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Flooding in high risk zones in the Metropolitan Area of Guadalajara, a paradigm shifts to watershed management and urban disasters

Inundaciones en zonas de alto riesgo en el Área Metropolitana de Guadalajara, un cambio de paradigma al manejo de cuencas y los desastres urbanos

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Abstract

Guadalajara, the second largest city in Mexico, has experienced accelerated urban growth since the year 2000, which has led to a change in land use and a decrease in recharge to aquifers, resulting in a considerable increase in points vulnerable to flooding. The positive and negative effects are two sides of the same coin, on the one hand, the proclaim excessive policies that seek to privatize water resources, and the other, to provide water to concessionaries in an excessive manner. The paradigm shift seen from the perspective of watershed management is precisely to solve environmental problems and associate them with urban hydrology projects, hydraulic infrastructure or a combination of these, with the aim of not modifying water courses and streams. The objective of this work is to determine peak flows for return period of 50 to 100 years, by means of probabilistic and statistical models and to identify through topographic cartography the annual periodic floods in the lower part of the basin, as results is to present a series of alternatives of solution through hydraulic works: channel rectification, silt removal works, to mention just a few.

Floods, Watershed management, Urban hydrology

Resumen

Guadalajara la segunda ciudad más importe de México ha experimentado un acelerado crecimiento urbano a partir del año 2000, esto ha propiciado un cambio de uso de suelo, además de disminución de recargas a los mantos acuíferos, como consecuencia un aumento considerable de puntos vulnerables a inundaciones. Los efectos positivos y negativos son cara de la misma moneda, por un lado, pregonan políticas desmedidas de pretender privatizar el recurso hídrico y por el otro dotar agua desmedidamente a concesionarios. El cambio de paradigma visto desde el manejo de cuencas es precisamente resolver problemas ambientales y asociarlos con proyectos de hidrología urbana, infraestructura hidráulica o una combinación de estas, con el objeto de que no sean modificados los cauces y arroyos. El objetivo este trabajo es determinar gastos picos para periodos de retorno de 50 a 100 años, mediante modelos probabilísticos y estadísticos e identificar por medio de cartografía topográfica las inundaciones periódicas anuales en la parte baja de la cuenca, como conclusiones es presentar una serie de alternativas de solución a través de obras hidráulicas: rectificación de cauces, obras de desazolve, por citar solo algunas.

Inundaciones, Manejo de cuencas, Hidrología urbana

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Introduction

The Covid 19 pandemic that broke out worldwide at the beginning of the year 2000, as well as the earthquakes that occurred during the week of September 19-23, 2022, put to the test the resilience of societies and governments that are failing not only in terms of public health in the face of health emergencies and natural disasters, but also in terms of Integrated Water Management. The deficit in water supply, deficiencies in water quality and overexploitation of aquifers, contamination of streams and the Santiago River, but above all flooding in a large part of the city, are some of the problems that directly affect the Guadalajara Metropolitan Area (Gleason, 2022). Of course, urban growth is the real cause and consequence of flooding, in other words, all the public policies implemented by the authorities have not helped much, since the real problem lies in the lack of connection of the collectors (Mexican Institute of Water Technology, 2021).

Highest risk areas in the city

The points of greatest vulnerability to flooding are all the overpasses, as well as the avenues: Lopez Mateos, Mexico, Calzada Independencia, low areas such as Expo Guadalajara, Plaza del Sol, the Osorio basin (Solidarity Park), Plaza Patria, which hydraulically is like a stopper, since it crosses the rainwater channel of the same name. In Tlajomulco de Zúñiga, the canals coming from Santa Anita and San José del Tajo, the Las Pintas canal, La Colorada stream, Chulavista, Unión del Cuatro, Adolf Horn Avenue, to name just a few, in short, the municipality of Tlajomulco is a vulnerable city because urban behavior is linked to the perverse interests of real estate developers (Hernández García and Colmenares López, 2020).

