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# Project Summary

# Storm Water Management Model User's Manual, Version 4

Wayne C. Huber, Robert E. Dickinson, Larry A. Roesner, and John A. Aldrich

**Version 4 of the U.S. Environmental Protection Agency's (EPA) Storm Water Management Model (SWMM) is the latest edition of this comprehensive computer model for analysis of quantity and quality problems associated with urban runoff. Both single-event and continuous simulation may be performed on catchments having storm sewers, combined sewers and natural drainage, for prediction of flows, stages and pollutant concentrations anywhere in the system. The EXTRAN Block solves the complete dynamic flow routing equations (the St. Venant equations) for accurate simulation of backwater, looped connections, surcharging, and pressure flow. Using the total SWMM package the modeler can simulate all aspects of the urban hydrologic and quality cycles, including rainfall, snowmelt, surface and subsurface runoff, flow routing through the drainage network, storage and treatment. Statistical analyses may be performed on long-term precipitation data and on output from continuous simulation. Version 4 is primarily micro-computer-based, although the Fortran code also may be compiled for use on mainframe computers.**

**Detailed descriptions are provided for all blocks (program modules). Simulation of hydrologic and quality processes is performed by the Runoff, Transport, EXTRAN, and Storage/Treatment Blocks. Overall program operation is monitored by the Executive Block, the Statistics Block is used for statistical analysis of output time series, the Graph Block for line-printer graphics of hydrographs and pollutographs, the Combine Block for combining output files, and the Rain and Temp Blocks for input of time series of precipitation, temperatures, wind speeds and evaporation. The Rain Block also incorporates statistical evaluation of long-term precipitation data formerly available only in the EPA SYNOP model. Detailed information is provided on the theoretical background of the model algorithms as well as on model input data and model use.**

***This Project Summary was developed by EPA's Environmental Research Laboratory, Athens, GA, to announce key findings of the research project that are fully documented in a two-part report (see Project Report ordering information at back).***

## Introduction

Urban runoff quantity and quality have long posed problems for cities that have for many years assumed the responsibility of controlling stormwater flooding and treatment of point sources of wastewater (e.g., municipal sewage). Within the past two decades, the severe pollution potential of urban nonpoint sources (principally combined sewer overflows and stormwater discharges) has been recognized, and federal, state and local legislation has been enacted for management and control. Massive studies and data collection efforts -- notably the EPA Nationwide Urban

Runoff Program of the early 1980s -- have led to a much better understanding of the problems of urban runoff and of methods available for its control. The advent of modern, high-speed computers in the 1960s and 70s led to the development of sophisticated tools for analysis of both the quantity and quality of urban runoff. The recent microcomputer "revolution" of the 1980s now makes these tools and data bases readily accessible to all engineers and scientists.

The EPA's SWMM was originally developed between 1969 and 1971 and was the first comprehensive model of its type for urban runoff analysis, although it has certainly not remained the only one. Maintenance and improvements to SWMM led to Version 2 in 1975, Version 3 in 1981 and now Version 4

The model may be used in both planning and design modes. The planning mode is used for an overall assessment of the urban runoff problem and proposed abatement options. This mode is typified by continuous simulation for several years using long-term (e.g., hourly) input of precipitation data. (Temperature data also are required if snowmelt is simulated.) The catchment schematization is usually "coarse" in keeping with the planning and overall assessment level of analysis. The Statistics Block may be used for frequency analysis of the long-term output time series of hydrographs and pollutographs (plots of concentration vs. time) and for identification of individual hydrologic events that may be of special interest for detailed design or other purposes. A design-level, event simulation also may be run using a detailed catchment schematization and shorter time steps for any desired precipitation input.

Although the historical basis of the model was for analysis of urban runoff quality problems, the model often is used for pure drainage, hydrologic and hydraulic analysis. The EXTRAN Block has proven especially valuable for sophisticated hydraulic analysis of urban drainage networks.

