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Physical parameters for the estimation of the return coefficient in the sewer of the La Chivera watershed

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Abstract. Estimating the amount of flow carried by the sanitary sewer system in a locality is essential for the design of new facilities. Having a record of the flow rates allows the adequate hydraulic design of a drainage system. The objective of this work is to determine the physical parameters for the estimation of the return coefficient that allows estimating the flow rates for the sanitary sewer of the La Chivera watershed, San José de Cúcuta, Colombia. In this sense, dry weather monitoring of the wastewater in the study area was carried out. The data collected in the field were used to construct the hourly flow variation curve or inflow hydrograph in the drainage system. The average hourly flow parameters were estimated with a value of 205.7 m^3/h, a value recorded at the 11th hour of the day. Similarly, the average daily flow was determined with a value of 180.3 m^3/h, while the maximum peak factor was 1.14. Finally, through the physical parameters of the sanitary sewer, the return coefficient was determined, which is 0.72, a value that represents the conditions of the study area.

1. Introduction
Urban drainage systems are part of the most important infrastructure of cities, essential in their planning and development [1]. Drainage systems such as sanitary sewers are a network of facilities that transport wastewater, essentially, and that expands with the increase of urban settlements [2,3]. For the design of new facilities for the expansion of sanitary sewer networks, it is necessary to be able to adequately estimate the flows that will be generated in their operation. Knowing the magnitude of these flows allows hydraulic designs to be made that guarantee the operation of all the components of a drainage system [4].

To determine the wastewater flows generated in the sewerage systems, it is necessary to have information on consumption and measurements taken in monitoring campaigns in each area. The primary purpose of these measurements is to obtain the real magnitude of the flows generated and to be able to calculate the factors that represent the consumption patterns [5]. These include physical parameters such as domestic wastewater flow (Q_{dom}), non-domestic wastewater flow such as industrial (Q_{ind}), commercial (Q_{com}) and institutional (Q_{inst}), maximum peak factor (F), maximum hourly flow (Q_{MH}), misconnection flow (Q_{CE}) and infiltration flow (Q_{INF}) [4].

The physical parameters for the hydraulic design of the drainage network make it possible to obtain an estimate of the return coefficient (C_r) of the wastewater in the area and, consequently, to increase the reliability of the wastewater flow estimates [5]. In residential areas, the value of C_r is directly related to

Q_{dom}, since it is the flow with the highest contribution to the drainage system [6]. Since all the water that supplies a residence has different uses in daily life, not all the supply will be discharged into the sanitary sewage collection system, and C_r is the ratio between consumption and discharge [7].

Obtaining the real and proper parameters of each drainage system is useful for planning the operation of the sewerage systems and the maintenance of the networks, as well as their small components [8,9]. Also, the information on these parameters provides an immediate vision of the operation in the drainage area and the system under study [1]. In addition, it even allows identifying critical locations and possible overflows that may occur in the drainage systems. Among the main causes, obstructions break in pipes or sewer lines, or even by improper operation of the system and vandalism [10].

The city of San José de Cúcuta, Colombia, did not have information on flow measurement campaigns in its urban drainage system at the time of initiating this study. Therefore, the monitoring of wastewater flow for 42 days, in dry weather, in the sanitary sewerage system, in the watershed called "La Chivera", was implemented in this research. It was possible to determine the real conditions applicable to the hydraulic design in the sanitary sewer network and the physical parameters about the study area to estimate the wastewater C_r.

2. Methodology
The research was developed using the following methodological details.

2.1. Study area
The study area is in the "La Chivera" watershed in the La Libertad neighborhood, San José de Cúcuta, Colombia, with a total area of 170.58 hectares. The watershed is part of communities 1 and 2, between the neighborhoods Torcoroma, Siglo XXI, San José, La Unión, Aniversario I and II, and San Martín. The selection of this watershed was based on the characteristics of the existing sanitary sewerage network, due to the topology of the sector, which has a closed network with a single discharge point. These characteristics greatly facilitate the monitoring of the wastewater flow to be carried out. In addition, the social stratum in the sector under analysis is practically uniform, giving it a homogeneous characteristic as a study sample.

