Diagnosis of the Hydraulic Structures of the Sewerage Management Unit 251 of Zone 2 in Bogota, Colombia

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Resumen— *La lluvia es un factor amenazante de gran importancia, que puede causar desbordamiento de ríos o acumulación de aguas lluvias causando dificultades de drenaje, colmatación de sumideros o fallas operativas del sistema de alcantarillado. Una de las zonas con alta vulnerabilidad por riesgo de inundación es la Zona 2. Una forma de analizar el estado de la Unidad de Gestión de Alcantarillado Pluvial 251 de la Zona 2 de la Empresa de Acueducto y Alcantarillado de Bogota, es verificar y valorar el estado de las estructuras hidráulicos que componen este sistema hidrosanitario.*

Palabras clave—Alcantarillado Pluvial, Estructuras Hidráulicas, Pozos, Sumideros, Unidad de Gestión de Alcantarillado.

***Abstract*— Rain is a threatening factor of great importance, which can cause river flooding or accumulation of rainwater causing drainage difficulties, sewage collapse, or operational failures of the sewerage system. One of the areas with high vulnerability to flood risk is Zone 2 in Bogota, Colombia. One way to analyze the state of the 251 Sewerage Management Unit of Zone 2 is to verify and evaluate the status of the hydraulic structures that make up this sanitary system.**

Keywords—Pluvial Sewerage, Manholes, Sinks, Sewer Management Unit.

I. Introduction

The Sewerage Management Unit 251 of Zone 2 of the Aqueduct and Sewerage Company (In Spanish Empresa de Acueducto y Alcantarillado de Bogotá - EAAB-ESP) is located in a flat topographic area with a certain amount of ripples, making Zone 2 more vulnerable to flooding. This locality is crossed by Salitre River totally channeled, this basin is essentially urban; it is the axis of the combined sewage system (rainwater and sanitary) through pipes, canals, or other structures drain rainwater from east to west to the Bogota River [1].

To do a diagnosis of the hydraulic structures of the UGA 251, a hydrological method that shows an optimal behavior of the maximum annular rainfall during a certain return period should be used. Subsequently, a hydraulic analysis of the area and its respective complementary structures that makes up the UGA 251 will be carried out, such as: fall camera, sinks, wells, among others.

The main objective of this investigation is to determine, if the operation of the hydraulic structures is optimal and adequate or if, on the contrary, these devices require preventive or total repair and maintenance.

II. Study Location

The storm sewer network of the Risk Management Unit 251 of Zone 2 of the EAAB-ESP, has an area of 100.17 ha and is a part of the Salitre Basin and also the Rio Nuevo sub-basin, serving the following neighborhoods: Las Ferias, Metropolis, Bellavista Occidental, and Jose Joaquin Vargas. To delimit drain areas, the shape information of the storm sewer networks of the UGA 251 of Zone 2 of EAAB-ESP was used [2], as shown in Figure 1.

Figure 1. Geographic Location of UGA 251
ArcMap 10.2.2

III. Hydrological Analysis

To obtain the design storms of the UGA 251, a series of maximum precipitation in 24 h greater than 20 years of the Salitre Pump House station was found, as shown in Table 1.

Table 1. Salitre Pump House Rain Gauge Station

NOTION	SALITRE PUMP HOUSE [2120196]
Latitude	4°68'61.92" N
Longitude	74°07'96.31" W
City	Bogota
Type	Pluviografic
Estado	Active
Instalation Date	1/01/1975
Suspension Date	NA
Elevation (m.a.s.l)	2580
Water Current	Bogota River

Precipitation analysis:

The study of the precipitation includes the analysis of maximum precipitation events in 24 h and frequency. The Figure 2 shows the maximum values of annual precipitation in 24 h .