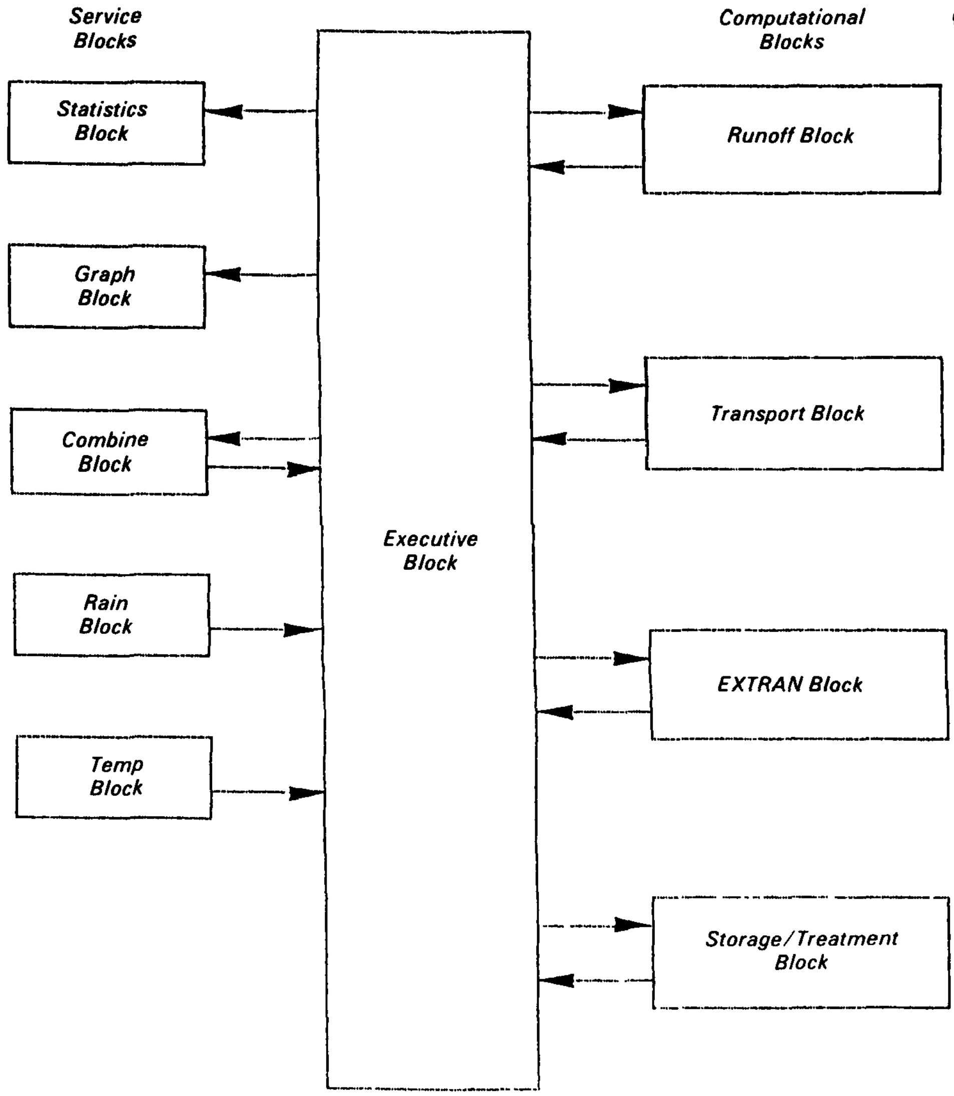


***Figure 1.*** *Relationship Among SWMM Blocks. Executive Block manipulates interface file and other off-line files. All blocks may receive off-line input (e.g., tapes, disks) and user line input (e.g., terminal, cards, etc.).*

## Overall SWMM Description

### *Computational Blocks*

An overview of the model structure appears in Figure 1. In simplest terms, the program is constructed in the form of four blocks (program modules):

1. The input sources. The Runoff Block generates surface and subsurface runoff based on arbitrary rainfall (and/or snowmelt) hyetographs, antecedent conditions, and hydrologic characteristics of the catchment. Dry-weather flow and infiltration into the sewer system may be generated using the Transport Block. Surface runoff quality is generated based on conceptual buildup-washoff relationships and/or rating curve relationships and by other optional mechanisms.

2. The central cores. The Runoff, Transport and EXTRAN (Extended Transport) Blocks route flows and pollutants through the sewer or drainage system. (Pollutant routing is not performed by EXTRAN.) The Transport and EXTRAN Blocks also may be used with natural cross sections, input in the format used by the Corps of Engineers, Hydrologic Engineering Center, HEC-2 model. The EXTRAN Block will solve the complete St. Venant equations for gradually varied, unsteady flow, and thus can produce very sophisticated simulations of flows and heads in the drainage network. In-system storage (e.g., detention ponds) may be simulated in both the Transport and EXTRAN Blocks.

