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RAINFALL FLOW AND SANITARY RUNOFF CALCULATION IN MICRO-BASIN TARANGO IN MEXICO CITY, MEXICO

Espejo-Montes Fátima de los Ángeles
Metropolitan Autonomous University, Azcapotzalco Unit, Division of Basic Sciences and Engineering
Metropolitan Autonomous University, Azcapotzalco Unit, Doctorate in Environmental Sciences and Engineering
Mexico

Gómez-Núñez Jersain
Metropolitan Autonomous University, Azcapotzalco Unit, Division of Basic Sciences and Engineering
Mexico

Gómez-Salazar Sergio
Department of Chemical Engineering. University Center for Exact Sciences and Engineering, University of Guadalajara
Mexico

Solís-Correa Hugo
Metropolitan Autonomous University, Azcapotzalco Unit, Division of Basic Sciences and Engineering
Mexico

Rojacques Mompremier
Metropolitan Autonomous University, Azcapotzalco Unit, Division of Basic Sciences and Engineering
Mexico

Barceló-Quintal Icela Dagmar
Metropolitan Autonomous University, Azcapotzalco Unit, Division of Basic Sciences and Engineering
Mexico

Abstract: In Mexico City, due to the excessive growth of the population, with more buildings, houses, other constructions and paving of streets, little permeable surfaces have been generated, increasing the volume of runoff that often causes flooding. Part of this problem was observed in the Tarango micro-basin, where the Río Puerta Grande stream is located, with a length of 6.3 km, where there are some 53 discharges of urban wastewater that are discharged directly into the stream, which produces contamination, affecting its quality. It belongs to an Area of Environmental Value due to its ecological importance, so it is important to know its rainfall flow in order to have hydraulic and hydrological data, in order to establish a future water treatment design. Objective for which the calculation of the flow of pluvial origin of runoff in the micro-basin was carried out, with a return period of 25 years, in addition to also considering residual discharges, for which a flow of 49.10 m^3/s was obtained, performing gauging to obtain the configuration of the channel, its speed and depth, in order to identify its behavior in dry season and after rains, comparing field data with the time adjustment curve (hydrograph).
Keywords: Tarango micro-basin, Puerta Grande River stream, rainfall flow, residual discharges

INTRODUCTION

Currently worldwide, water management faces an enormous challenge mainly when it comes to the contamination of water resources. The United Nations Organization indicates that 80% of wastewater is currently discharged without treatment, this is due to sanitation lack infrastructure, which causes a negative impact on the environment (UNWWAP, 2017). In Mexico, the total wastewater generated is around 228.7m3/s, of which 92% is collected and 8% is discarded to a natural source (CONAGUA, 2013).

In several regions of the country there are ravines generated by erosion of the land, that is, fractures over time, where runoff runs on the slopes and in other cases even rivers, these water bodies due to infiltrations in the groundwater table generate an environmental benefit. This water bodies also minimize soil erosion, generate forests and biota, creating important ecosystems for oxygenation, even in urban centers such as Mexico City, which is nestled in a valley and in there are ravines where their ecosystems are important for the oxygenation that helps to the city , however uncontrolled human settlements have turned these ravines into sewage drains that lead to infection sources, which it is necessary to apply a stricter ecological order (Dávila et. al, 2013).

The large urban sprawl of Mexico City has increased environmental contamination, continuously affecting the runoff generated by the rains, which in turn affects buildings and settlements on the ravine's slopes, also the pollution has affected the amount of water infiltration necessary for the Valley of Mexico, producing a danger of extinction for the fauna and flora of the region, as well as the loss of useful soils for forests and agriculture. In the southern part of the city, the topography allows that exist 74 ravines in eight municipalities: Álvaro Obregón, Cuajimalpa, Gustavo A. Madero, Iztapalapa, Magdalena. Contreras, Milpa Alta, Tlalpan and Xochimilco, most of which are concentrated in the first three municipalities, which have lost their agricultural and forestry activities due to urban sprawl. In year 2009, serious studies began on the importance of conserving the ravines and streams that make them up and in 2010 the Ministry of the Environment decreed 32 ravines in the city as Areas of Environmental Value (AEV) and in March of the same year, one comprehensive program was launched with the aim of rescuing these ravines, guaranteeing their conservation and establishing a strategy called the Federal District Government's Green Plan whose objective is to achieve equilibrium in the Valley of Mexico aquifer (Robles, 2008). The case study is located in this Mexico City, to the southwest of the Álvaro Obregón Mayor's Office, this contains most of the ravines, where the colonies that are found within it can be at high risk, due to runoff in times of rain given its geology. According to the Environmental and Territorial Planning Office of the Federal District (PAOT, 2010), the current hydrological system of this area contains eight river sub-basins, where the Tarango micro-basin is recognized as an Area of Environmental Value (Official Gazette CDMX, 2009) for its ravines that are important for the city, in addition of the great biodiversity of endemic species and the to be one of the city lungs due to its hydrology (Valencia, 2021). The towns above the ravine discharge wastewater of urban origin into two streams, called Río Puerta Grande and Río Colorado, where the first is located in the zone of Environmental Value, due to its ecological characteristics (Environmental Law for Land Protection in the Federal District, 2021), reason why the government, companies and civil society seek its cleanup and recovery, Figure 1

