CONTINUOUS SIMULATION CONCEPT: COMPARISON OF SWMM AND SMADA MODEL

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Abstract

The purpose of this paper is to compare the continuous simulation portions of the EPA's Storm Water Management Model (SWMM) and the Stormwater Management and Design Aid (SMADA). Due to the complexity of both models, only the hydrological portions of both programs will be investigated, specifically infiltration techniques and hydrograph generation methodology. In order to accomplish a comparative model, the characteristics of two developed watersheds located in Florida were used; one in Panama City and the other in the city of Miami. Earthinfo™ CD provided approximately ten years of continuous hourly rainfall data corresponding to each site that was used for the simulations.

Introduction

Continuous rainfall simulation is a concept that has been around for many years. However, due to its complexity, time constraints and availability of reliable data it has not been fully developed. With the increasing processor speed of computers, the widespread use of CD-ROM databases, and the development user-friendly computer programs, continuous simulation has become a more viable option. Hydrologic software with the capability of performing continuous simulation has been developed by universities, government agencies, and private firms. Two models will be compared in this paper; the Environmental Protection Agency (EPA) Stormwater Management Model (SWMM) and the University of Central Florida Stormwater Management and Design Aid (SMADA). Background of each model, model development, inputs and output will be compared.

Background

SWMM

SWMM is the United States Environmental Protection Agencies (EPA) Storm Water Management Model (SWMM). It is a comprehensive computer model developed for the analysis of quantity and quality problems associated with urban runoff. Both single-event and continuous simulation can be performed for prediction of flows, stages and pollutant concentrations. SWMM was originally developed in the FORTRAN programing language for the EPA between 1969 and 1971 (Metcalf and Eddy, 1971) and was the first comprehensive model of its type for urban runoff analysis. Maintenance and improvements to SWMM led to Version 2 in 1975, Version 3 in 1981 and now Version 4 (Huber, 1988 and Roesner, 1988). Version 4.3 of SWMM (November 1993) is the latest edition. Although the historical basis of this model was for analysis of urban runoff quality problems, the model often is used just for hydrologic and hydraulic analysis. SWMM can simulate all aspects of the urban hydrologic and water quality cycles, including rainfall, snowmelt, surface and subsurface runoff, flow routing through drainage networks, storage and treatment. The model also has the capability of performing statistical analyses on long-term continuous precipitation data and on output from continuous simulation. The model is designed for use by engineers and scientists experienced in urban hydrological and water quality processes. Although the user manual explains most computational algorithms, an engineering background is necessary to appreciate most methods being used and to verify that the model results are reasonable.

SWMM - Infiltration Equation: In order to account for the infiltration capacity of the soil, SWMM makes use of the Horton equation. The basic Horton equation is given as:

$$f = f_c + \left(f_o - f_c \right) e^{-kt} \tag{1}$$

where
- f = infiltration capacity of the soil, ft/sec
- f_c = ultimate value of f (at $t = \infty$), ft/sec
- f_o = Initial value of f (at $t = 0$), ft/sec
- t = time from beginning of storm, sec
- k = decay coefficient, sec^{-1}

As typical rainfall intensities in the State of Florida are less than most representative f_c and f_o for corresponding watersheds, an exaggerated decrease in infiltration capacity will occur, regardless of the actual volume of water entering the soil. This is possible due to the fact that Horton's infiltration equation is time based in nature rather than volume based. In order to correct this problem, SWMM uses the integrated form of the Horton Equation:

$$F = f_c t_p + \frac{\left(f_0 - f_c\right)}{k}\left(1 - e^{-kt_p}\right) \tag{2}$$

where F = cumulative infiltration at time t_p, in feet

Since this equation cannot be solved directly for t_p, an iterative solution becomes the only feasibile solution. Using the iterative solution, the result yields the infiltration rate at the end of the rainfall period as a function of the total amount of water infiltrated.

