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Management of Urban Wastewater on One of the Galapagos Islands

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Abstract: Since 1984, the Galapagos Islands have been included in the program UNESCO—MAB (Man and Biosphere Programme) due to the increasing need to safeguard their outstanding natural ecosystems and promote economic progress based on principles of sustainable development and environmentally friendly technologies. The Ecuadorian government, also by special laws, has legislated in favor of the environmental protection of the archipelago, with the intention to control the flow of migrants from the continent to the islands. Today, with the further problems created by the massive influx of tourists, is it necessary to establish planned areas of urban expansion that are already equipped with a suitable system of collection and treatment of wastewater. This paper focuses on the city of Puerto Ayora, the main town of the island of Santa Cruz, where increasing human pressure has led to, among various other consequences, an increase in water demand, which has highlighted the inadequacy of the current wastewater treatment system, based primarily on single-family septic tanks without additional depuration. Among the various actions proposed to solve the increasing health and environmental hazards, caused by the partially treated wastewater, a centralized sewer system for the drainage and the depuration of the wastewater produced by the users connected to the network has been proposed in order to serve the community of Puerto Ayora. This project is currently experiencing a slow implementation process due to technical difficulties. Our intention is to propose a different wastewater management system, which is modular, easily replicable and which requires low maintenance. A flexible and easily manageable system, such as that proposed, could be implemented in other contexts such as, for example, in developing countries. In this specific case, the main purpose of this study is to investigate how to ensure a healthy environment for tourists and residents, without neglecting our duty to respect the ecosystems of this extraordinary island, by defining a model of wastewater management which should be economically and technologically sustainable in this particular context. In fact, the soil, formed by lava rock does not allow for very deep excavations and being so far away from the mainland means that technologies that are easily maintainable on site must be deployed. The study was carried out according to the Millennium Development Goals, Ecuadorian legislation, the suggestions of the Pan American Health Organization, relevant scientific literature and some data collected from site surveys.

Keywords: galapagos; sustainability; wastewater management; wastewater treatment; water supply

1. Introduction

The archipelago of the Galapagos, in Ecuador, is recognized as one of the most important natural heritages in the world, especially for its unique flora and fauna. In the last decade, also in the island of Santa Cruz which is located in the city of Puerto Ayora, with the increase of human presence and the greater demand of goods and resources by residents of the island, the first signs of suffering from the fragile endemic ecosystems are beginning to manifest. Some monitoring studies, conducted along the coast and in some wells of Puerto Ayora, have shown the presence of high concentrations of pollutants, certainly resulting from the discharge of waste water [1–4].

The data provided by the National Institute of Statistics, arising from the latest national census, showed that in 2010 the total population of the Galapagos province consisted of 25,124 inhabitants, with 20,738 residents in urban areas and 4386 in rural areas, while the data of the national census of 2001 evidenced a population of 18,640 inhabitants and in the census of 1990 the population was 9785 inhabitants [5]. The rapid growth of the population which started in the 90s, though it has been moderated recently with laws enacted by the central government in the field of internal immigration, has led to a subsequent increase in the production of wastewater [4]. However, in these years, no technological innovations have been introduced to deal with the increasing amount of water that needs to be treated. Only in recent years did the city of Puerto Ayora decide to abandon homemade wastewater treatment plants, consisting of a septic tank that, after a not exhaustive treatment, discharged the effluent at the nearest site, and designed a collection system directed to a centralized urban wastewater treatment plan (WWTP). This project is currently being only slowly developed due to some construction problems; in fact, the volcanic soil of the island does not allow easily laying the deepest conduct of the sewer, and even more difficult is the construction of pumping stations, in addition to the difficulties of installing a sewerage system in an area already densely urbanized with some areas situated very close to the sea.

As in a similar study [6], our main objective was to investigate how to ensure a healthy environment for tourists and residents, and how to maintain the extraordinary ecosystems of this island by identifying a model of wastewater management that is economically and technologically sustainable. This paper aims at giving a possible solution for the treatment of urban wastewater in those particular situations where it is absolutely necessary to preserve the environment but bearing in mind the technical difficulties in doing so, such as the hard soils and distance from centralized service centers on the islands. For this last reason, the proposal of a vacuum or a pressure sewer system does not seem appropriate.

The need to propose a new model of treatment, for the new area of urban expansion called "*El Mirador*", stems from the need to make the municipality self-sufficient for the ordinary and extraordinary maintenance of the depuration system. Other advantages arise from the fact that, once the network of the main collectors are laid, this system can be improved and integrated each time there is an increase of the population. The slope of the collectors will be lower than in traditional gravity systems because it is not necessary to guarantee the self-cleaning devices of the pipes, for the reason that the solid material will be retained by the beds of phytoremediation. Moreover, the system of final filtration may be expanded according to increases in the population.

Furthermore, the modular structure of this system could be integrated into projects for neighborhoods with different populations, respecting, however, the principles of sustainable urbanism.

The study was carried out with particular reference to the new neighborhood under construction "*El Mirador*". The study took into account Goal 7 (Ensure environmental sustainability) of the Millennium Development Goals, national legislation, including the Special Law for Conservation and Sustainable Development of the Galápagos Province, the Plan of Conservation and Sustainable Development developed by the former Instituto Nacional Galápagos (INGALA) and following the suggestions of the Pan American Health Organization [7–9].

2. Area of Study

In accordance with the studies developed by the Charles Darwin Research Station (CDRS), a biological research station operated by the Charles Darwin Foundation and located on the shore of Academy Bay in the village of Puerto Ayora, the climate of Puerto Ayora is divided into two main seasons: the first, from January to May, is warmer and rainier than the second period, from June to December, which is drier and cooler. In the warmer season, the average monthly temperature ranges from 25.1 °C to 26.7 °C while the average monthly rainfall ranges between 52.6 mm and 81.6 mm. The cooler season is characterized by an average monthly temperature between 21.5 °C and 23.8 °C while the average monthly rainfall ranges between 10.4 mm and 32.9 mm [10]. As happens across the archipelago, the island of Santa Cruz is subject to the cyclic climatic phenomenon of "El Niño" that, with a frequency ranging from three to 11 years, brings anomalous increases of precipitation: for example, in 1983 in Puerto Ayora 2768.7 mm of rainfall was recorded in comparison to the annual average of 476.32 mm of rainfall per year [10].

The natural recharge of aquifers and the formation of small bodies of water surface occur primarily during the *garua* season (June–December), characterized by low temperatures, reduced amounts of evaporation of water, and fairly constant precipitation due to the fog formed by the collision of the warm ocean currents with the cooler highlands. There is little fresh water in the archipelago.

The island of Santa Cruz [10] is the second largest island (986 km^2), with a maximum altitude of 864 m.a.s.l. and has the largest population in the Province of Galapagos.

The Municipality of Santa Cruz (*Canton de Santa Cruz*) includes the capital Puerto Ayora. In addition to the main island, this Municipality also holds jurisdiction over the island of Baltra, Marchena, Pinta, Pinzon, Seymour and other islets. The population of the Municipality of Santa Cruz in 2010 (the year of the most recent census) was 15,393 inhabitants; 11,974 residents in the urban area of Puerto Ayora and the other 3419 residents in two major rural villages [5]. Data of the national census of 2001 evidenced a population in the Municipality of Santa Cruz of 11,388 inhabitants while in the census of 1990 the population was 5318 inhabitants; these data are in accordance with the marked increase of the population of the entire Province of Galapagos.

