Soc. B Biol. Sci.* **2008**, *363*, 447–465. [CrossRef]

15. Herrera-Franco, G.; Carrión-Mero, P.; Briones-Bitar, J. Management Practices for a Sustainable Community and Its Impact on Development, Manglaralto-Santa Elena, Ecuador. In Proceedings of the 17th LACCEI International Multi-Conference for Engineering, Education and Technology, Montego Bay, Jamaica, 24–26 July 2019. [CrossRef]
16. Paz-Kagan, T.; Ohana-Levi, N.; Shachak, M.; Zaady, E.; Karnieli, A. Ecosystem effects of integrating human-made runoff-harvesting systems into natural dryland watersheds. *J. Arid Environ.* **2017**, *147*, 133–143. [CrossRef]
17. Liebe, J.; van de Giesen, N.; Andreini, M. Estimation of Small Reservoir Storage Capacities in a Semi-Arid Environment. *Phys. Chem. Earth Parts A/B/C* **2005**, *30*, 448–454. [CrossRef]
18. Merchán-Sanmartín, B.; Aguilar-Aguilar, M.; Morante-Carballo, F.; Carrión-Mero, P.; Guambaña-Palma, J.; Mestanza-Solano, D.; Berrezueta, E. Design of Sewerage System and Wastewater Treatment in a Rural Sector: A Case Study. *Int. J. Sustain. Dev. Plan.* **2022**, *17*, 51–61. [CrossRef]
19. Ogilvie, A.; Riaux, J.; Massuel, S.; Mulligan, M.; Belaud, G.; Le Goulven, P.; Calvez, R. Socio-hydrological drivers of agricultural water use in small reservoirs. *Agric. Water Manag.* **2019**, *218*, 17–29. [CrossRef]
20. Martos-Rosillo, S.; Herrera-Franco, G.; Carrión-Mero, P.; Morante-Carballo, F.; Briones-Bitar, J.; Durán, A.; Upegui, J.V.; Lucic, M.C.; Mateos, L.; Bardales, J.D.; et al. Water Sowing and Harvesting (SyCA), Ancestral Techniques That Solve Problems of the XXI Century. In Proceedings of the 18th LACCEI International Multi-Conference for Engineering, Education and Technology, Virtual, 27–31 July 2020. [CrossRef]
21. Carrión-Mero, P.; Morante-Carballo, F.; Briones-Bitar, J.; Herrera-Borja, P.; Chávez-Moncayo, M.; Arévalo-Ochoa, J. Design of a Technical-Artisanal Dike for Surface Water Storage and Artificial Recharge of the Manglaralto Coastal Aquifer. Santa Elena Parish, Ecuador. *Int. J. Sustain. Dev. Plan.* **2021**, *16*, 515–523. [CrossRef]
22. Herrera-Franco, G.; Carrión-Mero, P.; Briones-Bitar, J. Ancestral Knowledge Application via "Albarradas" and "Tapes" in Water Management in Santa Elena Province, Ecuador. *Boletín Geológico Y Min.* **2020**, *131*, 75–88. [CrossRef]
23. Carrión, P.; Briones, J.; Herrera, G.; Sánchez, C.; Limón, J. Practical Adaptations of Ancestral Knowledge for Groundwater Artificial Recharge Management of Manglaralto Coastal Aquifer, Ecuador. *WIT Trans. Ecol. Environ.* **2019**, *217*, 375–386. [CrossRef]
24. World Bank. *Biodiversity, Climate Change and Adaptation: Nature-Based Solutions from the World Bank Portfolio*; World Bank: Washington, DC, USA, 2008.
25. Cohen-Shacham, E.; Walters, G.; Janzen, C.; Maginnis, S. (Eds.) *Nature-Based Solutions to Address Global Societal Challenges*; IUCN: Gland, Switzerland, 2016; pp. 1–97. ISBN 9782831718125.
