Flood risk management in urban areas by using SUDS and a Reactive Early Warning System: Case study in Barranquilla, Colombia

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Introduction

- The city of Barranquilla in Colombia has one of the major stormwater management issues in the world.
- Due to the lack of a stormwater drainage system in more than 90% of its urban area, the runoff flows on the streets during rain events with dangerous flow rates
- The permeable areas are little and the steep slopes of the city cause supercritical flow and flash floods on many streets with high velocities.
- This has negative consequences such loss of human life, damage to infrastructure, and economic losses.

May 9th 2017

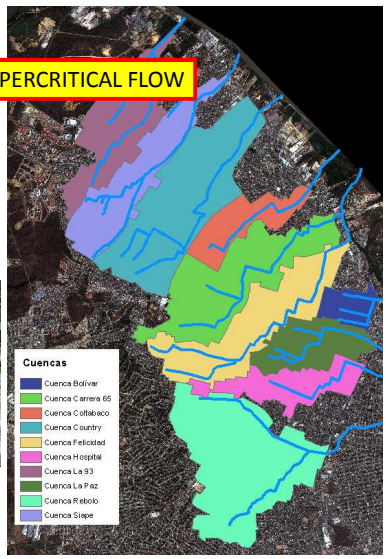
Watershed characteristics

Watershed	Area (Ha)	Main channel street length (Km)	Slope (%)
La 93	262	3.4	1.5
Siape	268	4.5	2.0
Country	371	2.8	3.1
Coltabaco	139	2.5	2.3
Carrera 65	356	4.4	1.9
Felicidad	337	4.4	1.9
Bolívar	68	1.0	1.0
La Paz	166	1.4	3.1
Hospital	164	3.2	2.0
Rebolo	522	3.0	2.0

SUPERCRITICAL FLOW

Source: El Universal Newspaper

Source: ADN Newspaper



Typical flow rates and velocities

	5 years			25 years			100 years		
Watershed	Flow rate (m3/s)	Velocity (m/s)	Depth (m)	Flow rate (m3/s)	Velocity (m/s)	Depth (m)	Flow rate (m3/s)	Velocity (m/s)	Depth (m)
93	66	8.3	1.1	92	9.3	1.3	113	9.9	1.5
Siape	85	9.0	1.3	111	9.8	1.5	131	10.4	1.7
Country	108	9.9	1.6	143	10.8	1.9	191	11.4	2.1
Coltabaco	40	8.8	0.6	53	9.8	0.7	63	10.4	0.8
65	104	10.8	1.4	137	11.8	1.7	164	12.5	1.9
Felicidad	95	10.2	1.3	128	11.2	1.6	153	11.8	1.9
Bolivar	21	5.3	0.6	28	5.9	0.7	33	6.2	0.7
La Paz	49	7.2	0.9	65	8.0	1.1	78	8.5	1.2
Hospital	44	4.3	1.1	60	4.8	1.4	73	5.1	1.6
Rebolo	140	10.5	1.8	191	11.6	2.3	234	12.2	2.6

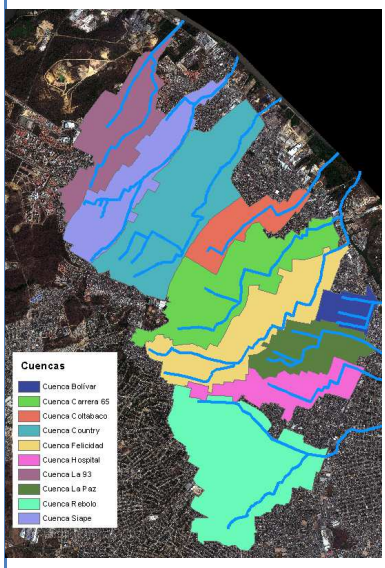
Stormwater master plan: Channeling for ending segments of streets

Foto: www.lachachara.org

Foto: Luis Rodriguez – El Herando

Foto: www.semana.com

Channeling for ending segments of streets



Street/Stream	Lenght (Km)	Cost (Millon US$)
Arroyo 84	2.4	33
Arroyo 82		
Arroyo 79		
Arroyo 21	3.4	40
Felicidad	3.4	42
Calle 75 y 76	2.4	33
Calle 65	2.3	30
Hospital	2.4	30
Calle 91 y 92	1.5	21
Calle 58	0.9	15
Arroyo 21	3.4	40
TOTAL	**19.7**	**251**

