Green Infrastructure Systems as part of the Solution for Flooding in Panama

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Nathaly A. Miranda

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Dedication

To my family, who have been my greatest support.

Abstract

This study aims to find solutions to mitigate the problem of flooding in Panama City. This was conducted in order to create a support containing Green Stormwater Infrastructures methods and proposals to guide the community towards more sustainable development. Panama has been notoriously affected by climate change, especially in terms of rainfall. There have been alterations in the rainfall regime that together with other factors such as pollution by disposals have caused serious problems of flooding in the capital city.

However, there are limitations such as the lack of soil studies and non-easily accessible environmental information, among other things, which complicate the collection of information for a more in-depth study on which methods would be more feasible according to the sector. Hence, one of the areas most affected by the floods (Juan Diaz Township and Domingo Diaz Av) was chosen as a case study, thus demonstrating that despite being an already developed area, small changes can be made to generate a great impact.

The paper can also be improved by collecting site-specific data, such as the percentage of evapotranspiration, more in-depth studies on types of plants that benefit green infrastructure systems, among others, but more time and money would have to be invested to obtain quick results . Future researchers can use this work as a starting point for the application of these systems in Panama.

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List of Abbreviations

1. SW: Stormwater
2. SWM: Stormwater Management
3. EPA: Environmental Protection Agency
4. MIDA: Ministry of Agricultural Development (Ministerio de Desarrollo Agropecuario)
5. MOP: Ministry of Public Works (Ministerio de Obras Publicas)
6. ICT: Information and Communications Technology
7. PNUD: Program of the United Nations for Development (Programa de las Naciones Unidas para el Desarrollo)
8. JTIA: Technical Board of Engineers and Architects (Junta Técnica de Ingenieros y Arquitectos)
9. ETESA: Electric Transmission Company S.A (Empresa de Transmisión Eléctrica S.A.)
10. ANAM: National Environmental Authority (Autoridad Nacional del Ambiente)
11. ENSO: El Niño-Southern Oscillation
12. ITCZ: Intertropical Convergence Zone
13. AW: Tropical Sabana
14. GSI: Green Stormwater Infrastructure
15. LEED: Leadership in Energy & Environmental Design
16. JTIA: Technical Engineering and Architecture Board
17. CAPAC: Panamanian Chapter of Construction
18. INTA: National Institute of Agricultural Technology

CHAPTER I: INTRODUCTION

“Everything should be made as simple as possible but not simpler” – Albert Einstein

The world is in constant flux, whether for better or for worse it is an endless movement, especially when it comes to the environment. It is easy to make a comparison between the Panama of 10 years ago and what exists today. Unfortunately, many of these changes have been negative, especially with the issue of flooding in the capital city.

According to Cambridge University Press, floods can be defined as a large amount of water covering an area that is usually dry; when we talk about floods in Panama we think about different causes and how to justify that although this problem has been there for many years, it has not been solved yet. While pilot program plans have been developed to reduce this problem, none have been materialized because the groups in charge do not take the issue as a priority. On the other hand, we know that solutions to reduce flooding in Panama are not an easy task, because it must start by changing the way of thinking of the population so that professionals in the construction sector can work as a team with building users.

There are various methods that can be applied to manage rainwater. Although they seem simple, they have been studied to generate a positive impact on the environment and users. However, rainwater management is a new topic in Panama, so the collection of information and case studies are scarce and could initially be time consuming when planning a design.

Through this research, it is intended to leave a basis for architects in Panama to start taking their designs to a more sustainable approach.

CHAPTER II: LITERATURE REVIEW

The development of Panama City began in the twentieth century. It had very particular obstacles such as: political, economic, and physical (mangroves and marshy areas); it was forced to expand eastward near the sea. The land fillings, the result of various constructions, temporarily solved the problem of the swamps, thus achieving the development of luxury urbanizations, while the lower classes had to locate in areas despised for their physical conditions. (Jurado L., 2003)

The City in 1960.

They began to venture into more rugged topography for the development of commercial and residential projects. There were areas that had all the services, but as their development progressed, they presented problems such as: flooding in neighboring low areas, as a result of the displacement of waters of rains through the paved streets. By this time, the largest area of land occupied by neighborhoods of spontaneous settlements were in the northern sector of the city, San Miguelito and Alcalde Díaz. This type of neighborhood also began to emerge in the East sector (Juan Diaz, Pedregal and Tocumen).

The City in 1980

The city became a compact nucleus, new urbanizations were built that surrounded hills with heights of 100 meters and more. The problem of flooding due to rain that began in 1960 worsened. The city developed more, so the percentage of streets increased, which led to the rapid displacement of rainwater towards the neighboring rivers, this exceeded the level from the water of the rivers and flooded the settlement areas of the poor population. (Jurado L., 2003)

The City today

The final development of the city has been a mixture of obstacles mentioned above and the lack of an adequate land use plan. This has resulted in a chaotic urban agglomeration; where there is no spatial order or a perceptible division of the different land uses. The development of the streets does not have a harmony and the spaces in the areas that were originally zones of emergency settlements have been greatly reduced, so the construction of roads in those places has been a real challenge, especially at the time of storm drains construction. (Jurado L., 2003)

Geo-Climatic Characteristics

Geography

Panama City is located at the north of the Gulf of Panama. It is positioned on a low and ground plain and with a swampy tendency. It is the capital of Panama, and the largest and most populated city in the country. It is officially reaching 880,691 inhabitants within its municipality and 1,446,792 inhabitants in its metropolitan area.

Weather

Panama has a tropical climate all year round. The weather is composed by two seasons: dry season from December to April and rainy season from May to November. Due to its climate and location, it is normally affected by different atmospheric phenomena, such as the ENSO (El Niño-Southern Oscillation) phenomenon, tropical storms, and cold fronts.

The rainy season is the longest. It runs from the end of April to the end of November, thus leaving only 4 months of dry season (December to March). These two seasons are produced by the intertropical convergence zone (ITCZ). Table 1 shows that the driest month is March, with a total rainfall average measurement of 11 mm and the wettest month is October, with 291 mm. Table 2, shows the temperature variation during the year.

According to Climate Data, Panama is classified as Aw by Köppen-Geiger and the average temperature is 27.0 ° C (Merkel, A., 2020). Elizabeth Murigi in the article *What Are the Characteristics of a Tropical Savanna Type of Climate?* (2018), for the World Atlas website, makes a very accurate definition about the tropical savanna climate (Murigi, 2018):

> “AW or AS: Tropical savanna
>
> climate has alternating dry and wet seasons
>
> Temperature: relatively hot since they lie within the tropical latitudes. Throughout the year, mean monthly temperatures soar above 64 °F (18 °C).

The dry season in savanna grasslands is cooler than the wet season by a few degrees. During the wet season, temperatures are between 78 to 86 °F (25 - 30 °C). In the dry period of the year, the temperature ranges between 68 to 78 °F (20 - 25° C). Temperatures are higher during the day as compared to nights. The highest temperatures are experienced just before the rainy season, which is October in the southern hemisphere and April in the northern hemisphere.

Precipitation: mainly in the form of rainfall. On average, this climatic zone receives between 800 and 1,600 millimeters of rain annually. As one moves away from the equator, the mean annual rainfall decreases. During the driest month, precipitation is less than 60 mm. Savanna regions have two seasons, dry and rainy. Rain falls mainly in summer. The rains fall from May to September in the northern hemisphere and from October to March in the southern hemisphere.

Winds: The prevailing winds in tropical grasslands are the Trade Winds. They are easterlies, blowing from east to west. These winds have an enormous impact on the rains in this climate zone. For example, rainfall in the savanna decreases from east to west. They are also the cause of the alternating dry and wet seasons. During summer, onshore winds bring rain and in winter, offshore winds keep the savanna region dry. The Trade Winds are strongest in summer.

Vegetation: mainly consists of tall grass and short deciduous trees. Trees such as acacias shed their leaves during the dry period of the year to avoid excessive loss of water to the environment through transpiration. They also tend to have broad trunks which store water to help them survive periods of prolonged drought. Tropical grasslands are moderately green during the rainy seasons, but the grass turns yellow and eventually dies down during dry periods. As one moves from the tropical savanna climate into desert regions, the vegetation is dominated by dwarf acacias and scrubs.”

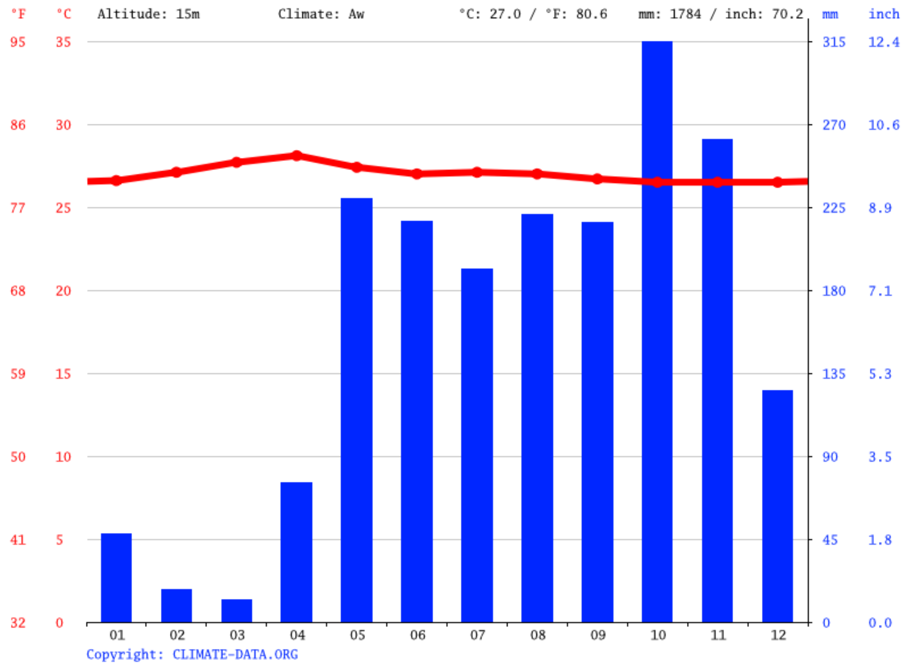


Table 1 Graph of the rainiest and driest months in Panama, Source: Climate-Data.org

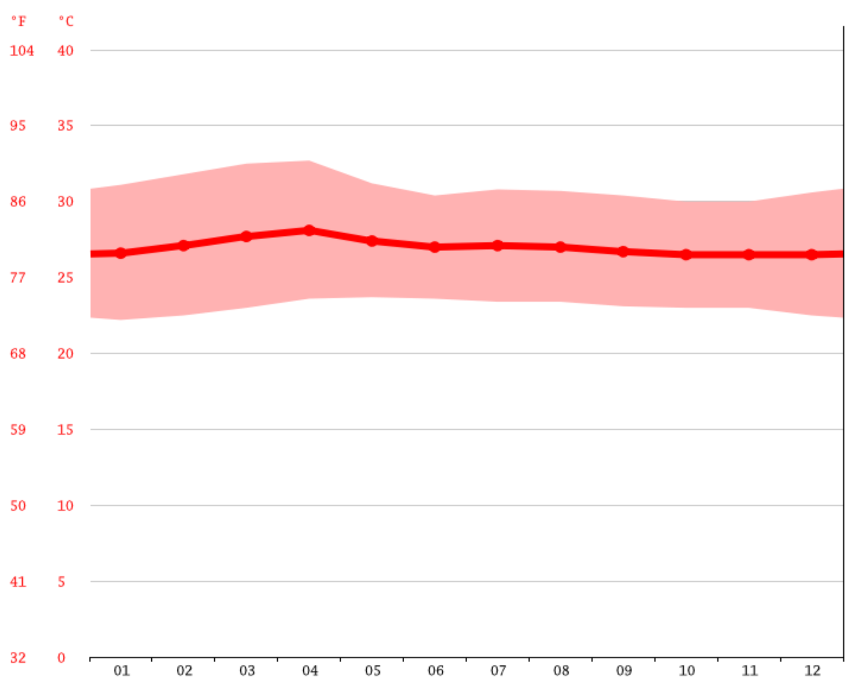


Table 2 Temperature Graph of Panama, Source: Climate-Data.org

Regarding temperature, the warmest month is April (Table 3), The average temperature is 28.1 ° C, and the coldest month is October with 26.5 ° C.

Additionally, table 3 shows a difference of 280 mm of precipitation between the dry and wet months. The relative humidity annual mean ranges between 76 and 91.7 percent, and evapotranspiration ranges between 1350 and 900 mm (ANAM, 2011); the lower relative humidity is reported on February during the dry season (62.7%), and the highest relative humidity is reported for the month of October (92%), coinciding with the rainy season.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Medium Temperature (°C)	26.6	27.1	27.7	28.1	27.4	27	27.1	27	26.7	26.5	26.5	26.5
Min Temperature (°C)	22.2	22.5	23	23.6	23.7	23.6	23.4	23.4	23.1	23	23	22.5
Max. Temperature (°C)	31.1	31.8	32.5	32.7	31.2	30.4	30.8	30.7	30.4	30	30	30.6
Medium Temperature (°F)	79.9	80.8	81.9	82.6	81.3	80.6	80.8	80.6	80.1	79.7	79.7	79.7
Min Temperature (°F)	72.0	72.5	73.4	74.5	74.7	74.5	74.1	74.1	73.6	73.4	73.4	72.5
Max. Temperature (°F)	88.0	89.2	90.5	90.9	88.2	86.7	87.4	87.3	86.7	86.0	86.0	87.1
Precipitation (mm)	44	16	11	70	212	201	117	204	200	291	242	116

Table 3 Historical Weather Data of Panama, Source:Climate-Data.org

Topography

According to Electric Transmission Company S.A (ETESA Hydrometeorology), the Republic of Panama has 3 morpho structural regions (Candanedo C y Fabrega O., 1999) (Figure 1):

a. Mountain regions: these regions are modeled on volcanic and plutonic rocks; however, there are uplift areas that are sedimentary in nature.

b. The Lowlands and Hills regions: consists of rugged landscape topographies, hills and hills with convex shapes in the upper parts and concave in the lower parts.

c. Low Regions and Coastal Plains: made up mainly of marine sedimentary rocks, they are depressed areas. These areas show a topography that varies from flat to slightly undulating and it has weak slopes.