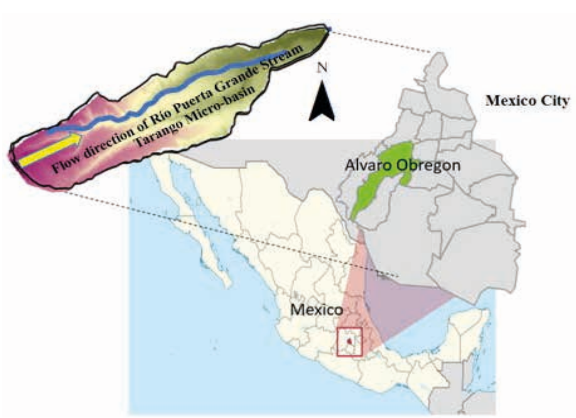

Figure 1. Tarango micro-basin, considered an Area of Environmental Value in Mexico City, Mexico

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The ravine where the stream is located receives around 53 wastewater discharges, mainly urban. Figure 2 indicates the most important ones, which discharge directly into the stream. This encourages the need to determine the runoff flow of these residual discharges for a possible treatment of this body of water. The amount of water in the stream varies depending on the climatic conditions, in the dry season the amount of water in the tributary is reduced, having these conditions a system of superficial wetlands can be considered, however, in the rainy season the amount of water increases, causing a larger flood area that would affect said system, since the speed of the water could not be controlled, nor the amount of it that would feed the treatment system.

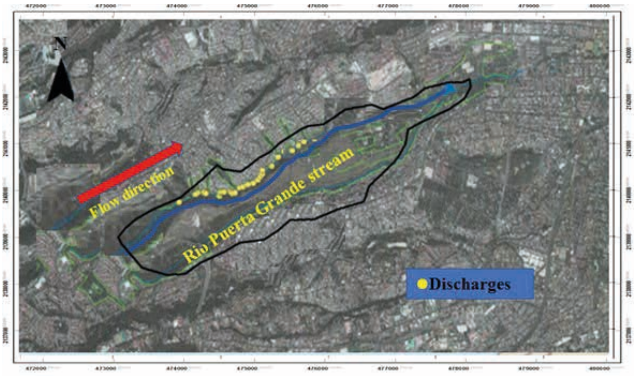


Figure 2. Main discharges located in the Río Puerta Grande River stream

For these reasons, complementary works would be necessary in order to properly direct the speed and quantity of water for the system proper functioning, as well as specific areas for storage and distribution of irrigation water. A determining factor for the elaboration of this project is to respect the speed and constant cost, conditions that are not fulfilled, because it is variable in the different seasons in the year. In the dry season, speed and expense are almost constant due to the amount of water that reaches the stream from wastewater discharges. In the rainy season, the speed and expense increased considerably due to the water amount is accumulated in a near dam, since the curtain of this has several works to intake and venting of the water, causing a flood area that could affect the treatment system. The population's wastewater is mixed with rainwater in the rainy season and any intervention in the area requires knowing the flow that runs off in the site, both rainwater and sanitary. This information will be the starting point for possible interventions, such as the implementation of treatment processes for these waters.

In present work, was determined the flow of the Puerta Grande River stream associated with the pluvial runoff as a consequence of the precipitation in the basin and the discharges of urban residual water. In addition, measurements were made in the stream to determine the gauging's, to know the flow, as well as the speed of the water in the stream and the concentration time calculation, where the value of stream slope was required, which was determined with the highest value of the basin, as well as the lowest value of this, considering the length of the stream. The gauging at different times was also determined, and the average flow was calculated, which was determined with the help of the Drinking Water and Sanitary Sewerage Manual from Conagua (2016),, and then to calculate the concentration time for to determine the detailed behavior of base discharge hydrograph.

METHODOLOGY

For the hydrological study, a Digital Elevation Model (DEM) was used, with which the bed of stream slope was calculated and with the direction of the flow, the trajectory of the water considering the micro-basin delimited surface, figure 3.

