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A first approach in hydrologic analyses of stormwater runoff under both pre- and post-development conditions using EPA's SWMM 5.0 modeling program. Case study Sebes, Romania

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ABSTRACT: This paper will present some aspects of the influence that urban environment has on stormwater runoff, influence enhanced by changes in land use and land cover. This study sought to estimate the stormwater discharges at the urbanized catchment's outlet using EPA's SWMM 5.0 modeling program and compare them to the ones generated prior to urbanization. The design storms used are for a 1-, 5-hour events with return periods of 2, 10, and 20 years.

Keywords: urban stormwater infiltration, land use, land cover, water resources, river basin management plans

1. INTRODUCTION

Originally a Dacian settlement, later incorporated into the Roman Empire, Sebeș (Mühlbach in German) was settled by the Saxons in the 12th century, first documented in 1245. Sebeș is located towards the southern area of Transylvania, on the Sebeș River, in the Alba County, Romania, having more than 25,000 inhabitants.

Our study area is a neighborhood of Sebeș, Mihail Kogălniceanu, constructed under communism, located in the north of the city, in the street of the same name (Mihail Kogălniceanu). It consists of approximately 100 four-storey buildings, a school, a kindergarten, a nursery, a clinic and two churches.

Changes in land use and land cover lead to modification in urban hydrological cycle [2]. Elements of urban design like roadways, driveways, sidewalks, gutters, pipes, drainage swales, parking, roofs, and grading are all intended for draining urban area in a rapid way. Most of the studies on how urban expansion modifies runoff are focus on increases in impervious surfaces. The impervious surfaces, not only indicates urbanization, but also play an important part in the impact of urbanization on the environment.

The overall objective of this study is to evaluate the impact of urban development by compare stormwater runoff under both pre- and post-development conditions. To meet this objective, different tasks should be performed: (1) catchment discretization (physical parameters); (2) determination of hydraulic parameters of the basin; (3) determination of effective rainfall; (4) governing equations; (5) use SWMM rainfall-runoff model to estimate stormwater runoff from the basin across a range of precipitation events;

Mathematical models of the rainfall-runoff process are use to examine changes produced when land use and land cover changes and to predict and manage future impacts. The EPA Storm Water Management Model (SWMM) version 5.0.022 is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of sub-catchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each sub-catchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps [4].

2. CATCHEMENT DISCRETIZATION

The study area (9.58 ha) is divided into 66 sub-catchments by identifying the dividing lines of water and the route of the existing sewerage network. The sub-catchment boundaries were determined by aggregating together sub-areas whose potential overland flow paths share a common direction and drain to the same collection channel. The resulting discretization is shown in Figure 1.

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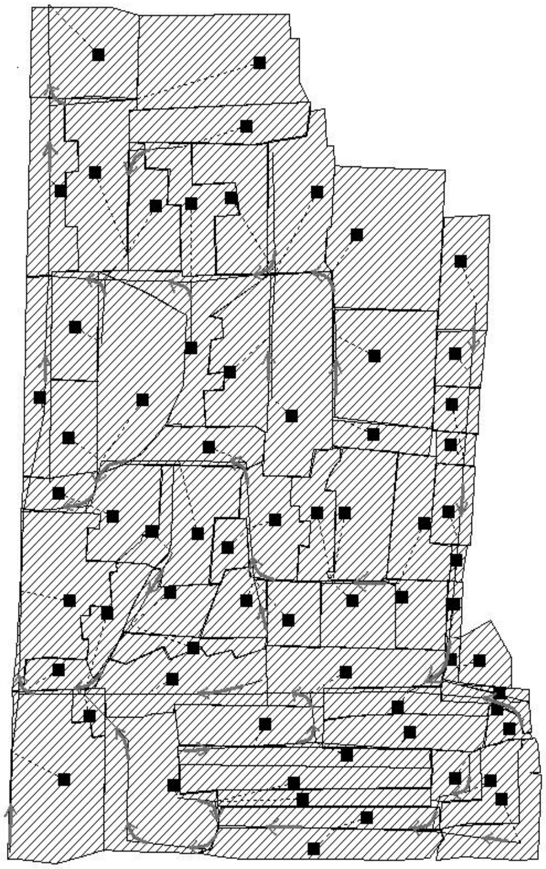

Figure 1. Discretization of the study area into sub-catchments

3. DETERMINATION OF THE HYDRAULIC PARAMETERS OF THE BASIN

For each sub-catchment was determinate the areas, its slopes, the width, percentage of pervious area, percentage of total impervious area and impervious area with no storage. Slopes characterizing overland flow in the sub-catchments will be the lot slope, which is about 0.4%, less for the park surface, sub-catchment S38, were the slope is 3%.