Horton Recovery: Horton's recovery constant (k′) is used to restore infiltration capacity of the soil during inter-event dry periods. When using continuous simulation procedures the infiltration capacity of the soil must be tracked from storm to storm. During dry periods, the infiltration capacity of the soil will increase. Therefore in using the continuous portion of SWMM, the Horton recovery equation is modified as:

$$f = f_o - (f_o - f_c)e^{-k'(t-t_w)} \tag{3}$$

where k' = decay coefficient for the recovery curve
t_w = projected time at which $f = f_c$, sec^{-1}

SWMM uses a user defined ratio (R) of k to find k′. An iterative procedure is used to determine the value of t_w. A detailed description of this procedure can be seen in the SWMM user's manual (Huber, 1985).

SMADA

SMADA (Storm Water Management And Design Aid) was developed as an educational tool for use in the civil/environmental departments at the University of Central Florida. It is composed of several Windows based modules to aid in hydrograph development, the design of pipe systems, statistical regresion analysis, and statistical distribution analysis. The hydrograph development portion of the program is capable of handling both single event and continuous simulation. The original release of SMADA was written in GW Basic (Wanielista, 1993). In 1987 the second release of SMADA was rewritten in Quickbasic, by Dr. Ronald Eaglin, improving the user interface. In its third release SMADA was ported to the PDS programing language adding the RETEN and REGRESS programs to the package. In 1991 SMADA was rewritten from scratch (version 4) in C++. The most recent version is 6 which is written Visual Basic. Continuous simulation analysis was added with revision 12 of version 6 (version number 6.12) of the SMADA program. Various incremental revisions add different capbabilities to the program and address various issues of bugs and capabilities (Eaglin, 1996).

SMADA - Infiltration Equation: SMADA uses a similar approach to account for infiltration. It begins with Horton's equation:

$$f = f_c + (f_o - f_c)e^{-kt} \tag{1}$$

This equation is then integrated to solve for cumulative infiltration resulting in:

$$F = f_c t + \frac{(f_0 - f_c)}{k}\left(1 - e^{-kt}\right) \tag{2}$$

Since infiltration is dependent on cumulative infiltration and not time, a series of substitution is performed to eliminate time from the equation. Rearranging eqn (1) and substituting into eqn (2) yields :

$$F = f_c t + \frac{(f_o - f_c)}{k} - \frac{(f - f_c)}{k} \quad (3)$$

Multiplying both sides of the equation by k :

$$Fk = f_c tk + f_o - f \quad (4)$$

Also rearranging eqn (1) to obtain a equation for e^{-kt} :

$$e^{-kt} = \left(\frac{f - f_c}{f_o - f_c}\right) \quad (5)$$

and taking the natural log of both sides of eqn (5) and solving for t yields:

$$t = \frac{\ln\left(\frac{f - f_c}{f_o - f_c}\right)}{-k} \quad (6)$$

Substituting eqn (6) into eqn (4) and solving for f, yields the Horton equation in terms of cumulative infiltration:

$$f = f_o - f_c \ln\left(\frac{f - f_c}{f_o - f_c}\right) - Fk \quad (7)$$

Recovery Equation: SMADA also uses a modified version of the Horton equation to account for recovery of infiltration capacity.

$$f_p = f_o - \left(f_o - f_t\right)e^{-k't} \quad (8)$$

Where f_t = the infiltration rate at some time t, inches/hour
k' = is the recovery coefficient
t = time to next storm event, hours

In using this equation, the iterative procedure used in SWMM is not necessary. Since all variables in the above equation are defined in either the selected rainfall data set or the required user-defined watershed parameters, the equation can be solved directly.

Data Collection and Analysis

Data for two watersheds were chosen, one located in Miami, Florida and the other located in Panama City, Florida. These sites were chosen on the basis of best available rainfall data with minimum missing data and geographic location. A detailed description of the sites selected is presented in Table 1.