The anarchic and disorderly growth has caused an atomized distribution of urban settlements and as a consequence a limited connectivity of functional spaces and scarce urban integration of the city, which reinforces the existence of segregated geographic spaces that mark the exclusion in the municipality (Caro *et al*, 2022), especially in the southeastern portion in the urban settlements on the Chapala highway and the Miguel Hidalgo international airport (Caro *et al*, 2022).

Figure 1 Vulnerable points to flooding in the southeastern portion of the MGA
Source: Watershed Water Flow Simulator, 2022.

At least 350 vulnerable points have been identified as areas susceptible to flooding, these are located in marginalized neighborhoods such as Martinica, Indígena, Las Pintas, El Quince and Ferrocarril, as well as roads with high vehicular flow such as Federalismo, Revolución, López Mateos and Mariano Otero avenues, in addition to Calzada Independencia, to name just a few. The objective then is to determine peak flows for return periods of 50 to 100 years, based on probabilistic and statistical models such as rainfall-runoff and to identify by means of INEGI and SIATL topographic cartography the annual periodic floods that occur in the lower part of the Guadalajara Metropolitan Area (AMG).

Background

The hydraulic infrastructure that was inaugurated in 2010 in the AMG has demonstrated its insufficient capacity with the construction of the El Dean regulating basin, since there are records of flooding due to overflows of the expanded regulating basin, in addition to the rest of the collectors, although they have increased their retention capacity, they have eventually been exceeded.

On the other hand, the works built on Avenida Patria or the Atemajac stream did not mitigate the torrential effects of the overflows in these channels, for example, channel enlargement works have been palliative upstream, but in the downstream streams both collectors continue to mix.

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Accelerated urbanization in the vicinity of the Cerro del Cuatro hill

Water runoff in the aforementioned areas is increasing, as is the case of El Colli hill and El Bosque de la Primavera, which is growing at a disorderly pace due to the lack of a land use plan and an integrated watershed management planning model.

In the capital of Jalisco, a storm can mean a series of catastrophes in very short return periods; at least 500 points vulnerable to flooding have been identified in the urban watersheds that make up the 12 municipalities of the AMG (Valdivia, 2022).

The city of Guadalajara does not need such heavy rains to generate a flood; just a 15 mm rainfall during one hour is enough for flooding to occur; the causes and consequences are a change in land use due to the large extensions of impermeable surfaces, which reduce infiltration and consequently increase surface runoff (ibid).

Another variable, of course, is the growth that transforms and diverts the watercourses; these watercourses may disappear, become fragmented or lose their conduction capacity due to encroachment or construction in flood plains; another factor is the drainage and sewage systems, especially in the first part of the city, which have been outdated and obsolete, as they are more than 50 years old.

Figure 2 Hydrological system transformed and modified by the invasion of watercourses
Source: Valdivia, 2022

1. State of the art

Zero Impact Urbanization. The new paradigm

There are many ways to control the effects of waterproofing, just think of thousands of ways to carry out processes of retention-detention of rainwater, obviously these measures are valued from the technical aspect and go from a non-structural measure that is the correct planning of a system of evacuation of rainwater, to structural measures consisting of defense works, essential to mitigate and control the peak flows of the hydrograph that produces the transit of downstream floods.

However, in some places where long-lasting rainfall occurs, it is necessary to evaluate the volume of the specific design rainfall, in order to know if the hydraulic works decrease the peak flows of the hydrograph, and if these are exceeded, we will be having adverse consequences due to extreme hydrometeorological phenomena caused by the increase in temperature and rainfall intensities (Ponce, 2008).

