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Characterization and Strategies for Implementing Sustainable Urban Drainage Systems in Consolidated Cities with High Flood Risk. Case Study: Barranquilla - Colombia

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Characterization and Strategies for Implementing Sustainable Urban Drainage Systems in Consolidated Cities with High Flood Risk. Case Study: Barranquilla - Colombia

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ABSTRACT: The city of Barranquilla, in Colombia, nowadays lacks from a storm sewer system and a stormwater management master plan. The stormwater runoff flows on the streets causing risk on the population and paralysis of urban activities during rain events every year. The construction of a conventional storm sewer system for the entire city would be economically unfeasible; therefore it is necessary to propose strategies for implementing alternatives of sustainable urban drainage systems including the conveyance system for managing urban watersheds, for reducing peak flow, for controlling pollution and for mitigating flood risk. A diagnose was conducted to understand the current conditions of the stormwater management in the city and to propose strategies for implementing Sustainable Urban Drainage Systems-SUDS as an alternative for urban stormwater management, including the implementation of a real-time stormwater monitoring system.

Keywords: Storm drainage: Barranquilla Streams; Sustainable Management; Peak flow

1 INTRODUCTION

The city of Barranquilla is located in the north of Colombia and has a population of about 1.8 million inhabitants. The city has an area of 120 km^2 divided into two basins, the Eastern and the Western basins (Figure 1). The Eastern basin covers most of the urban area of the city where stormwater runoff flows on the streets (urban-streams or named locally “Arroyos”) which discharge directly into the Magdalena River. The Western basin includes the streams that discharge into the Leon Stream and the Grande Stream which finally discharge into the Mallorquín estuary (Caribbean Sea). This paper is mainly focused on the Easter basin.

Figure 1. Urban Subwatersheds in the city of Barranquilla (left). Elevations STRM-90(USGS) and Esatern and Western Watersheds of Barranquilla (right).

The Eastern basin, currently lacks from a conventional storm sewer system in more than 90% of the area, therefore the stormwater runoff flows on the streets with supercritical flow that endanger people, paralyze the traffic, cause economic losses, and damages to the infrastructure of the city. In this basin many cars have been dragged downstream, and about two people are killed every year on average caused by the urban streams. Some of the streets that become urban streams are: Rebolo, Hospital, La Paz, Felicidad, Bolívar, Carrera 65, Coltabaco, Country, Siape and Calle 93. Figure 2 shows a typical urban-stream during a rainfall event. This condition occurs several times every year.

Figure 2. Drainage conditions (streams) during the winter season every year (Source: El Heraldo).

The alternatives proposed by the authors are focused on structural and non-structural solutions with emphasis on sustainable urban drainage system, including a monitoring/early warning flash flood system, restoration of urban watershed hydrology, progressive channeling, pollution control of stormwater runoff, and some regulatory proposals for encouraging SUDS implementation. The sustainable technologies are focused on maintaining or restoring natural hydrological conditions in urban watersheds. The Sustainable Urban Drainage Systems (SUDS) or technologies of Low Impact Development (LID) are defined by the Naval Facilities Engineering Command, Atlantic (NAVFAC, 2010) as *"a set of strategies of rain management to maintain or restore the natural hydrologic functions of a site…"* There is an extensive literature (USEPA, 2000, regulations and manuals of applications (USEPA, 2011) about these technologies. However, it is essential that the actions and interventions in urban watersheds in Barranquilla take into account the conditions and characteristics of the environment, especially in the Eastern basin where there is not storm sewer system.

The regulation, standards and incentives for watershed management are strategic to begin the implementation of sustainable management of urban watersheds in developing areas, to the progressively restoration of hydrological conditions, and to water quality management of consolidated urban areas. Providing benefits to citizens who apply SUDS technologies encourages the use and effectiveness of the proposed measures. This stimulus, whether cultural or tax based, must be evaluated economically. Besides, these strategies should be also applied to the developing urban areas of the Western basin, focusing on the conservation of natural hydrological conditions in order to avoid increasing peak flows, erosion, pollution, and flooding.

2 TOPOGRAPHIC CONDITIONS OF THE CITY

Barranquilla has steep slopes in most of the urban area with an average magnitude of 2%. Only near the Magdalena River the slopes are mild. The maximum elevation in Barranquilla is about 145 m over sea level. These conditions are related to the high speeds and short concentration times of the runoff, which cause flash floods.

3 PRECIPITATION AND ESTIMATION OF FLOW RATE AND VELOCITIES

The raining season is between April and June, and then between August and November. The annual average precipitation is 850 mm, from which about 420 mm rains between Augusto and October based on rainfall data from 1970 to 2009 (IDEAM). Rain intensity could be higher than 120 mm/hr during an hour. Figure 3 shows the non-exceedence probability of daily precipitation.