26. Eggermont, H.; Balian, E.; Azevedo, J.M.N.; Beumer, V.; Brodin, T.; Claudet, J.; Fady, B.; Grube, M.; Keune, H.; Lamarque, P.; et al. Nature-based Solutions: New Influence for Environmental Management and Research in Europe. *GAIA* **2015**, *24*, 243–248. [CrossRef]
27. Bouzouidja, R.; Cannavo, P.; Bodénan, P.; Gulyás, Á.; Kiss, M.; Kovács, A.; Béchet, B.; Chancibault, K.; Chantoiseau, E.; Bournet, P.-E.; et al. How to evaluate nature-based solutions performance for microclimate, water and soil management issues–Available tools and methods from Nature4Cities European project results. *Ecol. Indic.* **2021**, *125*, 107556. [CrossRef]
28. Chávez, M.Á.; Julieth, K.; Chang, R. Control De Inundaciones Y Diseño De Soluciones Viales Especiales En La Población De Ayangue, Cantón Santa Elena. 2017. Available online: http://www.dspace.espol.edu.ec/xmlui/handle/123456789/43450 (accessed on 9 February 2022).
29. Mullo, A.; Oquendo, C. *Estudio y Diseño de La Presa Colinar En Sacachún #1*; ESPOL: Guayaqui, Ecuador, 2021.
30. Ronaldo, N.; Stay, D. *Estudios y Diseños de Presa Colinar En La Comuna Sacachún, Provincia de Santa Elena*; ESPOL: Guayaqui, Ecuador, 2021.
31. Berhane, G.; Gebreyohannes, T.; Martens, K.; Walraevens, K. Overview of micro-dam reservoirs (MDR) in Tigray (northern Ethiopia): Challenges and benefits. *J. Afr. Earth Sci.* **2016**, *123*, 210–222. [CrossRef]
32. Kemeze, F.H. Economic valuation of supplemental irrigation via small-scale water harvesting. *Water Resour. Econ.* **2020**, *31*, 100160. [CrossRef]
33. Aristizábal, M.F.V. Albarradas: Pertinencia de Los Saberes Ancestrales Frente a La Colonialidad Del Desarrollismo. *Rev. Ciências Sociais* **2019**, *50*, 223–247. [CrossRef]
34. Instituto Nacional de Patrimonio Cultural San Biritute: Lluvia, Amor y Fertilidad; Guayaquil. 2012. Available online: https://issuu.com/inpc/docs/san_biritute_lluvia_amor_y_fertilid?embed_cta=embed_badge&embed_context=embed&embed_domain=www.patrimoniocultural.gob.ec&utm_medium=referral&utm_source=www.patrimoniocultural.gob.ec (accessed on 9 February 2022).
35. BGS-CODIGEM Mapa Geológico de La República Del Ecuador. Escala, 1:1000000. 1983. Available online: https://sni.gob.ec/coberturas (accessed on 15 June 2022).
36. Aspden, J.A.; McCourt, W.J.; Brook, M. Geometrical control of subduction-related magmatism: The Mesozoic and Cenozoic plutonic history of Western Colombia. *J. Geol. Soc.* **1987**, *144*, 893–905. [CrossRef]
37. Cediel, F.; Shaw, R.P.; Cáceres, C. Tectonic Assembly of the Northern Andean Block. *AAPG Mem.* **2003**, *79*, 815–848. [CrossRef]
38. Del Arco, N. *Geología del Ecuador. Fac. Ing. En Ciencias La Tierra La Esc. Super. Politécnica Del Litoral*; ESPOL: Guayaqui, Ecuador, 2003; p. 249. Available online: https://fdocuments.ec/document/libro-geologia-del-ecuador-por-ing-nunez-del-arco.html (accessed on 15 June 2022).
39. Berrezueta, E.; López, K.; González-Menéndez, L.; Ordóñez-Casado, B.; Benítez, S. Ophiolitic rocks and plagiorhyolites from SW Ecuador (Cerro San José): Petrology, geochemistry and tectonic setting. *J. Iber. Geol.* **2021**, *47*, 367–386. [CrossRef]

40. Aguayo, C.; Edwin, I. Levantamiento de Línea Base de La Gestión de Desechos Del Campus Como Zona de Amortiguamiento Del Bosque Protector Prosperina. 2019. Available online: https://www.scielo.org.mx/pdf/iit/v11n2/v11n2a5.pdf (accessed on 15 June 2022).
41. CADS; ESPOL. Proyecto de Evaluación de Vulnerabilidad y Reducción de Riesgo de Desastres a Nivel Municipal En El Ecuador. 2013. Available online: https://docplayer.es/72636535-Proyecto-de-evaluacion-de-vulnerabilidad-y-reduccion-de-riesgo-de-desastres-a-nivel-municipal-en-el-ecuador-echo-dip-bud-2011-91002.html (accessed on 15 June 2022).