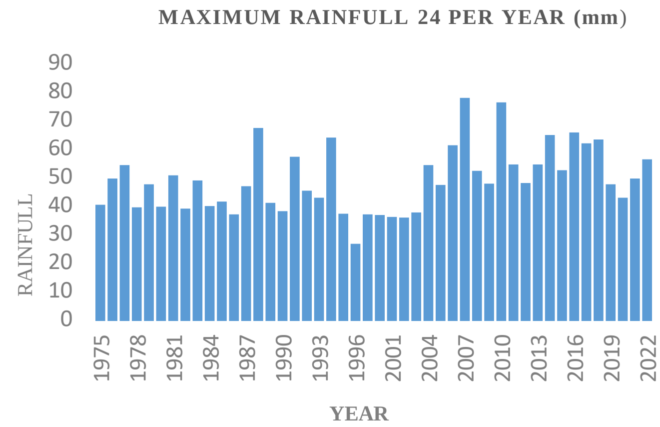

Figure 2. Maximum Rainfall 24h/ year (mm) graph

The probability model used is the Gumbel Function, according to the Technical Regulation of the Drinking Water and Basic Sanitation Sector (in Spanish RAS). Standard for the adjustment of hydrological information that contains the following equations [10]:

$$F(x) = \exp\left[-exp\left(-\frac{x-0.569}{0.138}\right)\right] \quad (1)$$

Where: **F(x):** Probability function**, x:** Rainfull average, and:

$$\boldsymbol{\alpha} = \frac{\sqrt{6}\boldsymbol{s}}{\boldsymbol{\pi}} \quad (2)$$

$\boldsymbol{\alpha}$ = confidence or probability level, and **s**= standard desviation.

$$\boldsymbol{\mu} = \bar{x} - 0.5772\alpha \quad (3)$$

$\boldsymbol{\mu}$ = Accumulated distribute function, $\bar{\boldsymbol{x}}$=precipitation average, and $\boldsymbol{\alpha}$ = confidence or probability level.

To get the precipitation for the 25-year return period, the frequency factor must be found, as shown in Eq (5).

$$y_T = -\ln\left[ln\left(\frac{T}{T-1}\right)\right] \quad (4)$$

y_T: frequency factor T: return period

$$x_T = \mu + y_T\alpha \quad (5)$$

$\boldsymbol{x_T}$= Maximum precipitation (mm)),$\boldsymbol{\mu}$= Average precipitations,$\boldsymbol{y_T}$ = frequency factor

Finally, the following values were obtained for each of the return period, as shown in Table 2.

Table 2. Maximum Rainfull 24 hours Results

Tr (years)	Y_t	x_T(mm)
5	1.49	55.91
10	2.25	62.53
25	3.19	70.90

Hyetographs of design

With the results obtained from the maximum rainfall in 24 h, a design storm was defined by which the pattern of distribution of the downpour was established in the time taken from precipitation studies through rainfall stations that measure the intensity and duration of the rain. The result of these studies, a typical duration of the downpour, was chosen for the region of Cundinamarca of 3 hours every 10. Below (Figure 3) demonstrates is the design storm for the 5- years design period.

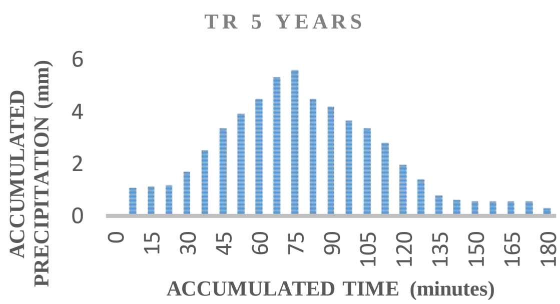

Figure 3.Design Storm for TR 5 years

IV. Analysis Of Storm Sewerage Cadastre

Local storm sewer network: It has a length of 14.50 kilometers, the diameter of greatest presence is 12" (2.70 km of network 18.61%), followed by 16" (1.9 km of network 13.15%), followed by 20" with a length of 1.67 kilometers (11.5% of the network) and the diameter of least presence is 6" with a length of 6.5 meters.