Table 1. Watershed Details

	Miami	Panama City
Watershed Total Area	14.7 Acres	40 Acres
Impervious Area	6.47 Acres	15 Acres
Directly Connected Impervious Area	85 Percent	80 Percent
Manning's n (Impervious)	0.01	0.01
(Pervious)	0.2	0.2
Slope	0.04	0.01
Additional Abstraction (Impervious)	0.01 inches	0.1 inches
Additional Abstraction (Pervious)	0.15 inches	0.2 inches
Horton Initial Rate	1.0 in/hr	30 in./hr.
Horton Limiting Rate	0.50 in/hr	5 in./hr.
Depletion Coefficient	0.10 /hr.	1.0 /hr.
Recovery Coefficient	0.05 /hr.	0.1 /hr.

The rainfall data was retrieved from Earthinfo^{tm} CD-ROM. Earthinfo^{tm}, a company located in Boulder, Colorado, collects data from proprietary hydrological databases namely the National Climatic Data Center, United States Geologic Survey, Environmental Protection Agency STORET, and Environmental Canada HYDAT, and provides this data in a DOS based CD-ROM format.

The rainfall used was the hourly rainfall exported from the Earthinfo CD. The period selected for Miami was from 1984 to 1992, and the period selected for Panama City was from 1972 to 1981. These periods were chosen due to the absence of problems related to data collection. One limitation of the Earthinfo^{tm} database is that sets of data could be combined, leading to erroneous information. The periods selected were manually checked for these inaccuracies.

SWMM Data Requirements: For hydrologic simulation in the Runoff Block, data requirements include area, imperviousness, slope, roughness, width (a shape factor), depressional storage, monthly evaportaion (optional), and infiltration parameters for the Horton equation. Additional data are required if simulation of snowmelt, subsurface drainage, and infiltration/inflow options are employed. These simulations were not considered in this paper. Through the use of the Rainfall block, rainfall data can be imported in several formats, including direct export from the Earthinfo^{tm} CDs. Additionally, SWMM has several other program blocks that each would require information. These blocks include a Transport block, a Storage/Treatment block, an Extended Transport block (EXTRAN), a statistics block, and a temperature block. Each of these blocks functions independently of the other, and since they were not necessary for the topics considered in this paper, will not be discussed further.

Output: Basic SWMM output consists of hydrographs and pollutographs (concentration vs. time) at any desired location in the drainage system. Depths and velocities are also available as are summary statistics on surcharging, volumes, continuity and other quantity parameters. The Statistics Block may be used to separate hydrographs and pollutographs into storm events and then compute statistics on parameters such as volume, duration, intensity, interevent time, load, average concentration, and peak concentration. Either metric or U.S. customary units may be used.

Most output is tabular. Graphics are accessed through exports to spreadsheets or other graphics packages and through third party software for pre- and post-processing. Links to Geographic Information Systems are also available (6,7).

SMADA

Data Requirements: Data requirements for SMADA include area, impervious area, initial abstraction, and infiltration parameters for the Horton equation. Hourly and fifteen minute rainfall data can be used, but it must be exported from EarthInfo^{tm} in comma delimited ascii format. An additional parsing program has been developed to convert the ascii format into a SMADA inport format.

Output: SMADA output is both tabular and graphical. In addition to hydrograph information the output includes length of interevent period, peak flow rate, time to peak, infiltration volumes, initial and final infiltration, and if pond routing is used, the initial and peak stages are also provided. The data can be easily imported into a spreadsheet for further data analysis.