60 Km left with flash flood issues!

Flood during construction: Calle 76 Stream May 12th 2017

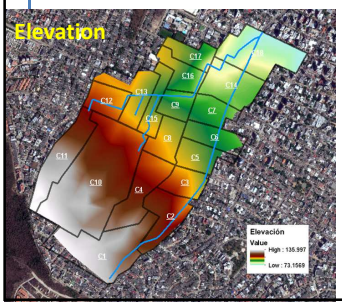
May 12th 2017

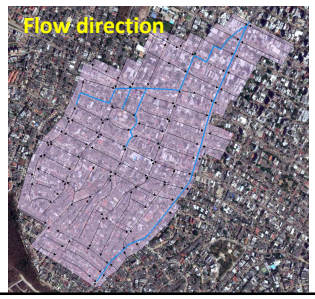
Purpose of the REWS

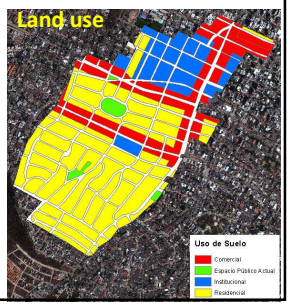
- The purpose of the REWS (Reative Early Warning System) is to account for an economic and effective Early Warning system that allows identifying flash flood risk based on a deterministic and semi-hydrological model.
- The REWS is complementary to a FEWS (Forecasting Early Warning System)
- The city of Barranquilla is currently on a channeling master plan attending up to 20% of the streams/streets with flash flood risk.

Fieldwork and monitoring

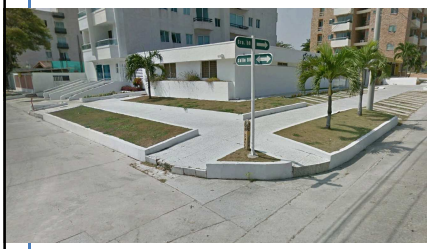
- Flow rate and rain gages
- Topography
- Flow direction
- Land used



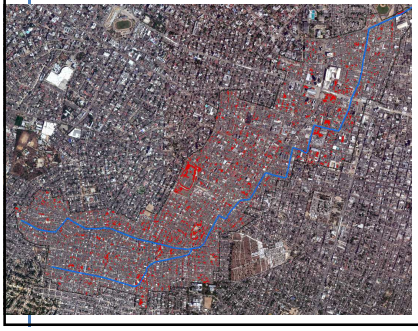




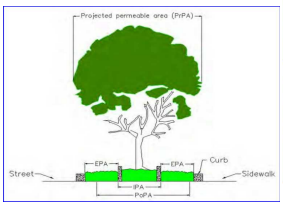
Fieldwork and monitoring



- Permeable/Impervious percentage area
- Satellite image analysis

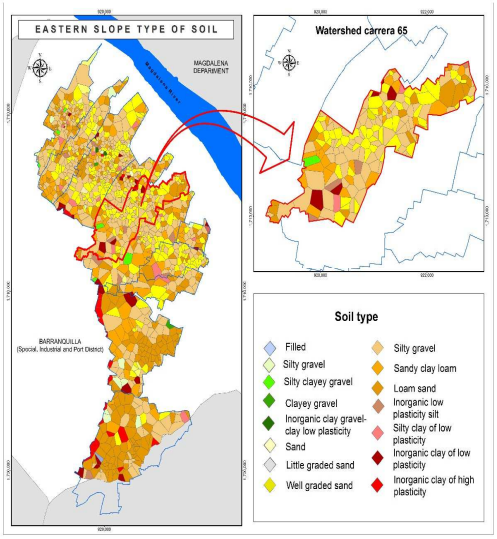


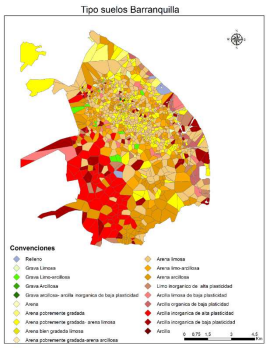
Tipo de Área	Porcentaje %
Área permeable efectiva	27
Área impermeable efectiva	73