The town of Puerto Ayora is divided into five sectors. The local council has decided to further expand the building area with a new neighborhood—*El Mirador*.

The idea of this research is to adapt the project of the urban plan of *El Mirador*, drafted by the Municipality of Puerto Ayora [11], considering the problems that emerged during the construction of a sewer in the city center, and to identify a model (a urbanistic base unit) able to be released in the most simple and functional way. This model has not yet been developed in practice, because it comes with the need to offer to the Municipality an alternative project, different to that developed in the preliminary draft, which could be better adaptable to the local context.

The project drafted by the Municipality involves the construction of 1135 rectangular lots (15 m × 20 m), with about 66 lots grouped to form 22 blocks (*manzanas*) (Figure 1), which represent the elemental unit both for the urban scheme for the proposal project and for the management of wastewaters. The urban planning project provides that within each block also a recreational area of a least 1500 m^2 will be realized. At the center of *El Mirador,* a sports field, a church, a medical clinic, and a children's playground will be built. The Municipality has proposed specific types of homes that must respect some specific dimensional and structural parameters [11]. The expected housing capacity for the new district is about 7000 [11] inhabitants.

In addition, there are 250 police officers and 100 marines who will be transferred to *El Mirador* and be housed in two barracks, which will be built at the border of the existing city.

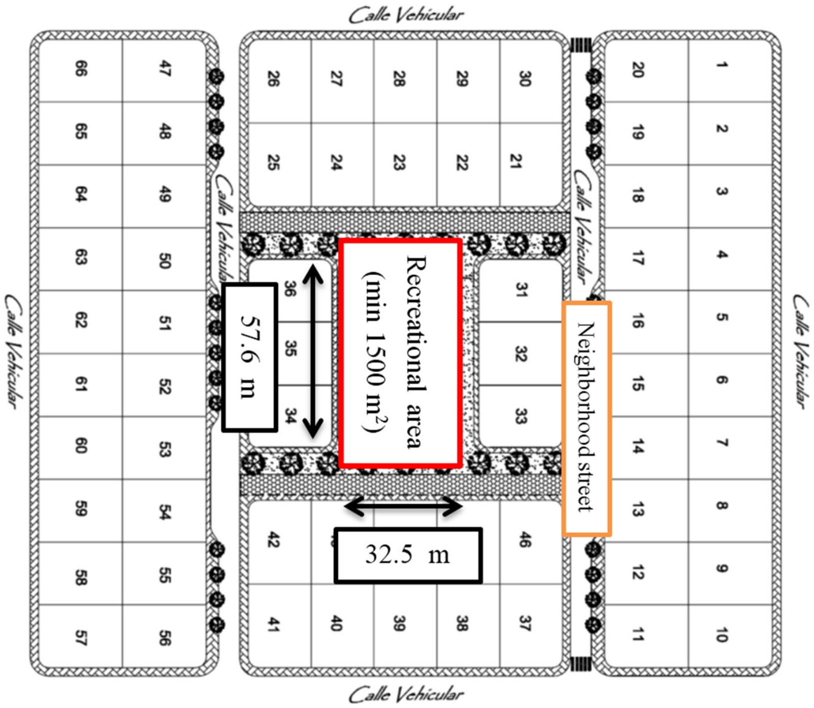

Figure 1. Typical structure of a block in El Mirador, composed by 66 lots [11].

3. Water Management in Santa Cruz

3.1. Water Supply

About 85% of the population of Santa Cruz receives their water (untreated and not for drinking) from the public network, about 10% of the population utilizes the rainwater for their water supply and the remaining 5% utilizes other sources. The main form of drinking water supply is through plastic bottles bought at the supermarket or from private companies that perform water purification.

The water distribution system in Puerto Ayora exploits both water extracted from a deep well, located on the Puerto Ayora-Bellavista road, and slightly brackish water from some *grietas* (cracks in the rocky soil of volcanic origin). The water is stored in tanks in the nearby hills and reservoirs serving the utilities of the city with a gravity system. The significant increase in the use of fertilizers in the rural areas and the more consistent spills, poorly treated by septic tanks, caused by the increase in water demand [10], especially in the urban area, has led to the pollution of surface water and groundwater.

The analysis of some samples of water, extracted from the well [12], and from surface sources [2], has shown that the chemical quality of the delivered water is acceptable and within the limits established by law for various physical and chemical parameters, however, are insufficient from a microbiological point of view.

For these reasons, the Municipality of Puerto Ayora initiated a project [3] involving the replacement of some *grietas* with a new underground source (*grieta La Camiseta*), connected through a pump to a supply line that feeds the tank located in *El Mirador*. The project also includes the construction of a desalination plant and a water purification plant, using reverse osmosis [3]. The new source (71.45 $L \cdot s^{-1}$) should ensure the coverage of water needs until 2036, and be of good quality from a microbiological point of view.

The maximum water flow to be supplied to *El Mirador* is estimated (2036) at 16.53 $L \cdot s^{-1}$ and will serve the new 1135 lots (about six inhabitants/lot, assumed by the designer for the dimensioning of the aqueduct) that will be built [3], which correspond approximately to 7141 inhabitants (including 250 people from the police station and 100 from the navy), supplied with 200 L/head/day.

3.2. Stormwater Drainage

Most of the roads have a rainwater drainage system, which is often insufficient due to poor maintenance. In some cases, these drains are completely buried and/or have no protective grids.

There are some areas of the city equipped with gully grating manholes with covers in concrete; these openings are small and therefore often clogged. The existing sewage network, thus, needs to be cleaned and maintained. In the new development area, there is no satisfactory sewage system in place.

3.3. Urban Wastewater

The town of Puerto Ayora has about 2900 buildings which could be connected to a sewer; about 400 are the buildings located near the sea, where the majority of the hotels and tourism services are located. A total of 95.4% of homes (2010 census) have a domestic wastewater collection system connected to a septic tank (other solutions are negligible or absent). Normally, the connections are built by the owners without any control, often in a rough way, and are thus frequently a source of contamination.

The Municipal Department of Water Management has estimated that just 10% of the septic tanks work well, while the rest have defects in terms of materials or maintenance [4,13].

One of the most important consequences of the lack of an effective wastewater treatment and collection system is that the wastewater, poorly depurated by the septic tanks, has infiltrated underground into the aquifer so as to make it unusable for the water supply.

GAD (*Gobierno Autónomo Descentralizado*—Decentralized Autonomus Government) of Santa Cruz is responsible for cleaning septic tanks, using tanker trucks that empty and clean the clogged tanks with clean water, and transferring the sewage to a location 27 km away from the city, where it is flushed into the ground without any treatment. These tankers unload the sludge at least three times a week. The cost of cleaning a septic tank, using the treatment proposed by the GAD, is around 120 USD per unit. This burden is not affordable for all families, who often leave their septic tank clogged up, thus promoting flooding with a consequent negative impact on the environment.

3.4. Towards a Municipal Sewage System for Puerto Ayora

There is no municipal sewer system in the entire urban area of Puerto Ayora. However, infrastructure is being set up for the drainage of wastewater with the following objectives [13]:

- coverage of approximately 100 ha of the existing urbanization, excluding *El Mirador*;
- reduction of the physical-chemical and bacterial pollutants in the groundwater (and the consequent reduction of diseases related to poor water quality);
- definitive closing of the disposal of septic tank sludge, placed 27 km along the road to Baltra.