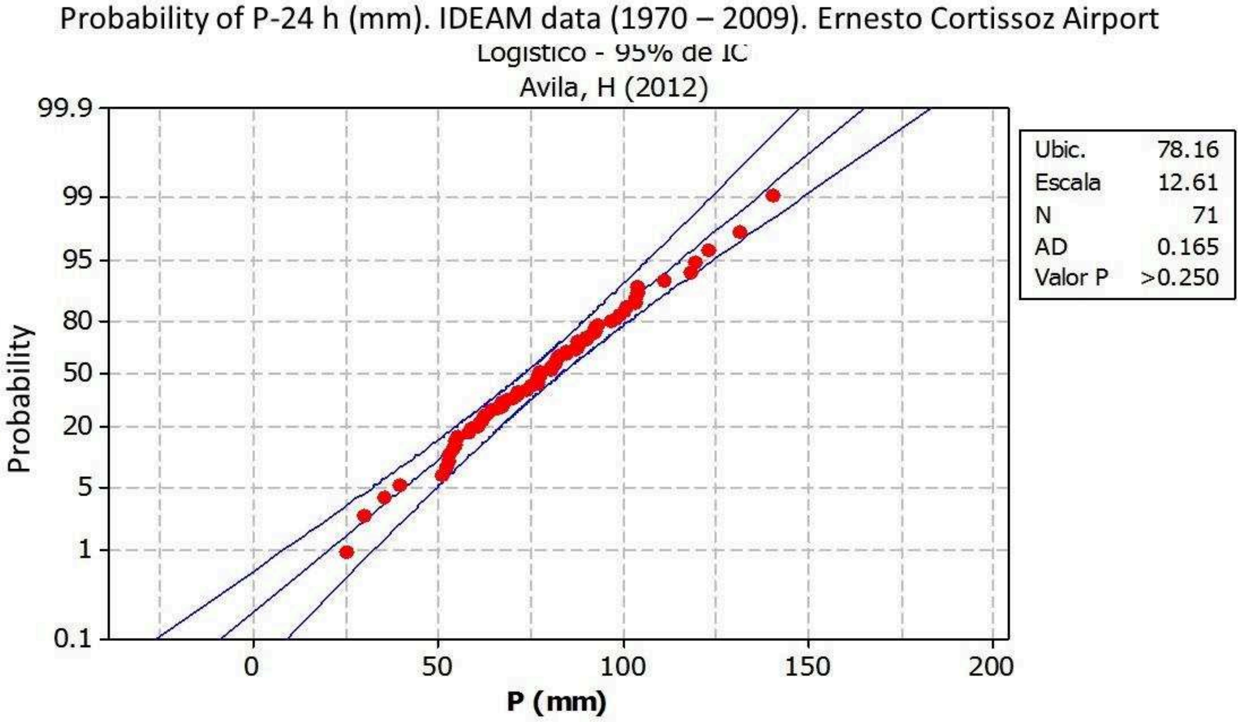

Figure 3. Non-exceedence probability of 24-h rainfall in Barranquilla (IDEAM data)

Based on field data, secondary information, and some assumed parameters supported by the condition of the watersheds, flow rates and velocities of some principal basins were estimated in the Eastern watershed by using the NRCS method and the Manning's equation (Table 1 and 2). The results show that flow rate for a 5-year return period are between 16 to 112 m^3/s and for a 100-year return period between 29 to 208 m^3/s. Speed varies between 4 to 8 m/s for a 5-year return period and from 5 to 10 m/s for a 100-year return period.

Table 1. Estimated peak flows at points of concentration for different return periods.

Watershed	Watershed Area (Ha)	Estimated peak flows at points of concentration (m3/s)					
		2 years	5 years	10 years	25 years	50 years	100 years
Calle 91	284	35	47	56	67	76	87
Siape	274	34	46	54	64	74	84
Country	534	58	78	92	110	127	144
Coltabaco	121	17	23	27	33	37	42
Carrera 65	369	45	61	72	86	99	113
Felicidad	422	46	62	73	87	100	114
La Paz	78	12	16	19	22	26	29
Hospital	223	27	37	44	52	60	68
Rebolo	543	59	80	94	113	129	147
Don Juan	857	83	112	132	159	183	208

Table 2. Estimated speed to peak flows in point of concentration.

