HYDROSEDIMENTOLOGICAL MODELING WITH A HIGH LEVEL OF DETAIL IN AN URBAN BASIN WITH A HIGH SLOPE

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INTRODUCTION

The objective of this research was to calibrate algorithms in SWMM model for accumulation and production of sediments by water erosion in the Mbotaby basin, in the city of Oberá, Misiones, Argentina (Fig. 1), using the hydrological-hydraulic model available, with the corresponding hydro-sedimentological measurements comparison. For the prediction techniques application of erosion-sedimentation processes, it is essential the description of hydrological and hydraulic processes involved in the generation and propagation of surface runoff. In this sense, in a previous work a hydrological-hydraulic model was developed, calibrated and put into operation in one of the most densely populated basins in the "Sierra Central de Misiones", characterized by having a steep topography. With regard to the production of sediments to date, data have been processed from 10 events where rainfall, water levels and sediment concentration were recorded simultaneously. In a region with different hydrological characteristics from the rest of the country, which still conserves large green areas with high power of urban development and no history of hydro-sedimentological modeling, it is intended to provide a technological tool at the service of sustainable planning of water resources and soil conservation.

DESCRIPTION OF THE STUDY AREA

Climate: Subtropical humid with 1925 mm of annual rainfall, with a maximum in 2017 of 2709 mm, hit by intense convective events by Southwest cold fronts.

Soils: Generally covered by clayey silt soils of reddish coloration. The main problem of these soils is severe erosion by excessive tillage, because it destroys natural soil structure, facilitating erosion. Particularly in urban areas, soils are highly vulnerable at the start of construction where they are naked natural compaction.

Slopes: The Fig. 2 presents the Obera slope map made by Digital Land Model. From which it can be appreciated that in Obera, almost 50% of it has slopes greater than 5%, with a maximum of 34%.

THE BASIN UNDER STUDY

It comprises the Mbotaby Creek basin, of Middle Parana basin, with 976.7Ha surface (Fig. 3). In the basin different zonifications are noticed, from the central district with a high population density, to ecological reserves areas. The average slope of the basin is 5.5%, and the average slope in the main channel is 2%.