The city's aqueduct system has a configuration based on the principle of hydraulic sectoring. The principle consists of dividing the aqueduct networks into sectors with controlled inflows and outflows. In this way, it is possible to know the behavior of water demand in each hydraulic sector, the working pressures in the network, and the total number of users per sector, among other characteristics [7]. The study watershed includes the following subsectors: 1801, 1802, 1803, 1803, 1805, 1807, 1808, and 50203, as shown in Figure 1. Similarly, Figure 1 shows the land uses present in the watershed, mostly residential land, but also institutional land use (schools, churches, health centers, and recreational areas) and commercial land use (supermarkets, restaurants, and hardware stores) to a lesser extent.

2.2. Dry weather monitoring
The flow of wastewater generated in the "La Chivera" watershed was monitored for 42 consecutive days in the sanitary sewer system. The flow measurement point was selected by identifying the confluence point of all the system's collectors. A study watershed was chosen, characterized as a closed network, whose drainage system converges to a final discharge point or final discharge collector. For the monitoring campaign, a SOFREL LT-US reference Data Logger ultrasonic flow meter was used, taking flow data every 15 minutes, 24 hours a day. The data were initially stored in the internal memory of the device and later transmitted to a web server (MyWebScada), from where the daily information was viewed and downloaded.

Precipitation is considered an external factor, which can affect the amount of wastewater carried by the drainage system in a rain event. The flow of wastewater is affected by the presence of clandestine storm sewer connections that discharge into the sanitary sewer system. These contributions can lead to an increase in this flow, which at some point in the operation may exceed the capacity of the collector

and cause the system to collapse. Thus, wastewater can reach the surface through wells or, in the worst case, through household connections [11].

To determine the dry weather monitoring period, the days in which rainfall events occurred were discarded. Two meteorological stations located in areas close to the study watershed were monitored. The Camilo Daza Airport station (16015010), categorized as main synoptic, and the Universidad Francisco de Paula Santander station (16015110), categorized as main climatic, were constantly consulted. Both stations are operated by "Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM)".
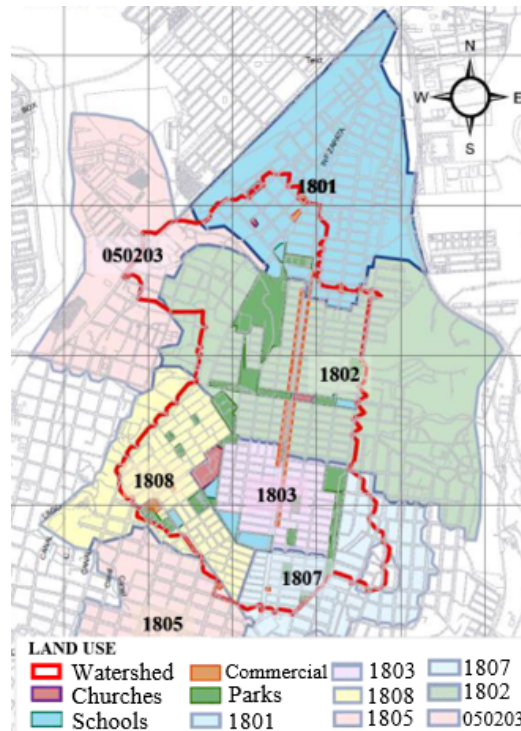

Figure 1. Hydraulic sectors of the aqueduct system in the study watershed and land uses.

