

# SWMM Theory

SWMM (Storm Water Management Model) simulates real storm events on the basis of rainfall (hyetograph) and other meteorological inputs and systems (characterization, catchment, conveyance, storage/treatment) to predict outcomes in the form of quantity and quality values. Since study objectives may be directed toward both complete temporal and spatial detail as well as to gross effects such as total pounds of pollutant discharged in a given storm, it is essential to have both time series output, i.e., hydrographs and "pollutographs" (concentrations versus time) and daily, monthly, annual and total simulation summaries available for review.

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## Urban Runoff Analysis

Urban runoff quantity and quality constitute problems of both a historical and current nature. Cities have long assumed the responsibility of control of Stormwater flooding and treatment of point sources (e.g., municipal sewage) of wastewater. Within the past several decades, the severe pollution potential of urban non-point sources, principally combined sewer overflows and Stormwater discharges, has been recognized, both through field observation and federal legislation. The advent of modern, high speed computers has led to the development of new, complex, sophisticated tools for analysis of both quantity and non-point pollution problems. The EPA Storm Water Management Model, SWMM, developed in 1969-71, was one of the first of such models, it has been continually maintained and updated, and is perhaps the best known and most widely used of the available urban runoff quantity/quality models.

Many of the changes that have occurred in SWMM during the past 15 years have been poorly documented and were not readily visible to users. This volume includes documentation of major changes to the model since its original development. Theory that underlies unchanged parts of the model may still be reviewed in the original documentation (Metcalf and Eddy et al., 1971a, 1971b, 1971c, 1971d) plus intermediate reports (Huber et al., 1975; Heaney et al., 1975). This volume supersedes Version 4 documentation (Huber et al., 1988) and includes essentially all material from that manual plus enhancements to the model made by XP Solutions.

## Urban Runoff Models

Models are generally used for studies of quantity and quality problems associated with urban runoff in which four broad objectives may be identified: screening, planning, design and operation. Each objective typically produces models with somewhat different characteristics with the different models overlapping to some degree.

### Screening Models

Screening models are preliminary, "first-cut" ("Level I"), desktop procedures that require no computer. They are intended to provide a first estimate of the magnitude of urban runoff quantity and quality problems, prior to an investment of time and resources into more complex computer based models. Examples of screening models include SWMM Level I procedures (Heaney et al., 1976; Heaney and Nix, 1977) and others: Howard (1976), Hydroscience (1976, 1979), Chan and Bras (1979).

### Planning Models

Planning models are used for an overall assessment of the urban runoff problem as well as estimates of the effectiveness and costs of abatement procedures. They may also be used for "first-cut" analyses of the rainfall-runoff process and illustrate trade-offs among various control options. They are typified by relatively large time steps (hours) and long simulation times (months and years), i.e., continuous simulation. Data requirements are kept to a minimum and their mathematical complexity is low.

SWMM has had this capability since 1976, following the earliest work of the Stanford Watershed Model (Crawford and Linsley, 1966) and the latter widely-used Corps of Engineers STORM model (Roesner et al., 1974; HEC, 1977a).

A planning model may also be run to identify hydrologic events that may be of special interest for design or other purposes. These storm events may then be analyzed in detail using a more sophisticated design model (Huber et al., 1986). SWMM can be used in both the planning and design mode. Planning or long-term models may also be used to generate initial conditions (i.e., antecedent conditions) for input to design models. They may occasionally be coupled to continuous receiving water models as well; for example, SWMM and STORM may be used as input to Medina's (1979) Level III Receiving Water Model.

## Design Models

Design models are oriented toward the detailed simulation of a single storm event. They provide a complete description of flow and pollutant routing from the point of rainfall through the entire urban runoff system and often into the receiving waters as well. Such models may be used for predictions of flows and concentrations anywhere in the rainfall/runoff system and can illustrate the detailed and exact manner in which abatement procedures or design options affect them. As such, these models are a highly useful tool for determining least-cost abatement procedures for both quantity and quality problems in urban areas. Design models are generally used for simulation of a single storm event and are typified by short time steps (minutes) and short simulation times (hours). Data requirements may be moderate to very extensive depending upon the particular model employed.

In its original form (Metcalf and Eddy et al., 1971a, 1971b, 1971c, 1971d), SWMM was strictly a design model. However, as described above, it may now be used in both a planning and design mode. In addition, it has acquired additional design potential through inclusion of the Extended Transport Model, Extran, developed by Camp, Dresser and McKee (formerly Water Resources Engineers). Extran is probably the most sophisticated program available for detailed hydraulic analysis of sewer systems (Shubinski and Roesner, 1973; Roesner et al., 1981; Roesner et al., 1987). Extran forms the basis of the Hydraulics mode of within the program.

## Operational Models

Operational models are used to produce actual control decisions during a storm event. Rainfall is entered from telemetered stations and the model is used to predict system responses a short time into the future. Various control options may then be employed, e.g., in-system storage, diversions, regulator settings.

These models are frequently developed from sophisticated design models and applied to a particular system; Schilling (1985) provides a review. Examples are operational models designed for Minneapolis-St. Paul (Bowers et al., 1968) and Seattle (Leiser, 1974).

## Other Models

SWMM is by no stretch of the imagination the only urban runoff model available, or necessarily the preferred one under some circumstances. Many other urban runoff models have been described in the literature and are too numerous to list here. However, good comparative reviews are available, e.g., Brandstetter (1977), Chu and Bowers (1977), Huber and Heaney (1980, 1982), Kibler (1982), Kohlhaas (1982), EPA(1983a), Whipple et al. (1983) and Hall (1984). EPA's water quality models are reviewed by Barnwell (1984). A general review of methods available for urban quality modelling and six operational urban quality models is provided by Huber (1985, 1986). Many more models are available for purely hydrologic and hydraulic analysis.

## Origin and Historical Developments

Under the sponsorship of the Environmental Protection Agency, a consortium of contractors — Metcalf and Eddy, Incorporated, the University of Florida, and Water Resources Engineers, Incorporated — developed, in 1969-71, the Storm Water Management Model, SWMM, capable of representing urban stormwater runoff and combined sewer overflow phenomena. Both quantity and quality problems and control options may be investigated with the model, with associated cost estimates available for storage and/or treatment controls. Effectiveness can be evaluated by inspection of hydrographs, pollutographs, pollutant loads, and modelled changes in receiving water quality.

The original project report is divided into four volumes. Volume I, the "Final Report" (Metcalf and Eddy et al., 1971a), contains the background, justifications, judgments, and assumptions used in the model development. It further includes descriptions of unsuccessful modelling techniques that were attempted and recommendations for forms of user teams to implement systems analysis techniques most effectively. Although many modifications and improvements have since been added to SWMM, the material in Volume I still accurately describes much of the theory behind updated versions. Documentation of some of the procedures included in the 1975 Version II (Huber et al., 1975) release of SWMM is also provided by Heaney et al. (1975).

Volume II, "Verification and Testing," (Metcalf and Eddy et al., 1971b), describes the methods and results of the application of the original model to four urban catchments.

Volume III, the "User's Manual" (Metcalf and Eddy et al., 1971c) contains program descriptions, flow charts, instructions on data preparation and program usage, and test examples. This was updated in 1975 by the Version II User's Manual (Huber et al., 1971) and in 1981 by the Version 3 User's Manuals (Huber et al., 1981; Roesner et al., 1981). This present report supersedes all of these previous documents.

Volume IV, "Program Listing" (Metcalf and Eddy et al., 1971d), lists the entire original program and Job Control Language (JCL) as used in the demonstration runs. Since many routines in the updated version are similar or identical to the original, it is still a useful reference, but on the whole should be disregarded since the present coding is, in most cases, completely different.

An extensive bibliography of SWMM usage is available (Huber et al., 1985) and is highly recommended for new users. Case studies mentioned in the bibliography are especially useful.

**EXTRAN** the program had its origin in the early 1960's as a model of San Francisco Bay [Shubinski, 1965]. Its early mode was a link-node receiving water model. In the early development of EXTRAN, a constant velocity approach was used, but this was later found to produce highly unstable solutions. Additional capability was added in the early 1970's to simulate the upland areas contributing stormwater runoff to San Francisco Bay.

This new model called EXTRAN was developed for the City of San Francisco in 1973 (Shubinski and Roesner, 1973; Kibler et al., 1975). At that time it was called the San Francisco Model and (more properly) the WRE Transport Model. Water Resources Engineers became wholly integrated into Camp Dresser & McKee, Inc. in 1980. In 1974, EPA acquired this model and incorporated it into the SWMM package, calling it the Extended Transport Model - EXTRAN - to distinguish it from the Transport Block developed by the University of Florida as part of the original SWMM package.

Another big increase in the model capabilities occurred in the middle 1980's when CDM undertook the simulation of Virginia Beach, Virginia, U.S.A., an area with multiple tidal bays and flat areas. The ability to model natural channels with arbitrary cross sections, variable storage areas (i.e., lakes and detention ponds) and multiple tidal boundaries was added to the EXTRAN Model by CDM in the middle 1980's.

Since the release of EXTRAN 2, the model has been refined, particularly in the way the flow routing is performed under surcharge conditions. EXTRAN 2 used surge tanks to model surcharged flow. EXTRAN 3 used an iterative solution to model surcharged flow based on a point junction formulation. EXTRAN 4 added a "Preissmann" slot to model surcharged flow as open channel flow. Most importantly in the 1980's, especially after the release of EXTRAN 4 in 1988, much experience has been gained in the use and misuse of the model by practicing engineers.

## A Description of SWMM

In simplest terms, SWMM is constructed in the form of "blocks" as follows:

1. **The input sources:** The Runoff Block generates surface and subsurface runoff based on arbitrary rainfall (and/or snowmelt) hyetographs, antecedent conditions, land use, and topography. Dry-weather flow and infiltration into the sewer system may be optionally generated using the Transport Block.
2. **The central cores:** The Runoff, Transport and Extended Transport (Extran) Blocks route flows and pollutants through the sewer or drainage system (Pollutant routing is not currently available in the Extran Block). Very sophisticated hydraulic routing may be performed with Extran.
3. **The correctional devices:** The Storage/Treatment Block characterizes the effects of control devices upon flow and quality. Elementary cost computations are also made.
4. **The effect (receiving waters):** SWMM does not include a receiving water model. The Receiving Water Block (Receive) is no longer included within the SWMM framework. However, a linkage is provided for the EPA WASP and DYNHYD models (Ambrose et al., 1986).

Quality constituents for simulation may be arbitrarily chosen for any of the blocks. The Extran Block is the only block that does not simulate water quality.

The Transport, Extran and Storage/Treatment Blocks may all use input and provide output to any block, including themselves. The Runoff Block uses input from no other computational block but may receive input from Rain and Temp Blocks for meteorological input. Within XP these "blocks" have been merged to the Runoff, Sanitary and Hydraulics modes. Some of the time series processing "blocks" now find themselves in the Utilities accessed from the Tools menu.

### Graph Block (replaced by Review Results)

Plots of hydrographs, pollutographs and other time series output may be obtained using the Graph Block. Measured as well as predicted time series may be plotted. Alternatively, the user may access the time series file (known in this manual as the "interface file") for plots by other graphics software.

### Rain Block (now Rain Utility)

Continuous simulation relies upon precipitation input using long-term data available on magnetic tapes from the National Weather Service (NWS) National Climatic Data Center in the United States or Atmospheric Environment Service in Canada. The Rain Block processes NWS tapes for input into the Runoff Block. A synoptic statistical analysis may also be performed on rainfall data, similarly to the EPA SYNOP program (Hydroscience 1976, 1979).

### Temp Block (now Temperature Utility)

In a similar manner, the Temp Block processes NWS long-term temperature data for input into the Runoff Block for snowmelt calculations.

### Statistics Block (now Statistics Utility)

Output from continuous simulation can be enormous if results for every time step are printed. Even the monthly and annual summaries contain more information than may easily be assimilated. The Statistics Block has the capability to review the time step 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 can thus be used to identify key events for further study and for many other screening and analytical purposes.

## Input Data Requirements

As will be seen from a review of following sections, the data requirements for SWMM may be extensive. Collection of the data from various municipal and other offices within a city is possible to accomplish within a few days. However, reduction of the data for input to the model is time consuming and may take up to three man-weeks for a large area (e.g., greater than 2000 acres). On an optimistic note, however, most of the data reduction is straight forward (e.g., tabulation of slopes, lengths, diameters, etc., of the sewer system).

SWMM is flexible enough to allow different modelling approaches to the same area and a specific, individual modelling decision upstream in the catchment will have little effect on the predicted results at the outfall. Furthermore, a lumped approach may often be used for preliminary modelling in which catchment properties are aggregated and only minimal data is needed. The user should realise that only portions of the overall model (e.g., one block) need be run at any one time.

## Verification and Calibration

Calibration is the adjustment of model parameters using one set of data. Verification is the testing of this parameter selection by using an independent data set. Although the simulation of many of the urban runoff processes found in SWMM is physically based, the concept fails in practice because the input data and the numerical methods are not accurate enough for many real applications. Furthermore, many computational procedures within the model are based upon limited data themselves and highly empirical, especially surface quality predictions. As a result, it is essential that local verification/calibration data be available at specific application sites to lend credibility to the predictions of any urban runoff model.

Calibration and verification data are usually in the form of measured flows and concentrations at outfalls or combined sewer overflow locations. However, it is important to note that detailed short-time-increment pollutographs during a storm are seldom needed for analysis of receiving water quality. Hence, total storm event loads or event mean concentrations are usually sufficient for quality calibration and verification (Note that quality concentrations without accompanying flows are of little value). SWMM has sufficient parameters that may be "adjusted," particularly in the Runoff Block, such that calibrating the model against measured data is usually readily accomplished.

Quantity (hydrograph) predictions are often "within the ball park" on the first try, given decent rainfall, area and imperviousness data. However, initial quality estimates may be off by orders of magnitude (Huber, 1985). Hence, quality predictions are not credible without adequate site-specific data for calibration and verification. At best, relative effects of pollution abatement alternatives may be studied if such data is not available.

## Metrification

Use of metric units for input and output of data and results is an option in all blocks as an alternative to U.S. customary units. In the Runoff and Transport Blocks, metric units are used strictly for I/O; all internal quantity calculations are still performed in units of feet and seconds (Feet-second units also apply to program generated error messages printed during the simulation). However, when used, the Storage/Treatment and Extran Blocks use metric units for internal calculations also. Most quality calculations use conventional concentration units (e.g., mg/l) and loads may be given in both pounds and kilograms, depending on the particular subroutine, although pounds will not be used if metric I/O is specified.

No attempt has been made to conform to SI standards or even customary metric units for some parameters. For instance, because of output format complications, metric pipe diameters are requested and printed in meters instead of the more usual millimeters. However, all units are clearly stated for both input and output. It should be a simple task to convert to other metric alternatives.

## Changes from SWMM V. 3 to SWMM V. 4

Many enhancements to SWMM were accomplished since SWMM 3.0 was released in 1981 (Roesner et al., 1981) and the release of EXTRAN 4 in 1989. These include:

1. Errors have been corrected for all blocks as best they are known and convergence problems improved.
2. "Hot Start" capability (restart from end of previous run).
3. Minor improvements to surcharge and flow routing routines.
4. Automatic adjustment of short pipe lengths.
5. SWMM output may be linked to the DYNHYD4 (water quantity) and WASP4 (water quality) programs for receiving water quality simulation (Ambrose et al., 1986). 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.
6. The microcomputer version permits greater manipulation of interface files and other scratch and I/O files. The program may be 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.
7. 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.
8. 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 may also be used. Continuous simulation is capable of using up to 10 rain gauges. Instead of processing continuous meteorological data in the Runoff Block, two new blocks have been added; Rain and Temp. These provide additional statistical analysis similar to the SYNOP program of Hydrosience (1976, 1979). It is also possible to process rainfall data with the SWMM Statistics Block.
9. Numerical methods have been improved in the Runoff Block. A variation of the extrapolation method (Press et al., 1986) is used to couple the nonlinear reservoir equations, evaporation, infiltration, and groundwater flow. There is no longer any distinction between single event and continuous. Runoff uses a wet, dry and intermediate (wet/dry) time step defined by the user.
10. This version of SWMM tries to use 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.
11. This version can be made more modular than the EPA Version 3 for the microcomputer. 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.
12. 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. Graph plots loadographs (mass/time versus time) and pollutographs (concentration versus time).
13. 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.
14. Microcomputer users will see the current time or time step printed on the screen during the simulation as well as other program messages.
15. Input and simulation of channels with irregular cross-sections, using either selected HEC-2 data lines or user generated input lines (in HEC-2 format). EXTRAN input lines (or data groups) have identifiers in columns 1 and 2, and all input is free format.
16. Power function cross sections for conduits (e.g., parabolic and elliptic channels).
17. Variable-sized storage junctions, input as stage-area data.
18. Pump operating curves, or dynamic head pumps.
19. Use of different boundary conditions at each outfall.
20. Interpolated stage time series boundary condition at an outfall, or h(t) boundary conditions.
21. Variable orifice discharge coefficients and orifice areas over time.
22. Flap gates are simulated in interior conduits.
23. "Hot start" input and output using saved files. This permits a restart of SWMM from the "middle" of a previous run.
24. Optional metric or American standard units. The program was converted to optional metric units (used both for input/output and internal calculations when employed).
25. Calculation errors in rectangular conduits have been fixed.
26. Alphanumeric conduit and junction names (instead of pure numbers) became optional in SWMM.
27. Output summaries and input error checking were substantially improved over version 3.0. Input and output have been enhanced to reflect a likely microcomputer environment.
28. Inclusion of data group identifiers on data input lines and free format input.

29. Surcharged weirs are included in the surcharge algorithm.
30. Two additional flow solutions were included in the model.

The goal of these modifications was the enhancement of the model capabilities and addressing the concerns of the model users. For example, EXTRAN problems described in the literature included the sole use of American units (Metric added), lag in updating (still a problem), program "bugs" (fixed), the program is too large to understand, and the program exceeds available computer memory (FORTRAN code changed to FORTRAN 77 and the advent of microcomputers) [Sjoberg, 1981].

## Changes from SWMM Version 4 to XPSWMM

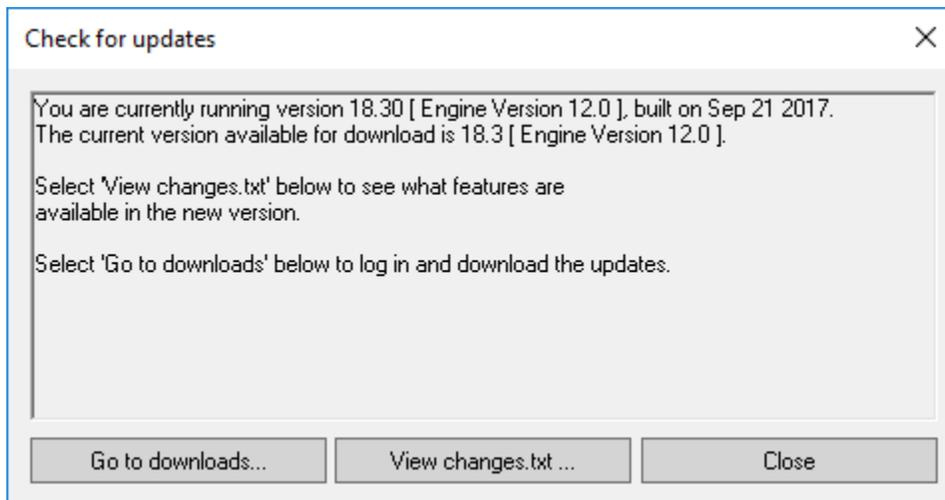
Many enhancements to SWMM have been accomplished since SWMM 4.0 was released in 1989 (Huber et al., 1989, Roesner et al., 1989). The majority of these changes have been accomplished in 1992/1993 by WP Software Pty Ltd. These include:

1. Several hundred bug fixes to the original SWMM code.
2. Vertically differentiated roughness in closed and open channels. Each conduit has two regions of roughness; a higher roughness when the depth is less than a predefined depth and normal roughness from the predefined depth to the crown of the conduit.
3. Shock losses from the transition from subcritical to supercritical flow.
4. The approach velocity in the side flow weir equations is now accounted for in the program.
5. Two EXTRAN simulations can be linked via a stage boundary condition. The time history of stage and flow is connected to the stage and flow history of a previous EXTRAN simulation. EXTRAN now has the ability to interface with EXTRAN.
6. The transition between open channel flow to pressure flow at weirs has been modified to enhance the stability of the solution.
7. A demand curve for outfalls, or a Q(t) boundary condition.
8. Natural channels have automatically defined "floodplains" to account for flows above the maximum channel depth.
9. Pondered flood water at EXTRAN nodes may optionally be returned to the main system.
10. The connection between closed conduits and open conduits has enhanced stability because of adjustments to junction ground elevations.
11. Greatly enhanced stability in the EXTRAN solution of conduit flows and junction depths.
12. Expansion/contraction losses due to changes in cross sectional area are simulated in conduits.
13. Entrance/exit losses at junctions are simulated in conduits.
14. The depth at an outfall is calculated one of three ways:
  - a. Outfall depth is fixed at the normal depth. This applies especially to natural channels.
  - b. Outfall depth is fixed at the critical depth.
  - c. Outfall depth is the minimum of the normal depth or the critical depth based on the conduit flow.
15. Rating curve boundary conditions for outfall, or a Q(h) boundary condition.
16. Irregular shaped closed conduits.
17. EXTRAN generates a better error analysis and continuity check.
18. Water quality in EXTRAN has begun to be implemented.
19. User defined weir exponents.
20. Transition to equivalent conduits when a weir surcharge was modified for increased stability.
21. User defined weir lengths as a function of depth.
22. User defined rating curves for weir flows.
23. One solution was implemented as the solution in XP-SWMM. It is an amalgam of the previous solutions in EXTRAN 4. The multiplicity of solutions affected program maintenance, and the surcharge iterations used for the first two solutions were the biggest cause of slow execution times in EXTRAN. The existing Version 4 solutions have been retained to provide compatibility with existing calibrated models.
24. The number of pollutants has been increased to 20 for all modules.
25. All modules can route all pollutants.
26. Number of landuses has been increased to 10 for all modules.
27. The Storage/Treatment module has been integrated into Transport allowing multiple STP's and BMP's within the one network.
28. STP's and BMP's are no longer constrained to the outlet of the system.
29. Utilities (Rainfall, Temperature, Wind, Statistics, etc.) are incorporated within the overall interface.
30. The number of hydraulic elements has been increased to 26 for all modules.
31. Weirs, Pumps and Orifices are consistent across all modules.
32. Infiltration method and parameters are now catchment dependent.
33. Rainfall Gauges may start at different times and include an optional multiplier.
34. Pollutant characteristics are local.
35. Flow divides now have explicitly defined flow paths.
36. Process (point-source) and constant flow are allowed for each pollutant.
37. Sophisticated user-defined equations are available for pollutant removal.
38. Time units are more flexible.
39. All modules can route flows through all conduit types.
40. The SCS method of hydrograph generation is now provided.
41. An EMC (Event Mean Concentration) method is now available for pollutant generation.

## Upgrades

Innovyze is continuously adding new features and upgrading XPSWMM and XPStorm. Users with active licenses are encouraged to upgrade to the latest version.

On the Help menu, select **Check for updates...**



Select **Go to Downloads...** to obtain the latest version of the software.

Select **View changes.txt...** to access a detailed list of software upgrades. This file may also be opened directly from your XPSWMM program folder.

## When Should SWMM be Used?

SWMM is a large, relatively sophisticated hydrologic, hydraulic and water quality simulation program. XPSWMM and XPstorm combines the sophistication of SWMM modeling with the ease of use of simple standard techniques (e.g., units hydrographs, linear reservoirs) described in hydrology texts and suitable for programmable hand-held calculators (e.g., Croley, 1977) or microcomputers (e.g., Golding, 1981). Many other smaller Fortran programs are available for urban hydrologic simulation and may be entirely suitable for a given problem. HSPF (Johanson et al., 1980) is one alternative for catchments that are primarily non-urban or that require more sophisticated simulation of pollutant interaction.

SWMM is certainly powerful 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 should be knowledgeable in modelling techniques such as; 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 simpler technique or model will not work. It may be borne in mind, however, that if calibration/verification data is available, SWMM may also be used as a very simple "black box" model with minimal input data.
3. Quality is to be simulated. Although there are other models that also simulate quality, SWMM is perhaps the most flexible of any. Of course, SWMM is often applied just to quantity problems.

A large body of literature on theory and case studies is available for SWMM. Since the model was originally introduced in 1971, a wealth of such information is available, including citation in hydrology texts (e.g., Viessman et al., 1977; Wanielista, 1978; Kibler, 1982). A bibliography of SWMM-related literature is available (Huber et al., 1985).

While any number of examples could be presented for when SWMM should not be used, attention is drawn to just one: when the user is already competent with an adequate alternative technique or model. It is far more important for the engineer/user to understand the methodology being utilized than it is for a model such as SWMM to be employed on the premise of a more sophisticated technique. XP-SWMM, of course, has the advantage that training in the model intricacies can be reduced by an order of magnitude compared with typical text-oriented programs, enabling a user to gain proficiency at a prodigious rate. 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.

## Modelling Caveats

The preceding section may be summarized by a few caveats for modelling in general and use of SWMM in particular.

1. Have a known project and modeling objective at the outset of work. Do not let the model capabilities or lack of them dictate the objective.
2. Use experienced personnel. A knowledge of engineering fundamentals is essential to proper model use and interpretation.
3. Use the simplest model suitable for the job. Although SWMM can be run in a very simple (e.g., minimal data) manner, there may be alternative models that require less initial effort to install. Sometimes a conclusion will be apparent simply from a review of data and prior studies, with no modelling necessary.
4. Start simple when learning. Obtain model familiarity by simulating very simple configurations for which the result is known, e.g., runoff from a steady rainfall onto an impervious surface.
5. Models are poor substitutes for data collection. Do not use the model to generate "real" data.
6. Examine the results critically. Is continuity preserved? Are predictions physically realistic? If not, review parameter estimates and model assumptions. Perhaps the model cannot simulate a particular physical process of interest.
7. Use one set of data for calibration and an independent set for verification of parameter choices.

8. Absolute magnitudes of quality predictions by SWMM or any other model are not to be trusted without calibration and verification data. At best, relative comparisons can be made between runs with differing conditions. Urban runoff quality processes involve too many unknown physical, chemical and biological factors to be simulated accurately.

## EXTRAN Overview

EXTRAN is a hydraulic flow routing model for both open channel and closed conduits in dendritic and looped networks. EXTRAN receives hydrograph input at specific nodal locations by interface file from an upstream block (e.g., the Runoff Block) and/or by direct user input. The model performs dynamic routing of stormwater and sanitary flows throughout the major storm drainage system to the outfall points of the receiving water system.

Since the flow in sewers is usually non-uniform, turbulent, and subject to backwater and surcharge, a model is required that simulates all of the terms in the one dimensional dynamic flow equation. The EXTRAN Model will simulate branched or looped networks, backwater due to tidal or non-tidal conditions, free-surface flow, pressure or surcharge flow, flow reversals, flow transfer by weirs, orifices and pumping facilities, and pond or lake storage. Types of channels that can be simulated include circular, rectangular, horseshoe, eggshape, baskethandle pipes, trapezoidal, parabolic, natural (irregular) channels, circular and rectangular orifices, and arbitrary closed conduit shapes. Simulation output takes the form of water surface elevations and discharge at selected network locations.

Read more about EXTRAN in the following sections:

[Introduction to EXTRAN](#)

[Conceptualization of the EXTRAN Drainage System](#)

[Basic Equations of EXTRAN](#)

## Inlet Control Theory

The design equations used to develop the inlet control nomographs are based on the research conducted by the National Bureau of Standards (NBS) under the sponsorship of the Bureau of Public Roads (now the Federal Highway Administration). Seven progress reports were produced as a result of this research. Of these, the first and fourth through seventh reports dealt with the hydraulics of pipe and box culvert entrances, with and without tapered inlets (4,7 to 10) These reports were one source of the equation coefficients and exponents, along with other references and unpublished FHWA notes on the development of the nomographs. (56,57)

Click this link for [further details on Inlet Control Theory](#).

## SWMM Interface File Format

Documentation of the SWMM routines may be found in the EPA SWMM User's Manual (Huber and Dickinson, 1988). The output is either in U.S. customary units or metric units depending on the value of parameter METRIC on data group B2.

Click this link for [further details on the SWMM Interface File Format](#).