The study area is within region C. Low regions and Coastal Plains. (Figure 2)

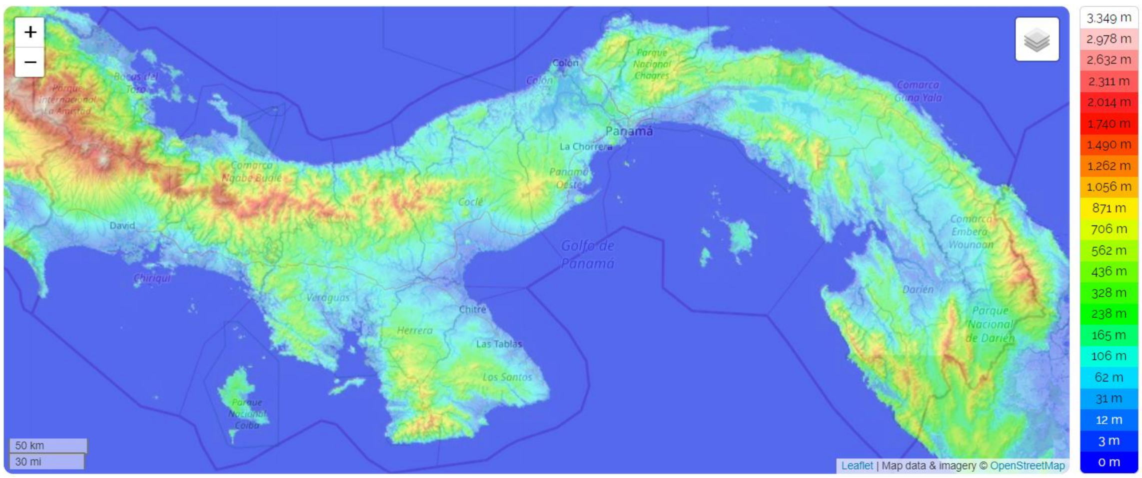


Figure 1 Panama Land Relief, Source: ETESA

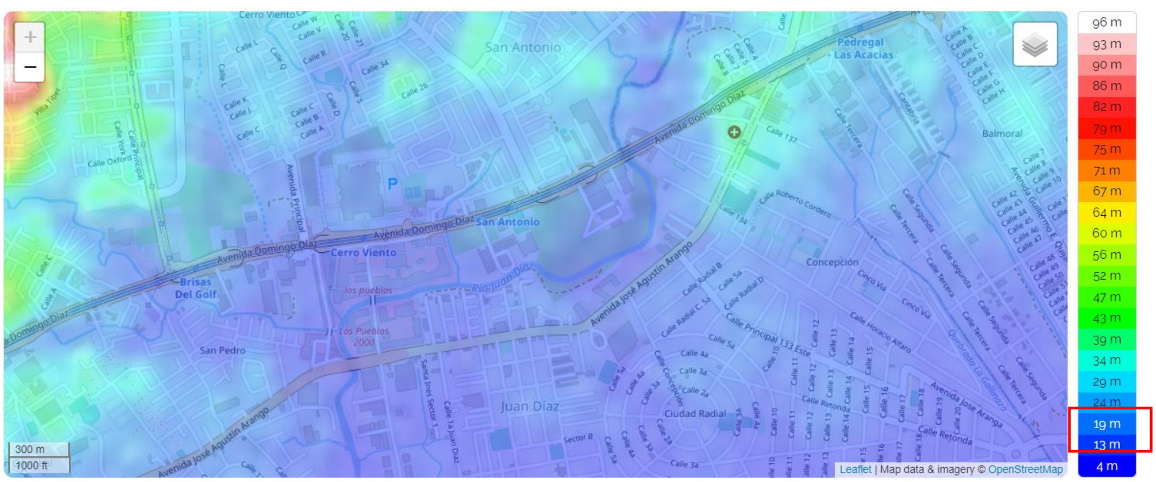


Figure 2 Domingo Diaz Av. and Juan Diaz Land Relief, Source: ETESA

Soils

There is documentation of standard penetration tests in the study area, in order from the most superficial to the deepest, it was found clayey sand with gravel and gravel with clay on the surface. Subsequently, light sandy clay with low plasticity and a sandy silt with low plasticity were found. Further down a loamy / loamy sand and well graded gravel and finally a low plasticity sandy loam.

The area for this study is in the region that belongs to the Cenozoic era and the Tertiary period, made up of sedimentary rock formations from the Tertiary and Quaternary of the Aguadulce groups and Las Lajas Formation and Panama Marine Phase. According to the Geological Map, used as a reference, it is shown that in the coastal sector the existing geological formations are:

Las Lajas Formation: belonging to the Aguadulce Group of the Recent Epoch of the Quaternary Period; This formation is composed of alluvium, consolidated sediments, sandstones, corals, conglomerates, and carbonaceous shale. This is the most recent geological formation in the Project area. It contains sedimentary rocks from the recent Quaternary, such as: sandstones, conglomerates, shales, tuffs, unconsolidated sandstones, and pumice.

Panama Marine Phase Formation: belonging to the Panama Group of the Epoch of the Tertiary Period; this formation consists of tuff sandstone, shale, algae limestone, and foraminifera, it is located in the sector of the South Coast of the South Corridor. It is the most extensive and oldest formation. At the regional level, it consists of sandstone, shale, algae limestone, and foraminifera from the lower to upper Oligocene of the Tertiary Period. (Alonso M., 2017)

The soils in Panama are leached, have a clay-loam texture, a slightly acidic pH, with a low phosphorous content and medium or low organic matter. They are red in color from iron sesquioxide. Since, it is derived from sedimentary rocks and basic volcanic rocks, it has a high content of calcium, magnesium, and potassium. Also, due to their texture, these soils have good drainage.

For Soil type we use the classification known as agrological capacity (Figure 3) or potential use, a system that was developed by the Soil Conservation Service of the United States Department of Agriculture. There are eight classes identified (Table 4), which are represented by Roman numerals, with a relationship between the progressive increase in numbering and a measure that conditions worsen. This classification considers characteristics such as depth, permeability, drainage, presence of rocks or stones, topography, erosion, risk of flooding, salinity, and fertility.

Soil Capability Classes	
Class I	They are suitable for annual crops. They can also be used to produce permanent crops, livestock, forestry, and protection. It has very few or no limitations that may restrict its use
Class II	They are suitable to produce annual crops. Lands of this class present some limitations that, alone or in combination, reduce the possibility of choice of crops or increase production costs due to the need to use management or soil conservation practices. They can be used for the activities indicated in the previous class.
Class III	They are suitable to produce annual crops. They can also be used in the same activities indicated in the previous class. Lands of this class present severe limitations that restrict the selection of crops or substantially increase production costs. It requires special conservation.
Class IV	Suitable to produce permanent or semi-permanent crops. Annual crops can only be developed occasionally and with very intense soil management and conservation practices, this due to the very severe limitations that these soils present to be used in this type of crops with a short vegetative period. Land of this class is also allowed

	to be used for livestock, forestry production and protection. It requires very careful handling.
Class V	This class is suitable for livestock activity, the natural forest management activity is also allowed when there is. The lands of this class present limitations and risk of erosion in such a way that annual or permanent crops are not suitable for it.
Class VI	Lands of this class are suitable for forestry activities (forest plantations). Plantations of permanent arboreal crops such as fruit trees can also be established, although the latter require intensive management and soil conservation practices. They are suitable for pasture. Other activities allowed in this class are natural forest management and protection. They have severe limitations.
Class VII	This class is suitable for the management of the natural forest, in addition to protection. The limitations are so severe that even forest plantations are not recommended on lands of this class. When there is forest in these lands, they must be protected to provoke the re-entry of the forest cover through natural regeneration. In some cases, and not as a rule, it is possible to establish forest plantations with relative success and also pastures.
Class VIII	The lands of this class present such severe limitations that they are not suitable for any direct economic activity of land use, so that they can only be dedicated for the protection of natural resources (soils, forests, water, fauna, landscape).

Table 4 Soil Capability Classes, Source: ACP

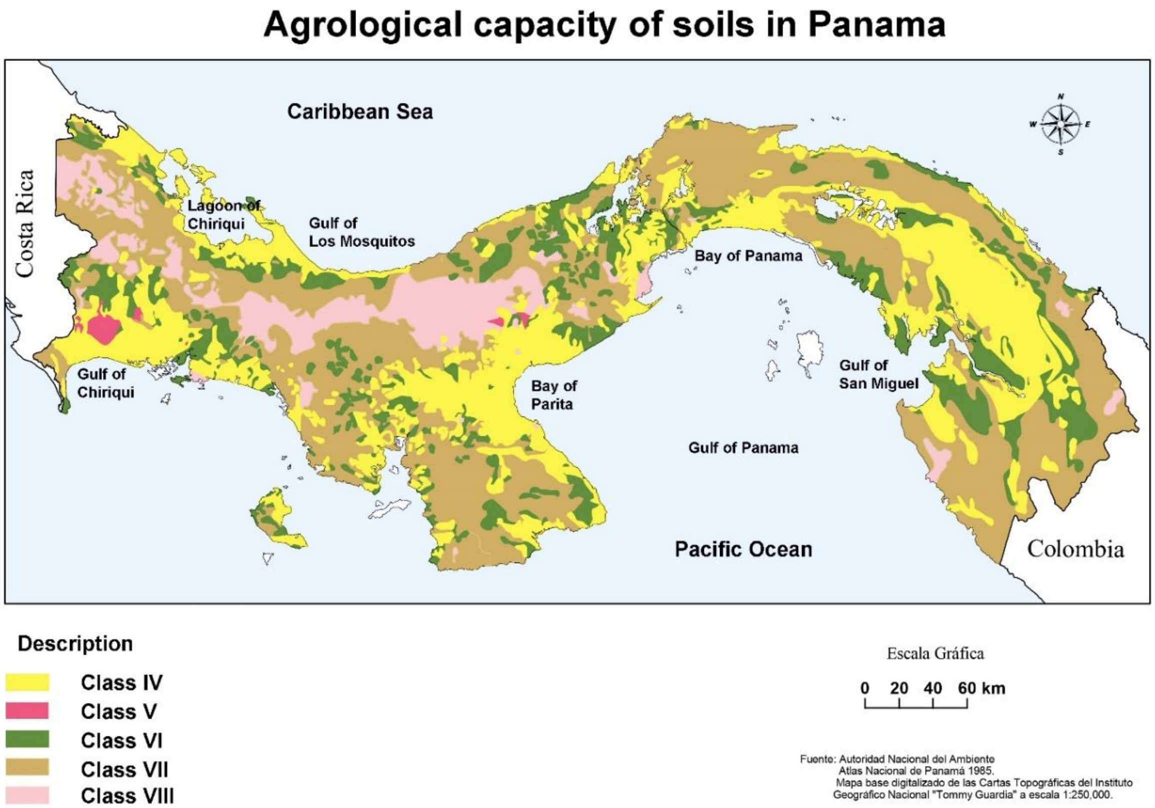


Figure 3 Agrological Capacity of Soils in Panama, Source: ANAM

Vegetation

The humid tropical forest is the dominant vegetation in the canal area, along the Caribbean coast and in most of the eastern half of the country. Other vegetation zones include tropical dry forests and grasslands on the Pacific coast, cloud forest in the highlands, alpine vegetation on the highest peaks, and mangrove forests on both coasts and around many islands. Among the flora, Panama has more than 10,000 species of plants, including approximately 1,200 species of orchids, 675 species of ferns, and 1,500 species of trees. (Lonely Planet, n.d.)

Domingo Díaz Avenue and Juan Diaz township

For the development of this research, Juan Díaz township was chosen, specifically Ave. Domingo Diaz.

One of the most important avenues in Panama City is Avenida Domingo Díaz, which connects with the interior of the city and functions as a connection point for large urbanizations.

This avenue borders Juan Diaz township and it works as a physical boundary between Juan Díaz and San Miguelito. Juan Diaz is part of the 25 townships in Panama City. This township is in the south-east zone of the metropolitan area and it has an area of 34.0320 km^2 which constitute 1.69% of the area of Panama City. (Gonzalez I., 2011)

Geological Information and Relief

The area of study is part of the geological compartment of the Central Isthmus of Panama and presenting volcanic material and sediment deposited in water (Santamaria F., 2009). The geology in the area near the mangroves is dominated by sedimentary formations from the Quaternary period. They belong to the Aguadulce group, Las Lajas formation, in which alluvium predominates, consolidated sediments, sandstones, mangroves, conglomerates and carbonaceous shales (Sociedad Audubon de Panama, 2002). (See page 8)

It presents a lowland topography, which makes it prone to flooding that fluctuates between 0 and 100 meters above sea level (m.a.s.l), and is divided as follows (Gonzalez I., 2011):

- The fluvial-marine plains of less than 20 meters, include the wetlands with their swamps, mangroves, and river reservoirs.

- Fluvial plains 20 to 49 meters high composed of alluvial plains and sedimentary rocks; these facilitate drainage and are located towards the central part of the village.

• Low Hills and Hills from 50 to 99 meters of altitude with lithological characteristics of magmatic effusions, dikes, and sedimentary rocks.

Weather

As it was mentioned previously (see page 4.), according to the Koppen classification, Panama has the Aw climate type, with average annual rainfall of 1 400 to 1 500 mm (55 to 59 inches) and a prolonged dry season. The precipitations in the country are characterized by being very intense and of short duration, and with some frequency periods with little or no precipitation are observed in some parts of the country, during the rainy season. (Moreno C., 2017)

Vegetation

Its vegetation is based on a productive system, with woody vegetation of a natural character and cultivated species. 23.84% corresponds to intervened vegetation and 22.16% of the territory of this district has mangroves.

Some of the main plant formations are:

• Halophytia or Halohelófilas spices = mangroves

• Helophytia or Hélofilas: vegetation that grows in intermittent fresh waters

• Pedophytia or Hydrophilicity: swamp vegetation

• Psammophytia or Psammofila: vegetation of sandy soils and beaches

Due to the growth of the population and the development of residential areas, the vegetation has decreased markedly. Currently the urbanized area comprises 54% of the township. (Gonzalez I., 2011)

Hydrography

Bathed by the rivers Tapia (east of the district), the Río Juan Diaz (central part of the district) and the Río Matías Hernández (west of the district), which discharge their waters into the Bay of Panama and the Pacific Ocean. Juan Diaz has one of the 80 water reservoirs in the country. This sector has an area of mangroves and swamps. (Figure 4 and Figure 5)

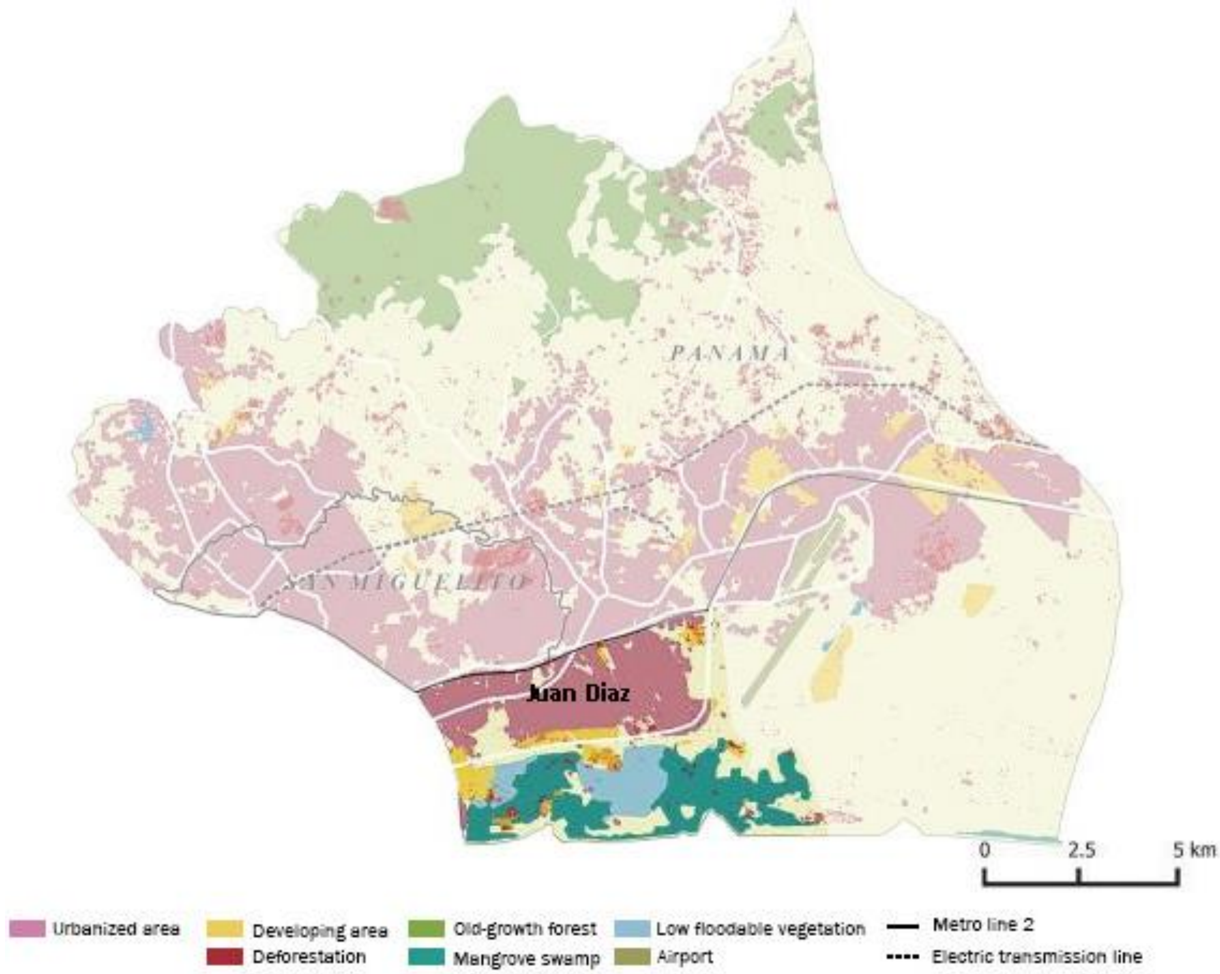


Figure 4 Juan Diaz Map, Source: La Prensa Newspaper

Figure 5 Juan Diaz Mangrove Source: La Critica Newspaper

Soils

Soils in this area are classified in two types:

• Type VI: non-arable with severe limitations, located to the north of the district and includes the populated part.