The new network will have a minimum depth of 0.6 m, a maximum distance between manholes of 80 m, a maximum gradient of 4%, no drop manholes, and a maximum outlet height of 60 cm. There are pumping stations in order to increase the water pressure in critical sections of the network, and to allow the expulsion of wastewater from low-lying areas or those areas where it is not possible to dig deep because of the hardness of the soil.

The sewer system will collect the urban wastewater for purification at a WWTP, which will use compact units. The system provides for gridding, flocculation and flotation through the addition of micro air bubbles. This should reduce BOD_5 by 90%, producing about 1.5 $m^3 \cdot d^{-1}$ of treated sludge that can be used, without further treatment, for example as fertilizers in agriculture. Meanwhile, the liquid effluent should meet the legal parameters for concentrations of chemical and biological pollutants so that they may be used to irrigate or be offloaded into the nearest *grieta*, located in the western part of the city, in conditions safe for the aquifer and marine ecosystems.

The plant is expected to be ready in three years [13], but building works are still in the initial stages.

The neighborhood *El Mirador* is not part of the current plan proposed for the town of Puerto Ayora; in the urban planning of the new district a preliminary draft of a water management system in

El Mirador was proposed, but it has not yet been realized, probably due to the difficulties encountered in the realization of the one in Puerto Ayora. Now, some citizens have the intention to build their own home in *El Mirador* so, unless alternatives are found, they will be forced to treat their own wastewater as has happened in the past in Puerto Ayora.

4. Design of a Semi-Decentralized System for the Wastewater Management in *El Mirador*

4.1. Strategic Choices

Even the construction of a WWTP for the new urban expansion could be designed with the idea to reuse the treated water and primary sludge. The treated sludge could be used for agricultural activities, while the treated water could be used to irrigate the gardens or green public spaces through subsurface irrigation.

During the evaluation of various alternatives, different systems for the wastewater collection were considered: the traditional gravity system, the pressure system and the vacuum system. In terms of feasibility and costs–benefits, the traditional gravity system, designed in such a way as to avoid deep and expensive excavations in soil, has been considered the most suitable.

Still on the basis of analysis of costs-benefits, the best solution for *El Mirador* was determined to be a system of wastewater management including the following measures: (i) avoid the installation of individual treatment systems, as it happens now in Puerto Ayora; (ii) take into account the physical aspects of the location; (iii) choose the technologies with proven efficiency in terms of sustainable maintenance, that can use local materials and resources as much as possible, which are not too expensive, and which do not require specialized personnel for the construction or for normal management and maintenance; (iv) ensure the reuse of treated water and sanitized sludge; and (v) use technologies which require minimum maintenance.

4.2. Wastewater Collection

El Mirador would probably benefit from a classic type of sewer system which has a series of PVC tubes, laid at least 80 cm below the road surface, working under gravity conditions. These tubes direct the wastewater to collectors of increasing diameters. The water then flows into a treatment plant. Vacuum sewage would be too expensive although the utilities next to the coastal area could be installed in “flood-proof” systems [14].

4.3. Wastewater Treatment

A reliable solution for *El Mirador* would be to connect tight groups of lots in a small drainage domestic network, which would mean that most of the treatment could be carried out at the level of individual blocks. The partially treated wastewater would then be collected by a network of deeper collectors to a final centralized treatment stage before being discharged.

The advantage of using small treatment plants is a flexible and manageable solution. Currently by law, anyone can build their own home at any time in *El Mirador*, which means that buildings will be scattered unevenly over the area, thus making a single centralized network of wastewater drainage impractical. In the early years of a hypothetical centralized network, organic material would probably be deposited within those sections with an insufficient wastewater flow due of the initially small number of houses; one solution would be to install one tank sediment flushing at the top of each collector at the expense of using a great amount of water. A centralized system must be installed deeply and over a wide area which would require expensive excavation or many intermediate pumping stations. Conveying the wastewaters in points near to the source of production, and taking advantage of ground slope, could solve the problems of deposit of material inside the pipes and may limit construction costs: The reduction of cost can be obtained considering the need to lay one deep collector able to connect the 22 local networks to many blocks.

In addition to the problems above, it is difficult to predict the future population and the actual timing of building works; once the deep collector is built, a semi-decentralized system would be the best solution, because it could be implemented by block whenever a sufficient number of owners require the planning permission to build their own home.

The extremely geometric structure of the plans for *El Mirador* divided into sub-districts of about 66 building lots with an area of slightly more than 2.76 ha (Figure 2) means that the green space between them would be the ideal location for small treatment plants. In addition, there are non-buildable areas of 1878 m^2 that have been dedicated to recreational use.

The design prepared by the municipality for the urbanization of the district provides that on every lot apartment blocks with a maximum of three floors can be built [11], with one family in each floor. Based on the most recent statistical studies [5], each family consists of an average of four persons. Given the difficulty to establish an exact value regarding the future number of occupants/lot, it was assumed that there would be five people per lot corresponding to a total population of 6025 inhabitants.

Blocks were designed according to the natural gradient of the topographic surface of the soil by trying to retain the geometric structure of the model block described in Figure 1 as much as possible but, in some cases, it was impossible to adopt this principle due to differences in elevation of the soil within the same block. After a preliminary analysis of the topographic surface, 16 spaces (Table 1) were designed to allocate the treatment plants (Figure 2).

Figure 2. Positioning of treated wastewater collector from constructed wetland systems.

Table 1. Division into blocks and corresponding expected population, and indication of the blocks where the treatment plants are installed.

Block Code	Nr of lots	Population	Receiving Block
MZ001	43	215	MZ002
MZ002	44	220	MZ003
MZ003	65	325	MZ004
MZ004	66	330	MZ005
MZ005	67	335	MZ010
MZ006	78	390	MZ012
MZ007	66	330	MZ013
MZ008	Sports field		
MZ009	66	330	MZ015
MZ010	66	330	INT
MZ011	Divided between MZ006, MZ012 and MZ016-MZ017		
MZ012	76	380	MZ016
MZ013	67	335	MZ018
MZ014	66	330	MZ019
MZ015	72	360	INT
MZ016	78	390	terminal
MZ017			
MZ018	54	270	MZ021
MZ019	66	330	EXT
MZ020	65	325	EXT
MZ021			
MZ022	30	500	exchange
Total	1135 + 2 barracks	6025	16 plants

The criterion used for the choice of where to allocate the domestic WWTP was the location with the lowest cost. We suggested treating the wastewater of a sub-basin within the same basin, but this would mean bringing together the waters in point at lower altitude, and pumping them in the area where the WWTP is installed. The construction of pumping stations and their management would result an additional cost. Consequently, exploiting the natural slopes of the soil and bringing together the waters from the adjacent block seems more reasonable. The following table shows how the blocks are distributed, how the expected population will be served, and how the treatment plants could possibly be installed.

Each block has an expected population of almost always less than 350 inhabitants.

Given the simplicity of the conformation of this space and regularity of the road system, this solution would use a shallow sewer of small size.

As police and navy barracks were planned as a single block, connected to a small group of 30 residential lots, we decided to dedicate a space, of about 2300 m^2 named INT, for the treatment plant in the area of the terrestrial terminal. This solution is particularly convenient because it is the place where, in the preliminary draft presented by the Municipality, it was thought a centralized WWTP should be installed for the entire neighborhood of *El Mirador*.

