



**Medio Ambiente**

Secretaría de Medio Ambiente y Recursos Naturales



**IMTA**

INSTITUTO MEXICANO  
DE TECNOLOGÍA DEL AGUA

# **One-Dimensional Modeling of a Rain Garden: Assessing Its Hydrological and Hydraulic Behavior**

M.I. Oscar Jesús Llaguno Guilberto  
M.I. Juan Manuel Figueroa Mendiola  
M.I. Jomaelah Morales Rayo  
M.I. Raúl Medina Mendoza



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October, 2025

# Problem statement



## Urban Population Growth Projections

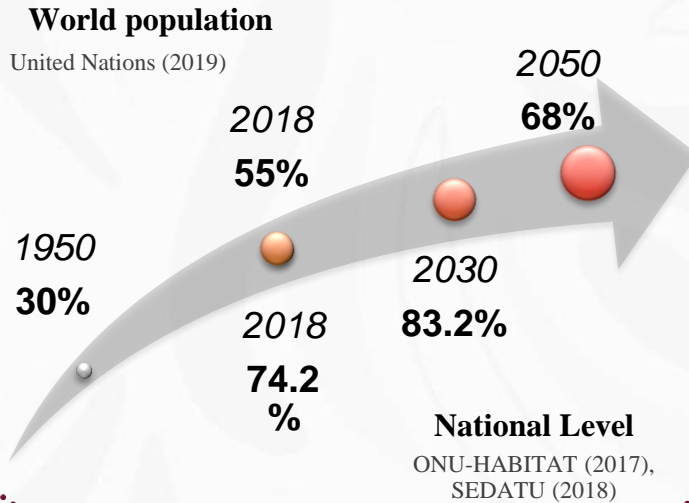


Figure 1. Pachuca, Hidalgo. ([www.visitmexico.com](http://www.visitmexico.com))



Figure 3. Urban Flooding in Chihuahua, Chih. ([www.notifamaestatal.blogspot.com](http://www.notifamaestatal.blogspot.com)).



Figure 2. Changes in Water Balance Resulting from Urbanization. Center of Watershed Protection (2013).

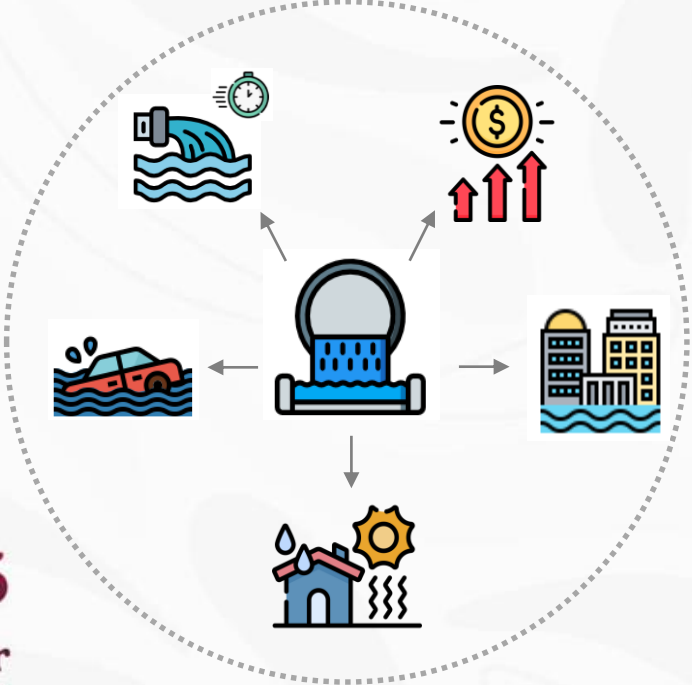


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## ¿Solution?

**Tradicional vs Innovative**

### Gray infrastructure



### Green infrastructure



VS



# What is Green Infrastructure?

It is a set of techniques for managing and treating stormwater, aimed at maintaining and restoring natural hydrology by preserving infiltration, evapotranspiration, and pre-urbanization runoff flows (Center for Watershed Protection, 2015).

## Benefits



## Drawbacks



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# How efficient is this green infrastructure?

Limited data hinders understanding of green infrastructure performance.



MANUAL PARA LA GESTIÓN DE LA INFRAESTRUCTURA VERDE EN LA CIUDAD DE LEÓN, GUANAJUATO



INFRAESTRUCTURA VERDE

SEPTIEMBRE 2020



# Case study

Efforts are underway to find a solution...

The evaluation of a rain garden at the IMTA facilities was carried out, specifically adjacent to the construction of an experimental wetland near the Hydrometeorology building.

Technique IV was selected for this area due to the substantial runoff generated during heavy rainfall.

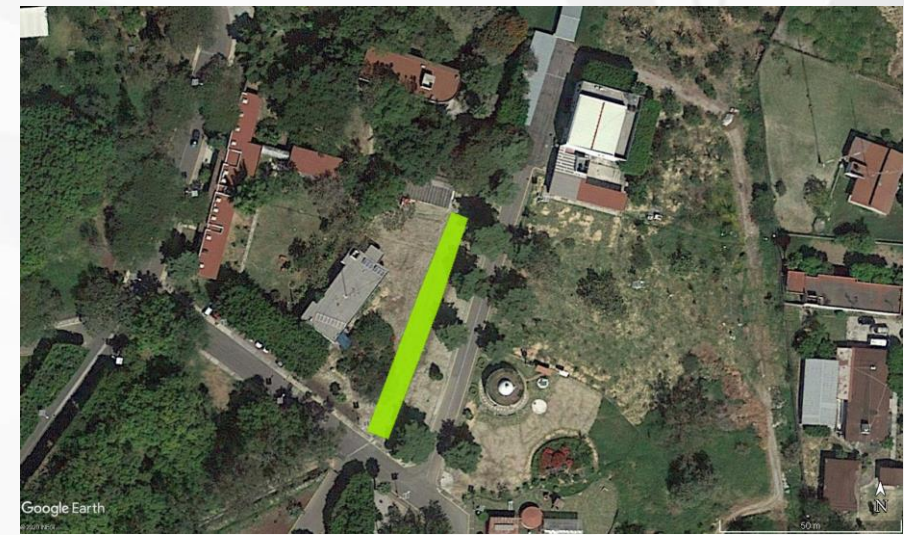
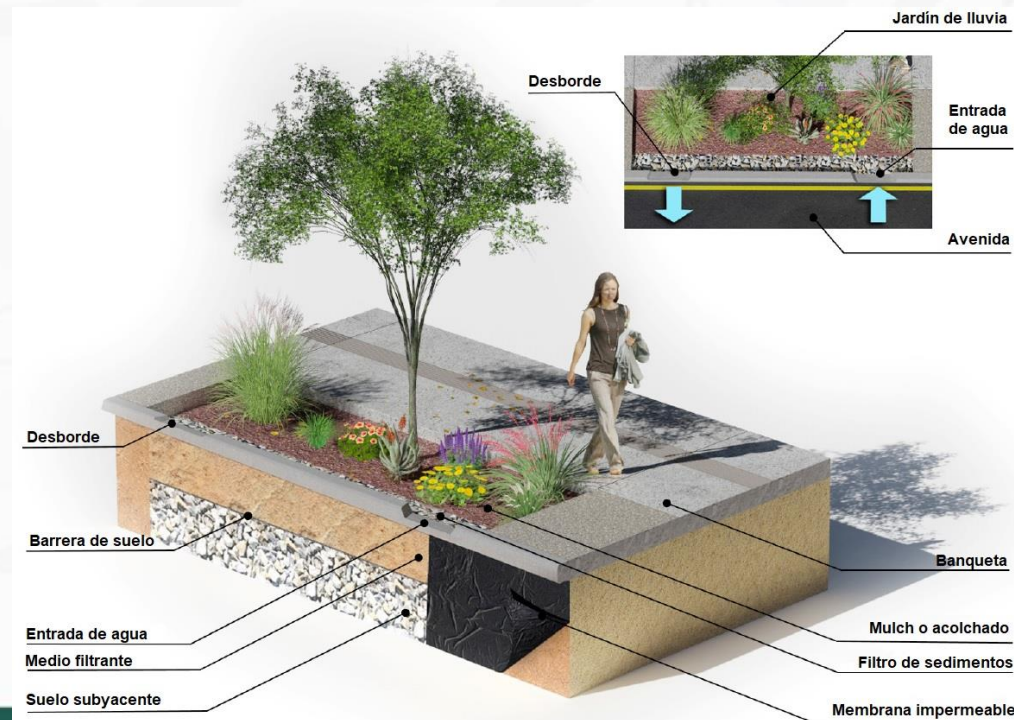


Figure 10. Rain garden location at IMTA facilities

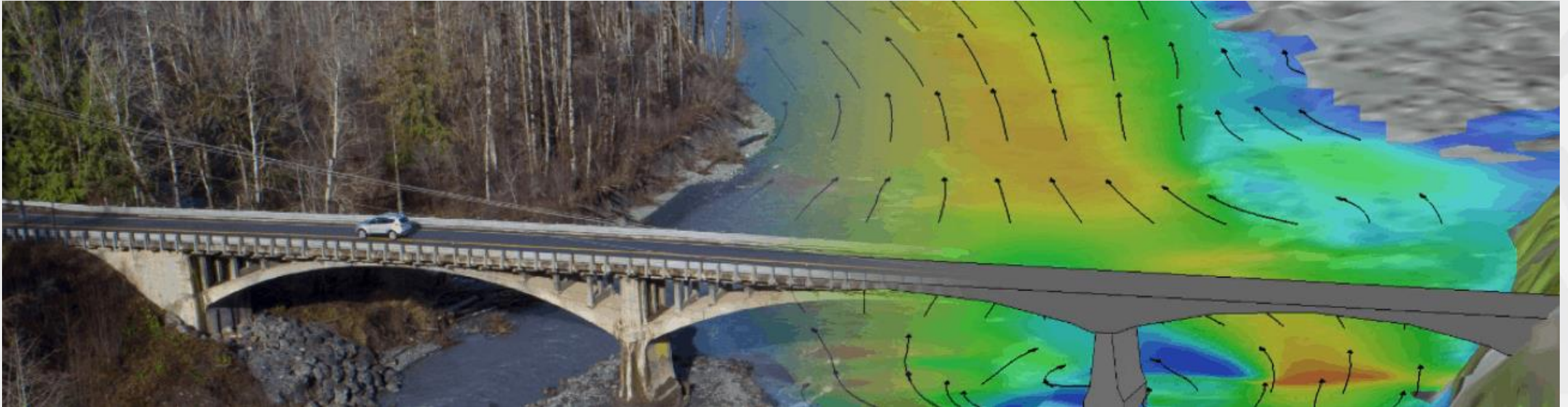


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Figura 11. Elementos de un jardín  
de lluvia. Adaptado de: IMPLAN  
(2017).

## Simulation models



Physical or computational models that simulate water behavior in rivers, reservoirs, and canals.