Table1. Sub-catchment parameters

Sub-catchment	Area (mp)	Procet imperv %	% Impervious with no storage	Width (m)	Terrain Slope
S1	3800	100	21	50.67	0.4
S2	3000	49	19	73.17	0.4
S3	700	76	0	13.21	0.4
S4	2000	93	17	33.50	0.4
S5	1500	50	0	27.27	0.4
S6	1400	96	60	24.10	0.4
S7	700	97	11	19.13	0.4
S8	500	96	15	16.31	0.4
S9	300	97	22	12.50	0.4
S10	800	100	45	15.69	0.4
S11	100	100	0	25.00	0.4
S12	200	100	0	22.22	0.4
S13	200	100	0	40.00	0.4
S14	700	97	95	28.00	0.4
S15	100	100	0	50.00	0.4
S16	400	100	0	100.00	0.4
S17	300	100	80	11.54	0.4
S18	1100	80	55	25.00	0.4
S19	1300	87	36	52.00	0.4
S20	1500	95	15	25.00	0.4
S21	1100	50	39	22.00	0.4
S22	700	94	29	15.91	0.4
S23	1500	74	100	15.00	0.4
S24	1700	77	38	32.69	0.4
S25	900	50	51	15.00	0.4
S26	1500	50	50	20.00	0.4
S27	1300	64	65	21.67	0.4
S28	1600	93	16	32.00	0.4
S29	2200	94	20	29.33	0.4
S30	900	95	54	15.00	0.4
S31	1300	96	44	30.95	0.4
S32	900	86	69	19.15	0.4
S33	3200	95	35	50.79	0.4
S34	300	87	21	30.00	0.4
S35	3800	75	35	54.29	0.4
S36	2400	85	17	60.00	0.4
S37	700	76	25	23.33	0.4
S38	900	60	0	28.13	3
S39	1100	45	45	28.95	0.4
S40	1700	75	18	42.50	0.4
S41	500	74	36	20.00	0.4
S42	1500	92	24	45.45	0.4
S43	1100	83	0	20.00	0.4
S44	3000	61	40	56.60	0.4
S45	500	72	0	25.00	0.4
S46	900	87	0	40.91	0.4
S47	1400	77	4	35.00	0.4
S48	500	94	12	20.00	0.4
S49	1400	67	0	56.00	0.4
S50	700	86	0	26.92	0.4
S51	1200	93	25	30.00	0.4
S52	1300	93	23	31.71	0.4
S53	3400	73	25	56.67	0.4
S54	900	100	33	45.00	0.4
S55	2100	42	0	84.00	0.4
S56	2000	77	28	35.71	0.4
S57	3300	54	24	47.14	0.4
S58	2400	72	38	48.00	0.4
S59	1800	70	44	40.91	0.4
S60	1700	88	45	28.33	0.4
S61	3900	70	54	43.33	0.4
S62	1500	27	0	35.71	0.4
S63	1400	80	40	31.11	0.4
S64	2500	89	11	50.00	0.4
S65	2700	81	39	49.09	0.4
S66	1900	57	0	38.00	0.4

Junctions and conduits

Because there are no data available on pluvial sewer network and the purpose of this study is just to compare the pre- and post-development stormwater runoff, the drainage network was created from on-site observation and was constructed and dimensioned with SWMM's tools.

4. PRECIPITATION AND DESIGN EVENTS

Precipitation is characterized by different rainfall amount, intensity, and duration. A analyze of rainfall distribution over a long period of time indicates that the frequency of occurrence of a given storm event follows a statistical pattern. A tool that characterizes an area's rainfall pattern is IDF Curve. IDF stands for

Intensity-Duration-Frequency.

Using the IDF curves the maximum intensity of rainfall was estimated for different durations (60 to 300 minutes) and return periods (2-, 10-, and 20-year), STAS 9470-73 [5]. In our study area, for 1 hour rainfall event, the 2-year storm is approximately 21 mm of rainfall, the 10-year storm is approximately 28 mm of rainfall and the 20-year storm is approximately 34 mm of rainfall. The 2-year storm has a 50 percent probability of occurring in any given year, the 10-year storm has a 10 percent probability of occurring in any given year, while the 20-year storm has a 5 percent probability of occurring in any given year.