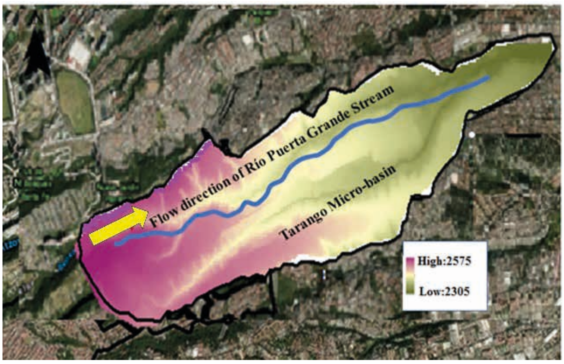


Figure 3. Delimitation of the Tarango micro-basin, where the Río Puerta Grande stream is located, obtained using the Digital Elevation Model (DEM) from the ArcGIS software

The use of the ArcGIS software allowed the discretization of the study area by means of a regular cells system, with which a matrix with a cell resolution of 5 x 5 m and it was built a mesh, from this were obtained the drainage data of the basin, the direction and accumulation of flow, and thus its delimitation was obtained. In Figure 2 is showed the result of the delimitation of the Tarango micro-watershed, where it indicates the Puerta Grande River stream location.

OBTAINING CLIMATOLOGICAL DATA

The reference station that was used in the area at first was that of Tarango, due to its location within it, however, this station only has 18 years of record, so closer weather stations had to be selected to the study area, located within a radius of 10 km, of which eight important stations were found, which are presented in figure 4.

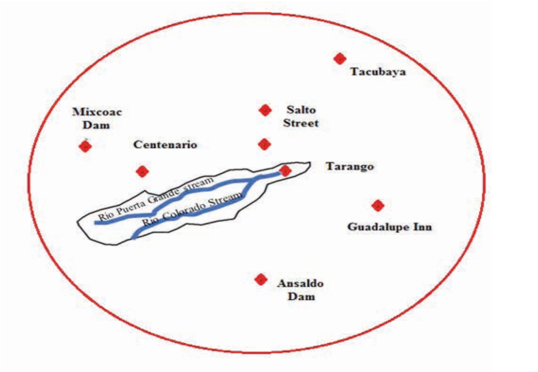


Figure 4. Meteorological stations located within a radius of 10 km, with respect to the Tarango micro-basin

For this study, data was collected on the maximum accumulated rainfall during 24 hours from the eight weather stations (CLICOM, 2021), for different available registry years.

OBTAINING THE MAXIMUM PRECIPITATION THROUGH A PROBABILITY FUNCTION

The Thiessen polygons method allowed calculating the maximum rainfall to complete a period of 42 years of registration. In order to know the precipitations associated with events for a longer return period, it was necessary to extrapolate by means of probability functions related to available meteorological data. These was: Normal, Log Normal and Gumbel. In the present study it was important to select which of them best described the rainfall data, where the standard error of fit (SE) was the criterion for selection, equation 1.

$$EE = \sqrt{\frac{(P_h - P_a)^2}{N - Np}} \quad [1]$$

Where in

P_h = historical precipitation

P_a = adjusted rainfall

N = data number

Np= parameter numbers

In order to be able to calculate the average rainfall incidence of the basin, a return period of 2 to 25 years was chosen.

DETERMINATION OF WATER FLOW THROUGH THE AMERICAN RATIONAL METHOD

With this method, three variables were considered that are directly proportional for the calculation of the maximum flow (**Q_{mid}**). The first variable was the rain Intensity (***I***), which begins instantly and continues indefinitely, with a runoff that will continue until the Concentration Time (t_c) is reached, at which time the entire basin is contributing to the flow (Beven, 2012, Michaildi, et.al, 2018, Beven, 2020). Another variable considered was the runoff Coefficient (***C***), between 0 and 1, which represents soil permeability and finally the area was calculated. The ***tc*** was calculated with equation 2 proposed by Kirpich, (Beven, 2020) because the study basin enters into the range of application of said equation, as it is of medium size and considerable slope.

$$t_c = 0.02L^{0.77}\, S^{-0.385} \quad [2]$$

Where in

t_c= concentration time [*min*]

L= maximum length at the outlet [m]

S= mean bed slope [m/m

The American Rational Method (Linsley and Franzini, 1974) was used to determine the maximum flow associated with a determined rain and the Return Time (**Tr**). This method can be used for areas from 0.01 km^2 and up to 4.86 km^2, where the Tarango microbasin area enters in this range, also considers that the rain falls over the entire basin with constant intensity, according to equation 3

$$Q = kCIA \quad [3\}$$

Where in

Q= rain runoff spending generated in one basin or in one sub -basin [*L/s*]