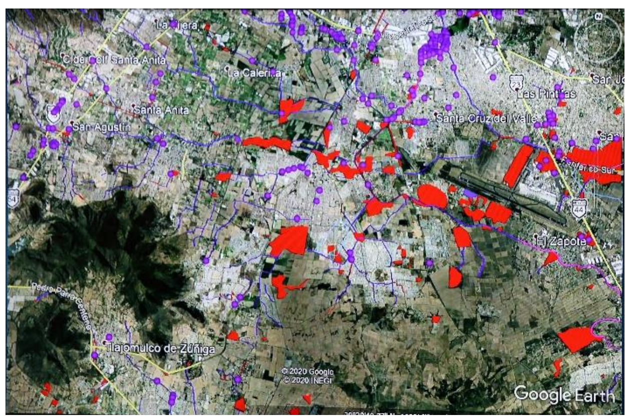

Figure 3 Santa Anita and its surroundings, the main focus of alert and flooding in the MGA
Source: Valdivia, 2022

Urbanization in high-risk areas is a phenomenon that has accelerated in recent decades in Latin America (it is predicted that in the coming years 90% of the population will be concentrated in medium-sized cities and metropolises), resulting in an accelerated and unrestrained exploitation of natural, fossil, energy and raw material resources, as well as large quantities of solid waste and consequently poor air quality due to high Greenhouse Gas (GHG) emissions, to name but a few (Bárcena, 2001).

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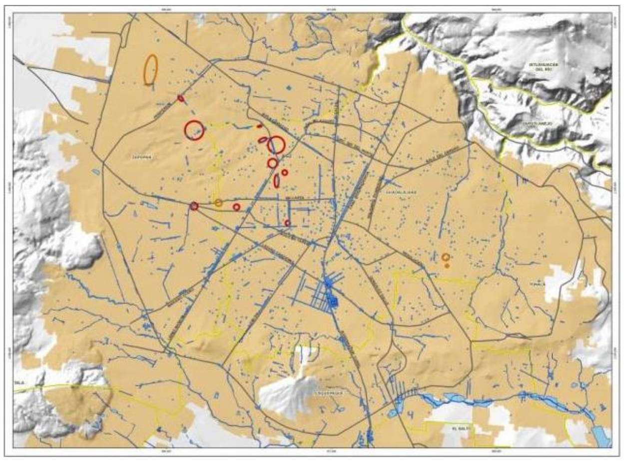

Figure 4 Identification of more than 350 points vulnerable to flooding
Source: Valdivia, 2018

The solution to the problem of periodic annual flooding in the AMG is a stormwater drainage system that integrally resolves the contributions of maximum floods due to the increase of peri-urban areas in the city (Dolz Ripollés, 1994), so that the drainage subsystems are part of the large hydrological subsystem of surface water.

It is important to clarify that the control of the maximum floods generated in the lower part of the AMG watershed must take into account all the interrelationships between rainfall intensities and their infiltration capacities, as well as the quality and quantity of runoff.

Effective planning for flood control must first study the watershed as a systemic unit, that is, a complete hydrological system that integrates a master plan for sustainable development through recharge areas to the aquifers, with the purpose of controlling surface runoff and reducing erosion as much as possible (Urías, 2017).

Most methods for calculating the design flood only consider the largest discharge of the maximum historical flood; however, when analyzing the operation of the overflow spillway, it is of utmost importance to have the hydrograph of the design flood, in other words, information on both its volume and the shape of the channel must be available (Vázquez, 1996).

On the other hand, it is essential to estimate and analyze events with a return period of up to 100 years, in order to design and have efficient hydraulic systems, such systems consist of pipes and sewers of commercial and economic diameters, as well as a system of collectors, canals and emitters both subway and above ground, this on the one hand because the lack of coordination in urban and territorial planning and the change from rural to urban land use forces many cities to undertake costly programs for flood control and mitigation of the effects of global climate change (Ramirez Hernandez, 2018).

All these contributions provide valuable information that allows projecting future scenarios, particularly on the threats that become floods in the lower part of the basin, however, such contributions lose sight of the historical and recent social processes involved in urban disasters (Duran, 2019).