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# Simulation models



## 1D Modeling

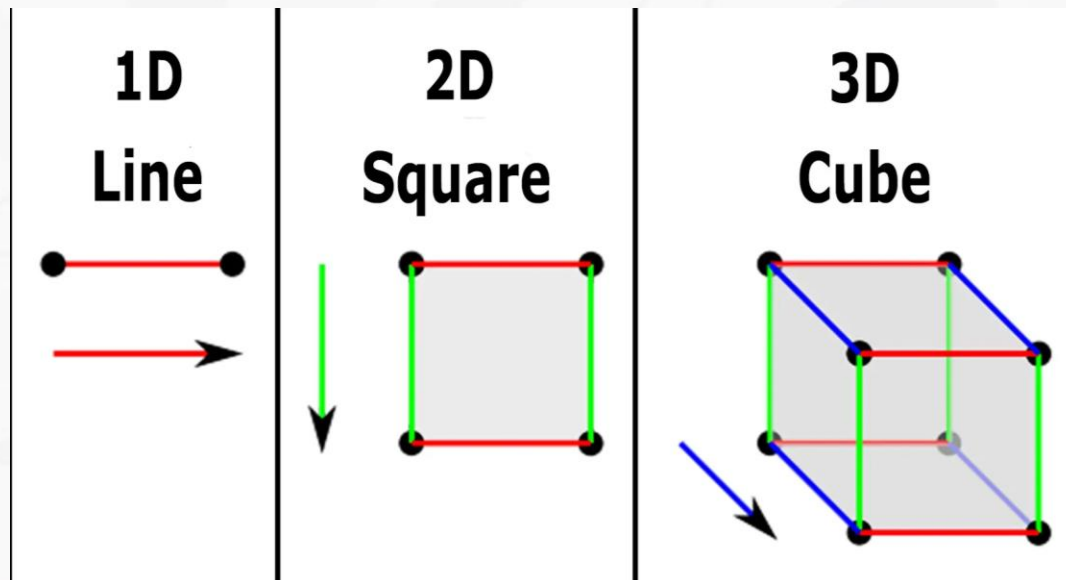
- Represents water flow in a single direction, such as in a canal or river.
- Flow occurs along a single plane, like a vector.

## 2D Modeling

- Represents water flow over an area or floodplain, incorporating movement in multiple directions.
- Flow occurs along both the x and y axes, like a matrix.

## 3D Modeling

- Represents objects with depth (z-axis), reflecting how we perceive reality.
- It allows simulation of three-dimensional flow, sediment transport, and temporal variations.



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# Solución

## Efforts are underway to find a solution...

The evaluation of a rain garden at the IMTA facilities was carried out, specifically adjacent to the construction of an experimental wetland near the Hydrometeorology building.

In terms of hydrology, rain gardens reduce runoff in the areas where they are implemented by promoting infiltration, evapotranspiration, and increasing the surface Manning's roughness coefficient.

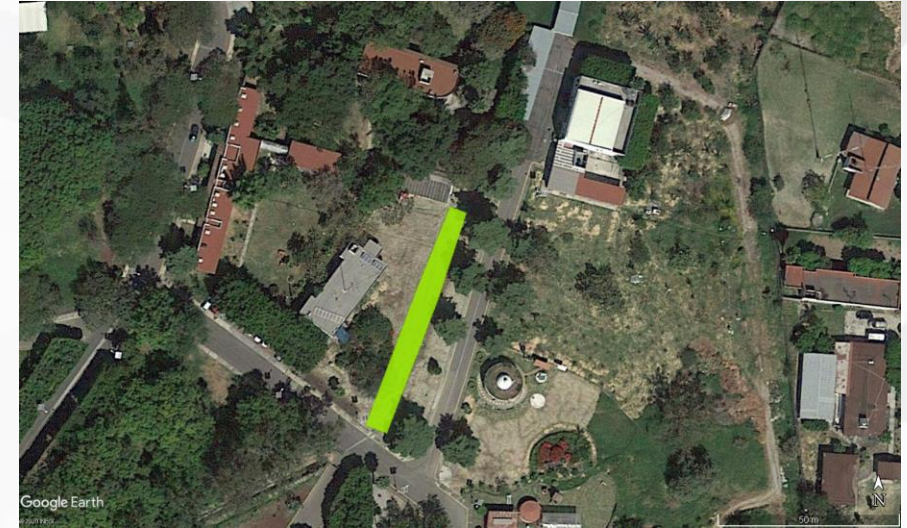


Figure 4. Rain garden location at IMTA facilities

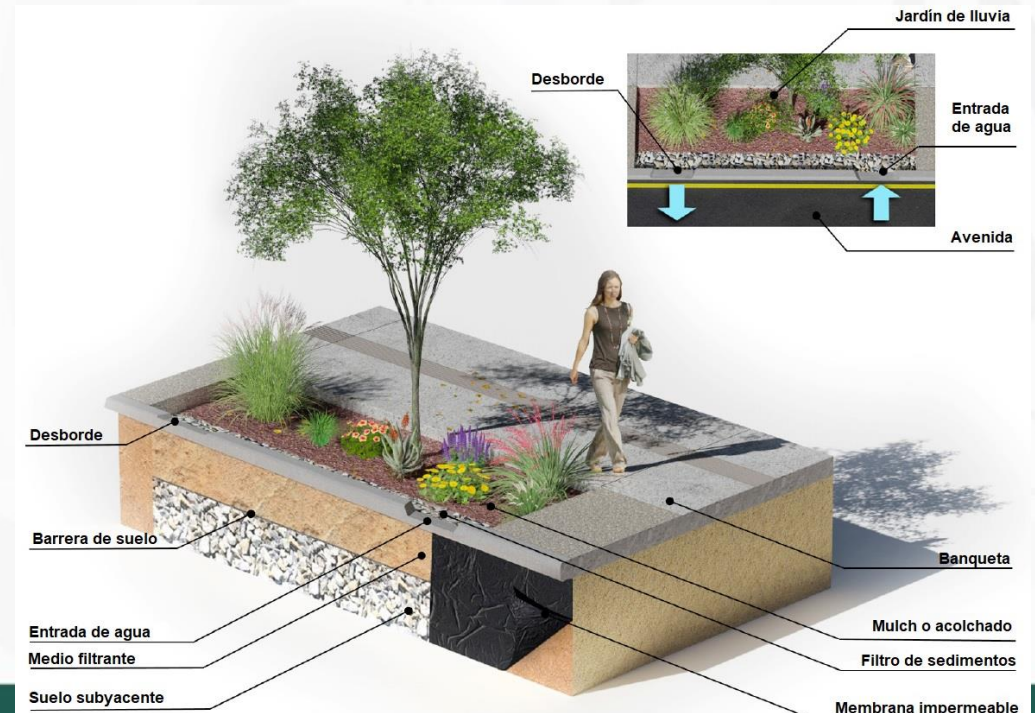
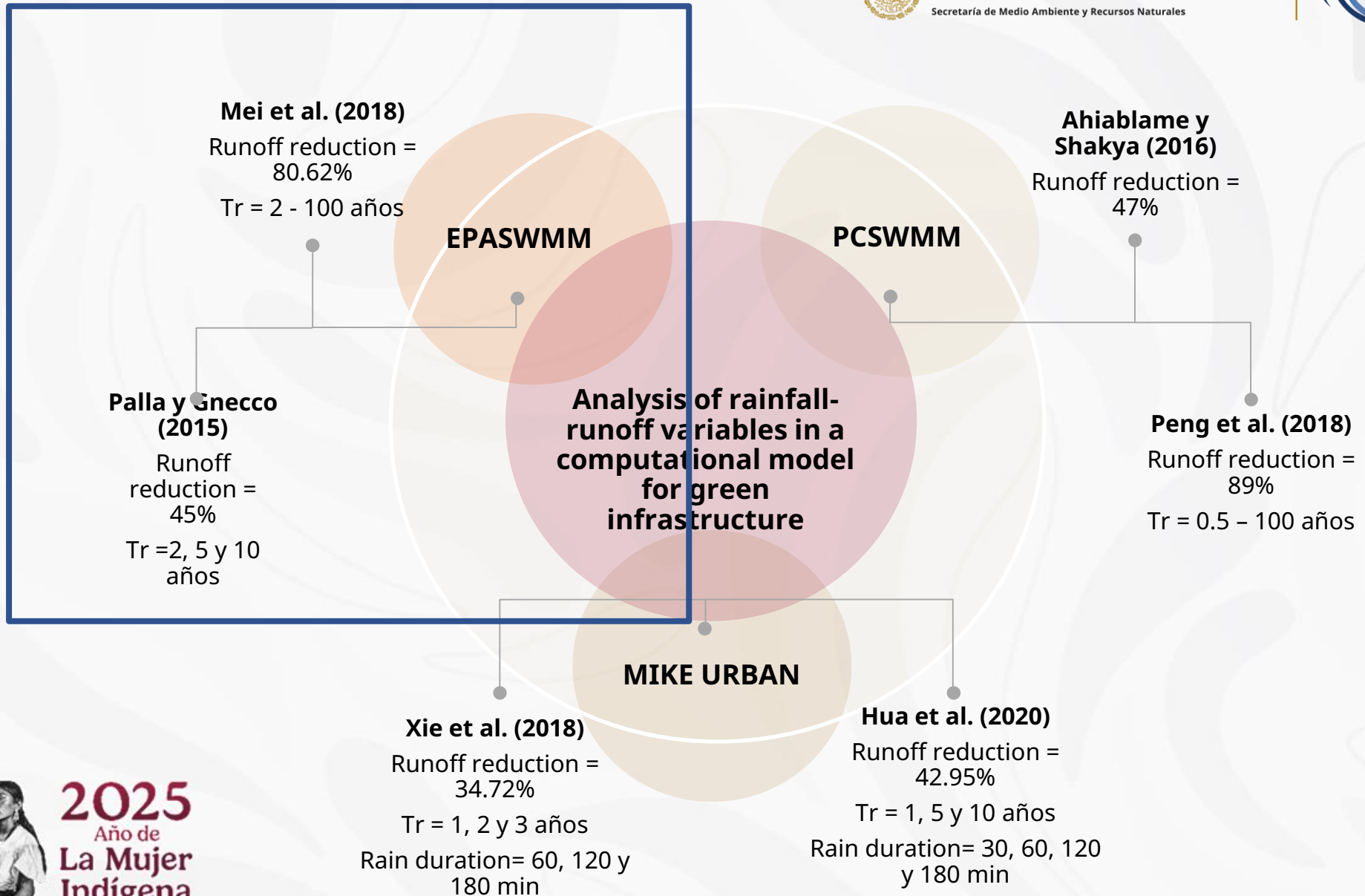


Figure 5. Elements of a rain garden.. Adaptaed: IMPLAN (2017).



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# Modelo 1D



# 1D Model SWMM

LID controls are practices designed to capture surface runoff while providing a combination of detention, infiltration, and evapotranspiration.



Tipos de LIDS en SWMM. Fuente: Manual, SWMM.