C= coefficient of runoff [dimensionless]

I = rain intensity [*mm/h*]

A = area [m^2]

Factor K is equal to 1/3600 with the purpose that hours and seconds be congruent and according to equation 3, and so that the runoff coefficient C could be dimensionless it was related to the following:

$$CIA = [\frac{mm}{h} m^2]$$

Equation 3 now is transformed and will be used how the equation 4

$$Q = \frac{CIA}{3600} \quad [4]$$

For the calculation of sanitary origin flow, the design of the delimitation of the Tarango micro-basin was made with ArcGIS software and for the delimitation of the micro-basin the Hydrologic Modeling software was used, which contains the functions, Flow Direction, Flow Accumulation, Flow Length, Stream Order, Stream to Feature, Stream Link, Snap Pour Point and Watershed (ESRI, 2021), with which the direction of the stream was obtained.

CALCULATION OF SPENDING AND RUNOFF COEFFICIENT

The runoff calculation expenses were calculated considering the concentration time, which is determined by the time it takes for the water to reach the basin exit, considering the most remote hydrologically, taking into account the time from which the runoff flow is constant at the maximum time. This more remote hydrologically is with which runoff water uses more time to get to the exit (Vélez and Botero, 2011). For the calculation of concentration time of the stream flow, the following physical characteristics of the basin: slopes, lengths, average elevations and the area of the basin, are presented in Table 1.

Tarango microbasin properties	Values in meters
Channel length	6300
Slope	0.042
Height 1m	2575
Height 2m	2305

Table 1. Characteristics of the Tarango microbasin

Subsequently, considering the type of soil and the slope for both were assigned the runoff coefficients (C), as shown in Table 2, and with this a layer (raster) of the slopes was generated by the ArcGis software from the MDE. After the slopes were also calculated with ArcGis and different surface types were assigned, according to the satellite image. To obtain the bed rugosity from the Rio Puerta Grande stream, the terrain rugosity was used, this was important for to know with detail the structure of this bed as well as to determine the water flow resistance of its channel and of the basin. With this, the terrain elevation was obtained through the Digital Elevation Model (DEM) that was processed by the Slope tool contained in the DEM Spatial Analysis module, with which the slope of the basin was calculated (Burrough to McDonnell, 1998). This was calculated in different percentages intervals, as be established by Soil Survey Manual, (2017).

For the calculation of sanitary origin flow, the design of the delimitation of the Tarango microbasin was made with ArcGIS software and for the delimitation of the microbasin the Hydrologic Modeling software was used, which contains the functions, Flow Direction, Flow Accumulation, Flow Length, Stream Order, Stream to Feature, Stream Link, Snap Pour Point and Watershed (ESRI, 2021), with which the direction of the stream was obtained.

To obtain the water consumption of the inhabitants and the calculation of them, it was obtained that at home there are approximately 4 inhabitants, obtaining a total of 66,876 inhabitant and for water consumption was obtained 142l/h/d, this last data was considered for a temperate climate and a rural area. On the other hand, it was important to know the average spending ($\boldsymbol{Q_{mid}}$) of the domestic wastewater contribution (black waters) on an average day of the year depending on the population and its contribution in each section of the network, for this calculation equation 5 was utilized. This equation considers the residual water contribution A_p, as a water fraction that is provided to each inhabitant and the value recommended by Conagua (2016) is 0.75.

$$Q_{mid} = \left(\frac{A_p P}{86400}\right) \qquad [5]$$

Where in

Q_{mid} = Average sewage (black waters) spending on l/s

A_p = contribution of sewage (black waters) in l/h/day (0.75)

P = number of inhabitants

Gauges are measurements of the water amount that passes through a cross section of the stream at an instant of time. These gauging was carried out by the wading method, in order to obtain the water speed and the gauging's section geometry in sections where the current had depths of less than 50 cm, with a fixed bottom and speeds less than 1 m/s, in order to respect the recommendations of the measuring equipment used. In addition, it was considered to carry out the gauging on days without the rain presence, with the aim of only considering water of sanitary origin. On the other hand, the sanitary runoff expenditure was calculated by means of equation 5 of average expenditure (Q_{mid}). This average expenditure was used to calculate the hourly curve over 24 hours, which was later compared and calibrated with the values measured at the gauging. With these sanitary runoff curves, the availability of water was obtained, which is useful for calculating the pollutant loads carried by the current, as well as for the calibration of future hydrological and hydraulic models that can determine the behavior of this current. The hourly variation coefficients considered correspond to Mexico City and are reported by Conagua (2016).