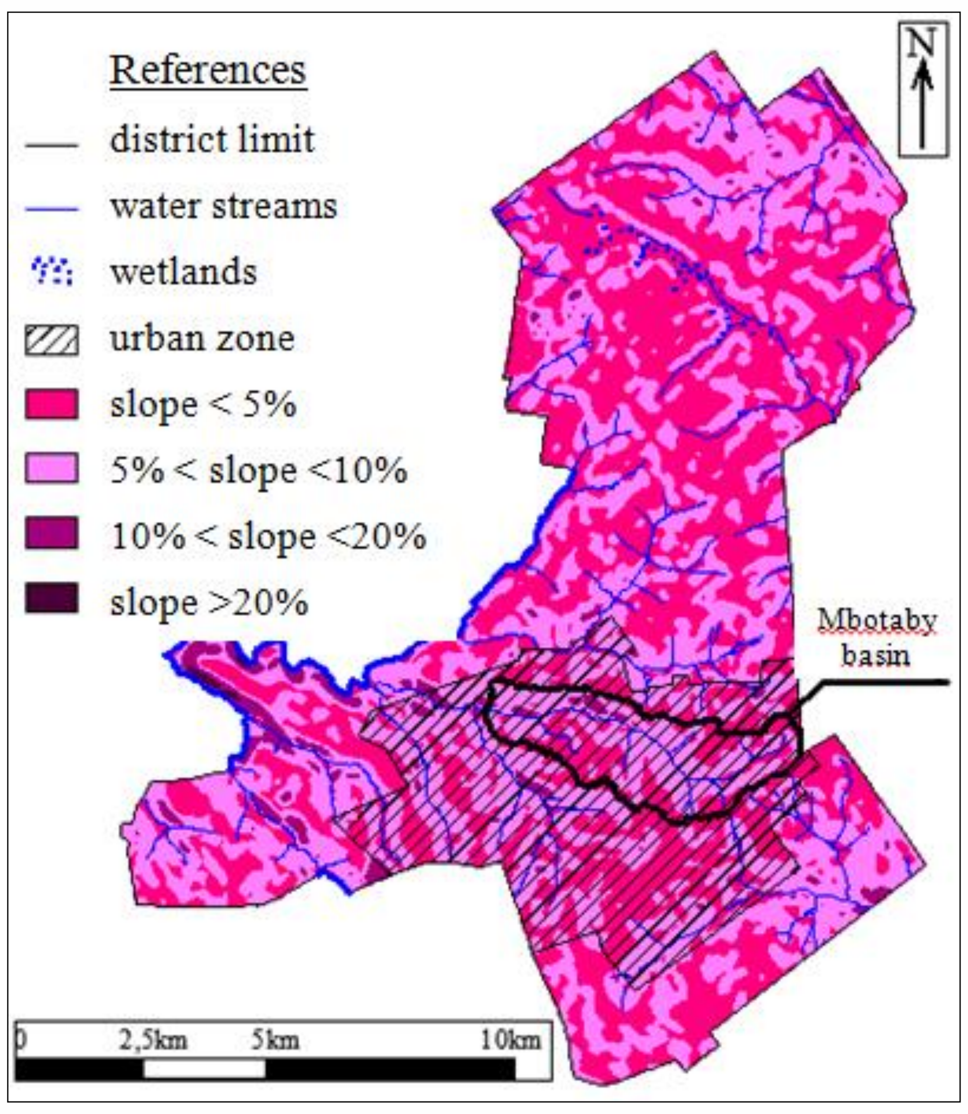

Fig. 2: Obera slop map.

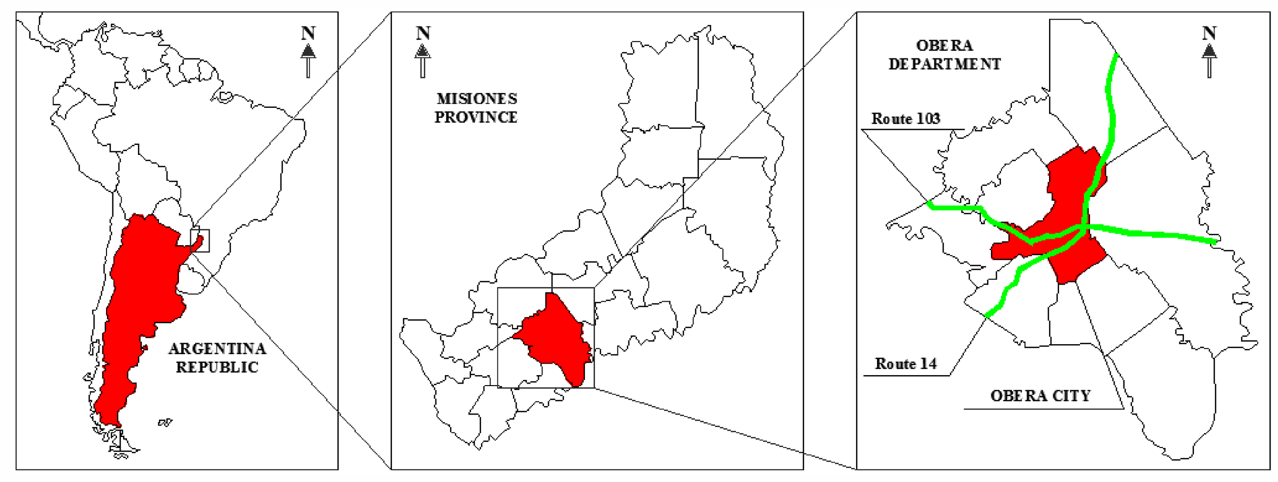

Fig. 1: Geographical location of Oberá.