Blocks MZ019 and MZ021 are located too close to the main collector and there is no place to put the treatment plant. For this reason, it is necessary to dedicate an area just outside the urban area of *El Mirador* (named EXT) to situate the plant. It was decided to choose two areas, INT and EXT, near the border of the town also because the semi-depurated water, after further treatment, could be reused to irrigate the nearby football field or the gardens at the entrance to the city (Figure 2).

With the designed configuration and estimating a daily water supply of 200 L/inhabitants, the district would need, when fully operational, 13.95 $L \cdot s^{-1}$ of water, slightly lower than the 16.53 $L \cdot s^{-1}$ [3] of supplied water expected in the new aqueduct project.

4.3.1. Preliminary Treatment

Especially for small WWTPs, gridding is the easiest system for pretreatment. In these plants, the material collected is often cleaned manually without the need for qualified technicians. Gridding is a low-cost technology and easily manageable. Among these, we can opt for a basket grid system, submerged in a drop manhole, guaranteeing a reduction of odors and insects [15]. Cleaning the grid is very easy but, periodically, the drop manhole needs to be cleaned with pressurized water.

4.3.2. Primary Treatment

Imhoff tanks are a valuable system that can be proposed for *El Mirador* given the simplicity of construction on site, non-use of electricity and the fact that they require constant but simple maintenance. The tanks with a rectangular section are often used to purify the wastewater of more than 50/100 equivalent inhabitants (EI) (depending on water availability per capita).

One of the main advantages of this type of treatment is the fact that a treatment unit can have both the sedimentation of solid sediments and, albeit modest, sludge digestion.

4.3.3. Secondary Treatment

The Imhoff tanks can be combined with technologies for natural secondary treatment, such as various types of constructed wetlands (easy maintenance): horizontal sub-surface flow, vertical sub-surface flow, surface impoundment, ecological units filtering and surface flow [15]. Given the urban context and the need to avoid odors and sanitary risks, horizontal sub-surface flow constructed wetlands are the best option, keeping the sliding layer of the wastewater sufficiently below the ground. The result is a very low environmental impact [15].

The water that comes out from the primary treatment, enters into the filtration system by a dispersion pipe and there it flows slowly onto a waterproof floor with a slight slope (0.5%–1%). The water flows down to the end part where there is a height control system which keeps a safe level of 5 cm–10 cm below the ground surface [15]. This type of phytoremediation removes most of the BOD_5 and suspended solids. The layer of gravel and rock acts both as a filter and as a skeleton to promote the growth of the root system of the vegetation that could be, for example, *Echinochloa Polystachya*.

For Ecuador *Echinochloa Polystachya* (German or Alemán grass) is an endemic reed and has the following characteristics: perennial, usually in colonies, culms coarse, 1 m–2 m tall, from a long creeping root base, glabrous; nodes densely hispid with appressed yellowish hairs; ligule a dense line of stiff, yellowish hairs; blades up to 2 cm–5 cm wide, panicle dense, 10 cm–30 cm long, racemes ascending; rachis scabrous spikelets closely set, nearly sessile, about 5 mm long; sterile floret staminate, the awn 2 mm–10 mm long; fruit rather soft, 4 mm long extending to a point 0.5 mm long [16].

A partial nitrification takes place around the surfaces of the roots, which are formed under aerobic conditions, followed by denitrification near the inert material in anaerobic conditions. Bacteria are killed due to the continuous transitions between aerobic and anaerobic zones into which the bacteria are forced throughout the entire process thus causing metabolic imbalances which kill most of the bacteria.

The beds of phytoremediation have been designed in order to maintain the following limits [17]:

- Maximum 10 g/m^2/day of BOD_5;
- Maximum hydraulic head of 40 mm/day;
- Minimum surface area of 2–3 m^2/ inhabitant. We adopted a water supply of 200 L/inhabitant/day and a theoretical characterization of wastewater described in Table 2 [15].

Table 2. Characterization of wastewater [15] and limits by law of discharge at sea [18].

Pollutants	Theoretical Value	Limit of Ecuadorian Law	Unit of Measure
Total solids	1230	1600	mg/L
Total dissolved solids	860	/	mg/L
Not volatiles	520	/	mg/L
Volatiles	340	/	mg/L
Suspended solids	400	100	mg/L
Not volatiles	85	/	mg/L
Volatiles	315	/	mg/L
Settleable solids	20	1	mg/L
BOD_5	350	100	mg/L
TOC	260	/	mg/L
COD	800	250	mg/L
Total nitrogen	70	15	mg/L
Organic nitrogen	25	/	mg/L
Ammonia	45	/	mg/L
Nitrites	0	/	mg/L
Nitrates	0	/	mg/L
Total phosphorus	12	10	mg/L
Organic phosphorus	4	/	mg/L
Inorganic phosphorus	8	/	mg/L

For each type of constructed wetland, it was calculated, referring to the minimum monthly temperature in Puerto Ayora, the theoretical reduction of BOD_5, N_{tot} and *Escherichia coli*, and we have obtained results slightly better than those found in the technical literature [15].

First, we calculated, depending on the temperature, the constants of degradation of the BOD_5 and N_{tot} starting from the constant estimated at 20 °C K_{BOD5} (20°) and K_{Ntot} (20°):

$$K_{BOD_5}\,(T) = K_{BOD_5}\,(20^\circ) \times \theta^{(T-20)}$$

$$K_{Ntot}\,(T) = K_{Ntot}\,(20^\circ) \times \theta^{(T-20)}$$

From the total area of each single system, depending on the number of beds estimated previously, the concentration (C_{out}) of BOD_5 and N_{tot} was calculated:

$$A_s = Q_p \times A_s = Q_p \times \frac{Ln\,(Cin\mathrm{BOD_5}) - Ln\,(Cout\mathrm{BOD_5})}{\mathrm{KBOD_5\,(T)}}$$

$$A_s = Q_p \times \frac{Ln\,(Cin\mathrm{Ntot}) - Ln\,(Cout\mathrm{Ntot})}{\mathrm{KNtot\,(T)}}$$

where A_s is the total area of the beds of phytoremediation and Q_p is the incoming daily flow of wastewater.

After these calculations, the concentration of *Escherichia coli* still remaining in the wastewater output has been estimated:

$$A_s = -\frac{365 \times Q_p}{KE.Coli} \times \ln\left(\frac{CinE.Coil \times Cno}{CountE.Coil \times Cno}\right)$$

where A_s is the total area of the beds of phytoremediation, Q_p is the daily flow of wastewater in input, $K_{E.Coli}$, constants of degradation of the *Escherichia coli*, $C_{inE.Coli}/C_{outE.Coli}$ concentration of *Escherichia coli* in/out the beds of phytoremediation and C_{no} the concentration which cannot be further removed by the installation [19].

The efficiency is appreciable: BOD_5 80%–90%, total nitrogen 35%–40%, total phosphorus 25%–30% [15]. The system manages to remove from 99.9% to 99.99% of fecal coliforms, for those for total and faecal streptococci, by retracting the treated wastewater within the limits fixed by the Ecuadorian law for discharge in fresh water.

In order to determine the size of the surface of a filtration bed [15], the expected removal efficiencies for BOD_5, total nitrogen, ammoniacal and organic nitrogen are generally used. In this case, there is the problem of having the bed entrance followed by the natural slope of the ground, but also the need to have relatively restricted spaces.