• Type VII: non-arable, with very severe limitations, suitable for pastures, forests, reserve lands, is in the southern part of the village and includes swampy areas and mangroves.

Storm water

Definition

Stormwater (SW) is the rainfall and snowmelt that steeps into the ground or runs off the land into storm sewer, streams, and lakes. This also includes runoff from activities like watering lawns, washing cars, and draining pools. (Queen's Printer for Ontario, 2016)

Hydrologic Cycle and why it is important?

It can be defined as the continuous circulation of water between the oceans, atmosphere, and land (Figure 6). Water is supplied to the atmosphere through evaporation and transpiration and it is returned to the earth through precipitation. Within the land phase, water is stored by vegetation, snow covers, bodies of water and underground soils. The water is transported between these storage compartments through land runoff, streamflow, infiltration, groundwater recharge, groundwater flow, and groundwater discharge, among other processes. (Queen's Printer for Ontario, 2016)

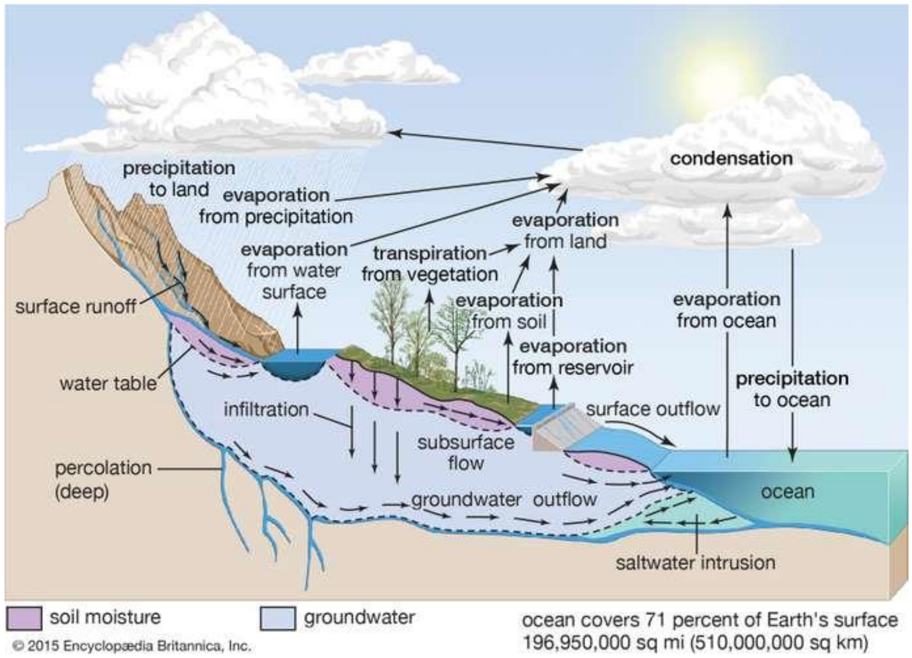


Figure 6 Hydrologic Cycle, Source: British encyclopedia

Urban Development and the Hydrologic cycle

The interaction between humans and nature sometimes brings consequences. In the field of construction, a non-properly studied action can affect an entire ecosystem, for example, the impact of construction in water. The intervention of humans with the water cycle occurs in different ways: the extraction of water for domestic, agricultural, and industrial uses; This water returns to nature in a degraded form. (Queen's Printer for Ontario, 2016)

Several aspects of the water cycle are affected by urban development. Mainly, infiltration is affected by the development of buildings (Figure 7). Besides this, created paved areas prevent rainwater from being absorbed by soils.

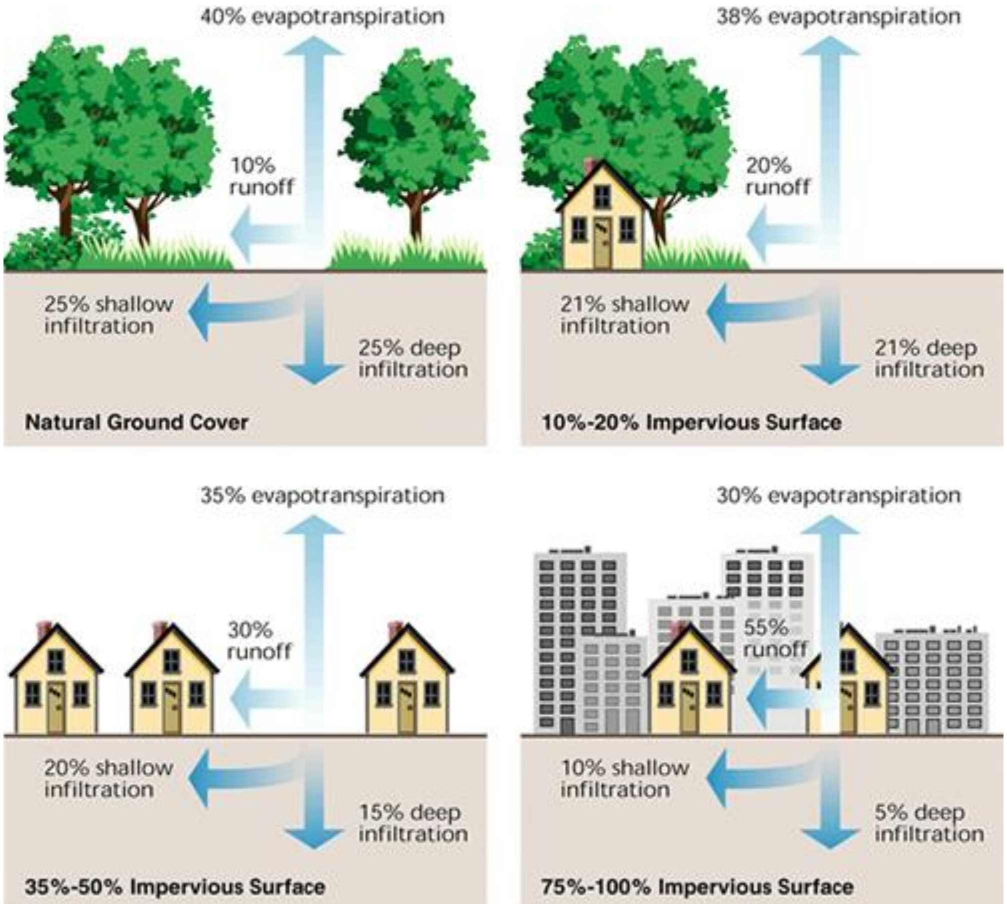


Figure 7 Stormwater behavior in different scenarios, Source: WNC Stormwater Partnership

Additionally, it is important to mention that urban development affects the runoff coefficient, because each material has a different rank (Table 5). Therefore, it affects the absorption of rainwater and the transportation of rainwater to a water body.

Description of Area	Runoff Coefficient
Business	
Downtown	0.70-0.95
Neighborhood	0.50-0.70
Residential	
Single-Family	0.30-0.50
Multiunits, detached	0.40-0.60
Multiunits, attached	0.60-0.75
Residential (suburban)	0.25-0.40
Apartment	0.50-0.70
Industrial	
Light	0.50-0.80
Heavy	0.60-0.90
Parks, Cemeteries	0.10-0.25

Playgrounds	0.20-0.35
Railroad Yard	0.20-0.35
Unimproved	0.10-0.30
Character of Surface	
Pavement	
Asphaltic and concrete	0.70-0.95
Brick	0.70-0.85
Roofs	0.75-0.95
Lawns, sandy soil	
Flat, 2%	0.05-0.10
Average, 2-7%	0.10-0.15
Steep, 7%	0.15-0.20
Lawns, heavy soil	
Flat, 2%	0.13-0.17
Average, 2-7%	0.18-0.22
Steep, 7%	0.25-0.35

Table 5 Runoff Coefficient, Source Storm Water Management Model

Stormwater Management

Stormwater management (SWM) is the method used to reduce runoff and improve water quality. When stormwater is absorbed into soil, it is filtered and ultimately recharges aquifers or flows into streams and rivers. (EPA, 2015)

According to EPA (2016), "In developed areas, impervious surfaces such as pavement and roofs prevent precipitation from naturally soaking into the ground. Instead, water runs rapidly into storm drains, sewer systems and drainage ditches, that can cause:

- Downstream flooding
- Stream bank erosion
- Increased turbidity (muddiness created by stirred up sediment) from erosion
- Habitat destruction
- Combined storm and sanitary sewer system overflows
- Infrastructure damage
- Contaminated streams, rivers and coastal water"

To solve these problems, we must know the causes (Table 6).

Stormwater Contaminant	Source

Suspended solids/sediment	Construction sites, roads, winter sanding
Nutrients (nitrogen and phosphorous)	Fertilizers, pet wastes, yard wastes
Metals	Cars
Oil and Grease	Cars, leaks, spills
Bacteria	Pet wastes
Pesticides and Herbicides	Yard and garden care
Heat (increased water temperature)	Exposure to air in warm season

Table 6 Stormwater Contaminants and their Sources. (Government of Ontario, 2016)

The appropriate System

As stated in NYC EP (2012), “the choice of stormwater management system will depend on the elevation of the existing sewers, multiple site conditions, and the preferences of the developer for the proposed project.”

If we want to have an effective system, we must ask ourselves the key question: what are we designing for? The correct answer is that we design for the worst-case scenario. The essential information to start the study will encompass data such as the average rainfall per year, evapotranspiration and infiltration of soils. It is important to make a study of the type of soil to determine the capacity and speed of its absorption.

Also, you must set a goal and establish a budget, so both things will be linked.

Green Stormwater Infrastructure

Defined by The Clean Water Act. In Section 502 as the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspiration stormwater and reduce flows to sewer systems or to surface waters (U.S. Government Publishing Office, 2018). There are several ways to design a Green stormwater infrastructure system (Table 7), ranging from the amount of time you plan to use the system to whether the design will include vegetation. But we must bear in mind that if we use various methods it will be easier to achieve an effective system.

Among the most used methods we can find:

GSI Method	Definition	Advantages	Disadvantages
Infiltration Trenches	These are stone-filled shallow excavations, this are made to create a temporary storage of SW runoff. They have a filter layer at the base of the trench which provides water quality enhancement of the SW as it moves. [a]	Can reduce runoff rates and volumes. Significant reduction in the pollutant load. Easy incorporation into site landscaping. [a]	Can only be used where soils allow the trench to empty within a short time. High failure rate due to poor maintenance. [a]
Grassed swales	Open channel with parabolic shape, the swale must be vegetated with flood tolerant plants. The vegetation should slow and filter SW. [b]	Promotes the slow and controlling movement of stormwater. [b]	Are not functional on flat terrain. They are not suitable for places with a high volume of rain. Can emit bad odors and be a breeding ground

			for mosquitoes.[b]
Pervious Pipe System	It is a perforated pipe located in stone-filled trenches and installed within the road along the rear yard lot line.[c]	Helps to sustain groundwater recharge. Maintain baseflows in nearby streams.[d]	It needs to be combined with other systems to avoid clogging with sediment or hydrocarbons. Can only be applied where floors allow storage to empty in a reasonably short time.[d]
Dry Ponds	They are ponds designed for the retention of rainwater, they are built to allow sediment and pollutants to settle. Water is stored 24 to 72 hours before it is discharge to a nearby stream.[e]	Control runoff. They Help improve water quality. They reduce erosion effects. Low Cost.[e]	Water can accumulate in the pond very quickly. Creates negligible groundwater recharge. Not useful to control multiple storm events. Requires a large area.[e]
Wet Ponds	Unlike dry ponds, these types of ponds maintain a	Remove pollutants.	Its size can increase dramatically

	permanent amount of water. [e]	Remove sediment. Compared to dry ponds, they are less expensive to install. [e]	because of rainstorms. [e]
Constructed Wetlands	Also known as shallow zones because their size is less than 0.5 m [c], it uses natural processes involving wetland vegetation, soils and the right microbes to improve water quality. [g]	Promote the construction of habitats for plants and animals. Are simple to construct. High Efficiency. Reuse of treated wastewater for irrigation. [f]	Its application to flood control is limited. [c] Require high land area. [c] May cause problems with pests. [f]
Infiltration Basins	Shallow reservoir for runoff storage and infiltration. It is built on relatively permeable soils. [a]	Provide adequate groundwater recharge. Reduce Local Flooding. Can be used for larger sites than infiltration trenches. [a]	Require fast flowing soils. Ineffective for flood control. Poor infiltration of the soils. Pretreatment of SW is required. [c]

Filters	Beds of sands or other media created to filter runoff and provide a better water quality control. [c]	Could be incorporated into most parking lot areas. [c] Long Design Life if properly maintained. Good for densely populated urban areas. [h]	Frequent Maintenance required. Costly to build and install. May have odor problems. [h]
Vegetated Filter Strips	Small dam and planted vegetation constructed perpendicular to the direction of flow and directs the flow of water towards the vegetation. [c]	Filter out pollutants. Promotes evaporation. [c] Easy to construct. Easily integrated into landscaping. [a]	Does not work on steep elevation terrain. It does not work for extreme events. Not suitable for draining runoff from hot spots. [a]
Pervious Pavements	It is a porous urban surface that traps precipitation and surface runoff, storing it in the reservoir while allowing it to slowly infiltrate the ground below. [i]	Reduce runoff volume by trapping and slowly releasing precipitation into the ground It can cool down the temperature of urban runoff.	Permeable pavement can clog with sediment and pollutants. Not as strong as regular traditional pavement.

		Can reduce the concentration of some pollutants. [i]	Not recommended for all soil types.[i]
Rain Garden	Small depressions in the ground that infiltrate stormwater. Rain gardens should be planted up with native vegetation. [a]	Require minimum land size. Reduce rate of run off. Easy to maintain. Easy to retrofit. [a]	The volume of reduction can be impacted according to their size. Susceptible to clogging. Not suitable for areas with steep slopes. [a]
Green Wall	All forms of vegetated wall surfaces.	Easy to install and maintain. Can Filter rainwater. Can help to reduce stormwater runoff. Can influence evapotranspiration and microclimate temperature.[j]	Can only support small plants. Require more maintenance. [j]
Green Roof	Multi-layered system that covers a roof with vegetation. This system is designed to intercept and	Reduces the volume of runoff and attenuates peak flows. Can be applied in high density developments.	High Cost. Requires maintenance. Any subsequent damage to waterproof membrane likely

	retain precipitation. [a]	No additional land take. [a]	to be more critical since water is encouraged to remain on the roof. [a]

Table 7 Green Stormwater Infrastructure Methods

Note: 1 Sources: CIRIA (a) Lake Superior Streams (b) Queen's Printer for Ontario (c) TRCA (d) County of Fairfax, Virginia, Emily Burton (e) EKBY's (f) Sudarsan, Renu, Baskar, Deeptha and Nithiyanantham (g) Structural BMP's- Volume 2 (h), Selbig W. and Buer N. (i), • Ostendorf, M., W. Retzlaff, K. Thompson, M. Woolbright, S. Morgan, S. Celik (j).

CHAPTER III: Problem Statement

One of the chronic problems in Panama City is flooding, mainly caused by rain, pollution and an outdated drainage system. According to Rodrigo Guardia Dall'Orso, on his article for the journal "La Prensa", 57% of the 2,717 natural events recorded between 1990 and 2013 correspond to floods. He alleges that the reason why he highlights Juan Diaz in his writing is due to the historical record of more than 30 thousand people affected in this district due to the floods.

Another article written by Carlos A. Gordon for the newspaper "La Estrella de Panama", relates two recorded events in which the water flow increased in a worrying way. On October 14th and 15th, 1986, a flood was registered. During this flood ,12 thousand people were affected in the area of Los Pueblos Mall and surrounding neighborhoods (Figure 8). The flow reached 845 m3 / s and the water level registered 6.90 meters. In addition, on September 17th and 18th, 2004, a storm appeared and brought with it a large amount of water in a short period of time, which produced an increase in the flow of rivers. Since their channels are narrow this in turn, generated an increase of river's water level. In this case the flow amounted to 928 m3 / s and the water level recorded was 7.24 meters.

Figure 8 Los Pueblos and Surrounding Neighborhoods map Source: Google Earth.