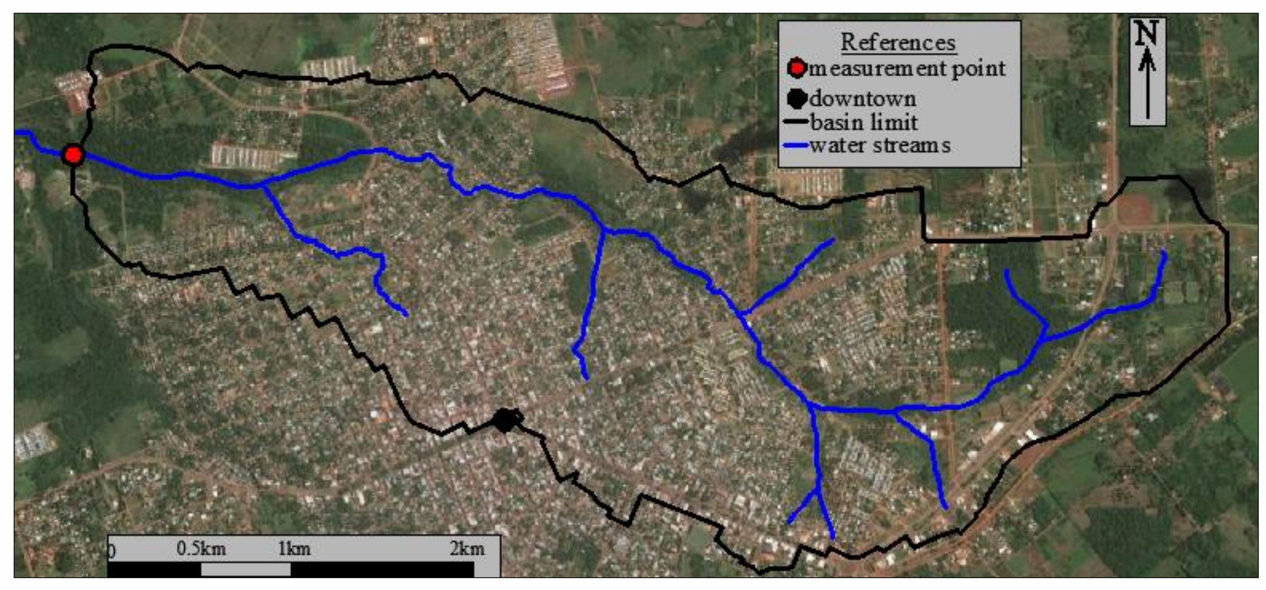

Fig. 3: Mbotaby basin (adapted from Google Earth®, 2013).

MATERIALS AND METHODS

Hydrologic-hydraulic model used: The model was implemented in the environment of SWMM 5.0ve, allowing to obtain flow variables such as flows, speeds and levels in each block, street, channels and water streams of the pluvial system. The detail level corresponds to a topology with at least 4 nodes in each side-street, 2 conduits per street and each block is represented by a tributary sub-basin (Fig. 4).

The respective sub-basins were established with their respective values of permeable and impermeable areas, directly and indirectly connected according to each zoning.

The modeling environment resulted from a surface area of 976.7ha, corresponding 24.5% to total impervious areas, of which 12.9% of the total are directly connected, and 75.5% of permeable areas.

The model was constituted by 972 tributary sub-basins, 2967 nodes and 3.742 conductive elements of the water surpluses (streets, ditches, drains, channels and water streams).

Hydro-sedimentological measurements: In order to compare the results obtained by modeling, hydro-sedimentological measurements were made at basin control point, in order to establish the flow rates of direct runoff and the concentrations of solids associated with the different recorded and modeled pluviographic events. The storms presented in this work are 10, which have different soil moisture conditions and several previous dry periods. The values of total precipitation vary in a range of 32 to 160mm, with average intensities between 3.8 to 13.3mm/h.

The hyetographs of rainfall were recorded by a digital pluviograph, located near the basin gravity center. Flow rates incurred by the basin were inferred by recording water levels in the control point and the calibrated H-Q curve. The output sediment concentrations were established by taking water samples and their subsequent processing in the laboratory (Fig. 5).

Erosion algorithms used: The SWMM water quality model was used to describe the dynamics in both the generation of sediments at the sub-basin level and the transport of them through the drainage network. Two different sediment generation algorithms were used. One for permeable areas, where the availability of material can be assumed to be infinite for an isolated event, and another for impervious areas where the material available for washing is limited and depends on the soil moisture conditions. The goodness of fit between observed and measured values was carried out by R^2, NSE, PBIAS and RSR.

Accumulation of pollutants in impermeable areas: An exponential accumulation model was used according to Equation 1. In the same accumulation follows an exponential growth asymptotically approaches a given maximum value. To reproduce the phenomenon of accumulation proceeded to model, for each registered event, a period before the storm equal to the amount of pre-event rainless days time (see Reference Manual of SWMM for more details).

$$B = C_1\left(1 - e^{-C_2 \cdot t}\right) \qquad [1]$$

Washing contaminant in impervious areas: The drag load in impervious areas was described by a potential function according to Equation 2.

$$W = C_8 \cdot B \cdot q^{C_9} \qquad [2]$$

Washing contaminant in permeable areas: For description of the washing and silting from pervious areas model drag flow curve described by Equation 3 it was used.

$$W = C_{10} \cdot q^{C_{11}} \qquad [3]$$

Sensitivity analysis: The 6 coefficients were increased by 20%, which allowed evaluating the percentage of increase of the total of solids released by the basin before the variation of each coefficient.

RESULTS

The values that best adjusted are:

C_1 = 1200 kg/ha; C_2 = 0.05 days^{-1}; C_8 = 0.010; C_9 = 1.6 the coefficient of drag C_{10} was adjusted for each zoning following the sediment distribution relations of the MUSLE [kg/l] (Rodriguez et al., 2015), finally the resulting C_{10} vary between a minimum for the central district of 360 kg/l and a maximum for the squares in boulevards of 1016 kg/l; C_{11} = 1.14.