RESULTS

RESULTS OF THE FLOW CALCULATION OF PLUVIAL ORIGIN THAT DRAINS INTO THE MICRO-BASIN

OBTAINING THIESSEN POLYGONS

The maximum annual rainfall of 24 hours per year at the study site was calculated using the Thiessen polygon method, indicated in Figure 5.

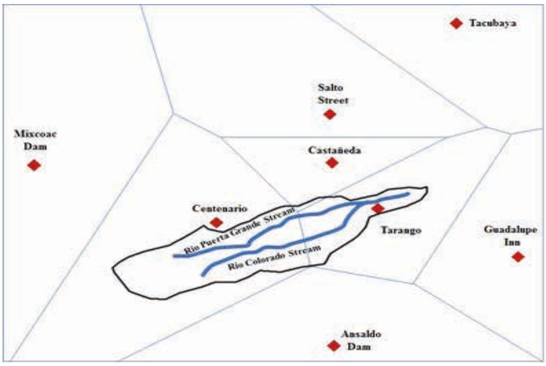


Figure 5. Thiessen polygons obtained according to the eight meteorological data

PROBABILITY DISTRIBUTION FUNCTIONS DETERMINATION TO OBTAIN MAXIMUM RAINFALL

In order to obtain the maximum rainfall in the micro-basin, three probability functions were tested with respect to the curve obtained from the historical annual rainfall from the meteorological stations indicated in Figure 4, from the years 1975 to 2021 (CLICOM, 2021). Normal function was the best curve that described the rainfall behavior in the area and that best it closed to the normal annual precipitation historical curve, which was built from the data from the meteorological stations, see figure 6, for an annual precipitation of 24 hours with respect to the historical data curve. The four curves were built with respect to return times (Tr) in years, it can be observed that the one obtained by Log Normal approached the points of the historical data curve.

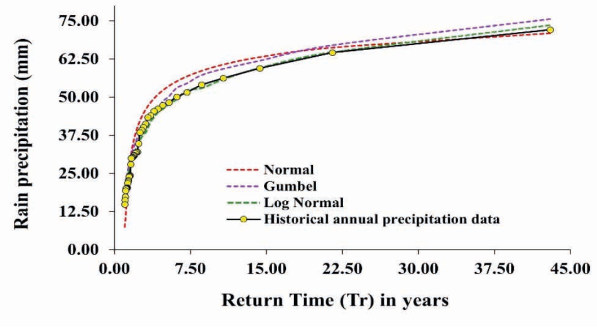


Figure 6. Maximum precipitation associated with Tr related to three probability functions, these are compared with the historical precipitation data curve

INTENSITY, DURATION AND FREQUENCY CURVES FROM RAINFALLS

With the obtaining and selection of the maximum pluvial precipitations, by means of the Log Normal probability function, the intensity, duration and frequency curves (IDF) of pluvial precipitation were obtained, associated with the return times (Tr) during 2, 5, 10 and 25 years, which are represented in figure 7.

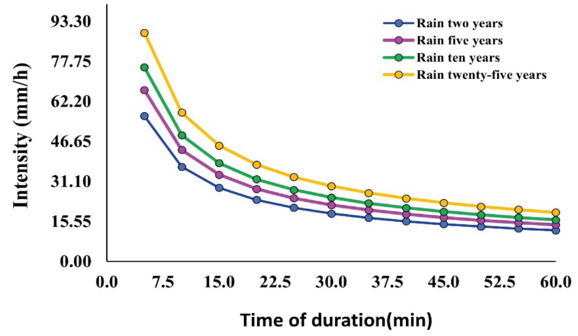


Figure 7. Intensity-Duration-Frequency curves for the study site

HYETOGRAPH

To determine the pluvial precipitation in the basin, as well as its intensity, its progressive increase, the obtaining of its maximum, its gradual decrease and the heights of the pluvial precipitation, bars diagrams were calculated and constructed, that is, hyetographs of precipitation and rainfall intensity in the basin, for a duration of 60 min with 5 min intervals and return times (Tr) for 2, 5, 10 and 25 years, these are indicated in figures 8 and 9 respectively (Campos, 2010).