Simulation Results

Total Monthly Runoff (inches) for Miami	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1984 SWMM 1	0.076	0.297	3.319	2.782	4.958	3.323	3.326	2.907	4.822	1.041	1.787	0.309
SWMM 2	0.076	0.294	3.505	2.919	5.001	3.355	3.335	3.021	4.893	1.024	1.771	0.304
SWMM 3	0.075	0.292	3.602	2.986	5.060	3.397	3.371	3.092	4.958	1.016	1.772	0.302
SMADA	0.000	0.122	2.954	2.455	4.017	2.712	2.478	2.504	3.847	0.595	1.254	0.168
1985 SWMM 1	0.149	0.021	0.593	1.462	1.523	2.803	5.385	6.779	3.968	2.291	0.602	1.518
SWMM 2	0.146	0.022	0.585	1.461	1.572	2.768	5.454	7.013	4.036	2.264	0.593	1.506
SWMM 3	0.145	0.022	0.581	1.475	1.609	2.765	5.505	7.168	4.107	2.270	0.588	1.504
SMADA	0.078	0.000	0.414	1.074	1.305	2.105	4.291	6.013	3.268	1.627	0.330	1.113
1986 SWMM 1	2.218	0.747	5.023	0.314	4.604	4.347	3.498	3.757	1.947	1.753	2.177	0.974
SWMM 2	2.202	0.743	5.110	0.309	4.734	4.429	3.479	3.836	1.918	1.734	2.194	0.958
SWMM 3	2.204	0.742	5.179	0.307	4.813	4.496	3.510	3.896	1.919	1.734	2.217	0.952
SMADA	1.740	0.557	4.141	0.209	3.936	3.435	2.646	3.037	1.379	1.257	1.645	0.600
1987 SWMM 1	0.382	1.220	1.685	0.164	2.293	3.436	2.510	1.429	4.970	2.066	2.185	1.890
SWMM 2	0.375	1.256	1.664	0.160	2.332	3.568	2.551	1.405	5.165	2.125	2.155	1.887
SWMM 3	0.373	1.282	1.660	0.159	2.386	3.642	2.580	1.403	5.316	2.164	2.147	1.895
SMADA	0.241	0.975	1.251	0.087	1.746	2.982	1.929	1.049	4.389	1.649	1.519	1.540
1988 SWMM 1	0.825	0.267	0.166	0.793	2.497	4.851	4.872	3.648	1.450	0.660	0.333	0.050
SWMM 2	0.813	0.262	0.163	0.786	2.549	4.955	4.871	3.709	1.486	0.647	0.327	0.050
SWMM 3	0.809	0.261	0.161	0.790	2.598	5.053	4.915	3.763	1.512	0.642	0.324	0.049
SMADA	0.511	0.172	0.088	0.613	2.064	3.930	3.773	2.859	1.072	0.441	0.179	0.022
1989 SWMM 1	0.290	0.307	0.385	0.941	0.434	5.022	1.571	6.650	2.655	1.162	0.442	0.271
SWMM 2	0.286	0.302	0.380	0.925	0.426	5.149	1.543	6.964	2.677	1.149	0.432	0.264
SWMM 3	0.284	0.301	0.377	0.923	0.422	5.258	1.540	7.126	2.719	1.148	0.427	0.261
SMADA	0.168	0.192	0.185	0.654	0.204	4.312	0.969	5.742	2.074	0.845	0.236	0.118
1990 SWMM 1	0.099	0.519	1.012	3.500	3.863	3.276	2.011	5.702	1.546	2.215	0.730	0.445
SWMM 2	0.098	0.509	1.014	3.579	3.991	3.374	2.037	5.906	1.530	2.227	0.721	0.441
SWMM 3	0.097	0.506	1.021	3.623	4.071	3.445	2.059	6.039	1.530	2.244	0.717	0.438
SMADA	0.028	0.342	0.663	2.864	3.227	2.812	1.421	4.990	1.052	1.689	0.501	0.249
1991 SWMM 1	0.695	0.896	1.017	2.615	1.102	3.326	3.273	4.698	5.181	11.970	0.519	0.071
SWMM 2	0.687	0.885	1.007	2.730	1.090	3.299	3.246	4.912	5.236	12.364	0.510	0.071
SWMM 3	0.685	0.881	1.003	2.812	1.088	3.301	3.259	5.066	5.297	12.636	0.505	0.071
SMADA	0.390	0.629	0.752	2.194	0.770	2.469	2.381	4.160	3.998	10.983	0.260	0.022
1992 SWMM 1	0.787	0.652	1.167	1.078	0.239	6.153	1.904	3.359	3.456	0.891	8.543	0.852
SWMM 2	0.779	0.645	1.160	1.086	0.236	6.226	1.915	3.402	3.562	0.880	8.669	0.844
SWMM 3	0.779	0.641	1.160	1.099	0.233	6.295	1.936	3.442	3.624	0.881	8.727	0.844
SMADA	0.573	0.447	0.898	0.857	0.152	4.884	1.440	2.701	2.850	0.600	7.452	0.315