# Rain garden design

## Preliminary Studies



Land Configuration  
(Topography)

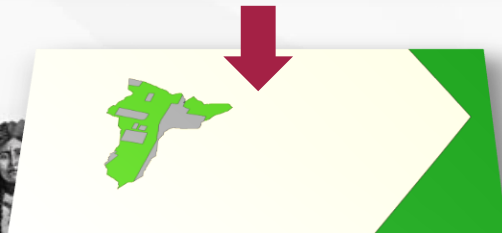


Watershed Delimitation

Area= 6451.30 m<sup>2</sup>



Geomorphological Parameters



Land Use, Vegetation, and Soil  
(Edaphology)

Hydrological Group (Type C Soil)



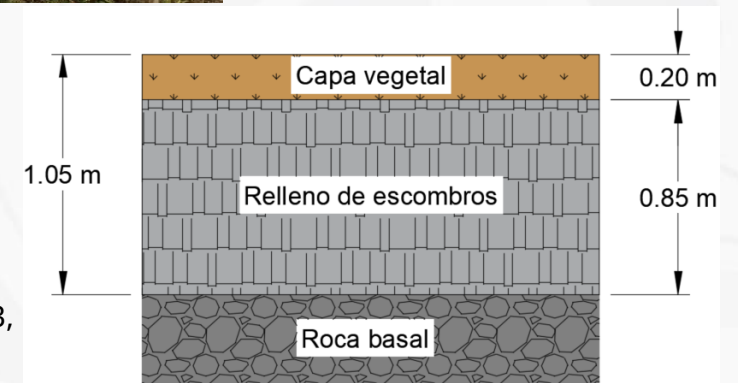
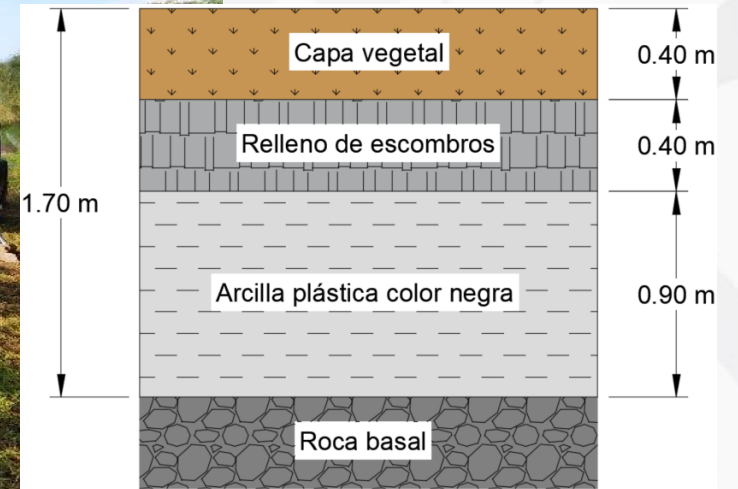
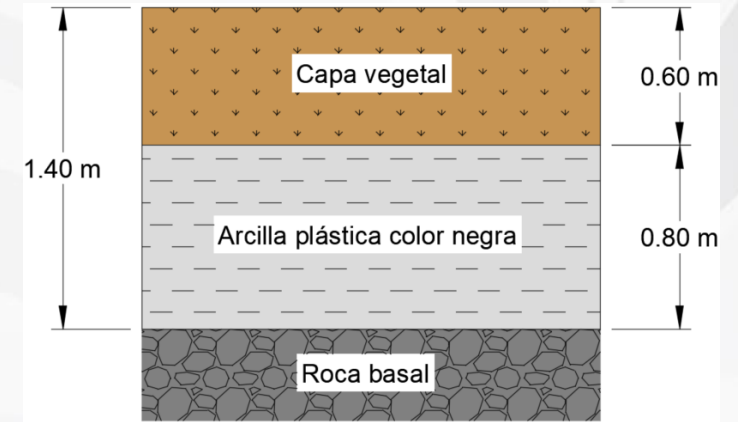
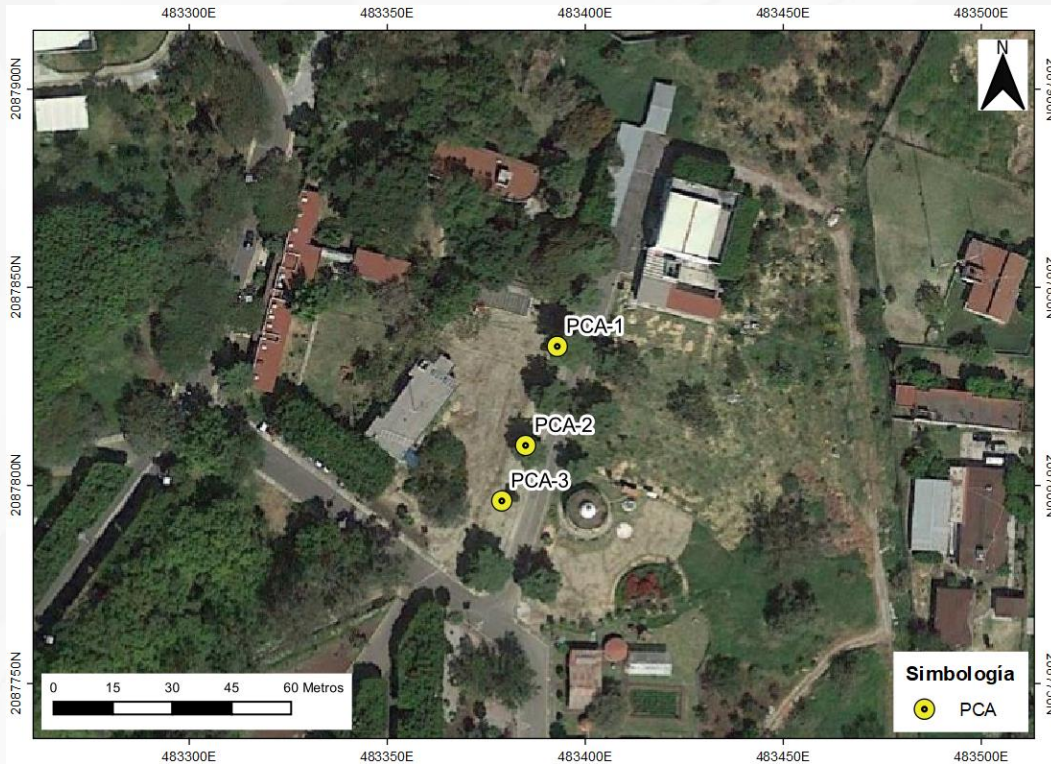
Delimitation of the Rain Garden  
Contribution Basin.



Indígena

# Rain garden design

## Geotechnical Study



Location of open-pit wells (PCA) used in the geotechnical study. Adapted from IMTA (2021a).

Stratigraphic profiles of PCA-1, PCA-2, and PCA-3, respectively. Adapted from IMTA (2021a).



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# Rain garden design

Area = 400 m<sup>2</sup>  
 Material Excavation: = 570.23 m<sup>3</sup>

## Subgrade Material Selection

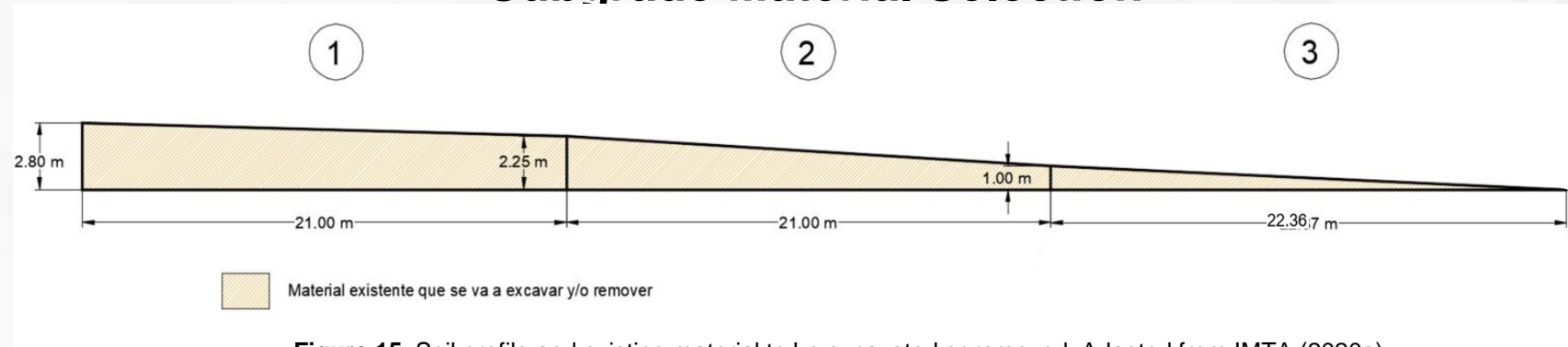


Figure 15. Soil profile and existing material to be excavated or removed. Adapted from IMTA (2020a).

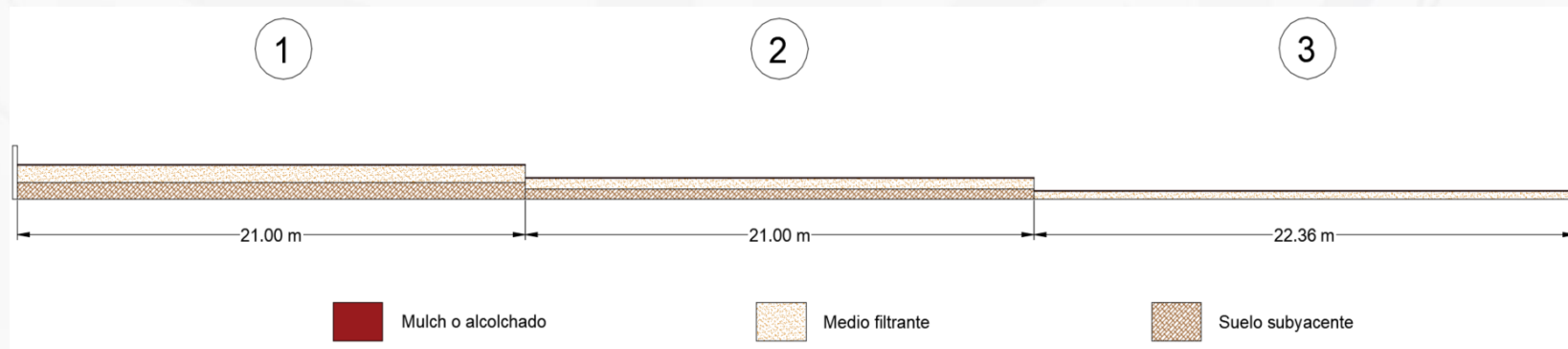


Figure 16. Soil profile showing different material layers. Adapted from IMTA (2020a).

Layer thicknesses and specifications. Adapted from IMTA (2020a).

Layer	Profundidad (m)			Specification
	1	2	3	
Mulch	0.05	0.05	0.05	Shredded hardwood
Filter Medium	0.65	0.40	0.30	Sand or silty sand
Underlying Soil	0.65	0.40	0.00	Hydrogeological soils (A or B)



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# Rain garden design

## Parámetros LID de SWMM

Tabla 2. Parámetros LID de SWMM para las unidades de IV.