42. Köppen, W. The thermal zones of the Earth according to the duration of hot, moderate and cold periods and to the impact of heat on the organic world. *Meteorol. Z.* **2011**, *20*, 351–360. [CrossRef]
43. INAMHI Tipos de Climas Del Ecuador. 2017. Available online: https://www.inamhi.gob.ec/mapas-climaticos/ (accessed on 10 April 2022).
44. GAD Provincia Santa Elena. *GAD Provincia Santa Elena Actualización Del Plan de Desarrollo Provincial y Ordenamiento Territorial de Santa Elena 2015-2023*; GAD Provincia Santa Elena: Santa Elena, Ecuador, 2015; p. 323.
45. Paltán Obregón, J.B. *Percepciones y Dinámicas Socioambientales En Manejo de Agroecosistemas: Casos de Las Comunas de Sacachún y Dos Mangas, Provincia de Santa Elena*; FLACSO Sede Ecuador: Quito, Ecuador, 2016; 137p.
46. Paz y Miño, M.E. *San Biritute: Lluvia, Amor y Fertilidad*; INPC: Guayaquil, Ecuador, 2012; ISBN 978-9942-07-335-8.
47. Xu, J.; Zhang, L.; Zhu, Y.; Gou, H. The Application of GPS-RTK in Engineering Measurement and Position. In Proceedings of the 2009 2nd International Symposium on Knowledge Acquisition and Modeling, KAM 2009, Wuhan, China, 30 November–1 December 2009; Volume 3, pp. 186–189.
48. Environmental Systems Research Institute. *ESRI ArcGis Desktop*; Environmental Systems Research Institute: Redlands, CA, USA, 2009.
49. Maidment, D. *Arc Hydro GIS for Water Resources*; ESRI Press: Redlands, CA, USA, 2002.
50. Moore, I.D.; Grayson, R.B.; Ladson, A.R. Digital terrain modelling: A review of hydrological, geomorphological, and biological applications. *Hydrol. Process.* **1991**, *5*, 3–30. [CrossRef]
51. Instituto Nacional de Meteorología e Hidrología–INAMHI. Available online: http://www.inamhi.gob.ec/ (accessed on 24 March 2022).
52. Escuela Superior Politecnica del Litoral. *Cálculo de Las Curvas IDF, a Partir de Registros de Lluvia Máxima En 24 Horas y Relaciones Duración LLuvia Promedio. Subdirección Reg. Noreste Obras Hidráulicas e Ing. Agric. para el Desarro. Rural*, 1st ed.; Escuela Superior Politecnica del Litoral: Guayaquil, Ecuador, 1978.
53. Carvajal, Á.D.; Fernández, T.M. Determination of Curve Number in Betancí Subwatershed (Córdoba, Colombia) through Remote Sensing and GIS. *Ing. Desarro.* **2017**, *35*, 452–470.
54. Critchley, W.; Sieger, K.; FAO. *Manual de Captación y Aprovechamiento Del Agua de Lluvia. Tomo I: Bases Técnicas y Experiencias En África y Asia*; Oficina Regional de la FAO para America Latina y el Caribe: Santiago, Chile, 1996.
55. Bureau of Reclamation. *Design of Small Dams*, 3rd ed.; A Water Resources Technical Publication: Washington, DC, USA, 1987; ISBN 978-8190309806.
56. Spencer, E. A Method of analysis of the Stability of Embankments Assuming Parallel Inter-Slice Forces. *Géotechnique* **1967**, *17*, 11–26. [CrossRef]
57. Clover Technology. *GALENA-Slope Stability*; Clover Technology: Robertson, Australia, 2003.
58. NEC-SE-GC Norma Ecuatoriana de La Construcción-NEC: NEC-SE-CM-Geotecnia y Cimentación; Quito. 2015. Available online: https://www.cconstruccion.net/normas_files/doc/NEC-SE-GC-Geot%C3%A9cnia-y-Cimentaciones.pdf (accessed on 9 February 2022).
59. Budhu, M. *Soil Mechanics and Foundations*, 3rd ed.; Wiley: Hoboken, NJ, USA, 2010; ISBN 978-0-470-55684-9.
60. Geo-Slope International Ltd. *GeoStudio*; Geo-Slope International Ltd.: Calgary, AB, Canada, 2007.
61. Das, B. *Fundamentos de Ingeniería Geotécnica*; Thomson Learning: Polanco, Mexico, 2013; ISBN 9781111576752.
62. Armas, R.; Horta, E. *Presas de Tierra*; ISPJAE: Cuidad de la Habana, Cuba, 1987.
63. *ASTM D2487*; Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System). American Society for Testing and Materials (ASTM): West Conshohocken, PA, USA, 2020.