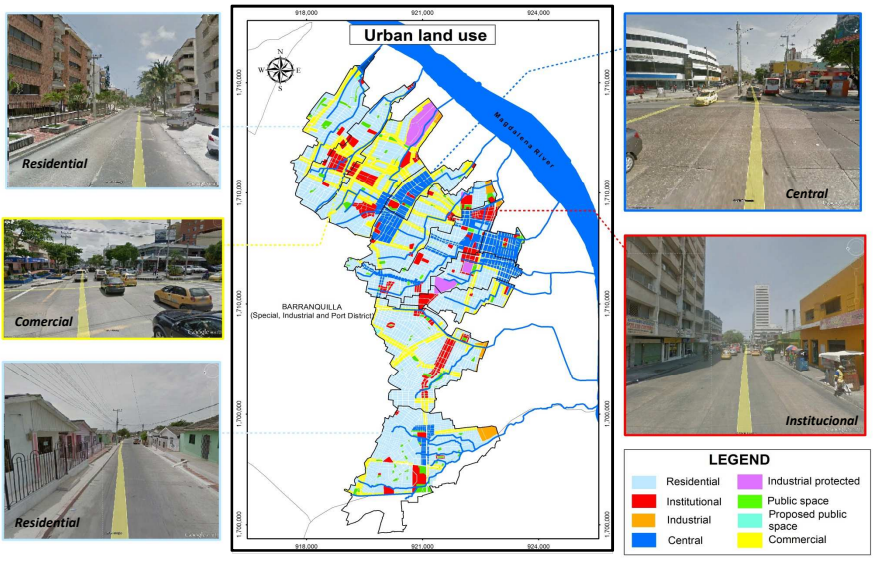
Type of soil

Type soil	Area (Ha)	Percentaje (%)
Sand	2984.02	86.71%
Clay	249.08	7.24%
Gravel	98.82	2.87%
Silt	75.43	2.19%
Other	34.15	0.99%



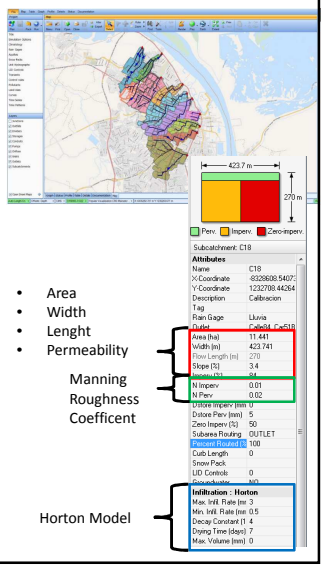


Land use



Modeling and Calibration

PCSWMM



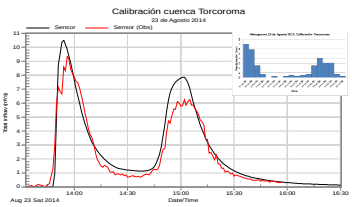
- Area
- Width
- Lenght
- Permeability

Manning Roughness Coefficent

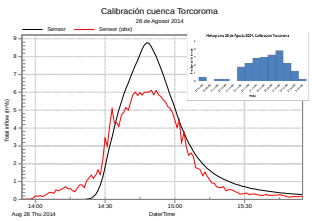
Horton Model

Model calibration – "Torcoroma" subcatchment

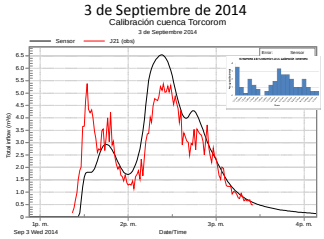
23 de Agosto 2014



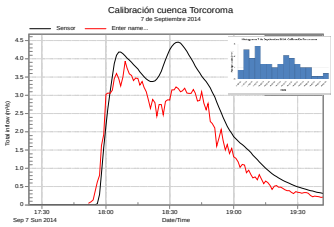
28 de Agosto 2014



3 de Septiembre de 2014



7 de Septiembre de 2014



Adjustment of calibration and validation scenarios

Event	R^2	NSE	ISE	ISE rating	Type
August 23rd 2014	0.93	0.9	2.91	Excelent	Calibration
August 28th 2014	0.86	0.81	4.6	Very good	Validation
September 3rd 2014	0.65	0.41	3.29	Very good	Validation
September 7th 2014	0.92	0.70	5.93	Very good	Validation