Watershed	Watershed Area (Ha)	Estimated speeds to peak flows at point of concentration (m/s)					
		2 years	5 years	10 years	25 years	50 years	100 years
Calle 91	284	5.5	6.2	6.6	7.0	7.4	7.7
Siape	274	5.5	6.1	6.5	6.9	7.3	7.6
Country	534	6.7	7.4	7.9	8.4	8.8	9.2
Coltabaco	121	4.2	4.7	5.0	5.4	5.7	6.0
Carrera 65	369	6.1	6.8	7.2	7.7	8.1	8.5
Felicidad	422	6.1	6.8	7.2	7.7	8.1	8.5
La Paz	78	3.7	4.1	4.4	4.7	4.9	5.2
Hospital	223	5.1	5.7	6.0	6.4	6.8	7.1
Rebolo	543	6.7	7.5	7.9	8.4	8.9	9.3
Don Juan	857	7.6	8.4	8.9	9.5	9.9	10.4

4 CHANNELING AND HYDRAULIC WORKS

One of the factors that directly affect the feasibility of channeling in the Eastern watershed is the length that needs to be channeled. Considering that most of the city lacks from storm sewers, channeling all the streets would be a very expensive alternative. However, channeling may start from downstream the main urban streams of each watershed and extend the length based on risk management and economic criteria. In this case, if the main urban streams of the city are channeled from catchments areas of 50 Ha, the channeling length would be about 62 Km all together, while if it is channeled from catchment areas of 10 Ha, the total length increases to 150 Km. The decision depends on economic and risk analysis. In any case, is not feasible to build channels or stormwater pipes in the whole city, but only in main channels closed to the downstream discharges. Therefore, it is necessary to implement measures from upstream to midstream to reduce peak flow and runoff pollution. Also, channeling by itself reduces the time of concentration and therefore increases the flood risk downstream, so it is necessary to complement channeling with other hydrological measurements.

5 RESTORATION OF THE HYDROLOGICAL CONDITIONS IN CONSOLIDATED URBAN WATERSHEDS

The restoration of the hydrological conditions in consolidated urban watersheds is essential for reducing the volume and peak runoff, as well as for stormwater pollution control. This purpose is achieved by using sustainable drainage technologies. However, the criteria for suitability, sizing and use of these technologies should be evaluated for each catchment individually to ensure their effectiveness and to increase the benefit/cost ratio. Also, advantages and limitations, land use, urban structure, among others factors should be taken into account.

5.1 *Maintenance and improvement of hydrological conditions in new constructions*

Natural hydrological conditions must be maintained or improved in new urban developments, parking or other new construction. It is not enough to regulate the percentage of pervious area of a building, because it does not ensure that the peak flow and runoff volume are minimized, and that water quality stays as the original condition. The runoff volume and peak flow projected for new construction must be equal or lower than the originally flow rate of the natural soil. Similarly, the surface runoff water quality at the building outlet should meet appropriate quality characteristics. The licenses for new construction should include, as part of the requirements, a hydrological study site that includes the original conditions and increased runoff volume and peak flow generated by construction, the expected water quality conditions, the site erosion control plan, and a drainage system design oriented to SUDS that maintain or improve original hydrological conditions.

5.2 *Reduction of runoff volume and peak flow*

The peak flow reduction, which has a direct impact on reducing flash flood risk, should be focused on temporary storage and increasing the time of concentration. This purpose may be achieved by using large concentrated tanks or small scatter tanks distributed in the city, by increasing surface roughness, and by increasing the flow path length in households before discharging to the street. Infiltration by rain gardens and permeable areas does not have a significant effect on reducing peak flow in consolidated urban areas, especially when available permeable areas are little. Rainfall intensity in Barranquilla is typically greater than 50 mm/hr and may be greater than 120 mm/hr, so effective runoff is large enough to cause dangerous urban streams in Barranquilla. However, rain gardens and permeable small areas are effective to infiltrate stored runoff from tanks and to control pollution during small rain events or during the first minutes of rainfall events in general.

5.3 *Reduction of direct connections and increase the time of concentration*

Currently stormwater runoff from buildings, parking lots and other structures drains directly to the streets without any damping. This condition causes a significant reduction on the time of concentration and therefore and increment in the peak flow downstream. Although, it is inevitable that stormwater runoff eventually reach the streets, it is possible to increase the travel path of the water before it is discharged to the streets. The route would increase the possibility of infiltration, temporary storage and ultimately increasing the time of concentration.

5.4 *Temporary and permanent storage*

Scatter residential storage tanks: Storage tanks are very effective in reducing runoff volume and peak flow. Barranquilla currently has a historical advantage related to the system of drinking water. The houses and buildings lower than 6 stories have water storage tanks that were built three decades ago when drinking water service was not continuous. Currently, most of these tanks are empty and unused, and can be used to store the runoff from each building. Water stored in tanks can be infiltrated slowly over a period no longer than 24 hours to restore the storage volume. Research conducted at the Universidad del Norte oriented to the implementation of sustainable technologies in Barranquilla (Avila et al, 2012), suggested that it is possible to reduce the volume of stormwater runoff by 30% by using scatter storage tanks.