Total Monthly Runoff (inches) for Panama City												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1972 SWMM 1	1.151	3.859	2.161	0.336	1.600	2.651	0.933	2.217	1.649	1.222	1.342	2.316
SWMM 2	1.141	3.821	2.124	0.327	1.579	2.630	0.914	2.170	1.613	1.201	1.332	2.307
SWMM 3	1.129	3.794	2.103	0.322	1.567	2.616	0.901	2.147	1.598	1.193	1.320	2.292
SMADA	0.600	2.714	1.410	0.210	1.080	1.889	0.540	1.335	1.080	0.810	0.810	0.570
1973 SWMM 1	2.153	2.171	4.854	1.934	2.941	2.518	2.834	1.997	2.588	0.344	1.117	0.000
SWMM 2	2.127	2.151	4.817	1.901	2.894	2.476	2.787	1.962	2.532	0.336	1.097	0.000
SWMM 3	2.109	2.135	4.795	1.883	2.872	2.465	2.769	1.936	2.500	0.332	1.084	0.000
SMADA	1.305	1.440	3.464	1.320	1.979	1.754	1.619	1.020	1.514	0.210	0.630	0.030
1974 SWMM 1	0.000	0.000	1.010	0.811	0.835	1.112	2.566	2.068	3.046	0.188	1.186	1.368
SWMM 2	0.000	0.000	0.987	0.798	0.823	1.091	2.516	2.035	3.015	0.185	1.166	1.358
SWMM 3	0.000	0.000	0.973	0.789	0.815	1.082	2.488	2.011	2.995	0.183	1.152	1.350
SMADA	0.000	0.000	0.600	0.480	0.510	0.630	1.455	1.050	2.069	0.120	0.750	0.900
1975 SWMM 1	4.154	1.493	2.186	2.258	1.001	0.120	8.084	4.025	2.957	2.422	1.045	1.606
SWMM 2	4.123	1.481	2.163	2.236	0.985	0.120	7.997	3.937	2.923	2.385	1.032	1.595
SWMM 3	4.102	1.470	2.148	2.219	0.972	0.118	7.954	3.890	2.898	2.365	1.019	1.581
SMADA	2.849	0.870	1.410	1.485	0.510	0.000	5.848	2.489	1.949	1.679	0.510	0.930
1976 SWMM 1	1.787	0.343	1.755	1.078	3.122	2.232	1.430	2.185	1.248	2.597	2.462	1.927
SWMM 2	1.774	0.339	1.739	1.075	3.082	2.198	1.403	2.133	1.226	2.576	2.449	1.903
SWMM 3	1.764	0.334	1.726	1.071	3.059	2.178	1.386	2.105	1.211	2.559	2.430	1.885
SMADA	1.170	0.150	1.110	0.900	1.889	1.440	0.840	1.290	0.690	1.739	1.559	1.140
1977 SWMM 1	2.194	0.944	1.681	0.263	0.519	0.192	3.924	3.869	2.138	0.536	1.762	1.902
SWMM 2	2.166	0.936	1.667	0.260	0.512	0.185	3.874	3.791	2.099	0.527	1.747	1.882
SWMM 3	2.148	0.929	1.655	0.257	0.506	0.181	3.847	3.744	2.075	0.519	1.732	1.870
SMADA	1.320	0.615	1.050	0.150	0.300	0.090	2.729	2.279	1.320	0.225	1.020	1.305
1978 SWMM 1	2.069	1.264	3.105	1.209	3.450	2.664	4.868	2.503	1.113	0.032	1.305	1.353
SWMM 2	2.038	1.256	3.082	1.194	3.412	2.608	4.795	2.447	1.096	0.032	1.291	1.341
SWMM 3	2.011	1.245	3.072	1.185	3.400	2.575	4.755	2.416	1.083	0.032	1.280	1.335
SMADA	1.140	0.750	2.249	0.870	2.489	1.574	3.149	1.514	0.660	0.000	0.780	0.960
1979 SWMM 1	3.204	2.527	0.567	2.513	2.266	1.704	4.794	3.185	3.626	0.032	1.362	1.223
SWMM 2	3.178	2.506	0.562	2.494	2.240	1.677	4.723	3.133	3.583	0.032	1.349	1.210
SWMM 3	3.158	2.490	0.556	2.479	2.222	1.667	4.681	3.109	3.553	0.032	1.332	1.199
SMADA	2.219	1.619	0.270	1.799	1.440	1.230	3.164	2.099	2.429	0.000	0.540	0.735