The EPA guidelines [17] state that the initial part of the filter, corresponding to about 30% of the length, is most subject to clogging. In this section, we assume that there is a strong loss of filtering capacity by estimating a project value of 1% of the theoretical value of the conductivity of the filling material. For the remaining 70%, a lower probability of clogging is assumed and, therefore, a conductivity value of the project amounting to 10% of the theoretical value is considered. As filling material, we chose a fill of very coarse gravel and pebbles with a typical diameter d10 between 16 and 32 mm, using a theoretical hydraulic conductivity of 10,000 m/day.

In our model, we chose materials coming from the demolition of buildings, such as bricks and concrete, broken up and washed. The use of local materials, such as volcanic lava and pumice and the use of a combination of inert materials having heterogeneous diameters, preferring rounded material to avoid breaking the waterproofing, is absolutely advisable.

According to the population estimation, we opted for a number of beds from five to eight for each block. One bed can be started at a time as the population grows and to ensure that at least one of the eight beds works in case of maintenance works of another.

In order to determine the size of the constructed wetland, in our model the depth of the beds is 0.8 m and the ratio length/width of the bed is 0.6. Each phytoremediation bed thus has a net size of 13 m from the inlet part of the wastewater and 11 m in the longitudinal direction for a total surface of 143 m^2/bed, just under 10% of the recreational area available; the cross-sectional area is equal to 10.4 m^2. According to calculations, the construction of between five and eight beds (143 m^2/bed) is estimated based on the estimated population per block. This is the real strength of the system: a treatment system that grows in accordance with the growth of the population of every single block.

In order to obtain the yield abatement, congruous with the discharge limits, the technical literature [15] recommends a hydraulic residence time (HRT) of between three and eight days.

According to Table 1, there are three types of possible blocks that have within them a similar number of lots:

- typology A: 43–44 lots
- typology B: 54 lots
- typology C: 65–78 lots

Wetlands plants are more often indicated because of they have modular characteristics and, therefore, are suitable to deal with the increase of the population of *El Mirador*.

By comparison with the alternative of activated sludge, an objection could be derived by the entity of initial costs. The following table shows the costs of construction and maintenance between an activated sludge plant (ASP) and a phytoremediation bed (PB) with the aim of directing a choice more economically sustainable (Table 3). In the case of choosing a semi-centralized system for *El Mirador*, such as that described until now, the most convenient choice is that of phytoremediation beds especially considering the management costs [15].

Table 3. Comparison of costs (USD) between an activated sludge plant (ASP) and a phytoremediation bed (PB) for blocks by 300 persons [15].

Item	**ASP**		**PB**	
	Total	**Per Inhabitant**	**Total**	**Per Inhabitant**
Building	201,500	672	302,000	1010
Management	14,334	47.78	8255	27.52
Capitalized total cost	351,632	1172.11	407,203	1357.00
Annual cost considering amortization in 20 years	19,131	63.77	16,256	54.18

The costs of the preliminary treatment are to be considered negligible because they are less than USD 1000 per block [20] and maintenance costs could be included in those of the Imhoff tanks. In favor of security, we consider the costs of construction of the sewer, similar with the proposed system and the traditional by gravity. The costs for the construction of the drying beds for the sludge are around USD 23/person with negligible costs of maintenance (<USD 1/person) [21]; we assumed using the same system of final disinfection for both plants, shown below, because we considered it more appropriate than the UV lamps or other traditional systems. The leachate from the drying beds, containing a large amount of pollutants, once diluted can be spilled in small quantities in an Imhoff tank in service at a phytoremediation system of a block already realized. For these last construction items, we can estimate a cost per person of about USD 100, which means the computation above is nearly the same. In Puerto Ayora, a system of collection and composting of bio-waste is already in operation; it would be an interesting opportunity considering the wastewater treatment system with the aim at encouraging applications of the use of treated waster and/or sludges in the agronomic field. From the treatment system using Imhoff tanks, an abundant production of sludge could be obtained that may be co-composted with bio-waste, and the subsequent sale of the resulting compost could be a good business for the Municipality, and could help in meeting the management costs of the plants. This production chain is important because it could be mean less fertilizers of chemical origin need to be imported.

4.3.4. Final Disinfection

The use of treated water to irrigate sports fields and public parks was considered, but the biological quality is not sufficient to respect the parameters of the law, and large volumes would be necessary. Similarly, we ruled out building an expensive underwater pipeline near the coast of Puerto Ayora to discharge the effluent, not totally depurated, into the sea because the water in this areas is already heavily contaminated with organic pollutants [2].

The most practical solution is to direct the waters of the main collectors to a single plant of final disinfection with the goal of breaking the additional pollutants still present in treated wastewater coming from individual phytoremediation plants. The flexibility of the system is in the fact that some beds, for example INT and EXT, may have their own self-disinfection system in such a way that the treated water could be made ready for reuse.

Between the various technological solutions, the dosage of Calcium hypochlorite, $Ca(ClO)_2$, is the most commonly used solution for small and medium size installations. In fact, it is easy to store and dispense, and is effective in combating microorganisms in wastewater [15]. However, due to growing concerns about possible toxic residues, $Ca(ClO)_2$ is being supplanted by systems such as UV and ozone. Another alternative is the disinfection by intermittent infiltration-percolation beds of sand, used in contexts where very high values of pollutant reduction and especially of the bacterial load [15] are required. This alternative was opted for a disinfection system driven based on the use of infiltration-percolation beds of sand and the discharge of treated water, containing concentration of pollutants much below the limits of law, at a point near the last purification plant. Although these systems are modular and can be expanded in line with population increases, they are easy to operate and maintain, material recovered on site can be used for construction and, especially, they do not leave chemical residues that could interfere with ecosystems.

The discharge of treated water, in an area where *the protection of fauna and flora in fresh water, hot or cold, in marine or estuarine waters, needs to be guaranteed* [7], not only has to ensure that the concentrations meet the Ecuadorian law for fecal coliform (200 CFU/100 mL) and ammoniac nitrogen (0.4 mg· L^{-1}) [18], but it must reach values of purification 10 times lower than the limits.

The area of the discharge end (Lagoon of Water Lilies) is a protected habitat and is commonly used as a recreational place but, because of the pollution caused mainly by *Escherichia coli* and fecal bacteria, bathing and direct contact should be banned.

In this case, we can consider the disinfected effluent as a tributary, which would increase the dilution of the polluted waters of the lagoon contributing to its slow environmental improvement. The process requires no chemicals and therefore is very suitable for a protected area of global importance such as the Galapagos National Park (PNG) and its marine reserve.

Odors cannot spread to the village, which is downwind of the prevailing wind direction, due to the low velocity values of the wind in the area and the barriers of vegetation.

In order to determine the size of the disinfection system to service *El Mirador*, we analyzed literature data [22]. Assuming a coefficient of infiltration in the main collectors of 0.5 L/s/km [14], a network of drainage water from the phytoremediation beds spans an estimated 3 km and, therefore, the daily inflow to the disinfection system would be 1100 m^3 (367 m^3/day for each line). We decided to use circular tanks, equipped with a filter with a surface area of 459 m^2, which is designed to cope with 20 spills per day and a daily hydraulic load equal to 0.8 m.