2.3. Estimation of return flow coefficient
The estimation of the physical parameters is explained below.

2.3.1. Infiltration flow rate and design flow rate. The infiltration flow was estimated using secondary information provided by the city's water and sewer service provider. The information consists of geotechnical studies carried out at different points within the drainage area or watershed. A total of 6 geotechnical studies were consulted and each one analyzed the type of soil, stratigraphic profiles, and soundings or explorations carried out at different depths (between 2 m and 5 m). The flow generated by the wrong connections must also be considered in the design of sewage collectors. Thus, the design flow rate (Q_{DT}) of wastewater drainage collectors is obtained by Equation (1) [7].

$$Q_{DT} = Q_{MH} + Q_{INF} + Q_{CE}. \tag{1}$$

2.3.2. Average daily wastewater flow rate. The hydraulic design of sanitary sewerage systems should be based on the mean daily flow (Q_{MD}), which is defined as the average flow in 24 hours obtained from the input data to the system [12]. This parameter is represented by Equation (2) [5].

$$Q_{MD} = Q_{dom} + Q_{ind} + Q_{com} + Q_{inst}. \tag{2}$$

2.3.3. Maximum hourly flow rate and maximum peak factor. The data obtained on daily and hourly flow variation were quantified and plotted to estimate the Q_{MH} of the sewerage system, the Q_{MD}, and the F of the system. The latter factor considers the variations in water consumption by the population [1]. The Q_{MH} calculated as shown in Equation (3) [13].

$$Q_{MH} = Q_{MD} * F. \tag{3}$$

2.3.4. Population estimation. To obtain the population data, it was necessary to apply surveys in a pilot test and determine the sampling variance characteristic of the study, with which the required sample of households for the study area was defined, and the number of households to be surveyed in the "La Chivera" watershed was estimated by stratified random analysis.

   After conducting the pilot test surveys to 2% of the registered users in the watershed for each stratum, the sample size was determined using Equation (4) [7].

$$n = \frac{\sum_{i=1}^{L} \frac{N_i^2 * S_i^2}{W_i}}{N^2 * D + \sum_{Ni}^{L} N_i * S_i^2}, \tag{4}$$

where n is the sample size, N_i the number of sampling units in stratum i, S_i^2 the sampling variance by stratum, W_i the fraction of observations assigned to stratum i, N the number of users in the watershed, L the number of strata in the population, B the limit for the estimation error and D is equal to $B^2/4N^2$ for estimating the population total.

2.3.5. Flow of the aqueduct system and net endowment. The flow provided by the aqueduct system (Q) to each hydraulic subsector located within the study watershed is quantified by the city's public utility company. The daily record of the monitoring of the macro meters of each subsector was obtained through the supervisory control and data acquisition (SCADA) system. These flows were supplied for the research and with the population projections made in the "La Chivera" watershed to estimate the real daily net supply of each inhabitant (D_{neta}).

2.3.6. Return coefficient. Generally, the main component of wastewater is domestic wastewater, which comes from individual homes and presents a latent variable that is dependent on factors such as the number of individuals, geographic location, climatic conditions, economic status, among other aspects [6]. By determining the physical parameters, it was possible to estimate the C_r for the design of sewers through dry weather monitoring of the "La Chivera" watershed, in the city of San José de Cúcuta, Colombia, using Equation (5) [13].

$$C_r = \frac{86400 * Q_{dom}}{P * D_{neta}}. \tag{5}$$

3. Results
The results obtained are presented below.

3.1. Inflows to the drainage system
Wastewater flow records were monitored during dry weather, which comprised a total of 29 days. Figure 2 shows the overlay of the total number of days (29) recorded as dry weather in the period during which the wastewater monitoring was conducted for the case study.