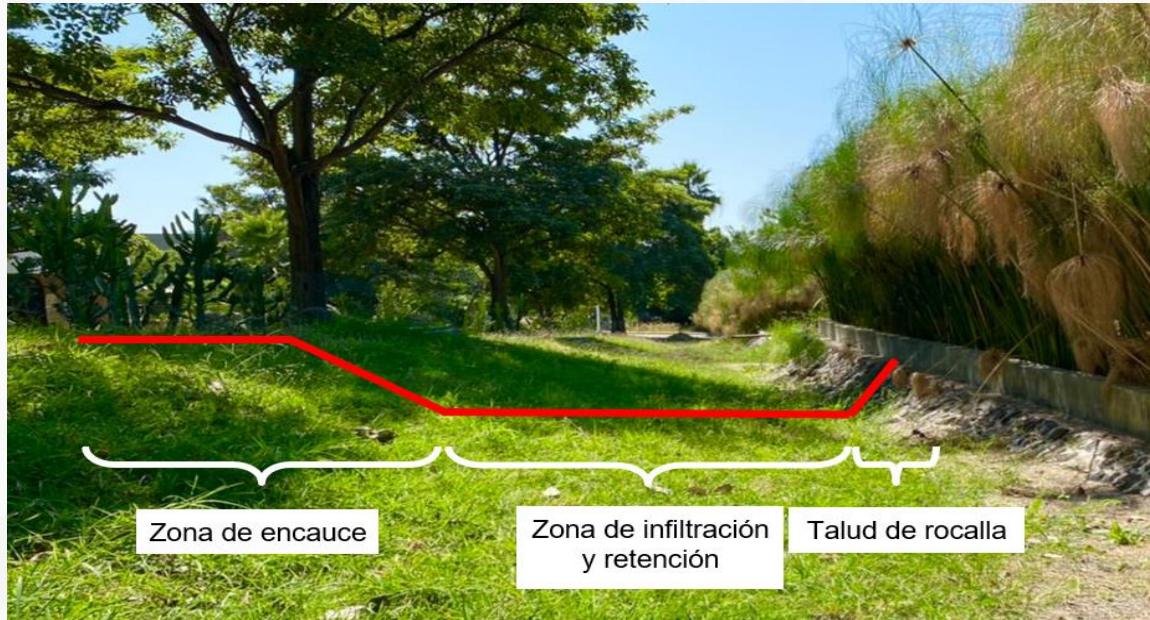
Capa	Parámetro	Parámetros de diseño			Unidades	Observaciones
		Escalón 1	Escalón 2	Escalón 3		
		Valor				
Surface	Berm height	304.8	304.8	304.8	mm	Profundidad máxima recomendada
	Vegetation volume fraction	0.1	0.1	0.1		Valor mínimo recomendado por Rossman (2015)
	Surface roughness	0.027	0.027	0.027		Chow et al. (1994)
	Surface slope	6.67	4.28	5.81	%	Obtenida del SIG
Soil	Thickness	600	400	200	mm	Capa vegetal
	Porosity	0.32	0.32	0.32		Promedio de la capa vegetal
	Field capacity	0.23	0.23	0.23		Ahiablame y Shakya (2016)
	Wilting point	0.1	0.1	0.1		Ahiablame y Shakya (2016)
	Conductivity	36	36	36	mm/hr	Promedio de la capa vegetal
	Conductivity slope	30	30	30		Valor por default
	Suction head	88.9	88.9	88.9	mm	Valor por default
Storage	Thickness	-	-	-	mm	No aplica
	Void ratio	-	-	-		No aplica
	Seepage rate	36	36	36	mm/hr	Valor por default
	Clogging	-	-	-		No aplica



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# Rain garden design

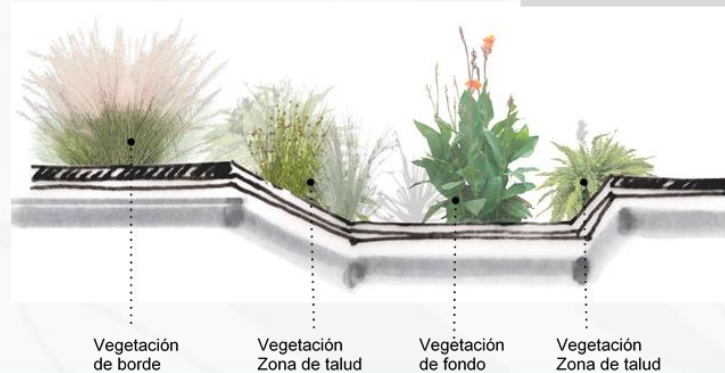
## Surface Design and Vegetation Selection



Rain garden areas: Viewed from upstream to downstream, starting at the highest part of the study area. Prepared by the authors.

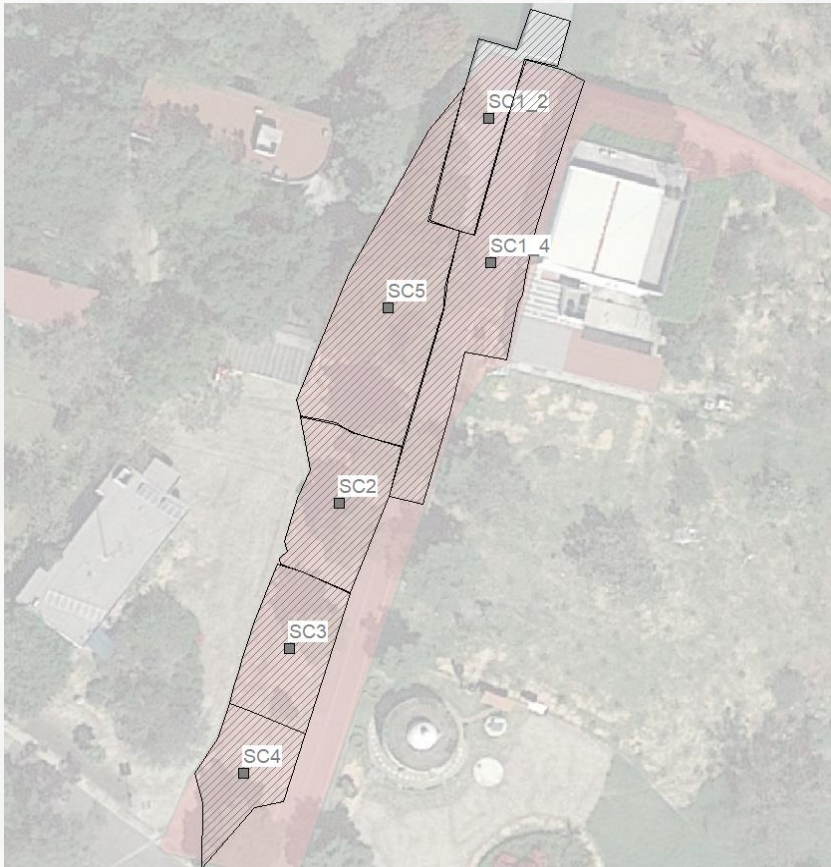
Vegetation characteristics, according to their location and function in the rain garden. Prepared by the authors based on IMTA (2021b).

Zone	Vegetation characteristics
Edge	Low resistance: Frames paths; primarily used in channel areas.
Slope	Moderate resistance: Frames slopes; primarily used in runoff areas.
Bottom	High resistance: Primarily used in infiltration areas.



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# Rain garden design



Types of LID Control in SWMM. Source: Manual, SWMM.

Design parameters for the 3 units (IMTA, 2021)

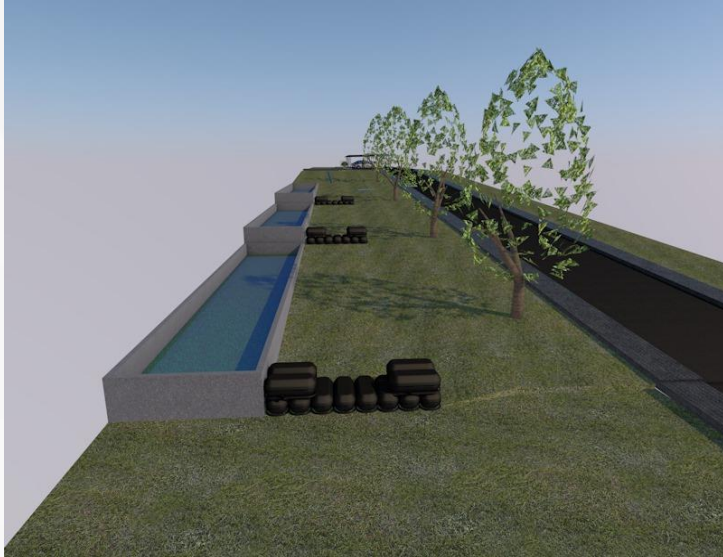
Name	Area (ha)	Width (m)	% Waterproof	Slope (%)
SC1_2	0.0193	10.56	99	2
SC1_4	0.04	13.94	36.52	2.29
SC2	0.03	32.31	21.32	7.21
SC3	0.015	35.42	18.21	7.92
SC4	0.02	14.57	5.97	11.17
SC5	0.05	13.05	16.52	7.1

**Contribution Area:** 1,743 m<sup>2</sup>, divided into 6 composite sub-basins.



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# Rain garden design



Front view of the spillways.



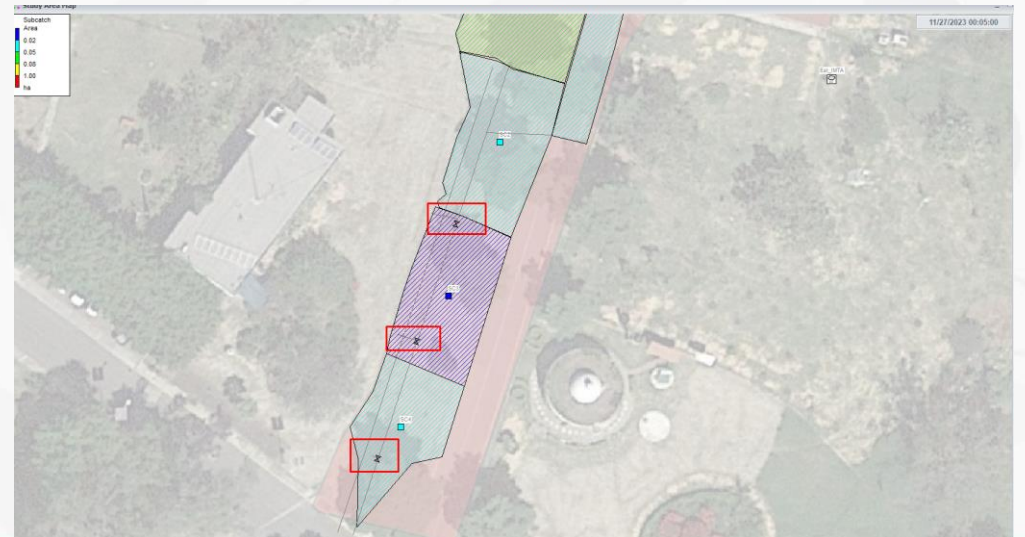
Geogrid Spillways

## Rain garden spillways



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Spillways in the SWMM Program



# Rain garden design

## Rainwater Harvesting System: Piping Design

### Caracterización del área de captación

#### Observación:

$$Q = C \cdot i \cdot A / 360$$

C= 0.95 Revisar Introducción a la Hidrología Urbana, Campos Aranda y norma NMX-AA-164-SCFI-2013  
i = 155 mm/h Isoyetas de la SCT