It is advisable to use a filler sand (d_{50} = 0.3 mm and a uniformity coefficient of about 2.2) with a height of 1.5 m, below which it is necessary to lay a layer of fine gravel of 10 cm and one of the most coarse gravels of 20 cm. The supporting structure must be made of reinforced concrete with a height of embankment containment greater than or equal to 2 m. The performance of these systems may guarantee a concentration of fecal coliforms less than 10^1–10^2 CFU/100 ml and a concentration of ammonia nitrogen less than 0.3 mg· L^{-1} [22].

4.3.5. The Sludge

The sludge can be used directly in agriculture. Another solution could be the use of drying beds; they are permeable beds filled with several drainage layers that, when loaded with sludge, collect percolated leachate and allow the sludge to dry by percolation and evaporation, though these may cause unpleasant odors. About 50%–80% of the volume of the sludge applied on a drying bed is removed as leachate [23]. An alternative is vegetated drying beds where the filter gravel and sand is covered by plants such as reeds and cattails. The root system of the plants, similarly to the system in constructed wetlands, forms a porous structure in the layer of solids and therefore maintains the capacity of the filter for a few years [23].

In order to size the drying beds we took into account that: (a) the Imhoff tanks are emptied 2.5 times per year (as average); (b) the maximum volume of sludge to be treated is 23 pit/m^3; (c) 20 Imhoff systems are planned, and thus four 110 m^2 beds would be needed. Each bed was calculated to be able to deal with 12.5 cycles of filling/emptying a year and have a maximum solids loading of 200 kg/m^2/year. These dimensions provide a mean drying time well above the minimum eight days required in such climatic conditions [23].

The leachates are very polluted [24,25], and it is recommended to store them in settling tanks and then discharged, in minimum ratio of 1:20, in Imhoff sub-basins with the greatest flow rate.

Our proposal is to place these plants in the *Valverde* recycling center, in order to have operators nearby and because the plants would be far enough away from the city; generally the cleaning of the Imhoff tanks happens once a year and, therefore, it is possible to consider that the costs of their cleaning out and the transport of the sludge would be negligible. We opted for drying beds to ensure the use of sludge in agriculture. For this option, the position of the *Valverde* recycling center is strategic because, since it is close to a rural area, it might be easier to distribute the dehydrated sludge in the agricultural field.

5. Recommendations to Improve the Rainwater Management

In order to protect the quality of surface water and groundwater resources, urban development must be designed to minimize the increases in surface runoff.

In more developed contexts, drainage networks are created that transfer large amounts of rainwater to the nearest final delivery. In other situations, where the realization of this infrastructure presents problems, or where it is not economical, there are viable alternatives.

While developing our model we took into account that:

- the average rainfall in recent years, because of climate change, has increased and created new problems
- meteorological events, especially in February to April, are short and strong
- rainwater flows on the surfaces on paved roads
- there are no historical data regarding rainfall events that last more than 24 h; six-hour measurements have only recently been made
- collection systems are currently present with the trap "wells to lose", which convey water and concentrate in a single point of dispersion, without a uniform distribution; most are clogged and/or totally underground.

The disposal of rainwater through the construction of a separate sewer or combined sewer would be impractical in some places because the pipes for the collection of rain water have very large diameters such that they could increase the costs of excavation. It may happen that in the inhabited centers, with high density of buildings, under roads there is not the possibility of laying pipes of large diameter due to the presence of other underground utilities or the presence of shallow foundations.

For *El Mirador* a mixed sewage system can be ruled out as it would oversize the phytoremediation plants. Moreover, excess rain water might be discharged to the sea or on the ground through the storm drains without proper treatment in case of heavy rainfall events.

Aiming at helping to prevent pollution of the groundwater in the subsoil, caused by diffuse sources, we chose to propose some solutions to filter pollutants in runoff [26]:

- **Bioretention basins:** These are rainwater treatment facilities for water quality control. Native vegetation is planted in shallow basins where water undergoes chemical-physical-biological processes before being removed in the soil by infiltration. This system can be exploited both in the existing urban area and in the new project, and rainwater from the roofs of houses can treated.
- **Infiltration and filter strips:** This contains and slowly filters the rainwater. It has a maximum depth of 30 cm in order not to be dangerous to children. In the infiltration and filter strips, the water is purified using the surface flow through the coating plant and the seepage through the upper matrix of the soil. The ditch is generally dry and after the rain it must empty itself generally within a few hours or at most within two days. The ditch should be made with a surface layer of organic soil of a thickness between 20 and 30 cm, and the vegetation should be native thus favoring plants in danger of extinction. These systems can be created at the side of new roadways, to store the water that runs off on them. This solution should help to offset the increase in traffic due to the expansion of the new urban area.
- **Flower beds:** The operation and the treatment capacity of run-off water are similar to those of the infiltration and filter strips but flower beds are more compact and, therefore, suited to an urban environment.
- **Draining pavements:** These allow the absorption and infiltration of rainwater directly from the road surface in the underlying soil, thus allowing the groundwater to be recharged. Clearly, the roads should be permeable. The use of draining pavements should not be limited to the new neighborhood under construction; in the case of rehabilitation and maintenance of existing roads, it is advisable to replace the waterproof coatings (such as asphalt and cemented paving) with draining pavements. Considering a coefficient of permeability of such surfaces around 70%, in

Puerto Ayora this solution does not guarantee the stagnation of water and groundwater recharge. On the streets, not yet paved, we recommend a consolidation of the road surface as to prevent lumps and bumps. It may take the flooring natural products with the help of stabilizers in order to obtain a manufactured product which looks like clay, but which has internal stability, bearing capacity and resistance to atmospheric agents. This technology can be used to create bike lanes, roads with low or medium density of traffic and parking.

- **Infiltration trenches:** An infiltration trench is a rock-filled trench with no outlet that receives stormwater runoff, it passes through some combination of pretreatment measures, such as a swale and detention basin, and into the trench. There, runoff is stored in the void space between the stones and infiltrates through the bottom and into the soil matrix; when bioretention basins are unfeasible, infiltration trenches can be used.
- **Absorbing wells:** The rainwater seeps and concentrates into the ground, through sumps consisting of hollow-body vibrated concrete that allows the direct runoff water in a permeable layer of gravel wrapped in a geotextile sheet to prevent the dispersal of the finer elements of sand and gravel.
- **Barrels for storing household rainwater:** The runoff from roofs is best in terms of quality because it is entirely accumulative and reusable for secondary household uses, for non-potable uses (for example flushing in the toilet) and for irrigation of the gardens. The tanks are made of plastic and can be placed above ground or underground. This is suitable for *El Mirador*, where we suggest the installation of these containers as mandatory. The types of houses for *El Mirador* would have three sizes: 40, 70 and 150 m^2. Using the method suggested by the WHO [27], the minimum tank volume is: 6 m^3, 10 m^3 and 21 m^3, respectively.

Our model for building a standard block of the neighborhood *El Mirador* is shown in Figure 3.