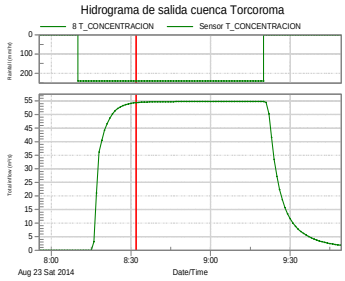
- Coefficient of determination (R^2)
- Nash-Sutcliff efficiency model (NSE) coefficients
- Integral Square Error (ISE).

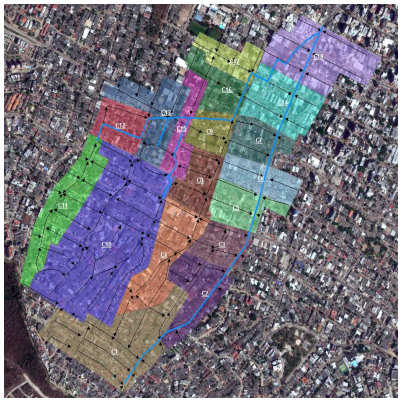
Time of concentration equation

A time of concentration equation was developed for Barranquilla, based on field data and modeling.

$$Tc\ (min) = 10.4 + 0.166 * A\ + 35.6 * L - 3.09 *\ So + 0.15 * P$$

T_c: Time of concentration (Minutes)
A: Watershed area (Ha)
L: Watershed length (Km)
S_o: Watershed slope (%)
P: Permeability (%)





Hazard analysis for urban flood

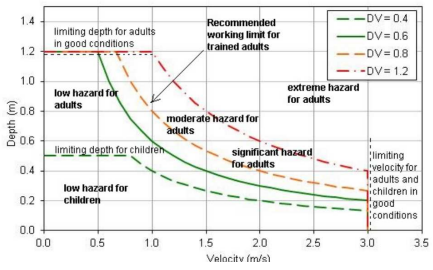
Several studies have been conducted regarding flood safety criteria for the implementation of early warning systems. Cox R.S. (2010) identified and evaluated the dangerous flow conditions associated with a person or a car based on hydrodynamic variables.

The Hazard Level (m^2/s) was defined as follow

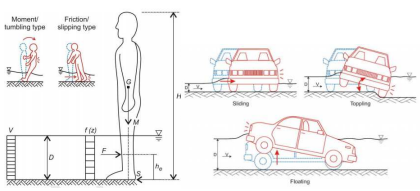
$$P\left(\frac{m^2}{s}\right) = v\left(\frac{m}{s}\right) * y\ (m)$$

Hazard level (m^2/s)	Color	Description
0 - 0.4		-
0.4 - 0.6		Low
0.6 - 0.8		Medium
0.8 - 1.2		High
> 1.2		Very High

Source : Cox, 2010



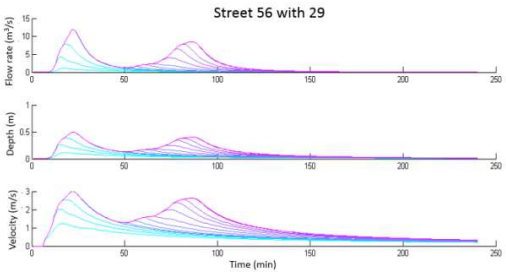
Source : Cox, 2010



Flow instability models for vehicles and people (Shand, 2011)

REWS Model

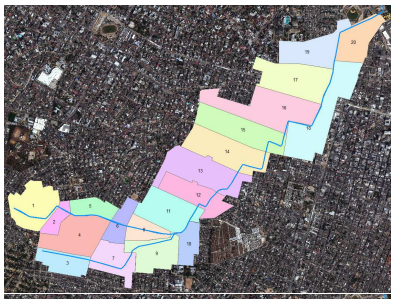
A rainfall event is modeled cumulatively by rainfall increment pulses in order to know the runoff conditions on each street intersection each minute.