The rainfall histograms were determined according to SR-1846-2/2007 [6].

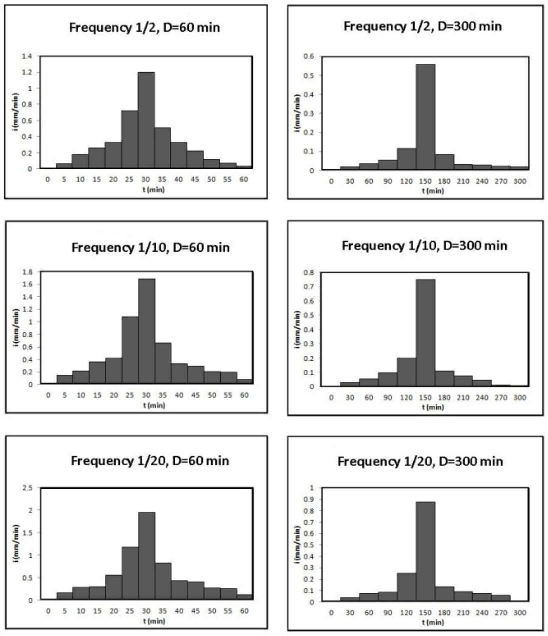

Figure 2. Rainfall events histograms

5. GOVERNING EQUATIONS

SWMM uses the Manning equation to express the relationship between flow rate (Q), crosssectional area (A), hydraulic radius (R), and slope (S) in all conduits [4].

$$Q = \frac{k}{n} A R^{2/3} S^{1/2} \qquad (1)$$

where:

Q - flow rate (ft/s, m/s)

k - is a conversion factor of length$^{1/3}$/ time, (1 m$^{1/3}$/s for SI, or 1.4859 ft$^{1/3}$/s for U.S. customary units)

n - the Manning roughness coefficient

S - the Slope (%)

A - cross-sectional area (ft^2, m^2)

R - hydraulic radius (ft, m)

In **SWMM** one can chose the infiltration equation between **Horton's Equation, Green-Ampt Method and Curve Number Method.**

There is no general agreement on which model is best. The Horton model has a long history of use in dynamic simulations, the Green-Ampt model is more physically-based, and the Curve Number model is derived from (but not the same as) the well-known SCS Curve Number method used in simplified runoff models [3].

In this study the **Green-Ampt Method** is used. This method for modeling infiltration assumes that a sharp wetting front exists in the soil column, separating soil with some initial moisture content below from saturated soil above. The input parameters required are the initial moisture deficit of the soil, the soil's hydraulic conductivity, and the suction head at the wetting front.

SWMM also allows the infiltration recovery rate to be adjusted by a fixed amount on a monthly basis to account for seasonal variation in such factors as evaporation rates and groundwater levels. This optional monthly soil recovery pattern is specified as part of a project's Evaporation data.

Routing Method. This option determines which method is used to route flows through the conveyance system. The choices are Steady Flow, Kinematic Wave and Dynamic Wave.

The Dynamic Wave routing is used in this study. It's the most powerful of the flow routing methods because it solves the complete one-dimensional Saint Venant equations of flow for the entire conveyance network. This method can simulate all gradually-varied flow conditions observed in urban drainage systems such as backwater, surcharged flow and flooding. Dynamic Wave can simulate looped conduit systems and junctions with more than one link connected downstream (bifurcated systems). The ability to simulate bifurcated systems allows one to model pipes and gutters in parallel [4].

6. RESULTS AND ANALYSES

The land surface hydrological response was generated by SWMM for six rainfall events. Simulations results are presented in Figure 3 and Figure 4. The simulations assumed no on-site detention of stormwater runoff under current conditions, because no development in this region had been constructed with hydrological detention volumes. The hydrograph is defined by a gradual rise and fall of the peak discharge and volume.

In pre-developement conditions almost all the amount of precipitation was retained by the sub-basin, a very small part becoming runoff.