. The correctional devices. The Storage/Treatment Block performs storage-index flow routing and simulates removal processes by removal functions or sedimentation theory. Elementary cost computations also may performed.

4. The effect (receiving waters). SWMM does not include a receiving water model, but a linkage to the EPA WASP and DYNHYD models is provided.

Simulation output is in the form of time series of hydrographs, heads (from the EXTRAN Block) and pollutographs at any desired location in the system. The Statistics Block also may be used to perform an event separation and frequency analysis of any time series, including input precipitation.

Quality constituents for simulation may be arbitrarily chosen for any of the blocks (except for EXTRAN, which does no quality simulation), although the different blocks have different constraints on the number and type of constituents that may be modeled.

### *Service Blocks*

n addition to the four computational ..ocks described above, six service blocks are used:

Executive Block. This block creates off-line files and monitors the sequential execution of all blocks. An "interface file" is used for transmission of output time series from one block for use as input to another.

Graph Block. Line-printer plots of hydrographs, pollutographs and certain other time series may be obtained using this block.

Combine Block. This block allows the manipulation of multiple interface files in order to aggregate results of multiple previous runs for input into subsequent blocks. In this manner large, complex drainage systems may be partitioned for simulation in smaller segments. An ASCII version of the interface file also may be created for ready access by other microcomputer software.

Rain and Temp Blocks. Continuous simulation relies upon precipitation input using long-term data available on magnetic tapes from the National Climatic Data Center in Asheville, NC (or from the Atmospheric Environment Service in Canada). Temperature, wind ed and evaporation data also may ..quired for some applications (e.g., snowmelt). The Rain and Temp Blocks process such long-term input data for use by SWMM. The Rain Block also may be used to perform an event separation and statistical analysis of rainfall data in the manner of the EPA SYNOP ("Synoptic Precipitation") model.

Statistics Block. This block has the capability to evaluate the time series output from a continuous (or single event) simulation, separate output into discrete storm events, rank the events according to almost any desired criterion (e.g., peak or average runoff rate, pollutant load, etc.), assign empirical frequencies and return periods to runoff and pollutant parameters, tabulate and graph the results, and calculate statistical moments. Output from this block thus may be used to identify key events for further study and for many other screening and analytical purposes.

## User Requirements

### *Personnel*

The model is designed for use by engineers and scientists experienced in urban hydrological and water quality processes. Although the user's manuals explain most computational algorithms, an engineering background is necessary to appreciate most methods being used and to verify that the model results are reasonable.

### *Computer Facilities*

SWMM Version 4 is principally microcomputer based, although the Fortran code may be compiled on any machine. The largest of the individual blocks is about 500 K bytes. Depending upon the memory capacity of the machine, an overlay procedure may or may not be necessary for compilation and linking of the whole model.

The compiled EPA version of the model requires an IBM PC, AT or compatible microcomputer with 640 K RAM. A math co-processor and hard disk are recommended. Execution times are on the order of a few to several minutes for most jobs. Simulation of large areas with many subcatchments and/or channels for many time steps, however, can require several hours on a microcomputer.

## Data Requirements

### *Input Data*

Depending upon the simulation objective, input data requirements can be minimal to extensive. For simulation of a complete drainage network, data collection from various municipal and other offices within a city is possible to accomplish within a few days, but reducing the data for input to the model may take up to 3 person-weeks for a large area (e.g., greater than about 2000 acres). For an EXTRAN simulation of sewer hydraulics, expensive and time-consuming field verification of sewer invert elevations often is required.

On an optimistic note, however, most data reduction--tabulation of slopes, lengths and diameters--is straightforward. SWMM is flexible enough to allow different modeling approaches to the same area. A specific, individual modeling decision upstream in the catchment may have little effect on the predicted results at the outfall. Furthermore, many problems lend themselves to a very low level of detail, especially for quality predictions. In such cases, input data requirements are greatly reduced. Input (and output) to all blocks can be in either U.S. customary or metric units.