The material with the greatest presence in the local rainwater network is concrete with a length of 8.59 kilometers (59.3% of the network), followed by gress with a length of 4.92 kilometers (34% of the local network), the next material is brick with 0.39 kilometers (2.7% of the local network) and the material with the lowest presence is polyethylene with 56 meters in length (only 0.4% of the local network), as shown in Figure 4**.**

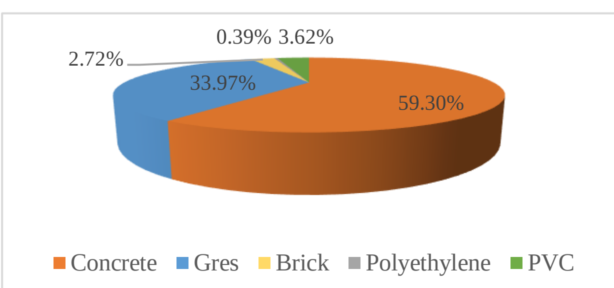

Figure 4. Local Network Pipe Materials Distribution

Storm Sewer Trunk Network: The trunk network has a length of 1.73 kilometers, the diameter with the greatest presence is 51" with a length of 0.62 kilometers (36% of the trunk network), the one that follows is 53" with a length of 0.23 kilometers (26% of the backbone network, the diameter ofleast presence is 59" with a length of 8.8 meters (0.51% of the trunk network).

The majority material is reinforced concrete with a length of 1.36 kilometers (79% of the backbone network), followed by coated reinforced concrete with a length of 0.103 kilometers (6% of the backbone network). The minority material of the backbone network is extra reinforced concrete with only 19.31m (1% of the backbone) and the remaining length 66.91m are unknown materials (4% of the backbone) as shown in Figure 5.

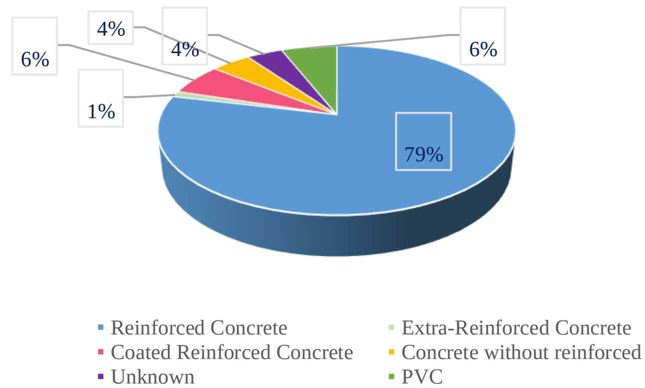

Figure 4. Trunk Network Pipe Materials Distribution

Storm Sewer Manholes: There are 327 storm sewer manholes that correspond to the UGA 251 networks, consist of 265 inspection wells (81% of the UGA 251) and 56 inspection manholes, as shown in Table 3**.**

Number of structures of manholes of the UGA 251

Hydraulic Structure	# of manholes	%
Sewer Manhole	265	81%
Inspection Camera	62	19%

Sinks: There are a total of 440 wells of which, 420 are in operation while the remaining 20 are not, therefore, the sink network has 95% system operation, as shown in Table 4.

Table 3. Number of sinkholes in operation

Sinkholes	# of sinkholes	%
Operate	420	95%
No Operate	20	5%

Field inspection: A visit was made to the study area, where information was taken from 100 sinks (22.72%) of the 440 existing sinks. The sinks were inspected and analyzed to see if they were clogged, their condition, grid and other obstructions, among other observations, as shown in Figure 6.

The main findings were as follows: 97 of the 100 sinkholes are in good condition, 77 of the 100 sinkholes have their structure cleared, 6 of the 100 are sealed, 8 of the 100 are covered by residue, and 9 of the 100 are covered by sediment.

The materials of the lid and the grid of the sumps were as follows: concrete with 72% being the majority material, steel with 9%, plastic with 18%, and the minority material was unknown.

Figure 5. PLS20870 AND PSL212355 Sinks of UGA 251
Own pictures

V. HYDRAULIC MODEL

The Environmental Protection Agency (EPA) software (SWMM) allows engineering professionals to perform a dynamic rainfall simulation model, which is used to implement a continuous simulation over an extended period. The program simulates the quantity and quality of water evacuated,especially in urban sewerage. SWMM's runoff *or hydrology module* functions as a series of beads into which rainwater fallsand runoff is generated. *SWMM's hydraulic transport module* is able to follow the evolution of the quantity and quality of runoff water in each basin, as well as the flow rate, the water level in the wells, the quality of water in each pipe, and channel during a simulation composed of multiple time intervals.