To carry out this research, the sector of Juan Díaz and San Miguelito was chosen, specifically the area that adjoins Domingo Díaz avenue.

The choice of this site was based on 3 reasons:

1. In recent years, it is one of the areas that has been most affected by floods in Panama City. (TVN News, 2016)
2. It is an area with high automobile and commercial traffic.
3. It is the township with the largest population in Panama City. (Cogley F., 2011)

An article written in 2016 by Ricardo Richards for the TELEMETRO newscast, reports that the MOP (Ministry of Public Works) in 2016 invested more than 4.5 million dollars in dredging, canalization and river and stream work. Half of the aforementioned figure was invested in Juan Diaz because it was one of the most affected sectors by the floods. In this district, the works that were carried out were only for cleaning and widening the riverbeds and streams. (Richards R., 2016)

For the development of this article, the writer interviewed the head of the Storm Drainage Section of the Maintenance Directorate of Panama Centro, Reynaldo Sanchez, who had indicated that the MOP can invest more than 10 million dollars in maintenance work but that it will be in vain because there is no culture of cleanliness within the population. (Richards R., 2016)

Over the years, pilot plans have been created to reduce flooding in different areas of Panama City, but the solutions that have been proposed have been temporary and the long-term plans have not been put in place. For the purposes of this research, a tour through the area of study was conducted and it was noticeable that the Panamanian culture has a big impact on the problem of drains. People can find all

Figure 9 Pollution in Av Domingo Diaz

kinds of garbage in the areas surrounding drains and at the entrance to the drains. The drain obstruction is critical and the smell that certain places have due to garbage and stagnant water represents a nuisance for users. Figure 9 is a clear example of this problem. In the photograph, we can see soda cans obstructing the course of the water towards the drainage and the flooded area. A surprising fact about the picture is that it was taken not even 30 minutes after it started to rain.

The Failures of the Initial Plan:

An outdated drainage system

The sewerage system in Panama City dates to 1960 and it has been maintained until today, except for some pipelines made by force in places more prone to flooding. It is important to mention that the first sewer systems in Panama date back to the 20th century and were combined systems. It was not until the middle of the last century that sewer

networks appeared in the cities of Panama and Colón. However, these systems ended in direct discharges to bodies of water

The sanitary sewer of Casco Antiguo, which was one of the first in the country, like the one in Colón, keeps this combined design, it was built to receive sewage and rainwater, but it does not have the necessary capacity, because its diameter is very small.

Nowadays, the suburban system is separate, it only receives wastewater, however, in some parts it is recharged with rainwater. This system does not work efficiently. (Madrid M., 2002)

In 1998, studies began to develop a plan for the sanitation of the city and the Bay of Panama; this sanitation would be carried out to:

- Improve sewer systems
- Identification of areas without sewers
- Infrastructure requirements for conduction and wastewater treatment of each area

However, it can be said that the sewerage system designed in 1960 was not feasible, since in those 38 years apart, Panama found it necessary to think about new options to solve a design that was only developed to solve a momentary problem. The 1960 system did not work because:

- The city grew
- Many informal settlements were made
- Pollution was changing patterns in nature.
- The design was not planned for a future scenario where these changes would occur.

Figure 10 Floods in Panama City Source La Prensa

In this way, the Panama City Sanitation Plan began to be developed as well as other projects such as "Dialogue of Water" which have sought to reduce flooding's in the city. However, the question that arises when we learn about all these proposals is: Why does the problem continue when time and money have been invested in developing programs like these?

Many times, a joint work is not carried out between the stakeholders and the community, carrying out technical solutions without the support of the community will result in a delay of the objective or a failure in the plan. For instance, the Panama City Sanitation plan was developed to recover the sanitary and environmental conditions of the metropolitan area and the elimination of contamination by untreated wastewater in urban rivers and in the coastal areas of the Bay of Panama. (Arjona E., 2013) Nevertheless, this project will take at least

3 decades to be completed. Currently (2020) the project has progressed 67% from its start date (2001), but it is known that the success of the sanitation depends so much on the works that are carried out, as well as the awareness of people (citizens, industrialists, merchants, public servants, among others) regarding the proper use of water and the final disposal of garbage. There have been factors that have affected the execution of some projects of the work, such as changes in the alignment of the pipes due to alterations in land uses, contractors that have not fulfilled their responsibilities and budgetary issues. (Testa M., 2020)

Furthermore, this is a problem that has affected the city for many years as time passes. The scenario becomes more complicated, more urban projects have been developed, leaving less space to correct existing problems. Besides, the culture factor plays a crucial role in all this. For example, we can find new constructions in which the land has had to be leveled with fillings, hence affecting the surrounding residential areas, such as Los Pueblos Mall (Figure 11 and Figure 12).

Figure 11 Land Fillings in Neighborhoods

Figure 12 Los Pueblos Mall Location Source: Google Maps

Los Pueblos was built after the residential area. Fillings were carried out at the time of the construction and as a result the existing houses are below the level of the square. During the tour carried out in this area, it was observed that in the areas that adjoin the Juan Diaz river, dikes were created (Figure 13) to prevent flooding during the rainy season. However, this method itself is not functional since that barrier of land, is not enough to prevent river overflows.

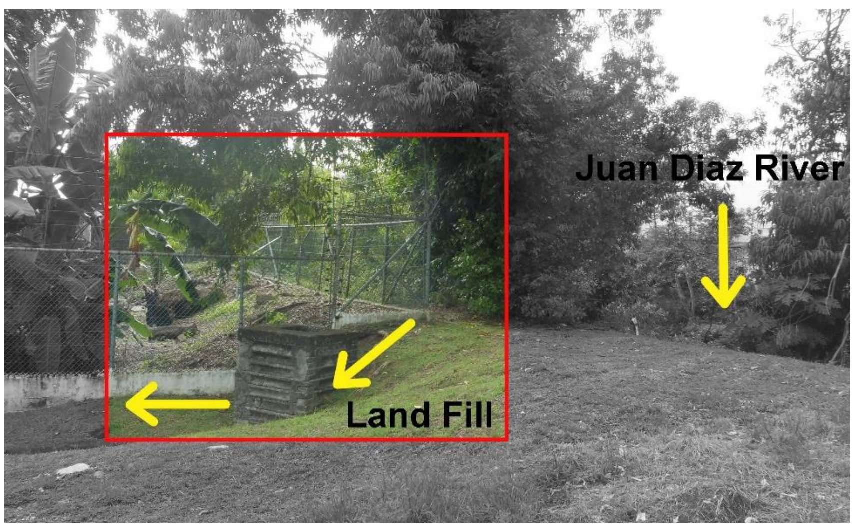


Figure 13 Dikes as a Protection barrier

Another factor that has affected these developments was that they were built before the streets existed and this brought consequences. For instance, not enough space for drains, residences are below street level, improvised and poorly channeled drains (Figure 14) and flooding's as is the case of Radial City Neighborhood in Juan Diaz (Figure 15). These are temporary solutions and are not part of a planned stormwater system.

Figure 14 Makeshift Drainage Channels in Radial City Juan Diaz

Figure 15 Location: Ciudad Radial Juan Diaz, Source: Google Earth

This type of improvised drainage can be found in most of the residential places of the selected area for this study. A characteristic of these drainage channels is that they are only found on one side of the road due to lack of space and planning. This residential area has a perimeter wall that separates the residences from surrounding places. Something curious about this wall is that some sectors have a small opening at the bottom so that the water can exit towards the drainage. However, taking into account the amount of rainwater falling into the area, the space is very small, and the openings are not properly distributed. (Figure 16)

Figure 16 Wall Openings for drainage

Climate change changes everything

Today's architectural design must be resilient. We live in an age where climate change has transformed nature so much, that climate studies that were developed 20 or 30 years ago, now are not enough to develop a stormwater efficient design. For example, in Panama this has caused that the previous stormwater systems are undersized to handle the new water regimes and they need to be supplemented by other systems-redundancy.

Over the years the rain pattern in Panama has changed, and this is one of the results of global warming. For instance, years ago it used to rain the same amount, but for a longer period, now the period is shorter. However, the amount of rainwater has not decreased (Arcia O., 2018). An example of how climate change affected

Panama happened in 2010 with one of the worst rain scenarios that the country has suffered. Between December 7th and the 9th, 2010, the Panama Canal basin was affected by the biggest storm in its history. Due to this, the interoceanic route was closed for 17 hours for the fourth time since 1914.

According to a report from the Panama Canal Authority, this rain event caused more than 500 landslides in Lake Alajuela and the largest amount of suspended sediment in the lake. This caused the collapse of the Federico Guardia Conte water treatment plant in Chilibre, which left the city without potable water for 40 days. On December 7th, cracks previously detected in one of the access roads of the Centenario Bridge gave way to rain and caused a landslide. (La madre de las lluvias, 2012)

In graph (Figure 17), a comparison between the rainy season from 1992 to 2015 shows a progressive increase in the amount of rain. From 2010 forwards the scenario is worrying. Notice that there is a great variation in a short period of time (2013 to 2015). The maximum annual pluvial precipitation was reduced by 58% (3500mm or 137.79 inches) and the amount of annual rainfall has changed drastically due to the climate change. In the image it can also be seen that because of the El Niño phenomenon (ENSO), in 2015 the annual amount of precipitation showed a deficit compared to the interannual average of the last 30 years (CONAGUA, 2018). Climate change has also altered the rainfall regime; now the precipitations have short duration and high intensity.

The information and design tools for drainage channels and stormwater management have not been updated and continue to be based on old patterns. In the article “A city that succumbs before short and intense rains” for the newspaper La Prensa (Arcia O., 2018), the writer talks about an interview with Luis Márquez, current secretary of the College of Civil Engineers of Panama, where he explains the use of the intensity, duration and frequency curve to define the construction model to be used in a project. The problem is that this method dates from 1972 and only serves as a guide when designing drainage channels and drains.

Indeed, the lack of preparation to face the climate changes that will come is notorious. The responsibility in this case is shared by the different authorities, but until there is not an institutional unification and till the interdependence continues to be predominant, we will not see lasting solutions.

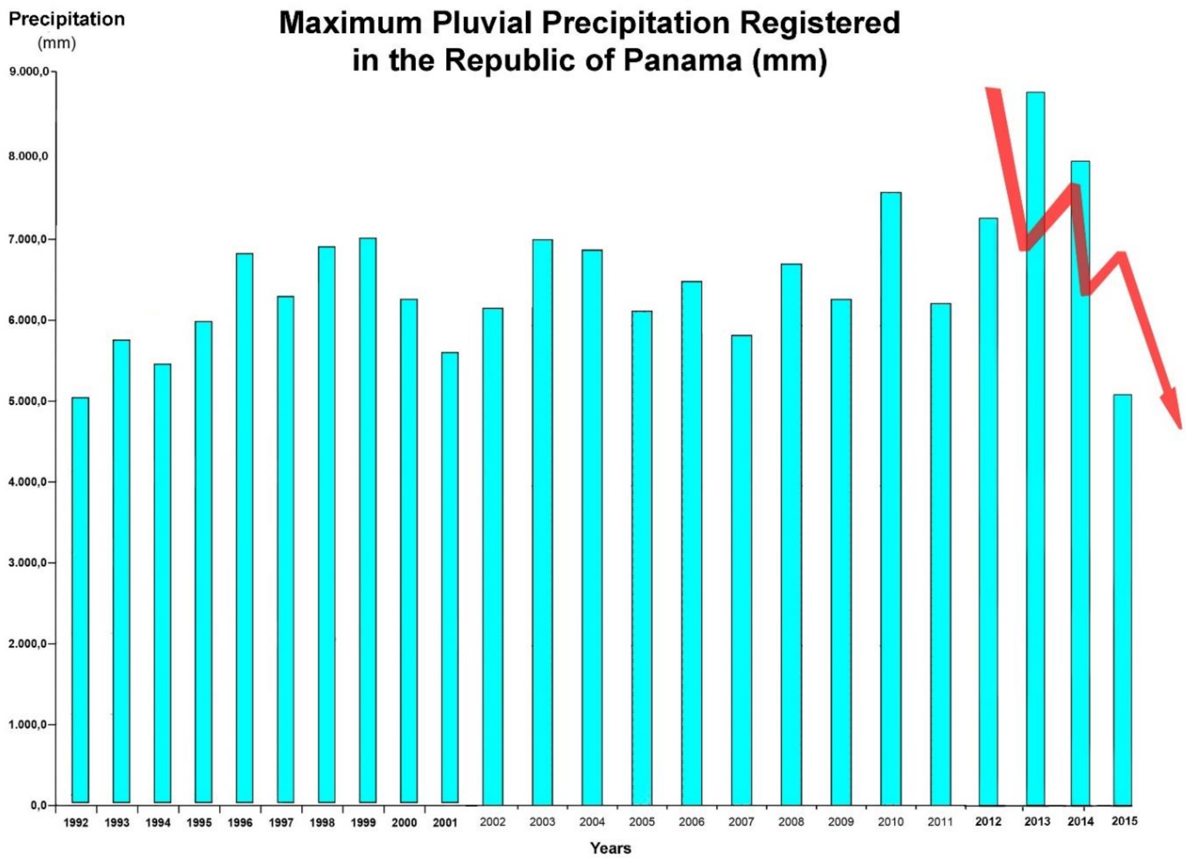


Figure 17 Maximum Annual Precipitation Registered in Panama (1992 to 2015), Source: INEC

ENSO phenomenon

According to INTA in its article entitled El Niño Phenomenon and the Southern Oscillation, it defines the ENSO (El Niño-Southern Oscillation) phenomenon as a "recurring climatic pattern that implies changes in the temperature of the waters in the central and eastern part of the tropical Pacific. In periods ranging from three to seven years, the surface waters of a large strip of the tropical Pacific Ocean warm or cool by between 1°C and 3°C, compared to normal". This phenomenon began to affect Panama in 2014. It consists of 3 phases: warm phase, cold phase and neutral phase. According to ETESA's Hydrometeorology, the warm phase consists of a warming of the water masses of the equatorial and eastern Pacific Ocean, producing an increase in the global average temperature. The cold phase is the opposite; it is a cooling of the equatorial Pacific oceanic mass and generates climatic variations contrary to the warm phase. This phenomenon changes the climatic patterns at the global level of pressure, precipitation, wind, solar radiation, among others. In Panama, it has caused rainfall deficits on the Pacific slope and an increase in the number of consecutive days without rain. It also creates excess of rain on the Caribbean slope.

In fact, it is evident that the appearance of these phenomena is more and more frequent. According to the World Organization and Climate Forecast Center, there is a 75% probability that the ENSO cold phase will affect Panama until February 2021. In other words, Panama will have more rainy days. (Jiménez T., 2020)

Tropical Storms

According to data provided by ETESA's Climatology for the Panama America newspaper, an average of 12 storms is recorded in a normal year. Nevertheless, as climate change progresses, this type of pattern is lost. By the beginning of September 2020, Panama had already experienced more than 13 tropical storms, thus exceeding the stipulated average, also the rain regime during this type of events consist of greater intensity and greater amount of water in a short period of time.

Tropical storms this year (2020) have increased 20% of the areas affected by floods compared to 2019 where 305 flood situations were registered. (Jiménez T., 2020). In addition, during the development of this research, Panama was affected by two hurricanes: ETA and IOTA.

Figure 18 was taken during the rains caused by hurricane IOTA. In the picture, we can observe the street completely flooded as a result of the large amounts of water, pollution, and drains clogged by wastes.