### *Calibration and Verification Data*

Calibration data are measured hydrographs and pollutographs for use in establishing values of input parameters for which *a priori* estimates are insufficient. For example, for simulation of surface runoff quantity, imperviousness often is used to calibrate hydrograph volumes, and subcatchment width (a shape parameter) often is used to calibrate hydrograph peaks. In many cases, it is possible to obtain good agreement between pedicted and measured hydrographs with little calibration effort. This is not true for quality simulation for which calibration data are essential to obtain credible simulations of pollutographs. Without such measured concentrations and loads, SWMM quality simulation is at best only suited for relative comparisons between control strategies and should not be relied upon for prediction of absolute magnitudes of concentrations and loads.

Verification data are provided in the form of additional measured hydrographs and pollutographs so that the parameter estimates made during the calibration phase can be checked. No firm numbers can be given for the required amount of calibration and verification events, but six of each should provide a robust calibration and verification.

## Changes for Version 4

Not all users will require Version 4, however, because in most respect the computations are identical to Version 3. Significant modifications ar listed below.

1. Input/output has been enhanced. All input is free-format with line (data group) identifiers. The line identifiers are now a requirement because the program uses them as the only means of separating one data group from another. Program-generated error messages make it easier to locate problems caused by improper entry of data. Input strings of up to 230 characters are allowed in SWMM 4. Strict column sequencing of input data is still possible as long as at least one space separates the fields.

Comment lines are allowed in this version of SWMM. A comment line begins with an asterisk in the first column. A template for full screen editing is included as an example for each block of SWMM. The templates include brief comments about each input field.

2. Errors have been corrected for all blocks as best they are known.

3. EXTRAN is available in a metric format and uses data group identifiers. Additional features include: a "hot start" capability (restart from end of previous run); natural channel cross sections, with cross-sections input as in HEC-2 (also available in the Transport Block); minor improvements to surcharge and flow routing routines; pump rating curves; and automatic adjustment of small pipe lengths.

4. SWMM output may be linked to the DYNHYD4 (water quantity) and WASP4 (water quality) programs for receiving water quality simulation. (These models are supported by the EPA Center for Exposure Assessment Modeling, Athens, GA.) Runoff, Transport, Storage/Treatment, and EXTRAN interface files can be read by both DYNHYD4 and WASP4. DYNHYD4 reads only the flows from the interface file. WASP4 reads water quality loading rates from Runoff, Transport, and Storage/Treatment. A model of an estuary, therefore, can include Runoff to generate surface pollutant loadings, Transport or EXTRAN for detailed simulation of surface routing network, DYNHYD4 for simulating a link-node estuary model, and WASP4 for simulating the water quality of the estuary under the stress of the Runoff or Transport pollutant loadings.

5. The microcomputer version permits greater manipulation of interface files and other scratch and I/O files. The Combine Block may he used to convert any interface file to formatted (ASCII/text) files capable of being read by programs such as Lotus 1-2-3 or other software. All interface files can be permanently saved and retrieved. Users can input their own interface files.

6. A subsurface routing package (quantity only) has been added to the Runoff Block. A separate accounting is made for the unsaturated and saturated zones, and the water table elevation can fluctuate. Baseflow to Runoff channel/pipes may be generated from the saturated zone.

7. The Runoff Block (through access to the Rain Block) will read the new National Weather Service format for precipitation tapes. In general, continuous simulation is easier, with several options for input of precipitation data and other time series. User-defined input time series also may be used. Continuous simulation is capable of using up to ten rain gages.

Instead of processing continuous meteorological data in the Runoff Block, two new blocks have been added--Rain and Temp. These include the capabilities of the former Subroutine CTRAIN in Runoff with additional statistical analysis similar to the SYNOP program used for EPA area-wide assessment procedures. It also is possible to process rainfall data with SWMM Statistics Block.

8. Numerical methods have been improved in the Runoff Block. A variation of the extrapolation method is used to couple the equations for nonlinear reservoir conditions, evaporation, infiltration, and groundwater flow. Subroutine Gutter no longer has convergence problems. There is no distinction any more between single event and continuous simulation, eliminating parameter ICRAIN. Runoff uses a wet, dry and intermediate (wet/dry) time step defined by the user, thus decreasing the time required for continuous simulation.

9. This version of SWMM uses more Fortran primitives. There is one subroutine to read interface files, one subroutine to write interface files, one clock subroutine, one file-opening routine, etc., for all blocks. The common functions of all blocks are exactly the same.

10. This version can be made more modular than the EPA Version 3 for mcrocomputer. It is possible to run files containing only the blocks of interest, saving the interface file for use by the next block. This permits file compression for ease of distribution and much faster execution times.