   The Q_{MH} was calculated with the four data recorded for each hour of each day of dry weather, resulting in a total of twenty-four (24) flow data per day. For each day of data, the ratio between Q_{MH}

and Q_{MD} was obtained. The value of the ratio represents the F corresponding to each monitoring day. Additionally, the relationship between the hourly flow rate (Q) and the Q_{MD} was calculated, the results are shown in Table 1.
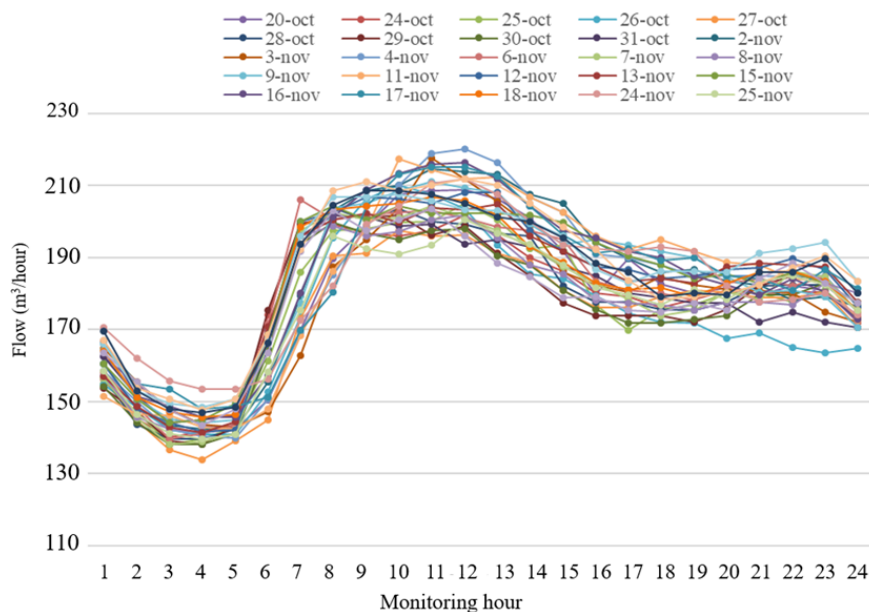

Figure 2. Hydrograph of inflow to the sewage system for each day of dry weather monitoring in the "La Chivera" watershed.

Table 1. Hourly flow rate of the sewage system in the "La Chivera" watershed.

Hour	Q (m³/hour)	Q/Q_{MD}	Hour	Q (m³/hour)	Q/Q_{MD}	Hour	Q (m³/hour)	Q/Q_{MD}
1	160.52	0.89	9	201.21	1.12	17	182.72	1.01
2	149.84	0.83	10	204.18	1.13	18	181.60	1.01
3	144.29	0.80	11	205.73	1.14	19	181.08	100
4	142.80	0.79	12	205.32	1.14	20	181.00	1.00
5	144.54	0.80	13	201.90	1.12	21	181.80	1.01
6	161.63	0.90	14	196.41	1.09	22	182.41	1.01
7	186.40	1.03	15	190.91	1.06	23	182.35	1.01
8	197.92	1.10	16	185.02	1.03	24	175.01	0.97

With the values obtained in Table 1, the definitive inflow hydrograph is constructed in the drainage system of the study area, which is shown in Figure 3. The determined value of the Q_{MH} characteristic of the "La Chivera" watershed was 205.73 m³/hour corresponding to the 11th hour of the day, the minimum nocturnal flow is at the 4th hour of the day with a value of 142.8 m³/hour , the Q_{MD} of 180.28 m³/hour , while the F is 1.14.

In the analysis of the information from the explorations carried out in the six geotechnical studies consulted to determine the Q_{INF}, no water table was found. The studies foresaw the presence of water at a depth of more than 10 m. Therefore, the Q_{INF} contributed to the sewerage network was determined to be negligible or null [5]. The Q_{CE} is also considered null when performing the monitoring campaign in dry weather and discarding rainy days with information from IDEAM weather stations.