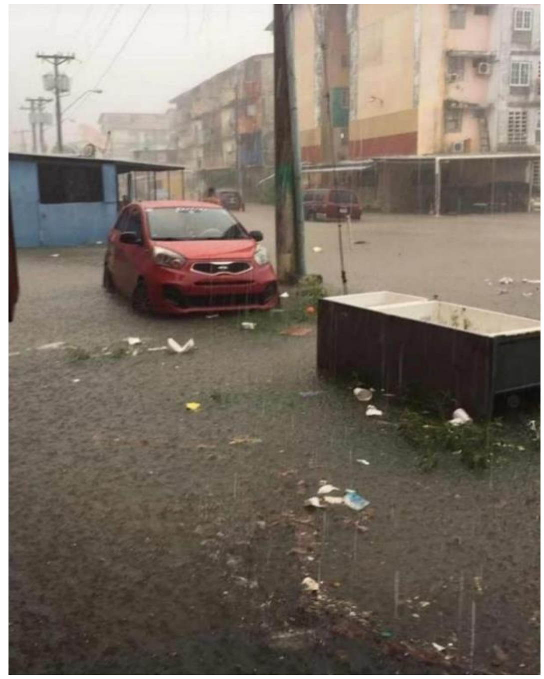


Figure 18 Rain floods in Panama, Source: Dia a Dia Newspaper

CHAPTER V: Analysis and Discussion

While the data was collected, an analysis was carried out on which SWM systems would be more appropriate and adaptable to different sites in Panama City. One of the data collection methods used was, site visits, carried out in two different types of scenarios: rainy day and dry day, in order to study the behavior of storm drainage and rainfall in the sector and the behavior of the community in place.

SWOT Analysis

Macro Systems:

Forces, natural systems, + human systems that are endogenous to the site (Figure 19); which affect the quantity, quality and rate of the water.

- Juan Diaz River
- The Mangrove
- The vegetation
- Population
- MOP

Figure 19 Macro Systems of the Study Area

Micro Systems

Forces, natural systems, + human systems that are endogenous to the site. These systems are mostly intervened by human force. This generates alterations in the ecosystem and as a result the alteration of the cycle of nature.

- Domingo Diaz Avenue
- Internal roads and sidewalks
- Buildings
- Pollution
- Lack of appropriate vegetation

Research Limitations

Before analyzing the data, it is important to mention some unforeseen events that complicated the collection of information and therefore affected the development of this research.

1. Lack of Studies about the topic: Unfortunately, Panama does not have a long time applying sustainable methods, therefore there is a lack of awareness of the environmental problems. There are not enough resources and as a result, the information is scarce. The data that you can collect is from superficial studies, and some are obsolete and do not work for new designs because the scenario has changed over time. These factors make this type of research complicated because they need more equipment and time to get deeper and obtain more accurate results.
2. Information is monopolized by institutions. Obtaining information about national studies in Panama is not an easy task. Public institutions often limit access to information when this should be free for all public. Another problem is that the information is not often on the web but only on physical documents. Therefore, the institution takes complete control over what it shares.

3. COVID-19: It has been a factor that has greatly affected the development of this research. Applying surveys and contacting specific people to be interviewed was not easy, but the restrictions due to this virus and the curfew in Panama limited the application of these methods. However, with the technology it was possible to conduct videoconference interviews. Culture is something that also influences this point, since normally Panamanian communities are not very interested in participating in surveys and applying online surveys in this case is not so feasible because the number of respondents will be very low and would not represent a weight value when analyzing the results.
4. Hurricane ETA and IOTA: Another event that altered the collection of information was the presence of these 2 phenomena in Panama. The increase of rainfall due to these extreme events altered some visits to the site. Also, the flow of rainwater on those days is not the amount that normally falls in Panama. On the other hand, the positive side is that many people realized that we are not prepared for these types of scenarios and that a change in the management of rainwater is urgent.

Data Collection Instruments

As part of the data collection a quantitative research method was applied, and 20 Architects from the Republic of Panama were interviewed (see Appendix A). To briefly describe the profile of the interviewees, it can be mentioned that the age range is between 27 and 53 years and the type of architectural business is not specified. Most of them are dedicated to the development of all types of projects (residential, commercial, institutional). The questions included personal knowledge about the subject under development and their opinion as professionals; This data is essential to make decisions when establishing solutions for the topic in research. Among the information collected, we can mention methods than can be used to educate the community and motivate them to contribute to caring for the environment.

We obtained the following results through the interview conducted:

1. The floods in Panama are due to the poor city planning (in terms of drainage), contamination and soil erosion. There are very few studies based on these issues and there are even few soil studies that guide us on what type of construction can be carried out in a certain place. The poor design of the regional stormwater system complicates the new constructions.
2. Between Civil Engineers and Architects, the one who has more responsibility in a design is the Civil Engineer.
3. Although they allege that designing for better stormwater management is extremely important, not something that they usually add to their projects. The main reason for this to happen is that the client is not interested in making the investment.
4. 56% of the interviewers considered that government intervention is the most important factor is to engage the community, since they consider that it should start in the highest order of the hierarchy according to power. On the other hand, the remaining 44% consider that instead of waiting for actions from the government, it is more convenient to work individually and, in this way, analyze the type of population with which we are going to interact and speak in the common language. As a matter of fact, we know that the use of technical language is useless in these types of situations. Therefore, we must find a way to communicate to the members of the community.
5. 100% of the knowledge acquired about SWM has been thanks to their own experiences, complemented with documentaries, social networks, and the Internet. Here in Panama, there are no Universities with degrees in Architecture with a program that cover sustainable topics such as water management, energy saving, among others. Therefore, there is a lack of information from the formative stage of architects.
6. Most of the participants agree that the community has also been responsible for the flood problems. Although it is not the heart of the matter, it has contributed to the worsened the situation. Not only poor

waste management, but also informal settlements affect the urban development of the country. Besides this, the lack of education of Panamanians when it comes to caring for and knowing how to use public areas has influenced the functionality of the buildings.

CHAPTER V: Solutions

After analyzing the results obtained from the collected information and the interviews carried out, the most successful methods for the study area were selected. However, the results will not be limited only to the Juan Diaz - Avenida Domingo Diaz sector, but these systems can be also applied to other areas of Panama City as well as the implementation of other systems mentioned in Table 7. However, it should be mentioned that applying these solutions will not bring an immediate change, since the process to develop it will take time, especially the part of engaging the community.

Applicable Stormwater Management systems in Panama

Based on the climatological data analyzed and the existing problem in the selected area for this study (Av. Domingo Diaz, Juan Diaz). It can be said that the application of simple methods would generate a great impact, since the level of affectation is high. Therefore, making little changes such as cleaning the drains in the area and increasing the development of green areas or raingarden in projects would reduce the percentage of flooding.

Some of the methods that could be applied in new and existing constructions are:

Note: Some of these methods do not contain extensive information due to the scarce information or studies on the subject in Panama.

Pervious Pavement:

The type of pervious pavement most used in Panama is porous concrete (Figure 20). It is an economical alternative because of the absence of fine aggregate in the mix, which causes it to become porous, allowing water to filter through the pores. However, now with the construction of LEED certified buildings the overuse of concrete in parking lots and sidewalks has been reduced.

Nevertheless, the key to the success of these pavements is in the maintenance it receives (Table 7). It is very important to apply cleaning methods that penetrate deeply into void spaces to eliminate the retained sediments. For example, combining high pressure washing with vacuum suction. (Selbig W. and Buer N., 2018)

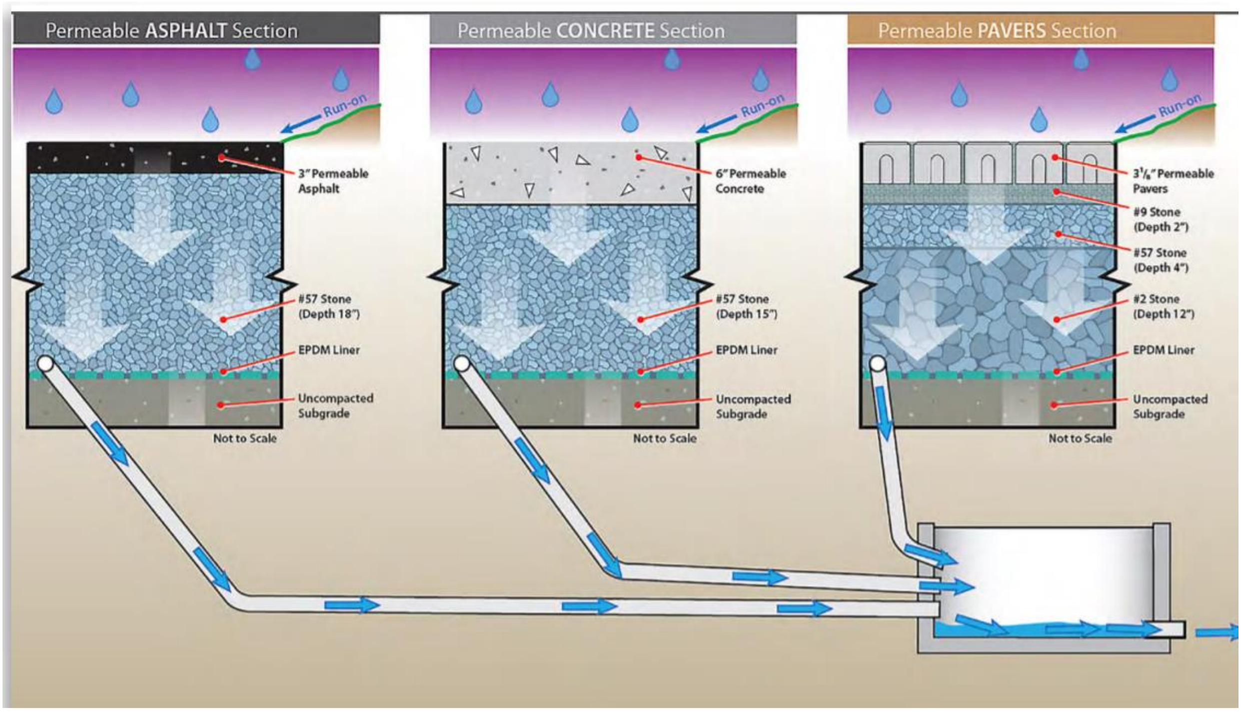


Figure 20 Pervious Pavement, Source: Hydraulic, water-quality, and temperature performance of three types of permeable pavement under high sediment loading conditions.

Making a change in the sidewalks of the Study Area is feasible, because the investment cost is not so high. It is aesthetically attractive, and it is a method that has been already applied. And in this case, the construction sector has knowledge about the topic. A good example for the application of this method in Panama is in “Ciudad del Saber” (Figure 21), the designer used grass pavers in the parking area. These pavers are made of concrete. It consists in a type of open-cell unit paver in which the cells are filled with soil and planted with turf, where the runoff coefficients are similar to grass coefficients. (Table 5)

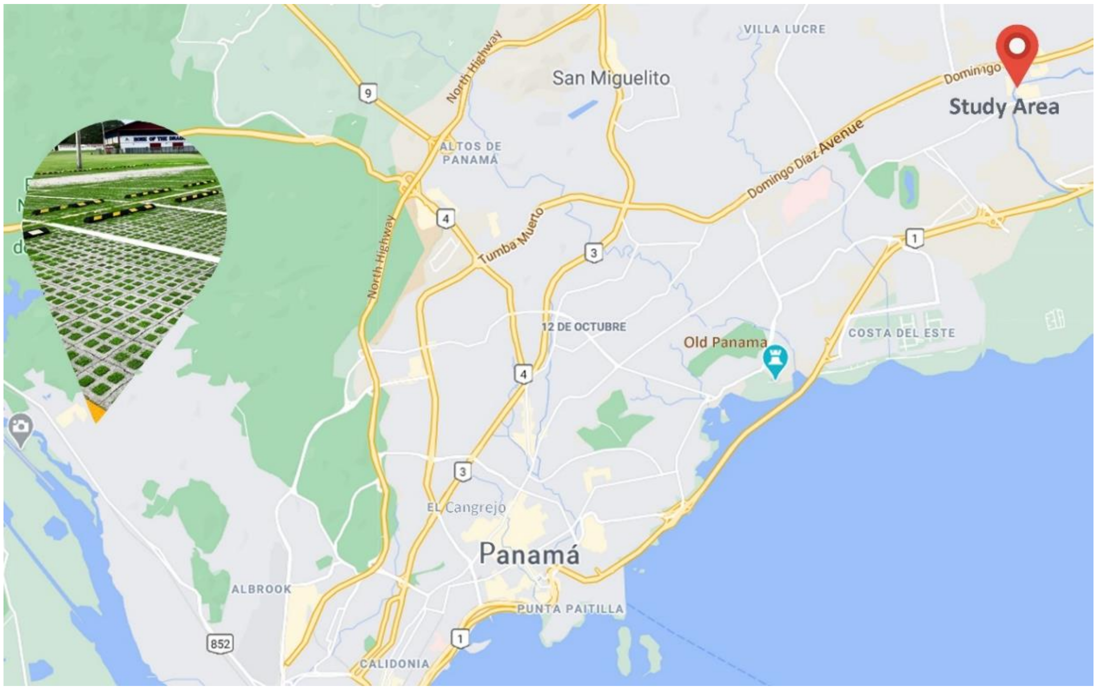


Figure 21 Grass Pavers in Ciudad del Saber

Infiltration Trenches

In the case of infiltration trenches (Figure 22), the application of these systems in regular designs is not registered in any data. This is a method that has been applied in Panama, but sometimes it is carried out empirically. Also, it is used for larger problems, for example, as a method to slow down the flow of rivers, such as the infiltration trenches that were built on the sides of the Curundu river. (Figure 23) This procedure is recommended for the study area and it could be placed on the sides of the Juan Diaz River to reduce the flow of water during the rainy season.

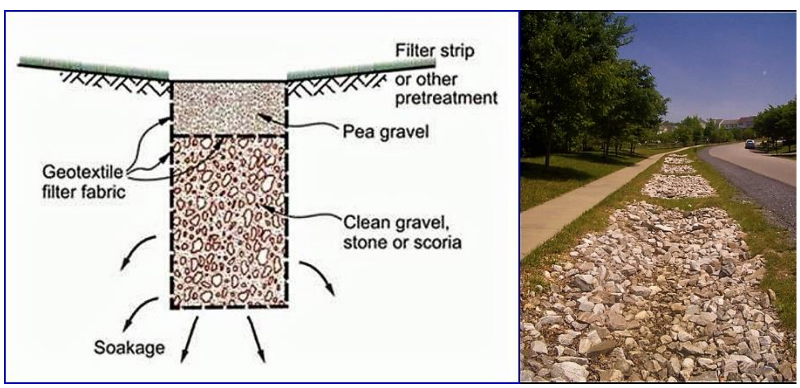


Figure 22 Infiltration Trenches Design, Source: SSWM, 2016

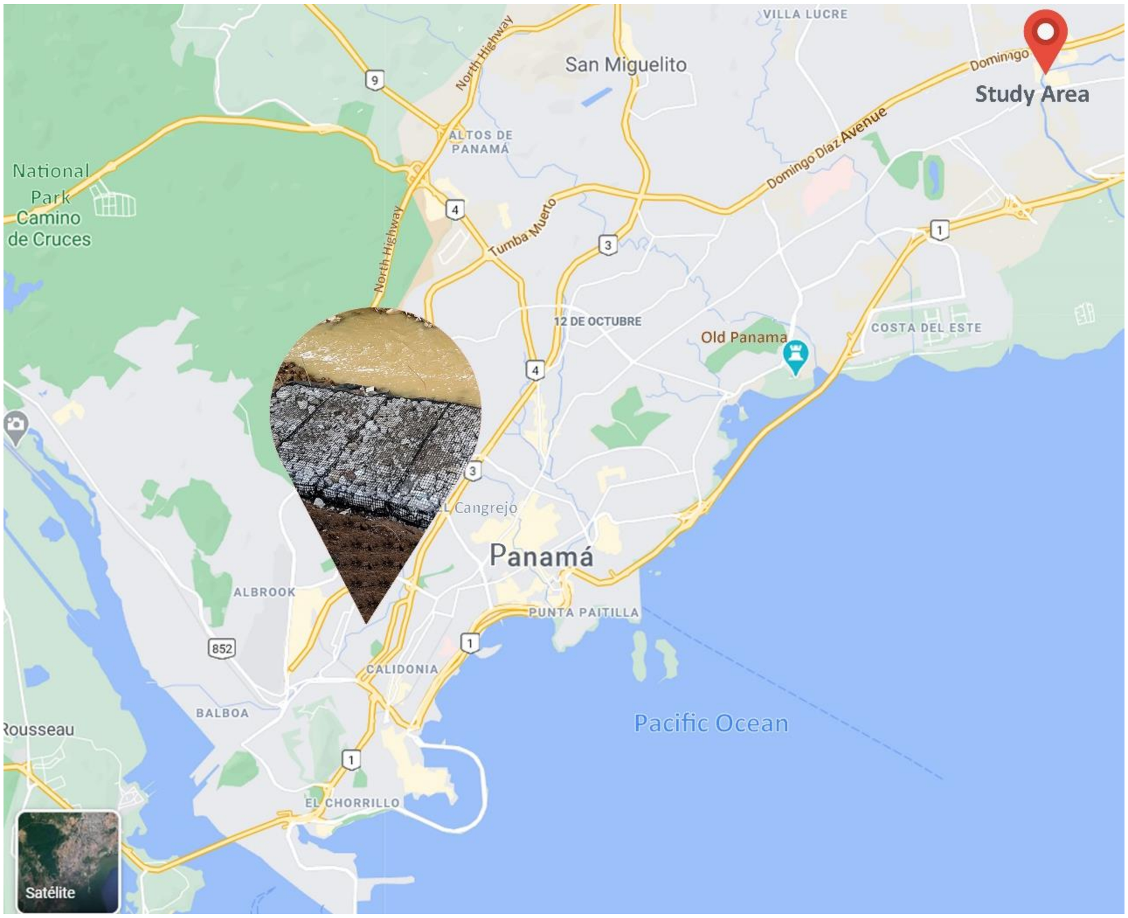


Figure 23 Infiltration Trenches in Curundu

Pervious Pipe Systems:

Like the previous method, this system is not normally used in designs. It is more used for drainage in walls, Sanitary drainage by exfiltration and Drainage in various sports applications (Figure 24). Nevertheless, there is a new method called sustainable urban drainage system (Figure 25) that is being implemented to control stormwater. This system can be described as permeable deposits which are part of the infrastructure, destined to filter, retain and infiltrate rainwater. (Setisa, 2018) (Table 7)

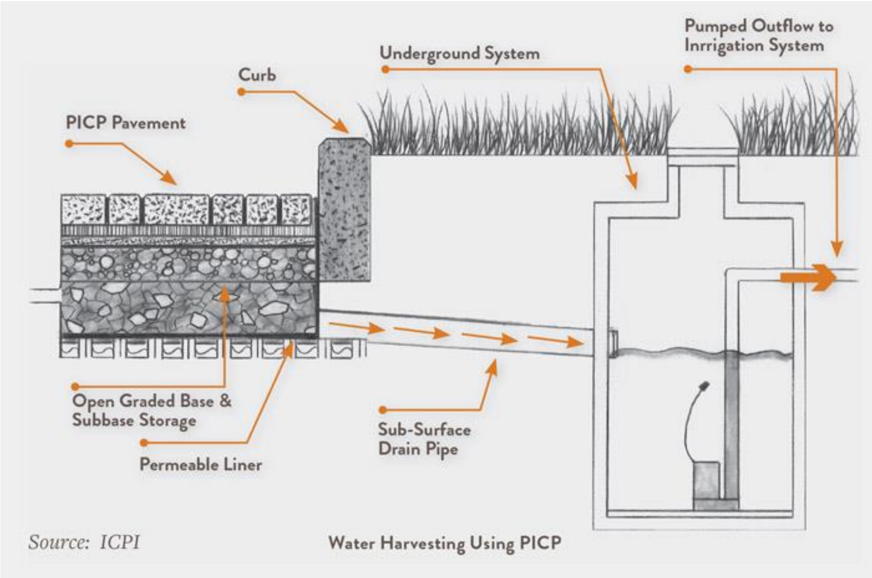


Figure 24 Pervious Pipe Systems, Source: Outdoor Living by Belgard (2016)

Figure 25 sustainable urban drainage system

Another more widely used system is the drainage of treated water through an infiltration tunnel (Figure 26 and Figure 27). This system is composed of one or more tunnel modules and two end plates. It is recommended to use this system in new constructions instead of existing ones, since it requires a sufficiently permeable ground at a minimum distance of 80 cm from the groundwater levels.

Figure 26 Infiltration Tunnel, Source: Setisa

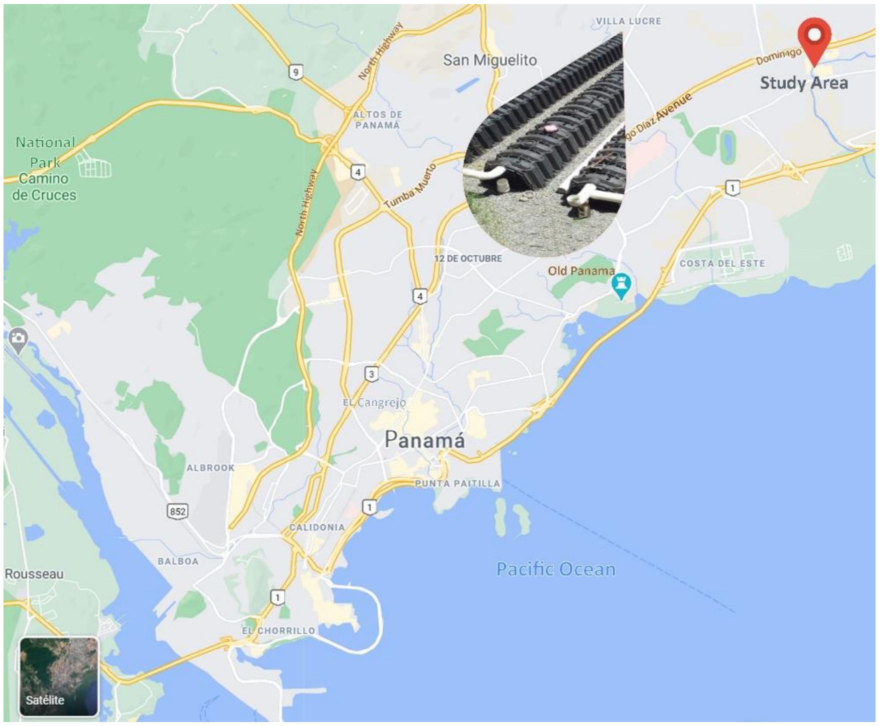


Figure 27 Sustainable Urban Drainage System

Rain Garden:

One of the main benefits of this method (Figure 28) is that it does not need a lot of space to be built, which makes it ideal for existing constructions (Table 7). However, it is important to study the type of land on which the application of the system will be carried out, especially in Panama City because it has different types of soil and that affects the effectiveness of the method in the SWM. Since, the use of this method is not well known in Panama, it is common for green spaces to be sow with plants that are aesthetically pleasing. Nevertheless, it is possible to find a few examples, like in Ciudad del Saber (Figure 29), but these are projects that have a design directed towards sustainability.

This method could be applied on the sidewalks of the study area, as in other areas of Panama City to reduce the number of paved sidewalks. This not only contributes to the reduction of water flow, but it also increases the percentage of evapotranspiration and infiltration of water into soils and a decrease in the water level of the drainage channels as a result.

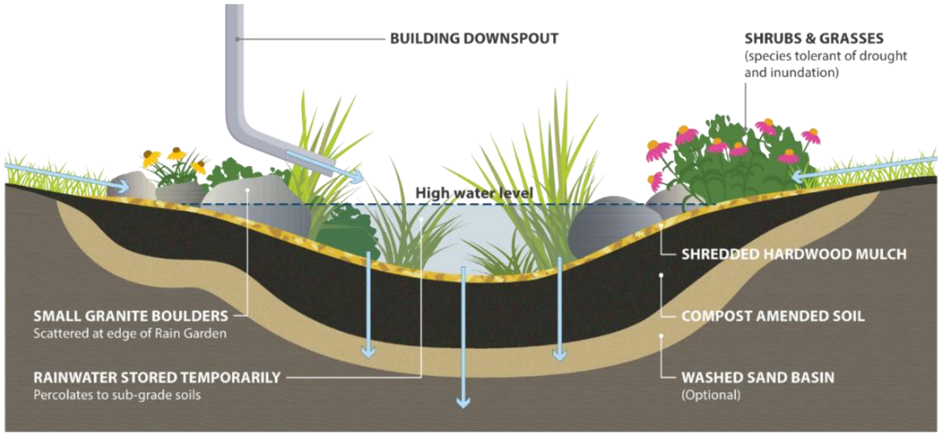


Figure 28 Rain Garden Section, Source: Toronto and Region Conservation Authority (2020)

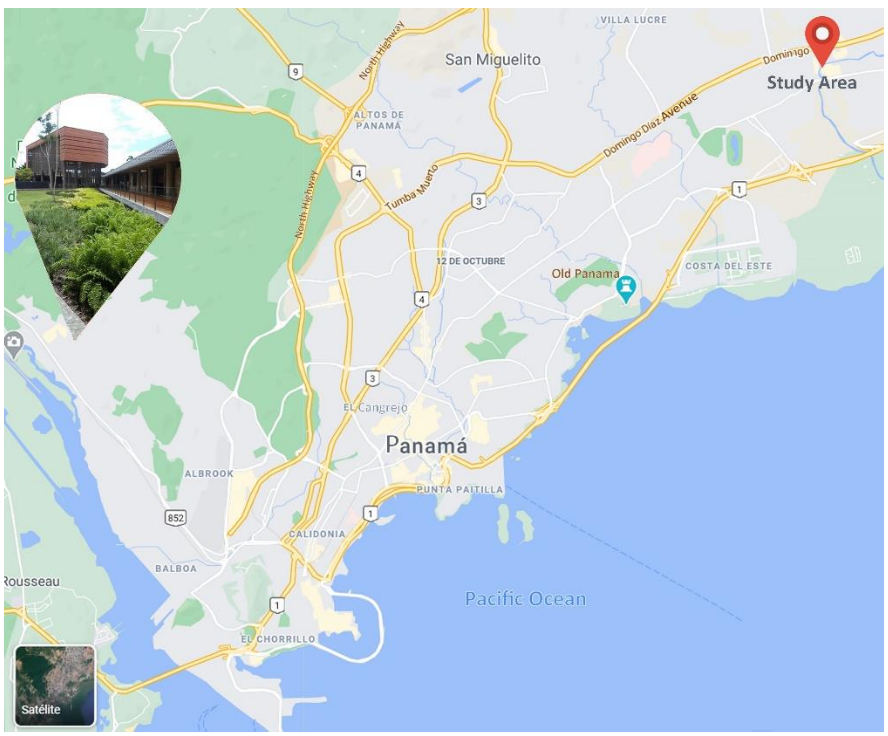


Figure 29 Rain garden in Ciudad del Saber

For the elaboration of rain gardens, it is necessary to consider the type of plants that are going to be used. These plants must be native shrubs, perennials, and flowers (The Groundwater Foundation, 2020). According to The Ground Water

Foundation, in the design of a rain garden, typically six to twelve inches of soil is removed and altered with tillage, compost and sand to increase water infiltration. Besides this, as a rule, native vegetation should be incorporated into a rain garden. Native plants do not require fertilizer, have good root systems, and are better at utilizing the water and nutrients available in their native soils than non-native species. (The Groundwater Foundation, 2020)

Another suggestion is to use plants with fibrous roots. This type of roots has a high absorption level of water and nutrients and they are good to prevent soil erosion. (Critical Site Products, 2020). Table 8 shows some of the plants that could be incorporated into raingardens in Panama.

Plants for GSI

Name	
Calliandra surinamensis Benth. (Mimosaceae) [1]	
Warszewiczia coccinea (Vahl) Klotzsch [2]	

Nectandra lineata (Kunth) Rohwer [2]	
Brassicaceae Brassica Campestris [3]	
Apiace Myrrhidendron donnell-smithii [4]	

Salvia polystachya Ort. [5]	
Cymbopogon citratus [6]	
Paspalum atratum [7]	

Pasto Angletom (Dichantium aristatum) [8]	
Pasto Decumbens (Brachiaria decumbens) [9]	

Note: Source: 1. Molina R. (2015), 2. Perez, R. and Condit R. (2009), 3. Pollock, S. (2011), 4. STRI Research Portal (2020), 5. Alipi, A. y Pichardo J. (2009), 6. Patricia P. (Abril, 2020), 7. Cook B., Pengelly B., Schultze-Kraft R., Taylor M., Burkart S., Arango J., Guzmán J., Cox K., Jones C., Peters M., Atratum P. (2020), 8. Agroactivo (2020), 9. MIDA (2009)

Table 8 Type of Plants for GSI

Green Wall

The use of green walls as GSI is still a new concept, but a study developed in Portland, Oregon showed that a green wall can be planned in order to help with GSI. It is more recommended to have a rainwater collection system for the irrigation of the green wall, since the support it provides to the SWM is minimal, but it is still a good option to use the collected rainwater.

For the elaboration of the green walls, the types of plants chosen should meet the following criteria:

1. Sun tolerance

2. Tolerance to rain
3. Little maintenance
4. Plants from the area

Table 9 shows some plants that can be used for green walls in Panama.

Name	Specification	Picture
Pteridophyta [1]	Semi-sun exposure, abundant amount of water.	
Buganvilla [2]	Sun exposure, moderate amount of water.	
Geranium [3]	Sun exposure, moderate amount of water.	

Bellis perennis 4	Low maintenance, Semi-sun and sun exposure, moderate amount of water.	

Table 9 Plants for Green Wall

Note: Source: 1. Atencio C. (2016), 2. Barreneche P. (2010), 3. Bendel M. (2016), 4. Nováková Z. (2002)

On the other hand, in Panama the use of green walls is greater than the use of green roofs. A good example of the application of this method can be found in Global Business Terminal A (Figure 30) where they used this system for the exterior facades.

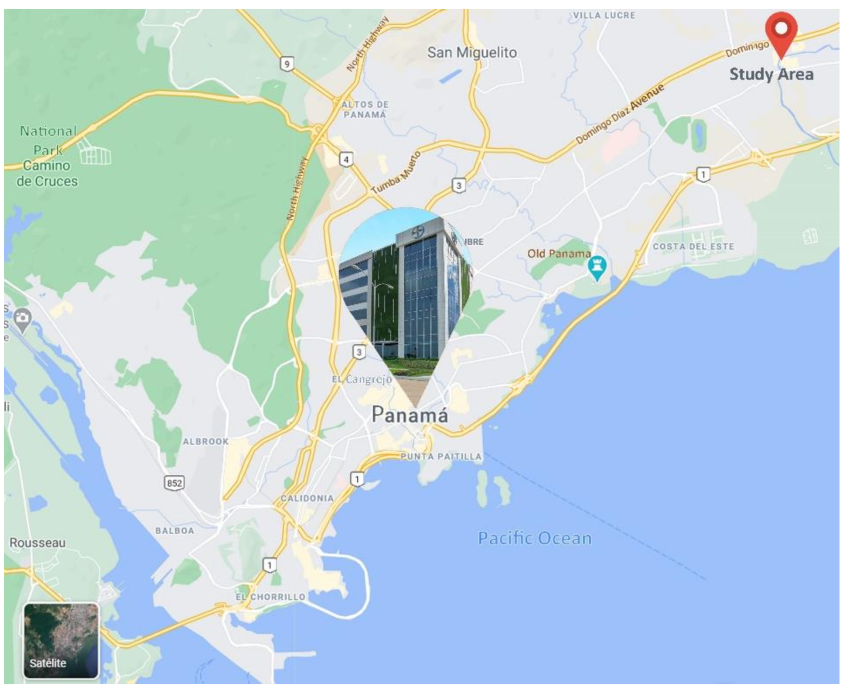
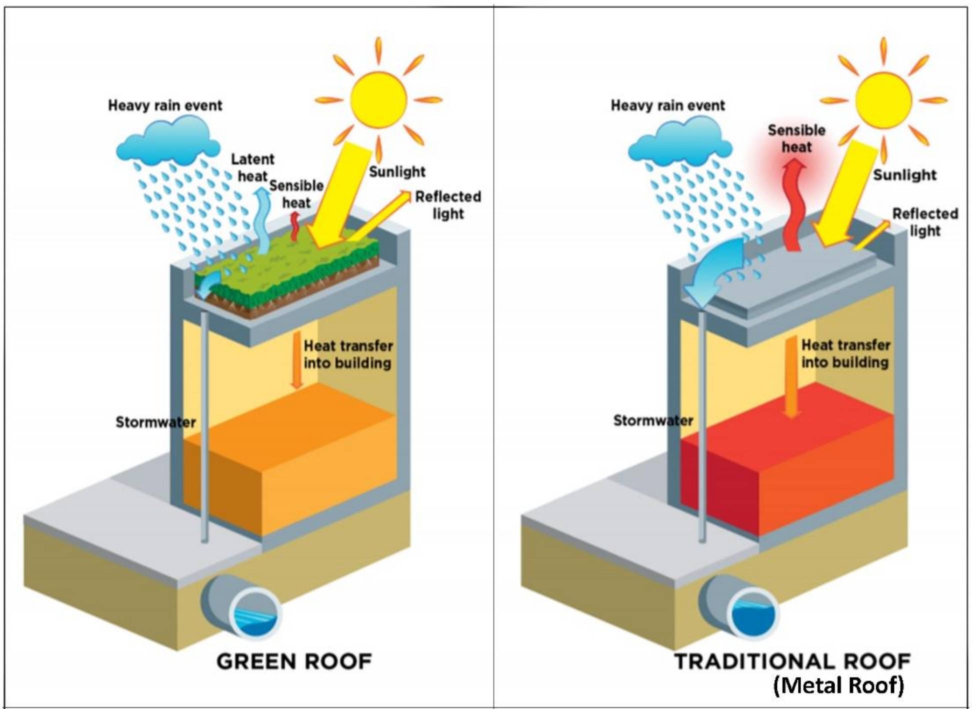


Figure 30 Green Wall in Global Business Terminal A, Source: Google Maps

Green Roofs

Despite the fact, that green roofs can be expensive, the price-earnings analysis may reflect that it is a feasible investment (Figure 31). According to a study carried out by the University of Michigan in 2006, it showed that although the installation of a green roof is more expensive during its lifetime and it would save money mainly in energy costs (U.S. Environmental Protection Agency, 2018). A comparison was made of the price and the period of life of green roofs vs. metal roofs (which are the most used in Panama) (Figure 27), and it was based on the study published by the University of Michigan and assuming that the roof will last 30 years (which is the minimum), in the middle of the period of life we would have already recovered the investment in energy savings.