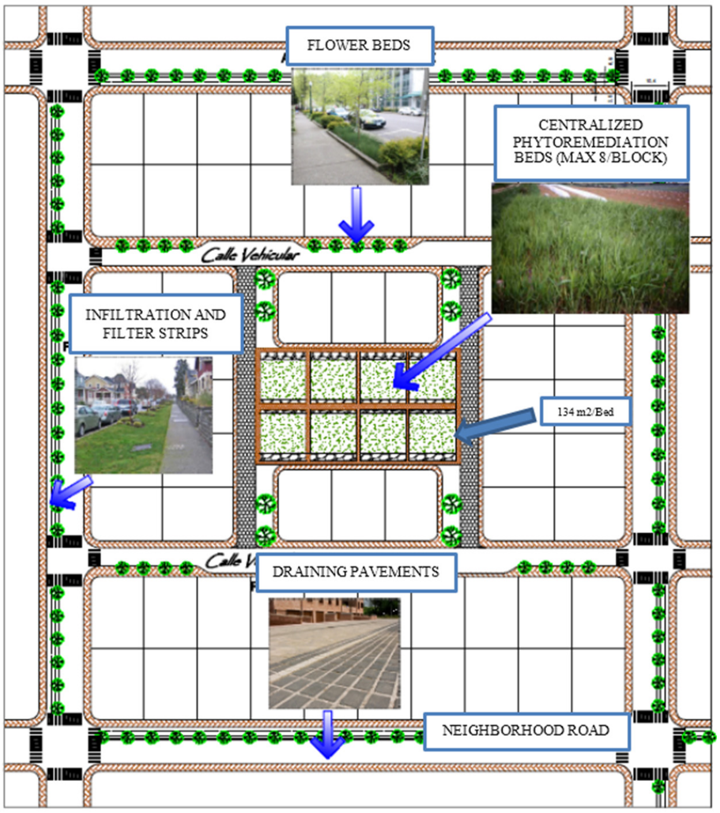

Figure 3. Proposed solution for the rainwater treatment in *El Mirador*.

For each block, we propose to maintain the draining pavement on every neighborhood road; in the blocks we designed, we propose installing phytoremediation or alternatively bioretention basins; in the areas where there are problems with water drainage, it is possible to install infiltration trenches or absorbing wells.

In order to avoid wasting tap water for watering the gardens, three types of tanks for the collection of the rain water, coming from surface of the roofs based on the typological scheme of houses planned, have been provided. The population should be informed by an awareness campaign to prevent accidental spills of oil from motor vehicles. Vehicles should be washed in special car washes that provide at least a settling of wastewater and the removal of oil and detergents.

Residents should also be encouraged to clean the streets in front of their homes, to avoid water stagnation in their property, and to report any problems in the drainage system.

6. Results

The proposed constructed wetlands plants have certainly construction costs greater than the other considered alternatives, but the investment costs have a payback less than the useful life of the plants. Combining those systems with specific actions for the infiltration of rainwater into the ground could provide the following environmental benefits:

- maintenance that does not require use of non-specialized workforce and can be inexpensive;
- very low electricity consumption, concentrated only in the last stage of filtration;
- during the entire process, chemicals that can pollute the environment are never used;
- thanks to the mild temperatures of the area, a high performance in the biological processes of degradation of the pollutants was obtained;
- the creation of green areas and wetlands could contribute to the development of habitats for local wildlife;
- the reed pruning can be used to make a high quality compost;
- the sludge from the Imhoff tanks can be co-composted with the reed pruning or the organic fraction of the urban solid waste [28];
- the presence of green areas can reduce the urban heat island effect [29].

These reasons, in addition to those already highlighted, make this approach very competitive and able to satisfy the pressing need for an appropriate system of wastewater treatment for the new neighborhood *El Mirador,* and we think it is a valuable proposal that should be presented to the Municipality of Puerto Ayora.

7. Conclusions

The objective of this work was to analyze the management of wastewater for the district of *El Mirador*. Our analysis highlights the need for a domestic sewer system connected to semi-centralized treatment systems (which consist of Imhoff and constructed wetlands) followed by a centralized plant for disinfection.

In this context, due to the limited land surface available, the phytoremediation system combined with intermittent infiltration-percolation beds cannot depurate the domestic wastewater produced by more than 6000 people. However, this method of phytoremediation means that the beds are modular and can be constructed as the blocks that are connected to the system grow. In addition, unlike a large centralized network, the sewage connections within the blocks do not require deep excavations and, thus, do not create problems when the ground is difficult to excavate. Only the Imhoff tanks require deep excavations, without ever reaching the level of the water table.

In terms of sustainability, the supply of water from the new aqueduct may not be sufficient to meet the needs of all the residents of *El Mirador*. However, tanks to use the rainwater from the roofs should help to bridge this deficit.

By adopting the very restrictive design criteria suggested by the EPA [17], the system could cope with 6000 users.

Regarding the rainwater, we have given some general indications on the simplest methods for channeling these flows without using a gravity piping system.

El Mirador would have few areas with potential danger of water stagnation and runoff. In fact, our system ensures that at every point in the neighborhood, there is water absorption by the soil.

The proposed wastewater system management uses simple operative solutions, able to ensure respect for the environment despite the strict regulations.

We want to further demonstrate the fact that, for new urbanization, a system of division into blocks of about 300 people each is extremely convenient from the point of view of management and maintenance. The phytoremediation beds have a higher initial cost, than an activated sludge system, but they have lower operating costs and a much simpler technology; this is a huge advantage in contexts in developing countries or in those places where it is very difficult to keep up with technologically advanced instrumentation.

In response, our system can offer the following advantages: the modular scheme is based on a phytodepuration system with a capacity up to eight beds; being a standard scheme makes it easy to replicate; it does not require advanced technologies; the consumption of electricity is very limited, maintenance operations are constituted by occasional drain of sludge and pruning of the reeds; and after a careful evaluation of the initial conditions it could be realized autonomously in another place on the island. This flexible and easily manageable system could be also implemented in developing countries, such as Sub-Saharan Africa, where the favorable climatic conditions could further increase the efficiency of the phytodepuration beds.

In this case, the soil, formed by lava rock, does not allow the realization of very deep excavations and is the major problem encountered; this approach requires, however, deep excavations only for the laying of the Imhoff tanks and some parts of the main collectors.

In this context, it was decided to adopt this scheme because we think it is a system that can operate in a way compatible with population growth, which will contribute to the environmentally sustainable management of the cycle of wastewater and the rain water by simple and replicable procedures. The reuse of rainwater and dehydrated sledges is an issue that needs to actively involve the population, and this could provide an impetus to promote environmental education programs, with the purpose of increasing public awareness of various environmental issues.