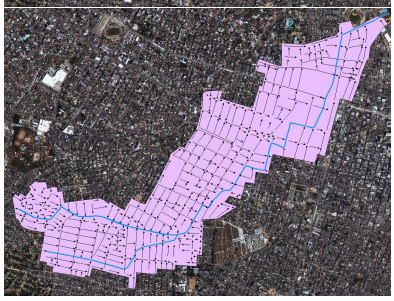


Felicidad Watershed: Results

Drainage area of 336 Ha and main stream length of 4.8 Km.

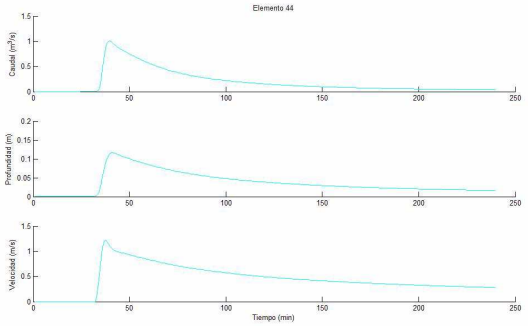
The watershed was divided into 20 sub-catchment with areas between 5 and 30 Ha.

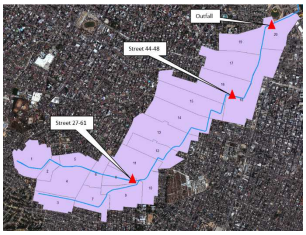




Real time modeling: Rainfall-Runoff

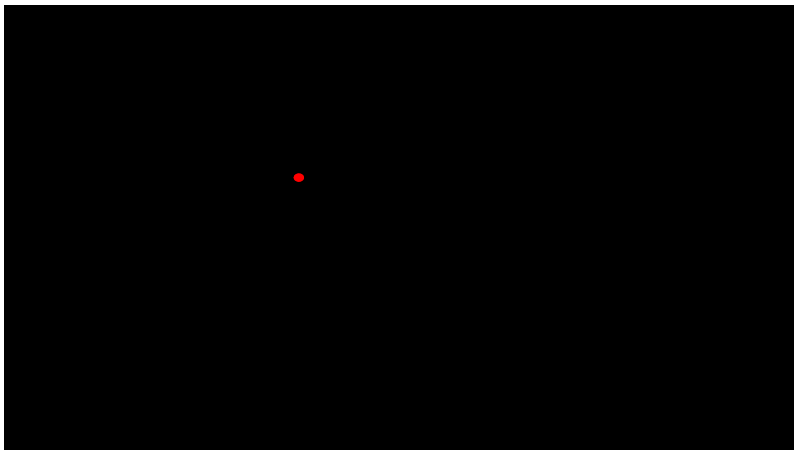
The August 23th 2014 rainfall event was performed with 120 simulations and it was generated 120 flow, depth and velocity graphs.



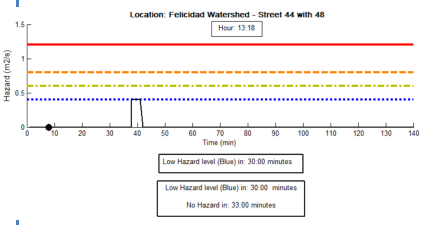


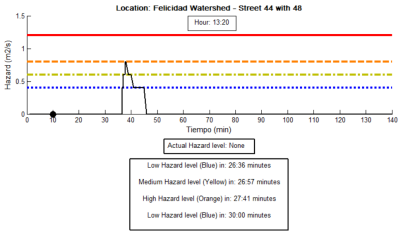
Maximum flow conditions in Felicidad watershed			
Variable	**Street 27-61**	**Street 44 -48**	**Outfall**
Drainage area (ha)	63.4	252.2	336
Peak Flow (m^3/s)	10	54	68
Max Depth (m)	0.24	0.96	0.8
Max Velocity (m/s)	4.10	5.6	8.2
Hazard level (m^2/s)	0.98	5.37	6.56