Cost per sq.m	Cost per sq.m
129.04 USD$	74.40 USD$
Average Life	Average Life
30 to 50 yrs	40-70 yrs

Figure 31 Roof Comparison

The application of this system in the study area would be beneficial not only to reduce the problem of flooding, but also to reduce energy consumption and increase the comfort of users in buildings that have applied the system. According to EPA: Green roofs help to reduce local ambient air and surface temperatures, increase evapotranspiration, which shifts a roof's energy balance. The net effect produced by green roofs, reduces the temperature of the roof and air directly above it during day and night. All of these benefits provided support for the roof's energy budget, which is the balance of incoming and outgoing energy flows. This includes latent and sensible heat exchange, shortwave and longwave radiation exchange, heat conduction, and thermal storage. (U.S. Environmental Protection Agency, 2018)

In addition to the benefits of green roofs (Figure 32), stormwater management is one of the main benefits. According to a paper published for the 9th Annual Green Roof & Wall Conference in Philadelphia, some green roofs, in light and medium rain events, have been found to retain almost all rainfall and to delay peak runoff during heavy rainfalls. One study quantified the effectiveness of green roofs systems on sloped roofs, commonly found in residential areas. The sloped green roofs retained 94.2% of rainwater light rain events (<0.2 cm), but only retained 63.3% during heavy events (>1 cm). vegetation and growing substrate are important determinants of SW performance. (Ostendorf, M., W. Retzlaff, K. Thompson, M. Woolbright, S. Morgan, S. Celik, 2011)

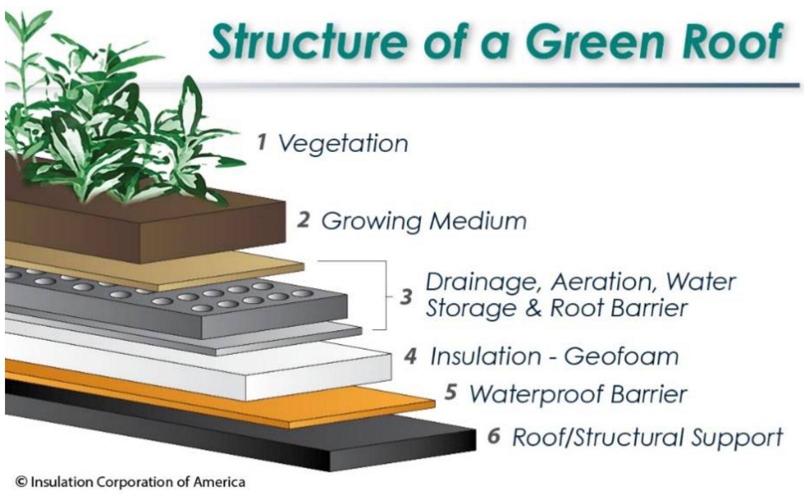


Figure 32 Green Roof, Source: Corporation of America

However, this method could be applied in a simple way. This involves only placing gutters on the roofs and directing the water to the areas of the garden that you want to keep with more humidity or, in a complex way, which is using the SW for irrigation and for toilets, this includes a collection, conduction, filtering, storage and distribution area. Additionally, if you want to use it for human consumption, a purification treatment process must be included, so that the health of the consumers is protected. (Robles M., Näslund-hadley E., Ramos M. y Paredes J., 2015)

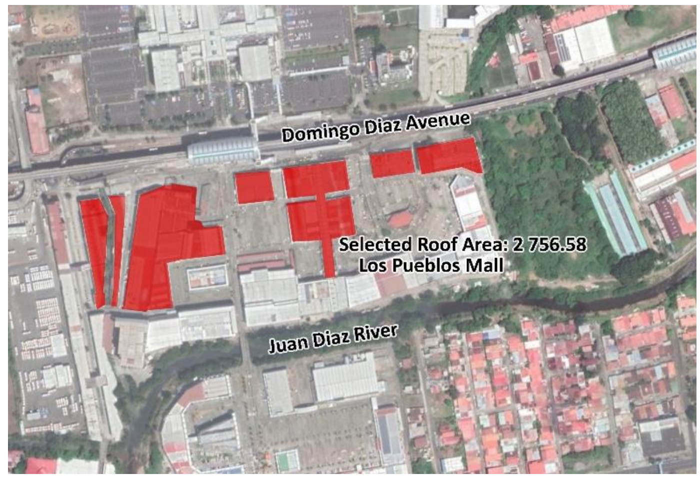


Figure 33 Selected Roof Area in los Pueblos Mall, Domingo Diaz Avenue, Source: Google Maps

An analysis of the area selected for this study was carried out, and some of the roofs that pass in front of Domingo Diaz Avenue and that are part of Los Pueblos Mall (Figure 33) were selected for the application of Green Roofs. The sum of the selected roof area is 2 756.58 sq.m, according to The Low Impact Development Center, Inc. (LID Center), on its Urban Design Tools Website says that a 2.5-inch thick extensive green roof would retain approximately 0.50 gallons of water per square foot, or 40% of it, if we apply this number on the selected roof area we could save around 1, 300 gals.

Applying this system to the selected roofs would significantly reduce the amount of excess water that saturates the sewers, and this, together with the other systems mentioned above, would represent a positive change for the Domingo Diaz Avenue sector.

Also, it is possible to make an approximate calculation of the amount of RW retain in slope green roofs. Assuming that during the wettest month (October, see page 6) the 291 mm of rain is the result of 15 days of light rain event and 16 days of heavy events. Then, it could be said that, during those 15 days we are saving 9.09 mm of rain per day and for the 16 days we could save 5.77 mm of rain per day. (Figure 34)

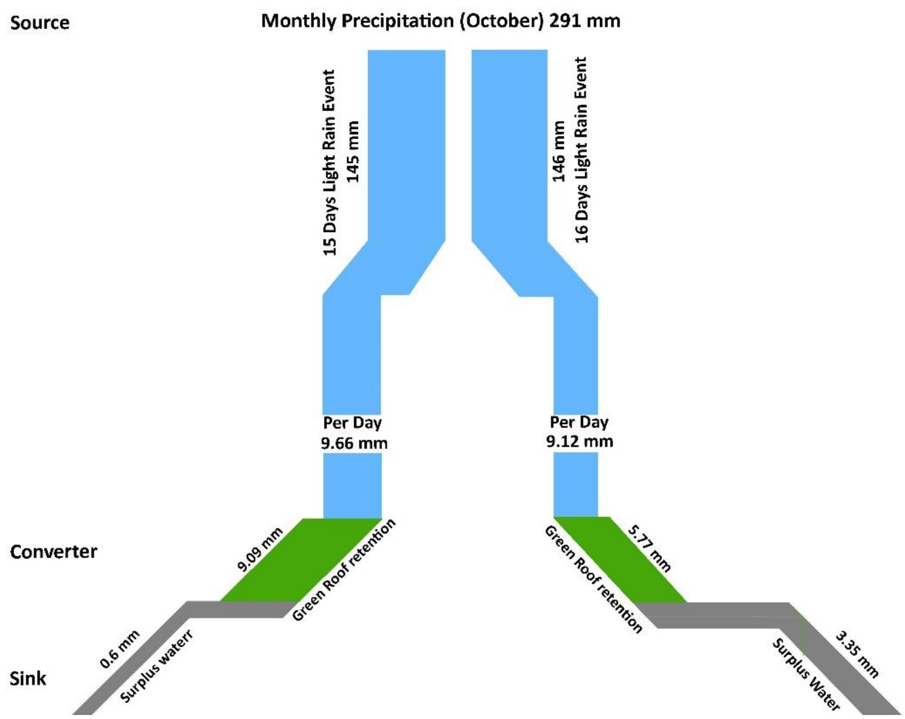


Figure 34 Sankey Diagram - Green Roofs

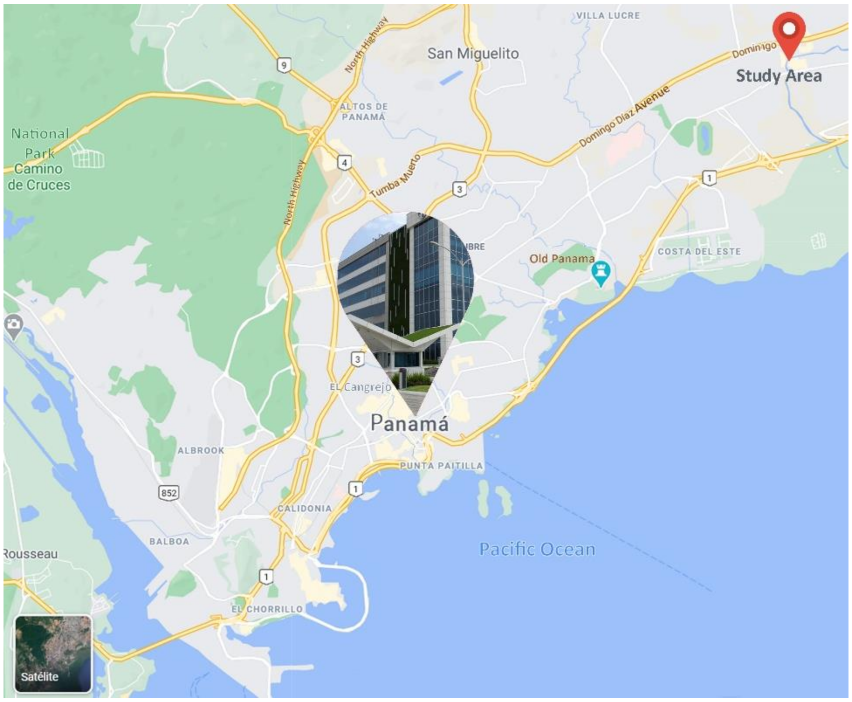


Figure 35 Green Roof in Global Business Terminal A, Source: Google Maps

The implementation of green roofs in buildings in Panama is also a new issue, therefore, there are not many buildings with this type of system. However, on April 4th, 2018, the Green Roofs and green rooftop and terraces program was created by the preliminary draft Law No. 78 in the Republic of Panama. (National Assembly of Panama, 2018)

Reaching Community

As the data was collected and analyzed for this research, one of the results obtained through interviews and data, was that the community behavior impacts negatively in the problem of the place. While cleaning up and enlarging sewage systems is time-consuming and expensive, the process of involving the community in the new change is not far behind.

Firstly, the help of the Government to carry out this task is essential. However, the political system in Panama is too divided, there is conflict over the issues that represent priority in the Legislative Assembly and most of the times there is low citizen participation in the decision making to create new laws. As a result, in 2015, the President of the National Assembly of Panama at that time, Rubén de León, requested support from the Program of the United Nations for Development (PNUD), to carry out an initiative with the objective to strengthen citizen participation mechanisms in legislative initiatives and throughout of the process of discussion of the laws of the legislative body. It is important to mention that Panama is governed by democracy. Therefore, citizen participation is a right and a duty. (PNUD, 2016)

According to PNUD (see page ix), in its report "Strengthening mechanisms for citizen participation in Panama City", citizen participation allows legislators to consider the broadest spectrum of views on the issues under discussion, in such a way that the representative function is exercised in a constant, permanent and genuine dialogue during the process of producing laws. If these mechanisms do not exist, the laws approved by legislative powers lose quality. (PNUD, 2016)

However, the community is aware of the political division within the Legislative Organ, and as a result, there is the lack of credibility regarding the promises of changes in Panama by the legislative assembly. While analyzing all these factors, it is easy to realize that this challenge cannot fall solely on the government, especially since the government in Panama lasts only 5 years. This means that, new people will be in charge due to the change of the government and the progress of many projects that were in development during the previous government are generally lost if they were not achieved.

Therefore, it is necessary that public and private institutions participate in the elaboration of plans for community education. To achieve this objective, the intensive and efficient use of Information and Communication Technologies (ICTs) is central, since they are tools that allow instant interaction regardless of the physical distance between the participants in the communication. (PNUD, 2016) One aspect that should be improved especially in public institutions is to avoid monopolizing information, the information from studies carried out in Panama must be easily accessible; this problem often limits professionals when investigating to make a design, since the information that can be obtained is very limited, and in some cases, outdated. This will contribute to the creation of new studies that would benefit the country especially in the field of architecture.

Secondly, the next target should be the professionals. The combination of online and in person programs for professionals in the construction sector would be effective for motivating professionals to use GSI methods. These interactions could be given through workshops or courses where they could talk about:

1. Why is it necessary to make a change in the regular design?
2. How can you plan to achieve a GSI design?
3. GSI Methods that can be found in Panama

One of the main entities that should be involved is the Technical Engineering and Architecture Board (JTIA). This is a public law entity that regulates engineering and architecture in Panama. Throughout the year they are in charge of training and giving talks on innovative topics to professionals in the construction sector. Thus, it can be a useful tool to reach professionals in a fast way.

In addition, another entity that will play a crucial role is the Panamanian Chamber of Construction (CAPAC), which is a non-profit organization that aims to promote, develop, protect and defend the activities of the construction industry in the country. They are also in charge of the training of professionals in the construction sector. They offer various types of training, among which we can find environmental training. Therefore, dialogue to include the SWM topic should not be a problem.

On the other hand, the interviews carried out during this investigation reflected that there is a lack of credibility towards the government on the part of construction professionals, It is for this reason that in question number 2 of the interview (See page 35) the municipality was not taken into account, since what happens in a construction is not directly associated with the Municipality. Certainly, it has a little influence but mainly the blame will fall on the professional who handled the design. Also, it is very noticeable that the government is not strict regarding this issue. There is no law that regulates waste, or penalties for dumping garbage in places other than landfills. A good example for this issue can be found in the Bay of Panama or in the mangroves of Juan Diaz (Figure 36 and Figure 37), usually groups of people meet to clean up, and their work does not last, since the community begins to contaminate the area again.

Figure 36 Mangroves in Juan Diaz

Figure 37 Cleaning carried out in the Bay of Panama, Source: MareaVerdePanama

As a result, the action of few is in vain due to the lack of laws that sanction this irresponsible behavior. One of the solutions would be to propose, through citizen consultations and citizen participation, a law that prohibits littering in places that are not intended for throwing garbage and fees for fines for those who violate the law. Also, it is important that if this type of regulation is established. The government needs to provide the community with the necessary tools to make it easier to comply with this. This means placing garbage cans at a certain distance, indicating places for garbage disposal and continue including the recycling culture. Public places should have more garbage cans with different colors so it represents the type of garbage that will be thrown in them (Figure 38).