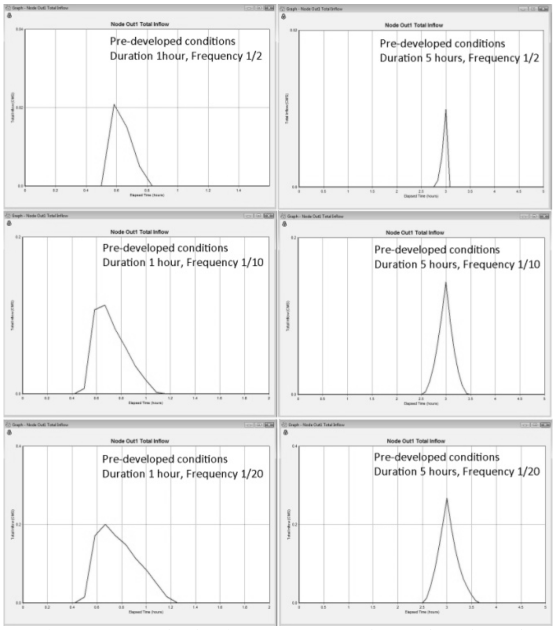

Figure 3. Hydrologic Response of Pre-developed conditions

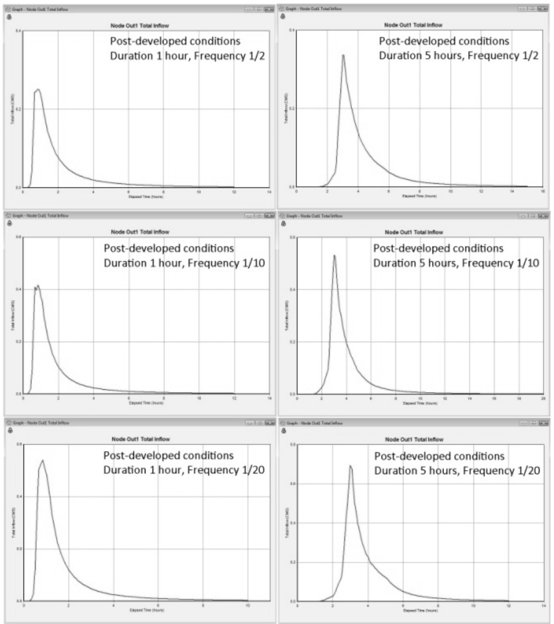

Figure 4. Hydrologic Response of Post-developed conditions

For a better understanding of the effect of impervious areas on runoff generation, runoff coefficient was calculated for every runoff event (Tabel 2). The impervious area represents 76% of this sub-basin, generating a runoff coefficient, on an average value of 0.74.

Tabel 2. Runoff coefficient

Precipitation event	Site condition	Rainfall Frequency	Total runoff volume (mc)	Precipitation (mm)	Runoff coefficient
1 hour	pre-developed conditions	1/2	12.291	20.16	0.0064
		1/10	127.507	28.44	0.0468
		1/20	291.451	33.84	0.0899
	post-developed conditions	1/2	1393.749	20.16	0.7217
		1/10	2004.467	28.44	0.7357
		1/20	2409.277	33.84	0.7432
5 hours	pre-developed conditions	1/2	4.424	28.98	0.0016
		1/10	167.512	41.40	0.0422
		1/20	390.065	50.40	0.0808
	post-developed conditions	1/2	2025.202	28.98	0.7295
		1/10	2944.656	41.40	0.7425
		1/20	3616.487	50.40	0.7490

The small values of runoff coefficient for pre-developed conditions can be explained by the fact the precipitation events used have no more than 50 mm of rain. Pompiliu Miță and Simona Mătreață conclude that water retain by a forest soil in b.h. Humăria for 50 mm of rain is more than 40 mm (besides litter and crowning retention) [1].

7. CONCLUSIONS

This paper has summarized the non-calibrated simulation as one analyzes the amplitude and the timing of runoff response to changes in land use and land cover produced in urbanized watersheds. Pre-developed and post-developed surface runoffs were compared for six-rainfall events. The simulations assumed a rainfall regime and channel network faithful as possible to the existing, focusing mainly on the land cover changes from pre- to post-development conditions. Necessary data and information of the study area have been collected and measured on site as the input of models.

Rainfall, land-use and land-cover, the drainage system, the soil and hydraulic conditions in developed areas provide a useful model for evaluating the sub-catchments runoff.

Alterations of the hydrologic regime as a result of development, increase imperviousness, include: modification of the flow pattern, increase in runoff volume, increases in flow frequency, duration, and peak runoff rate, reduce in infiltration (implicitly groundwater recharge).

For more accurate results model calibration is a need.

6. ACKNOWLEDGEMENT

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