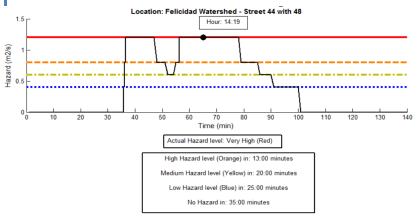
Reactive Early Warning System

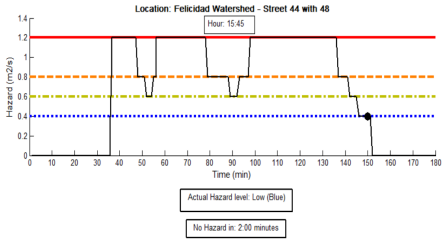


Results – Reactive Early Warning System









SUDS retrofitting: Pilot Tests

- A residential existing building was retrofitted for improving its stormwater system by using SUDS.
- Number of floors: 5
- Underground parking
- Gardens located in front of the building
- Existing non-used underground tank for drinking water

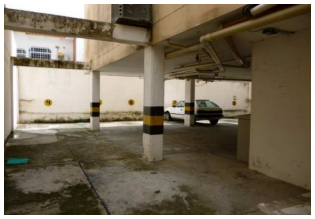
Characteristics of the existing drainage system

Area of the property: 544m^2

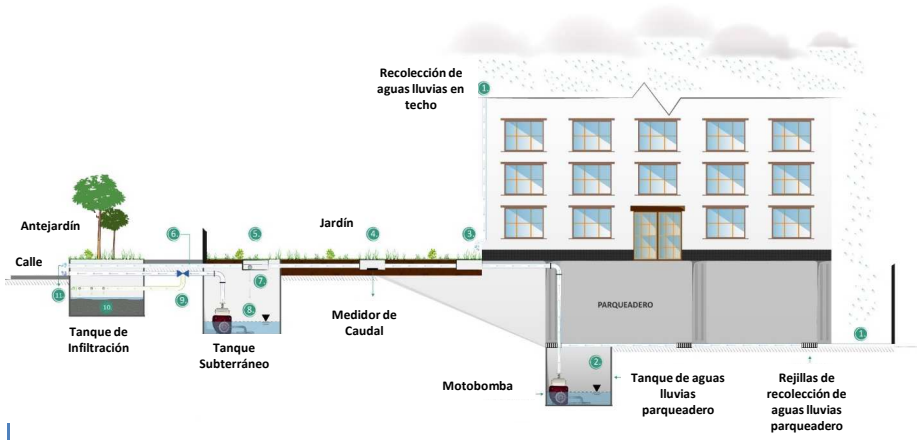
Effective area draining to the underground tank: 273m^2

Tank´s storage capacity: 27m^2

Runoff is discharged directly to the street



Schematic layout of the retrofitting



Retrofittings

Pipe and valves systems for controling dischages to the garden or the street

Water level gage

Garden retrofitting

Flow measuring boxes

Some results

Event:

Rainfall: 79 mm

Weir height: 1 cm

Runoff volume: 21,6 m^3

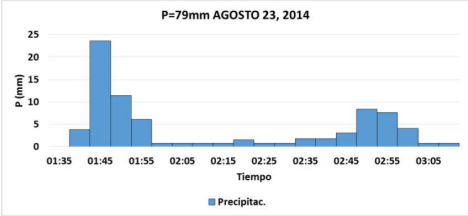
Peak flow in the building: 21,5 L/s

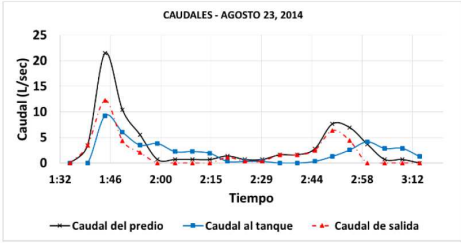
Peak flow discharge: 12,2 L/s

Peak flow reduction: 43%

Storage runoff volume: 2,7 m^3

Runoff volumen reduction: 13%





Results

Configuración	Precipitación (mm)	Volumen Total (m3)	Volumen almacenado (m3)	Reducción de volumen (%)
Bloqueo total de tubería de salida	100	27	27	100
Vertedero en entrada del tanque (1cm)	79,0	21,6	2,7	13
Vertedero en entrada del tanque (1cm)	32,5	8,9	2	22
Vertedero en tubería de salida (4cm)	43,0	11,8	4,2	36
Vertedero en tubería de salida (2cm)	19,6	5,4	0,54	10
Vertedero en tubería de salida (2cm)	163,0	44,5	13,4	30
Vertedero en tubería de salida (1cm)	14,0	3,9	1	26
Vertedero en tubería de salida (1cm)	24,0	6,7	0,91	14