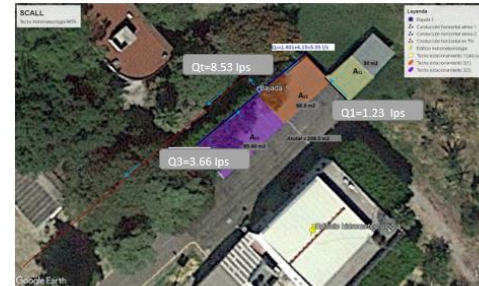
para 5min TR- 10 años (SCT)

Q1= 1.23  
Q2= 3.64  
Q3= 3.67  
8.54

### Distribución de las áreas tributarias del techo de captación

Áreas Tributarias y bajadas propuestas en campo									
N	Área tributaria (m2)	Área (m2)	Q (m3/s)	Q (l/s)	Conducción	Bajada	Q (l/s) por bajada	Diámetro mínimo (mm)	Diámetro mínimo (pulgadas)
1	1	30.00	0.001	1.23	Hacia At2	-	-	-	-
2	2	88.90	0.004	3.64	4.86	-	-	-	-
3	3	89.60	0.004	3.66	3.66	Bajada 1	8.53	100	4
			8.53						

### Distribución de las áreas tributarias consideradas en el proyecto



### Diseño hidráulico de conducciones para el SCALL

#### Distribución de los tramos de tuberías en el proyecto

#### Gasto acumulado por tramos de tubería de conducción

Tramo	Tipo	Bajada correspondiente	Q (lps)
Conducto 1	Aéreo	-	1.23
Conducto 2	Aéreo	Bajada 1	4.86
Conducto 3	Aéreo	-	8.53
Conducto 4	Terrestre	No aplica	8.53
Conducto 5	Terrestre	No aplica	8.53

#### Área horizontal

1.5.5.5

SE LA TUBERÍA

100 200 300

1010 2010 3010

4010 5010 6010

7010 8010 9010

10010 11010 12010

13010 14010 15010

16010 17010 18010

19010 20010 21010

22010 23010 24010

25010 26010 27010

28010 29010 30010

31010 32010 33010

34010 35010 36010

37010 38010 39010

40010 41010 42010

43010 44010 45010

46010 47010 48010

49010 50010 51010

52010 53010 54010

55010 56010 57010

58010 59010 60010

61010 62010 63010

64010 65010 66010

67010 68010 69010

70010 71010 72010

73010 74010 75010

76010 77010 78010

79010 80010 81010

82010 83010 84010

85010 86010 87010

88010 89010 90010

91010 92010 93010

94010 95010 96010

97010 98010 99010

100010 101010 102010

103010 104010 105010

106010 107010 108010

109010 110010 111010

112010 113010 114010

115010 116010 117010

118010 119010 120010

121010 122010 123010

124010 125010 126010

127010 128010 129010

130010 131010 132010

133010 134010 135010

136010 137010 138010

139010 140010 141010

### Cálculo del diámetro de los tramos de tubería - INSTALACIÓN PLUVIAL

Tramo	Tipo	Q (l/s)	Øv (cm)	Øv (pulg)	Øv propuesto (pulgadas)
Conducto 1	pvc	1.23	4.7	2	2
Conducto 2	pvc	3.64	-	-	-
Conducto 3	pvc	3.66	9.1	4	4
		7.30			

### Cálculo del diámetro del colector pluvial

Tramo	Tipo	Q (l/s)	Øh (cm)	Øh (pulg)	Øh propuesto	Área mojada (m2)	Perímetro mojado	Radio hidráulico	n (adimensional)	S (adimensional)	Q 100% (l/s)	V 100% (l/s)	d/D
Conducto 4	pvc	8.53	9.8	3.9	4	0.0079	0.3142	0.025	0.009	4	14.959	1.905	57%
			10.0										

### En resumen, se requiere:

- El conducto 1 un diámetro de 2 pulgadas (mínimo) y una longitud de 5 m
- El conducto 2 un diámetro de 4 pulgadas (mínimo) y una longitud de 12.7 m
- El conducto 3 un diámetro de 4 pulgadas (mínimo) y una longitud de 12.8 m
- Una bajada de un diámetro de 4 pulgadas y una longitud de 2.5 m
- Un registro a la bajada
- El conducto 4 un diámetro de 4 pulgadas (mínimo) y una longitud de 4 m
- Un registro en la esquina
- El conducto 5 un diámetro de 4 pulgadas (mínimo) y una longitud de 60 m.

### DATOS DE CAMPO

Conducto	Inicio	Fin	Longitud (m)	Diámetro (pulgadas)
H4	Registro	1 esquina	4.3	4
H5	1 esquina	inicio muro	22.3	4

## Downpipe Design

# Rain garden design



Gutters and Downspouts

## Collection system



4-inch conduit to rain garden



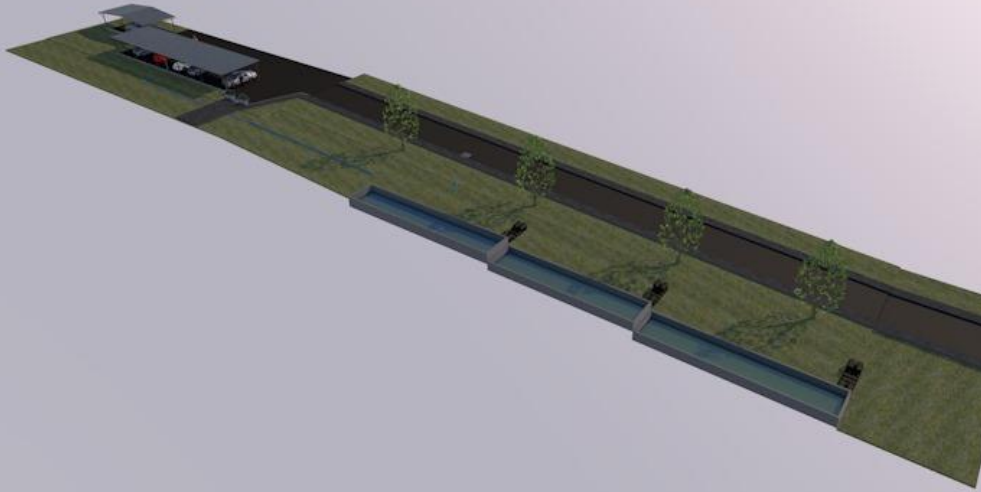
Grate and conduit to rain garden



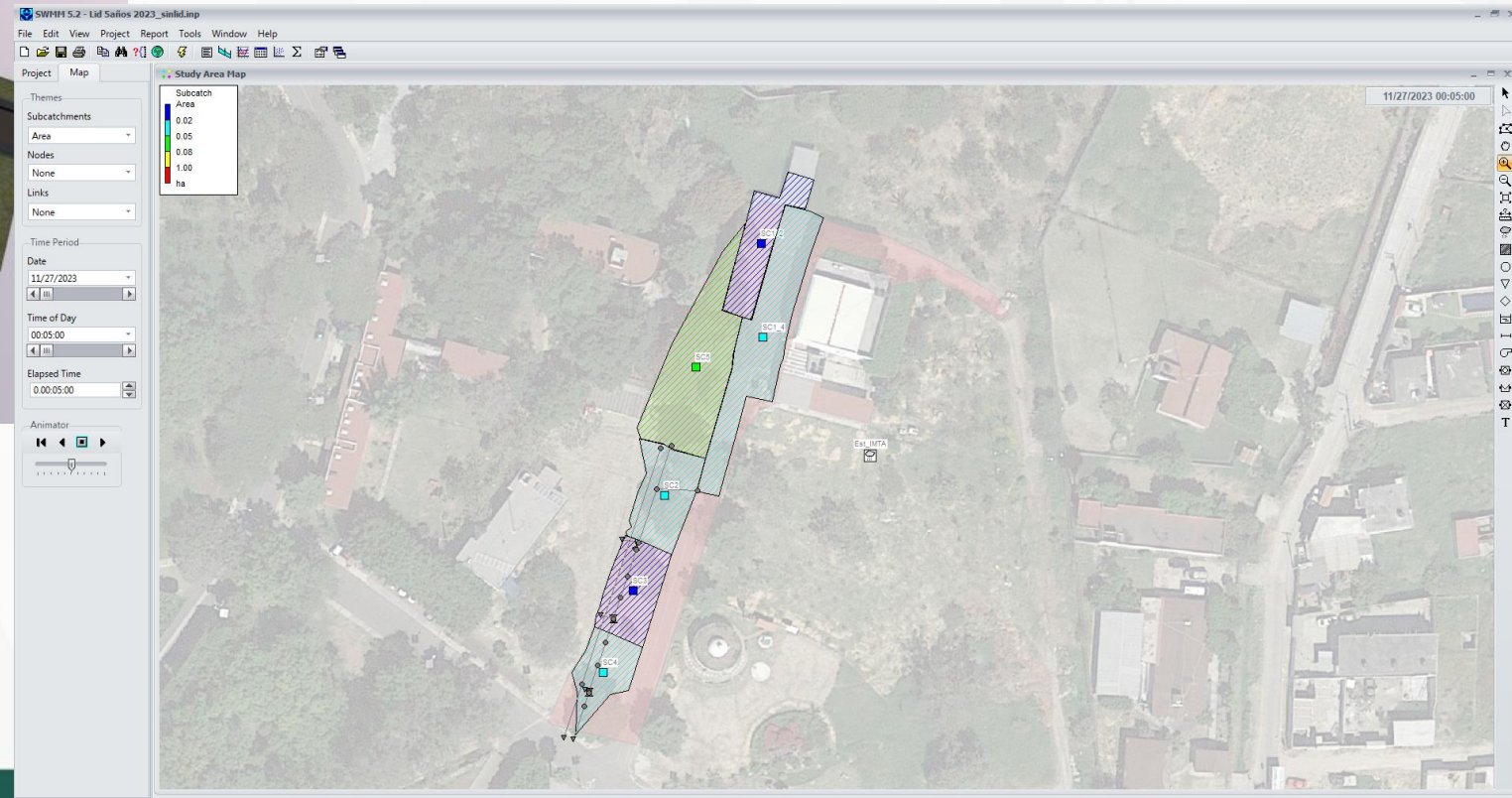
# Simulation Model

3 weirs, 1 rain gauge, 16 nodes, 2 outlets, 16 pipes, 3 LIDs, and 6 subbasins in the SWMM program

Rain garden design: Simulation model



Side view of the rain garden



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# Results

Hydrograph peaks decrease by approximately 50%–54% for the 2-, 5-, 10-, and 20-year return periods. For the 50-year return period, the reduction is around 40%.

Rain gardens are effective for infiltration and runoff retention.