11. The Graph Block is no longer limited to 200 data points. An unlimited number of points for both measured and predicted graphs can be plotted on the line printer. The Graph Block plots loadographs (mass/time versus time) or pollutographs (concentration versus time). Enough information is provided about the interface file (containing the hydrograph and pollutograph time series) to permit the use of better graphic capabilities of microcomputers.

12. The user has more control over printout in this version of SWMM. Most printout can be bypassed at the user's discretion. Error messages are summarized at the end of a run instead of being printed every time step.

13. Microcomputer users will see the current time or time step, as well as other program messages, printed on the screen during the simulation.

## When Should SWMM Be Used?

SWMM is a large, relatively sophisticated hydrologic, hydraulic and water quality simulation program. It is not appropriate for all applications or for all personnel, and alternative hydrologic models exist. A large body of literature on theory and case studies is available for SWMM. A bibliography of SWMM related literature is available (EPA/600/3-85/077).

SWMM is certainly formidable both in terms of its size and capabilities. Who, then, should use SWMM and for what purposes? Some criteria for usage are given below:

1. The engineer must be knowledgeable of the modeling techniques (e.g., non-linear reservoirs, kinematic waves, St. Venant equations, buildup-washoff equations). An appreciation for how physical processes may be simulated in a Fortran program is a necessity. As a corollary, the engineer is assumed to be familiar with the problem to be solved and with customary techniques for handling it. A clear problem definition is a prerequisite to any solution methodology.

2. By virtue of the problem size (e.g., sewer system with hundreds of pipes) or complexity (e.g., hydraulic controls, backwater), a sophisticated model must be used. It may be borne in mind, however, that if calibration/verification data are available, SWMM also may be used as a very simple "black box" model with minimal input data, at the expense of computer overhead to manage the program size and off-line files.

3. Quality must be simulated. Although other models also simulate quality, SWMM is perhaps the most flexible. Of course, SWMM often is applied just to quantity problems.

Users more familiar with an adequate alternative methodology are probably better advised to remain with that methodology. In the final analysis, the engineer/analyst is responsible for the decisions made using any technique of analysis; the technique or model is only a tool that must be clearly understood by those using it.

## The Stormwater and Water Quality Model Users Group

This group began as the EPA SWMM User Group and has functioned since 1973 as a forum for discussing all aspects of stormwater quantity and quality modeling. The SWMM program has benefited greatly from user feedback, and the User Group has been a particularly useful means for disseminating information on SWMM and other models. The group is open to all interested modelers. Semiannual meetings are held in the United States and Canada. Information about the group is published in the newsletter of the Center for Exposure Assessment Modeling, which appears periodically. Further information about the Users Group and the newsletter can be obtained from Mr. Thomas 0. Barnwell, Jr., Center for Exposure Assessment Modeling, Environmental Research Laboratory, USEPA, College Station Road, Athens, Georgia 30613 (telephone: (404) 546-3210).

## SWMM Availability

The program (Fortran source code and executable code for microcomputers) is available from the EPA Center for Exposure Assessment Modeling, (CEAM) listed above. Documentation is available from the National Technical Information Service (NTIS -- see last page) and from the report authors. Limited support is also available from the University of Florida. Future updates and improvements will be made through the newsletter of the CEAM.

## Disclaimer

Every attempt has been made to ensure that the SWMM program performs as represented in the documentation, but as with all large computer models, some lingering bugs will persist. The use of SWMM and interpretation of its output must remain the sole responsibility of the user. Neither EPA nor the model authors can assume responsibility for model use or decisions based on model use.

*Wayne C. Huber and Robert E. Dickinson are with the University of Florida, Gainesville, FL 32611; Larry A. Roesner and John A. Aldrich are with Camp, Dresser and McKee, Inc., Maitland, FL 32751 and Annandale, VA 22003, respectively.*
*Thomas O. Barnwell, Jr., is the EPA Project Officer (see below).*
*The complete report consists of two parts, entitled "Storm Water Management Model, Version 4--,"*
*"Part A: Users Manual," (Order No. PB 88-236 641/AS; Cost: $44.95)*
*"Part B: EXTRAN Addendum," (Order No. PB 88-236 658/AS; Cost: $19.95)*
*The above reports will be available only from: (cost subject to change)*
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*College Station Road*
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