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References

1. Ragazzi, M.; Catellani, R.; Rada, E.C.; Torretta, V.; Salazar-Valenzuela, X. Management of Municipal Solid Waste in One of the Galapagos Islands. *Sustainability* **2014**, *6*, 9080–9095. [CrossRef]
2. Córdova, D.R.; Medina, J.L.; Nakaya, S. *Monitoreo de Calidad del Agua en la Zona Costiera de Bahía Academia en la Isla Santa Cruz. (Monitoring Water Quality in the Coastline Area Academy Bay on Santa Cruz)*; Parque Nacional Galápagos y Agencia de Cooperación Internacional del Japón: Puerto Ayora, Ecuador, 2008. (In Spanish)
3. Consulambiente Cia. Ltda. *Estudios y Diseno Definitivos Para la Construccion, Operacion y Mantenimiento del Sistema de Agua Potable Para Puerto Ayora (Studies and Final Design for the Construction, Operation and Maintenance of the Water System for Puerto Ayora)*; Canton Santa Cruz, Provinca Galapagos: Puero Ayora, Ecuador, 2012. (In Spanish)
4. Gobierno Autonòmo Decentralizado Municipal de Santa Cruz. *Alcantarillado Sanitario y Tratamiento Aguas Residuales de la Expansión de Puerto Ayora (Sewerage and Sewage Treatment Expansion in Puerto Ayora)*; Gobierno Autonòmo Decentralizado Municipal de Santa Cruz: Puerto Ayora, Ecuador, 2007. (In Spanish)

5. Instituto Nacional de Estatisticas y Censos (INEC). Censo de Poblacion Y Vivienda 2011 Census of Population and Housing 2011; Quito, Ecuador, 2011. Available online: http://www.ecuadorencifras.gob.ec/ (accessed on 3 September 2014). (In Spanish)
6. Collivignarelli, C.; de Felice, V.; di Bella, V.; Sorlini, S.; Torretta, V.; Vaccari, M. Assessment of sanitary infrastructures and polluting loads in Pojuca river (Brazil). *Water Pract. Technol.* **2012**. [CrossRef]
7. Environmental Ministry of Ecuador. Texto Unificado de Legislación Ambiental (Environmental Regulation). Available online: http://www.google.it/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CCIQFjAA&url=http%3A%2F%2Fwww.miliarium.com%2Fpaginas%2Fleyes%2Finternacional%2FEcuador%2FGeneral%2FTextoUnificado%2FLibroVI-Anexo1.doc&ei=119AUPijM8r-4QSiZw&usg=AFQjCNEJzwhh8zfH3q_YsRiQUZ (accessed on 3 September 2014).
8. Organization of the Petroleum Exporting Countries (OPEC). OPEC Annual Statistical Bulletin 2012. Available online: http://www.opec.org/opec_web/static_files_project/media/downloads/publications/ASB2012.pdf (accessed on 3 September 2014).
9. United Nations (UN). The Millenium Development Goals. Available online: http://www.un.org/millenniumgoals/ (accessed on 3 September 2014).
10. Charles Darwin Research Station (CDRS). *Galápagos Report 2009–2010*; Parque Nacional Galapagos (PNG): Puerto Ayora, Ecuador. Available online: http://www.galapagospark.org/oneimage.php?page=ciencia (accessed on 3 September 2014). (In Spanish).
11. Gobierno Autónomo Descentralizado Municipal de Santa Cruz. *Proyecto de "Urbanizacion El Mirador" en Terrenos y el Gobierno Municipal de Santa Cruz (Project of Urbanization "El Mirador" in the Municipal Government of Santa Cruz)*; Santa Cruz Municipality: Puerto Ayora, Ecuador, 2010. (In Spanish)
12. Gobierno Autónomo Descentralizado Municipal de Santa Cruz. Diagnóstico Sistema Asentamientos Humanos (Diagnosis Human Settlement System). Available online: http://www.gobiernogalapagos.gob.ec/wp-content/uploads/downloads/2013/08/PDOT-Santa-Cruz-2012_2_segundo1.pdf (accessed on 3 September 2014).
13. Gobierno Autonòmo Decentralizado Municipal de Santa Cruz. *Construccion del Sistema de Alcantarillado Sanitario y Tratamiento de Aguas Servidas Para Puerto Ayora (Construction of Sanitary Sewer System and Wastewater Treatment for Puerto Ayora)*; Santa Cruz: Puerto Ayora, Ecuador, 2012. (In Spanish)
14. Euromec. Water Treatment Plants. Available online: http://www.euromec.net/ (accessed on 3 September 2014).
15. Verlicchi, L.; Masotti, P. *Depurazione Delle Acque di Piccola Comunità (Water Treatment for Small Community)*; Hoepli: Milano, Italy, 2005. (In Spanish)
16. FAO. Grassland species. Available online: http://www.fao.org/ag/agp/agpc/doc/gbase/data/pf000230.htm (accessed on 31 August 2015).
17. EPA. Constructed Wetlands Treatment of Municipal Water. Available online: http://www.epa.gov/ORD/NRMRL (accessed on 3 September 2014).
18. Ministero dell'Ambiente della Repubblica dell'Ecuador. Texto Unificado de Legislación Ambiental (Unified Text of Environmental Legislation). Available online: http://www.google.it/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CCIQFjAA&url=http%3A%2F%2Fwww.miliarium.com%2Fpaginas%2Fleyes%2Finternacional%2FEcuador%2FGeneral%2FTextoUnificado%2FLibroVI-Anexo1.doc&ei=119AUPijM8r-4QSiZw&usg=AFQjCNEJzwhh8zfH3q_YsRiQUZ (accessed on 31 August 2015). (In Spanish)
19. APAT. *Linee Guida per la Progettazione e Gestione di Zone Umide Artificiali per la Depurazione di Reflui Civili (Guidelines for the Design and Management of Constructed Wetlands for Civil Wastewater)*; APAT: Firenze, Italy, 2005. (In Italian)
20. OPPO. Il Sito Delle Fontane e dell'Impiantistica Idraulica (The Site of Fountains and Hydraulic Installations). Available online: http://www.oppo.it/materiali/griglia_cestello.htm (accessed on 31 August 2015).
21. AFD and the European Commission's ACP-EU Water Facility. How to Select Appropriate Technical Solutions for Sanitation—Methodological Guide n 4. Paris, France, 2010. Available online: http://www.pseau.org/outils/ouvrages/pdm_ps_eau_cms_guide_n_4_how_to_select_appropriate_technical_solutions_for_sanitation_2010.pdf (accessed on 31 August 2015).
22. Brissaud, F.; Salgot, M.; Bancolè, A.; Campos, C.; Folch, M. Residence time distribution and disinfection of secondary effluents by infiltration percolation. *Water Sci. Technol.* **1999**, *40*, 215–222. [CrossRef]

23. Eawag/Sandec (Department of water and sanitation for developing countries). *Faecal Sludge Management—Sandec Training Tool, Module 5*; Doulaye Konè & Sylvie Peter: Dubendorf, Switzerland, 2008.
24. Rada, E.C.; Istrate, I.A.; Ragazzi, M.; Andreottola, G.; Torretta, V. Analysis of electro-oxidation suitability for landfill leachate treatment through an experimental study. *Sustainability* **2013**, *5*, 3960–3975. [CrossRef]
25. Raboni, M.; Torretta, V.; Viotti, P.; Urbini, G. Experimental plant for the physical-chemical treatment of groundwater polluted by municipal solid waste (MSW) leachate, with ammonia recovery. *Ambient. Agua* **2013**, *8*, 22–32.
26. Provincia autonoma di Bolzano. *Linee Guida per la Gestione Sostenibile Delle Acque Meteoriche (Guidelines for the Sustainable Management of Stormwater)*; Provincia autonoma di Bolzano: Bolzano, Italy, 2008.
27. Centro Panamericano de Ingegneria Sanitaria y Ciencias del Ambiente—World Health Organization. *Guía de Diseño Para Captación del Agua de Lluvia (Design Guide for Capturing Rainwater)*; Centro Panamericano de Ingegneria Sanitaria y Ciencias del Ambiente: Lima, Perù, 2004.
28. SSWM. (Co-) composting (Large Scale). Available online: http://www.sswm.info/content/co-composting-large-scale (accessed on 31 August 2015).
29. Blue Green Dream. Available online: http://dtvirt35.deltares.nl/products/30585 (accessed on 31 August 2015).