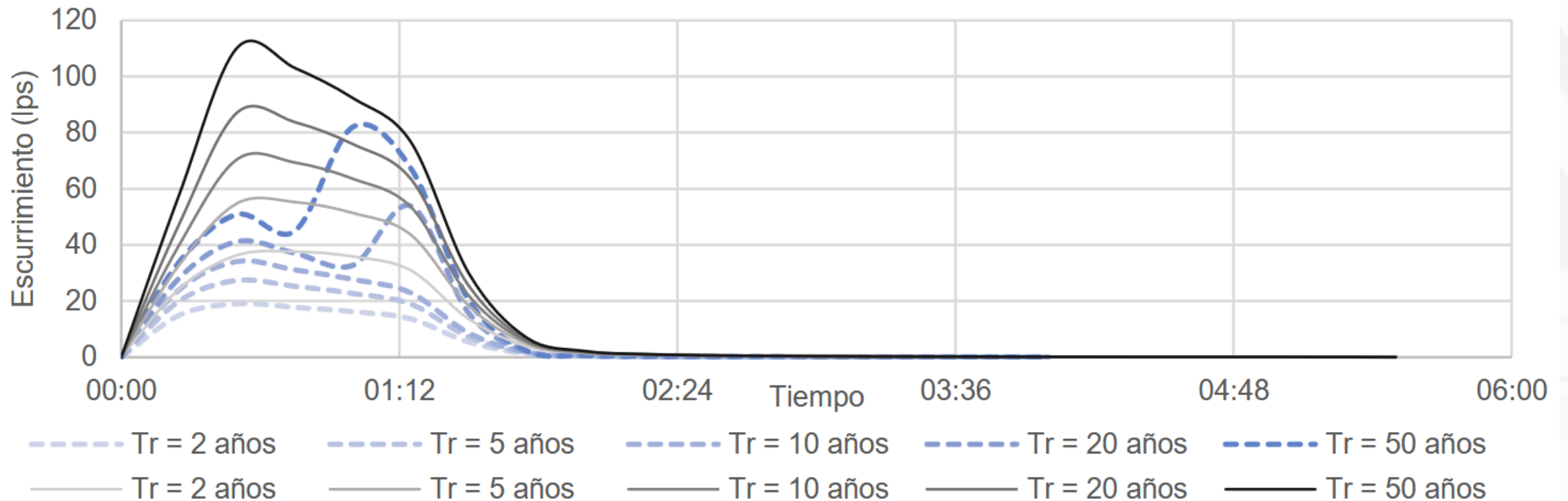
Runoff Hydrographs: Natural condition (solid lines) vs. Technique IV (dotted lines) for a 60-minute storm and various return periods.



# Results

The figure shows that runoff fluctuations occur for the 20- and 50-year return periods. This is because the rain garden becomes saturated within the first 45–60 minutes, after which water retention ceases, allowing runoff to pass through and creating secondary peak flows that decrease as rainfall subsides.

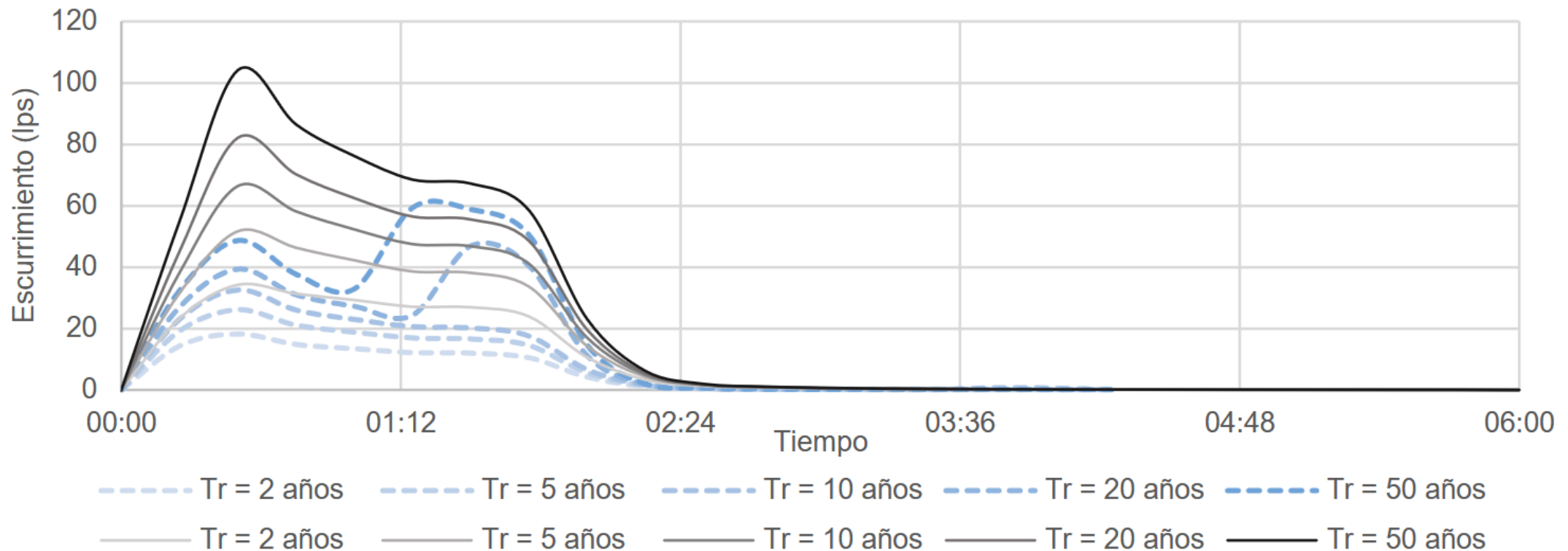
Runoff Hydrographs: Natural condition (solid lines) vs. Technique IV (dotted lines) for a 90-minute storm across various return periods.



# Results

For the 2-, 5-, and 10-year return periods, runoff decreases steadily. For the 20- and 50-year return periods, fluctuations occur, indicating that the rain garden cannot retain the larger runoff volumes, consistent with previous simulations.

Runoff Hydrographs: Natural condition (solid lines) vs. Technique IV (dotted lines) for a 120-minute storm across various return periods.



# Results

Research confirms that VI techniques are recognized as sustainable and easy-to-implement measures. They are cost-effective and show promise for urban stormwater management by effectively controlling runoff volumes and mitigating flood damage.

The literature indicates that factors influencing the design and construction of VI systems vary according to regional climatic conditions, as each system must be tailored to the desired runoff retention volume.

These findings support previous analyses using computer models for runoff reduction.

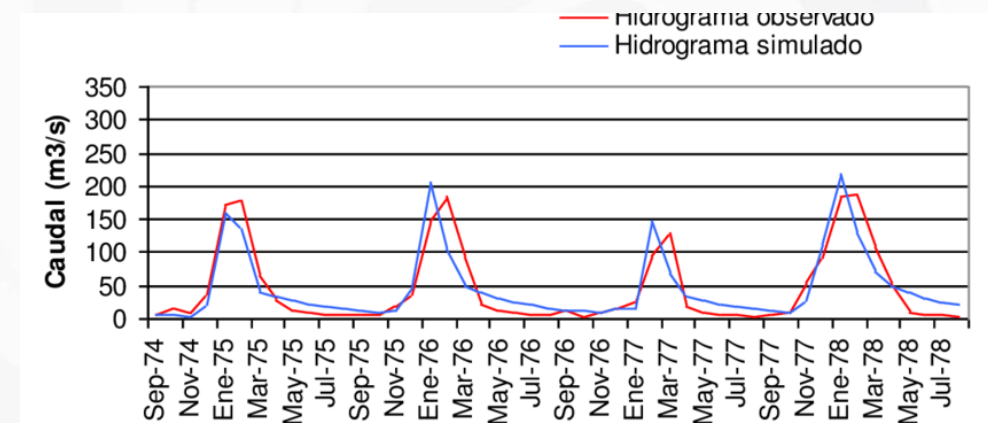
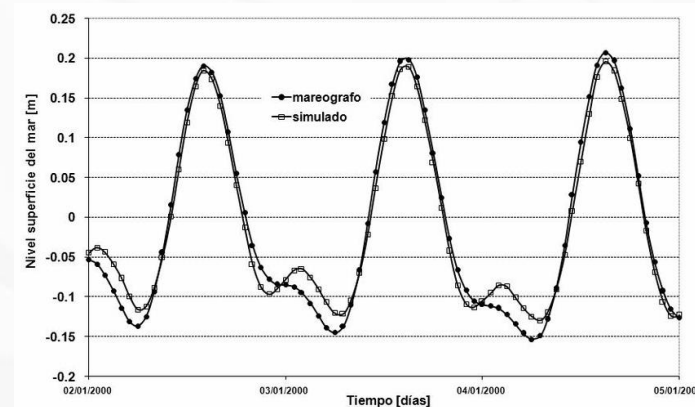
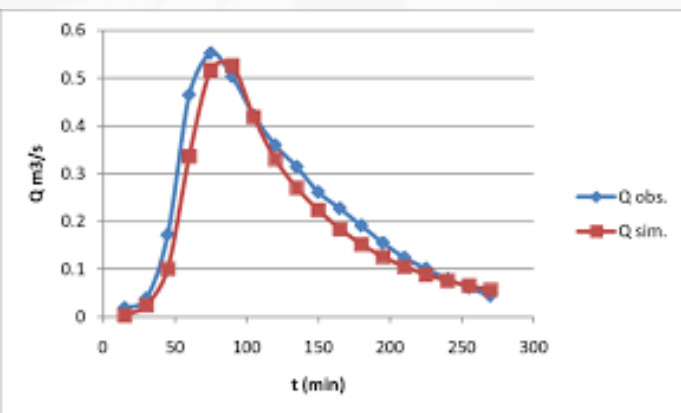


# How to Validate Data?

## Calibration.

Model calibration is the process of adjusting model parameters to match observed data, ensuring that the model accurately represents the system or phenomenon it simulates.

- Compare simulation outputs with measured system values.
- Adjust model parameters, inputs, and assumptions.
- Use optimization algorithms to improve accuracy.