Topology of storm sewer networks: For the elaboration of the hydraulic model of the UGA 251 in the EPA SWMM software, the information was taken from the metadata provided by the EAAB-ESP which included the information of grade levels, initial batting levels, final raft dimensions, diameters, lengths, and pipe materials for the different local networks, trunk networks, wells, sinks, discharges, and their interconnections.

Afferent areas: Figure 7 shows the layout of 337 afferent areas to which information was included for the return period of 5 and 10 years.

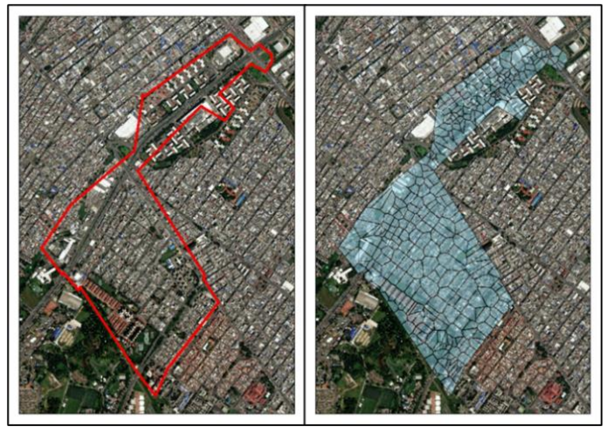

Figure 6. Simplified Distribution Areas of UGA 251

ArcMap 10.8

Curve Number (CN): it is a hydrological parameter that allows to characterize the potential of runoff in a hydrographic basin and is determined by physical characteristics of the territory such as the type, density, and treatment of the covers, as well as by the hydrological group of soil [5]. For the determination of the CN of the afferent areas, the metadata of land cover and use of the department of Cundinamarca was used, the values of the NS-085 table of the EAAB-ESP for the different hydrological groups of soils were considered, and with the help of the ArcMap software, the CN was calculated for each of the afferent areas of UGA 251.

Percentage of permeable and impermeable area: For the determination of the percentage of permeable and impermeable area of the UGA 251 - EAAB-ESP, a Digital Elevation Model (DEM) classification of the study area was carried out. It was obtained from the official NASA website [6] and processed by ArcMap software to obtain a Raster, Hard areas (covered by houses and roads) and soft areas (green areas) were classified.

Average slope of the afferent areas: To obtain the average slope of the afferent drainage areas, the Raster obtained was processed and classified for each of the afferent areas of the UGA 251 - EAAB-ESP.

Adopted values: Manning's coefficient of n for surface flow over the permeable area of the study area, adopted value 0.15. Manning's coefficient of n for surface flow over the impermeable area of the study adopted a value 0.012.For storage (height) of the permeable zone, a value of 3 mm was adopted, and for storage (height) of the impermeable zone, a value of 1 mm was adopted. For the hydrological model, the design storms (Hyetograms) of the return periods of Tr 5 were taken for the diagnosis of the storm sewer networks of the UGA 251.

Inconsistencies: The procedure to complete the topology of the sewerage networks that did not have information, consisted of weighting the information of the upstream section as the downstream section of the segment, in order to give continuity to the system.

However, with these adjustments assumed, it was evident that at the time of the migration of the information to the Geodatabase by the EAAB-ESP staff, some error may have been made at the time of typing or design errors occur in reality.

VI. Hydraulic Modeling Results

For a return period of 5 years: of the 371 sections evaluated, 82 enter load throughout the rain event (22% of the rainwater network). The speed of the design complies with the speed parameter according to the NS 085 standard of the EAAB-ESP, the speed range is in the range of 0 to 5 m/s.

The following Table 5 shows the maximum flows generated in the discharges where the sum of the same generated in the sewer rainwater network of the UGA 251 results in 6932.35 l/s o 6.93 m^3/s for a 5-year design storm.

Table 4. Hydraulic Diagnosis Results

DISCHARGE ID	Maximum Flow discharge (L/s)
Calle 74ª Discharge	261.83
Canal Salitre Discharge	22.98
Canal Salitre 2 Discharge	893.36
Canal Salitre 3 Discharge	328.07
Canal Salitre 4 Discharge	136.59
Interceptor Rio Nuevo Discharge	2106.38
Interceptor Rio Nuevo 2 Discharge	3183.14
Q TOTAL L/s	**6932.35**

The following figures shows the hydraulic modeling results about maximum and minimum velocities (Figure 8), hydraulic capacity sections (Figure 9), and pluvial flows (Figure 10).