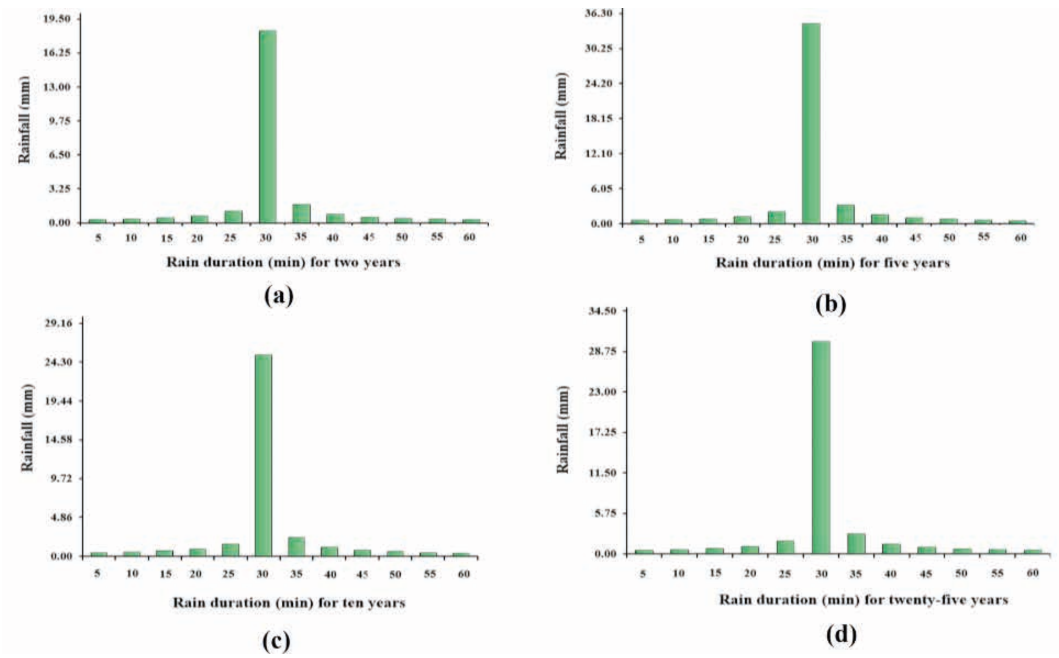


Figure 8. Precipitation hyetographs on the study site

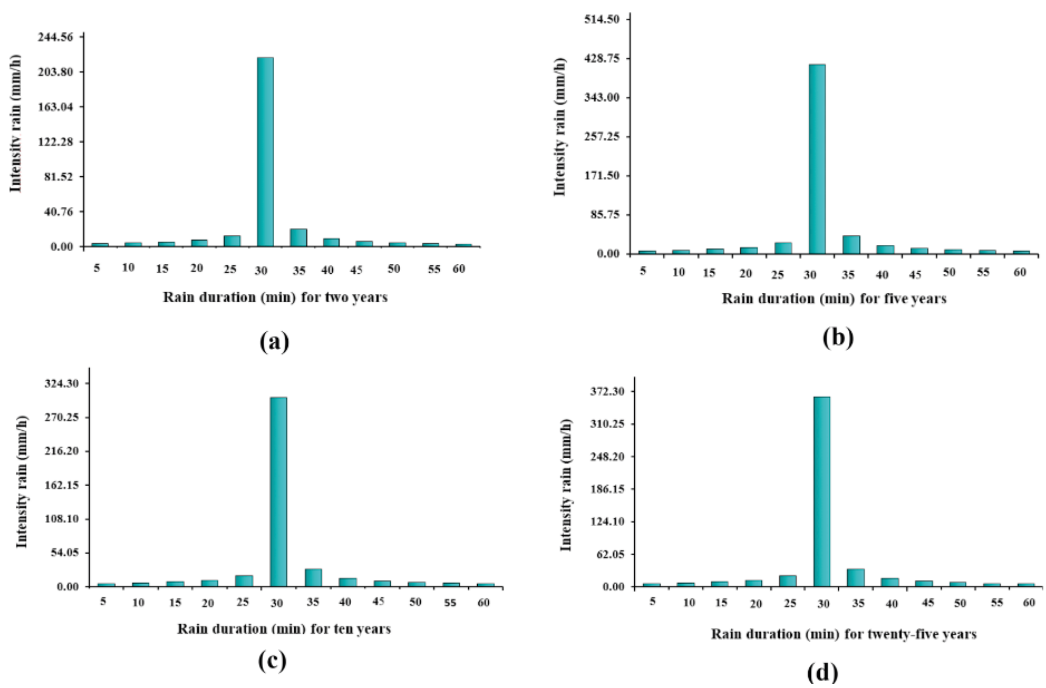


Figure 9. Intensity rain hyetographs on the study site

The maximum flow values generated by rainwater reached values of up to 51.2, 57.9, 68.3 and 80 m³/s for a return period of 2, 5, 10 and 25 years, respectively, these data are presented in table 2.