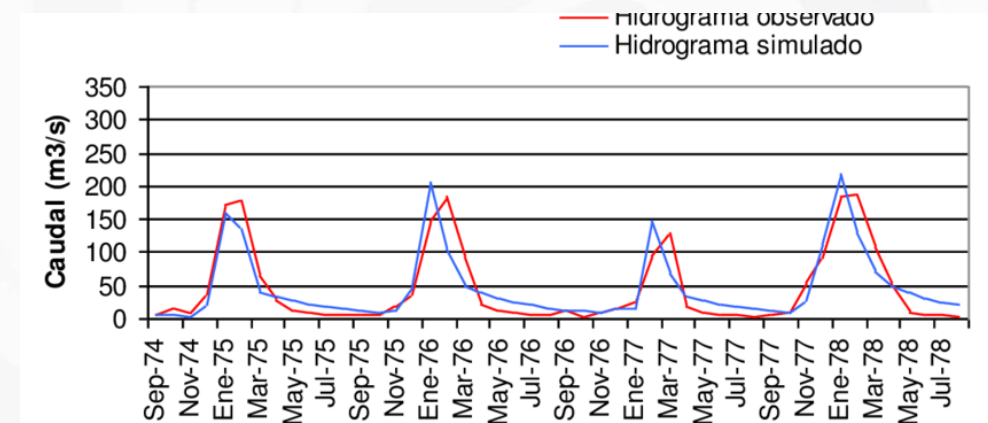
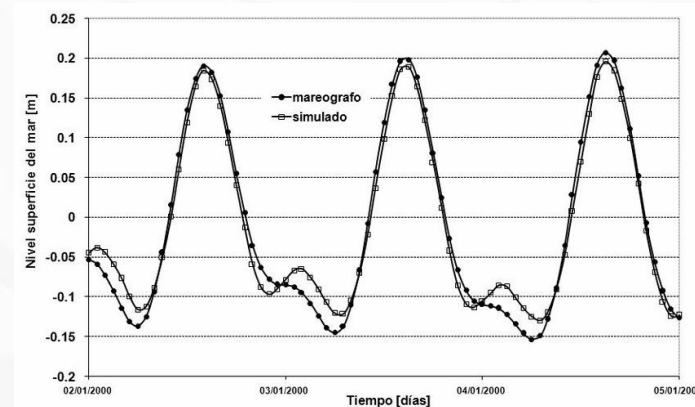
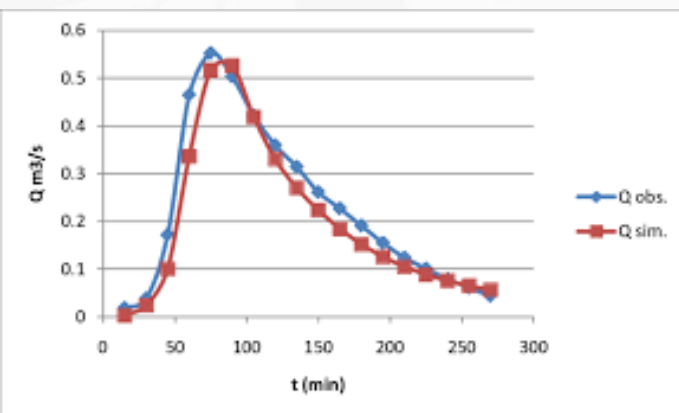


# Calibration and parameter tuning

Calibration.

Calibration is the process of adjusting model parameters to match observed data, ensuring that the model accurately represents the system or phenomenon being simulated.

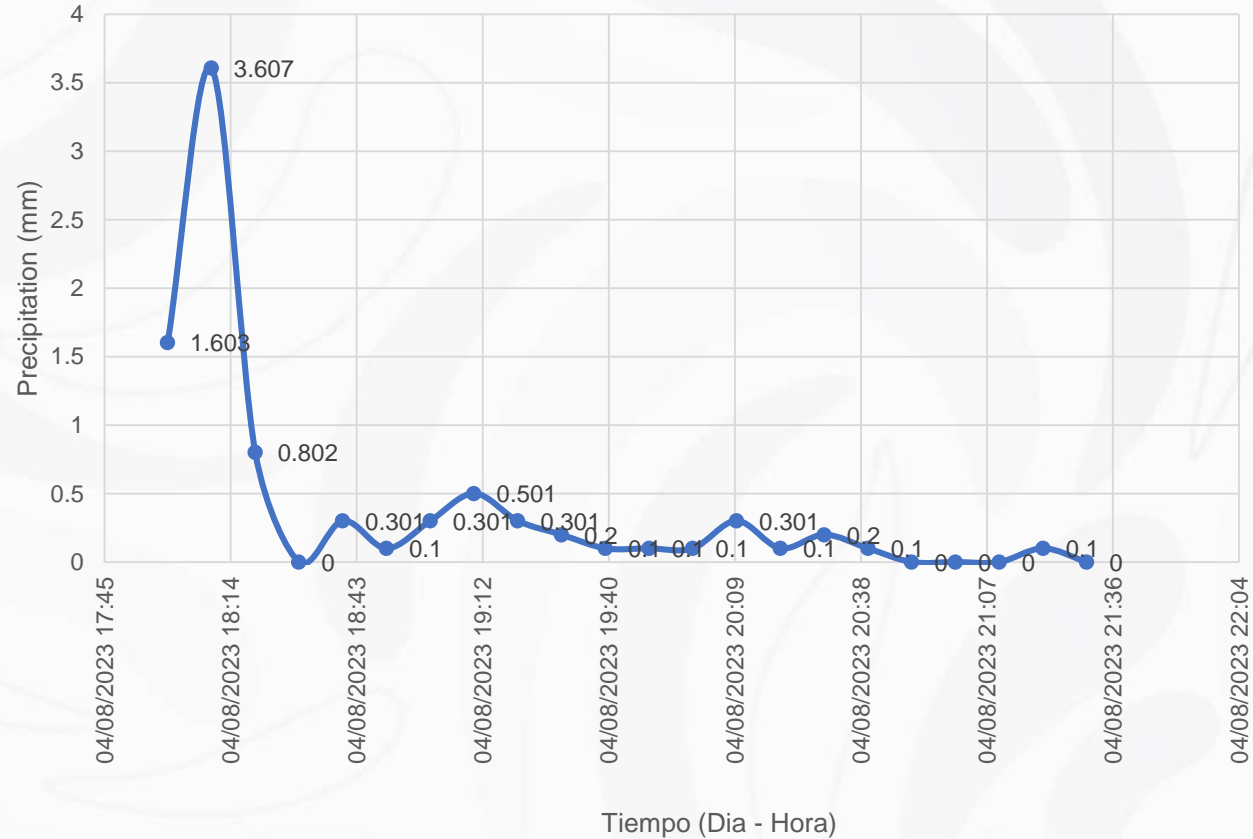
- Compare simulation outputs with measured system values.
- Adjust model parameters, inputs, and assumptions.
- Apply optimization algorithms to improve accuracy.



# Calibration and parameter tuning

Design Parameters for the 3 Units (IMTA, 2021)

Fecha	Precipitación (mm)
04/08/2023 18:00	1.603
04/08/2023 18:10	3.607
04/08/2023 18:20	0.802
04/08/2023 18:30	0
04/08/2023 18:40	0.301
04/08/2023 18:50	0.1
04/08/2023 19:00	0.301
04/08/2023 19:10	0.501
04/08/2023 19:20	0.301
04/08/2023 19:30	0.2
04/08/2023 19:40	0.1
04/08/2023 19:50	0.1
04/08/2023 20:00	0.1
04/08/2023 20:10	0.301
04/08/2023 20:20	0.1
04/08/2023 20:30	0.2
04/08/2023 20:40	0.1
04/08/2023 20:50	0
04/08/2023 21:00	0
04/08/2023 21:10	0
04/08/2023 21:20	0.1
04/08/2023 21:30	0



**Precipitation: 8.81 mm over 3 hours**

Rainfall Hyetograph: August 4, 2023



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# Calibration and parameter tuning

Scenario: August 4, 2023



Spillway in SC2



Rain garden profile

The hydraulic model indicates a water height of 21 cm at the spillway in SC2. The water footprint extends approximately 10 meters.



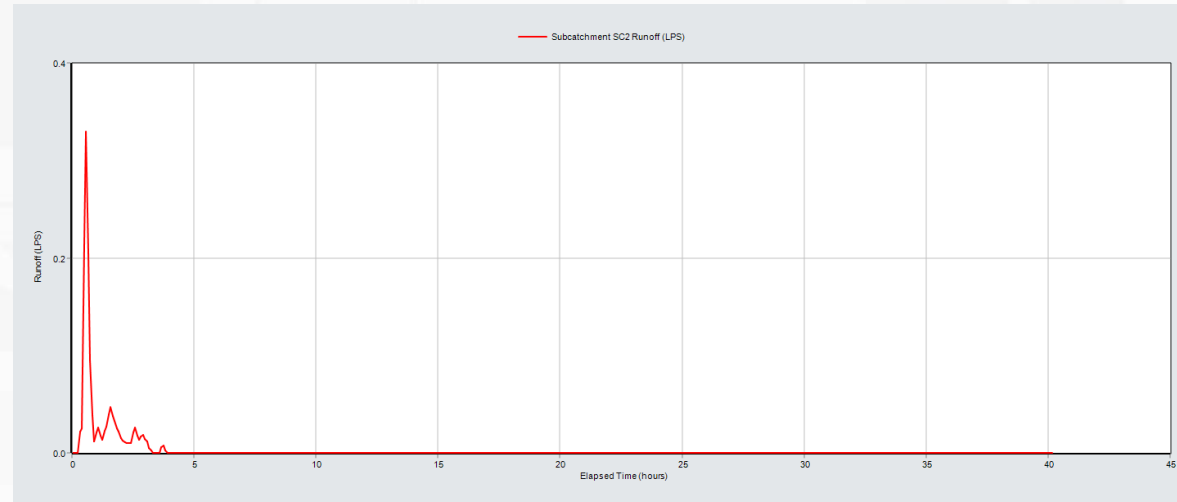
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# Calibration and parameter tuning

Scenario: August 4, 2023



SC1\_4 Basin Flow Discharge



SC1\_4 Discharge Pipe

Runoff from the SC1\_4 basin reaches the basin through a 4-inch pipe, with a very small flow rate and pipe depth of less than 2 cm.



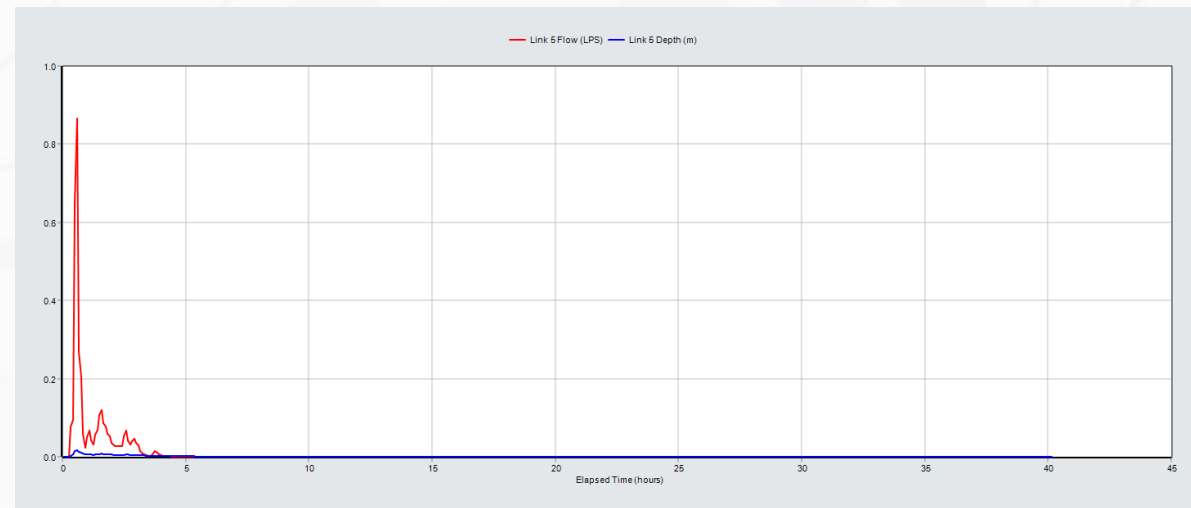
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# Calibration and parameter tuning