Finally, it can be understood that it is urgent to take planning measures in the expansion and growth of the AMG that are linked to the climatological conditions of the basin, but above all that allow an orderly basin management in order to be able to solve or mitigate flooding problems without resorting to actions that only delay or aggravate the consequences.

Materials and methods

The study focuses on identifying areas susceptible to flooding, developing risk maps that allow estimating the probability of future damages and losses associated with the issue of urban disasters. This will be achieved by increasing resilience to adaptation to Global Climate Change, which make up the hydrological and urban system in the AMG, with a vision of improving the quality of life in the most vulnerable sectors of the city's population (CMM, 2013).

The estimation of peak runoff is too complex, due to the involvement of various factors such as: soil types, relief, vegetation cover, recharge areas, precipitation, dimensions of watercourses and streams. For these reasons, runoffs (surface and subsurface) should be analyzed by grouping different sections that have a common hydrological behavior.

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The rainfall-runoff model was used to determine the peak flow rate. This method consists of determining a base precipitation height, which is associated with a duration of 1 hour and a return period of 10 years. From this, the specific design precipitation height of the basin under study is determined, for which the precipitation is affected by 3 factors that are related to the duration of the storm, the area of the basin and the return period chosen to interpolate the data.

These factors were estimated after several analyses, the purpose of which was to establish a congruent relationship between the amount of rainwater and runoff volumes. Their values have been arranged in a practical range as shown in Table 1.

Duration of storm (hr)	Recommended factor	Basin area (km²)	Recommended factor	Return period (años)	Recommended factor
0.50	0.79	1.00	1.00	2	0.67
1.00	1.00	10.00	0.98	5	0.88
2.00	1.20	20.00	0.96	10	1.00
8.00	1.48	50.00	0.92	25	1.15
24.00	1.50	100.00	0.88	50	1.25

Table 1 Adjustment factors to determine the specific design rainfall
Source: Regional Management of Aguas del Valle de México

Precipitation analysis

In order to know the peak discharge of an extraordinary flood, it is necessary to analyze the climatological information of the study area, the most interesting being the maximum precipitation that has historical records. Precipitation is the primary source of runoff; therefore, knowledge of its values is fundamental in cases where there are no hydrometric stations or when there is insufficient quantity and quality.

The measurement of precipitation is a very relevant activity for the development of hydrological studies; such information is relevant for the determination of the amount of rainwater. Climatological stations are the fluctuating set of atmospheric conditions, characterized by the states and evolutions of the weather in a determined portion of space (Conagua, 2013), although some of these have instruments to measure other parameters, such as: humidity, wind, temperature, evaporation, to name just a few.

With the maximum precipitation data collected from the National Meteorological Service, the climatological stations to extract information are: Zapopan its coordinates are 103° 23'31" longitude and 20° 43' 13" latitude for the first one and San Pedro Tlaquepaque station are 103° 18' 38" longitude and 20° 38'18" latitude, both stations have influence in the AMG and have a data sample with 59 years of record from 1951-2010 (SMN, 2010).

The maximum rainfall occurs from July to October, the average total annual rainfall has values of approximately 983.6 mm for the Zapopan station and a value of 970 mm for the Tlaquepaque station.

The runoff coefficients in urbanized areas Cnu and urbanization index Iu were determined based on the experience of the studies conducted in the El Ahogado and Presa Osorio watersheds, determining conservative values of 0.15 and 0.80, respectively. Both values were obtained from the topographic charts Guadalajara East (F13D65 b and F13D65 f) Esc. 1:20000 and with observations made during field visits (INEGI, 2021).

Results and discussion

The results to be obtained are basically, as already mentioned, peak flows for return periods of 100 (before and after urbanization) under the Zero Hydrological Impact paradigm, which is to reduce the impacts caused by peak flows.

The main problem continues to be the poor management of rainwater during the rainy season; the combined drainage systems and infrastructure of existing dams and canals in the basin have been insufficient. This problem is caused by a poor integration policy, especially when land use changes are authorized and large extensions of protected natural areas begin to be urbanized.