64. Gestiriego Riego Por Goteo en El Cultivo del Maíz. Available online: https://www.gestiriego.com/riego-por-goteo-en-el-cultivo-del-maiz/ (accessed on 9 February 2022).
65. El Comercio El Maíz Ya Está Listo para la Cosecha. Available online: https://www.elcomercio.com/actualidad/negocios/maiz-ya-listo-cosecha.html (accessed on 9 February 2022).
66. Mateos Del Vas, J. *Análisis Comparativo Sobre la Producción de Sandía Bajo Riego Localizado e Inundación en El Sureste Español*; Universidad Politécnica de Cartagena: Cartagena, Spain, 2017; pp. 1–107.
67. Cultivo de la Sandía y El Melón-ABC Rural-ABC Color. Available online: https://www.abc.com.py/edicion-impresa/suplementos/abc-rural/cultivo-de-la-sandia-y-el-melon-780377.html (accessed on 9 February 2022).
68. Grupo Cooperativo Cajamar Boletín Informativo-Dosis de Riego Cultivo de Melón N° 157. 2015, pp. 6–7. Available online: https://www.cajamar.es/pdf/bd/agroalimentario/innovacion/investigacion/documentos-y-programas/boletin-huerto-157-1496658321.pdf (accessed on 29 June 2022).
69. Instituto Nacional de Investigaciones Forestale. *Agenda Técnica Agrícola Chihuahua*; Instituto Nacional de Investigaciones Forestale: Ciudad de México, México, 2017.
70. Cultivo de Cebolla-Origen, Cultivo, Usos y Más-Agrotendencia.Tv. Available online: https://agrotendencia.tv/agropedia/el-cultivo-de-cebolla/ (accessed on 9 February 2022).

71. Cultivo de Tomate: Producción y Manejo Agronómico-Agrotendencia.Tv. Available online: https://agrotendencia.tv/agropedia/el-cultivo-de-tomate/ (accessed on 9 February 2022).
72. De, E.; De, D.E.T.; Granja; Sosa Medina, J.M.; Guillén Rodríguez, B. Revista Agropecuaria Granja. 2014. Available online: http://anuariosatlanticos.casadecolon.com/index.php/GRANJA/issue/view/298 (accessed on 9 February 2022).
73. Hernandez, E.; Beaver, L. *Guía Para La Producción Comercial de La Calabaza Tropical*; Universidad de Puerto Rico: San Juan, Puerto Rico, 2015; pp. 1–9.
74. Carrión-Mero, P.; Morante-Carballo, F.; Herrera-Franco, G.; Jaya-Montalvo, M.; Rodríguez, D.; Loor-Flores de Valgas, C.; Berrezueta, E. Community-University Partnership in Water Education and Linkage Process. Study Case: Manglaralto, Santa Elena, Ecuador. *Water* **2021**, *13*, 1998. [CrossRef]
75. Merchán-Sanmartín, B.; Aucapeña-Parrales, J.; Alcívar-Redrován, R.; Carrión-Mero, P.; Jaya-Montalvo, M.; Arias-Hidalgo, M. Earth Dam Design for Drinking Water Management and Flood Control: A Case Study. *Water* **2022**, *14*, 2029. [CrossRef]
76. Herrera-Franco, G.; Carrión-Mero, P.; Aguilar-Aguilar, M.; Morante-Carballo, F.; Jaya-Montalvo, M.; Morillo-Balsera, M. Groundwater Resilience Assessment in a Communal Coastal Aquifer System. The Case of Manglaralto in Santa Elena, Ecuador. *Sustainability* **2020**, *12*, 8290. [CrossRef]
77. Mohammadzadeh-Habili, J.; Khalili, D. Assessment of Artificial Recharge Dams and Improvement of Their Groundwater-Recharge Capacity. *J. Hydrol. Eng.* **2020**, *25*, 04020011. [CrossRef]
78. Carrión-Mero, P.; Montalván, F.J.; Morante-Carballo, F.; Loor-Flores de Valgas, C.; Apolo-Masache, B.; Heredia, J. Flow and Transport Numerical Model of a Coastal Aquifer Based on the Hydraulic Importance of a Dyke and Its Impact on Water Quality: Manglaralto—Ecuador. *Water* **2021**, *13*, 443. [CrossRef]
79. Blanc, E.; Strobl, E. Is Small Better? A Comparison of the Effect of Large and Small Dams on Cropland Productivity in South Africa. *World Bank Econ. Rev.* **2014**, *28*, 545–576. [CrossRef]
80. MVOTMA. *Manual de Diseño y Construcción de Pequeñas Presas*; Ministerio de Ambiente, Vivienda y Desarrollo Territorial: Bogota, Colombia, 2011; Volume 1, p. 101.