Scenario: August 4, 2023



Discharge from the 6-inch SC1-2 pipeline



Discharge rate from the SC1-2 pipeline

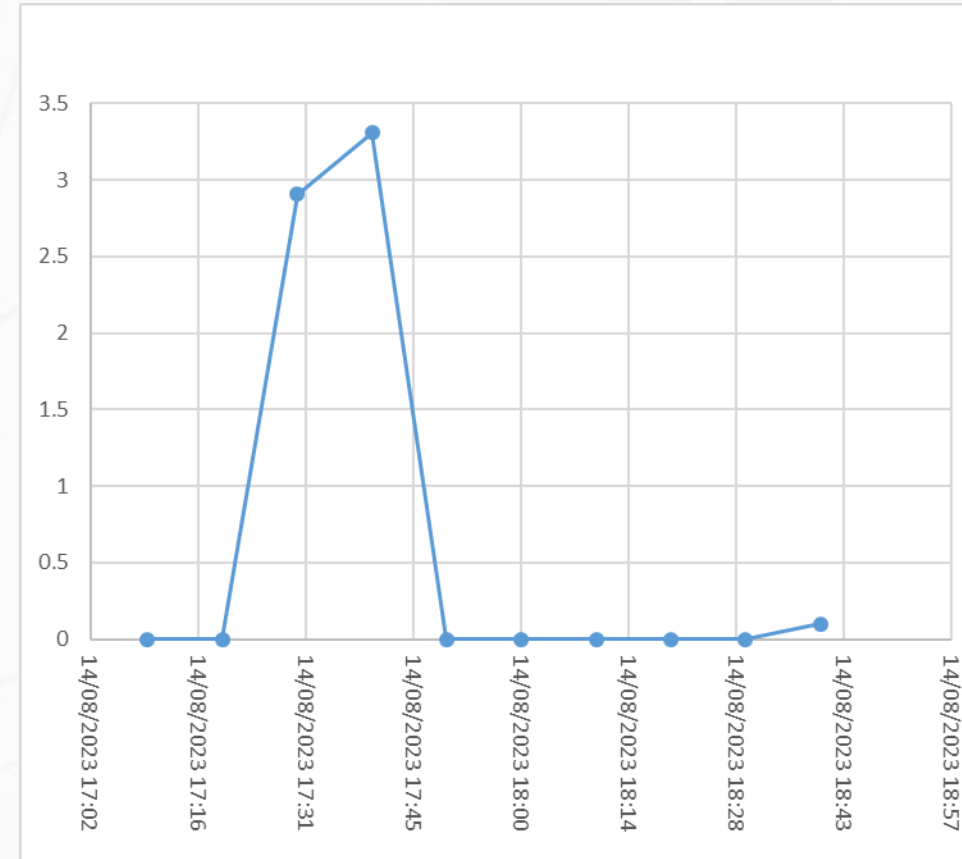
The discharge from SC1-2 had a flow height of 0.02 m and a flow rate of 0.87 l/s during the May rain event.



# Calibration and parameter tuning

Scenario: August 14, 2023

Fecha	Precipitación (mm)
14/08/2023 17:10	0
14/08/2023 17:20	0
14/08/2023 17:30	2.906
14/08/2023 17:40	3.307
14/08/2023 17:50	0
14/08/2023 18:00	0
14/08/2023 18:10	0
14/08/2023 18:20	0
14/08/2023 18:30	0
14/08/2023 18:40	0.1



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# Calibration and parameter tuning

Scenario: August 14, 2023



First Spillway – SC2



Event: August 14, 2023

Results:

- First spillway: peak water level of 0.18 m
- Second spillway: peak water level of 0.01 m

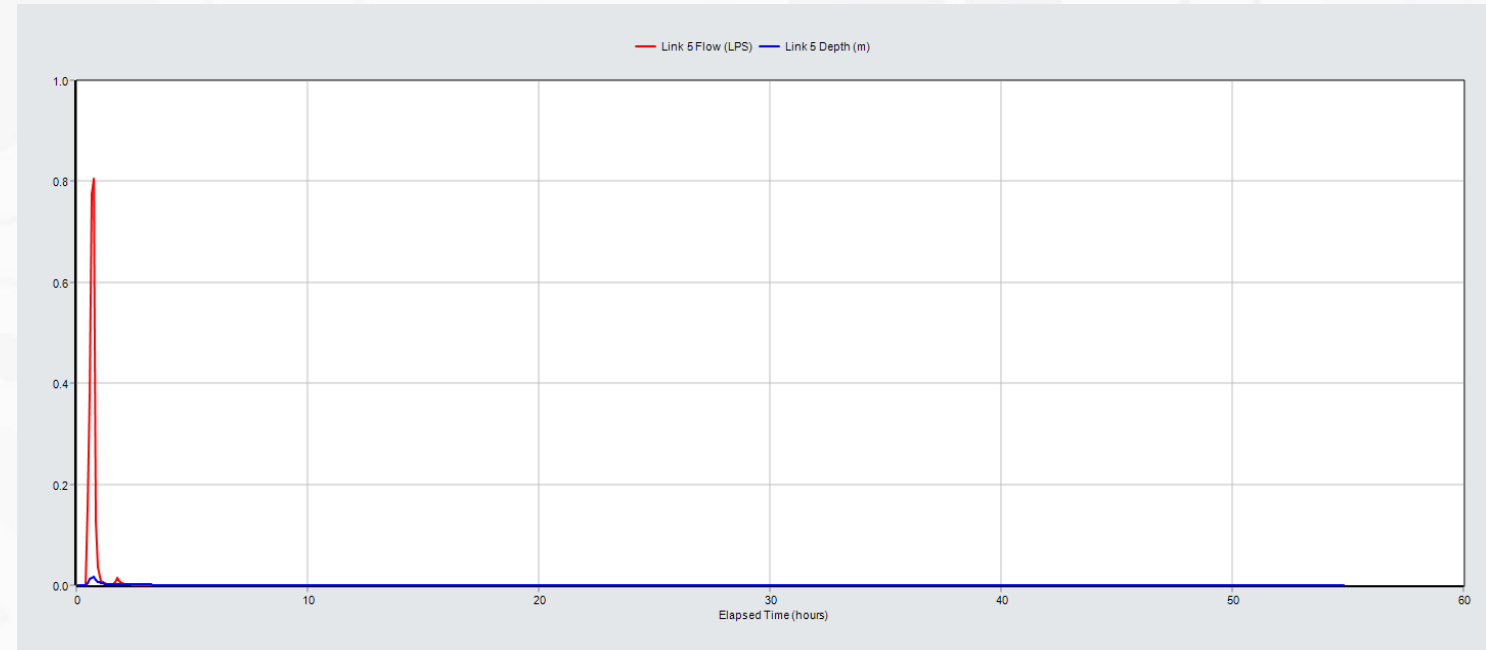


# Calibration and parameter tuning

Scenario: August 14, 2023



Flow Discharge from 4-Inch Pipeline to the LID - August 14, 2023



Pipeline: Collecting flows from the SC1-4 subbasin

The pipeline depth was less than 1 cm, indicating very low flow rates.



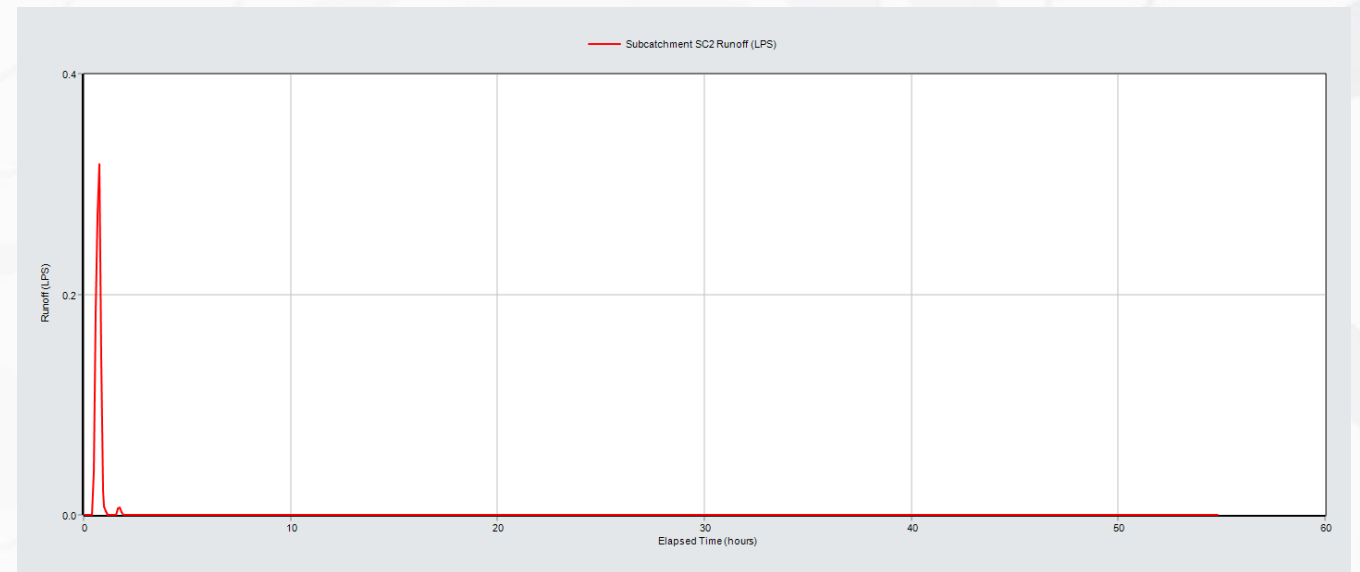
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# Calibration and parameter tuning

Scenario: August 14, 2023



Flow Discharge from 6-Inch Pipeline to the LID – August 14, 2023



Discharge rate of the SC-2 subbasin.

**Observations:** Peak flow of 0.32 L/s occurs at the time of maximum rainfall in the hyetograph.



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# Calibration and parameter tuning

## Results

### Difference between field measurements and the numerical model

Rainfall	Total pp (mm)	Field	Model	Relative error
		H. Weir SC2 (cm)	H. Weir SC2 (cm)	SC2 (%)
04/08/2023	8.81	18	21	9.52
14/08/2023	6.63	15	18	11.11



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## Results and Conclusions

The established relative error (RE) indicates a confidence level of 85%, meaning that the results are within acceptable limits. Therefore, the hydraulic model can be considered calibrated and will be used for simulating scenarios across different return periods.

A summary of this section highlights the sensitivity of the first spillway in SC2, which provides the greatest flow retention in the basin. Consequently, floods with higher precipitation require proper maintenance to ensure optimal retention capacity.

It is important to note that there is currently no continuous monitoring system for LID parameters, such as temperature, precipitation, relative humidity, and evaporation. According to IMTA (2020), the approximate cost of implementing such monitoring is 71,174.70 Mexican pesos (exchange rate as of November 2020).

Therefore, ongoing data collection for future rainfall events will be crucial to evaluate the LID's performance over time.



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**M.I. Oscar Jesús Llaguno Guilberto**  
Mexican Institute of Water Technology  
E-mail: [oscar\\_llaguno@tlaloc.imta.mx](mailto:oscar_llaguno@tlaloc.imta.mx)



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