The results obtained based on the rainfall-runoff model (Triangular Unit Hydrograph) for a return period from 2 to 100 years were as follows:

- Basin area, Ac = 48.75 km²
- Equivalent constant slope in the upper and lower parts of the Garabato and

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Seco creeks (Taylor-Schwarz method). S = 0.01229

- Length of main channel, lc = 11439.47 m
- Time of concentration (Kirpich's formula)
- Peak expenditures (before and after urbanization) for 100-year return periods (as shown in Figure 1).

$$tc = \left(\frac{lc}{\sqrt{Si}}\right)^{0.77} \qquad (1)$$

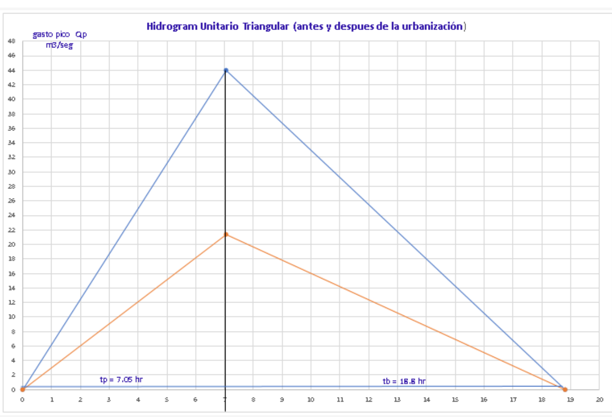
$$tc = \left(\frac{11439.7}{0.01229}\right)^{0.77} = 7.25\ hr$$

Elevation (msnm)	Segment length (m)	Pending segment	$\sqrt{Si}$	$\frac{li}{\sqrt{Si}}$
1800-1750	202.84	0.2465	0.4965	408.53
1750-1700	1622.74	0,0308	0.1755	9246.38
1700-1650	3637.91	0.0137	0.1170	31093.24
1650-1640	499.87	0.0200	0.1414	3535.14
1640-1630	764.22	0.0131	0.1145	6674.41
1630-1620	1211.21	0.0083	0.0911	13295.38
1620-1610	732.18	0.0137	0.117	6257.94
1610-1600	1267.29	0.0079	0.0889	14255.23
1600-1590	1501.2	0.0067	0.0819	18329.67
	11439.47			103095.92

Table 2 Slope for each segment in Garabato and Seco streams, to obtain the constant equivalent slope by the Taylor-Schwarz method
Source: Own Elaboration

$$S = \left(\frac{li}{\sqrt{Si}}\right)^{2} \qquad (2)$$

$$S = \left(\frac{11439.47}{103095.92}\right)^{2} = 0.0123$$



Graph 1 Triangular Unit Hydrograph (HUT) for the upper and lower watershed of the MGA
Source: *Own Elaboration*

Conclusions

Knowledge of the destructive effects of the transit of maximum floods along a channel allows us to take preventive measures in the event of overflows in channels and streams caused by high intensity storms.

This will provide the necessary elements to determine possible solutions to improve the hydrological behavior of the Garabato and Arroyo Seco streams, the latter of which captures most of the runoff upstream of the AMG watershed; these estimates were mainly peak costs for return periods of up to 100 years, affected by runoff coefficients in urbanized areas and vegetation cover.

The new settlements in the suburban periphery of the AMG have presented severe flooding, which in some places has accentuated the risks and disasters. To answer these questions, we must begin by understanding the natural process of the hydrological cycle and the hydrographic basins.

In summary, irreversible urban growth has modified the natural hydrological and hydrographic system of the El Garabato and Arroyo Seco streams. In addition, many of the new housing complexes, such as in the municipality of El Salto and Tlajomulco de Zúñiga, are being developed in areas that are totally vulnerable to flooding, since they are located in topographically flat areas, which increases the risk of flooding, hence the need to establish a paradigm shift in the management of watersheds and natural disasters.

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