According to the land use classification of the study area (Figure 1), the "La Chivera" watershed has a total area of 170.58 hectares, where 16.34 hectares belong to park use, 3.1 hectares for commercial

use, 5.53 hectares for institutional use, and 145.61 hectares for residential use. The calculations yielded the flow corresponding to the area according to land use, such as Q_{inst} of 1390.5 m^3/month, Q_{com} of 2146.4 m^3/month, and Q_{ind}, it was established that in the study area there is no land-use categorized as industrial, i.e. this flow has a null value. The contribution of Q_{dom} to the drainage system resulted in a value of 175.363 m^3/hour, which corresponds to 97.27% of the average daily flow that enters the sewage system in the studied watershed. By calculating the flow rates for the different land uses, as unit flows, we obtain that the Q_{inst} is 0.36 m^3/hour and the Q_{com} is 0.97 m^3/hour.
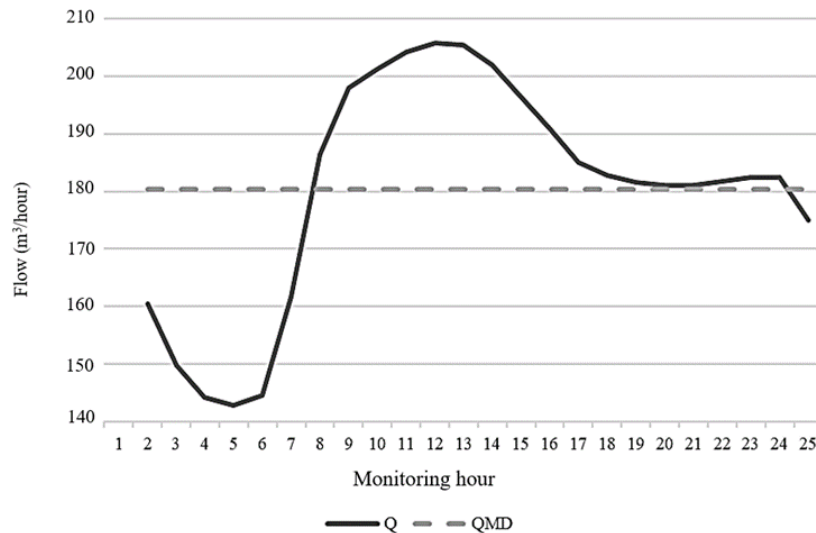

Figure 3. Inflow hydrograph in the sewerage system under study.

3.2. Average daily water flow rate

With the records of the flow provided by the aqueduct system to each hydraulic subsector located within the study watershed, delivered by the public utility company, the calculation of the average daily flow of drinking water (Q_{MD}-AP), delivered to each hydraulic subsector and in turn to the entire watershed, was performed. The Q_{MD}-AP values obtained were 243.36 m^3/hour for the 170.58 hectares, resulting in a unified flow of 1.47 m^3/hour of residential or domestic use. For a population of 34997 inhabitants (value obtained from the application of the survey in a pilot test) and a Q_{MD}-AP of 243.32 m^3/hour, a D_{neta} of 166.8 liters per inhabitant per day was determined.

3.3. Return coefficient

For a population of 34997 inhabitants, a D_{neta} of 166.8 liters per inhabitant per day and a Q_{dom} of 175.63 m^3/hour, a C_r of 0.72 was obtained, adjusted to the current behavior of the sewerage network in the "La Chivera" watershed. This factor represents the fraction of a unit of potable water used for domestic purposes that reaches the sewerage system network.

4. Conclusions

Water flow monitoring was carried out in the "La Chivera" watershed during dry weather, excluding days with rainfall events. With these data collected in the field, the hourly flow variation curve was constructed, in which it was possible to estimate the physical parameters of maximum hourly flow of 205.73 m^3/hour, mean daily flow of 180.28 m^3/hour, maximum peak factor of 1.14. It was also possible to establish that the minimum nocturnal flow is at 4:00 a. m. with a value of 142.8 m^3/hour and the flows corresponding to the area according to land use in the study zone (industrial wastewater flow= 1390.5 m^3/month and commercial wastewater flow= 2146.4 m^3/month). Through the physical parameters of the sanitary sewer, the return coefficient was determined with a value of 0.72, relevant for estimating the wastewater flow for future designs of sanitary sewer systems.

Acknowledgments

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