81. Potter, P.E. A Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain Area, Virginia and Tennessee. V. C. Miller. *J. Geol.* **1957**, *65*, 112–113. [CrossRef]
82. Bharath, A.; Kumar, K.K.; Maddamsetty, R.; Manjunatha, M.; Tangadagi, R.B.; Preethi, S. Drainage morphometry based sub-watershed prioritization of Kalinadi basin using geospatial technology. *Environ. Challenges* **2021**, *5*, 100277. [CrossRef]
83. Abboud, I.A.; Nofal, R.A. Morphometric analysis of wadi Khumal basin, western coast of Saudi Arabia, using remote sensing and GIS techniques. *J. Afr. Earth Sci.* **2017**, *126*, 58–74. [CrossRef]
84. Chanson, H. Embankment overtopping protection systems. *Acta Geotech.* **2015**, *10*, 305–318. [CrossRef]
85. Velastegui-Montoya, A.; de Lima, A.; Adami, M. Multitemporal Analysis of Deforestation in Response to the Construction of the Tucuruí Dam. *Int. J. Geosci.* **2020**, *9*, 583. [CrossRef]
86. Havel, J.E.; Kovalenko, K.E.; Thomaz, S.M.; Amalfitano, S.; Kats, L.B. Aquatic invasive species: Challenges for the future. *Hydrobiologia* **2015**, *750*, 147–170. [CrossRef]
87. Derua, Y.A.; Kahindi, S.C.; Mosha, F.W.; Kweka, E.J.; Atieli, H.E.; Wang, X.; Zhou, G.; Lee, M.; Githeko, A.K.; Yan, G. Microbial larvicides for mosquito control: Impact of long lasting formulations of *Bacillus thuringiensis* var. *israelensis* and *Bacillus sphaericus* on non-target organisms in western Kenya highlands. *Ecol. Evol.* **2018**, *8*, 7563–7573. [CrossRef]
88. Serrano-Coronel, G.; Chipana-Rivera, R.; Moreno-Pérez, M.F.; Roldán-Cañas, J. Study of vertical water flows contribution to the crop water consumption in suka kollus using a mixed drainage system. *Agric. Water Manag.* **2018**, *206*, 86–94. [CrossRef]
89. Rivera, R.C.; Moreno-Pérez, M.F.; Velasco, R.C.; Roldán-Cañas, J. Performance of pre-hispanic irrigation systems in the Andean region of Bolivia. *Agric. Water Manag.* **2016**, *170*, 180–188. [CrossRef]
90. Mohammad-Hosseinpour, A.; Molina, J.-L. Improving the Sustainability of Urban Water Management through Innovative Groundwater Recharge System (GRS). *Sustainability* **2022**, *14*, 5990. [CrossRef]
91. Maheshwari, B.; Varua, M.; Ward, J.; Packham, R.; Chinnasamy, P.; Dashora, Y.; Dave, S.; Soni, P.; Dillon, P.; Purohit, R.; et al. The Role of Transdisciplinary Approach and Community Participation in Village Scale Groundwater Management: Insights from Gujarat and Rajasthan, India. *Water* **2014**, *6*, 3386–3408. [CrossRef]
92. Alataway, A.; El Alfy, M. Rainwater Harvesting and Artificial Groundwater Recharge in Arid Areas: Case Study in Wadi Al-Alb, Saudi Arabia. *J. Water Resour. Plan. Manag.* **2019**, *145*, 1–13. [CrossRef]
93. Gonzalez, D.; Dillon, P.; Page, D.; Vanderzalm, J. The Potential for Water Banking in Australia's Murray–Darling Basin to Increase Drought Resilience. *Water* **2020**, *12*, 2936. [CrossRef]