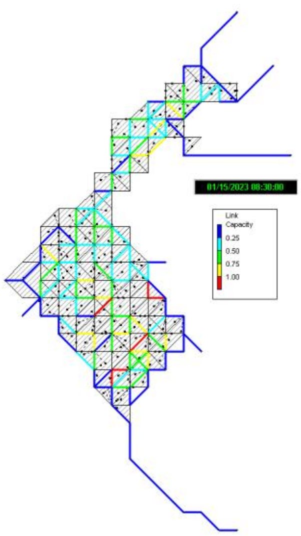

Figure 8. Maximum and Minimum Velocities- Tr 5 years EPA SWMM

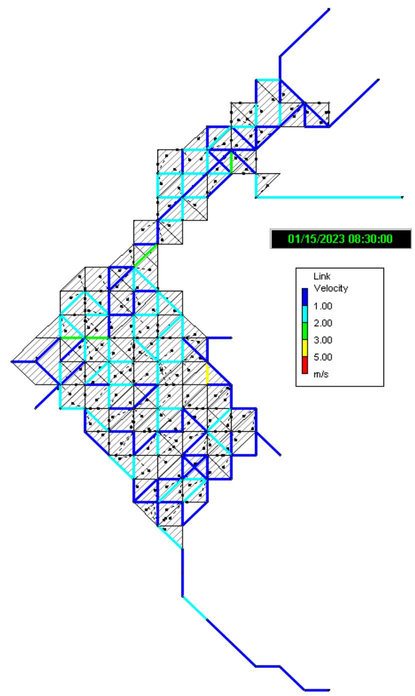

Figure 9. Hydraulic Capacity Sections- Tr 5 years EPA SWMM

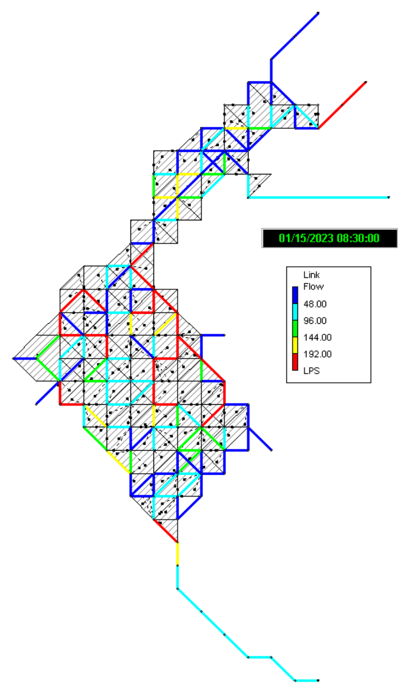

Figure 10. Pluvial Flows- Tr 5 years EPA SWMM

VII. CONCLUSIONS AND RECOMMENDATIONS

The hydraulic model allowed to make a diagnosis of the hydraulic structures that component the UGA 251 of Zone 2 of the EAAB-ESP. The rainwater network meets the entire maximum speed required for concrete is less than 5 m/s, for PVC is less than 9 m/s and for fiberglass GRP must not exceed.

When diagnosing the 371 sections, only 5 of them do not meet the maximum filling ratio (Y/d). The alternative for the storm sewer network of the UGA 251 of Zone 2 of the EAAB- ESP to be optimal would be to rehabilitate those 5 sections that fail by filling capacity. Therefore, only 236.4 meters of pipe length of the 14.50 kilometers of rainwater network of the UGA have to be repaired.

From the work carried out in the field it is concluded that: 97% of the sinks are in good condition, 77% have a grid, 9% of them their lid is full of waste and 6% of them were sealed. The alternative is to repair the 23 wells that lack a grid, clean 9 of them and uncover 6 of them for maintenance.

To avoid the phenomenon of flooding, the hydraulic structures must have an optimal state and preventive maintenance on a semi-annual basis. The grids must remain impeccable avoiding accumulation of sediments and solid waste.

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