Tr (años)	Q (m³/s))
2	31.17
5	36.75
10	41.64
25	49.10

Table.2 Maximum flow generated in the basin

RESULTS OF THE FLOW SANITARY ORIGIN THAT RUNS OFF IN THE MICRO-BASIN

Considering the micro-basin delimitation, indicated in figure 10, the elevation profile was obtained, the highest part is presented in brown, which was located at 2,575 masl, and the lowest part, at 2,305 masl, in green color.

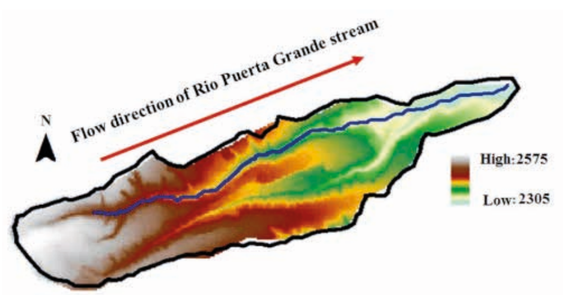


Figure 10. Delimitation the Tarango micro-basin

RESULTS OF Q CALCULATION AND RUNOFF COEFFICIENT

From the data obtained by equation 2, a concentration time of 56 minutes was obtained, which was determined with characteristics upper and lower of the height from basin, as well as the channel length for obtain its slope. In Figure 11a present results of the slopes obtained using the ArcGIS software and figure 11b, the runoff coefficients (Beven, 2012).

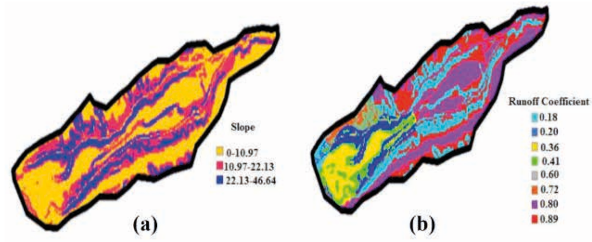


Figure 11. (a). Slopes from the Tarango micro-watershed. (b). Runoff coefficients

The Río Puerta Grande and Río Colorado streams roughness were obtained by assigning roughness values (Chow, 1994) using the ArcGIS software, Figure 12a. In Figure 12b is showed the entire terrain roughness, which was divided into three ranges of values: low, medium and high.

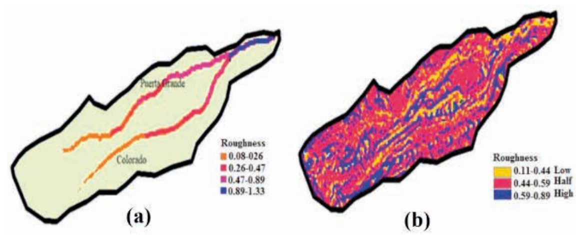


Figure 12. (a). Roughness in the Puerta Grande and Colorado streams. (b). Roughness of the Tarango micro basin entire

Table 3 shows the results of the relationship of the 24 neighborhoods (the table has been written for each locality with their original names), the number of households and when considering 4 inhabitants per household, result the number per colony with one total of 66,876 inhabitants in the study site where its waters are discharged into the stream. The water supply considered was of 142 L/inhabit/d, this value is recommended by Conagua (2016), according to a temperate climate and because the study site is an urban area.

Habitants	Houses	Suburbs		Houses	Habitants
198	55	Tlacuihtlapa-El Ruedo	Lomas de Tarango	443	1,595
58	16	La milagrosa	Águilas Sección Hornos	76	303
155	10	Palmas Axotitla	San Clemente	1,900	7,384
163	14	Palmas Zotoltitla	Águilas 1° y 2° Parque	110	396
444	139	Tlacuitlapa	Ponciano Arriaga	401	1,445
3,1177	231	Belém de las Flores	Arturo Martínez	399	1,435
635	199	Puerta Grande	U.H. Démet Bosques de Tarango	1,833	6,600
1,650	424	Lomas de Puerta Grande	Fueguinos Lomas de la Águilas	828	2,982
1,970	538	Herón Proal	Tlacuitlapa, Ampliación	1,172	4,219
1,782	495	Fraccionamiento Ex Hacienda de Tarango Cooperativa Poder Popular	Colinas de Tarango	1,239	4,262
7,310	2,031	Águilas 3° Parque	La Mexicana	2,496	8,986
7,724	2,146	Colinas del Sur	Lomas de Guadalupe Residencial Tarango	501	1,803