Total Monthly Runoff (inches) for Panama City												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1980 SWMM 1	2.193	0.495	4.301	3.218	1.313	3.649	3.713	2.827	2.079	1.612	0.953	0.147
SWMM 2	2.164	0.488	4.252	3.162	1.291	3.599	3.641	2.774	2.050	1.593	0.945	0.145
SWMM 3	2.145	0.482	4.220	3.132	1.279	3.571	3.607	2.752	2.032	1.583	0.936	0.143
SMADA	1.320	0.240	2.924	2.189	0.750	2.534	2.519	1.964	1.260	0.990	0.555	0.060
1981 SWMM 1	0.707	3.152	1.923	0.036	0.482	1.303	2.313	2.864	0.393	0.654	0.738	1.851
SWMM 2	0.704	3.122	1.895	0.036	0.478	1.290	2.270	2.815	0.387	0.650	0.721	1.835
SWMM 3	0.700	3.108	1.884	0.035	0.474	1.276	2.241	2.789	0.380	0.641	0.711	1.817
SMADA	0.450	2.129	1.350	0.000	0.300	0.720	1.245	1.694	0.120	0.240	0.420	0.990

Analysis and Results

During the analysis of the continuous simulation, obvious differences in methodology are causing the discrepancies between the two programs. The same set of data, watershed characteristics and rainfall statistics, were used in both programs. SMADA consistently produced lower amounts of rainfall excess. This was due to its handling of additional abstraction in cases where very small rainfall amounts occurred. In many small rainfall events no runoff was recorded, all rainfall went to infiltration and abstraction and no excess was recorded.

The recovery methodology used by SWMM differs from that of SMADA in that SWMM has a user defined coefficient that is multiplied by the decay coefficient to obtain this value for k'. The problems occur when trying to estimate a reasonable value for this variable. SMADA is similar in the fact that the user must identify both coefficients, but unlike SWMM, there is no correlation between the recovery and decay coefficients. Futher examination into these differences should be explored.

Conclusions

Of these models SMADA is easier to use. The graphical input is easy to learn and understand, and the output is easier to work with. The biggest impediment to SWMM usage is the user interface, with its lack of windows like interfaces (GUI) and spreadsheet ready output. SWMM is still run in a batch mode (the user constructs an input file with an text editor), unless third-party software is used for pre- and post-processing.

The values given by SWMM are more conservative than those provided by SMADA and further research is needed to determine which is more accurate. SWMM also has the advantage of being able to read the export file created by the Earthinfo CD directly, whereas this file must be first parsed to use SMADA.

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