The total pairs of data evaluated, Total Solids (TS) registered and modeled, amount to 88 (two events discarded).

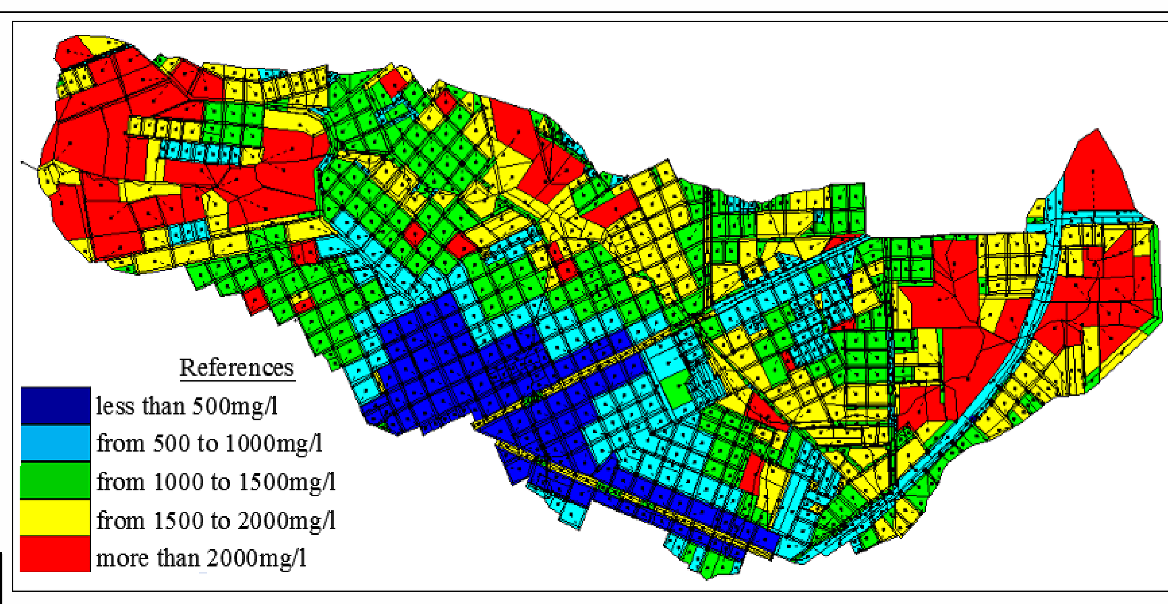

Fig. 4: Maximum total solids in the runoff by sub-basin (07-19-2014).

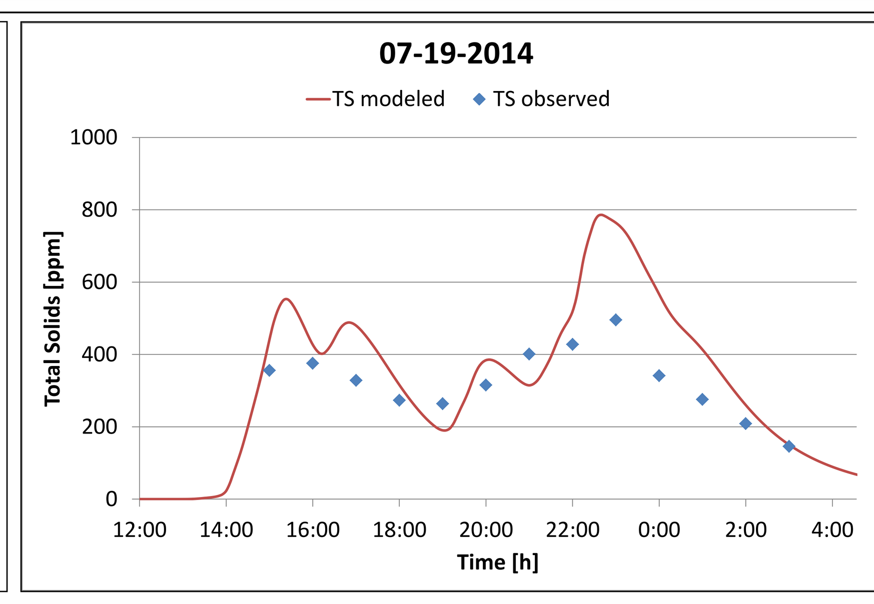

Fig. 5: Total solids modeled and observed (07-19-2014).