Large storage tanks: These tanks consist of large storage structures to be built in hydraulically and hydrological strategic sectors in the city to reduce peak flows and retain debris, floating and entrained sediment by streams.

Storages roofs: Concrete roofs may be effective for storing effective rainfall. However, roof in Barranquilla were not design for supporting the load required for this purpose. Also, it would be necessary to waterproof the roof properly to avoid filtration problems.

Rain gardens: Concave shape of gardens and subsurface storage in permeable areas can contributes with damping the runoff volume. These measures are most effective upstream and midstream of the watersheds, especially if the slopes are not very high.

5.5 *Recovery and increase permeabe areas*

The reduction in infiltration capacity in Barranquilla is a natural response to the development of urban areas. However, the paving practice has spread to areas where there should be permeable areas such as gardens, frontyards and backyards. Results from a research conducted at the Universidad del Norte (Avila et al, 2012) have shown that in some basins of the city, recovery permeable areas in Barranquilla is important only for reducing the runoff volume for small rainfall events, but has no significant effect reduction of peak flow given the characteristics of precipitation and the percentage of available retrofitting garden area. However, modifying the soil to improve storage capacity and infiltration of gardens can contribute in managing stormwater runoff.

6 STORMWATER MONITORING SYSTEM

The city is lacking also from enough measured hydrological data that allows implementing hydrological alternatives based on the hydrograph management. Therefore, a stormwater monitoring system is being implemented by the Universidad del Norte since 2013, as part of a research program that contributes to the strategies and actions for managing stormwater runoff in Barranquilla. The system has 12 rain gauges distributed in different parts of the city, level and speed sensors for the urban streams, hydrological and hydraulic models, and a web platform so that citizens are informed about the raining conditions (Figure 4). Monitoring will not only reduce the risk of urban flash flood by keeping the people informed, but also will have valuable information to develop studies, designs and research projects to improve stormwater management in Barranquilla.

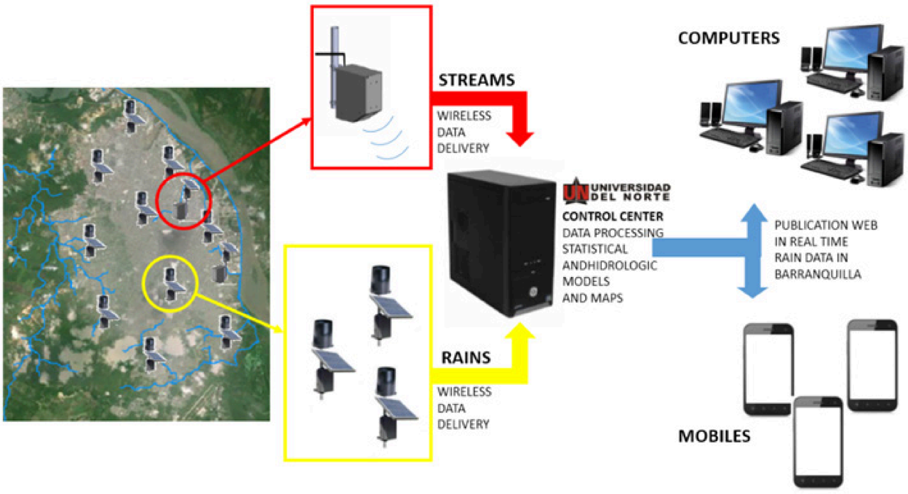

Figure 4. Stormwater monitoring system for the city of Barranquilla implemented by the University of North. Source: Authors.

Figure 5. Location of rain gauges monitoring network (left) and rain gauge installed (right). Source: Authors.

7 CONCLUSION

The stormwater drainage problem in Barranquilla is one of the most critical and challenging in Latin America. Runoff flows through the streets at high velocities, risking the population every year. However, given the current urban conditions, a traditional stormwater drainage oriented to conveying system only, is not a feasible solution. Alternatives for adaptation and mitigation of peak flow and pollution through SUDS are highly applicable in the Eastern basin of Barranquilla. However, the type and specifications will depend on the specific characteristics of each watershed, land use and other natural and urban factors.

The implementation of a pilot projects for the use of SUDS in existing properties is an important practice in the process of incorporating these technologies to people in consolidated cities, as well as offering technical and scientific assistance in order to demonstrate to citizens these initiatives, which are highly dependent on the acceptance and implementation by the public.

Finally, the implementation of a stormwater monitoring network is the starting point to have a clear understanding of the behavior of the rainfall-runoff relationship in the city that allows dynamic and hydrological, and more intelligent management of urban stormwater runoff solutions.

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