Configuración	Precipitación (mm)	Caudal pico del predio (L/s)	Caudal pico de salida (L/s)	Reducción (%)
Bloqueo total de tubería de salida	100	-	-	-
Vertedero en entrada del tanque (1cm)	79	21,49	12,25	43,0
Vertedero en entrada del tanque (1cm)	32,5	14,33	5,72	60,1
Vertedero en tubería de salida (4cm)	43	15,90	15,30	3,8
Vertedero en tubería de salida (2cm)	19,6	12,71	11,76	7,5
Vertedero en tubería de salida (2cm)	163	18,49	16,26	12,1
Vertedero en tubería de salida (1cm)	14	12,71	12,71	0,0
Vertedero en tubería de salida (1cm)	24	11,56	11,24	2,8

Using dispersed tank for reducing peak flow by land use

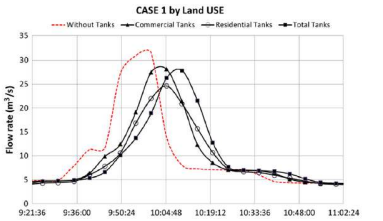


Fig. 7. Case 1: hydrographs using 25-mm tanks

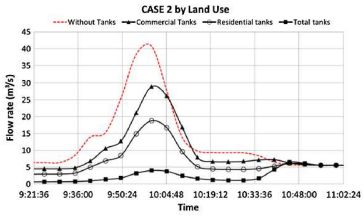


Fig. 8. Case 2: hydrographs using 100-mm tanks

Table 7. Results of Case 2 Using 100-mm Tanks with Type 1 Storage Operation

Variable	Peak flow (m^3/s)	Volume (m^3)	Flow reduction (%)	Volume reduction (%)
Without tanks	40.8	236,900	—	—
Total tanks	6.4	100,400	84	58
Residential tanks	18.8	166,700	54	30
Commercial tanks	28.9	198,600	29	16
Upstream tanks	24.2	180,500	41	24
Downstream tanks	24.6	180,200	40	24

Avila, H., Avila, L., and Sisa, A. (2016). "Dispersed Storage as Stormwater Runoff Control in Consolidated Urban Watersheds with Flash Flood Risk." *J. Water Resour. Plann. Manage.*, 10.1061/(ASCE)WR.1943-5452.0000702, 04016056.

Using dispersed tank for reducing peak flow Equivalent volumen estimation

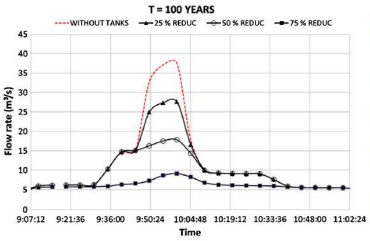


Fig. 9. Case 3: hydrographs using Type 2 storage operation

Table 10. Results of Case 3 Using for 100-Years Return Period

Variable	25% reduction	50% reduction	75% reduction	Without tanks
Peak flow (m^3/s)	19.4	12,57	6.4	25.6
Total inflow (m^3)	155,700	149,300	133,700	161,300
Runoff volume reduction (%)	3	7	17	—
Equivalent tank capacity (mm)	4.0	8.0	19	—

Avila, H., Avila, L., and Sisa, A. (2016). "Dispersed Storage as Stormwater Runoff Control in Consolidated Urban Watersheds with Flash Flood Risk." *J. Water Resour. Plann. Manage.* , 10.1061/(ASCE)WR.1943-5452.0000702 , 04016056.

Conclusions

- The REWS proposed in this study was based on a deterministic and semi-distributed hydrological model. Therefore, the runoff and hazard forecasting depend on the rainfall data collected each minute.
- The implementation REWS represents both an economic and effective measure to reduce flash flood risk. However, a Forecasting Early Warning System combined with the REWS would reduce the uncertainty and improve the prediction and reliability. Other applications will be implemented for public users, such as social networks, twitter, real time reports, citizen watch, among other actions to improve the application.
- SUDS are an excellent alternative for managing peak-flow in consolidaded urban watersheds if they are implemented in large scale. Feasable alternatives and social awarness are necesary to make it atractive for public and the local goverment.

Thank you!

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