Table 1: Modeling summary results of all the events.

	Parameters	Event	11-19-2013	01/11/2014	02-20-2014	04/09/2014	05/04/2014	07/01/2014	10/06/2014	10-31-2014	11-30-2014	01/01/2015
Storm	Previous humidity	[adm]	II	II	II	I	II	II	II	III	I	III
	Rainfall	[mm]	44.4	31.6	77.4	41.4	38.6	58	53.8	41.8	127	160
	Duration	[h]	6	7	11	9	10	12	14	11	23	12
	Average intensity	[mm/h]	7.4	4.5	7	4.6	3.9	4.8	3.8	3.8	5.5	13.3
Runoff	Modeled	[dm^3]	132	61	317	48	87	166	151	137	342	1227
	Observed	[dm^3]	133	51	371	45	83	170	172	168	363	1050
	Difference	[%]	-0.5	19.8	-14.6	6.3	4.8	-2.9	-12.6	-18.3	-5.9	16.9
	R^2	[adm]	0.88	0.84	0.8	0.64	0.73	0.9	0.83	0.88	0.72	0.74
Sediment production	Modeled	[T]	94	37.5	270.6	39.8	55.2	117.2	116.3	84.2	318.9	1162.9
	Observed	[T]	72	29.6	359.9	52.3	45.3	90.8	119.9	104.4	423.3	1108.1
	Difference	%	30.6	26.5	-24.8	-23.9	21.9	29.1	-2.9	-19.3	-24.7	4.9
	R^2	[adm]	0.96	0.58	0.7	0.39	0.7	0.68	0.9	0.48	0.65	0.34
	NSE	[adm]	-1.06	-2.86	0.68	-3.77	-4.03	-0.97	0.5	-0.26	0.64	0.32
	PBIAS	[%]	-18.1	-23	2.4	43.3	-20.7	-24.2	7.4	5.3	3.4	-6.7
	RSR	[adm]	1.44	1.97	0.56	2.18	2.24	1.41	0.71	1.12	0.6	0.82

Table 2: Results of the sensitivity analysis of the sediment production model.

Event	Previous humidity	Net rainfall [mm]	Total sediment SWMM calibrated [T]	Sediment production variation					
				Accumulation in impermeable areas		Drag in impermeable areas		Drag in permeable areas	
				C_1	C_2	C_8	C_9	C_{10}	C_{11}
11-19-2013	II	12.4	94	4.00%	3.60%	1.50%	3.80%	16.00%	63.80%
01/11/2014	II	5.6	37.5	6.20%	5.40%	4.30%	11.90%	13.80%	29.30%
2-20-2014	II	30.8	270.6	3.90%	3.20%	0.20%	0.10%	16.10%	98.30%
04/09/2014	I	5.7	39.8	11.80%	8.80%	6.70%	6.70%	8.20%	22.40%
05/04/2014	II	8.3	55.2	5.50%	4.80%	4.80%	3.30%	34.60%	8.50%
7-19-2014	II	15.9	117.2	4.50%	3.90%	1.60%	4.70%	15.50%	62.50%
10/06/2014	II	15.3	116.3	4.80%	4.20%	1.40%	4.10%	15.20%	72.40%
10-31-2014	III	14.8	84.2	0.80%	0.80%	0.40%	1.10%	19.20%	81.80%
11-30-2014	I	44.4	318.9	6.70%	3.10%	0.00%	0.00%	13.30%	66.10%
01/01/2015	III	126.5	1162.9	0.10%	0.10%	0.00%	0.00%	19.90%	199.00%
Variation for all the events analyzed				**2.60%**	**1.80%**	**0.50%**	**1.20%**	**17.40%**	**134.60%**

CONCLUSIONS.

With satisfactory results, the SWMM has proved to be an effective and easy-to-apply tool for hydro-sedimentological modeling of urban basins in the highland area and humid subtropical climate. The difference between the volumes recorded and modeling both runoff and sediment, and the value of the adjustment parameters used goodness follows that the implemented models have an acceptable fit. It is considered a methodological achievement that with modeling tools of medium complexity can be established a satisfactory description of the processes studied. To describe the erosion phenomena, a model was needed to allow a high level of detail, due to the great influence that slopes have on the dynamics of surface runoff and its implications in erosive processes. Sensitivity analysis shows that the most important parameters in the calibration are drag coefficients permeable areas. It is estimated that the hydro-sedimentological models calibrated will advance managing director surplus surface water plan, currently nonexistent in the city of Oberá, as well as allowing the evaluation of performance of structural and non-structural works tending to mitigate the negative effects of urbanization on the environment.

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