Table 3 Relationship of neighborhoods and inhabitants per house

CALCULATION OF Q_{MID} BY THE RESIDUAL DISCHARGE'S CONTRIBUTION

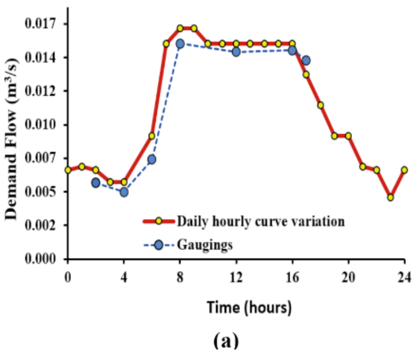
The Q_{mid} was obtained to know the contribution of domestic wastewater (water blacks) per day, along the stream, calculated by means of equation 5 in which the average flow was 0.110 m3/s and that using a contribution of 75% is obtains an average flow of 0.82 m^3/s

GAUGING'S OBTAINING

The gauging's were carried out by the wading method, in order to obtain the measurement of speeds, as well as the section geometry. It was used in sections where the current had depths less than 50 cm, with a fixed bottom and surface velocities less than 1 m/s, according to the recommendations of the equipment used.

WASTEWATER DISCHARGE HYDROGRAPH

This hydrograph considers the hourly variation of residual water that is contributed to the stream and its construction was carried out with the Conagua (2016) methodology; where the number of inhabitants of the site is considered, shown in Table 4, the water volume that is provided as drinking water and the percentage of water that is discharged as residual, all is based on an hourly variation typical of the Mexico City. Subsequently, this theoretical hydrograph is calibrated with seven gauging's carried out at different schedules and wastewater discharge sites located along the Puerta Grande River stream. Figure 13a shows the curve of the theoretical hourly hydrogram over 24 hours, with the line in red; as well as the gauging's carried out at blue points. Figure 13b shows the curve of the hourly hydrogram calibrated with the gauging's and that more accurately represents the residual water runoff (Enriquez et al.,1993)



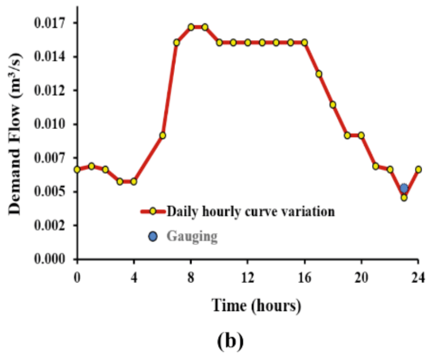


Figure 13. (a). Hydrograph based on the coefficient of variation and gauging at seven sites along the stream bed. (b). Hydrograph with gauging at the end of the stream.

CONCLUSIONS

Through the Thiessen polygons, the influence areas of neighboring stations were obtained based on those that have records from other years, since the reference station Tarango does not contain complete data for the study.

The pluvial precipitations with the probability distribution functions were determined, for this, three statistical models for the return times (Tr) were worked on: Normal Distribution, Gumbel Distribution and Log Normal Distribution, the latter was the that best approached to the historical curve of pluvial precipitations data and had the smallest statistical error, hence, it was used for the calculations of the maximum rainfall, as well as the curves of intensity, duration and frequency of rainfall related to Tr.

Once the above was calculated, rain storms hyetographs were generated for a duration of 60 min, which represent the accumulated precipitation that occurs at the site of interest every 5 min and is associated with different Tr.

Using the American Rational method, the rainwater runoff flow in the Tarango micro-basin was estimated with 83 m^3/s in a return period of 25 years.

It was important to know the wastewater contribution because in the dry season it is the only measurement factor for the proposal of one treatment system for water of the Rio Puerta Grande stream.

The determination of the residual water's runoff hydrograph in dry season is important in the stream, since it is these waters that are contaminating it, hence it will be important to treat them for its ecological value since they are located in an Environmental Value Zone, in addition to belong to one of the most important ravines in Mexico City.

The average flow rate calculated in the dry season was 82 L/s, which is the amount of water that would need to be treated; however, this was outdated with respect to the proposal in the CONAGUA, (2016), for which was necessary to adjust the hydrogram obtained to a concentration time of one hour, since the sanitary discharge peak occurred at 10 am, with 0.015 m3/s of spending while the decline occurred at 5 pm with 0.006 m^3/s of spending.

The field measurements difference with respect to the hourly curve at the end of the channel was minimal, since a 4.5% standard deviation was obtained.

The hourly curve of the hydrograph in figure 6a obtained with respect to the gauging measurements in the field was very close to the curve obtained at some points

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