Figure 38 Recycling Station in Bio Museum Panama, Source: La Estrella de Panama Newspaper

Furthermore, it is necessary to prepare talks to explain the objective of the garbage classification and how it should be carried out, since it is a topic that has been trying to be implemented in Panama and it is noticeable that the level of ignorance regarding the community is high. Panama currently has 26 recycling stations installed by the Mayor's Office of Panama, through its Pilot Plan and the Zero Waste Alliance. (Redacción Digital La Estrella, 2019)

Finally, the last target is the rest of the community, specifically the people who live near the study area of this work. According to the map (Figure 39), it can be seen that in Juan Diaz most of the people have low socioeconomic level, with a monthly income of 400 US to 1000 US dollars (with the best being 1000 US dollars). In Panama, it is common that people of this social status do not have access to a good education. The educational level of many may be between school and high school studies. Therefore, they do not have enough knowledge in terms of current relevant issues.

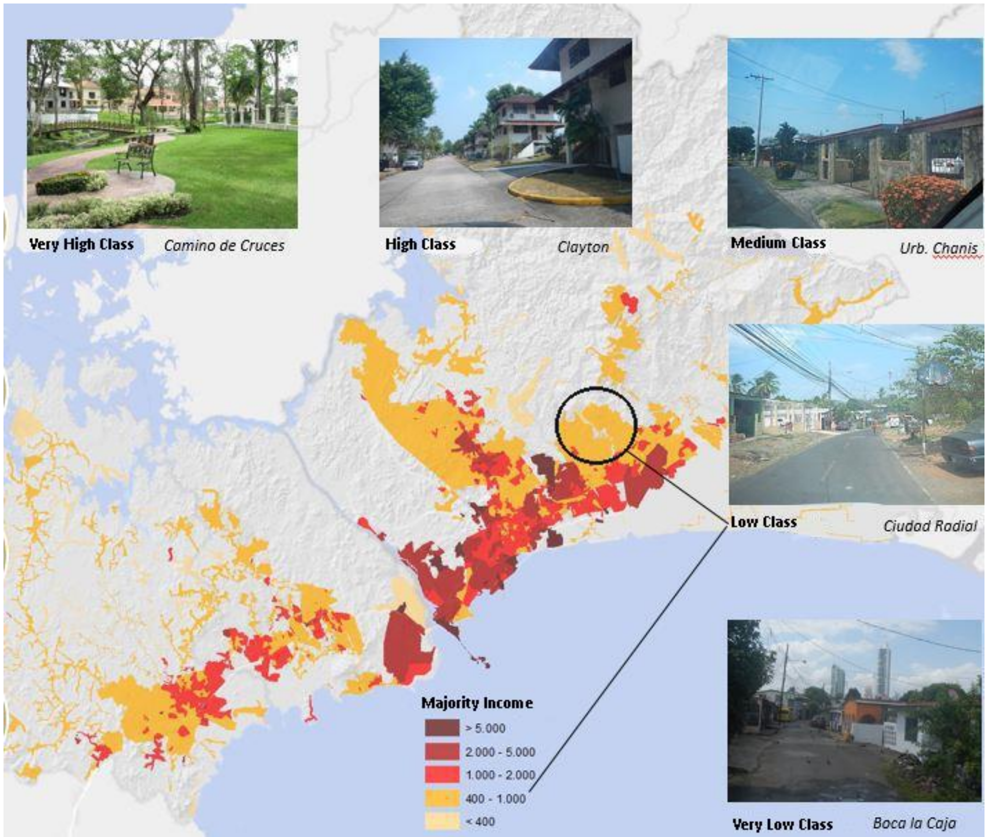


Figure 39 Socioeconomic distribution, Source: INEC, 2010

For this population it is necessary to apply measures aimed at 2 groups of people: youth and adults. In the first place, it is important to educate people from their youth. Schools should apply this type of topics such as recycling and taking care of the environment, so that the polluting culture that the Panamanian population has will begin to change. Also, the Universities that teach the Architecture Degree should consider adding to the study plan subjects that are related to sustainable design, specifically SWM or GSI, since it is a current problem in Panama. Right now, no University has classes that teach these topics, and it was one of the results reflected in the interview (see page 42).

When it comes to the adults, it will be a more difficult process because changing a culture takes time and effort. However, one of the alternatives to start the process is to motivate the community to contribute through training, planning, regulations, community micro-projects and awareness raising. The idea of creating awareness among the community is to teach them that all the garbage they throw out culminates in saturating the drainage, in some water body (river, mangrove, beach), affecting themselves (floods, bad smells due to accumulation of garbage, diseases) and aquatic species are also affected. In other words, all this economically affects the well-being of the community itself.

Another idea that can be applied, is the creation of community garden and rain gardens areas, in this case the community participates and can receive a benefit, and through this they can develop an interest in caring for green areas. In addition, it would be beneficial to generate a plan for the creation of new jobs focused on the recycling field. Another effective way to motivate population is through jobs or some type of economic remuneration.

Results

Two images were created to have a visual idea of the impact that the application of the selected SWM methods would generate and the contribution of the community to the reduction of waste in the area. It should be mentioned that the results will not be 100% accurate to what can be seen in the images, but they do represent an approximate.

Figure 40 Los Pueblos Mall Before the application of SWM methods and community collaboration

For this first image (Figure 40), some of the selected methods were applied, the dimensions of the place were considered to choose the methods that were consistent and try to make a more accurate projection (Figure 41). It is important to mention that the area selected for the study is an existing space. Therefore, in some sectors, there will not be enough space to apply more than 2 SWM methods.

1. Canals with drop-shaped obstacles

2. Native Vegetation or plants for SWM

3. Pervious Pavements

4. Recyclable garbage container

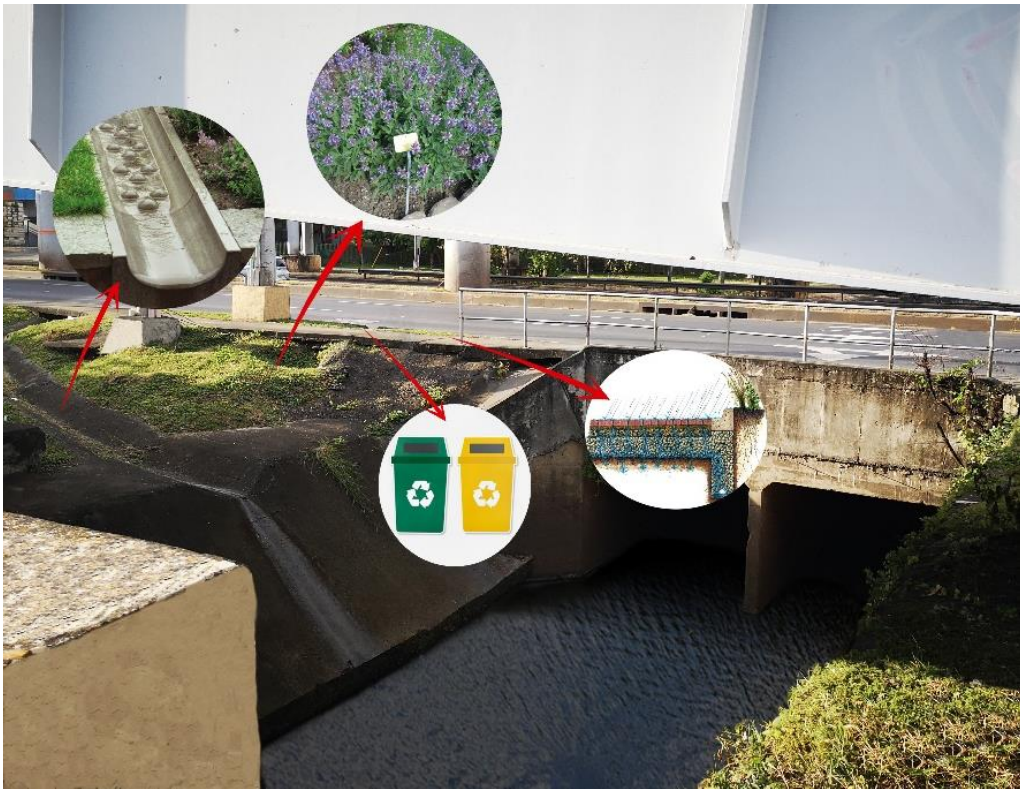


Figure 41 Possible view of Los Pueblos Mall after the application of SWM methods and community collaboration

For the second image (Figure 42) we take one of the main views of the study area (the division between Avenida Domingo Diaz and the Pueblos Mall) so that the selected methods can be observed both by users and by people who pass by in cars. The purpose of this is to provide the community with the facility to understand through visual images what is happening in the place regarding SW. (Figure 43 and Figure 44)

For this representation the following GSI methods were applied:

1. Infiltration trenches
2. Plants for SWM
3. Pervious Pavement
4. Green Walls
5. Green Roofs
6. Recyclable garbage container

Figure 42 View between Domingo Diaz AV and Los Pueblos Mall before the application of SWM methods and community collaboration

Figure 43 Possible view between Domingo Diaz AV and Los Pueblos Mall after the application of SWM methods and community collaboration

Figure 44 Green Infrastructure: Green Walls and Green Roof

CHAPTER VII: Conclusion

To conclude this study, it could be said that the challenge of incorporating stormwater management systems in Panama is a teamwork of all citizens. There are still many issues that must be solved so that change can be generated in the medium term instead of a long-term plan. For example, rainwater is a free resource, if it is well managed, it could bring many benefits. But until the regulations for this topic are not solved, the problem of flooding will continue.

In first place, through this research it was possible to verify that many of the factors that limit a change in the architectural designs are due to the lack of information and not enough research on sustainable topics. Like stormwater management, as well as the elaboration of many pilot programs for contamination reduction and solving the floods issue in Panama City, of which many are currently on hold.

Secondly, government participation as the main stakeholder is the key to start the change. Since they have the authority and resources to begin engaging the community in the learning process, but it cannot be overlooked that the education received by future professionals is also important to create more resilient designs and the need to have a regulatory framework that incorporates citizen participation in the planning processes of a given territory or institution.

And finally, we must be aware that to generate a cultural change requires patience, perseverance, and financial support. In addition, medium and long-term goals must be set, and the effectiveness of each stormwater management method applied must be documented. Since this is a new topic in Panama hence it requires a study process to verify which methods will be most effective.

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Appendix A

Interview

1. In your opinion, what factors have caused the floods in Panama City?
2. Who has more responsibility when designing a project and planning to prevent future flooding in the area? And why?
   a. Civil engineer
   b. Architect
   c. Both
3. As an architect / engineer on a scale of 1 to 5 (5 being the highest level), how important should be designing for a better rainwater management? Not only to create a temporary solution or what last 10 years, but something that can continue to function throughout the life of the building.
4. Do you think that the community has some responsibility in the issue of floods in the capital city?
5. How can the community be involved so they can be aware of simple things like throwing out the garbage in the right place, protecting green areas and helping them to realize the function of the project you designed?
6. Currently, what knowledge do you have about rainwater design? And where did you get that knowledge?
   - College
   - Work experience
   - Internet

Chapter V Illustrations:

1. 

2. 

3. 

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6. 

Vocabulary

Overland Runoff

Water that travels over the ground surface to the channel.

Stream flow

Movement of water via channels

Groundwater flow

Movement of water through the subsurface

Infiltration

Penetration of water through the ground surface

Groundwater recharge

Water that reaches saturated zone

Legislative Assembly of Panama

It is the State Organ responsible for creating laws in Panama.

Evapotranspiration

Is the sum of evaporation and transpiration.

Citizen Participation

It is a space for dialogue between the State, the owners of a project and the public.

Information and Communications Technology (ICT)

All communication technologies, including the internet, wireless networks, cell phones, computers, software, middleware, among others.

ENSO

El Niño and La Niña are the warm and cool phases of a recurring climate pattern across the tropical Pacific.

Relative Humidity:

Amount of vapor in the air.

Agrological Capacity:

Land use efficiency of the soils.

Evaporation

It is the process by which a liquid turn into gas.

Water Runoff

The part of rainfall or snow melt, that appears in uncontrolled surface streams.

Sanitary Sewer

Underground pipe or tunnel system for transporting sewage from houses and commercial buildings

Stream

Small narrow river.

Precipitation

Rain, snow, sleet, or hail that falls to the ground.

Groundwater

Water that exists underground in saturated zones beneath the land surface.

Infiltration

Permeation of a liquid into something by filtration.

Wastewater

Any water that has been contaminated by human use.

Body of Water

Any significant accumulation of water, generally on a planet's surface.

Dike

It is a barrier used to regulate or hold back water from a river, lake, or even the ocean.

Green Roof Price in Panama

QAD050 **m²** **Cubierta verde, sistema Urbanscape "KNAUF INSULATION".**

Cubierta plana no transitable, no ventilada, ajardinada extensiva, pendiente del 1% al 5%, compuesta de: formación de pendientes (no incluida en este precio); capa separadora bajo impermeabilización (no incluida en este precio); membrana impermeabilizante (no incluida en este precio); **membrana antirraíces Urbanscape "KNAUF INSULATION", de polietileno de baja densidad, de color negro**; **lámina drenante y retenedora de agua, Urbanscape C "KNAUF INSULATION", con depósito de agua, formada por membrana de poliestireno reciclado reforzado y perforaciones en la parte superior**; **sustrato Urbanscape Green Roll (HTC GR) de lana mineral, de 40 mm de espesor** y **tepe Urbanscape Sedum-mix**.

Descompuesto	Ud	Descomposición	Rend.	Precio unitario	Precio partida
mt14lbk010	m²	Membrana antirraíces Urbanscape "KNAUF INSULATION", de polietileno de baja densidad, de color negro, para cubiertas ajardinadas extensivas.	1.100	5.68	6.25
mt14lbk020a	m²	Lámina drenante y retenedora de agua, Urbanscape C "KNAUF INSULATION", con depósito de agua, formada por membrana de poliestireno reciclado reforzado y perforaciones en la parte superior, para cubiertas ajardinadas extensivas.	1.100	25.12	27.63
mt14lbk030	m²	Sustrato Urbanscape Green Roll (HTC GR) de lana mineral, de 40 mm de espesor, para cubiertas ajardinadas extensivas.	1.100	16.96	18.66
mt14lbk040	m²	Tepe Urbanscape Sedum-mix, para cubiertas ajardinadas extensivas.	1.100	58.80	64.68
mo039	h	Jardinero.	0.268	12.79	3.43
mo113	h	Ayudante de jardinería.	0.268	8.08	2.17
	%	Medios auxiliares	2.000	122.82	2.46
	%	Costes indirectos	3.000	125.28	3.76
Coste de mantenimiento decenal: $ 40,65 en los primeros 10 años.				Total:	129.04

Table 10 Green Roof Price in Panama, Source:

Metal Roof Price in Panama

QTA010 m² Cubierta inclinada de lámina de acero.

Cubierta inclinada de **panel sándwich lacado+aislante+galvanizado** de **50** mm de espesor, con una pendiente mayor del 10%.

Descompuesto	Ud	Descomposición	Rend.	Precio unitario	Precio partida
mt13dcg010d	m²	Panel sándwich (lacado+aislante+galvanizado), espesor total 50 mm.	1.100	52.96	58.26
mt13ccg020h	m²	Remate lateral de acero galvanizado, espesor 0,8 mm, desarrollo 250 mm.	0.300	6.41	1.92
mt13ccg020k	m²	Remate lateral de acero galvanizado, espesor 0,8 mm, desarrollo 500 mm.	0.200	8.82	1.76
mt13ccg020l	m²	Remate lateral de acero galvanizado, espesor 0,8 mm, desarrollo 750 mm.	0.150	12.03	1.80
mt13ccg030d	Ud	Tornillo autorroscante de 6,5x70 mm de acero inoxidable, con arandela.	3.000	0.85	2.55
mo050	h	Montador de fachadas y techos de paneles metálicos.	0.209	13.22	2.76
mo096	h	Principiante de montador de fachadas y techos de paneles metálicos.	0.209	8.41	1.76
	%	Medios auxiliares	2.000	70.81	1.42
	%	Costes indirectos	3.000	72.23	2.17
Coste de mantenimiento decenal: $ 21,58 en los primeros 10 años.				Total:	74.40

Table 11 Metal Roof Price in Panama, Source: