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STORM WATER MANAGEMENT MODEL

USER'S MANUAL

Version III

By

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FOREWARD

The Environmental Protection Agency was created because of increasing public and governmental concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

Mathematical models are an important tool for use in analysis of quantity and quality problems resulting from urban storm water runoff and combined sewer overflows. This report is an updated user's manual and documentation for one of the first of such models, the EPA Storm Water Management Model (SWMM). Detailed instructions on the use of the model are given and its use is illustrated with case studies.

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PREFACE

There is seemingly never enough time to write a manual and document a computer program in the manner it deserves. This SWMM Version III User's Manual has been under preparation in one form or another for six years, yet it will be found upon examination that some aspects of the model are covered in much more detail than others, and some coverage is downright sparse, notably case studies. The tendency to add "one more thing" to the model has unfortunately proven all too irresistable, to the detriment of as much testing and demonstration as would be desirable. Nonetheless, with a few exceptions most coding is not radically new; much deals just with improved input/output. Hence, much reliance has been placed on the continuous testing of the model during its development over the past 12 years.

Writing of the various text has also been accomplished in steps. Hence, references on various topics, e.g., snowmelt, storage/treatment, were current at the time of writing which may have been two or three years ago. SWMM quality routines are most continually in a state of flux due to new developments in the literature. The user should remain familiar with current information and alter his/her modeling practices as necessary.

Some parts of the model are completely new, some are similar if not identical to the first release in 1971. The most significant change since the 1975 Version II release is the inclusion of the Extended Transport Block for quantity routing. This is documented separately by Camp, Dresser and McKee in an addendum to this volume. Other major changes include: continuous simulation, completely revised storage/treatment routines, snowmelt, surface quality generation, a statistical analysis block, updated graphical and tabular output, and scour-deposition computations in the Transport Block. Parts of the model that remain basically unchanged include the flow routing techniques of the Runoff and Transport Blocks. From a software point of view, the program is no shorter, but nor is it much longer for any particular block.

An attempt has been made to provide adequate information in this manual for most users to conceptualize a stormwater problem and simulate it using SWMM. As a result, some of the text is rather lengthy, approaching a hydrology textbook in style in places. Unfortunately, it will still be the user's responsibility to seek out the proper references for additional information on modeling, especially when dealing with water quality.

The authors hope that the user is not "put off" by the length of this volume and the size of the SWMM program. Aside from the fact that it requires a large computer core (about 400 K bytes) the program may often be easily and usefully run with a minimum of input, say a dozen data cards. For small systems in which time step requirements are not severe, the model is very economical as well, and is within the reach of most users. It is by no means the only engineering tool of its kind available, but it has benefited greatly from its longevity and feedback from model users. The authors hope such feedback will continue, and earnestly solicit suggestions for improvements. Although no major support for model changes is likely to be forthcoming, the EPA Storm Water and Water Quality Model Users Group (formerly the SWMM Users Group) remains a convenient forum. Announcements of corrections, changes and new options will be made through that group, managed by Mr. Thomas O. Barnwell, EPA, Athens, Georgia 30605.

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ABSTRACT

The EPA Storm Water Management Model (SWMM) is a comprehensive mathematical model for simulation of urban runoff quantity and quality in storm and combined sewer systems. All aspects of the urban hydrologic and quality cycles are simulated, including surface runoff, transport through the drainage network, storage and treatment, and receiving water effects. (The latter component is currently under revision by the EPA.) This volume applies to Version III of SWMM and is an update of two earlier User's Manuals issued in 1971 and 1975. It should be coupled with Addendum I in order to run the Extran Block (detailed hydraulic flow routing) developed by Camp, Dresser and McKee.

Detailed descriptions are provided herein for all blocks (except the Receiving Water Block): Runoff, Transport, Storage/Treatment, Combine, Statistics and Graph (part of the Executive Block). The latter three blocks are "service" blocks while the first three are the principal computational blocks. In addition, extensive documentation of new procedures is provided in the text and in several appendices.

This report was submitted in partial fulfillment of cooperative agreement CR-805664 by the University of Florida under the sponsorship of the U.S. Environmental Protection Agency. Work was completed as of November 1981.

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ACKNOWLEDGEMENTS

Maintenance and updating of the EPA SWMM has been continuous since its inception in 1969-70. Over the several intervening years, many individuals have contributed to its improvement, most notably EPA colleagues Richard Field, Harry Torno, Chi-Yuan Fan, Doug Ammon and Tom Barnwell. Harry Torno and Tom Barnwell have also managed the SWMM Users Group, through which many helpful suggestions for improvements have come, including those from the large contingent of Canadian users.

Regarding specific components of SWMM Version III, the Green-Ampt infiltration routines were reviewed, programmed and tested by Dr. Russell G. Mein, Department of Civil Engineering, Monash University, Clayton, Victoria, Australia while on a sabbatical at the University of Florida. He also provided valuable review and testing of other model components. The earliest implementation of continuous simulation in the Runoff and Storage/Treatment Blocks was done by George F. Smith, now with the Office of Hydrology, National Weather Service, Silver Spring, Maryland. Basic formulation of the snowmelt routines was done following the work of Proctor and Redfern, Ltd. and James F. MacLaren, Ltd., Toronto, who were under contract to the Ontario Ministry of the Environment and the Canadian Environmental Protection Service. Runoff Block surface quality changes were the subject of masters research at the University of Florida by Douglas C. Ammon, now with the EPA, Storm and Combined Sewer Branch, Cincinnati. Revision of Transport Block scour/deposition routines is based on work with Dennis Lai, Clinton-Bogert Associates, Fort Lee, New Jersey. Many lasting improvements in SWMM programming were made by W. Alan Peltz, now with General Electric, Atlanta.

Several others contributed to changes in the model. The card ID system and the user-defined default values and ratios were suggested by the Corps of Engineers, Hydrologic Engineering Center, Davis, California. The programming basis has been aided by Dr. William James, McMaster University, Hamilton, Ontario and exposure to his FASTSWMM programs. Emphasis upon proper use and objectives of SWMM modeling has been enhanced by conversations with the late Murray McPherson, Marblehead, Massachusetts, Eugene Driscoll, Oakland, New Jersey, Dr. Dominic DiToro, Manhattan College, New York City, John Mancini, Lincoln, Nebraska, Dr. Paul Wisner, Ottawa University, Charles Howard, Vancouver, B.C., and several others. UF is additionally grateful to Reinhard Sprenger, Templeton Engineering, Winnipeg, for improvements to the Extran Block, to Christian Eicher, Gore and Storrie, Ltd., Toronto, for several important corrections to the overall program, to Robert Johnson, Lehigh University, Bethlehem, Pennsylvania, for comments on the compatability with CDC machines, to Tom Jewell, Union College, Schenectady, New York, for analysis of surface washoff and other comments, and to Tom Meinholz and Richard Race, formerly of Envirex, Inc., Milwaukee, for suggestions on making the program more suitable to prototype configurations.

The Extended Transport Block has been an invaluable addition to the SWMM package. Developed by Water Resources Engineers (now a part of Camp, Dresser and McKee), Extran may be the most widely used portion of SWMM. Dr. Larry Roesner and the late Dr. Robert Shubinski of CDM, Annandale, Virginia have given generously of their time in enhancing Extran and in making other useful suggestions to SWMM modeling.

At the University of Florida, salutary programming and testing has been conducted by J. Jay Santos, Efi Foufoula, Michael Kennedy, Kelly Nead and Christina Neff. Typing has been performed by Linda Trawick, Jeanette Heeb, Kim Karr and the College of Engineering Word Processing Center. Figures were drafted by Terri Schubert, Micky Hartnett and Anelia Crawford. Computations were performed at the Northeast Regional Data Center on the University of Florida campus, Gainesville.

SECTION 1

INTRODUCTION

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 two 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, but is by no means the only one. Since its original development, 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 occured to SWMM during the past ten years have been poorly documented and not readily visible to users. This volume includes documentation (of both the theory and programming details) of major changes to the model since its original development. This documentation is located primarily in the appendices whereas the text consists primarily of the User's Manual. 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).

URBAN RUNOFF MODELS

Objectives

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, and the different models overlap 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. Only after the screening model indicates its necessity should one of the latter models be used. 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.

Various continuous simulation models are reviewed in Appendix I. SWMM has had this capability since 1976, following the earliest work of the Stanford Watershed Model (Crawford and Linsley, 1966) and the later 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. Planning or longterm 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 accurate 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 in the public domain for detailed hydraulic analysis of sewer systems (Shubinski and Roesner, 1973, Roesner et al., 1981).

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. 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 many 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 (1979, 1980). In spite of the scores of models described in the literature, Huber and Heaney (1979, 1980) identified only 14 operational (i.e., documented, tested and available for general use) water quality models. A much larger number of strictly hydrologic and hydraulic models is available.

DEVELOPMENT OF THE STORM WATER MANAGEMENT MODEL

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 a comprehensive mathematical model capable of representing urban stormwater runoff and combined sewer overflow phenomena. The SWMM portrays correctional devices in the form of user-selected options for storage and/or treatment with associated estimates of cost. Effectiveness is portrayed by computed treatment efficiencies and modeled 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, judgements, and assumptions used in the model development. It further includes descriptions of unsuccessful modeling 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 the 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 release of SWMM is 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., 1975). This present report supersedes both of these previous two 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 many cases, completely different.

All three original contractors have continued to modify and improve the SWMM, as have numerous other users since its release. Through EPA research grants, the University of Florida has conducted extensive research on urban runoff and SWMM development, and has evolved into an unofficial "clearinghouse" for SWMM improvements. There has clearly been a large benefit from the fact that SWMM is in the public domain and non-proprietary since the present version reflects the input and critical assessments of over ten years of user experience. Of course, lingering "bugs" are the responsibility of the present report authors alone.

As described earlier, this report is both a SWMM Version III User's Manual and also documentation of new procedures. As much as possible, input formats for large card groups (e.g., input of subcatchment information) are compatible with earlier versions and will not necessarily have to be rearranged. However, some changes are quite visible, such as a two-column identifier on each card (in the manner of Hydrologic Engineering Center programs). Hence, it must be assumed by the user that <u>all</u> input must be prepared anew for this SWMM version.

OVERALL SWMM DESCRIPTION

Overview

The comprehensive Storm Water Management Model uses a high speed digital computer to simulate real storm events on the basis of rainfall (hyetograph) inputs and system (catchment, conveyance, storage/treatment, and receiving water) characterization to predict outcomes in the form of quantity and quality values. The simulation technique -- that is, the dynamic representation of the physical systems identifiable within the model -- was selected because it permits relatively easy interpretation and great versatility and flexibility in model representation of prototype situations.

Since the program objectives are particularly directed toward both complete time and spatial effects and also to gross effects (such as total pounds of pollutant discharged in a given storm), it is considered essential to work with both continuous curves (magnitude versus time), referred to as hydrographs and "pollutographs," and with daily, monthly, annual and total simulation summaries (for continuous simulation).

An overview of the Model structure is shown in Figure 1-1. In simplest terms the program is constructed in the form of "blocks" as follows:

1) The input sources:

   The Runoff Block generates surface runoff based on arbitrary rainfall 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 core:

   The Transport and Extended Transport Blocks carry and combine the inputs through the sewer system.

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):

   The Receiving Block routes hydrographs and pollutographs through the receiving waters, which may consist of a stream, river, lake, estuary, or bay.

Quality constituents for simulation may be arbitrarily chosen for any of the blocks, although the different blocks have different constraints on the number and type of constituents that may be modeled. The Extended Transport Block is the only block that does not simulate water quality.

As indicated in Figure 1-1, the Transport, Extended Transport and Storage/Treatment Blocks may all use input and provide output to any block, including themselves. The Runoff Block uses input from no other block, and the Receiving Block provides output for no other block.

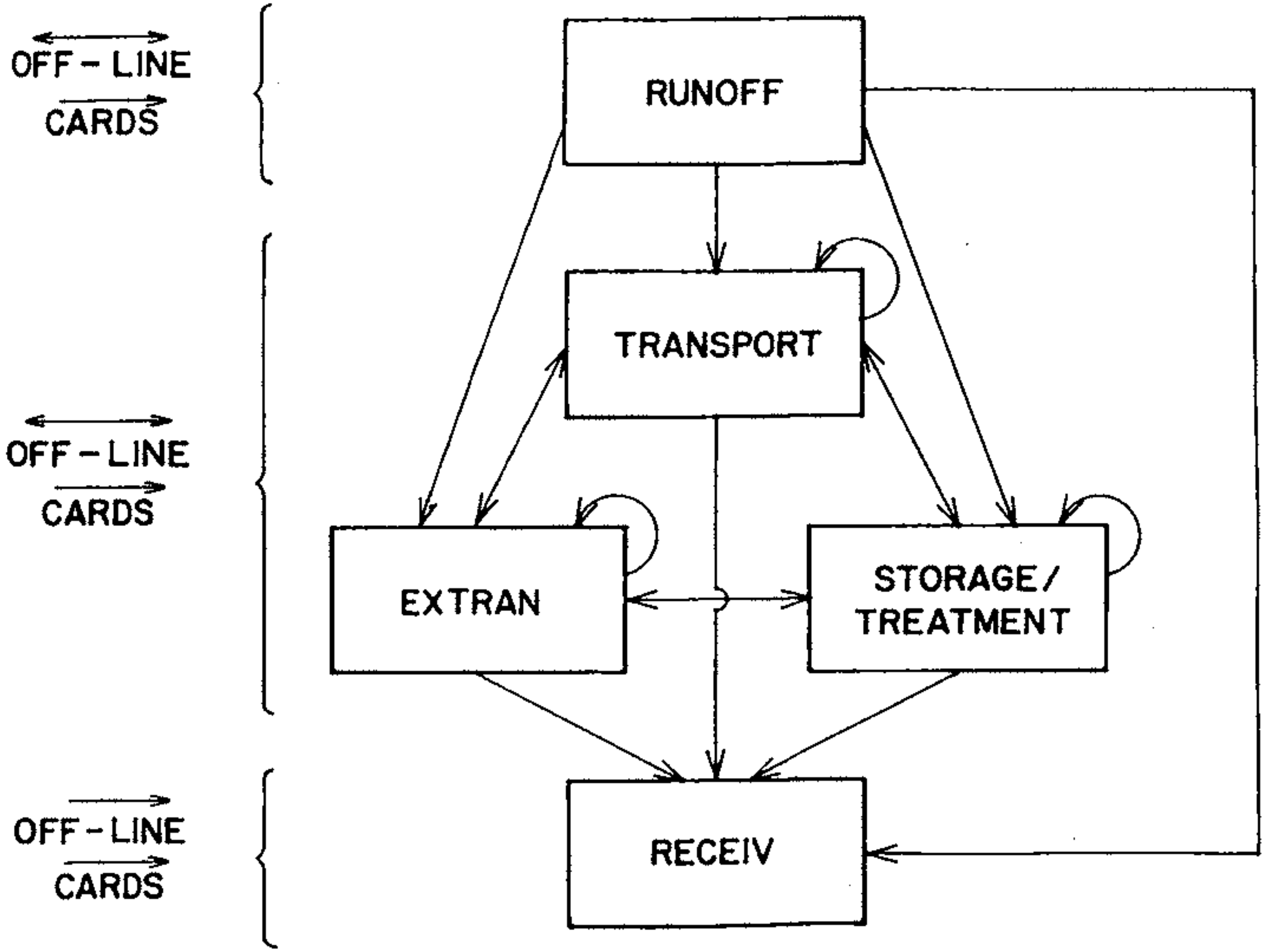

Figure 1-1. Overview of SWMM Model Structure, Indicating Linkages Among the Five Computational Blocks.

Service Blocks

Executive Block --

In addition to the five computational blocks mentioned above, two service blocks are utilized, the Executive and Combine Blocks. The Executive Block assigns logical units (disk/tape/drum), determines the block or sequence of blocks to be executed, and, on call, produces graphs of selected results on the line printer. All access to the computational blocks and transfers between them must pass through the MAIN program of the Executive Block. Transfers are accomplished on offline devices (disk/tape/drum) which may be saved for multiple trials or permanent record using appropriate job control language (JCL).

Combine Block --

This block allows the manipulation of data sets (files stored on offline devices) in order to aggregate results of previous runs for input into subsequent blocks. In this manner large, complex drainage systems may be partitioned for simulation in smaller segments.

Statistics Block --

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.

Total Simulation

In principle, the capability exists to run all blocks together in a given computer execution, although from a practical and sometimes necessary viewpoint (due to computer core limitations), typical runs usually involve only one or two computational blocks together with the Executive Block. This approach may be used to avoid overlay and, moreover, allow for examination of intermediate results before continuing the computations. Further, it permits the use of intermediate results as start-up data in subsequent execution runs, thereby avoiding the waste of repeating the computations already performed.

This manual expands on these block descriptions by providing for each block:

1) descriptions of the program operation,

2) instructions on data preparation with tables for data card input requirements, and

3) examples of the application of procedures described with sample I/O information reproduced.

There are two exceptions. The user's manual and documentation for the Extended Transport Block has been prepared by Camp, Dresser and McKee (Roesner et al., 1981) as an addendum to this report and is available as a separate document. Thus, Section 5 of this report merely introduces EXTRAN.

Similarly, the Receiving Block is currently (May 1981) undergoing extensive revisions at the EPA Athens, Georgia, Environmental Research Laboratory. This revised routine will combine the best features of the EPA Dynamic Estuary Model and its many derivatives, such as the Receiving Block. Hence, documentation from the Athens EPA effort will be utilized as a supplement to this report when available in the future, and Section 8 only outlines RECEIV capabilities.

Detailed SWMM Summary

A concise description of most features of SWMM is given in Table 1-1, adapted from similar tables prepared by Huber and Heaney (1979, 1980). Except for the Receiving Block, an indication of almost all modeling techniques is included in the table.

USER REQUIREMENTS

Computer Facilities

A large, high-speed computer is required for operation of the SWMM, such as an IBM 370, Amdahl 470, UNIVAC 1108 or CDC 6600. The largest of the blocks requires on the order of 90,000 words of storage. Through considerable efforts, users have been able to adapt different blocks of the program to various mini-computers, but only with extensive use of off-line storage and increase in execution time. Execution time is discussed in Section 2.

Data Requirements

As will be seen from a review of following sections, the data requirements for the 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). The SWMM is flexible enough to allow different modeling approaches to the same area, and a specific, individual modeling decision upstream in the catchment will have little effect on the predicted results at the outfall.

Verification and Calibration

The SWMM is designed as a "deterministic" model, in that if all input parameters are accurate, the physics of the processes are simulated sufficiently well to produce accurate results with minimal calibration. This 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, 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. These data are usually in the form of measured flows and concentrations at outfalls or combined sewer overflow locations. Note that quality measurements without accompanying flows are of little value. The 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.

METRIFICATION

Use of metric units for input and output of data and results is now allowed in the Runoff, Transport and Storage/Treatment Blocks as an alternative to U.S. customary units. (Metric I/O to the Extran and Receive Blocks may be added in the future.) For the most part, the metric units are used strictly for I/O; all internal quantity calculations are still performed in ft-sec units. (These units will apply to program generated error messages printed during the simulation.) 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. Thus, metric units (e.g., m^3/sec or, in some places, cms for brevity) are obtained merely by a conversion factor for printing.

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 card input and printed output. It should be a simple task to convert to other metric alternatives.

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 manner of personnel. For instance, hydrologic routing (e.g., prediction of runoff from rainfall) may be performed simply using standard techniques (e.g., unit hydrographs, linear reservoirs) described in hydrology texts and suitable for programmable hand-held calculators (e.g., Croley, 1977) or micro-computers (e.g., Golding, 1981). In addition, many other, smaller Fortran programs are available for urban hydrologic simulation that may be entirely suitable for a given problem and much easier to implement on a given computer system. Notable among the hundreds of such programs are the Corps of Engineers, Hydrologic Engineering Center program STORM (Roesner et al., 1974, HEC, 1977a) for continuous simulation and the Illinois State Water Survey program ILLUDAS (Terstreip and Stall, 1974) for single event simulation and pipe sizing. Both have good documentation and user support and have been extensively tested and utilized by engineers other than the model developers.

SWMM has similar attributes but is certainly more formidable in terms of its size and capabilities. Who, then, should use SWMM and for what purposes? Some guidelines are given below for when SWMM probably _is_ appropriate:

1. The engineer is 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 its 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 SWMM may also 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 is to be simulated. Although there are other models that also simulate quality, SWMM is perhaps the most flexible of any.

4. A large body of literature on theory and case studies is desired. Since SWMM 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).

The primary technical disadvantage of SWMM is its lack of routines for soil moisture accounting and sub-surface flow routing, e.g., as in HSPF (Johanson et al., 1980). It is thus seldom suitable for largely pervious, non-urban areas.

While any number of other examples could be presented for when SWMM should not be used, attention is drawn to just one: the user is already familiar 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. 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.

Table 1-1. Summary of EPA Storm Water Management Model (SWMM) Characteristics

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Applicable Land Drainage Area

(1) Urban; (2) General nonurban; (3) Unsuitable for lands requiring soil moisture accounting and generation of base flow from ground water.

Time Properties

(1) Single event or continuous simulation; both modes have an unlimited number of time steps, although former usually $\leq$ 200, depending on portions of model utilized; (2) Precipitation: input at arbitrary time intervals for single event simulation (typically 1-15 min) and usually at one-hour intervals for continuous simulation; for snowmelt daily max-min temperatures required for continuous, temperatures at arbitrary intervals for single event; (3) Output at time step intervals (or multiples); daily, monthly, annual, and total summaries for continuous simulation; (4) Time step arbitrary for single event (typically 5 minutes) and usually one hour for continuous, Extran transport model time step depends on stability criteria, may be as small as a few seconds.

Space Properties

(1) Small to large multiple catchments: (a) surface: lumped simulation of overland flow with allowance for up to 200 subcatchments and six input hyetographs, up to 200 gutter/pipes may be simulated by non-linear reservoir routing, (b) channel/pipes: one-dimensional network, up to 159 conduit/noncondult elements for original transport model, up to 187 conduits in Extran transport model, up to two in-line storage units in original transport model, (c) catchment area may be disaggregated and modeled sequentially for simulation of areas too large for existing SWMM dimensions; (2) Storage/treatment simulated separately, receiving input from upstream routing; (3) Output from surface, channel/pipe, or storage/treatment simulation may serve as new input for further simulation by the latter two modules.

Physical Processes

(1) Flow derived from precipitation and/or snowmelt; snow accumulation and melt simulated using temperature-index methods developed by National Weather Service, snow redistribution (e.g., plowing, removal) may be simulated; (2) Overland flow by nonlinear reservoir using Manning's equation and continuity, depression storage, integrated Horton or Green-Ampt infiltration (lost from system), recovery of depression storage via evaporation between storms during continuous simulation, also exponential recovery of infiltration capacity; (3) Channel/pipes: (a) nonlinear

reservoir formulation for gutter/pipes in surface runoff module, includes translation and attenuation effects, (b) kinematic wave formulation in original transport model assumes cascade of conduits, cannot simulate backwater over more than one conduit length, surcharging handled by storing water at surcharged junction pending available flow capacity; (c) Extran transport model solves complete St. Venant equations including effects of backwater, flow reversal, surcharging, looped connections, pressure flow, (d) infiltration and dry weather flow may enter conduit of either transport simulation; (4) Storage routing using modified Puls method assuming horizontal water surface, outlets include pumps, weirs, orifices; (5) Surface quality on basis of linear or non-linear buildup of dust/dirt or other constituents during dry-weather and associated pollutant fractions, power-exponential washoff with decay parameter a power function of runoff rate; optional concentration prediction as power function of flow rate only (rating curve); erosion by Universal Soil Loss Equation; (6) Dry-weather flow quantity and quality on basis of diurnal and daily variation, population density and other demographic parameters, buildup of suspended solids in conduits by dry weather deposition using Shield's criterion; (7) Quality routing by advection and mixing in conduits and by plug flow or complete mixing in storage units, scour and deposition of suspended solids in conduits (original transport model) using Shield's criterion; (8) Storage/treatment device simulated as series-parallel network of units, each with optional storage routing; (9) Treatment simulation: (a) use of arbitrary user-supplied removal equations (e.g., removal as exponential function of residence time); (b) use of sedimentation theory coupled with particle size-specific gravity distribution for constituents.

Chemical Processes

(1) Ten arbitrary conservative constituents in Runoff module, rainfall quality included, choice of concentraton units is arbitrary; erosion of "sediment" is optional; (2) Four constituents may be routed through the original transport module (with optional first order decay), three through the storage/treatment module and none through Extran (quantity only).

Biological Processes

(1) Coliform washoff may be included; (2) Biological treatment may be simulated.

Economic Analysis

Amortized capital plus operation and maintenance costs for control units are determined.

Mathematical Properties

(1) Deterministic model; (2) Surface quantity: iterative solution of coupled continuity and Manning equations, Green-Ampt or integrated form of Horton infiltration (infiltration rate proportional to cumulative infiltration, not time); (3) Surface gutter/pipe routing: non-linear reservoir assuming water surface parallel to invert; (4) Channel/pipes: (a) original transport: implicit finite difference solution to modified kinematic wave equation, (b) Extran transport: explicit finite difference solution of complete St. Venant equations, stability may require short time step; (5) Storage/sedimentation: modified Puls method requires table look-up for calculation of outflow ; (6) Surface quality, quality routing and treatment: algebraic equations, no iterations required once flows and conduit volumes are known.

Computational Status

(1) Coded in Fortran IV, approximately 25,000 statements long; (2) Has been run on IBM 370 series, UNIVAC 1108, CDC 6600, Amdahl 470, VAX 11/780, Prime 550 and others, may be run in modular form (surface runoff, original or Extran transport, storage/treatment, receiving water, plus executive and service routines, e.g., plotting, file combining), largest module requires about 90,000 words or 360K bytes of storage; (3) Available on a magnetic tape; (4) Requires up to five off-line storage files.

Input Data Requirements

(1) Historical or synthetic precipitation record, uses National Weather Service precipitaton tapes for continuous simulation, monthly evaporation rates; for snowmelt: daily max-min (continuous) or time-step (single event) temperatures, monthly wind speeds, melt coefficients and base melt temperatures, snow distribution fractions and areal depletion curves (continuous only), other melt paremeters; (2) Surface quantity: area, imperviousness, slope, width, depression storage and Manning's roughness for pervious and impervious areas; Horton or Green-Ampt infiltration parameters;(3) Channel/pipe quantity: linkages, shape, slope, length, Manning's roughness, (Extran transport also requires invert and ground elevation, storage volumes at manholes and other structures), geometric and hydraulic parameters for weirs, pumps, orifices, storages, etc., infiltration rate; (4) Storage/sedimentation quantity geometry, hydraulic characteristics of outflows (5) Surface quality: (Note: several parameters are optional, depending upon methods used) land use, total curb length, catchbasin volume and initial pollutant concentrations, street sweeping interval, efficiency and availability factor, dry days prior to initial precipitation, dust/dirt and/or pollutant fraction parameters for each land use or pollutant rating curve coefficients, initial pollutant surface loadings, exponential and power washoff coefficients, erosion parameters for Universal Soil Loss Equation, if simulated; (6) Dry weather flow on basis of diurnal and daily quantity/quality

variations; population density, other demographic parameters; (7) Optional particle size distribution, Shields parameter and decay coefficients for channel/ pipe quality routing; (8) Storage/treatment: parameters defining pollutant removal equations, parameters for individual treatment options, e.g., particle size distribution, maximum flow rates, size of unit, outflow characteristics, optional dry-weather flow data when using continuous simulation; (9) Storage/treatment costs: parameters for capital and operation and maintenance costs as function of flows, volumes and operating time; (10) Data requirements for individual modules much less than for run of whole model; large reduction in data requirements possible by aggregating (lumping) of subcatchments and channel/pipes, especially useful for continuous simulation; (11) Metric units optional for all I/O.

Ease of Application

(1) Nonproprietary model available from EPA, Athens, GA or University of Florida, Department of Environmental Engineering Sciences, Gainesville; (2) Updated user's manual and thorough documentation of most routines published as EPA reports, no one report covers all model aspects; (3) Test cases documented in several EPA and other reports; (4) Short course proceedings also useful for model applications; (5) U.S. and Canadian users groups with newsletters and semi-annual meetings permit publication of changes; (6) Due to its age (originally published in 1971), availability, documentation, examples of SWMM usage are widely available in the literature; (7) Frequent model update/corrections/improvements are often difficult to learn about, new model released approximately on a bi-annual basis; (8) Size of model most frequent deterrent to use, however, see item 10 above under Input Data Requirements; (9) Initial model setup often moderately difficult due to size.

Output and Output Format

(1) Input data summary including precipitation; (2) Hydrographs and pollutographs (concentrations and loads versus time) at any point in system on time step or longer basis, no stages or velocities printed; (3) Extran transport also outputs elevation of hydraulic grade line; (4) Surcharge volumes and required flow capacity, original transport model will resize conduits to pass required flow (optional); (5) Removal in storage/treatment units, generated sludge quantities; (6) Summaries of volumes and pollutant loads for simulation period, continuity check, initial and final pounds of solids in conduit elements; (7) Daily (optional), monthly, annual and total summaries for continuous simulation, plus ranking of 50 highest hourly precipitation runoff and pollutant values; (8) Line printer plots of hyetographs, hydrographs, and pollutographs; (9) Costs of simulated storage/treatment options; (10) Statistical analysis of continuous (or single event) output for frequency analysis, moments and identification of critical events.

Linkages to Other Models

(1) SWMM contains its own receiving water model, RECEIV; (2) Individual modules and the total SWMM model have been linked to the HEC STORM model, the QUAL-II model, simplified receiving water models, and others; (3) Individual modules (e.g., surface runoff, receiving water) have been altered by various groups.

Personnel Requirements

(1) Environmental engineer familiar with urban hydrological processes for data reduction and model analysis; (2) Systems programmer for model setup and off-line storage file usage.

Costs

(1) Model available upon receipt of cost of magnetic tape plus a nominal charge (about $125 from University of Florida or no other charge from EPA); (2) Data assembly and preparation may require multiple man-weeks for a large catchment or urban area; (3) Example computer execution costs given in user's manual, on the order of $20 for a surface runoff and transport run for a single storm event with about 50 subcatchments and channel/pipes, use of Extran transport can be more costly due to short time step, continuous simulation of one subcatchment with snowmelt for two years costs about $20; (4) Extensive calibration may be required to duplicate measured quality results, quantity calibration relatively simple; (5) National Weather Service precipitation tapes for continuous simulation cost about $200 for a 25-year hourly record.

Model Accuracy

(1) Quantity simulation may be made quite accurate with relatively little calibration; (2) Quality simulation requires more extensive calibration using measured pollutant concentrations, quality results will almost certainly be very inaccurate without local measurements; (3) Extran transport accurately simulates backwater, flow reversal, surcharging, pressure flow; original transport routines may be used at less cost if these conditions not present; (4) Sensitivity to input parameters depends upon schematization, however, surface quality predictions are most sensitive to pollutant loading rates.

SECTION 2

EXECUTIVE BLOCK, GRAPH ROUTINES AND SYSTEM REQUIREMENTS

BLOCK DESCRIPTION

Functions

The Executive Block performs three functions:

1) assignment of logical units and files,

2) control of the sequencing of computational blocks, and

3) graphing of data files by the line printer.

No computations as such are performed. The relationship of the Executive Block to other blocks is shown in Figure 2-1.

Program Operation

The Executive Block assigns logical units and files, and controls the computational block(s) to be executed. These functions depend on reading in a few data cards which must be supplied according to the needs of a given computer run.

Since the various blocks use logical devices for input and output of computations, the Executive Block has provision for assigning logical unit numbers by reading two data cards. Logical units and data sets are discussed later. The first card may contain up to 20 integer numbers, corresponding to 10 input and 10 output units. It is not necessary, however, to make such a large number of assignments for the usual run; in fact, there have been few occasions during the development and testing of the model when more than four units have been needed. The files that are produced on these units are saved (during the run) for use by a subsequent computational block; also, the information contained in them can be examined directly by using the graphing capability of the Executive Block. The other unit assignments on the second data card are for scratch files, i.e., files that are generated and used during execution of the program, and are erased at the end of the run. Again, there is provision for up to five such units, but only one or two are typically needed. The unit numbers are passed from the Executive Block to all pertinent blocks in the labeled COMMON/TAPES/.

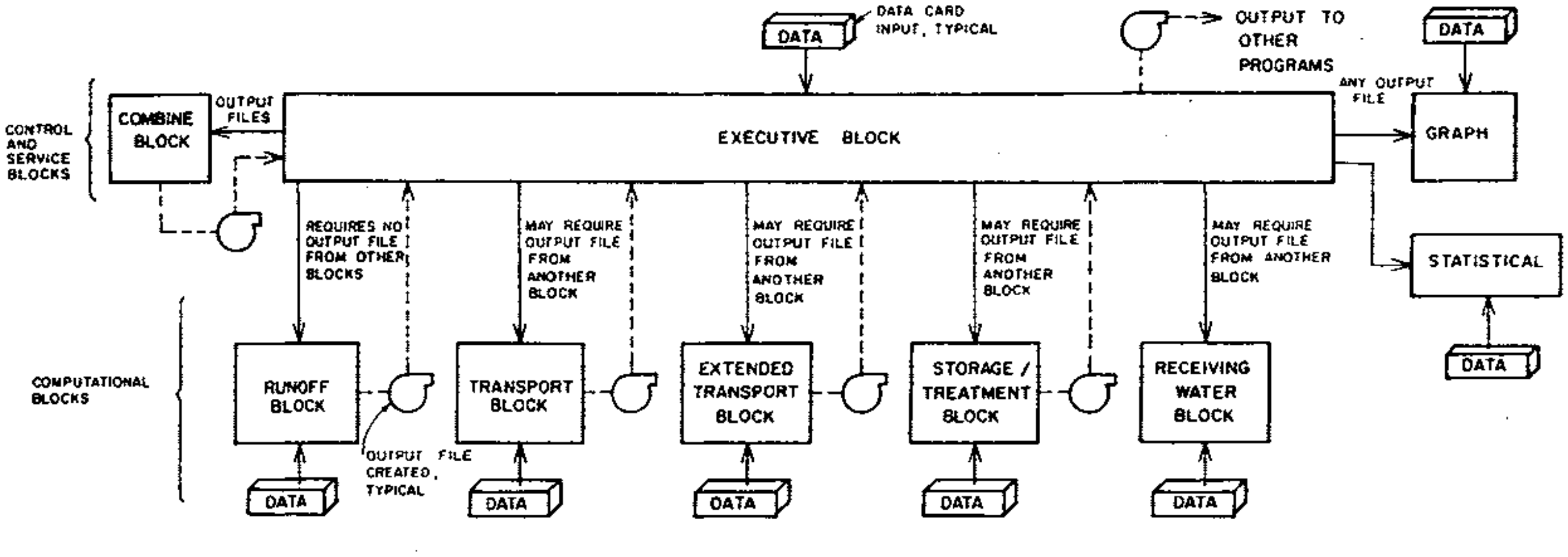


Figure 2-1. Relationship of Executive Block to Other Blocks

The graphing subroutines enable hydrographs and pollutographs to be plotted on the line printer for selected locations for output data files (e.g., predicted results) as well as measured data that are input by the user. Predicted and measured results may be plotted on one graph for comparison. Operation of the graph routines is described later. The subroutines include GRAPH, called from the main executive program only, in which control information, titles, and measured data, if any, are read.

Subroutine HYSTAT is called from GRAPH for computation of hydrograph volumes, durations, peak flows, and times of peaks. This is done for both predicted and measured hydrographs.

Subroutine CURVE is called from GRAPH to coordinate the actual plotting. It is also called directly from the Runoff, Extran and Receive blocks, in which case control information, titles, etc. are supplied from those blocks, bypassing subroutine GRAPH. Subroutine CURVE performs the following operations:

1) Determines maximum and minimum values of arrays to be plotted, calculates the range of values, and selects appropriate scale intervals using subroutine SCALE.

2) Computes vertical axis labels based upon the calculated scales.

3) Computes horizontal axis labels based upon the calculated scales.

4) Joins individual parts of the curve using subroutine PINE.

5) Outputs final plot using subroutine PPLOT.

Subroutine SCALE calculates ranges and scaling factors. Subroutine PINE joins two coordinate locations with appropriate characters in the output image array A of PPLOT. Subroutine PPLOT initializes the plotting array, stores individual locations, and outputs the final image array A for the printer plot.

INTERFACING BETWEEN COMPUTATIONAL BLOCKS

Data may be transferred or interfaced from one block to another through the use of the tape/disk assignments on card group *1. The interface tape/disk (file) header consists of descriptive titles, the user-supplied pollutant and unit names, the simulation starting date and time, the name of the block generating the interface file, the number of time steps and time step size, the total catchment or service area, and the number of locations (inlets, outfalls, elements, etc.) and pollutants found on the interface file. Also included are the location identifiers for which flow and pollutant data are transferred, a conversion factor for converting the flow dimensions found on the interface file to the internal SWMM dimension of cfs and the type of pollutant concentration units. Following the file header are the flow and pollutant data for each time step (up to the total number of time steps) for each of the specified locations. The detailed organization of the interfacing file is shown in Figure 2-2, and example Fortran statements that will write such a file are shown in Figure 2-3. These figures may be used as guidelines for users who may wish to write or read an interfacing file with a program of their own. Further information on required pollutant identifiers, etc. may be found in the Runoff Block card input data description.

The title and the values for the starting date and time from the first computational block are not altered by any subsequent block encountered by the Executive Block. All other data may (depending on the block) be altered by subsequent blocks. The individual computational blocks also have limitations on what data they will accept from an upstream block and pass to a downstream block. These limitations are summarized in Table 2-1. Detailed discussions are presented in the computational block sections.

Table 2-1. Interface Limitations for Each Computational Block.

Block	Input	Output[a]
Runoff	-	200 elements (inlets), 10 pollutants
Transport	80 elements (inlets), 4 pollutants	80 elements (non-conduits), 4 pollutants
Extended Transport	187 junctions (inlets), no pollutants (ignored if on the file)	187 junctions
Storage/Treatment[b]	10 elements (inlets or non-conduits), 3 pollutants	10 elements, 3 pollutants
Receive	50 elements (inlets non-conduits or outfall), 6 pollutants	--

[a]The interface file may contain up to 10 pollutants from which a lesser number may be selected by following blocks. The number of pollutants found on the output file from any block is the lesser of the number in the input file or that specified on cards within the block.

[b]Although the Storage/Treatment Block will read and write data for as many as 10 elements, the data for only one element have passed through the storage/treatment plant; the rest are unchanged from the input file.

	VARIABLE NAME	DESCRIPTION[a]
FROM FIRST COMPUTATIONAL BLOCK	(TITLEZ(I),I = 1,38)	Title from first computational block; format is 38A4.
	IDATEZ	Starting date; six-digit number, year-month-day, e.g., July 20, 1979 is 790720.
	TZERO	Starting time of day, hours and fraction, e.g., 5:30P.M. is 17.5.
FROM INTERFACING COMPUTATIONAL BLOCK	(TITLE1(I),I = 1,38)	Title from interfacing computational block; format is 38A4.
	SOURCE(I),I = 1,5)	Name of interfacing computational block; format is 5A4.
	NSTEPS	Number of time steps of flow/pollutant data on interface file.
	DTSEC	Time step size, seconds.
	NLOCAT	Number of locations (inlets, manholes, outfalls, etc.) on interface file.
	NPOLL	Number of pollutants on interface file.
	TRIBA	Tributary or service area, acres.
	(LOCNOS(K),K = 1,NLOCAT)	Location numbers for which flow/pollutant data are found on interface file.
	((PNAME(L,J),L = 1,2),J = 1,NPOLL	NPOLL pollutant names; format for each is 2A4.
	((PUNIT(L,J),L = 1,2),J = 1,NPOLL	NPOLL pollutants units, e.g., mg/l, MPN/l, JTU, μmho, etc., format for each is 2A4.
	(NDIM(J),J = 1,NPOLL)	Parameter to indicate type of pollutant concentration units. =0, mg/l. =1, "other quantity" per liter, e.g., for bacteria, units could be MPN/l. =2, other concentration units, e.g., JTU, μmho, °C, pH.
	QCONV	Conversion factor to obtain units of flow of cfs, (multiply values on interface file by QCONV to get cfs).
FLOW AND POLLUTANT DATA FOR EACH LOCATION, REPEAT FOR EACH TIME STEP	TIME	Running time, beginning at TZERO, hours and fraction. First entry on file is at TZERO + DTSEC/3600. TIME is continuous and is not reset at end of a day.[b]
	IDATE	Date for this time step, six-digit number, year-month-day, e.g., November 24, 1979 is 791124.
	TIMDAY	Time of day for this time step, hours and fraction, e.g., 12:45A.M. is 0.75.
	(Q(K),(POLL(J,K),J=1,NPOLL),K=1, NLOCAT)	Flow and pollutant loads for NLOCAT locations at this time step. Q(K) must be the instantaneous flow at this time (i.e., at end of time step) in units of length^3/time. POLL(J,K) is the flow rate times the concentration (instantaneous value at end of time step) for J'th pollutant at K'th location, e.g., units of cfs · mg/l or m^3/sec ·JTU[c].

[a] Unformatted unless specified. Use an integer or real value as indicated by the variable name.
[b] Elapsed time is thus TIME-TZERO.
[c] If units other than cfs are used for flow, this will be accounted for by multiplication by parameter QCONV.

Figure 2-2. Detailed Organization of SWMM Interfacing File.

FILE HEADER	WRITE(NOUT)	(TITLEZ(I),I=1,38)
	WRITE(NOUT)	IDATEZ,TZERO
	WRITE(NOUT)	(TITLE1(I),I=1,38)
	WRITE(NOUT)	(SOURCE(I),I=5),NSTEPS,DTSEC,NLOCAT,NPOLL,TRIBA
	WRITE(NOUT)	(LOCNOS(K),K=1,NLOCAT)
	WRITE(NOUT)	((PNAME(L,J),L=1,2),J=1,NPOLL)
	WRITE(NOUT)	((PUNIT(L,J),L=1,2),J=1,NPOLL)
	WRITE(NOUT)	(NDIM(J),J=1,NPOLL)
	WRITE(NOUT)	QCONV

NOUT is the interface file or logical unit number (see the subsection "INITIAL JOB SET-UP").

FLOW AND POLLUTANT DATA FOR EACH LOCATION: REPEAT FOR EACH TIME STEP	IF(NPOLL.GT.0) WRITE(NOUT)TIME,IDATE,TIMDAY,(Q(K),(POLL(J,K),J=1, NPOLL),K=1,NLOCAT)
	IF(NPOLL.LT.1) WRITE(NOUT)TIME,IDATE,TIMDAY,(Q(K),K=1,NLOCAT)

Note: The interface file should be set up (using JCL) for variable block sizes (VBS). The time step read/write statements must include IF statements to test for the appearance of pollutants.

Figure 2-3. Fortran Statements Required to Generate an Interface File.

Computer System Requirements

The Storm Water Management Model can be run on a machine having core storage capacity of approximately 400 K bytes (or equivalent) and using overlay. Current core requirements of each block are shown in Table 2-2. In addition, the program uses peripheral storage devices which may consist of disk, tape, or drum units, depending on the machine configuration.

The program has undergone detailed testing on the University of Florida Amdahl 470 V/6-II running under OS/MVS Release 3.7 JES2 NJE Release 3 (as of September 1979). Thus, SWMM should be compatible with any IBM or Amdahl machine. Experience has shown that the program may be run fairly easily on UNIVAC machines but can require minor programming changes for use on CDC equipment (see discussion of Fortran, below). In any event, users are regretfully warned that there are undoubtedly many "bugs" remaining in the program, subtle and otherwise, for which they must be on the alert.

Table 2-2. Lengths of SWMM Blocks (in bytes)[a]
(Lengths are for overlay structure shown in Table 2-5.)

Block	Length Alone	Length with Executive/Graph
Executive/Graph[b]	142,100	--
Runoff	226,900	369,000
Transport	95,300	237,400
Extran	135,500	277,600
Storage/Treatment	98,000	240,100
Combine	22,000	164,100
Statistics	173,700	315,800

[a]On the UF IBM system, approximately 20 K bytes are added to the storage requirement for each off-line file accessed. E.g., if the Runoff Block accesses three different off-line files, it requires about 60,000 additional bytes of storage.

[b]Includes all required IBM library and overhead procedures.

Program Compilation, Execution Time and Cost

A sample of the compilation and execution times with run costs for separate program blocks is shown on Table 2-3. This table incorporates the

Table 2-3. Example Execution Times and Costs (See also Table II-6.)

Block/ Schematization	No. Time Steps	Simulation Duration	No. Quality Constituents	CPU[a] Seconds	Cost,[b] $
Runoff					
7 Subcat. (ICRAIN = 1)	3624	5 mo.	6	14	4.50
1 Subcat. (ICRAIN = 2)	17,520	24 mo.	6	14	4.50
Runoff + Transport					
29 Subcat., 34 Gutter/ pipes, 50 Elements	100	100 min.	8 (Runoff) 4 (Transp.)	10.9	4.09
Storage/Treatment[c]					
1 Deten. unit (plug flow) 1)	8760	12 mo.	2	18.4	5.97
2)	50	50 hr.	1	1.13	1.17
3)	100	100 hr.	1	1.34	1.67

[a]Compilation time not included.

[b]Costs are <u>total</u> costs at approximately <u>half</u> the commercial rate, including CPU time, disk I/O, printing, etc.

[c]Runs 1) and 3) used removal equations. Run 2) used a particle size distribution.

savings which were made by storing compiled blocks of the program in a permanent job library (load modules). At most computer installations, there is a daily or monthly charge for storing load modules. If the SWMM is going to be used more than a few times, it would be advisable to use load modules.

From the Central Processing Unit (CPU) and execution times in this table, it may be possible to extrapolate a time and cost estimate for other machines. A systems analyst can obtain these figures.

Fortran

All coding is in Fortran IV. Attempts have been made to follow American National Standards Institute Fortran (1978) but some instructions may be machine dependent. Wetzel and Johnson (1976) describe programming modifications that were necessary in order to run SWMM on a CDC 6400. Although some of their modifications have been incorporated into the present version, others might still be necessary. Examples are shown in Table 2-4.

At the University of Florida, the program is routinely used with the Fortran H extended compiler. Some but not all of the program has also been run under Fortran G.

Logical Units

Logical units or file numbers are simply the numbers assigned to various input/output devices for use in the program. At most installations, logical units for the card reader, line printer and card punch are as given below:

I/O Device	Logical Unit
Card Reader	5
Line Printer	6
Card Punch	7

SWMM is programmed under the assumption that the card reader and line printer are so defined (no cards are punched by SWMM). However, in an attempt to allow versatility, all READ and WRITE statements use parameters N5 and N6 for the logical unit numbers of the card reader and line printer respectively. These are defined only once,

```
N5 = 5
N6 = 6
```

near the beginning of the Executive Block MAIN program and passed to all other blocks through the labeled COMMON/TAPES/. Thus, if other logical units are required for the card reader and line printer, the only programming changes required should be at the above location.

Other I/O units include tapes, disks and drums. Such devices are typically assigned logical units between 1 and 20 (but not 5, 6 or 7) by appropriate JCL.

Table 2-4. Possible Fortran Modifications for CDC Machines

IBM Machines	CDC Machines	Comment
STOP 1000	STOP '1000'	Without the delimeters, the statement number may be interpreted in octal on CDC.
ARSIN(Y)	ASIN(Y)	Different names of library functions for arc-sine.
READ(MTAPE,END=300) . . . 300 CONTINUE	READ(MTAPE) IF (EOF(MTAPE)) 300,200 200 CONTINUE . . . 300 CONTINUE	End of file check is different.
FORMAT ('_***')	FORMAT (4H_***)	The asterisk is sometimes a delimeter on CDC.

Sample Job Control Language (JCL)

As a rule, JCL is highly machine dependent; in fact, it often differs on two identical machines at different installations. Therefore, the SWMM cannot include JCL that is universally applicable. The following remarks, however, may be useful in gaining insight into what is involved on systems such as an IBM 370/165 or Amdahl 470.

Usually, the interfacing file and scratch file assignments require JCL to be supplied for each unit. The rules for such JCL must be ascertained from the systems programmers at the installation, since there is considerable variation in unit number availability, etc. In general, one should only set up the units needed in a given run, since there may be a charge for file space that is reserved, even if it is not used.

Most users will prefer to store a compiled version of SWMM on a disk rather than to compile and execute from cards or tape. Such an example is shown in Table 2-5. This example is for an IBM operating system such as is used on the University of Florida's Amdahl 470.

The following is a description of Table 2-5.

Line 0 is the job card unique to the University of Florida Computing Center.

Lines 3-4 are for execution and overlay of the SWMM source coding and load modules (compiled portions stored on disks).

Lines 5-10 contain dummy subroutines to be compiled, instead of retrieving them from disk storage.

Lines 12-14 describe the load module data set. The SWMM program is stored on a data set named "UF.A0063473.NEW.SWMM".

Lines 16-86 describe the overlay structure used at the University of Florida (see below). The compiled version of each subroutine is stored in the data set with a name the same as the subroutine name. "INCLUDE" cards list subroutines and "INSERT" cards list labeled common blocks.

Lines 87-100 describe scratch disk files to establish unit numbers to be used for interface files and scratch file assignments in the Executive Block. Other JCL could be used to save a file after running the program; these will be "lost" when the run is over. An example of a disk unit number is //GO.FXXFØØ1 DD... where XX stands for the symbolic unit number.

Table 2-5. Sample Job Control Language for Compilation and Execution of SWMM.

JCL is for IBM Operating System OS/MVS Release 3.8. Also shown is the overlay structure for subroutines and the location of sample input data. Files RBDATA, TBDATA, BLOCK, STRDAT and LABELS are Block Data subroutines.

```
//SWMMIII JOB (1006,3473,15,9,0),'SWMM JCL',CLASS=A,REGION=400K
/*PASSWORD
/*ROUTE  PRINT LOCAL
// EXEC FORTXCLE,LPARM='LIST,MAP,OVLY'
//FORT.SYSIN DD *
      SUBROUTINE RECEIV
      RETURN
      END
      SUBROUTINE COMBIN
      RETURN
      END
/*
//LKED.SYSLMOD DD SPACE=(CYL,(5,1,1))
//LKED.SYSUT1 DD SPACE=(CYL,(5,2))
//LKED.LIB DD DSN=UF.A0063473.NEW.SWMM,DISP=SHR
//LKED.SYSIN DD *
 INCLUDE LIB(MAIN,GRAPH,CURVE,PPLOT,HYSTAT)
 INCLUDE LIB(PINE,SCALE)
   OVERLAY ALPHA
   INCLUDE LIB(RUNOFF,RBDATA)
   INSERT TIMER,SUBCAT,QUALTY,CQSHED,DETAIL,GUTCOM
     OVERLAY BETA
     INCLUDE LIB(HYDRO,WSHED,GUTTER,GQUAL,GAMP)
     INCLUDE LIB(MELT,FINDSC,AREAL)
     INCLUDE LIB(QSHED,BUILD)
       OVERLAY GAMMA
       INCLUDE LIB(RHYDRO)
         OVERLAY DELTA
         INCLUDE LIB(CTRAIN)
         OVERLAY DELTA
         INCLUDE LIB(QHYDRO,ERROR)
       OVERLAY GAMMA
       INCLUDE LIB(HCURVE)
     OVERLAY BETA
     INCLUDE LIB(PRINTR)
   OVERLAY ALPHA
   INCLUDE LIB(TRANS,TBDATA,FIRST,FINDA,RADH,VEL)
   INCLUDE  LIB(NEWTON,CIRCLE,DEPTH,PSI,DPSI)
   INCLUDE LIB(ROUTE,QUAL,PCT)
   INCLUDE LIB(TSTORG,TINTRP)
   INSERT TST
   INSERT  DRWF,TABLES,NAMES,PSIDPS,NEW81
     OVERLAY BETA
     INCLUDE LIB(SLOP)
     OVERLAY BETA
     INCLUDE LIB(TSTRDT)
     OVERLAY BETA
     INCLUDE LIB(INFIL)
     OVERLAY BETA
     INCLUDE LIB(FILTH)
     OVERLAY BETA
     INCLUDE LIB(DWLOAD)
     OVERLAY BETA
     INCLUDE LIB(INITAL)
     OVERLAY BETA
     INCLUDE LIB(PRINTF,PRINTQ)
```

(continued)

Table 2-5 (concluded). Sample Job Control Language for Compilation and Execution of SWMM.

```
        INSERT NEW80
       OVERLAY  ALPHA
       INCLUDE LIB(EXTRAN,BLOCK,TRANSX)
       INSERT FILES,BD
       INSERT BND,HYFLOW,CONTR,PIPE,TRAP,STORE,OUT,EXSTAT,SURCHG
       INSERT ELEV,JUNC,ORF,WEIR,PUMP
         OVERLAY BETA
         INCLUDE LIB(INDATA)
           OVERLAY GAMMA
           INCLUDE LIB(TIDCF)
         OVERLAY BETA
         INCLUDE LIB(INFLOW)
         OVERLAY BETA
         INCLUDE LIB(DEPTHX,HYDRAD)
           OVERLAY GAMMA
           INCLUDE LIB(BOUND)
           OVERLAY GAMMA
           INCLUDE LIB(HEAD)
         OVERLAY BETA
         INCLUDE LIB(OUTPUT)
       OVERLAY  ALPHA
       INCLUDE LIB(STRT)
       INSERT  S1,S2
         OVERLAY BETA
         INCLUDE LIB(STRDAT)
         OVERLAY BETA
         INCLUDE LIB(STCOST)
         OVERLAY  BETA
         INCLUDE LIB(CONTRL,UNIT,PLUGS,EQUATE,INTERP)
       OVERLAY ALPHA
       INCLUDE LIB(STATS,SORT,MOMENT,SBTABL,POINTS,LABELS)
//GO.FT01F001 DD UNIT=SYSDA,SPACE=(TRK,(100,10)),
//    VOL=SER=WORK01,DCB=(RECFM=VBS,BLKSIZE=4240,BUFNO=1)
//GO.FT02F001 DD UNIT=SYSDA,SPACE=(TRK,(100,10)),
//    VOL=SER=WORK01,DCB=(RECFM=VBS,BLKSIZE=4240,BUFNO=1)
//GO.FT03F001 DD UNIT=SYSDA,SPACE=(TRK,(100,10)),
//    VOL=SER=WORK01,DCB=(RECFM=VBS,BLKSIZE=4240,BUFNO=1)
//GO.FT04F001 DD UNIT=SYSDA,SPACE=(TRK,(100,10)),
//  VOL=SER=WORK01,DCB=(RECFM=VBS,BLKSIZE=4240,BUFNO=1)
//GO.FT08F001 DD UNIT=SYSDA,SPACE=(TRK,(100,10)),
//    VOL=SER=WORK01,DCB=(RECFM=VBS,BLKSIZE=4240,BUFNO=1)
//GO.FT09F001 DD UNIT=SYSDA,SPACE=(TRK,(100,10)),
//    VOL=SER=WORK01,DCB=(RECFM=VBS,BLKSIZE=4240,BUFNO=1)
//GO.FT10F001 DD UNIT=SYSDA,SPACE=(TRK,(100,10)),
//    VOL=SER=WORK01,DCB=(RECFM=VBS,BLKSIZE=4240,BUFNO=1)
//GO.SYSIN DD *
    0     9     9   10    10     9     9    10
    1     2     3    4     8
RUNOFF
........RUNOFF DATA
TRANSPORT
........TRANSPORT DATA
EXTRAN
........EXTRAN DATA
STORAGE
........STORAGE TREATMENT DATA
STATS
........STATS BLOCK DATA
ENDPROGRAM
/*EOF
```

Lines 102-114 contain data for the run (described below).

Note that the Extran Block uses the same graph subroutines as does the rest of SWMM. It is unnecessary to use a separate set of graph routines just for that block.

Overlay Procedures

The SWMM model was constructed as an overlay program because it can then be executed in an area of main storage that is not large enough to contain the entire model at one time. The linkage editor subdivides the model so that it can be loaded and executed segment by segment. The total main storage required is approximately 400 K bytes using the overlay structure illustrated in Table 2-5.

First, there is the root segment which is always in main storage and includes all the subroutines of the Executive Block.

Second, there is a group of subroutines on the same level, (ALPHA level), which is called a segment. Only one ALPHA segment can be in main storage at a time with the root segment (Executive Block).

Next, there is another group of subroutines on the next lower level, (BETA level). Only one BETA segment can occupy main storage simultaneously with the ALPHA segment. Thence follow GAMMA and DELTA segments which behave similarly.

With the JCL and overlay setup as shown, all the SWMM blocks can be run either independently or sequentially in a continuous string. The Combine and Receive Blocks are the only blocks that cannot be run for this example. They could be run simply by removing the dummy subroutine cards at the beginning of the JCL and then by adding an OVERLAY ALPHA and INCLUDE LIB(COMBIN) card, etc. A systems programmer would be helpful in setting up the overlay on other machines. For instance, Wetzel and Johnson (1976) describe a segmented load procedure for CDC machines.

Dummy Subroutines

Use of dummy subroutines is not confined to the Combine and Receive Blocks. Rather, they may be used to avoid compiling or having in permanent storage any of the subroutines called by the SWMM Executive Block. These sub-programs are RUNOFF, TRANS (Transport), RECEIV (Receive), STRT (Storage/Treatment), COMBIN (Combine), EXTRAN (Extended Transport), STATS (Statistics) and GRAPH (graphing routine). The latter routine is always required and is part of the Executive Block. All others are needed only for specific applications and may be "dummied" in the manner of the Combine Block (as in Table 2-5), if not required.

Scratch Data Sets

A "scratch data set" is simply off-line storage (e.g., disk or drum) that is used during program execution. However, the contents are erased (lost) at the end of the simulation. These are established by assignment of logical units in lines 87-100 in Table 2-5 using IBM JCL, for example. Alternatively, it may be wished to save output from a block for future runs of subsequent blocks. In this case, appropriate JCL must be provided for this purpose.

Ordinarily, scratch data sets will be used for parameters JIN, JOUT and NSCRAT of the Executive Block. With only two exceptions, parameters JIN and JOUT are used only to transfer data between blocks, as explained elsewhere within this section. One exception is that a JIN data set may be needed for rainfall input from a tape to the Runoff Block when continuous SWMM is being used. The second exception is that a JOUT data set must be used to store processed event data in the Statistics Block. (This data set cannot be transferred to other SWMM blocks.) The NSCRAT files are used for miscellaneous tasks within each block, most typically to store output for later printing. Current requirements are shown in Table 2-6.

The following presents a detailed explanation of the scratch data sets used for the parameters for the example of Table 2-5. These are used to make a typical run of the SWMM. The unit numbers assigned to the various data sets are arbitrary. Any desired values compatible with the descriptions of lines 87-100, Table 2-5, could be used. Furthermore, the following definitions assume Runoff, Transport, Storage/Treatment and Statistics are to be run in order. However, various sequences may be used, and the parameters would correspond to the sequence defined in lines 104-114 of Table 2-5. Line 101 tells the computer that input data follow. Line 102 is tape/disk assignments and corresponds to card group *1 of the Executive Block Card Data Section. Line 102 may be interpreted as follows:

JIN(1),	JOUT(1),	JIN(2),	JOUT(2),	JIN(3),	JOUT(3),	JIN(4),	JOUT(4)
0	9	9	10	10	9	9	10

Here, JIN(N) = I refers to an input device or file and JOUT(N) = I refers to an output device or file. For example, a typical read statement in a FORTRAN program may be READ(I,80). The I is replaced by the symbolic unit number of an input device (e.g., card reader). As discussed previously, on most computer systems, I is equal to 5 for reading cards and 6 or 7 for writing or punching output. The same applies to JIN(N) = I or JOUT(N) = I where I is substituted with the symbolic unit number of an input or output device such as a tape or disk unit, as defined by lines 87-100. Since the numbers 5, 6, and 7 have standard meanings, their descriptions are omitted.

JIN(1) = unit number of tape/disk input into the first block to be run (Runoff Block). JIN(1) = 0 means there is no tape/disk input.

Table 2-6. Scratch Data Sets Required by SWMM

1. Runoff Block

   NSCRAT(1) - Always required.
   NSCRAT(2) - Required for continuous SWMM.
   NSCRAT(3) - Required for continuous SWMM with snowmelt.
   NSCRAT(4) - Required for single event SWMM if it is desired to avoid limitation of 200 rainfall hyetograph entries.

2. Transport Block

   NSCRAT(1) - Always required.
   NSCRAT(2) - Always required.

3. Storage/Treatment Block

   None required.

4. Receiving Water Block[a]

   NSCRAT(1) - Always required (quantity and quality),
   NSCRAT(2) - Required for quality simulation.
   NSCRAT(3) - Required for quality simulation if
   NSCRAT(4)   restart option is used.

5. Extended Transport Block (EXTRAN)

   NSCRAT(1) - Always required.
   NSCRAT(2) - Always required.

6. Combine Block

   None required.

7. Statistics Block[b]

   None required.

[a]Also, a value for JOUT must be specified for Receiving Block quantity.

[b]However, a value for JOUT must be specified for the processing of event data in the Statistics Block.

JOUT(1) = unit number of tape/disk output from the first block to be run (Runoff Block). JOUT(1) = 9 means there is such output to be saved and lines 97-98 describe the disk utilized.

JIN(2) = unit number of tape/disk input to the second block to be run (Transport Block). (This is normally the same as the output number from the preceding block.) JIN(2) = 9 means there is such input (from the Runoff Block) and lines 97-98 describe the disk utilized.

JOUT(2) = unit number of tape/disk output from the second block to be run (Transport Block). JOUT(2) = 10 means there is such output to be saved and lines 99-100 describe the disk utilized.

JIN(3) = unit number of the tape/disk input to the third block to be run (Storage/Treatment Block). (This is normally the same as the output unit number from the preceding block.) JIN(3) = 10 means there is such input (from the Transport Block) and lines 99-100 describe the disk utilized.

JOUT(3) = unit number of the tape/disk output from the third block to be run (Storage/Treatment Block). JOUT(3) = 9 means there is such output to be saved. (Note that Runoff output will be written over.)

JIN(4) = unit number of the tape/disk input to the fourth block to be run (Statistics Block). (This is normally the same as the output unit number from the preceding block.)

JOUT(4) = unit number of tape/disk output from the fourth block to be run (Statistics Block), JOUT(4) = 10. (Note that Transport output will be written over.)

JIN(5) = JIN(10) and JOUT(5) - JOUT(10) allow more than just four blocks to be run sequentially and are defined similarly if required.

Line 103 is scratch tape/disk assignments and corresponds to card group *2 of the Executive Block Card Data. Line 103 may be interpreted as follows:

NSCRAT(1),	NSCRAT(2),	NSCRAT(3),	NSCRAT(4),	NSCRAT(5),
1	2	3	4	8

Here, NSCRAT(N) = I refers to an input/output device or file. I is substituted with the symbolic unit number of an input/output device such as a tape or disk unit defined in lines 87-100. There should be a scratch tape/disk assignment for NSCRAT(1) through NSCRAT(5). Most blocks do not use all NSCRAT(I) tape/disk assignments (see Table 2-6); however, there is no storage or CPU time charged for the ones not used at most installations.

INSTRUCTIONS FOR DATA PREPARATION

Block Selection

The instructions for data preparation are divided into two parts corresponding to control of the SWMM block selection and graphing capability. Figure 2-4 and Table 2-8 at the end of these instructions give the procedure for data card preparation.

The program controls the computational block(s) to be executed by reading alphanumeric information, CNAME, on sentinel cards. Thus, for example, CNAME might be RUNOFF. The program compares this word with a dictionary of such words (first eight characters). If a match is found, as it would be in this case, control is passed to the appropriate block. Here, for example, a call would be made to the Runoff Block. After execution of the Runoff Block, control is returned to the Executive Block.

The program again reads a sentinel data card, which might indicate that another block is to be executed. For example, if the Transport Block is to be executed, the control word TRANSPORT would be given, etc. If results are to be graphed, the control word GRAPH would be on the sentinel card, or, if the run is to be terminated, the word ENDPROGRAM is given on the card. A summary of the control words and corresponding action is given in Table 2-7.

The use of control words on sentinel cards allows considerable flexibility in utilization of the Storm Water Management Model. The most common type of run involves execution of one of the computational blocks along with the graphing of results on the line printer. Thus, for the Runoff Block, such a run would be made by appropriate use of the words RUNOFF, GRAPH, and ENDPROGRAM. If the entire model were to be run with graphical output at the end of, say for example, the Transport and Storage/Treatment Blocks, the sequence would be RUNOFF, TRANSPORT, GRAPH, STORAGE, GRAPH, and ENDPROGRAM.

Graph Routine

Capabilities --

When called from the Executive Block, the graph routines will plot predicted and/or measured hydrographs and pollutographs for specified locations. Such hydrographs and pollutographs will be called simply "graphs" in the following discussion. Predicted graphs can be generated by the Runoff, Transport, Extended Transport, and Storage/Treatment blocks. Thus, their output files may be input to the graph routines. Measured graphs (or data otherwise input on cards by the user) may also be plotted whether or not predicted graphs are produced. Thus, the graph routines may be treated as stand-alone programs and used independently of the other SWMM blocks. When

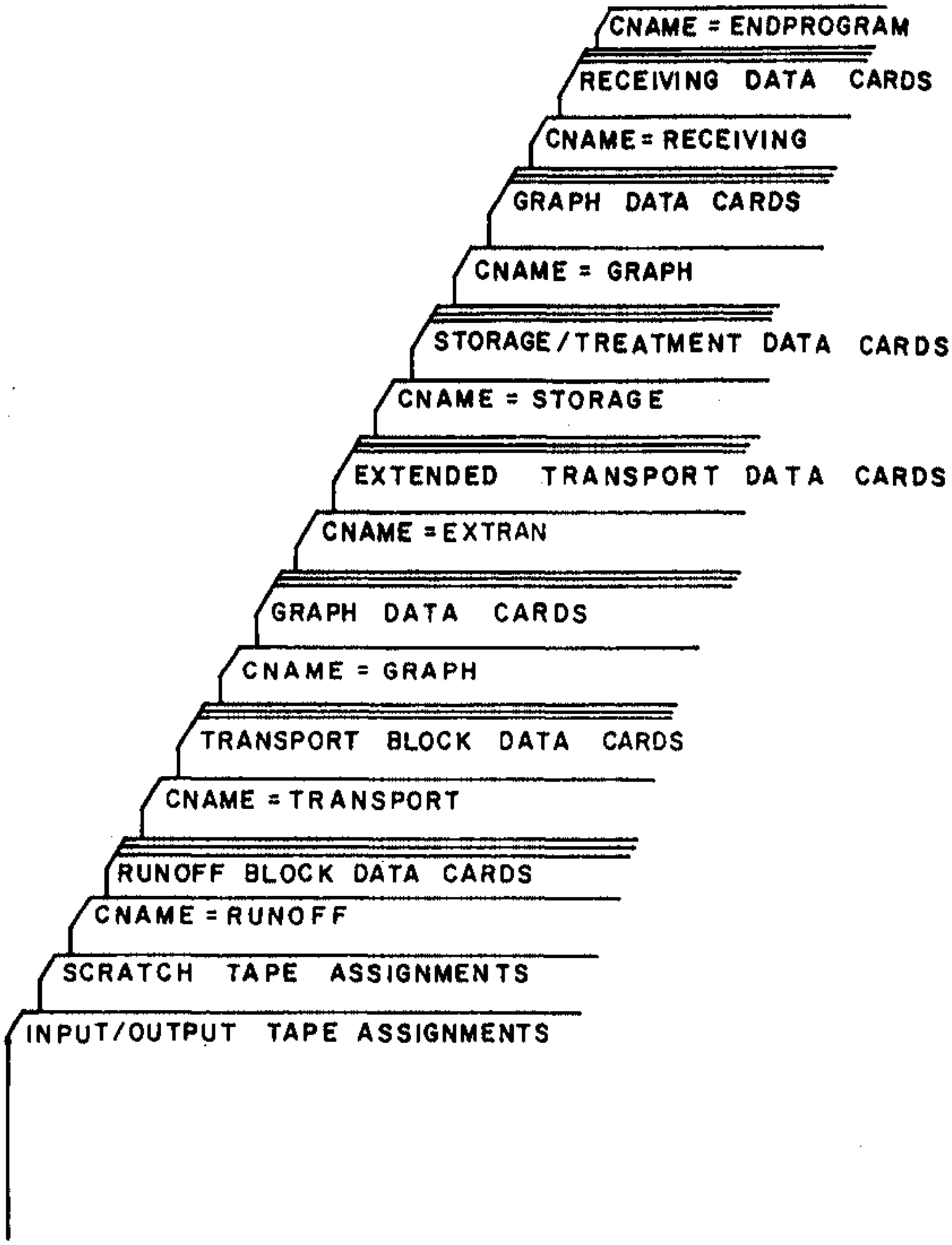


Figure 2-4. Hypothetical Card Arrangement for a Comprehensive SWMM Run.

Table 2-7. Summary of Control Words and Corresponding Action for MAIN Program[a]

Control word	Action to be taken
RUNOFF	Execute Runoff Block
TRANSPORT	Execute Transport Block
EXTRAN	Execute Extended Transport (Extran) Block
STORAGE	Execute Storage/Treatment Block
RECEIVING	Execute Receiving Water Block
COMBINE	Execute Combine Block
STATS	Execute Statistics Block
GRAPH	Produce graphs on line printer
ENDPROGRAM	Terminate run
Any other word	Terminate run[b]

[a] Program compares first eight characters only.
[b] Up to 20 more cards will be examined for a possible match prior to terminating the run.

predicted and measured graphs are available for the same location, they will be overprinted on one plot for comparison purposes. This greatly facilitates calibration work.

A few simple statistics are also computed for each hydrograph and are printed below each plot: volume, peak, time of peak, and duration. When both the measured and predicted hydrographs are plotted on the same plot, the above statistics and differences (absolute and percent) are also given for the overlapping time period.

The final plot is produced by printing of array "A", dimensioned 51 (vertical) by 101 (horizontal). Both the vertical and horizontal scales are determined on the basis of the range of the input data. The left-most plotting location (at the left vertical axis) corresponds to the graph value at the start of the simulation (TZERO). When more than 100 points are to be plotted, the program selects points such that the final output will consist of up to 100 points. For instance, if 200 equally spaced (in time) data points were input, only every other one would be plotted. The actual choice of points plotted depends on the number read in, their range, and whether points are "bunched" in some portion of the plot.

The particular graph routines used in SWMM "fill in" between separated points, horizontally or vertically, to form a continuous line. Thus, it is sometimes difficult to determine exactly the points that were input for plotting, except that they are usually the end points of line segments.

Input Parameters and Options --

Graphs (hydrographs or pollutographs) may be plotted for only one location at a time. Overprinting of graphs from several locations on just one plot is not allowed.

The routine will plot graphs of measured data, predicted data or both for a location. If measured and predicted graphs are both supplied for the same location, they will be overprinted on one plot for comparison.

Plots for up to ten locations for predicted and ten locations for measured may be requested during one call to GRAPH. The locations need not be the same. For example, the routine may be used to plot only predicted or only measured graphs. If there is a need to plot more than ten locations, GRAPH may simply be called again.

The routine will always plot hydrographs (when supplied) but will plot pollutographs only if NQP > 0 (card A1). Any three from a group of up to ten pollutants may be plotted (card B1), assuming the pollutant is available. Any group of pollutants (as many as ten) may be input to GRAPH. The parameter IPOL selects the IPOLth pollutant on the interfacing tape.

The time scales for input of measured graphs need not be the same as for predicted graphs, nor does the time spacing of measured graphs have to be constant. The plot will run from the minimum to the maximum times of the predicted or measured graphs. Several options are available for input of the times associated with graph ordinates (card D1).

Input of the horizontal axis label is not required, and it always reads "Time of Day, in Hours". The times are actually elapsed time, beginning at the start of the simulation (TZERO). Conversion to hour of day does not include a reset at midnight. Thus, if a simulation period begins at, say, 10 p.m. and lasts four hours, the graph abscissa will run from 22 to 26 hours.

Vertical axis labels are either "Flow in cfs" or else the name and units of the pollutant being plotted. All pollutographs are plotted in concentration units. The same units are required for both predicted and measured pollutograph inputs. Hydrographs are plotted in units of cfs, (or m^3/sec if METRIC = 1) and measured data must be entered in these same units. "Loadographs" (e.g., lb/min vs. time) cannot be plotted.

The input format of all measured data may be supplied by the user (card E2). This should considerably facilitate the use of data already prepared under an arbitrary format. In addition, the number of data values per card may be varied (LCARD on card E1).

Measured data may be read from cards (MEAS=1) or may be previously stored as card images on off-line file number MFILE and read from that file (MEAS=2 on card A1). Retrieval from file MFILE may avoid reading voluminous card data more than once. Of course, appropriate job control language must be supplied by the user to ensure the permanent storage of file MFILE.

Examples --

Sample input data are shown in conjunction with Runoff, Transport and Storage/Treatment runs.

Table 2-8. Executive Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			I/O tape/disk assignments.		
*1	20I4	1-4	Input tape assignment for first block to be run.	JIN(1)	0
		5-8	Output tape assignment for first block to be run.	JOUT(1)	0
		9-12	Input tape assignment for second block to be run (usually the same as the output tape from first block).	JIN(2)	0
		13-16	Output tape for second block to be run.	JOUT(2)	0
		. . . .		. . . .	
		77-80	Output tape for tenth block to be run.	JOUT(10)	0
			Scratch tape-disk assignments.		
*2	5I4	1-4	First scratch tape assignment.	NSCRAT(1)	0
		5-8	Second scratch tape assignment.	NSCRAT(2)	0
		9-12	Third scratch tape assignment.	NSCRAT(3)	0
		13-16	Fourth scratch tape assignment.	NSCRAT(4)	0
		17-20	Fifth scratch tape assignment.	NSCRAT(5)	0
			REPEAT CARD *3 FOR EACH BLOCK TO BE CALLED, AFTER EXECUTION OF PRECEDING BLOCK.		
			Control cards indicating which blocks in the program are to be called.		

Table 2-8 (continued). Executive Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
*3	3A4	1-12	Name of block to be called. Names must start in column 1. All blocks may be called more than once if overlay is not used or, if overlay is used, one or more blocks may be repeated if overlay is set up for this. See subsection "Initial Job Set-Up". CNAME = RUNOFF for Runoff Block, = TRANSPORT for Transport Block, = EXTRAN for Extended Transport (Extran) Block, = RECEIVING for Receiving Water Block, = STORAGE for Storage/Treatment Block, = COMBINE for Combine Block, = STATS for Statistics Block, = GRAPH for GRAPH subroutine, = ENDPROGRAM for ending the SWMM simulation.	CNAME	None
			Card *3 is the last Executive Block card unless the graph routines are called. From card *3, control is passed to the appropriate block. When execution of that block is complete, control returns to card *3. Read card groups A1-E3 only if GRAPH has been called on card *3.		
			General graph information.		
A1	2X	1-2	Card identifier = A1.	--	Blank
	I3	3-5	File (logical unit) where predicted graph information is stored. Will usually = JOUT value of desired block. If zero, only measured data will be plotted.	NTAPE	None

Table 2-8 (continued). Executive Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
	6I5	6-10	Number of locations (e.g., inlets) for which predicted hydrographs (and pollutographs) are to be plotted. Maximum = 10.	NPLOT	0
		11-15	Input and plot measured data. = 0, No measured data (on cards) to be plotted. = 1, Read (and plot) data from cards. = 2, Read (and plot) data stored as card images on file MFILE.	MEAS	0
		The following two parameters are not required if MEAS = 0.			
		16-20	File (logical unit) where measured data are stored. Not required if MEAS ≤ 1. (If zero, defaults to card reader.)	MFILE	N5
		21-25	Number of locations (e.g., inlets, manholes) for which measured data are to be input and plotted (MEAS = 1,2). Maximum = 10.	MPLOT	0
		26-30	Number of pollutants graphed. (Maximum = 5).	NQP	0
		31-35	Metric units used for input-output. = 0, U.S. customary units. = 1, Metric units used, indicated in brackets [ ] in remainder of table.	METRIC	0
			Pollutant selection card. IF NQP = 0 (CARD A1), SKIP TO CARD C1. OTHERWISE, REPEAT CARD B1 NQP TIMES.		
B1	2X	1-2	Card group identifier = B1.	--	Blank
	I3	3-5	Pollutant identifier from sequence on interfacing file. E.g., if IPOL(1) = 3, first pollutant graphed will be third on interfacing file. User must know sequence, as determined from input to preceding block (e.g., card group J3 of Runoff Block). If IPOL = 0, pollutant is not found on interfacing file and is input only from cards.	IPOL	0

Table 2-8 (continued). Executive Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
		***	If IPOL ≠ 0, omit all the following *** parameters since they will be obtained from the interfacing file. For discussion of these parameters, see card group J3 of the Runoff Block and its discussion.		
	2A4	6-13	Pollutant name	PNAME(1) PNAME(2)	Blank
	2A4	14-21	Pollutant units.	PUNIT(1) PUNIT(2)	Blank
	I4	22-25	Type of units. = 0, mg/l. = 1, "other" per liter, e.g., MPN/l. = 2, other concentration units, e.g., JTU, pH.	NDIM	0
			IF NPLOT = 0, SKIP TO CARD C2. Locations (e.g., inlets, manholes) for plotting of predicted output. Supply NPLOT values, (maximum of 10).		
C1	2X	1-2	Card identifier = C1.	--	Blank
	I3	3-5	First location to be plotted.	IPLOT(1)	None
	9I5	6-10	Second location to be plotted.	IPLOT(2)	None
			Last location to be plotted.	IPLOT (NPLOT)	None
			IF MPLOT = 0, SKIP TO CARD D1. Locations (e.g., inlets, manholes) for input and/or plotting of measured data. Supply MPLOT values, (maximum of 10).		

Table 2-8 (continued). Executive Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
C2	2X	1-2	Card identifier = C2.	--	Blank
	I3	3-5	First location to be input and plotted.	KPLOT(1)	None
	9I5	6-10	Second location to be input and plotted.	KPLOT(2)	None
			. . . .	. . . .	
			Last location to be input and plotted.	KPLOT (MPLOT)	None
			Title Card.		
D1	2X	1-2	Card identifier = D1.	--	Blank
	16A4	3-66	Title to be printed at bottom of each plot.	TITL	Blank
			IF MPLOT = 0, SKIP REMAINING CARD GROUPS. OTHERWISE READ MPLOT GROUPS OF CARD GROUP(S) E1 (AND POSSIBLY E2 AND E3) A TOTAL OF NQP + 1 TIMES.		
			First, for measured hydrograph, MPLOT groups of cards E1, E2 and E3:		
E1	2X	1-2	Card identifier = E1.	--	Blank
	I3	3-5	Measured data for this graph and location corresponding to sequence on card C2. = 0, No measured data to be entered for this location. = 1, Input measured data according to remaining parameters and format of card E1.	MDATA	0

Table 2-8 (continued). Executive Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			The following parameters are not required if MDATA = 0.		
	3I5	6-10	Number of graph ordinates per card (MTIME > 0) or pairs of time-graph ordinates per card (MTIME = 0). Maximum = 16.	LCARD	None
		11-15	Option for time of graph ordinates. = 0, Enter a time with each ordinate. Cease input of time-ordinate pairs when entered time is > TQUIT. > 0, The time for each ordinate will be computed starting at TMZERO and using time increment DTMHR. Read a total of MTIME ordinates. Maximum = 201 ordinates for either case.	MTIME	0
		16-20	Units of time if MTIME= 0. Not required if MTIME > 0. = 0, Time is in minutes. = 1, Time is in hours.minutes (i.e., decimal point between hours and minutes). = 2, Time is in decimal hours (and may have values > 24).	MUNIT	0
	3F10.0	21-30	Initial time (decimal hours) of measured data if MTIME > 0. Value of TMZERO is added to times entered if MTIME = 0. May be used to provide a time offset for measured data, avoiding revision of their times.	TMZERO	0.0
		31-40	A time greater than TQUIT ends entry of time-ordinate pairs if MTIME = 0. Not required if MTIME > 0.	TQUIT	0.0
		41-50	Time increment (hours) if times of graph ordinates are calculated (MTIME > 0). Not required if MTIME = 0.	DTMHR	0.0

Table 2-8 (concluded). Executive Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			Card groups E2 and E3 are not required if MDATA = 0 for this graph and location.		
E2	2X	1-2	Card identifier = E2.	--	Blank
	19A4	3-78	Format by which measured data of card group E3 will be read. Include beginning and final parentheses. If card is left blank the default format will be used.	FIRMAT	(2X, F8.0, 7F10.0)

*** Note: If MEAS ≤1 (card A1) this card will be read *** from the card reader (unit N5). Otherwise, the formatted read will be from unit number MFILE (card A1).

Card Group	Format	Card Columns	Description	Variable Name	Default Value
E3	--	--	Card identifier is optional.	--	--
			Time (if MTIME = 0) and graph ordinate, LCARD pairs (if MTIME = 0) per card, according to format of card E2. Entries are stopped when a time is > TQUIT (this time is not included as a data entry). If MTIME > 0, only YVAL will be read, a total of MTIME values, LCARD values per card according to format of card E2. Units of hydrograph ordinate must be cfs [m^3/sec if METRIC = 1], and pollutograph ordinates must be concentrations corresponding to NDIM of card group B1.	TIMX (optional) and YVAL	0.0 0.0

Repeat card groups E1, E2 and E3 for remaining MPLOT-1 locations for measured hydrograph inputs. Then, input MPLOT groups of cards E1, E2 and E3 for first pollutograph, second pollutograph, etc., up to NQP pollutographs. Note, data for the MPLOT locations must appear in the order in which the locations were entered on card C2. There will be a total of MPLOT·(NQP+1) entries of card group(s) E1 (and possibly E2 and E3).

At the end of graph input, control is returned to card *3 of the Executive Block.

SECTION 3

COMBINE BLOCK

BLOCK DESCRIPTION

In order to add the capability of modeling larger areas, the Combine Block has been added to the Storm Water Management Model. This block has two main objectives.

The first objective is to collate different data sets into one, e.g., two separate output data sets, one Transport and one Storage/Treatment, are to be input into the Receiving Water Block. The Combine Block would be used to collate the two output data sets into one which, in turn, would be input into the Receiving Water Block.

The second objective is to combine different data sets and nodes into a single data set and one node, e.g., using the Transport Block on two different drainage networks gives two separate output data sets. Both data sets go to the same treatment facility at the same inlet node. This program would be used to combine the two different Transport output data sets into one data set with a single node which then could be input into the Storage/Treatment Block.

The Combine Block can be used in a number of different ways and gives the Storm Water Management Model the capability of simulating the largest and most diverse cities. For example, Figure 3-1 shows how the Combine Block was used on a combination of SWMM runs for Lancaster, Pennsylvania.

INSTRUCTIONS FOR DATA PREPARATION

Collate

The first objective is to collate two different output data sets from Runoff, Transport, Storage/Treatment, Extran, or any combination thereof. This new data set could then be used as input into any block (Transport, Extran, Storage/Treatment or Receiving Water), except Runoff. For example (Figure 3-2), an output file from Transport area 'A' with manhole numbers 5, 6, 12 was collated with an output file from Transport area 'B' with manhole numbers 1, 3, 6, 19. Manhole number 6 is common between both output data sets, therefore the hydrographs and pollutographs from both manholes are added together. The new output file produced from the Combine Block has manhole numbers 1, 3, 5, 6, 12, 19. This new data set could then be used as input to any other block, including Transport itself.

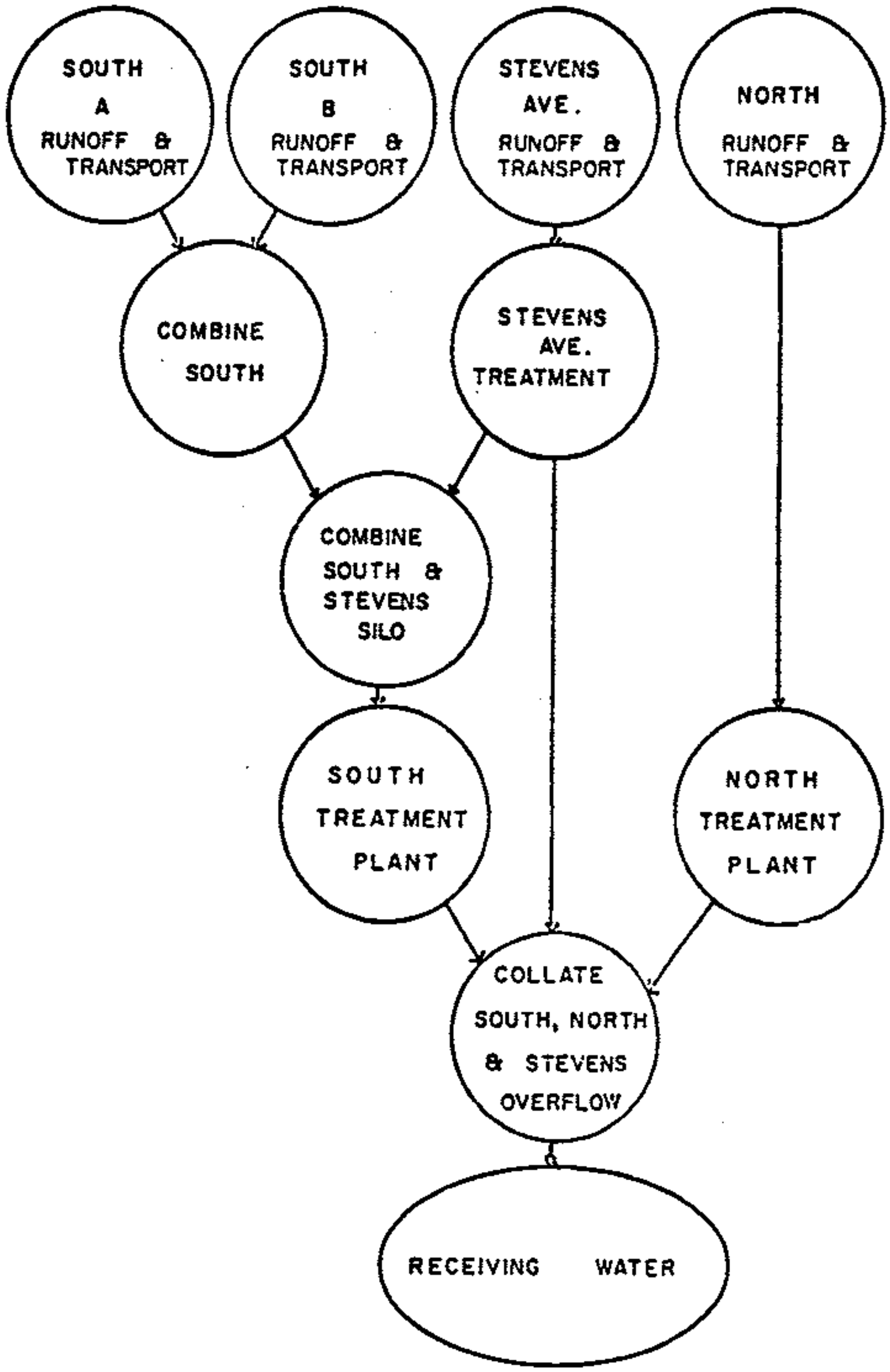


Figure 3-1. Combination of SWMM Runs for Overall Lancaster Simulation.

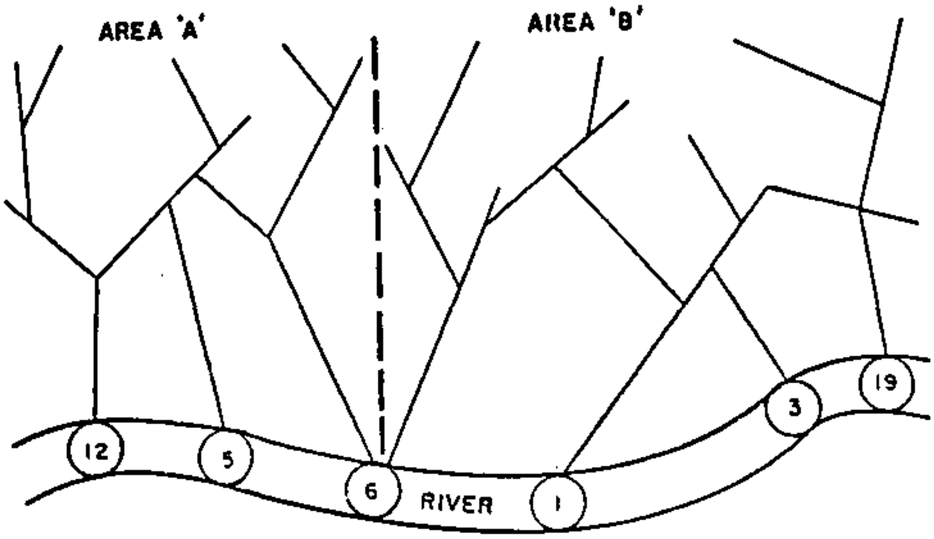


Figure 3-2. Hypothetical Drainage Network to Be Collated.

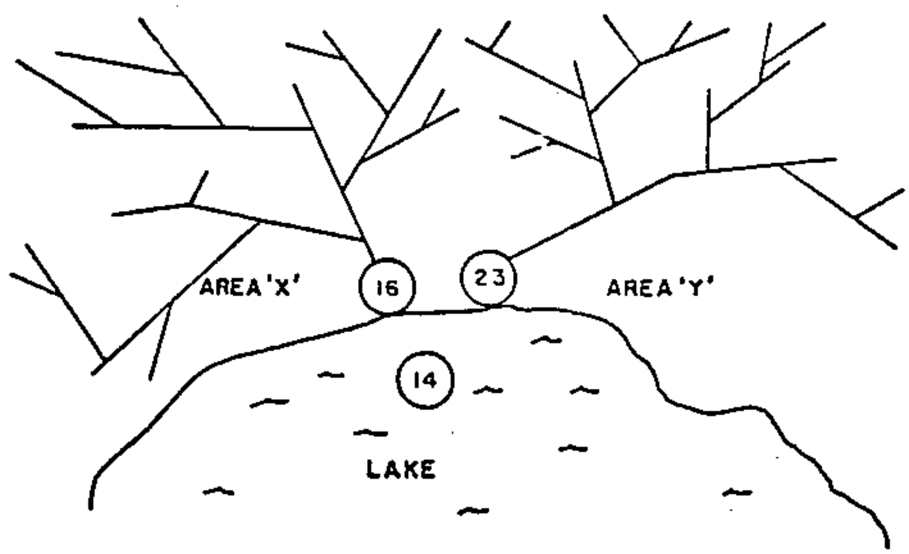


Figure 3-3. Hypothetical Drainage Network to Be Combined.

Combine

The Combine section combines two different files and output locations into a single file with one output location. For example (Figure 3-3), an output file from Transport area 'X' with manhole number 16 and an output data set from Transport area 'Y' with manhole number 23 are to be used as input into the Receiving Water Block junction number 14. The Combine portion of the Combine Block would be used to combine the two output data sets into one data set with one location, assigned the new number, 14. This number would correspond to the junction number of the Receiving Water Block. The Combine Block card data are shown in Table 3-1.

Quality Options

The two different input files may have different quality constituents, especially if a Runoff file is combined/collated with a Transport file, etc. The user is responsible for knowing the contents of each input file and may specify on card C1 the constituents to be used from each. For instance, if BOD_5 is the first constituent to be placed on the output file, and if it is the third on file 1 and seventh on file 2, then NPOS2(1) = 3 and NPOS2(1) = 7. The description (name, units and type of units) will be copied from the first input file. Constituents not accessed will not be placed on the output file.

If a constituent is contained on one file but not the other, it may still be used. However, the file for which the constituent position (NPOS1 or NPOS2) is zero will be assumed to have zero concentration for that constituent.

If NPOLL = 0 on card A1 no quality constituents will be placed on the new output file regardless of whether they are on the input files.

Timing

Both input files must utilize the same time step. An error message will be printed if they differ. If the starting time (TZERO) is different for the two input files, the output file will begin at the earlier TZERO using zeroes for the other file until its series begins. Similarly, if one input file ends before the other, zeroes will be used until the end of the other file.

Files

The two off-line files (unit numbers) used as input are specified by parameters NDATAS(1) and NDATAS(2), and the output file by parameter NDOUT. Note that Executive Block parameters JIN and JOUT are not used at all by the Combine Block. Nor does the Combine Block advance the "counter" for parameters JIN and JOUT as all other blocks do. For instance, if the following sequence were performed: 1. Runoff-A, 2. Runoff-B, 3. Combine (Runoff-A and Runoff-B), 4. Transport, then JIN(3) and JOUT(3) would refer to the Transport Block run and not to the Combine Block run.

Table 3-1. Combine Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
A1	2X	1-2	Card identifier = A1.	--	Blank
	I3	3-5	Program control.	ICOMB	1
			= 1, Collate only.		
			= 2, Combine only.		
	I5	6-10	Number of quality constituents to be placed on new file.	NPOLL	0
			Title cards: two cards with heading to be printed on output.		
B1	2X	1-2	Card identifier = B1.	--	Blank
	2X	3-4	Skip.	--	Blank
	19A4	5-80	Title, 2 cards, to be placed as first title on output file.	TITLE	Blank
B2	2X	1-2	Card identifier.	--	Blank
	I3	3-5	Output file number.	NDOUT	None
	I5	6-10	Node number on output file for combined location. (Not required if ICOMB = 1.)	NODEOT	None
			Input data set numbers.		
B3	2X	1-2	Card identifier.	--	Blank
	I3	3-5	First input file number.	NDATAS(1)	None
	I5	6-10	Second input file number.	NDATAS(2)	None

Table 3-1 (continued). Combine Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			Pollutant identification card not required if NPOLL = 0.		
C1	2X	1-2	Card identifier = C1.	--	Blank
	20I3	3-5	Constituent 1 position on file 1.	NPOS1(1)	0
		6-8	Constituent 1 position on file 2.	NPOS2(1)	0
		.	.	.	
		.	.	.	
		.	.	.	
			Constituent NPOLL position on file 1.	NPOS1(NPOLL)	0
			Constituent NPOLL position on file 2.	NPOS2(NPOLL)	0

END OF COMBINE BLOCK CARDS.

Program now seeks new input from Card #3 of Executive Block.

SECTION 4

RUNOFF BLOCK

BLOCK DESCRIPTION

Introduction

The Runoff Block has been developed to simulate both the quantity and quality runoff phenomena of a drainage basin and the routing of flows and contaminants to the major sewer lines. It represents the basin by an aggregate of idealized subcatchments and gutters. The program accepts an arbitrary rainfall or snowfall hyetograph and makes a step by step accounting of snowmelt, infiltration losses in pervious areas, surface detention, overland flow, gutter flow, and the constituents washed into inlets leading to the calculation of a number of inlet hydrographs and pollutographs.

The Runoff Block may be run in the single event or continuous mode. With the slight exception of snowmelt, all computations are done identically for the two cases. In addition, continuous SWMM produces extra daily, monthly and annual summary output which single event SWMM does not. The main difference between single event and continuous operation is basically that the latter uses data sets (off-line storage) for storage of precipitation and temperature input data instead of dimensioned arrays, thus eliminating any restriction on the number of time steps. Even in the single event mode, the only time step limitation is imposed by the allowed input of only 200 precipitation and air temperature values. Since the input time intervals for precipitation and air temperatures do not have to equal the computational time step, this may impose a limit for single event simulation of either greater or less than 200 time steps. (The limit of 200 precipitation values may be bypassed by setting file NSCRAT(4) $\neq 0$.)

The overall catchment may be divided into a maximum of 200 subcatchments for single event simulation and 30 for continuous simulation although such high limits are only rarely needed. These, in turn, may drain into a maximum of 200 (or 30) gutter/pipes plus inlets. Inlet flows and pollutographs may be placed on the interfacing file for input to subsequent blocks. However, these blocks have their own limitations on the number of inflow locations they will accept. See Table 2-1 for details.

This section describes the program operation of the Runoff Block, provides instructions on data preparation and input data card formats, shows sample runs, and presents the results of a calibration of the Runoff Block.

Program Operation

The relationships among the subroutines which make up the Runoff Block are shown in Figure 4-1. Subroutine RUNOFF is called by the Executive Block to gain entrance to the Runoff Block. The program prints "ENTRY MADE TO RUNOFF MODEL" and then acts as the driver routine for the block. Subroutine RUNOFF directly calls subroutines HYDRO and PRINTR. Although BLOCK DATA is not actually a subroutine, it is automatically activated by RUNOFF and initializes some variables. Subroutine PRINTR reads tape headers, and prints the table headings and results of the quantity and quality simulations.

Subroutine HYDRO computes the hydrograph ordinates and the watershed quality contributions with the assistance of six core subroutines, i.e., RHYDRO, QHYDRO, WSHED, QSHED, BUILD and GUTTER. It initializes all variables to zero before calling RHYDRO to read in the rainfall hyetograph and information concerning the inlet drainage basin. Subroutine CTRAIN is called from RHYDRO if the continuous simulation mode is selected. Its purpose is to read long-term precipitation/temperature histories from National Weather Service (NWS) magnetic tapes. If quality is to be simulated, subroutine QHYDRO is called for input of parameters and subroutine ERROR prints its error messages. QSHED and BUILD are then called to initialize the watershed constituent loads. Next HYDRO sets up an ordering array to sequence the computational order for gutter/pipes according to the upstream and downstream relationships.

HYDRO then sets up a DO loop to compute the hydrograph ordinate for each incremental time step. In each step, subroutine WSHED is first called to calculate the rate of water flowing out of the idealized subcatchments. If snowmelt is simulated subroutines AREAL and MELT are called from WSHED and subroutine FINDSC from AREAL. Additionally, subroutine GAMP is called from WSHED if the Green-Ampt model is used to simulate infiltration. If quality is to be simulated, QSHED and BUILD are called to compute the watershed quality contributions from catchbasins, erosion, dust and dirt, and other sources. GUTTER is then called to compute the instantaneous water depth and flow rate for the gutter/pipes and to route the flow. Water flowing into the inlet point, be it from gutter/pipes or direct drainage from subcatchments, is summed for a hydrograph ordinate. A continuity check is then made for the disposition of rainfall water in the form of runoff, detention, and infiltration and evaporation losses. The error in continuity is computed and printed as a percentage of precipitation. With the assistance of subroutine HCURVE, HYDRO plots the rainfall hyetograph and the runoff hydrograph for the total drainage basin. Subroutine GQUAL routes quality in each gutter/pipe for the flow values computed in subroutine GUTTER.

Interfacing and the Use of Off-line Computer Storage

The Runoff Block transfers hydrographs and pollutographs for as many as 200 inlets and 10 constituents through an assigned tape or disk to other SWMM blocks (see Section 2). However, the other blocks may only accept part of this output. These restrictions may be circumvented by making a single

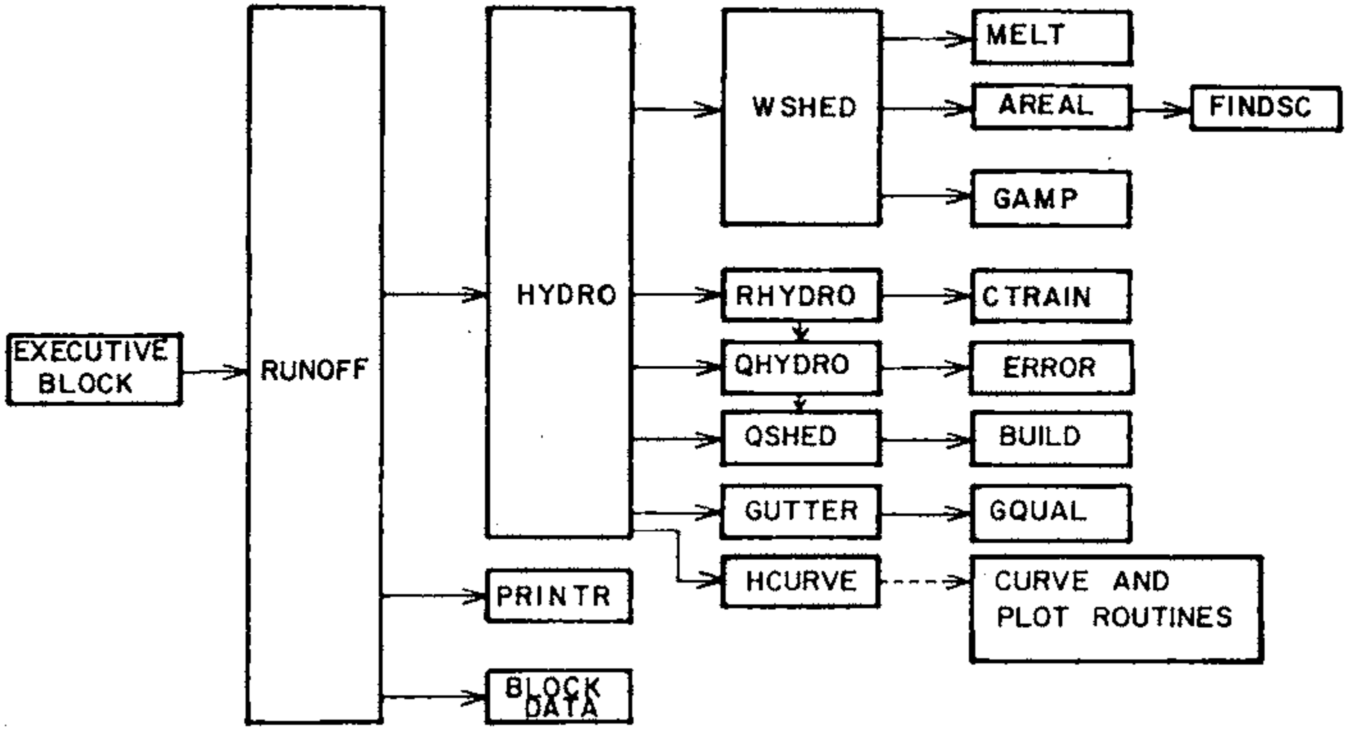


Figure 4-1. Structure of Runoff Block Subroutines.

run of the Runoff Block and generating a permanent data set that will allow several runs of other blocks utilizing different portions of the output. If this is the first computational block, the title, and values for the starting date and time and time step size will remain throughout all subsequent blocks.

One or two scratch data set are required for the single-event mode and as many as three scratch data sets are required for the continuous mode; see Table 4-1. In the continuous mode the additional data sets are used to provide the program with a continuous feed of precipitation data so that there is effectively no limit on the length of the simulation.

Table 4-1 Runoff Data Set Allocations

JIN(1)[a] = Input unit for NWS precipitation tape, read only, required for continuous SWMM only (ICRAIN = 1 or 4 only, card B1).

NSCRAT(1) = Scratch data set, always required. Used for temporary storage of output data to be printed.

NSCRAT(2)[b] = Data set used for storage of processed precipitation values (and temperatures if snowmelt is used) for continuous SWMM, ICRAIN $\neq$ 0. File can be saved and used as input for subsequent Runoff runs if desired, (ICRAIN = 2), thus avoiding reprocessing of precipitation (and temperature) records. Can also be used to contain precipitation data for single event SWMM (ICRAIN=0) thus avoiding time step restrictions.

NSCRAT(3)[b] = Input data set for NWS temperature tape, read only, required only for continuous SWMM with snowmelt, ICRAIN = 1 or 4 and ISNOW = 2.

NSCRAT(4) = Temporary storage of precipitation input data; may be used to avoid possible limit of 200 time steps with single event SWMM.

JOUT(1)[a] = Output unit for transfer of Runoff results to subsequent blocks. Not required if no subsequent blocks are used or graphing is not desired.

[a]Subscript "one" is used if Runoff is the first block run in a SWMM simulation. See explanation of Executive Block (Section 2).

[b]Although files NSCRAT(2) and NSCRAT(3) are protected for an individual run of continuous SWMM using Runoff and Storage/Treatment, care should be taken during subsequent SWMM runs to insure that other blocks using scratch files do not accidently access the same files and write over them, thus eliminating them.

INSTRUCTIONS FOR DATA PREPARATION

Introduction

Instructions on the use of the Runoff Block are divided into five subsections; general input and control data, meteorological data processing, surface quantity, surface quality and print control. These subsections follow the order of the input data cards shown in Table 4-28 at the end of this section. Figure 4-45 shows the layout of the data cards. The user should refer to the latest documentation in the appendices and the original SWMM documentation (Metcalf and Eddy et al., 1971a). Many individual parameters are explained in more detail in the footnotes to Table 4-28.

Basic Runoff Data Sources

Importance of Runoff Block Data --

The Runoff Block forms the source of runoff and quality hydrographs and pollutographs for most SWMM applications. Although the other SWMM blocks allow direct input of hydrographs and pollutographs from cards, either bypassing the interfacing file or in addition to it, in most cases these will be generated by the conversion of rainfall/snowmelt into runoff and pollutant loads in the Runoff Block. Hence, the input data for this block are probably the most important in the model.

Key data requirements and sources are mentioned during discussions of individual card groups later. However, the general types of data are discussed briefly at this point.

Meteorological Data --

Precipitation data are usually obtained from on-site gages maintained by an agency that has performed rainfall-runoff monitoring such as a local consulting firm, 208 agency, or city, county, state or federal agency. In the unfortunate event of a missing rain gage, precipitation data are then obtained from the nearest National Weather Service (NWS) station. The fundamental data are precipitation hyetographs for the duration of the simulation. (See subsequent discussion for use of synthetic rainfall data.) When snowmelt is simulated, air temperatures and wind speed are needed in addition.

Surface Quantity Data --

Flow routing data are usually derived from topographic maps, aerial photos and drainage system plans. These are customarily obtained from the local agency responsible for drainage, usually the city or county. Especially for topographic maps, there is great variation in the quality of such data. Some cities, for instance, have 1:200 scale topographic maps complete with outlines of roads and structures. Slopes are easily derived from the one or two foot contours found on such maps. In other cities, the only contour information available may be the 1:24000 scale USGS quadrangle maps from which gross parameter estimation is often the only possibility. Seekers of basic quantity data must be prepared to spend one to five days at the municipal engineer's office to locate needed maps, plans etc. in public files.

A significant problem remains: the reliability of such data sources. Most municipal offices contain design drainage drawings, but recent as-built information is very rare. In older cities, design drawings may date back several decades and only serve as a guide to what actually exists in the field. This most often affects sewer slopes and cross sections (due to deterioration of old sewers). Finally, combined sewer regulators and other hydraulic control locations are often different from design drawings because of deterioration and maintenance. In many instances, hydraulic connections exist that are not included on any plans because of pragamatic action of maintenance crews. In summary, all such data should be field checked.

Surface Quality Data --

Data required to formulate pollutographs are the most conceptual and ambiguous of any SWMM input data. Such data and their possible sources are discussed later. At this point it is only re-emphasized that unless actual field sampling of runoff quality has been performed, typically by a 208 or pollution control agency, the credibility of predicted quality results cannot be established.

Default Parameters

A characteristic of past SWMM versions has been the inclusion of default values for many quantity and quality parameters. Although this practice is continued in a few instances, it is now discouraged, either by removal of a default option altogether, or else by forcing the user to insert the default parameters. This latter option is easily accomplished through the use of "default" and "ratio" cards -- see footnotes 23 and 24 to Table 4-28. Thus, the user is encouraged at least to consider the values of Manning's n, depression storage or infiltration parameters, for instance. Representative values and guidelines for selection of such parameters are included in this volume.

General Input and Control Data (Card Groups A1 - B2)

The first three card groups are concerned with a label for the output and general operating parameters. The labels of card A1 will be placed on the interfacing file for future identification of the output. Most individual parameters are self-explanatory. However, further information on several parameters (e.g., infiltration) may be found in subsequent discussions of those topics. The computational time step, DELT, is discussed in conjunction with rainfall data and flow routing (surface quantity) parameters. Also, the user should avoid printing large amounts of unnecessary output and use the parameters IRPRNT, ICNTNS, and IPRDAY judiciously (especially for continuous simulations).

Meteorological Data Processing (Card Groups C1-F1)

Snowmelt Data --

General Parameters -- Card groups C1 through F1 are used to read all pertinent meteorological data. Within these cards, groups C1-C5 are concerned with snowmelt, if simulated. Additional snowmelt parameters are found in card groups I1-I3. Since snowmelt procedures are discussed in detail for those card groups and in Appendix II, only minimal information is given here.

On card C1, the watershed elevation is used only to compute average atmospheric pressure, which in turn has only a minimal effect on results. Hence, it is not a "sensitive" parameter. The free water holding capacity of a snow pack is the volume of water (as a depth, in inches) within the pack that can be held as liquid melt prior to releasing runoff. In the model it simply acts as an intermediate reservoir; the larger its volume, the greater the delay in the appearance of runoff following the conversion of snow to liquid water. Unfortunately, as is the case for most snowmelt parameters, very few data exist that permit estimation of this parameter in urban areas, let alone make distinctions among three types of snow covered areas as required on card C1. However, some available information is summarized in Table 4-2.

In natural areas, a surface temperature (SNOTMP) of 34 to 35°F (1-2°C) provides the dividing line between equal probabilities of rain and snow (Eagleson, 1970, Corps of Engineers, 1956). However, parameter SNOTMP on card C1 might need to be somewhat lower in urban areas due to warmer surface temperatures.

The snow gage correction factor accounts for the error in snow gage measurements. The value of SCF is usually greater than 1.0 (the gage tends to underestimate the catch) and increases as a function of wind speed. Representative values are shown in Figure 4-2 (Anderson, 1973). In practice, SCF can be used as a calibration factor to account for gains or losses of snow if data are available to determine it.

During non-melt periods (i.e., sub-freezing weather) the temperature of the snow pack follows the air temperature, but with a delay, since temperature changes cannot occur instantaneously. Heat exchange and temperature changes during this period are explained in Appendix II with reference to equations II-15 and II-16. The weighting factor, TIPM, is an indicator of the thickness of the "surface" layer of the snow pack. Values of TIPM $\leq$ 0.1 give significant weight to temperatures over the past week or more and would indicate a deeper layer (thus inhibiting heat transfer) than TIPM values greater than about 0.5 which would essentially only give weight to temperatures during the past day. In other words the pack will both warm and cool faster (i.e., track the air temperatures) with higher values of TIPM. Anderson (1973) states that TIPM = 0.5 has given reasonable results in natural catchments, although there is some reason to believe that lower values may be appropriate. No data exist for urban areas.

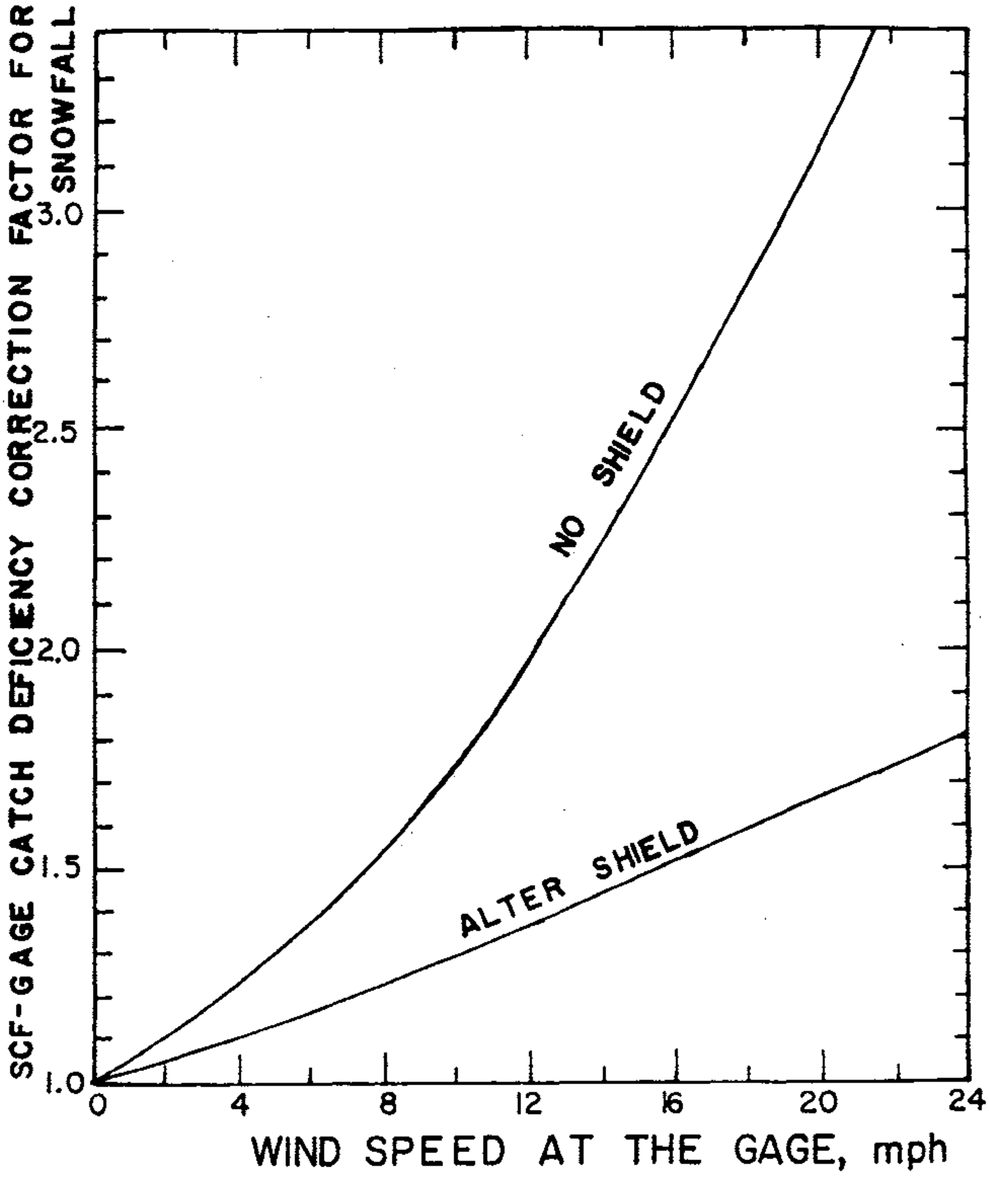


Figure 4-2. Gage Catch Deficiency Factor (SCF) Versus Wind Speed. (After Anderson, 1973 p. 5-20).

Heat transfer within the snow pack is less during non-melt periods than during melt periods due to the presence of liquid water in the pack for the latter case. Parameter RNM simply multiplies melt coefficients (described for card groups I1-I3) to produce a lower "negative melt coefficient" for use during non-melt periods. A typical value for natural areas is 0.6, with values for urban areas likely to be somewhat higher because of the higher density of urban packs. The higher the value of RNM, the more rapid is the heat gain or loss of the pack in response to air temperature changes.

The catchment latitude and the longitude correction (described in footnote 14 to Table 4-28) are used only to compute hours of daylight for the catchment. Computations are insensitive to small errors in these values.

Table 4-2 Snowpack Free Water Holding Capacity
(Anderson, 1973, Corps of Engineers, 1956)

Model input (card C1) is

$$FWFRAC = FW_{max}/WSNOW$$

where FWFRAC = free water holding capacity as a fraction of snowpack depth,

FW_{max} = maximum depth of free water stored in pack, inches, and

WSNOW = snowpack depth, inches water equivalent.

Snowpack Conditions	FWFRAC
Typical deep pack (WSNOW > 10 in.)	0.02-0.05
Typical shallow early winter pack	0.05-0.25
Typical shallow spring pack or with slush layer	0.20-0.30

FWFRAC increases as pack density increases, pack depth decreases, slush layer increases, ground slope decreases.

NWS Temperature Data -- Continuous SWMM requires a complete time history of daily maximum and minimum temperatures, from which hourly temperatures are synthesized by sinusoidal interpolation (see Appendix II). These max-min temperatures are on the NWS card deck 345, "WBAN Summary of Day", as shown in Figure 4-3. A magnetic tape containing these card images is available for most first-order NWS stations and others within the U.S. from the NOAA National Weather Records Center in Asheville, NC (phone

CARD DECK 345 ABAH SUMMARY OF DAY

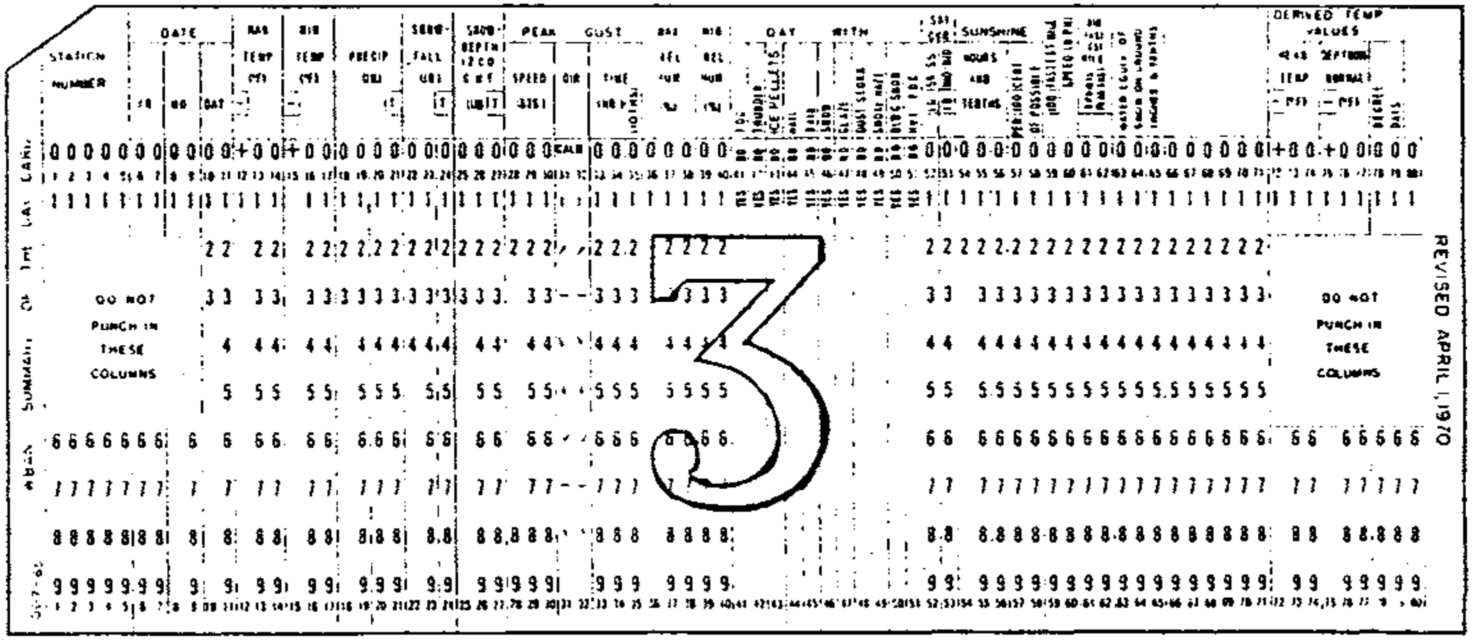


Figure 4-3. Card Image of National Weather Service Card Deck 345, "Summary of Day".

704, 258 2850). A record of 25 years costs approximately $100. Such a record, corresponding to the precipitation record, is required for continuous simulation of snowmelt. Values are interpolated for missing dates. Parameter LOCAT3 is seen to be located in columns 1-5 of card deck 345 (Figure 4-3).

Wind Data -- Wind speeds, entered on card C2, are used only for melt calculations during periods of rainfall (equation II-8). The higher the values of wind speed, the greater are the convective and condensation melt terms. Of course, if the simulation covers a large city, the wind speeds entered on card C2 can only be considered gross estimates of actual highly variable speeds. Average monthly speeds are often available from climatological summaries (e.g., NOAA, 1974).

Areal Depletion Curves -- Areal depletion curves account for the variation in actual snow covered area that occurs following a snowfall. They are explained in detail in Appendix II, some of which is repeated herein.

In most snowmelt models, it is assumed that there is a depth, SI, above which there will always be 100 percent cover. (Values of SI are input in card group I2.) In some models, the value of SI is adjusted during the simulation; in SWMM it remains constant. The amount of snow present at any time is indicated by the parameter WSNOW, which is the depth (water equivalent) over the snow covered areas of each subcatchment. This depth is non-dimensionalized by SI for use in calculating the fraction of areas that is snow covered, ASC. Thus, an areal depletion curve (ADC) is a plot of WSNOW/SI versus ASC; a typical ADC for a natural catchment is shown in Figure 4-4. For values of the ratio AWESI = WSNOW/SI greater than 1.0, ASC = 1.0, that is, the area is 100 percent snow covered.

Some of the implications of different functional forms of the ADC may be seen in Figure 4-5. Since the program maintains snow quantities, WSNOW, as the depth over the total area, AT, then the actual snow depth, WS, and area covered, AS, are related by continuity,

$$\mathrm{WSNOW} \cdot \mathrm{AT} = \mathrm{WS} \cdot \mathrm{AS} \tag{4-1}$$

where WSNOW = depth of snow over total area AT, ft water equivalent,
AT = total area, ft^2,
WS = actual snow depth, ft water equivalent, and
AS = snow covered area, ft^2.

In terms of parameters shown on the ADC, equation 4-1 may be rearranged to read

$$\mathrm{AWESI} = \frac{\mathrm{WSNOW}}{\mathrm{SI}} = \frac{\mathrm{WS}}{\mathrm{SI}} \cdot \frac{\mathrm{AS}}{\mathrm{AT}} = \frac{\mathrm{WS}}{\mathrm{SI}} \cdot \mathrm{ASC} \tag{4-2}$$

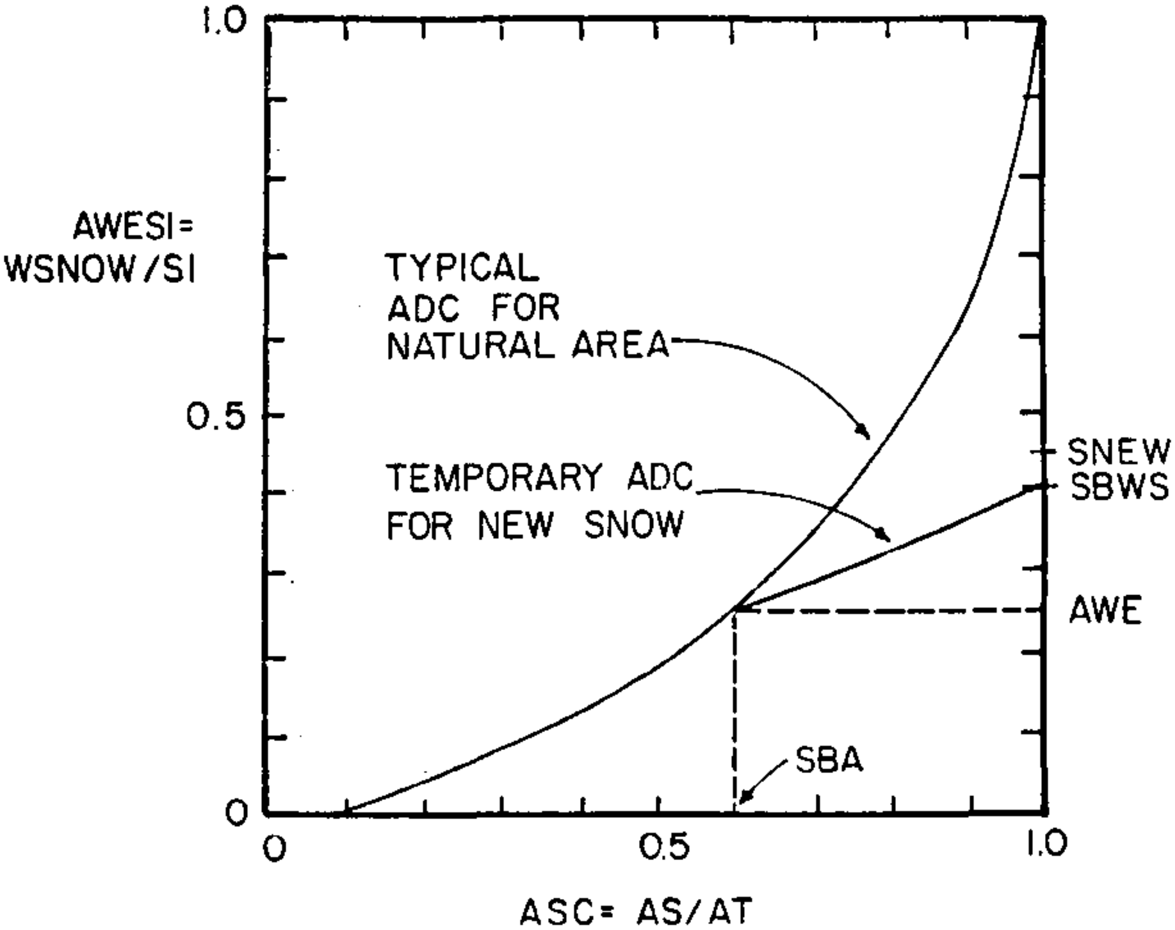


Figure 4-4. Actual Areal Depletion Curve for Natural Area. (After Anderson, 1973, p. 3-15).

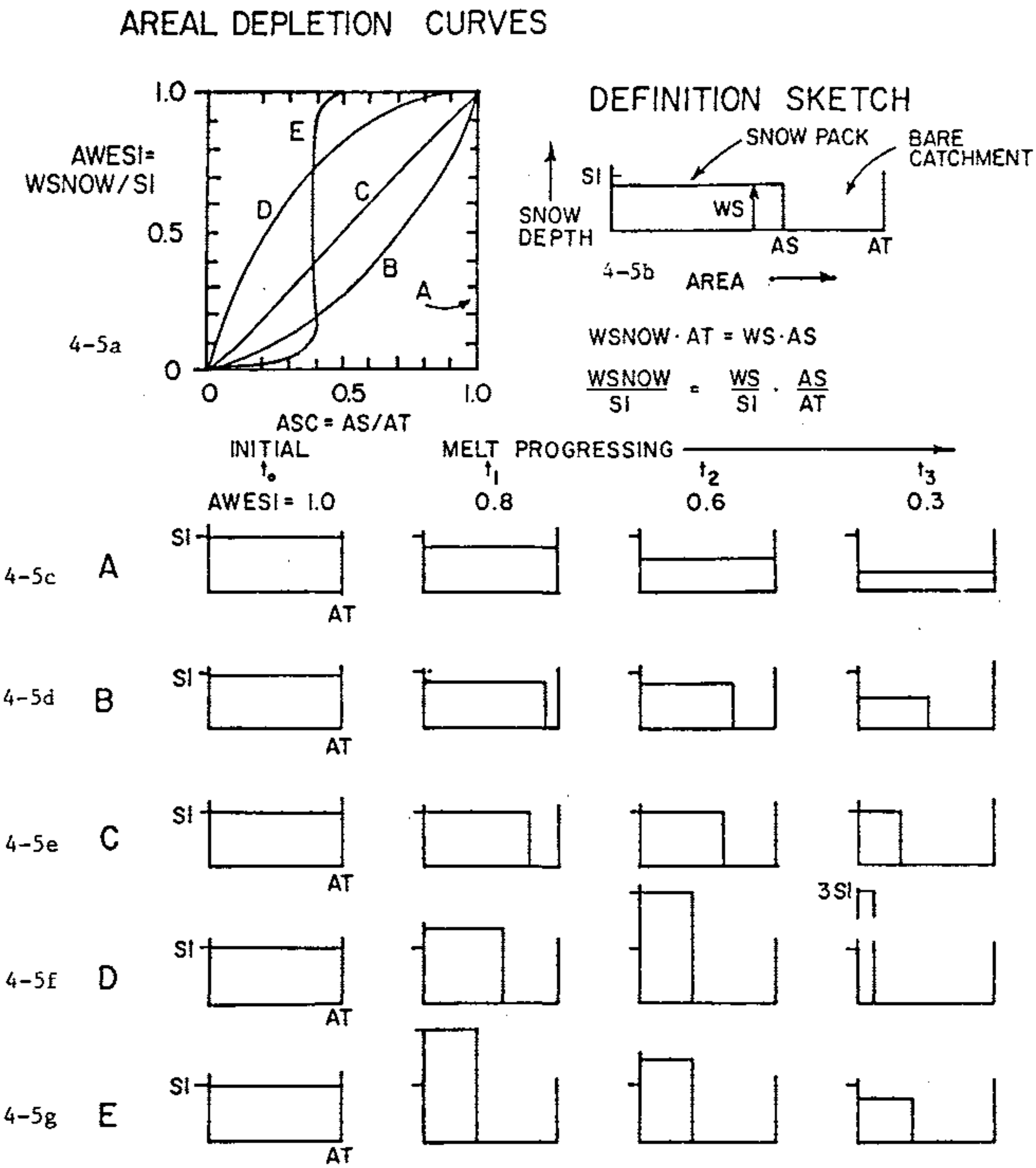


Figure 4-5. Effect on Snow Cover of Areal Depletion Curves.

Equation 4-2 can be used to compute the actual snow depth, WS, from known ADC parameters, if desired. It is unnecessary to do this in the program, but it is helpful in understanding the curves of Figure 4-5. Thus,

$$WS = \frac{AWESI}{ASC} \cdot SI \qquad (4\text{-}3)$$

Consider the three ADC curves, B, C and D. For case B, AWESI is always less than ASC; hence, WS is always less than SI as shown in Figure 4-5d. For case C, AWESI = ASC, hence WS = SI, as shown in Figure 4-5e. Finally, for case D, AWESI is always greater than ASC; hence WS is always greater than SI, as shown in Figure 4-5f. Constant values of ASC at 100 percent cover and 40 percent cover are illustrated in Figures 4-5c, curve A, and Figure 4-5g, case E, respectively. At a given time (e.g, t_1 in Figure 4-5), the area of each snow depth-area curve is the same and equal to AWESI · SI, (e.g., 0.8 SI for time t_1).

Curve B on Figure 4-5a is the most common type of ADC occurring in nature, as shown in Figure 4-4. The convex curve D requires some mechanism for raising snow levels above their original depth, SI. In nature, drifting might provide such a mechanism; in urban areas, plowing and windrowing could cause a similar effect. It is seen that such a convex curve acts to delay melt because of the inhibiting effect on heat transfer of deep snow packs. A complex curve could be generated to represent specific snow removal practices in a city. However, the program utilizes only one ADC curve for all impervious areas and only one ADC curve for all pervious areas. This limitation should not hinder an adequate simulation since the effects of variations in individual areas are averaged out in the city-wide scope of most continuous simulations.

The two ADC curves for impervious (card C3) and pervious (card C4) areas are input by the user, as are values of SI for each subcatchment (card I2). The program does not require the ADC curves to pass through the origin, AWESI=ASC=0; they may intersect the abscissa at a value of ASC > 0 when ASC = 0.

The preceding paragraphs have centered on the situation where a depth of snow greater than or equal to SI has fallen and is melting. (The ADC curves are not employed until WSNOW becomes less than SI.) The situation when there is new snow is discussed in Appendix II.

Air Temperatures --

For single event snowmelt simulation, air temperatures are input in card group C5. These may be obtained from instrumentation at the catchment or from the nearest NWS station. The temperatures are constant over the time interval DTAIR (card B2). Hence, DTAIR should be an integer multiple of DELT.

Precipitation Data --

Choice of Rainfall Data -- Without doubt, rainfall data are the single most important group of hydrologic data required by SWMM. Yet, they are often prepared as an afterthought without proper consideration of the implications of their choice. The following discussion will briefly describe options for rainfall input and their consequences. Only rainfall is considered since for snow it is the physics of snowmelt rather than snowfall which is important in determining runoff.

SWMM requires a hyetograph of rainfall intensities versus time for the period of simulation. For single event simulation this is usually a single storm, and data for up to six gages may be entered (if the user is fortunate enough to have multiple gages for the catchment). For continuous simulation, hourly data from only one gage are required; these are usually obtained from the nearest NWS station. Thus, for continuous simulation, the options are fewer since a satisfactory generator of a synthetic hourly rainfall sequence is not usually available, or probably even desirable. Hence, a historical rainfall sequence is used.

For single event simulation, on the other hand, synthetic sequences are indeed an option in lieu of historical records. However, several pitfalls exist in the use of synthetic hyetographs that may not be obvious at first thought. As a prelude, consider the objectives of hydrologic quantity and quality modeling.

Modeling Objectives -- These were treated broadly in Section 1. More specifically, models might be used to aid in urban drainage design for protection against flooding for a certain return period (e.g., five or ten years), or to protect against pollution of receiving waters at a certain frequency (e.g., only one combined sewer overflow per year). In these contexts, the frequency or return period needs to be associated with a very specific parameter. That is, for rainfall one may speak of frequency distributions of interevent times, total storm depth, total storm duration or average storm intensity, all of which are different (Eagleson, 1970, pp. 183-190). Traditional urban drainage techniques often utilize frequencies of depths given durations, taken from intensity-duration-frequency (IDF) curves, which are really conditional frequency distributions. But for the above objectives, and in fact, for almost all urban hydrology work, the frequencies of runoff and quality parameters are required, not those of rainfall at all. Thus, one may speak of the frequencies of maximum flow rate, total runoff volume or duration or of total pollutant loads. These distributions are in no way the same as for similar rainfall parameters, although they may be related through analytical methods (Howard, 1976, Chan and Bras, 1979, Hydroscience, 1980). Finally, for pollution control, the real interest may lie in the frequency of water quality standards violations in the receiving water, which leads to further complications.

Ideally an analyst would develop costs and benefits for designs at several frequencies in preparation for an economic optimization. In practice, it is often difficult to accomplish this for even one case.

However, continuous simulation offers an excellent, if not the only method for obtaining the frequency of events of interest, be they related to quantity or quality. Advantages are discussed in Section 1 and Appendix I along with several other models besides SWMM that will perform similar tasks. But continuous simulation has the disadvantages of a higher cost and the need for a continuous rainfall record. This has led to the use of a "design storm" or "design rainfall" or "design event" in a single event simulation instead of continuous. Of course, this idea long preceded continuous simulation, before the advent of modern computers. It is the choice of the design event, as it will be termed herein, that may lead to problems.

Design Events -- Two methods of obtaining design events are considered: 1) use of a historical sequence and 2) generation of a synthetic sequence. Synthetic sequences are usually constructed by the following steps:

1. A storm duration is chosen, either on an arbitrary basis or to coincide with the assumed catchment time of concentration, t_c, i.e., equilibrium time during a steady rainfall at which outflow equals a constant fraction of inflow (or outflow equals inflow on a catchment without losses). The latter method itself has difficulties because of the dependence of t_c on rainfall intensity and other parameters (Eagelson, 1970).

2. A return period is chosen in order to select the total storm depth for the specified duration from intensity-duration-frequency (IDF) curves.

3. A time history for the storm is assumed, usually on the basis of historical percentage mass curves. If peak intensities are at the beginning of the storm, the hyetograph takes on the appearance of a decaying exponential curve. If the peak intensities are near the middle, a "circus tent" hyetograph results (Figure 4-6). The hyetograph is shaped such that depths (or average intensities) for any duration centered about the peak match those from the IDF curve.

4. The continuous hyetograph of Figure 4-6 must then be segmented into a histogram for input to most digital models.

This procedure was apparently first detailed by Keifer and Chiu (1957) and then by Tholin and Keifer (1960) in Chicago. It has since been emulated by many others.

Many problems with this procedure have been enumerated for construction of synthetic hyetographs (McPherson, 1978, Patry and McPherson, 1979) and the underlying Rational Method and IDF curves on which it is based (McPherson, 1969). These reports may be seen for details, but some key points are given here:

1. IDF curves themselves may consist of components of several different storms. They in no way represent the time history of a real storm.

2. When frequencies are assigned to total storm depths (independent of duration) they generally do not coincide with the conditional frequencies of depth given duration obtained from IDF curves. For instance, the two historical storms shown on Figure 4-6 for comparison with the "5-year" synthetic storm of 2.28 in (58 mm) have return periods (based on total depth) of 4.6 and 5.8 years, but total depths of only 1.61 and 1.85 in (41 and 47 mm), respectively. Thus, IDF curves cannot be used to assign

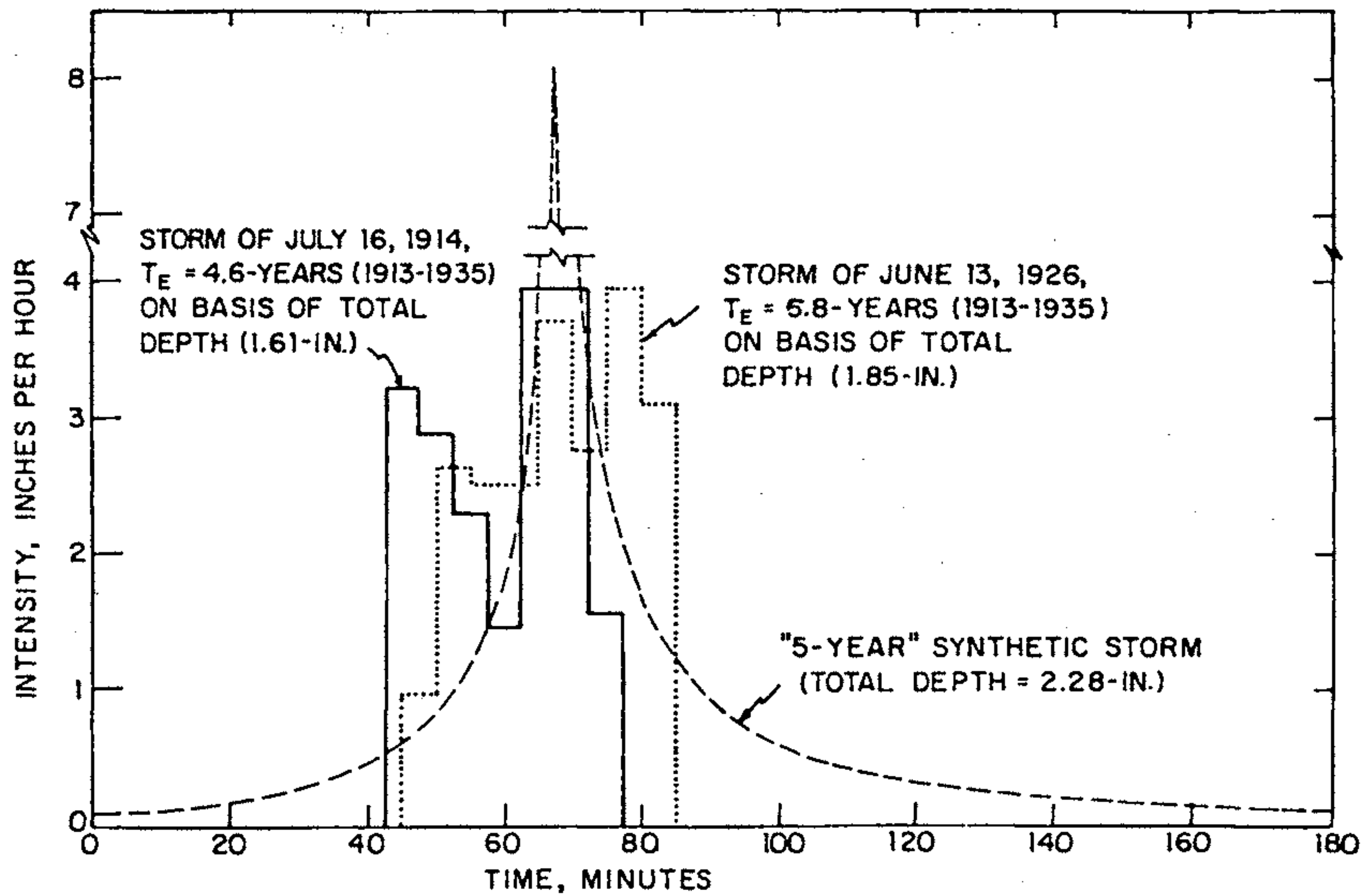


Figure 4-6. Comparison of Synthetic Versus Actual Storm Patterns, Chicago. (After McPherson, 1978, p. 111.)

frequencies to storm volumes. If synthetic hyetographs are thence used for studies of detention storage or pollutant loads, where volumetric considerations are key, no frequency should be assigned to the results.

3. Although the time history assigned to a synthetic storm may represent an average of many storms, there is often considerable variability (see P. Bock, Discussion of Tholin and Keifer, 1960). If a frequency could be assigned to a synthetic storm, it would probably be considerably rarer than its nominal frequency, because the joint probability of all time sequences within the storm corresponding to those of an IDF curve is very low. The two historical storms shown on Figure 4-6 certainly do not mimic the synthetic storm.

4. Antecedent conditions must still be chosen arbitrarily when using a design event (either a synthetic or historical storm).

5. A synthetic design event is one that "never really happened." McPherson (1978) emphasizes the need to design with a real (historical) event to insure credibility in the eyes of the public.

6. There is evidence that synthetic design events may produce an overdesign if the objective is a design for a given return period. Marsalek (1978a,b) has compared continuous simulation results of flood peaks and volumes versus return period with results obtained by single event simulations using the same model with input of n-year synthetic events of the type described earlier. Flood peaks are always higher for the synthetic events. Flood volumes are higher for most synthetic events, depending on the method of generation of the event, because the return periods assigned to the synthetic volumes are incorrect.

Design Event Alternatives -- In spite of all of its problems, use of a design event may still be required. Fortunately, there are ways in which this may be accomplished satisfactorily.

Foremost among these is the use of continuous simulation as a screening tool. As stated earlier, continuous simulation for several years of a large catchment with inclusion of spatial detail can be expensive. Instead, representative smaller catchments may be simulated from which critical events may be selected for a more detailed, single event simulation. Thus, from a simple long-term continuous simulation, critical subsets may be identified for further analysis. Walesh and Snyder (1979) present ideas along this line.

Continuous simulation may also be used to "calibrate" a synthetic design event. That is, the design hyetograph may be adjusted such that it produces flows or volumes that correspond for its return period to those produced by a continuous simulation run. This has been done in studies in northern Virginia (Shubinski and Fitch, 1976) and Denver (B. Urbonas, personal communication, 1979). Proper adjustment of antecedent conditions can also cause results from synthetic design events to match historical results (Wenzel and Voorhees, 1978).

In any event, several storm events should be processed for design considerations. These may be selected from a continuous simulation run, as suggested above or chosen from the historical record on another basis. For urban drainage or flood control design, it may be desirable to choose a particular, well-known local rainfall event and make sure that a design will handle that storm.

Calibration of the model remains important for any application. It has been suggested (M. Terstriep, personal communication, 1979) that use of a synthetic design event for analysis of a new system may not be any worse than using historical data in an uncalibrated model.

National Weather Service Precipitation Data -- Hourly precipitation values (including water equivalent of snowfall depths) are available for 25 year periods for most first-order NWS stations around the U.S. (Similar data are available in Canada from the Atmospheric Environment Service.) Magnetic tapes containing card images of NWS Card Deck 488, "USWB Hourly Precipitation" (Figure 4-7) are available from the NOAA National Weather Records Center in Asheville, NC (phone 704, 259 0682) at a cost of about $150. The same data are also available for shorter periods for multiple cities.

Having obtained these data for a continuous simulation, they are read directly from the tape in subroutine CTRAIN. The required NWS ID number is read on card D1. Starting dates for the simulation are given on card B1, ending dates on card D1. The station name (card D1) is only for printing purposes.

The highest 50 hourly rainfall depths are printed following the precipitation tape processing. These may be used to aid in selection of events of interest. If ICRAIN = 4 (card B1), input ceases at card D1, and processed precipitation (and temperature) data may be reviewed prior to the rest of the simulation run, if desired.

Card Input of Precipitation Data -- For single event simulation, precipitation hyetographs may be input for up to six gages in card groups E1 and E2. Any one of the six gages may then be assigned to a subcatchment. The time interval for input of hyetograph intensities, THISTO, (the same for all hyetographs) must be either equal to the computation time step, DELT (Card B2), or an integer multiple or integer fraction (e.g., 1/2, 1/5, etc.) thereof. If THISTO is an integer fraction of DELT, the average intensity over time step DELT is used in computations.

Up to 200 hyetograph ordinates may be entered without using a scratch file (NSCRAT(2)). Depending on the relationship between DELT and THISTO, this may impose a limitation on the run less than, more than or equal to 200 time steps. When ICRAIN = 3 (card B1) or when NSCRAT(4) $\neq$ 0, the precipitation data input from cards are stored on an off-line file instead of in an array, eliminating any limit on the number of time steps.

Temporal Rainfall Variations -- The required time detail for rainfall hyetographs is a function of the catchment response to rainfall input. Small, steep, smooth, impervious catchments have fast response times, and vice versa. As a generality, shorter time increment data are preferable to longer time increment data, but for a large (e.g., 10 square miles, 2.6 km^2)

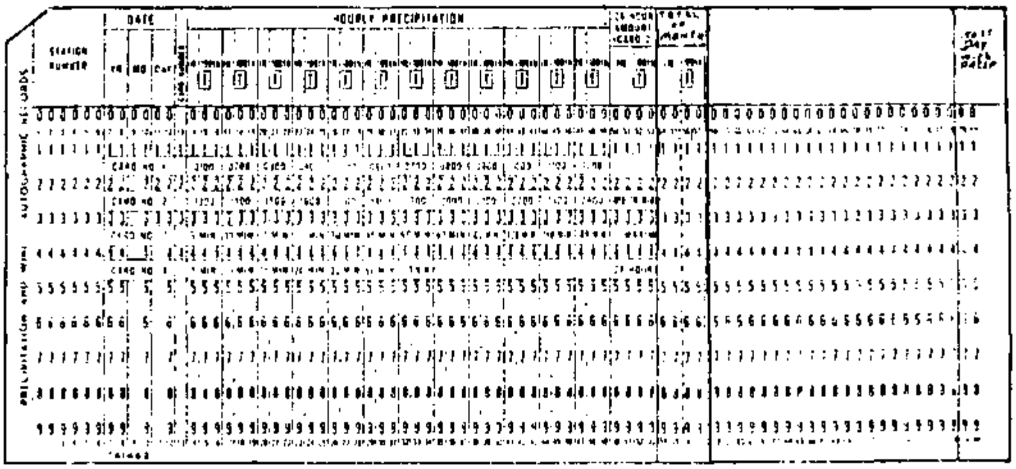


Figure 4-7. Card Image of National Weather Service Card Deck 488, "Hourly Precipitation".

subcatchment (coarse schematization), even the hourly inputs used for continuous simulation may be appropriate.

The rain gage itself is usually the limiting factor. It is possible to reduce data from 24-hour charts from standard weighing-bucket gages to obtain 5 minute increment data, and some USGS gages produce no better than 5 minute values. Shorter time increment data may usually be obtained only from tipping bucket gage installations.

Of course, the necessary time increment for rainfall is closely coupled to the computational time step, DELT. This is discussed subsequently in conjunction with flow routing parameters.

Spatial Rainfall Variations -- Even for small catchments, runoff and consequent model predictions (and prototype measurements) may be very sensitive to spatial variations of the rainfall. For instance, thunderstorms (convective rainfall) may be very localized, and nearby gages may have very dissimilar readings. For modeling accuracy (or even more specifically, for a successful calibration of SWMM), it is essential that rain gages be located within and adjacent to the catchment.

SWMM inputs the spatial variability by the assignment of one of up to six gages to a particular subcatchment. (Clearly, there is no point in the input of more gage data than there are subcatchments.) If multiple gages are available, this is a much better procedure than is the use of spatially averaged (e.g., Thiessen weighted) data, because averaged data tend to have short-term time variations removed (i.e., rainfall pulses are "lowered" and "spread out"). In general, if the rainfall is uniform spatially, as might be expected from cyclonic (e.g., frontal) systems, these spatial considerations are not as important. In making this judgment, the storm size and speed in relation to the total catchment must be considered. It should be noted that a moving or "kinematic" storm may only be simulated in SWMM by using multiple gages. Storm motion may very significantly affect hydrographs at the catchment outlet (Yen and Chow, 1968, Surkan, 1974, James and Drake, 1980).

Evaporation Data (Card F1) --

An average monthly evaporation rate is required for the month being simulated in the single event mode, or for all months in the continuous mode. This rate is subtracted from rainfall and snowmelt intensities at each time step and is also used to replenish surface depression storage but for no other purposes. For instance, it is not used to account for sublimation from snow or exfiltration from soil. Evaporation data may usually be obtained from climatological summmaries (NOAA, 1974) or NWS or other pan measurements (e.g., from NWS Climatological Data). Single event simulations are usually insensitive to the evaporation rate, but evaporation can make up a significant component of the water budget during continuous simulation.

Surface Quantity Input Data (Card Groups G1-I3)

Runoff Flow Routing Procedures and Options --

Card groups G1 through I3 input data used to establish flow routing and snowmelt parameters for the Runoff Block. Snowmelt will be discussed subsequently. Flow routing is accomplished using three types of elements:

1. subcatchment elements (overland flow),
2. gutter elements (trapezoidal channel flow), and
3. pipe elements (circular channel flow).

Subcatchment elements receive rainfall and snowmelt, account for losses due to evaporation and infiltration (via Horton's equation or the Green-Ampt equation), and permit surface depression storage to account for losses such as ponding or retention on grass or pavement. Flow from subcatchments is always into gutter/pipe elements or inlets. A tree-network of gutter/ pipes may be used to simulate smaller drainage elements of the sewer system. If they are used, they route hydrographs (and pollutographs) from subcatchments to inlets (e.g., entry points to the main sewer system). Inlet flows are placed on the interfacing file for transmital to subsequent SWMM blocks. However, the Runoff Block is often used by itself if the more sophisticated routing procedures of the Transport or Extended Transport Blocks are not required (discussed below).

Flow routing for both subcatchments and gutter/pipes is accomplished by approximating them as non-linear reservoirs. This is simply a coupling of a spatially lumped continuity equation with Manning's equation. A detailed description is presented in Appendix VI and the SWMM Final Report (Metcalf and Eddy et al., 1971a). Should the capacity of a gutter/pipe be exceeded, "surcharge" is indicated, and excess water is stored at the upstream end until the gutter/pipe can accept it.

Input Data Preparation --

Preparation of these input data cards requires two tasks: 1) discretization of the physical drainage system and 2) estimation of the coefficients necessary to characterize the catchment. These tasks require varying amounts of effort depending on the level of detail desired by the user.

Very useful additional information for these tasks is contained in short course proceedings prepared by the University of Massachusetts (DiGiano et al., 1977). The Runoff Block example is particularly good because of the emphasis on data reduction from typical municipal maps and plans. The SWMM user is encouraged to review these proceedings for alternative explanations and examples. Further useful information is contained in the User's Manual prepared for Canadian SWMM applications (Proctor and Redfern and James F. MacLaren, 1977) and in the SWMM-related references discussed in Section 1.

Discretization of the Catchment --

Definition -- Discretization is a procedure for the mathematical abstraction of the physical drainage system. For the computation of hydrographs, the drainage basin may be conceptually represented by a network of hydraulic elements, i.e., subcatchments, gutters, and pipes. Hydraulic properties of each element are then characterized by various parameters, such as size, slope, and roughness coefficient.

Subcatchments represent idealized runoff areas with uniform slope. Parameters such as roughness values, depression storage and infiltration values are taken as constant for the area and usually represent averages, although pervious and impervious areas have different characteristics within the model. If roofs drain onto pervious areas, such as lawns, they are usually considered part of the pervious area, although conceivably, they could be treated as miniature subcatchments themselves.

Discretization begins with the identification of drainage boundaries using a topographic map, the location of major sewer inlets using a sewer system map, and the selection of those gutter/pipes to be included in the Runoff Block system. Note that discretization of the sewer system involves choices that affect elements to be used in either of the subsequent Transport Blocks (see below). An example will illustrate some of these points.

Example -- Two possible discretizations of the Northwood catchment in Baltimore (Tucker, 1968, Huber et al., 1979) are indicated in Figures 4-8 and 4-9 (Metcalf and Eddy et al., 1971a). A "fine" approach was used in Figure 4-8, resulting in 12 subcatchments and 13 pipes leading to one inlet. In Figure 4-9, a "coarse" discretization was used, resulting in five subcatchments and no gutter/pipes. "Storm Conduits" shown in Figure 4-9 could either be simulated by the Transport Block or ignored, feeding all subcatchment flows to the one inlet. The outlet to the creek then represents the downstream point in the simulation. (This could lead, in a larger system, to inlets in the Transport Model.)

A comparison of hydrographs produced by the two methods is shown in Figure 4-10 (Metcalf and Eddy et al., 1971a), in which the differences are relatively minor. Additional calibration effort could bring the two schematizations into better agreement with each other and with the measured hydrograph. Techniques for this purpose are discussed later as are techniques for aggregation of subcatchments.

Required Amount of Detail -- It is anticipated that only a very coarse discretization will be used for continuous simulation. Although up to 30 subcatchments and gutter/pipes or inlets are allowed, a typical continuous simulation might include only one subcatchment and no gutter/pipes. This economy in the amount of detail simulated is prompted to save computer time and because detail simply is not required for continuous simulation which serves as a screening and planning tool (see Section 1 and Appendix I). Moreover, reasonable agreement is possible between hydrographs produced by coarse and fine schematizations as will be discussed later under "subcatchment aggregation".

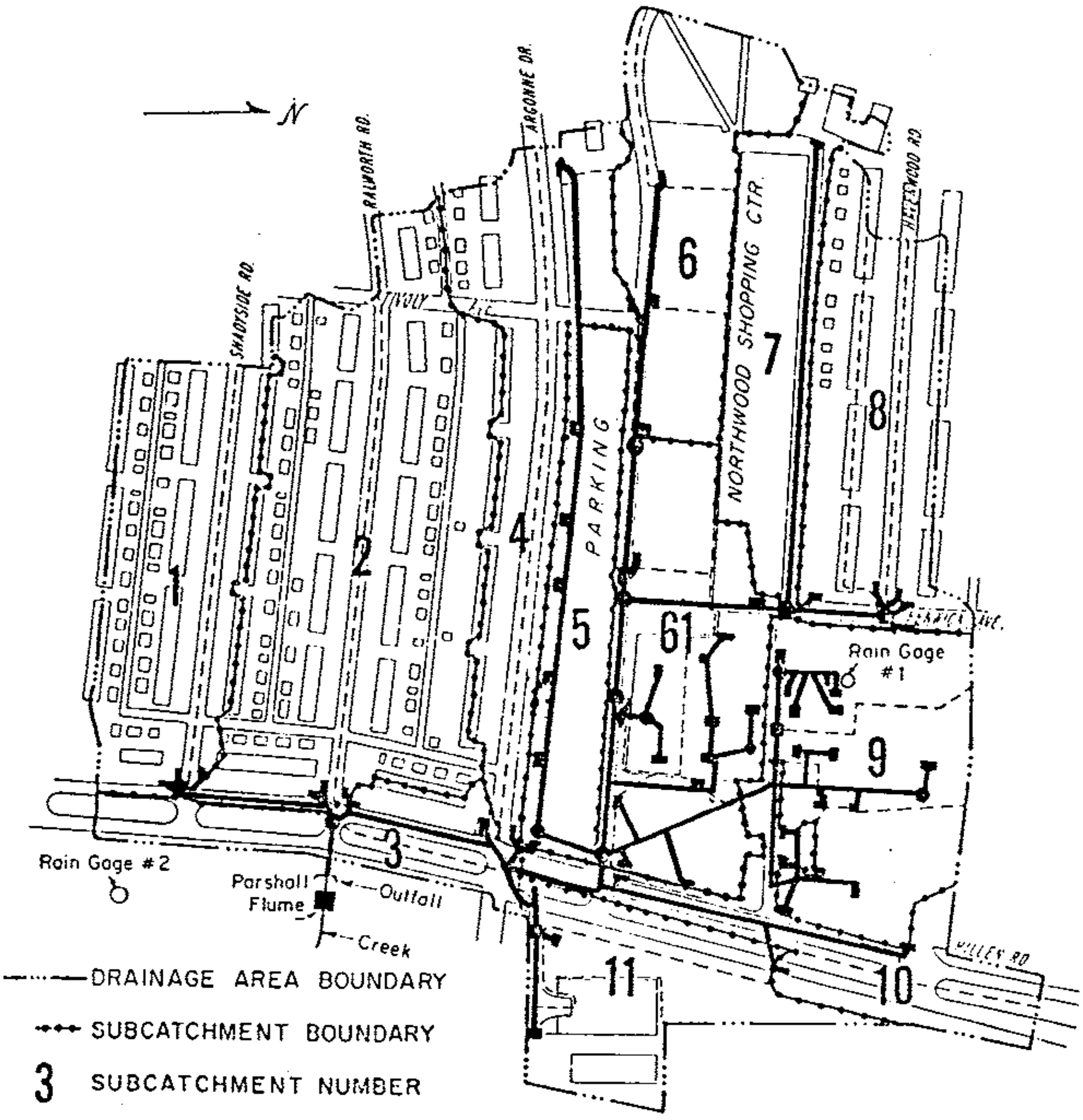


Figure 4-8. Northwood (Baltimore) Drainage Basin "Fine" Plan. (After Metcalf and Eddy et al., 1971a, p. 50)

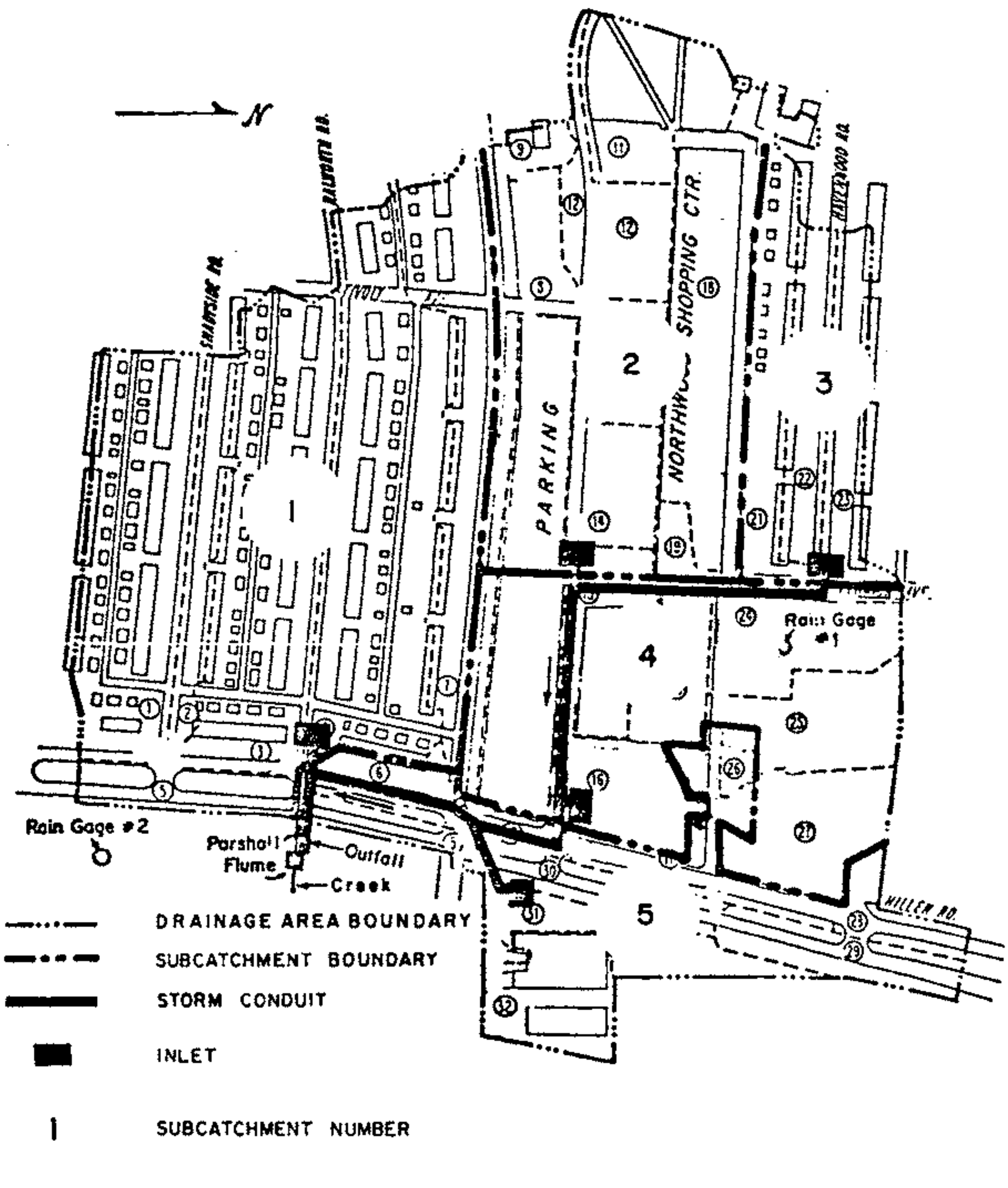


Figure 4-9. Northwood (Baltimore) Drainage Basin "Coarse" Plan.
(After Metcalf and Eddy et al., 1971a, p. 51)

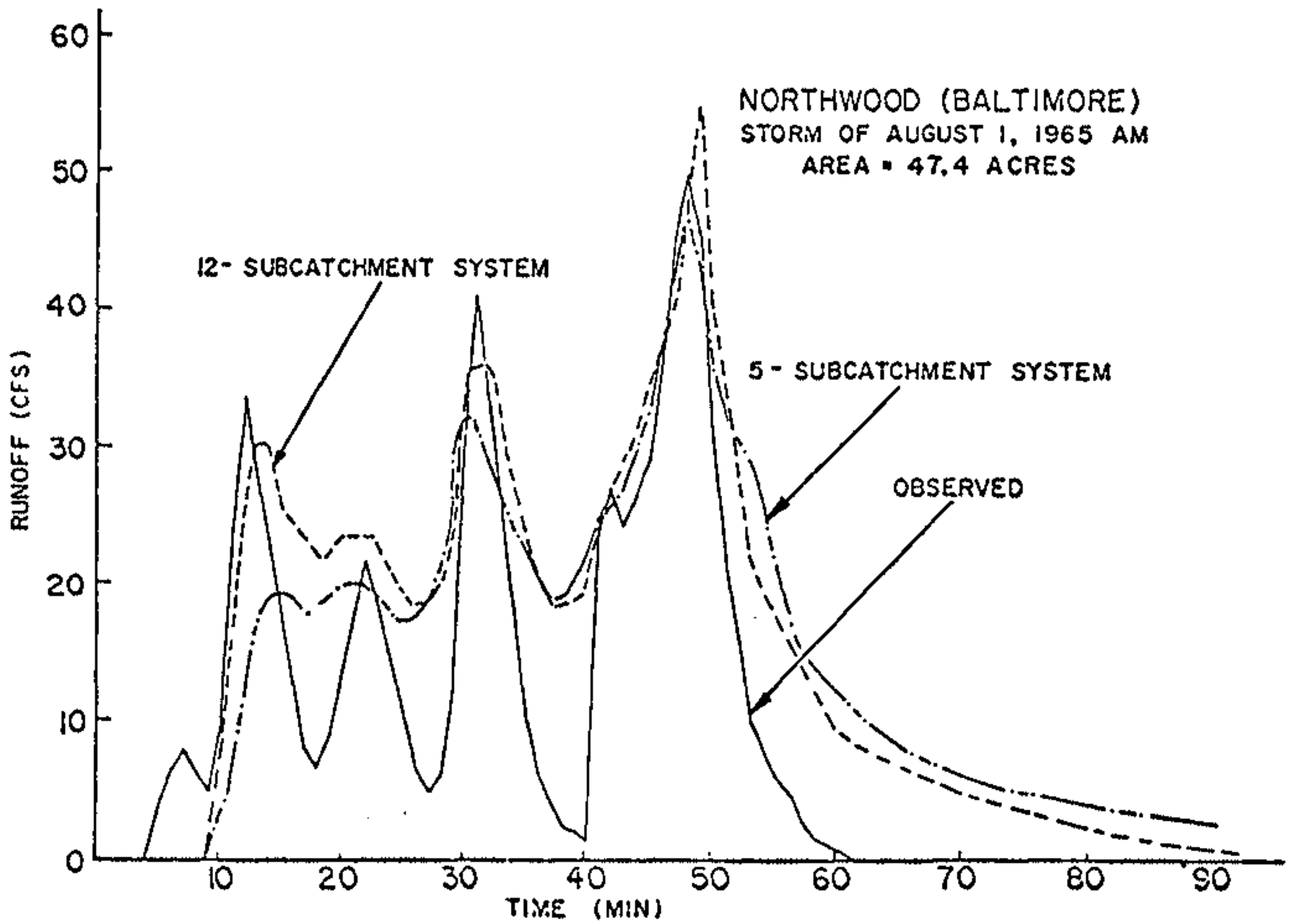


Figure 4-10. Effect of Coarsening Subcatchment System, Northwood (Baltimore). (After Metcalf and Eddy et al., 1971a, p.74)

Should flow routing be desired during continuous simulation, Runoff Block gutter/pipes may be used. (The Transport Blocks are intended primarily for a detailed storm event analysis.)

For single event simulation, the amount of detail should be the minimum consistent with requirements for within-catchment information. Obviously, no information can be obtained about upstream surcharging if the upstream conduits are not simulated and subcatchments are not provided to feed them. In addition, sufficient detail needs to be provided to allow within-system control options to be tried for different areas and land uses. If, however, the primary objective is simply to produce a hydrograph and pollutograph at the outlet, utilizing a single rain gage, then one subcatchment will often (but not always) serve as well as many.

A final constraint on the amount of detail is dictated by personnel requirements for data reduction. Once data resources (e.g., maps, plans) are gathered, discretization of the catchment can occupy one to three person-days (a longer time for more subcatchments) with perhaps an additional 15 to 30 minutes per subcatchment for their input parameters. Finally, there is no one "right" way to accomplish the discretization, especially since decisions at this stage can be compensated for during the later calibration phase.

Choice of Sewer System Flow Routing -- There are many criteria that influence the choice of the block used for sewer system routing: Runoff, Transport or Extended Transport. Several of these are give in Table 4-3; much more extensive information is contained in the sections of this report and SWMM documentation (Metcalf and Eddy et al., 1971a, Roesner et al., 1981) pertaining to each block.

Regarding flow routing methods, no backwater effects can be calculated (i.e., in an upstream direction) in the Runoff and Transport Blocks because each conduit element simply provides an inflow to a downstream element with no effect of the latter on the former. Thus, both Runoff and Transport Block routing acts as a "cascade" of elements, each discharging into the next with no other interactions. On the other hand, the solution of the complete St. Venant (gradually varied flow) equations by the Extended Transport Block provides for backwater effects and much more, as indicated in Table 4-3. This is at the cost of considerable extra complexity and computer time.

As a practical matter, the Runoff Block is often used to simulate smaller diameter pipes, e.g., less than 30 in (762 mm) and one of the two Transport Blocks for the larger trunk sewer system. The larger the catchment being simulated, the less important becomes the simulation of small conduits, far upstream. Conduits of less than a 12 in (305 mm) diameter are rarely simulated. Also, in spite of the fact that Runoff Block trapezoidal conduits are called "gutters", it should almost never be necessary to simulate flow in a roadside curb and gutter channel, unless the catchment is extremely small.

Table 4-3. Flow Routing Characteristics of Runoff, Transport and Extended Transport Blocks.

	Runoff Block	Transport Block	Extended Transport Block
1. Flow routing method	Non-linear reservoir, cascade of conduits	Kinematic wave, cascade of conduits	Complete equations, interactive conduit network
2. Relative computational expense for identical network schematizations	Low	Moderate	High
3. Attenuation of hydrograph peaks	Yes	Yes	Yes
4. Time displacement of hydrograph peaks	Weak	Yes	Yes
5. In-conduit storage	Yes	Yes	Yes
6. Backwater or downstream control effects	No	No[a]	Yes
7. Flow reversal	No	No	Yes
8. Surcharge	Weak	Weak	Yes
9. Pressure flow	No	No	Yes
10. Branching tree network	Yes	Yes	Yes
11. Network with looped connections	No	No	Yes
12. Number of pre-programmed conduit shapes	2	13	6
13. Alternative hydraulic elements (e.g., pumps, weirs, regulators)	No	Yes	Yes
14. Dry weather flow and infiltration generation (base flow)	No	Yes	Yes
15. Pollutograph routing	Yes	Yes	No
16. Solids scour/deposition	No	Yes	No
17. Card input of hydrographs/pollutographs	No	Yes	Yes

[a]Backwater may be simulated as a horizontal water surface behind a storage element.

Numbering Schemes -- Subcatchments may be assigned any numbers between 1 and 9999. This is true also for gutter/pipes and inlets except that inlet numbers corresponding to Transport Block manholes must be less than or equal to 1000. Also, Receive Block junctions have a maximum number equal to the number of junctions. Thus, inflows to such junctions must be numbered accordingly. To be on the safe side, it is often a good idea to reserve relatively low numbers for inlets, etc. that are transfered to subsequent blocks.

Internally, the Runoff Block assigns subscripts (internal numbers) in the order in which the gutter/pipes or subcatchment cards are read in. Some error messages use these numbers. It is not necessary to state specifically the inlets to be transfered to subsequent blocks, since all inlets at the downstream end of any subcatchment-gutter/pipe flow routing chain are placed in that category and are printed out.

Within the above confines, considerable latitude exists for numbering schemes. Thus, subcatchments may feed gutter/pipes with the same number; subcatchments or gutter/pipes may be given numbers in a certain range (e.g., 200 - 299) based on certain characteristics; etc. The Transport Block numbering scheme allows even more latitude since it includes non-conduits (e.g., manholes).

Gutter/Pipe Parameters (Card Groups G1 and G2) --

Routing and Time Step Considerations -- As mentioned earlier, the non-linear reservoir method of gutter/pipe flow routing is described in Appendix V and the original documentation volume (Metcalf and Eddy et al., 1971a). Since the formulation produces a spatially "lumped" configuration (i.e., there is no dependence upon longitudinal distance for a given gutter/pipe element), flows introduced at the "upstream end" of such an element are distributed horizontally over the entire water suface area. The implication is that a concentrated inflow into one "end" of a simulated gutter/pipe is a reasonable approximation to the true situation in which gutter/pipes receive distributed inflows along their lengths.

At each time step, an iterative (Newton-Raphson) scheme is used to solve the non-linear difference equation used to approximate the differential equation of the non-linear reservoir. Depending upon the choice of parameters for the gutter/pipe and the size of the time step, DELT, convergence problems can arise. These usually occur with a gutter/pipe of relatively small volume (e.g., short length and diameter) coupled with too long a time step. In such a case, the continuity equation may try to force a negative volume to be calculated because there is not enough "real water" in the gutter/pipe to satisfy the outflow rate. In such a case, the volume and outflow are set to zero and a warning message is printed by subroutine GUTTER. This correction only approximates the true occurrence and results in a small error in continuity.

Most convergence problems of this or other natures can be cured either by decreasing the time step or increasing the gutter/pipe dimensions.

Analysis of a similar finite difference approximation for a linear reservoir routing technique indicates that negative volumes cannot occur if

$$DELT \leq \frac{2 \cdot \forall}{Q} \cong \frac{2 \cdot GLEN}{V} \qquad (4\text{-}4)$$

where DELT = computational time step, sec,
$\forall$ = volume of water in gutter/pipe, ft^3,
Q = outflow from gutter/pipe, cfs,
GLEN = length of gutter/pipe, ft, and
V = velocity of flow through gutter/pipe, ft/sec.

The requirement of equation 4-4 is thus a suggestion for Runoff Block gutter/pipe routing, since a stability analysis of the non-linear routing scheme has not been accomplished. Note, however, that if gutter/pipes are used for continuous simulation, with a one-hour time step, their dimensions should be quite large.

As a general rule, accuracy of the scheme increases as the time step decreases, but it should seldom be necessary to decrease the time step to less than one minute; most often DELT is between one and five minutes. The choice of the time step is also linked to the rainfall hyetograph input, discussed earlier.

Parameter Selection -- Most gutter/pipe parameters are self explanatory and little interpretation is needed. The slope and roughness are combined into one parameter for further use in the program, using Manning's equation. Thus,

$$GCON = \frac{1.486}{G6} \cdot \sqrt{G3} \qquad (4\text{-}5)$$

where GCON = routing parameter,
G6 = Manning's roughness, n, and
G3 = invert slope, ft/ft.

Thus, equivalent changes in the routing can be made through changes in either the slope or roughness.

The invert slope is usually given on drainage maps or may easily be calculated from invert elevations and conduit lengths. Tables of Manning's roughness coefficients are given in many references; see for instance Chow (1959) or ASCE-WPCF (1969).

Subcatchment Parameters (Card Groups H1 and H2) --

Subcatchment Schematization -- Many hydrologic models obtain a distributed effect (spatially) by subdividing the overall catchment into subcatchments, predicting runoff from the subcatchments on the basis of their individual properties, and combining their outflows using a flow routing scheme. This procedure is followed in SWMM, in which subcatchments are idealized mathematically as spatially lumped, non-linear reservoirs, and their outflows are routed via the gutter/pipe (or a subsequent Transport Block) network.

Each subcatchment is schematized as in Figure 4-11, in which three or four subareas (depending on whether snowmelt is simulated) are used to represent different surface properties as enumerated in Table 4-4. The slope of the idealized subcatchment is in the direction perpendicular to the width. Flow from each subarea moves directly to a gutter/pipe or inlet and does not pass over any other subarea. (Thus, it is not possible to route runoff from roofs over lawn surfaces, for instance.) The width of the pervious subarea, A2, is the entire subcatchment width, whereas the widths of the impervious subareas, A1, A3, A4, are in proportion to the ratio of their area to the total impervious area, as implied in Figure 4-11. Specification of each subarea is through the use of parameters WAREA and WW(3) on Card H1, PCTZER on Card B2 and SNN1 on Card I1. If desired, any subcatchment may consist entirely of any one (or more) types of subareas.

Table 4-4. Subcatchment Surface Classification

Subarea	Perviousness	Depression Storage	Snow Cover and Extent: Single Event	Snow Cover and Extent: Continuous
A1	Impervious	Yes	Bare	Normally bare, but may have snow cover over 100% of Subarea A1 plus Subarea A3.
A2	Pervious	Yes	Constant fraction, SNCP, of area is snow covered.	Snow covered subject to areal depletion curve.
A3	Impervious	No	Bare	Same as Subarea A1.
A4	Impervious	Yes	100% covered.	Snow covered subject to areal depletion curve.

Of course, real subcatchments seldom exhibit the uniform rectangular geometries shown in Figure 4-11. In terms of the flow routing, all geometrical properties are merely parameters (as explained below) and no inherent "shape" can be assumed in the non-linear reservoir technique. However, in terms of parameter selection, the conceptual geometry of Figure 4-11 is useful because it aids in explaining the flow routing.

Routing and Time Step Considerations -- The routing and time step discussion given earlier for gutter/pipes applies almost identically for subcatchments. A detailed explanation of the non-linear reservoir equations is also given in Appendix V. The routing is performed separately for each of

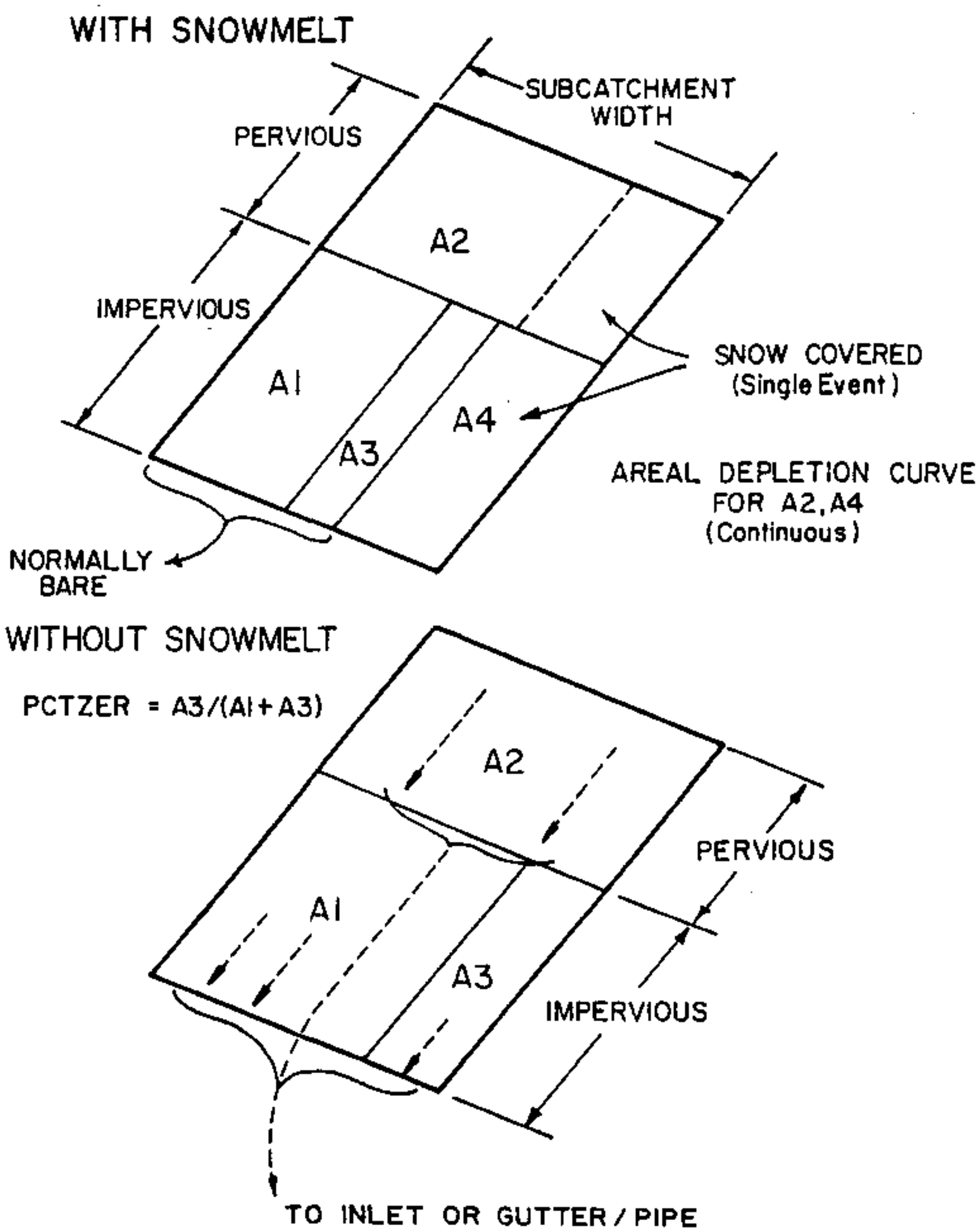


Figure 4-11. Subcatchment Schematization. Flows from pervious and total impervious subareas go directly to gutter/pipe or inlet. (E.g., flow from the pervious subarea does not travel over impervious area.)

the three or four subareas of the subcatchment. The same comments apply regarding convergence and time step considerations as given with reference to equation 4-4, except that V and Q are the volume and outflow of water, respectively, from each subarea within the subcatchment. In fact, convergence problems are rarely encountered during subcatchment routing because total subcatchment volumes (area times depth) are usually large compared to outflow volumes.

Parameter selection is aided with reference to Figure 4-12 in which the subcatchment "reservoir" is shown in relation to inflows and outflows (or losses). The outflow to gutter/pipes and inlets is computed as the product of velocity (from Manning's equation based on the difference between total depth and depression storage), depth and width,

$$Q = W \cdot \frac{1.49}{n}(d - d_p)^{5/3} S^{1/2} \tag{4-5}$$

where Q = WFLOW = subcatchment (or subarea) outflow, cfs,
W = WW(1) = subcatchment width, ft,
n = WW(5) or WW(6) = Manning's roughness coefficient,
d = WDEPTH = water depth, ft,
d_p = WSTORE = depth of depression (retention) storage, ft, and
S = WSLOPE = slope, ft/ft.

The Fortran parameters listed above are the Runoff Block parameters. When combined with the continuity equation (see Appendix V) and divided by the surface area, a new routing parameter is defined for the pervious and total impervious subcatchment areas and used in all subsequent calculations:

$$WCON = - \frac{W \cdot 1.49}{A \cdot n} S^{1/2} \tag{4-6}$$

where WCON = routing parameter used in subroutine WSHED, ft-sec units, and
A = surface area of pervious or total impervious subarea, ft^2.

Note that the width, slope and roughness parameters are combined into one parameter. Thus, equivalent changes may be caused by appropriate alteration of any of the three parameters. (However, see further comments below on the subcatchment width.) Flows computed in the Runoff Block and transfered to subsequent blocks are instantaneous values at the end of a time step.

Subcatchment Width -- If overland flow is visualized (Figure 4-11) as running downslope off an idealized, rectangular catchment, then the width of the subcatchment (card H1) is the physical width of overland flow. This may be further seen in Figure 4-13 in which the lateral flow per unit width, q_L, is computed and multiplied by the width to obtain the total inflow into the gutter. (As mentioned previously, the SWMM gutter/pipes can only receive a concentrated inflow, however, and do not receive a distributed inflow in a specific fashion.) Note also, in

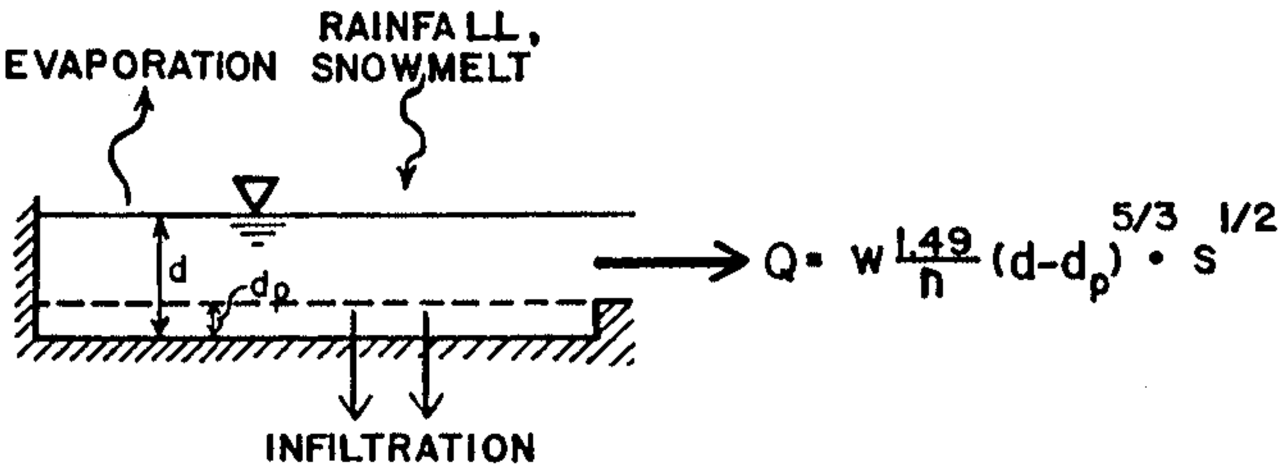


Figure 4-12. Non-linear Reservoir Representation of Subcatchment.

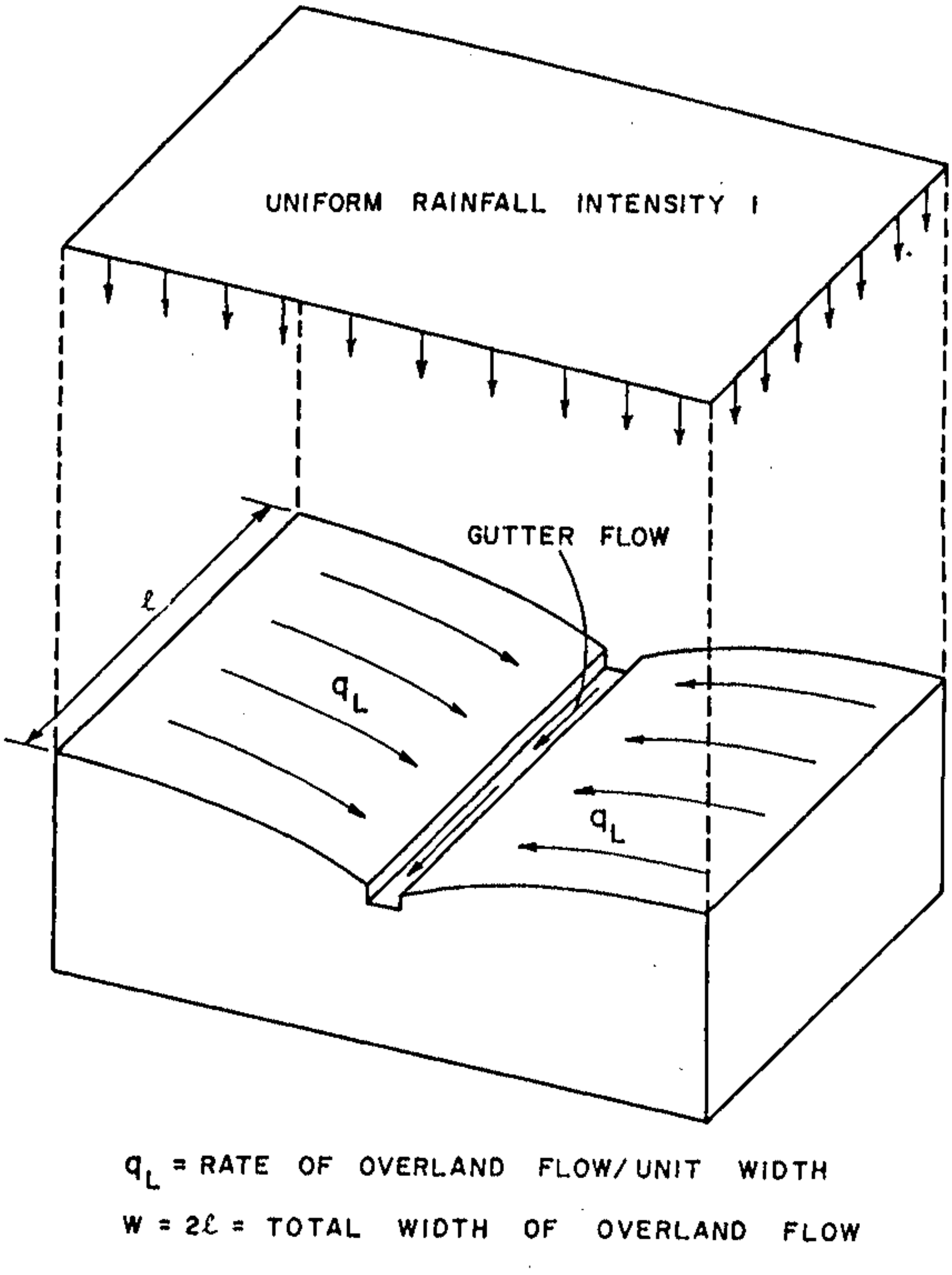


Figure 4-13. Idealized Subcatchment-Gutter Arrangement Illustrating the Subcatchment Width.

Figure 4-13, that for this idealized case, if the two sides of the subcatchment are symmetrical, the total width is twice the length of the drainage channel.

Since real subcatchments will not be rectangular with properties of symmetry and uniformity, it is necessary to adopt other procedures to obtain the width for more general cases. This is of special importance, because if the slope and roughness are fixed, (see equation 4-6), the width can be used to alter the hydrograph shape.

For example, consider the five different subcatchment shapes shown on Figure 4-14. Catchment hydraulic properties, routing parameters and time of concentration are also given. The latter is calculated using the kinematic wave formulation (Eagleson, 1970, p. 340),

$$t_c = \left[\frac{L}{a\, i^{*m-1}}\right]^{1/m} \tag{4-7}$$

where t_c = time of concentration, sec,
L = subcatchment length, ft,
i^* = rainfall excess (rainfall minus losses), ft/sec, and
a,m = kinematic wave parameters.

The kinematic wave formulation assumes that the runoff per unit width (velocity times depth) from the subcatchment is

$$q_L = ad^m \tag{4-8}$$

where q_L = flow per unit width, ft^2/sec, and
d = depth of flow, ft.

Parameters a and m depend upon the velocity equation used for normal flow. For Manning's equation,

$$a = \frac{1.49}{n} S^{1/2} \tag{4-9}$$

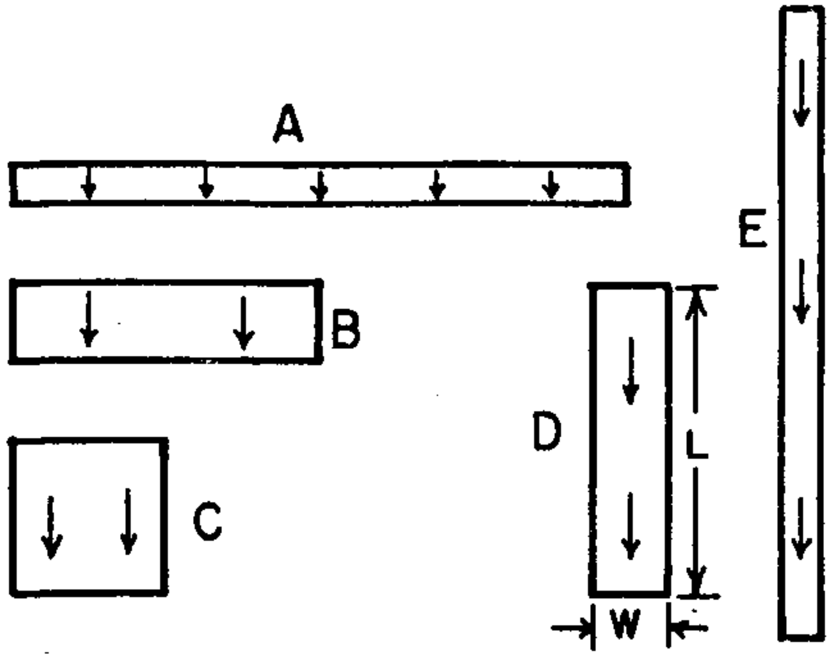
and

$$m = 5/3 \tag{4-10}$$

Note that the units of a depend upon the value of m, and for Manning's equation, feet-second units should be used for all calculations. The subcatchment length may be computed for the assumed rectangular shape simply by dividing the area by the width.

Finally, note the dependence of time of concentration upon the rainfall intensity. As i^* increases, t_c decreases. The calculation using equation 4-7 is consistent with the definition of t_c given earlier: t_c is the time to equilibrium, at which inflow equals outflow (for an impervious catchment).

Outflow hydrographs for continuous rainfall and for rainfall of duration 20 min are shown on Figure 4-15. These were computed by the Runoff Block non-linear reservoir equations (Appendix V) using a time



Slope = 0.01
Imperviousness = 100%
Depression Storage = 0
n = 0.02
Equilibrium outflow = i*A = 0.926 cfs

DELT = 5 min = 300 sec

i* = Rainfall = 1.0 in/hr = 0.000023148 ft/sec

Shape	A (ft^2)	W (ft)	L (ft)	t_c[a] (min)	WCON[b] (ft-sec units)
A	40,000	800	50	3.7	-0.149
B	40,000	400	100	5.7	-0.0745
C	40,000	200	200	8.6	-0.03725
D	40,000	100	400	13.0	-0.018625
E	40,000	50	800	19.7	-0.0093125

[a]Equation 4-7
[b]Equation 4-6

Figure 4-14. Different Subcatchment Shapes to Illustrate Effect of Subcatchment Width.

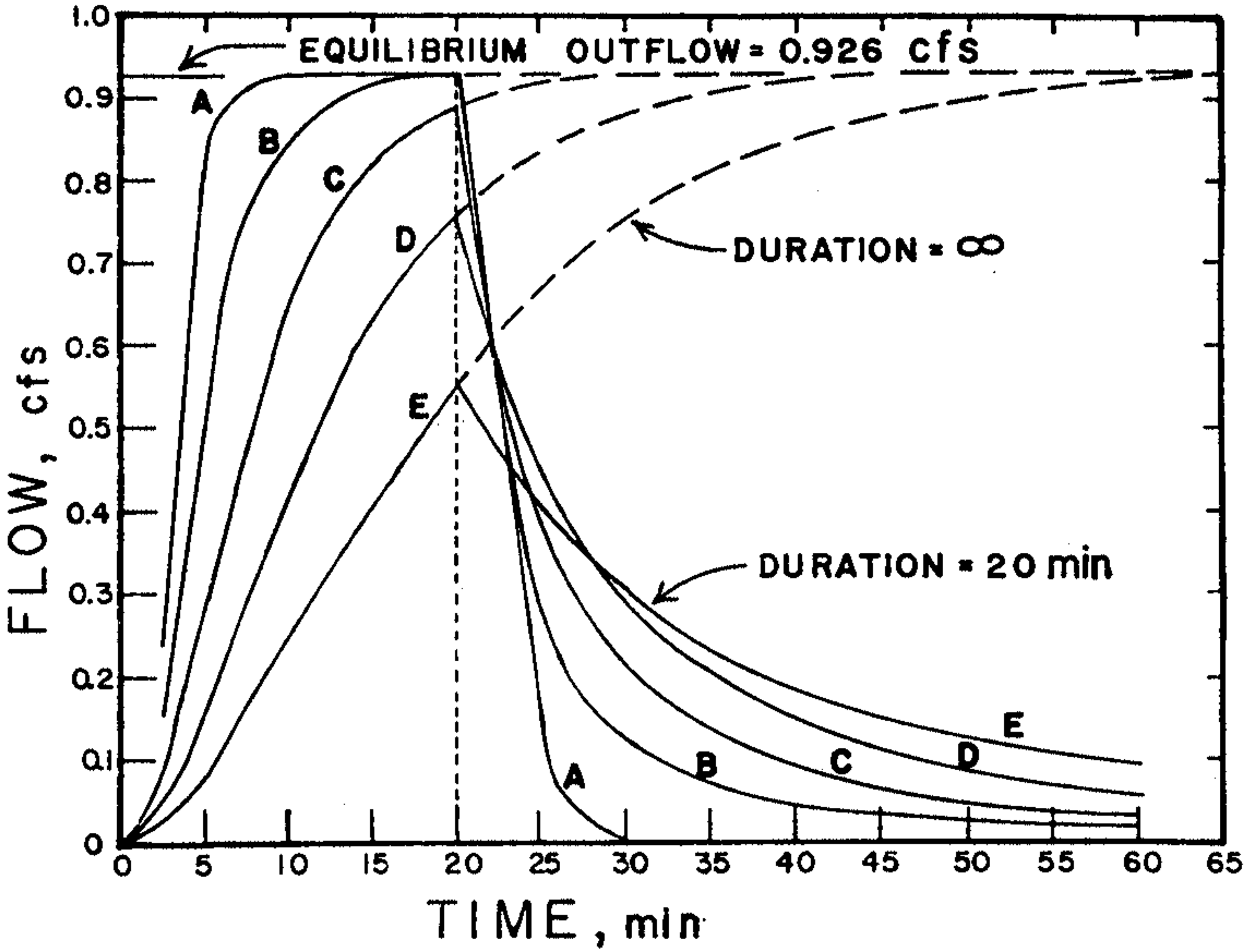


Figure 4-15. Subcatchment Hydrographs for Different Shapes of Figure 4-14.

step of 5 min. Clearly, as the subcatchment width is narrowed (i.e., the outlet is constricted), the time to equilibrium increases. Thus, it is achieved quite rapidly for cases A and B and more slowly for cases C, D and E. The kinematic wave computation of t_c (Figure 4-14) is not particularly accurate for the non-linear reservoirs in which the asymptotic value of equilibrium outflow is approached exponentially. However, it may be used for guidance.

Two routing effects may be observed. A storage effect is very noticeable, especially when comparing hydrographs A and E for a duration of 20 min. The subcatchment thus behaves in the familiar manner of a reservoir. For case E, the outflow is constricted (narrow); hence, for the same amount of inflow (rainfall) more water is stored and less released. For case A, on the other hand, water is released rapidly and little is stored. Thus case A has both the fastest rising and recession limbs of the hydrographs.

A shape effect is also evident. Theoretically, all the hydrographs peak simultaneously (at the cessation of rainfall). However, a large width (e.g., case A) will cause equilibrium outflow to be achieved rapidly, producing a flat-topped hydrograph for the remainder of the (constant) rainfall. Thus, for a catchment schematized with several subcatchments and subject to variable rainfall, increasing the widths can tend to cause peak flows to occur sooner. In general, however, shifting hydrograph peaks in time is difficult to achieve through adjustment of Runoff Block flow routing parameters. The time distribution of runoff is far and away the most sensitive to the time distribution of rainfall. Further discussion of the effect of subcatchment width on hydrograph shapes will be given below under "Subcatchment Aggregation and Lumping".

What is the best estimate of subcatchment width? If the subcatchment has the appearance of Figure 4-13, then the width is approximately twice the length of the main drainage channel through the catchment. This is perhaps the best single approximation. However, if the drainage channel is on the side of the catchment as in Figure 4-14, the width is just equal to the length of the channel.

Most real subcatchments will be irregular in shape and have a drainage channel which is off center, as in Figure 4-16. A simple way of handling this case is given by the University of Massachusetts Proceedings (DiGiano et al., 1977). A skew factor is computed,

$$\gamma = \frac{A_2 - A_1}{A} \tag{4-11}$$

where γ = skew factor, $0 \le \gamma \le 1.0$,
A_1 = area to one side of channel, ft^2,
A_2 = area to other side of channel, ft^2, and
A = total area, ft^2.

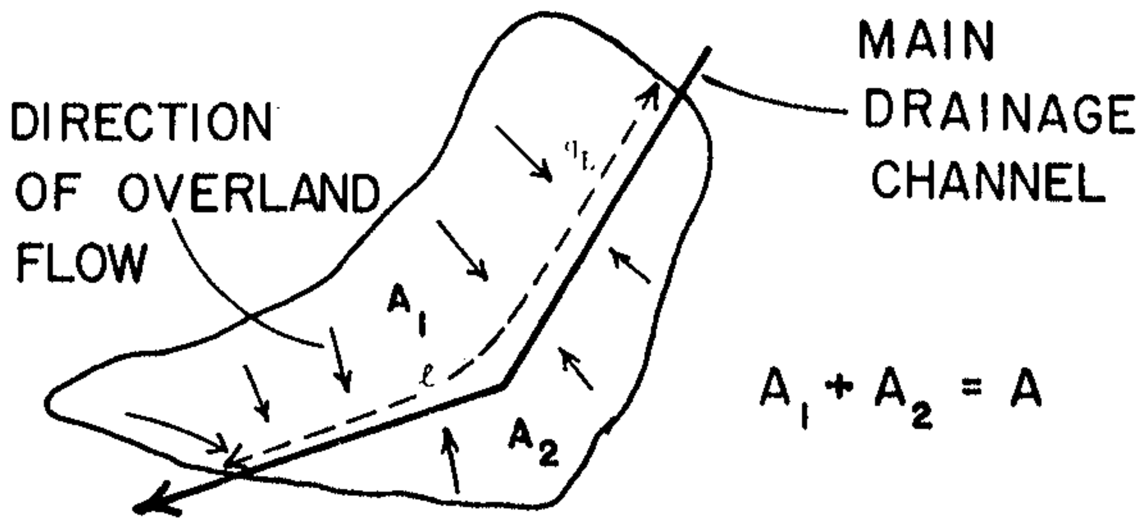


Figure 4-16. Irregular Subcatchment Shape for Width Calculation. (After DiGiano et al., 1977, p. 165.)

Then the width is simply weighted between the two limits of ℓ or 2ℓ as,

$$W = (2 - \gamma)\ell \tag{4-12}$$

where W = subcatchment width, ft, and
ℓ = length of main drainage channel, ft.

To reiterate, changing the subcatchment width changes the routing parameter WCON of equation 4-6. Thus, identical effects to those discussed above may be created by appropriate variation of the roughness and slope.

Subcatchment Area -- In principle, the catchment and subcatchment area can be defined by constructing drainage divides on topographic maps. In practice, this may or may not be easy because of the lack of detailed contour information and the presence of unknown inflows and outflows. This may be most noticeably brought to the modeler's attention when the measured runoff volume exceeds the measured rainfall volume. Since the latter depends upon the catchment area, the area may be at fault.

From the modeling standpoint, there are no upper or lower bounds on subcatchment area (other than to avoid convergence problems, as discussed earlier). Subcatchments are usually chosen to coincide with different land uses and with drainage divides. Further guidance is given later while discussing subcatchment aggregation.

Imperviousness -- The percent imperviousness of a subcatchment is another parameter that can, in principle, be measured accurately from aerial photos or land use maps. In practice, such work tends to be tedious, and it is common to make careful measurements for only a few representative areas and extrapolate to the rest.

Care must be taken to insure that impervous areas are hydraulically (directly) connected to the drainage system. For instance, if rooftops drain onto adjacent pervious areas, they should not be treated as impervious in the Runoff Block. On the other hand, if a driveway drains to a street and thence to a stormwater inlet, the driveway would be considered to be hydraulically connected. Rooftops with downspouts connected directly to a sewer are definitely hydraulically connnected.

Should rooftops be treated as "pervious", the real surrounding pervious area is subject to more incoming water than rainfall alone and thus might produce runoff sooner than if rainfall alone were considered. In the unlikely event that this effect is important (a judgment based on infiltration parameters) it could be modeled by altering the infiltration parameters or by treating such pervious areas as separate subcatchments, and increasing their rainfall by the ratio of roof area plus pervious to pervious alone. Since the roof areas would then not be simulated, continuity would be maintained.

Further information on the concept of hydraulically connected impervious areas is contained in USGS studies (Jennings and Doyle, 1978) and documentation of the ILLUDAS model (Terstriep and Stall, 1974).

For continuous simulation in which very large subcatchments are being used, even spot calculations of imperviousness may be impractical. Instead, regression formulations have been developed in several studies (Graham et al., 1974, Stankowski, 1974, Manning et al., 1977, Sullivan et al., 1978). These typically relate percent imperviousness to population density, and are compared in Figure 4-17 (Heaney et al., 1977). The New Jersey equation (Stankowski, 1974) is perhaps the most representative,

$$I = 9.6\ PD_d^{(0.53\ -\ 0.0391\ \log_{10}\ PD_d)} \qquad (4\text{-}13)$$

where I = WW(3) = imperviousness, percent, and
PD_d = population density in developed portion of the urbanized area, persons per acre.

The "developed portion" excludes large segments of undeveloped (i.e., natural or agricultural) lands that may lie within the area being simulated. Also note that the relationships shown in Figure 4-17 were all developed for large (city-wide) urban areas as a whole. Their use may be tenuous for smaller sub-basins.

Slope -- The subcatchment slope should reflect the average along the pathway of overland flow to inlet locations. For a simple geometry (e.g., Figures 4-13 and 4-14) the calculation is simply the elevation difference divided by the length of flow. For more complex geometries, several overland flow pathways may be determined, their slopes calculated, and a weighed slope computed using a path-length weighted average. Such a procedure is described in the University of Massachusetts Proceedings (DiGiano et al., 1977, pp. 101-102).

Manning's Roughness Coefficient, n -- Values of Manning's roughness coefficient, n, are not as well known for overland flow as for channel flow because of the considerable variability in ground cover for the former, transitions between laminar and turbulent flow, very small depths, etc. Most studies indicate that for a given surface cover, n varies inversely in proportion to depth, discharge or Reynolds's number. Such studies may be consulted for guidance (Petryk and Bosmajian, 1975, Chen, 1976, Christensen, 1976, Graf and Chhun, 1976, Turner et al., 1978, Emmett, 1978), or generalized values used (Chow, 1959, Crawford and Linsley, 1966). Successful use of the Stanford Watershed Model (Crawford and Linsley, 1966) was accomplished with the values given in Table 4-5.

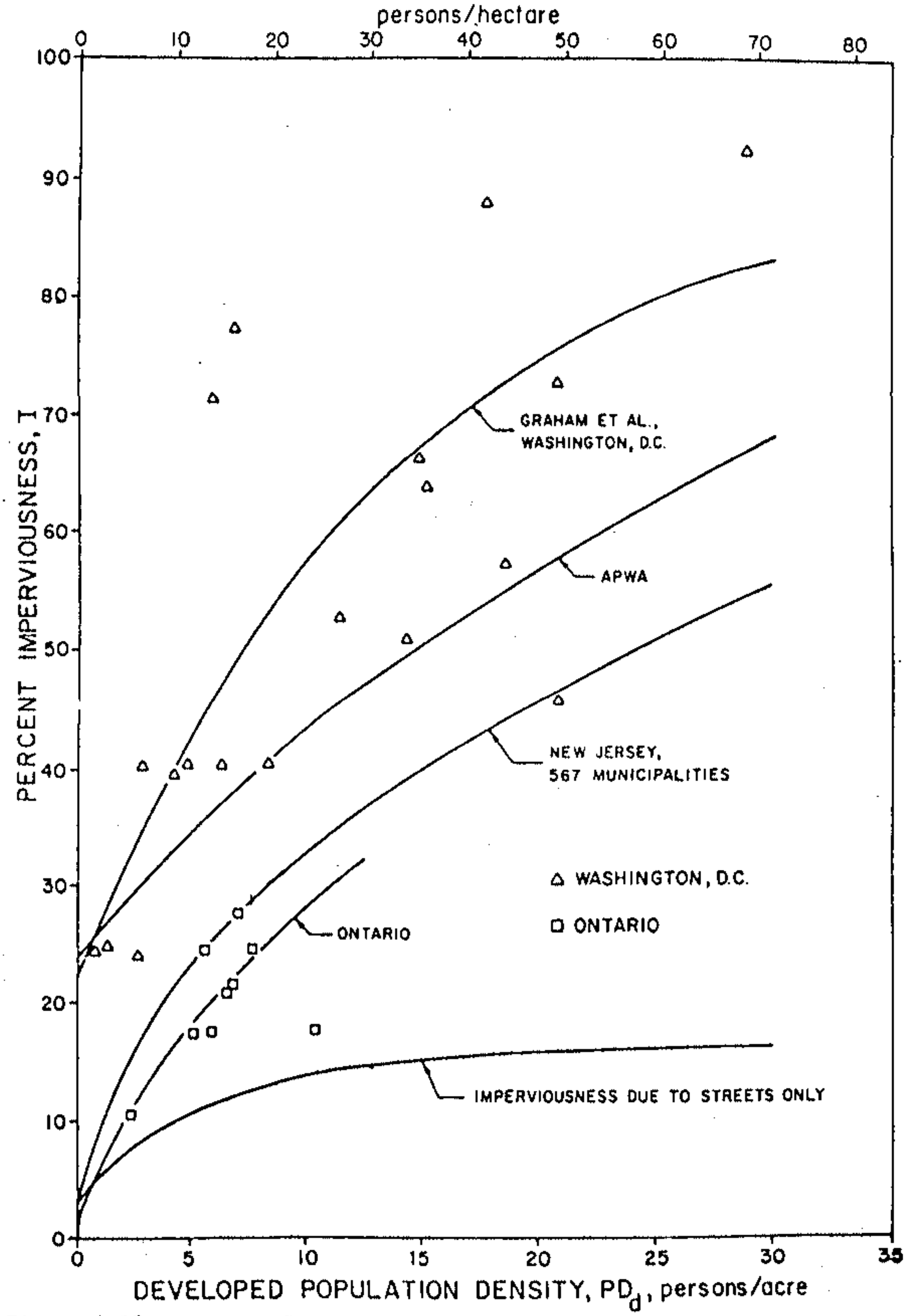


Figure 4-17. Percent Imperviousness Versus Developed Population Density for Large Urban Areas. (After Heaney, et al., 1977, p. 105)

Table 4-5. Estimate of Manning's Roughness Coefficients. (Crawford and Linsley, 1966)

Ground Cover	Manning's n for Overland Flow
Smooth asphalt	0.012
Asphalt or concrete paving	0.014
Packed clay	0.03
Light turf	0.20
Dense turf	0.35
Dense shrubbery and forest litter	0.4

Depression Storage -- Depression (retention) storage is a volume that must be filled prior to the occurrence of runoff on both pervious and impervious areas (see Figure 4-12); a good discussion is presented by Viessman et al. (1977). It represents a loss or "initial abstraction" caused by such phenomena as surface ponding, surface wetting, interception and evaporation. In some models, "depression storage" also includes infiltration in pervious areas. In the Runoff Block, water stored as depression storage on pervious areas is subject to infiltration (and evaporation), so that it is continuously and rapidly replenished. Water stored in depression storage on impervious areas is depleted only by evaporation. Hence, replenishment typically takes much longer.

As described earlier (e.g., Table 4-3), a percent PCTZER (card B2) of the impervious area is assigned zero depression storage in order to promote immediate runoff. This percentage is the same for all subcatchments. Should variation among subcatchments be desired, PCTZER may be set to zero, and zero values for WSTORE entered in card group H1 as needed.

Depression storage may be derived from rainfall runoff data for impervious areas by plotting runoff volume (depth) as the ordinate against rainfall volume as the abscissa for several storms. The rainfall intercept at zero runoff is the depression storage. Data obtained in this manner from 18 urban European catchments (Falk and Niemczynomicz, 1978, Kidd, 1978a, Van den Berg, 1978) are summarized in Table 4-6. The very small catchments (e.g., less than 1 ac or 0.40 ha) were primarily roadway tributaries to stormwater inlets and catchbasins.

Table 4-6 Recent European Depression Storage Data (Kidd, 1978b)

Catchment Name	Country	Area (ac)	Paved Area (ac)	Imperviousness (%)	Slope (%)	Depression Storage (in)	No. of Events	Reference
Lelystad Housing Area	Netherlands	4.94	2.17	44	0.5	0.059	10	Van den Berg, 1978
Lelystad Parking Lot[a]	Netherlands	1.73	1.73	100	0.5	0.035	10	"
Ennerdale Two	U.K.	0.088	0.079	89	3.1	0.020	6	Kidd, 1978a
Ennerdale Three	U.K.	0.022	0.022	100	3.0	0.016	9	"
Bishopdale Two	U.K.	0.146	0.111	76	2.4	0.018	11	"
Hyde Green One	U.K.	0.120	0.085	71	2.2	0.019	7	"
Hyde Green Two	U.K.	0.209	0.103	49	2.0	0.020	8	"
School Close One	U.K.	0.113	0.070	62	1.7	0.009	11	"
School Close Two	U.K.	0.177	0.097	55	0.9	0.026	11	"
Lund 1:75	Sweden	0.072	0.072	100	2.1	0.005	11	Falk and Niemczynowicz, 1978
Klostergarden 1:76	Sweden	0.081	0.081	100	0.9	0.041	11	"
Klostergarden 1:77	Sweden	0.083	0.083	100	2.3	0.020	13	"
Klostergarden 2:76	Sweden	0.020	0.020	100	3.3	0.019	11	"
Klostergarden 2:77	Sweden	0.019	0.019	100	4.1	0.013	12	"
Klostergarden 3:76	Sweden	0.076	0.076	100	3.1	0.022	11	"
Klostergarden 3:77	Sweden	0.102	0.102	100	2.3	0.022	13	"
Klostergarden 4:76	Sweden	0.068	0.068	100	1.6	0.020	10	"
Klostergarden 4:77	Sweden	0.069	0.069	100	1.9	0.022	13	"

[a] 55% brick pavement. Other catchments have primarily asphalt pavement.

The data were aggregated and a regression of depression storage versus slope performed as part of a workshop (Kidd, 1978b). The data are plotted in Figure 4-18 along with the relationship developed by the workshop,

$$d_p = 0.0303 \cdot S^{-0.49} \text{ , } (r = -0.85) \tag{4-14}$$

where d_p = WSTORE = depression storage, in, and

S = WSLOPE = catchment slope, percent.

Viessman et al. (1977, p. 69) illustrate a similar but linear plot in which depression storage values for "four small impervious areas" range from 0.06 to 0.11 in (1.5 to 2.8 mm), considerably higher than the values shown in Figure 4-18. The reason for this discrepancy is not known, but it appears that the recent European data may be better suited to provide depression storage estimates, mainly because of their extent.

Separate values of depression storage for pervious and impervious areas are required for input in card group H1. Representative values for the latter can probably be obtained from the European data just discussed. Pervious area measurements are lacking; most reported values are derived from successful simulation of measured runoff hydrographs. Although pervious area values are expected to exceed those for impervious areas, it must be remembered that the infiltration loss, often included as an initial abstraction in simpler models, is computed explicitly in SWMM. Hence, pervious area depression storage might best be represented as an interception loss, based on the type of surface vegetation. Many interception estimates are available for natural and agricultural areas (Viessman et al., 1977, Linsley et al., 1949). For grassed urban surfaces a value of 0.10 in (2.5 mm) may be appropriate.

As mentioned earlier, several studies have determined depression storage values in order to achieve successful modeling results. For instance, Hicks (1944) in Los Angeles used values of 0.20, 0.15 and 0.10 in (5.1, 3.8, 2.5 mm) for sand, loam and clay soils, respectively, in the urban area. Tholin and Kiefer (1960) used values of 0.25 and 0.0625 in (6.4 and 1.6 mm) for pervious and impervious areas, respectively, for their Chicago hydrograph method. Miller and Viessman (1972) give an initial abstraction (depression storage) of between 0.10 and 0.15 in (2.5 and 3.8 mm) for four composite urban catchments.

In SWMM, depression storage may be treated as a calibration parameter, particularly to adjust runoff volumes. If so, extensive preliminary work to obtain an accurate _a priori_ value may be pointless since the value will be changed during calibration anyway.

Infiltration* -- Infiltration from pervious areas may be computed by either the Horton (1933, 1940) or Green-Ampt (1911) equations described

*The infiltration section was prepared by Dr. Russell G. Mein, Monash University, Clayton, Victoria, Australia.

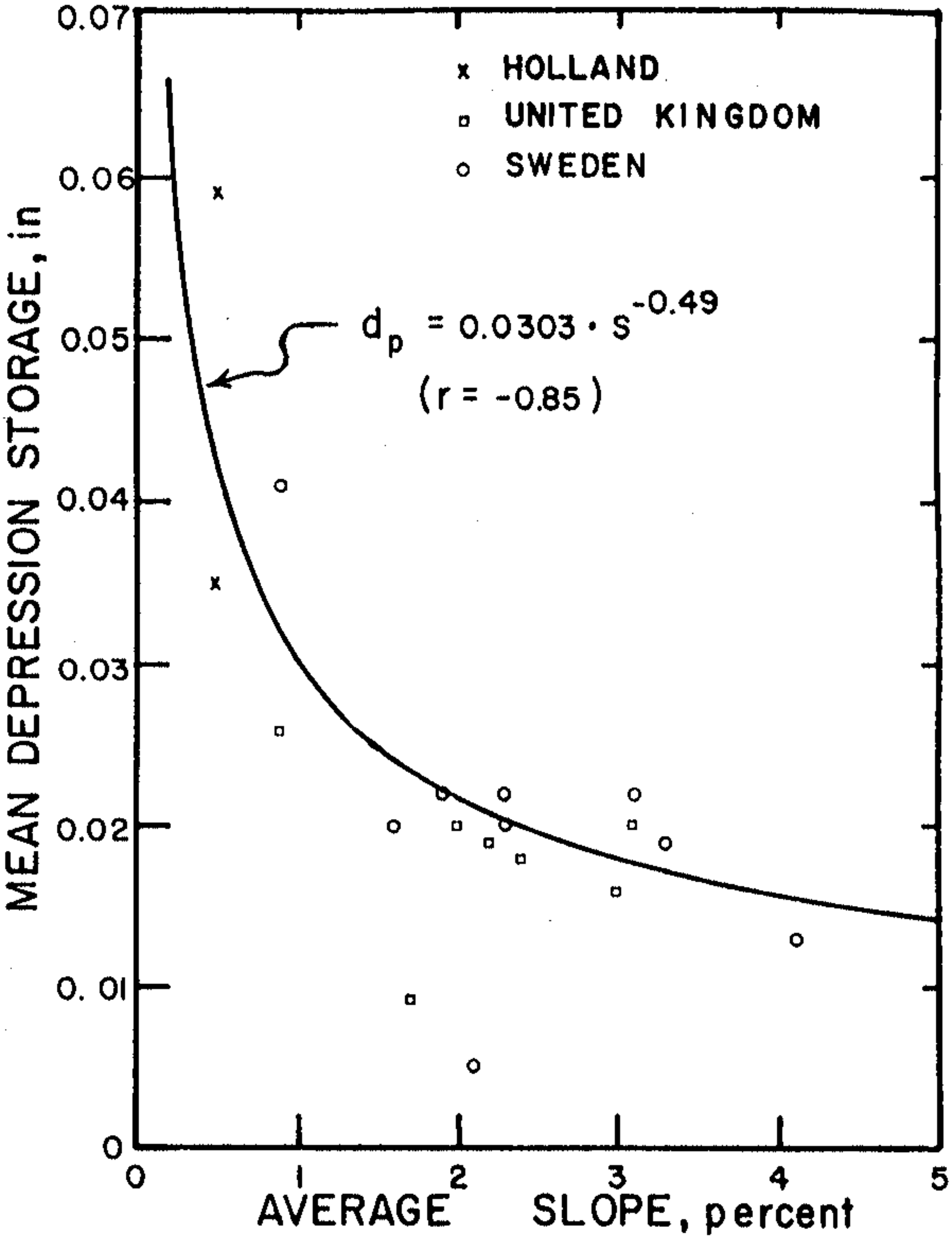


Figure 4-18. Depression Storage vs. Catchment Slope (after Kidd, 1978b). See Table 4-6 for catchment data.

below. A complete description of the theoretical background and programming details for both is given in Appendix V. The user has the option of which method to be used for all subcatchments (parameter INFILM, card B1). Parameters required by the two methods are quite different.

<u>Horton Infiltration</u> -- Infiltration capacity as a function of time is given by Horton (1933, 1940) as

$$f_p = f_\infty + (f_o - f_\infty)\, e^{-\alpha t} \qquad (4\text{-}15)$$

where f_p = infiltration capacity into soil, ft/sec,

f_∞ = minimum or ultimate value of f_p (WLMIN), ft/sec,

f_o = maximum or initial value of f_p (WLMAX), ft/sec,

t = time from beginning of storm, sec, and

α = decay coefficient, (DECAY), sec^{-1}.

This equation describes the familiar exponential decay of infiltration capacity evident during heavy storms. However, the program does not use equation 4-15 directly; rather the integrated form is used in order to avoid an unwarranted reduction in f_p during periods of light rainfall. Details are given in Appendix V.

Required parameters for card group H1 are f_o (WLMAX), f_∞ (MLMIN) and α (DECAY). In addition a parameter used to regenerate infiltration capacity (REGEN, card B2) is required for continuous simulation. Although the Horton infiltration equation is probably the best-known of the several infiltration equations available, there is little to help the user select values of parameters f_o and α for a particular application, (fortunately, some guidance can be found for the value of f_∞). Since the actual values of f_o and α (and often f_∞) depend on the soil, vegetation, and initial moisture content, ideally these parameters should be estimated using results from field infiltrometer tests for a number of sites of the watershed and for a number of antecedent wetness conditions. If it is not possible to use field data to find estimates of f_o, f_∞, and α for each sub-catchment, the following guidelines should be helpful.

The U.S. Soil Conservation Service (SCS) has classified most soils into Hydrologic Soil Groups, A, B, C, and D, dependent on their limiting infiltration capacities, f_∞. A listing of the groupings for more than 4000 soil types can be found in the SCS Hydrology Handbook (1972, pp. 7.5-7.26); a similar listing is also given in the <u>Handbook of Applied Hydrology</u> (Ogrosky and Mockus, 1964, pp. 21.12-21.25), but the former reference also gives alternative groupings for some soil types depending on the degree of drainage of the subsoil.

The best source of information about a particular soil type is a publication entitled "Soil Survey Interpertations" available from the local SCS office. Information on the soil profile, the soil properties, its suitability for a variety of uses, its erosion and crop yield potential, and other data is included on the sheet provided. A copy of the listing for Conestoga silt loam is shown in Figure 4-19.

Alternatively, values for f_∞ according to Musgrave (1955) are given in Table 4-7. To help select a value within the range given for each soil group, the user should consider the texture of the layer of least hydraulic conductivity in the profile. Depending on whether that layer is sand, loam, or clay, the f_∞ value should be chosen near the top, middle, and bottom of the range respectively. For example, the data sheet for Conestoga silt loam identifies it as being in Hydrology Group B which puts the estimate of f_∞ into the range 0.15-0.30 in/hr, (3.8-7.6 mm/hr). Examination of the texture of the layers in the soil profile indicates that they are silty in nature, suggesting that the estimate of the f_∞ value should be in the low end of the range, say 0.15 - 0.20 in/hr, (3.8 - 5.1 mm/hr). A sensitivity test on the f_∞ value will indicate the importance of this parameter to the overall result.

Table 4-7. Values of f_∞ for Hydrologic Soil Groups (Musgrave, 1955)

Hydrologic Soil Group	f_∞ (in/hr)
A	0.45 - 0.30
B	0.30 - 0.15
C	0.15 - 0.05
D	0.05 - 0

For any field infiltration test the rate of decrease (or "decay") of infiltration capacity, α, from the initial value, f_o, depends on the initial moisture content. Thus the α value determined for the same soil will vary from test to test.

It is postulated here that, if f_o is always specified in relation to a particular soil moisture condition (e.g., dry) and for moisture contents other than this the time scale is changed accordingly (i.e., time "zero" is adjusted to correspond with the constant f_o), then α can be considered a constant for the soil independent of initial moisture content. Put another way, this means that infiltration curves for the same soil, but different antecedent conditions, can be made coincident if they are moved along the time axis. Butler (1957) makes a similar assumption.

PA-SOILS-1
REVISED 6-71
FILE CODE SOILS-12

CECA CECI
CECB CECJ
CECH CECE
CECC CECD

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
HARRISBURG, PENNSYLVANIA

SOIL SURVEY INTERPRETATIONS

Pennsylvania Date 7/28/71 Subject to Change SOIL: CONESTOGA silt loam
MLRA 148

MAP SYMBOLS: See Pg...

BRIEF DESCRIPTION Deep, well drained upland soils formed from weathered micaceous or shaly limestone and calcareous schist and phylite. They have a silt loam surface layer, a silty clay loam subsoil. Bedrock occurs at about 75 inches.

Hydrology Group B Irrigation Group 1 Drainage Group NA

ESTIMATED PHYSICAL AND CHEMICAL PROPERTIES

Depth To Bedrock (ft) 5+ Depth To Seasonal High Water Table (ft) 4+ Flood Hazard None

Depth in Inches From Surface	Classification: USDA Texture	Unified	AASHO	Coarse Fraction Than 3 In	Percent Passing Sieve: No. 4 (4.7 mm)	No. 10 (2.0 mm)	No. 40 (.42 mm)	No. 200 (.074 mm)	Range in Permeability Inches/Hr	Available Moisture Capacity In./in of soil	Reaction pH	Shrink-Swell Potential
0-15	SIL	ML	A-4	-	90-100	90-100	80-100	60-90	0.63-2.0	.16-.20	4.5-6.5	low
15-43	SICL	ML,CL, MH,CH	A-4, 5,6 7	0-5	90-100	90-100	80-100	60-90	0.63-2.0	.12-.16	4.5-5.5	low
43-75	SH SIL	GM,ML CL,MH CH	A-2 A-5 A-7	0-15	35-90	35-85	35-85	30-80	0.63-2.0	.06-.10	5.6-7.8	low
75+	- - - - - - - -	- - -	- - -	- -	MICACEOUS LIMESTONE - -			- - - -	- - - -	- - - -	- - - -	- - - -

SUITABILITY OF SOIL AS A SOURCE OF ---

TOPSOIL	SAND AND GRAVEL	ROADFILL
GOOD to 15 inches	UNSUITABLE	FAIR to POOR; A-4, 5, 6, 7

SOIL FEATURES AFFECTING SPECIFIED ENGINEERING USES

Use	Major Soil Feature Affecting Use
Highway and Road Location	Moderate potential frost action; cuts and fills needed
Ponds-Reservoir Area	Moderate perm.
Ponds-Embankments	Fair to poor stability and compaction; fair to poor resistance to piping
Drainage	NA
Sprinkler Irrigation	Moderate intake rate; moderate perm.; high available moisture capacity
Terraces or Diversions	Fair to poor stability
Grassed Waterways	High available moisture capacity; moderate fertility
Winter Grading	Fair trafficability
Pipeline Construction and Maintenance	All features are favorable

SOIL LIMITATIONS FOR COMMUNITY DEVELOPMENT

Use	Phase	Degree of Limitation	Major Soil Feature Affecting Use
Septic Tank Filter Fields	0-6% 6-12% 12-35%	SLIGHT MODERATE SEVERE	HGWC Slope; HGWC Slope
Sewage Lagoons	0-3% 3-6% 6-35%	MODERATE MODERATE SEVERE	Moderate perm. Slope; moderate perm. Slope
Low Buildings With Basements	0-6% 6-12% 12-35%	SLIGHT MODERATE SEVERE	 Slope Slope
Lawns and Landscaping	0-6% 6-12% 12-35%	SLIGHT MODERATE SEVERE	 Slope Slope
Parking Lots and Streets in Subdivisions	0-3% 3-6% 6-35%	SLIGHT MODERATE SEVERE	 Slope Slope
Sanitary Land Fills	0-6% 6-12% 12-35%	SLIGHT MODERATE SEVERE	 Slope Slope

Figure 4-19a
Figure 4-19. Soil Conservation Service Soil Survey Interpretation for Conestoga Silt Loam (found near Lancaster, PA).

MLRA 148 SOIL: CONESTOGA silt loam

SOIL LIMITATIONS FOR RECREATIONAL USES

Use	Phase	Degree of Limitation	Major Soil Features Affecting Use
Campsites - Tents	0-6%	SLIGHT	
	6-15%	MODERATE	Slope
	15-35%	SEVERE	Slope
Campsites Trailers	0-3%	SLIGHT	
	3-6%	MODERATE	Slope
	6-35%	SEVERE	Slope
Low Buildings Without Basements	0-6%	SLIGHT	
	6-15%	MODERATE	Slope
	15-35%	SEVERE	Slope
Paths and Trails	0-15%	SLIGHT	
	15-25%	MODERATE	Slope
	25-35%	SEVERE	Slope
Picnic and Play Areas	0-6%	SLIGHT	
	6-15%	MODERATE	Slope
	15-35%	SEVERE	Slope
Athletic Fields	0-3%	SLIGHT	
	3-6%	MODERATE	Slope
	6-35%	SEVERE	Slope
Golf Fairways	0-6%	SLIGHT	(moderate on eroded phase)
	6-15%	MODERATE	Slope (severe on eroded phase)
	15-35%	SEVERE	Slope

LAND CAPABILITY, SOIL LOSS FACTORS, AND ESTIMATED "B" MANAGEMENT YIELDS

Soil Phase	Capability	Soil Loss Factors K	T	T/K	Corn bu.	Oats bu.	Wheat bu.	Soy-beans				Alfalfa Hay T.	Clover-Grass Hay T.	Pasture: Blue-Grass c.a.d.	Pasture: Tall Grass-Legume c.a.d.
0-3%	I	.43	4	9.3	135	80	50	45				5.5	3.5	160	315
3-6%	IIe	.43	4	9.3	135	80	50	45				5.5	3.5	160	315
3-6% sev.	IIIe	.43	3	7.0	125	75	45	35				5.0	3.5	160	285
6-15%	IIIe	.43	4	9.3	125	75	45	35				5.0	3.5	160	285
6-15% sev.	IVe	.43	3	7.0	110	65	40	-				4.5	3.0	135	255
15-25%	IVe	.43	4	9.3	110	65	40	-				4.5	3.0	135	225
15-25% sev.	VIe	.43	3	7.0	-	-	-	-				-	-	115	-
25-35%	VIe	.43	4	9.3	-	-	-	-				-	-	115	-

WOODLAND

Soil Phase	Erosion Hazard	Equip. Restrict.	Seedling Mort.	Plant Compet. C	Plant Compet. R	Wind Throw Hazard	Species To Favor in - - Natural	Species To Favor in - - Plantation	Species and Site Index	Ord. Group
0-6%	1	1	1	3	2	1	RO	TP	Ex. 85+	
6-15%	2	1	1	3	2	1	A	BW	RO	
15-35%	3	2	1	3	2	1	SM	L	A	
							TP	NSp	SM	
							BW	WP	Ex. 95+	
									TP	

1 = Slight 2 = Moderate 3 = Severe

WILDLIFE

Soil Phase	Grain and Seed Crops	Grass and Legumes	Wild Herb Upland Plants	Hardwood Trees, Shrubs, Vines	Coniferous Woody Plants	Wild Herb Wetland Plants	Shallow Water Dev.	Shallow Excavated Ponds	Openland Wildlife Habitat	Woodland Wildlife Habitat	Wetland Wildlife Habitat
0-3%	1	1	1	1	1	4	4	4	1	1	4
3-6%	2	1	1	1	1	4	4	4	1	1	4
6-15%	2	1	1	1	1	4	4	4	1	1	4
15-25%	3	2	1	1	1	4	4	4	2	1	4
25-35%	4	2	1	1	1	4	4	4	2	1	4

1 Good 2 Fair 3 Poor 4 Very Poor

Figure 4-19b

Values of α found in the literature (Viessman et al., 1977, Linsley et al., 1975, Overton and Meadows, 1976, Wanielista, 1978) range from 0.67 to 49 hr^{-1}. Nevertheless most of the values cited appear to be in the range 3-6 hr^{-1} (0.00083 - 0.00167 sec^{-1}). The evidence is not clear as to whether there is any relationship between soil texture and the α value although several published curves seem to indicate a lower α value for sandy soils. If no field data are available, an estimate of 0.00115 sec^{-1} (4.14 hr^{-1}) could be used. Use of such an estimate implies that, under ponded conditions, the infiltration capacity will fall 98 percent of the way towards its minimum value in the first hour, a not uncommon observation. Table 4-8 shows the rate of decay of infiltration for several values of α.

Table 4-8. Rate of Decay of Infiltration for Different Values of α.

α value hr^{-1} (sec^{-1})	Percent of decline of infiltration capacity towards limiting value f_∞ after 1 hour.
2 (0.00056)	76
3 (0.00083)	95
4 (0.00111)	98
5 (0.00139)	99

The initial infiltration capacity, f_o, depends primarily on soil type, initial moisture content, and surface vegetation conditions. For example, Linsley et al. (1975) present data which show, for a sandy loam soil, a 60 to 70 percent reduction in the f_o value due to wet initial conditions. They also show that lower f_o values apply for a loam soil than for a sandy loam soil. As to the effect of vegetation, Jens and McPherson (1964, pp. 20.20 - 20.38) list data which show that dense grass vegetation nearly doubles the infiltration capacities measured for bare soil surfaces.

For the assumption that the decay coefficient α is independent of initial moisture content to hold, f_o must be specified for the dry soil condition. The continuous version of SWMM automatically calculates the f_o value applicable for wetter conditions as part of the moisture accounting routine. However, the user of the single-event version of SWMM is required to specify the f_o value for the storm in question, which may be less than the value for dry soil conditions.

Published values of f_o vary depending on the soil, moisture, and vegetation conditions for the particular test measurement. The f_o values listed in Table 4-9 can be used as a rough guide. Interpolation between the values may be required.

Table 4-9. Representative Values for f_o.

A.	DRY soils (with little or no vegetation): Sandy soils: 5 in/hr Loam soils: 3 in/hr Clay soils: 1 in/hr
B.	DRY soils (with dense vegetation): Multiply values given in A. by 2 (after Jens and McPherson, 1964)
C.	MOIST soils (change from dry f_o value required for single event model version of SWMM only): Soils which have drained but not dried out (i.e., field capacity): divide values from A and B by 3. Soils close to saturation: choose value close to f_∞ value. Soils which have partially dried out: divide values from A and B by 1.5-2.5.

For continuous simulation, infiltration capacity will be regenerated (recovered) during dry weather. SWMM performs this function whenever there are dry time steps - no precipitation or surface water - according to the following equation (see Figure V-3, Appendix V).

$$f_p = f_o - (f_o - f_\infty)\, e^{-\alpha_d (t-t_w)} \qquad (4\text{-}16)$$

where α_d = decay coefficient for the recovery curve, $\sec^{-1}$, and

t_w = hypothetical projected time at which $f_p = f_\infty$ on the recovery curve, sec.

In the absence of better knowledge of α_d, it is taken to be a constant fraction or multiple of α,

$$\alpha_d = R\,\alpha \qquad (4\text{-}17)$$

where R = constant ratio, probably << 1.0, (implying a "longer" drying curve than wetting curve). The parameter R is represented in the program by REGEN (card B2).

On well drained porous soils (e.g., medium to coarse sands), recovery of infiltration capacity is quite rapid and could well be complete in a couple of days. For heavier soils, the recovery rate is likely to be slower, say 7 to 14 days. The choice of the value can also be related to the interval between a heavy storm and wilting of vegetation. The value of α_d is then,

$$\alpha_d = 0.02/D \qquad (4\text{-}18)$$

where $\alpha_d = R\alpha$ = recovery curve decay coefficient, day^{-1}, and
D = number of days required for the soil to dry out (recover).

The factor of 0.02 in equation 4-18 assumes 98 percent recovery of infiltration capacity (i.e., $e^{-0.02} = 0.98$). The value of R may then be calculated from equation 4-17. For example, for $\alpha = 4.14$ day^{-1} and drying times of 3, 7 and 14 days, values of R are 1.61×10^{-3}, 6.90×10^{-4} and 3.45×10^{-4} respectively.

Green-Ampt Infiltration -- The second infiltration option is the Green-Ampt equation (1911), which, although not as well known as the Horton equation, has the advantage of physically based parameters which, in principle, can be predicted *a priori*. The Mein-Larson (1973) formulation of the Green-Ampt equation is a two-stage model. The first step predicts the volume of water, F_s, which will infiltrate before the surface becomes saturated. From this point onward, infiltration capacity, f_p, is predicted directly by the Green-Ampt equation. Thus,

For $F < F_s$

$$f = i \quad \text{and} \quad \begin{cases} F_s = \dfrac{S_u \cdot IMD}{i/K_s - 1} & \text{for } i > K_s \\ \\ \text{No calculation of } F_s & \text{for } i \leq K_s \end{cases} \tag{4-19}$$

For $F \geq F_s$:

$$f = f_p \quad \text{and} \quad f_p = K_s\left(1 + \frac{S_u \cdot IMD}{F}\right) \tag{4-20}$$

where f = infiltration rate, ft/sec,

f_p = infiltration capacity, ft/sec,

i = rainfall intensity, ft/sec,

F = cumulative infiltration volume, this event, ft,

F_s = cumulative infiltration volume required to cause surface saturation, ft,

S_u = average capillary suction at the wetting front (SUCT), ft water,

IMD = initial moisture deficit for this event (SMDMAX), ft/ft, and

K_s = saturated hydraulic conductivity of soil, (HYDCON) ft/sec.

Infiltration is thus related to the volume of water infiltrated as well as to the moisture conditions in the surface soil zone. Full computational details are given in Appendix V.

Like the Horton equation, the Green-Ampt infiltration equation has three parameters to be specified S_u (SUCT), K_s (HYDCON) and IMD (SMDMAX). Again, estimates based on any available field data should take precedence over the following guidelines. No default values are provided.

The "Soil Survey Interpretation" sheet (see Figure 4-19) available for most soils from the SCS shows values of "permeability" (hydraulic conductivity) for the soil, K_s. However these values are taken from data for disturbed samples and tend to be highly variable. For example, for Conestoga silt loam the values range from 0.63 to 2.0 in/hr (16 to 51 mm/hr). A better guide for the K_s values is as given for parameter f_∞ for the Horton equation; theoretically these parameters (i.e., f_∞ and K_s) should be equal for the same soil. Note that, in general, the range of K_s values encountered will be of the order of a few tenths of an inch per hour.

The moisture deficit, IMD, is defined as the fraction difference between soil porosity and actual moisture content. Sandy soils tend to have lower porosities than clay soils, but drain to lower moisture contents between storms because the water is not held so strongly in the soil pores. Consequently, values of IMD for dry antecedent conditions tend to be higher for sandy soils than for clay soils. This parameter is the most sensitive of the three parameters for estimates of runoff from pervious areas (Brakensiek and Onstad, 1977); hence, some care should be taken in determining the best IMD value to use. Table 4-10, derived from Clapp and Hornberger (1978), gives typical values of IMD for various soil types.

Table 4-10 Typical Values of IMD (SMDMAX) for Various Soil Types

Soil Texture	Typical IMD at Soil Wilting Point
Sand	0.34
Sandy Loam	0.33
Silt Loam	0.32
Loam	0.31
Sandy Clay Loam	0.26
Clay Loam	0.24
Clay	0.21

These IMD values would be suitable for input to <u>continuous</u> SWMM; the soil type selected should correspond to the surface layer for the particular subcatchment. For <u>single event</u> SWMM the values of Table 4-10 would apply only to very dry antecedent conditions. For moist or wet antecedent conditions lower values of IMD should be used. When estimating the particular value it should be borne in mind that sandy soils drain more quickly than clayey soils, i.e., for the same time since the previous event, the IMD value for a sandy soil will be closer in value to that of Table 4-10 than it would be for a clayey soil.

The average capillary suction, S_u, is perhaps the most difficult parameter to measure. It can be derived from soil moisture - conductivity data (Mein and Larsen, 1973) but such data are rare for most soils. Chu (1978) gives average values of the product of $S_u \cdot IMD$ for a range of soils, but these are not based on measurements. Fortunately the results obtained are not highly sensitive to the estimate of S_u (Brakensiek and Onstad, 1977). The approximate values which follow result from a survey of the literature (Mein and Larsen, 1973, Brakensiek and Onstad, 1977, Clapp and Hornberger, 1978, Chu, 1978). Published values vary considerably and conflict; however, a range of 2 to 15 in (50 to 380 mm) covers virtually all soil textures. Table 4-11 summarizes the published values.

Table 4-11. Typical values of S_u (SUCT) for Various Soil Types.

Soil Texture	Typical Values for S_u (inches)
Sand	4
Sandy Loam	8
Silt Loam	12
Loam	8
Clay Loam	10
Clay	7

It is very difficult to give satisfactory estimates of infiltration equation parameters that will apply to all soils encountered. Whichever infiltration equation is used, the user should be prepared to adjust preliminary estimates in the light of any available data whether they be infiltrometer tests, measurements of runoff volume, or local experience.

Subcatchment Aggregation and Lumping --

As discussed earlier, it is desirable to represent the total catchment by as few subcatchments as possible, consistent with the need for hydraulic detail within the catchment. That is, if the only interest is in hydrographs and pollutographs at the catchment outlet, as is likely for continuous simulation, then one subcatchment should suffice for the simulation (although up to 30 can be used for continuous simulation). For a single event, detailed simulation, the number of subcatchments needed is a function of the amount of hydraulic detail (e.g., backwater, surcharging, routing, storage) that must be modeled. In addition, enough detail must be simulated to allow non-point source controls to be evaluated (e.g., detention, street sweeping). Finally, multiple subcatchments are the only means by which a moving (kinematic) storm may be simulated. Coupled spatial and temporal variations in rainfall can significantly alter predicted hydrographs (Yen and Chow, 1968, Surkan, 1974, James and Drake, 1980).

Clearly, the required volume of input data (and personnel time) decreases as the number of subcatchments decreases. How then, can subcatchments be aggregated or "lumped" to provide hydrographs and pollutographs that are equivalent to more detailed simulations?

The most complete study of this question is contained in the Canadian SWMM report (Proctor and Redfern and J. F. MacLaren, 1976a) in which the effect of lumping is compared on real and hypothetical catchments. Similar work has been performed independently by Smith (1975). In both studies it is shown that a single equivalent lumped catchment can be formulated by proper adjustment of the subcatchment width.

In SWMM, Runoff and Transport simulation of the drainage network (i.e., conduits and channels) adds storage to the system and thus attenuates and somewhat delays the hydrograph peaks. When the drainage network is removed from the simulation, subcatchment runoff feeds "instantaneously" into inlets, with consequent higher and earlier hydrograph peaks. The key to aggregation of subcatchments is thus the replacement of the lost storage. This is best acccomplished through variation of the subcatchment width, although the same effect could be achieved through variation of the slope or roughness (see discussion of equation 4-6). However, it is assumed that reasonable average values of the latter two parameters for the total catchment may be obtained by weighting individual subcatchment values by their respective areas. (For the roughness an area-weighted harmonic mean may be used, although it is probably an unnecessary refinement). Hence, the subcatchment width is a more logical parameter to be adjusted.

It was shown in the discussion of the subcatchment width, that reducing its value increases storage on the subcatchment. Hence, as subcatchments are aggregated and drainage network storage lost, the total catchment width, i.e., the sum of the subcatchment widths, must be reduced accordingly. This may be seen in Figure 4-20 for a very schematized drainage network in which the subcatchment widths are nominally twice the length of the drainage conduits (Smith, 1975). The lumped catchment could be represented by a single subcatchment, as in the bottom sketch of Figure 4-20, in which the width is approximately twice the length of the main drainage channel. Experience indicates (Smith, 1975, Proctor and Redfern and J. F. MacLaren, 1976a) that good results can be obtained with no channel/conduit network. However, the Canadian study (Proctor and Redfern and J. F. MacLaren, 1976a) does illustrate the routing effect of an "equivalent pipe" in the Transport Block. Note that if the storm duration is long compared to the catchment time of concentration, and if the rainfall intensity is constant, the peak flows obtained for either a lumped or detailed simulation will be about the same, since equilibrium outflow must ultimately result (see the discussion of Figure 4-15).

Several examples of lumping using real rainfall data on real catchments are shown by Proctor and Redfern and James F. MacLaren (1976a) and Smith (1975). An instructive example for the 2330 ac (943 ha) West Toronto

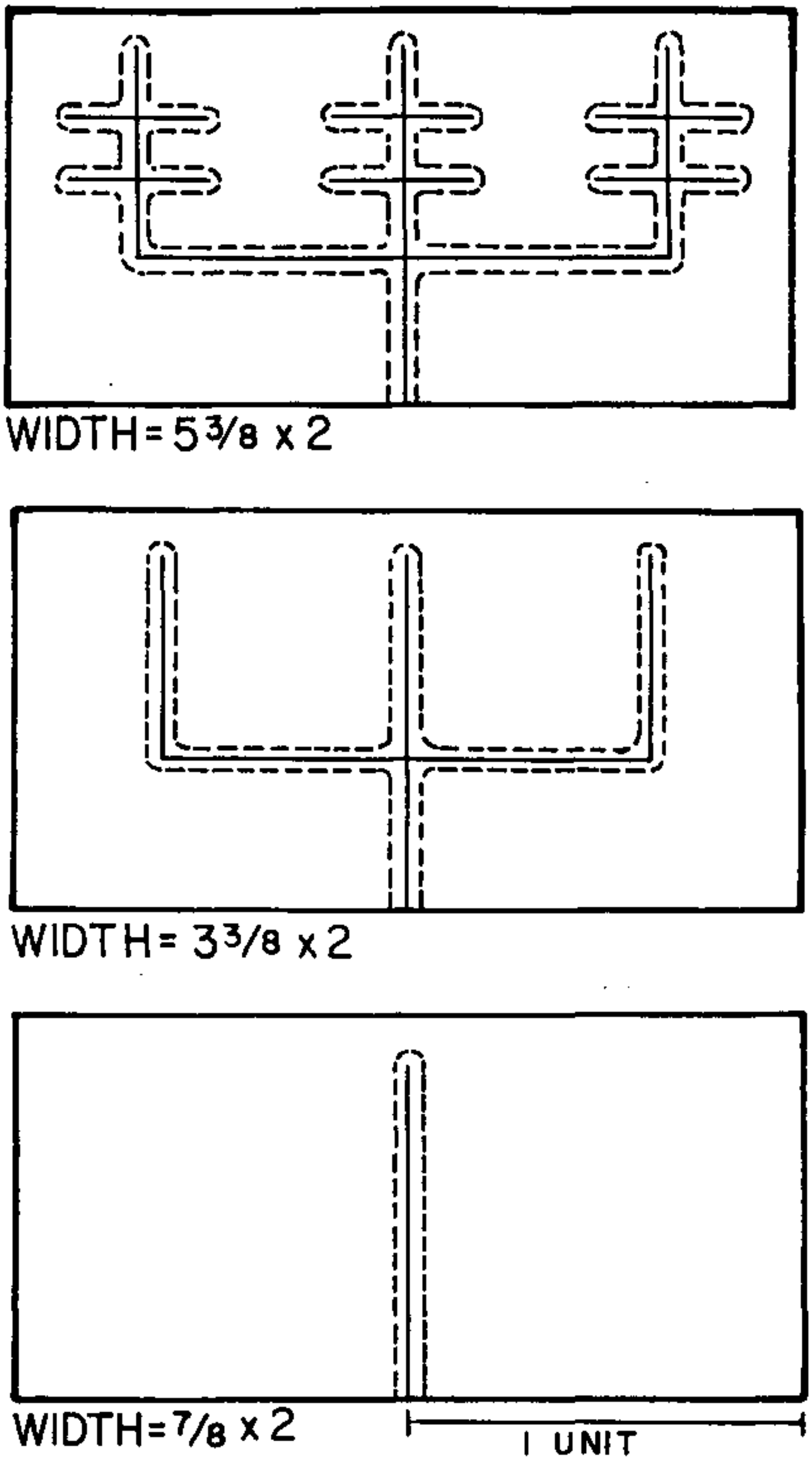


Figure 4-20. Effect of Changing the Level of Discretization on the Width of Overland Flow. (After Smith, 1975, p. 57.)

area is taken from the former reference and shown in Figure 4-21. A Runoff-Transport simulation using 45 subcatchments and including the drainage network is compared with three Runoff-only simulations with no drainage network. The best agreement, in terms of matching of peak flows, between the detailed and lumped simulations occured for a single subcatchment width of 60,000 ft (18,000 m) which is about 1.7 times the length of the main trunk conduit in the actual system. Even if a factor of two had been used (i.e., a width of 70,600 ft or 21,500 m) as a first guess, agreement would not be bad. The timing of the peaks for the single subcatchment representation is somewhat early, but adequate for most purposes. Recall that it is difficult to change the timing of subcatchment hydrograph peaks by changing only the width.

It is assumed that when subcatchments are aggregated, other parameters required on card H1 are simply areally weighted. When this is done, very little difference in runoff volume occurs between the aggregated and detailed representations. Differences that do result are usually from water that remains in storage and has not yet drained off of the lumped catchment, or from very slightly increased infiltration on the lumped catchment, again due to the longer presence of standing water on pervious areas (because of the reduced width).

To summarize, many subcatchments may be aggregated into a single lumped or equivalent subcatchment by using areally weighted subcatchment parameters and by adjustment of the subcatchment width. The lumped subcatchment width should be approximately twice the length of the main drainage channel (e.g., the trunk sewer) through the catchment in order to match hydrograph peaks. The effect on runoff volume should be minimal.

Runoff quality predictions are affected by aggreagtion of subcatchments to the extent that hydrographs and surface loadings are changed. When areal weighted averages of the latter are used for a lumped catchment, total storm loads are essentially the same as for a detailed simulation. Pollutographs of concentration versus time then vary only because of hydrograph variations.

Snowmelt Parameters (Card Groups I1-I3) --

Overview of Procedures -- Following the earlier work of the Canadian SWMM study by Proctor and Redfern and James F. MacLaren (1976a, 1976b, 1977) snowmelt simulation has been added for both single event and continuous simulation. Since snowmelt computations are explained in detail in Appendix II, only an outline is given here. Most techniques are drawn from Anderson's (1973) work for the National Weather Service (NWS). For continuous simulation, daily max-min temperatures from the NWS "WBAN Summary of the Day, Deck 345" are converted to hourly values by sinusoidal interpolation, as explained earlier.

Urban snow removal practices may be simulated through "redistribution fractions" input for each subcatchment (discussed below), through alteration of the melt coefficients and base temperatures for the regions of

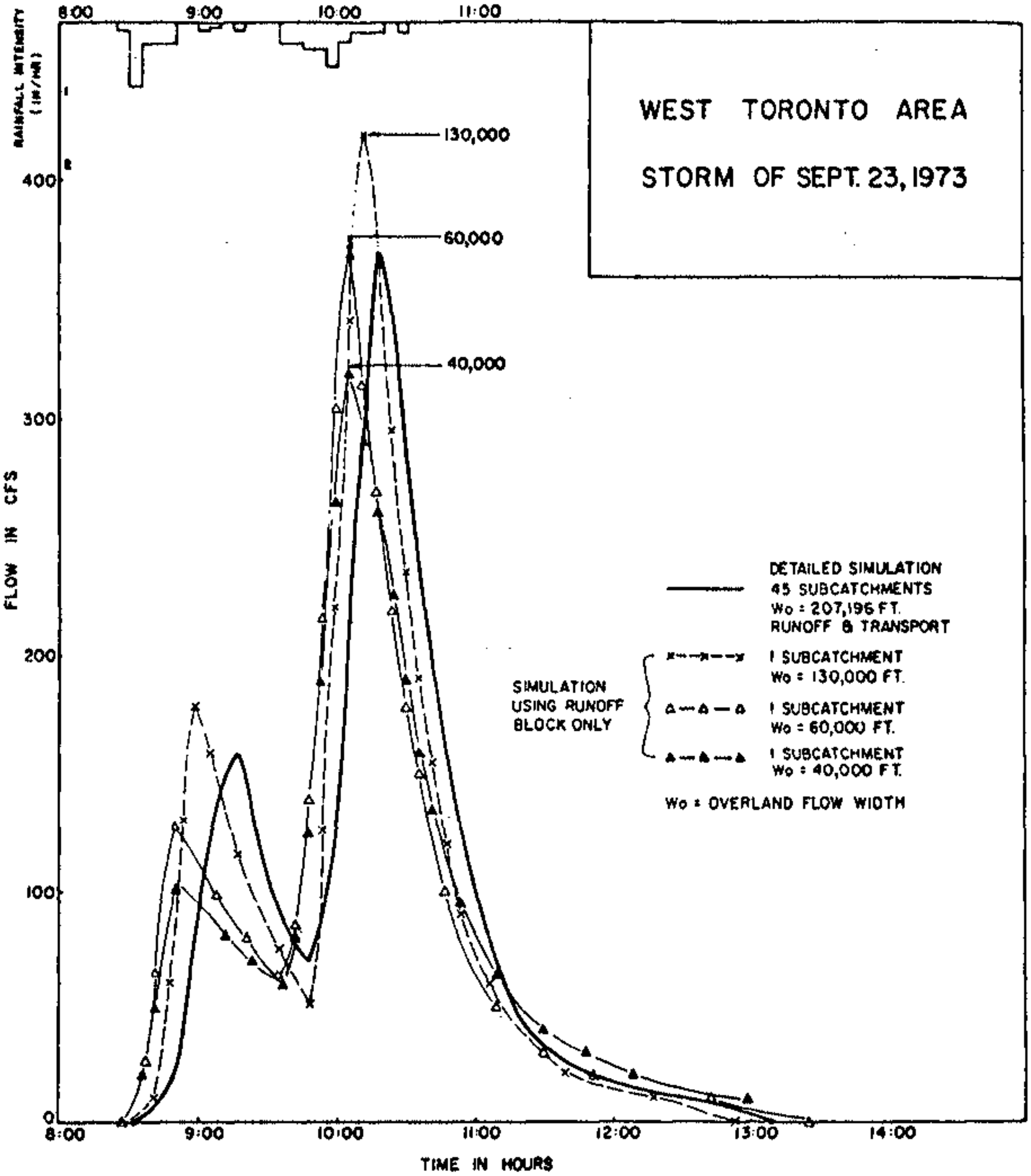


Figure 4-21. Effect on Hydrographs of Changing Subcatchment Width for West Toronto Area. (After Proctor and Redfern and J.F. MacLaren, 1976a, p. 216.)

each subcatchment, and through the areal depletion curves used for continuous simulation. Anderson's temperature-index and heat balance melt equations are used for melt computations during dry and rainy periods, respectively. For continuous simulation, the "cold content" of the pack is maintained in order to "ripen" the snow before melting. Routing of melt water through the snow pack is performed as a simple reservoir routing procedure, as in the Canadian study.

The presence of a snow pack is assumed to have no effect on overland flow processes beneath it. Melt is routed in the same manner as rainfall.

Subcatchment Schematization -- When snowmelt is simulated, a fourth subarea is added to each subcatchment as illustrated in Figure 4-11. The properties of each subarea are described in Table 4-4. The main purpose of the fourth subarea is to permit part of the impervious area (subarea A4) to be continuously snow covered (e.g., due to windrowing or dumping) and part (subareas A1 plus A3) to be "normally bare" (e.g., streets and sidewalks that are plowed). However, during continuous simulation, the normally bare portion can also have snow cover up to an amount WEPLOW (card I2) inches water equivalent (in. w.e.). (All snow depths and calculations are in terms of the equivalent depth of liquid water.) The snow covered and normally bare impervious areas are determined from fraction SNN1 (card I1). During single event simulation, subarea A4 retains 100 percent snow cover until it has all melted. During continuous simulation, an areal depletion curve, discussed earlier, is used.

Similarly, for single event simulation, a fraction SNN2 (card I1) of the pervious area remains 100 percent snow covered. During continuous simulation, the whole pervious area is subject to an areal depletion curve.

Initialization -- Initial snow depths (inches water equivalent) may be entered using parameters SNN3, SNN4 (card I1) and SNN7 (card I2). This is likely to be the only source of snow for a single event simulation although snowfall values may be entered as negative precipitation in card group E2. During continuous simulation, the effect of initial conditions will die out, given a simulation of a few months.

No liquid runoff will leave the snow pack until its free water holding capacity (due to its porosity) has been exceeded. The available volume is a constant fraction, FWFRAC (card C1) of the snow depth, WSNOW. Hence, initial values of free water, FW, should maintain the inequality

$$FW \leq FWFRAC \cdot WSNOW \qquad (4\text{-}21)$$

Melt Equations -- During periods of no rainfall, snowmelt is computed by a degree-day or temperature index equation,

$$SMELT = DHM \cdot (TA - TBASE) \qquad (4\text{-}22)$$

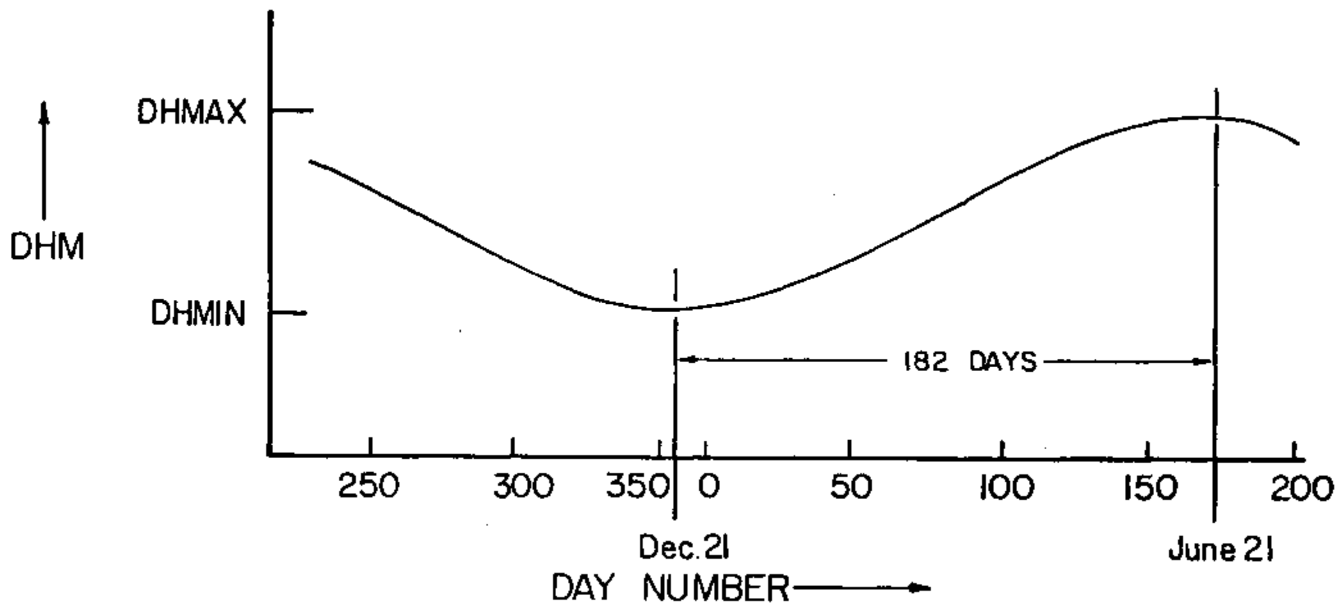


Figure 4-22. Seasonal Variation of Melt Coefficients for Continuous Simulation.

where SMELT = snowmelt rate, in. w.e./hr,
DHM = melt coefficient, in. w.e./hr-°F,
TA = air temperature, °F, and
TBASE = snowmelt base temperature, °F.

There is no melt when TA $\leq$ TBASE. For single event simulation, the melt coefficient, DHM, remains constant. For continuous simulation it is allowed to vary sinusoidally from a minimum value on December 21 to a maximum value on June 21 (see Figure 4-22) in order to reflect seasonal changes.

Melt coefficients and base melt temperatures may be determined both theoretically and experimentally. Considering the former, it is possible to first write a snowmelt equation from a heat budget formulation that includes all relevant terms: change in snow pack heat storage, net short wave radiation entering pack, conduction of heat to the pack from underlying ground, net (incoming minus outgoing) longwave radiation entering pack, convective transport of sensible heat from air to pack, release of latent heat of vaporization by condensation of atmospheric water vapor, and advection of heat to snow pack by rain. (It is assumed here that the pack is "ripe", i.e., just at the melting point, so that rain will not freeze and release its latent heat of fusion.) The equation may then be linearized about a reference air temperature and reduced to the form of equation 4-22. Exactly this procedure is followed in a detailed example presented in Appendix III.

Alternatively, observed melt, in inches per time interval, may be plotted against temperature for that time interval, and a linear relationship developed of the form of equation 4-22. An often-cited such development for natural areas is illustrated in Figure 4-23 taken from the Corps of Engineers (1956). Viessman et al. (1977) also present a good discussion of degree-day equations. In the highly desirable but unlikely event that snowmelt data are available, the experimental procedure of Figure 4-23 is probabaly best for urban areas due to the considerable variation of snow pack and meteorological conditions that will be encountered, making reasonable theoretical assumptions more difficult.

For natural areas, considerable range in melt coefficients exits, on the order of 0.0006 to 0.008 in/hr-°F (0.03 to 0.4 mm/hr-°C). Although base melt temperatures are nominally near the freezing point (i.e., 32°F or 0°C) they may be considerably lower depending on the exposure of the site and meteorological conditions. For instance, for the linearization performed in Appendix III a base melt temperature of 9°F (-13°C) was computed, which is valid only over the range of air temperatures used in the linearization (approximately 30 to 40°F or -1 to 5°C).

If the effects of snow removal practices (e.g., street salting) and land surface factors are known, different melt coefficients and base melt temperatures may be entered for the different snow covered subareas of a subcatchment. For instance, street salting lowers the freezing point in

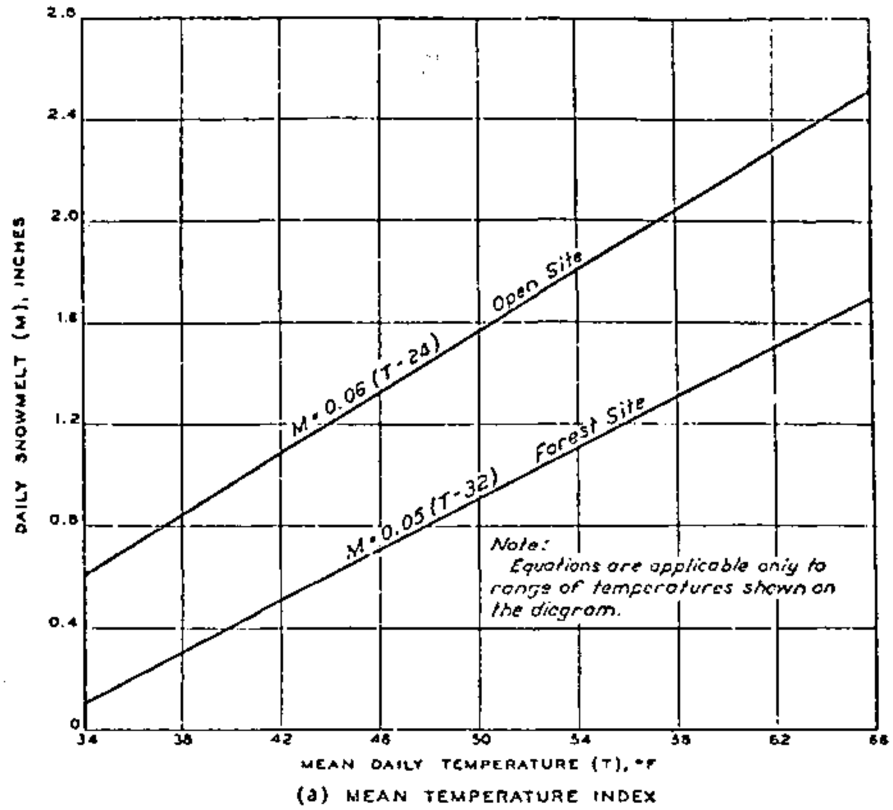


Figure 4-23. Degree-Day Equations for Snow Melt. (After Corps of Engineers, 1956, plate 6-4).

proportion to the concentration of the chemical. Handbook values (Chemical Rubber Co., 1976, pp. D218 - D267) for freezing point depression are plotted versus concentration in Figure 4-24 for several common roadway salting chemicals. Thus, the base melt temperature computed for pure water might be lowered by an amount taken from Figure 4-24 if an idea is known about the likely concentration on the roadway. The concentration will depend upon the amount of chemical applied and the amount of snowfall and might not be easily computed. An interesting alternative would be to let SWMM predict it!

During periods (i.e., time steps) with rainfall, good assumptions can be made about relevant meteorological parameters for the complete heat balance melt equation. It then replaces the degree-day equation for "wet" time steps. A detailed explanation may be found in reference to equation III-8 in Appendix III. Melt during these time steps is linearly proportional to air temperature and wind speed.

Areal Depletion Parameters -- In the earlier discussion of areal depletion curves it was noted that there would be 100 percent cover above a depth of SI inches water equivalent. Values of SI for impervious and pervious areas are read on card I2.

For natural areas, Anderson (1973) recommends that a distinction be made on the basis of areal homogeneity. For a very heterogeneous area there are likely to be areas that receive little snow, or else it will quickly melt. The value of SI for such areas might be about the maximum depth anticipated. For homogeneous areas a much lower value would be appropriate.

No specific information is available for urban areas; however, they are likely to be quite heterogeneous, especially if large, aggregated subcatchments are being used for the continuous simulation. Hence, a high value is probably indicated. Whichever values are used, they should be consistent with the form of the areal depletion curves entered in card groups C3 and C4. In general (depending somewhat on the areal depletion curve), the higher the value of SI, the more "stacked up" on a catchment is the snow, and snowmelt will occur at a lower rate over a longer time.

Snow Redistribution -- The program allows (during continuous simulation) snow that falls on the normally bare impervious areas to be redistributed according to the fractions given as SFRAC on card I2. This is intended to simulate plowing and other snow removal practices in urban areas. Snow depths above WEPLOW inches water equivalent are thus redistributed according to Figure 4-25.

The value of WEPLOW depends upon the level of service given the particular impervious area. That is, at what snow depth do removal practices start? Some guidelines are provided by Richardson et al. (1974) in Table 4-12.

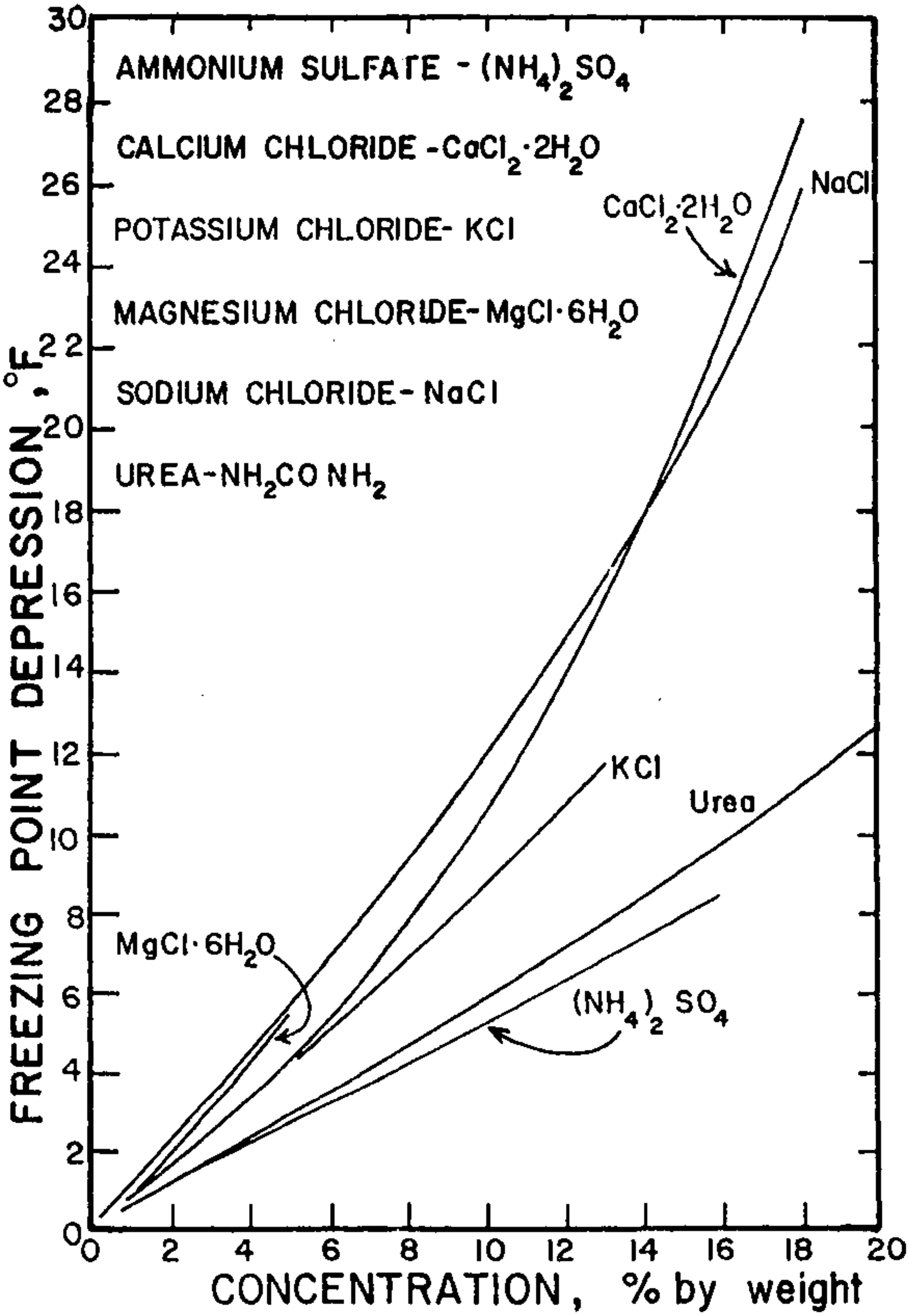


Figure 4-24. Freezing Point Depression Versus Roadway Salting Chemical Concentration. Compiled from data from CRC (1976).

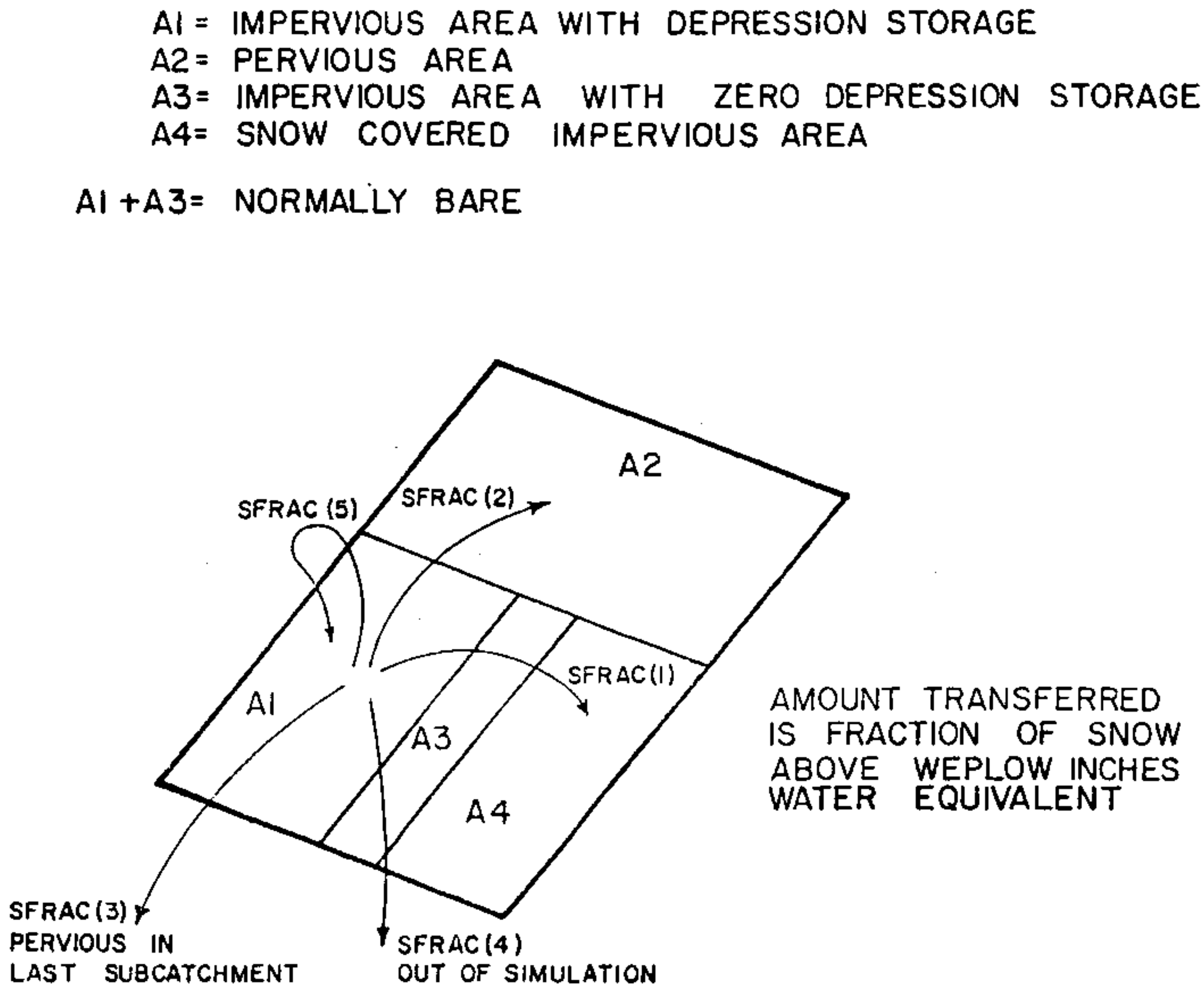


Figure 4-25. Illustration of Snow Redistribution Fractions.

Table 4-12. Guidelines for Levels of Service in Snow and Ice Control. (Richardson et al., 1974.)

Road Classification	Level of Service	Snow Depth to Start Plowing (Inches)	Max. Snow Depth on Pavement (Inches)	Full Pavement Clear of Snow After Storm (Hours)	Full Pavement Clear of Ice After Storm Hours
1. Low-Speed Multilane Urban Expressway	• Roadway routinely patrolled during storms • All traffic lanes treated with chemicals • All lanes (including breakdown lanes) operable at all times but at reduced speeds • Occasional patches of well-sanded snow pack • Roadway repeatedly cleared by echelons of plows to minimize traffic disruption • Clear pavement obtained as soon as possible	0.5 to 1	1	1	12
2. High-Speed 4-Lane Divided Highways Interstate System ADT greater than 10,000	• Roadway routinely patrolled during storms • Driving and passing lanes treated with chemicals • Driving lane operable at all times at reduced speeds • Passing lane operable depending on equipment availability • Clear pavement obtained as soon as possible	1	2	1.5	12
3. Primary Highways Undivided 2 and 3 lanes ADT 500 -- 5000	• Roadway is routinely patrolled during storms • Mostly clear pavement after storm stops • Hazardous areas receive treatment of chemicals or abrasive • Remaining snow and ice removed when thawing occurs	1	2.5	2	24
4. Secondary Roads ADT less than 500	• Roadway is patrolled at least once during a storm • Bare left-wheel track with intermittent snow cover • Hazardous areas are plowed and treated with chemicals or abrasives as a first order of work • Full width of road is cleared as equipment becomes available	2	3	3	48

The five fractions, SFRAC, should sum to 1.0 and are defined on the basis of the ultimate fate of the removed snow. For instance, if snow is plowed from a street onto an adjacent impervious or pervious area, fractions SFRAC(1) or SFRAC(2) would be appropriate. It may also be transfered to the last subcatchment (e.g., a dumping ground) or removed from the simulation (i.e., removed from the total catchment) altogether. Finally, it may be converted to immediate melt. Should variations in snow removal practices need to be simulated, different subcatchments can be established for different purposes and the fractions varied accordingly.

Surface Quality Input Data (Card Groups J1-L1)

Overview of Quality Procedures --

For most SWMM applications, the Runoff Block is the origin of water quality constituents. Although effects of dry-weather flow and scour and deposition may be included in the Transport Block, (dry-weather flow quality may also be included in the Storage/treatment Block), the generation of quality constituents (e.g., pollutants) in the storm water itself can only be included in the Runoff Block.

Several mechanisms constitute the genesis of stormwater quality, most notably buildup and washoff. In an impervious urban area, it is usually assumed that a supply of constituents is built up on the land surface during dry weather preceding a storm. Such a buildup may or may not be a function of time and factors such as traffic flow, dry fallout and street sweeping. With the storm the material is then washed off into the drainage system. The physics of the washoff may involve rainfall energy, as in some erosion calculations, or may be a function of bottom shear stress in the flow as in sediment transport theory. Most often, however, washoff is treated by an empirical equation with slight physical justification.

As an alternative to the use of a buildup-washoff formulation, quality loads (i.e., mass/time) may be generated by a rating curve approach in which loads are proportional to flow to some power. Such an approach may also be justified physically and is often easier to calibrate using available data.

Another quality source is catchbasins. These are treated in SWMM as a reservoir of constituents in each subcatchment available to be flushed out during the storm.

Erosion of "solids" may be simulated directly by the Universal Soil Loss Equation (USLE). Since it was developed for long term predictions (e.g., seasonal or annual loads), its use during a storm event in SWMM is questionable. But it is convenient since many data are available to support it.

A final source of constituents is in the precipitation itself. Much more monitoring exists of precipitation quality at present than in the past, and precipitation can contain surprisingly high concentrations of many parameters. This is treated in SWMM by permitting a constant concentration of constituents in precipitation.

Many constituents can appear in either dissolved or solid form (e.g., BOD, nitrogen, phosphorus) and may adsorbed onto other constituents (e.g., pesticides onto "solids") and thus be generated as a portion of such other constituents. To treat this situation, any constituent may be computed as a fraction ("potency factor") of another. For instance, five percent of the suspended solids load could be added to the (soluble) BOD load. Or several particle size - specific gravity ranges could be generated, with other constituents consisting of fractions of each.

Up to ten quality constituents may be simulated in the Runoff Block. All are user supplied, with appropriate parameters for each. All are transferred to the interface file for transmittal to subsequent SWMM blocks, but not all may be used by the blocks; see the documentation for each block.

Up to five user supplied land uses may be entered to characterize different subcatchments. Street sweeping is a function of land use, and individual constituents. Constituent buildup may be a function of land use or else fixed for each constituent. Considerable flexibility thus exists.

When gutter/pipes are included, quality constituents are routed through them assuming complete mixing within each gutter/pipe at each time step. No scour, deposition or decay-interaction during routing is simulated in the Runoff Block.

Output consists of pollutographs (concentrations versus time) at desired locations along with total loads, and flow-weighted concentration means and standard deviations. The pollutographs may be plotted using the graph routines of the Executive Block (Section 2). In addition, summaries are printed for each constituent describing its overall mass balance for the simulation for the total catchment, i.e., sources, removals, etc. These summaries are the most useful output for continuous simulation runs.

In the following material, the processes described above will be discussed in more detail. The various parameters will be related to individual card groups as appropriate.

Quality Simulation Credibility --

Although the conceptualization of the quality processes is not difficult, the reliability and credibility of quality parameter simulation is very difficult to establish. In fact, quality predictions by SWMM or almost any other surface runoff model are almost useless without local data for the catchment being simulated to use for calibration and verification. If such data are lacking, results may still be used to compare relative effects of changes, but parameter magnitudes (i.e., actual values of predicted concentrations) will forever be in doubt. This is in marked contrast to quantity prediction for which reasonable estimates of hydrographs may be made in advance of calibration.

Moreover, as will be discussed, there is disagreement in the literature as to what are the important and appropriate physical and chemical mechanisms that should be included in a model to generate surface runoff quality.

The objective in the Runoff Block has been to provide flexibility in mechanisms and the opportunity for calibration. But this places a considerable burden on the user to obtain adequate data for model usage and to be familiar with quality mechanisms that may apply to the catchment being studied. This burden may often be ignored, leading ultimately to model results being discredited.

In the end then, there is no substitute for local data, that is, flow and concentration measurements, with which to calibrate and verify the quality predictions. Without such data, little reliability can be placed in the predicted magnitudes of quality parameters.

Quality Constituents --

The number and choice of constituents to be simulated must reflect the user's needs, potential for treatment and receiving water impacts, etc. Almost any constituent measured by common laboratory or field tests can be included, up to a total of ten. The name and concentration units are entered as A-format variables in card group J3. These will be passed to subsequent blocks (see Section 2) and are used as column headings for tabular output of concentrations, as illustrated in Figure 4-26. This heading style is used in both the Runoff and Transport Blocks.

Options for concentration units are reasonably broad and broken into three categories, indicated by parameter NDIM in card group J3. Most constituents are measurable in units of milligrams per liter, mg/l. Although parameters such as metals, phosphorus or trace organics are often given as micrograms per liter, μg/l, the output of concentrations for NDIM=0 is F10.3 (allowing for three decimal places), and it is expected to be compatible with reported values of such parameters. Thus, the use of mg/l should suffice for all parameters for which the "quantity" of the parameter is measured as a mass (e.g., mg).

A notable exception to the use of mass units is for bacteria, for which constituents such as coliforms, fecal strep etc. are given as a number or count per volume, e.g., MPN/l. Setting NDIM=1 accounts for these units (or any other type of "quantity" per liter, including mass if desired). Concentration output for these constituents is given an E9.3 format.

A third category covers parameters with specialized concentration-type units such as pH, conductivity (μmho), turbidity (JTU), color (PCU), temperature (°C), etc. These are simulated using NDIM=2. For these parameters, interpretation of concentration results is straightforward, but "total mass" or "buildup" is mostly conceptual. Since loads (e.g., mass/time) are transmitted in terms of concentration times flow rate, whichever concentration units are used, proper continuity of parameters is readily maintained. Of course, simulation of a parameter such as temperature could only be done to the zeroth approximation in any event since all Runoff Block constituents are conservative.

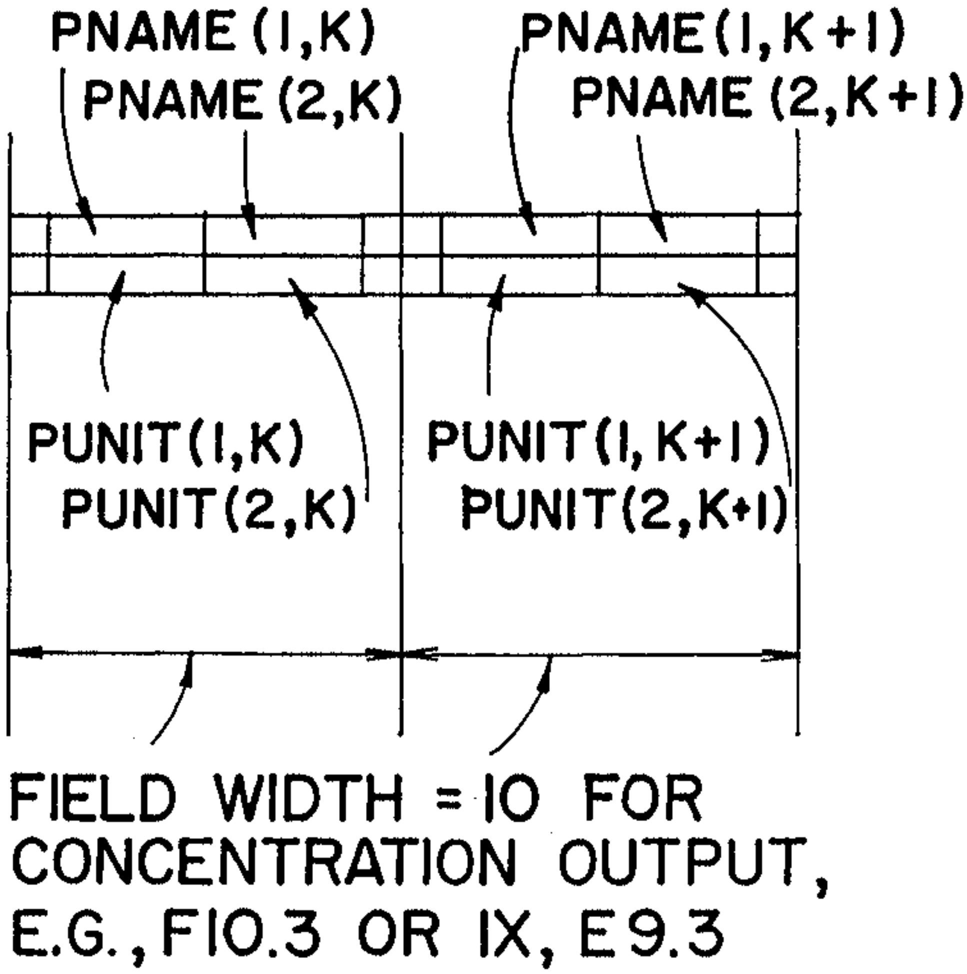


Figure 4-26. Layout of Quality Constituent Headings. Parameters PNAME and PUNIT are entered in card group J3, Table 4-28.

Land Use Data (Card Group J2) --

Each subcatchment must be assigned only one of up to five user supplied land uses. The number of the land use is used as a program subscript, so at least one land use card must be entered. Street sweeping is a function of land use and constituent (discussed subsequently). Constituent buildup may be a function of land use depending on the type of buildup calculation specified for each in card group J3. The buildup parameters DDLIM, DDPOW, and DDFACT in card group J2 are used only when constituent buildup will be a function of "dust and dirt" buildup. This is discussed in detail below.

The land use name, LNAME, will be printed in the output using eight columns. The land use types are completely arbitrary, but they could reflect those for which data are available and, of course, those found in the catchment, or an aggregate thereof.

Buildup --

Background -- One of the most influential of the early studies of stormwater pollution was conducted in Chicago by the American Public Works Association (1969). As part of this project, street surface accumulation of "dust and dirt" (anything passing through a quarter inch mesh screen) was measured by sweeping with brooms and vacuum cleaners. The accumulations were measured for different land uses and curb lengths, and the data were normalized in terms of pounds of dust and dirt per dry day per 100-ft of curb or gutter. These well known results are shown in Table 4-13 and imply that dust and dirt buildup is a linear function of time.

Table 4-13 Measured Dust and Dirt (DD) Accumulation in Chicago by the APWA in 1969 (APWA, 1969).

Type	Land Use	Pounds DD/dry day·100 ft-curb
1	Single Family Residential	0.7
2	Multi-Family Residential	2.3
3	Commercial	3.3
4	Industrial	4.6
5	Undeveloped or Park	1.5

The dust and dirt samples were analyzed chemically, and the fraction of sample consisting of various constituents for each of four land uses was determined, leading to the results shown in Table 4-14.

Table 4-14 Milligrams of Pollutant Per Gram of Dust and Dirt (Parts Per Thousand By Mass) For Four Chicago Land Uses From 1969 APWA Study (APWA, 1969).

Parameter	Land Use Type: Single Family Residential	Multi-Family Residential	Commercial	Industrial
BOD_5	5.0	3.6	7.7	3.0
COD	40.0	40.0	39.0	40.0
Total Coliforms[a]	$1.3x10^6$	$2.7x10^6$	$1.7x10^6$	$1.0x10^6$
Total N	0.48	0.61	0.41	0.43
Total PO_4 (as PO_4)	0.05	0.05	0.07	0.03

[a]Units for coliforms are MPN/gram.

From the values shown in the table, the buildup of each constituent (also linear with time) can be computed simply by multiplying dust and dirt by the appropriate fraction. Since the APWA study was published during the original SWMM project (1969-1971), it represented the state of the art at the time and was used extensively in the development of the surface quality routines (Metcalf and Eddy et al., 1971a, Section 11). In fact, the formulation and data may still be used in this present version of SWMM should the user wish to rely upon highly site specific results for Chicago. Needless to say, unless the application is in Chicago this is not recommended. Several useful studies have been conducted since the pioneering APWA work which permit much more selectivity.

Of course the whole buildup idea essentially ignores the physics of generation of pollutants from sources such as street pavement, vehicles, atmospheric fallout, vegetation, land surfaces, litter, spills, anti-skid compounds and chemicals, construction, and drainage networks. Lager et al. (1977a) consider each source in turn and give guidance on buildup rates. But the rates that are (optionally) entered into the Runoff Block only reflect the aggregate of all sources.

Available Studies -- The 1969 APWA study (APWA, 1969) was followed by several more efforts, notably AVCO (1970) reporting extensive data from Tulsa, Sartor and Boyd (1972) reporting a cross section of data from ten US cities, and Shaheen (1975) reporting data for highways in the Washington, D.C. area. Pitt and Amy (1973) followed the Sartor and Boyd (1972) study with an analysis of heavy metals on street surfaces from the same ten U.S. cities. More recently, Pitt (1979) reports extensive data gathered both on the street surface and in runoff for San Jose. A drawback of the earlier studies is that it is difficult to draw conclusions from them on the relationship between street surface accumulation and stormwater concentrations since they were seldom measured simultaneously.

Amy et al. (1975) provide a summary of data available in 1974 while Lager et al. (1977a) provide a similar function as of 1977 without the extensive data tabulations given by Amy et al. Perhaps the most comprehensive summary of surface accumulation and pollutant fraction data is provided by Manning et al. (1977) in which the many problems and facets of sampling and measurements are also discussed. For instance, some data are obtained by sweeping, others by flushing; the particle size characteristics and degree of removal from the street surface differ for each method. Some results of Manning et al. (1977) will be illustrated later. Surface accumulation data may be gleaned, somewhat less directly, from references on loading functions that include McElroy et al. (1976), Heaney et al. (1977) and Huber et al. (1979, 1980).

Ammon (1979) has summarized many of these and other studies, specifically in regard to application to SWMM. For instance, there is evidence to suggest several buildup relationships as alternatives to the linear one, and these relationships may change with the constituent being considered. Upper limits for buildup are also likely. Several options for both buildup and washoff are investigated by Ammon, and his results are partially the basis for formulations in this version of SWMM. Recently, Jewell et al. (1980) also provide a useful critique of methods available for simulation of surface runoff quality and ultimately suggest statistical analysis as the proper alternative. Many of the problems and weaknesses with extensive data and present modeling formulations are pointed out by Sonnen (1980) along with guidelines for future research.

To summarize, many studies and voluminous data exist with which to formulate buildup relationships, most of which are purely empirical and data-based, ignoring the underlying physics and chemistry of the generation processes. Nonetheless, they represent what is available, and modeling techniques in SWMM are designed to accommodate them in their heuristic form.

Buildup Formulations -- Most data, as will be seen, imply linear buildup since they are given in units such as lb/ac-day or lb/100 ft curb-day. As stated earlier, the Chicago data that were used in the original SWMM formulation assumed a linear buildup. However, there is ample evidence that buildup can be nonlinear; Sartor and Boyd's (1972) data are most often cited as examples (Figure 4-27). More recent data from Pitt (Figure 4-28) for San Jose indicate almost linear accumulation, although some of the best fit lines indicated in the figure had very poor correlation coefficients, ranging from $0.35 \leqq r \leqq 0.9$. Even in data collected as carefully as in the San Jose study, the scatter (not shown in the report) is considerable. Thus, the choice of the best functional form is not obvious. Whipple (1977) has criticized the linear buildup formulation included in the original SWMM, although it is somewhat irrelevant since the user has long been able to insert his/her own desired initial loads, calculated by whatever procedure was desired, in card group L1. However, linear buildup between storms during continuous simulation has indeed been used in SWMM, until this present version.

The choice of the proper functional form must ultimately be the responsibility of the user. The program provides three options for dust and dirt buildup (Table 4-15) and three for individual constituents (Table 4-16). They are the same three, as seen from the tables, namely:

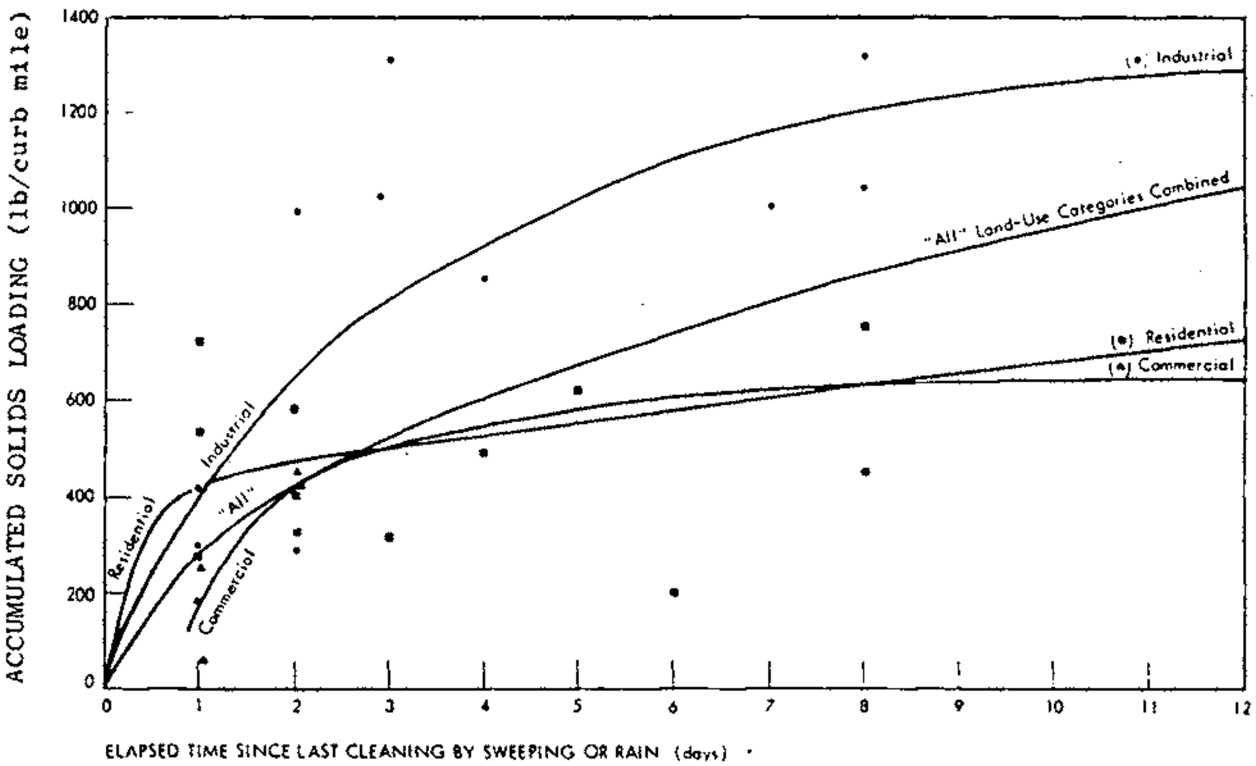


Figure 4-27. Non-linear Buildup of Street Solids. (After Sartor and Boyd, 1972, p. 206.)

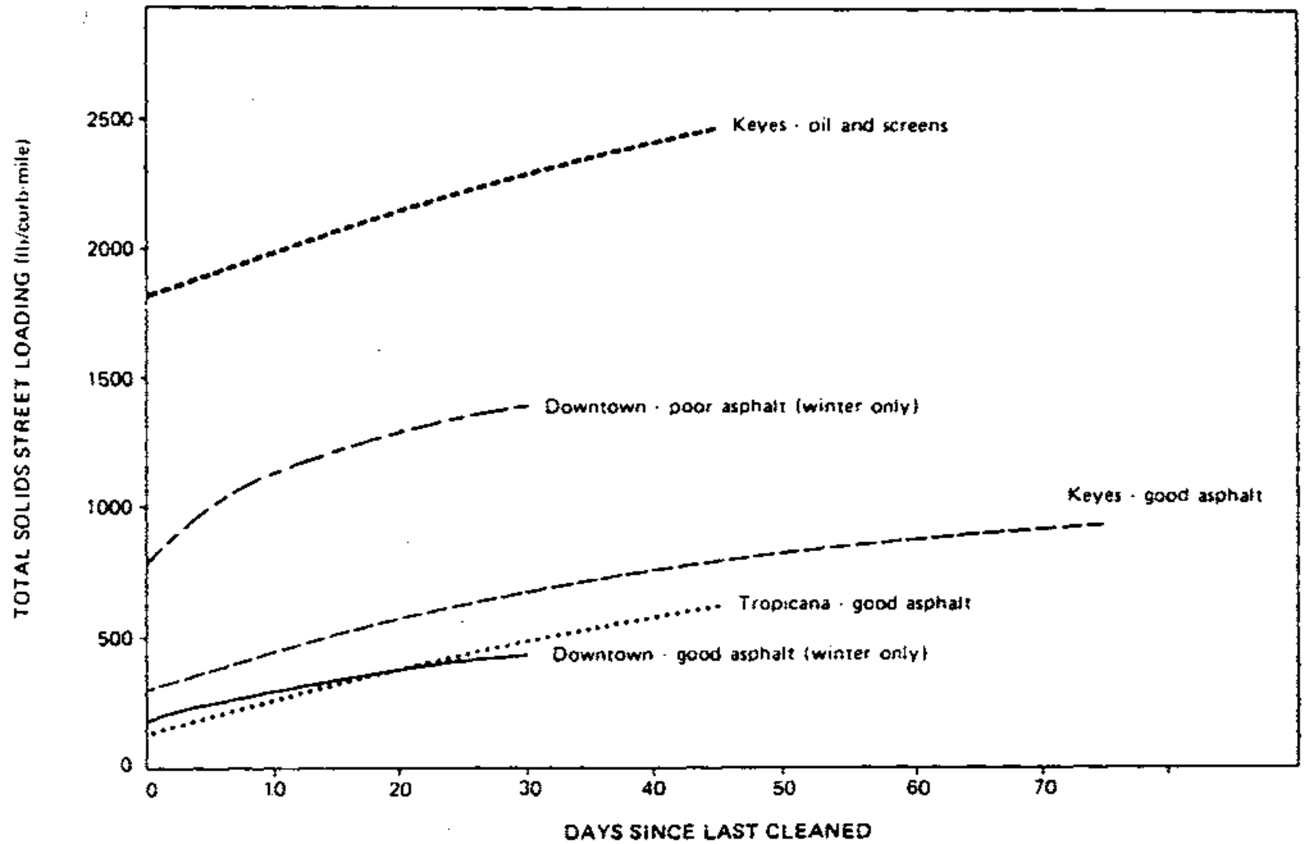


Figure 4-28. Buildup of Street Solids in San Jose. (After Pitt, 1979, p. 29.)

Table 4-15. Buildup Equations and Units for Dust and Dirt.

Enter parameters on Card Group J2. For metric input substitute kg for lb, ha for ac and km for 100-ft.

DD = Dust and Dirt, lb. t = time, days.

METHOD (Card Group J2)	Type	Equation	Equation Number
0	Power-Linear	$DD = DDFACT \cdot t^{DDPOW}$	(4-23)
		$DD \leq DDLIM$	
1	Exponential	$DD = DDLIM \cdot (1-e^{-DDPOW \cdot t})$	(4-24)
2	Michaelis-Menton	$DD = DDLIM \cdot t/(DDFACT+t)$	(4-25)

Units for Card Input of:

METHOD	JACGUT	DDLIM	DDPOW	DDFACT
0	0	$lb \cdot (100\ ft\ curb)^{-1}$	Dimensionless	$lb \cdot (100\ ft\text{-}curb)^{-1} \cdot day^{-DDPOW}$
	1	$lb \cdot ac^{-1}$	Dimensionless	$lb \cdot ac^{-1} \cdot day^{-DDPOW}$
	2	lb	Dimensionless	$lb \cdot day^{-DDPOW}$
1	0	$lb \cdot (100\ ft\ curb)^{-1}$	day^{-1}	Not Used
	1	$lb \cdot ac^{-1}$	day^{-1}	Not Used
	2	lb	day^{-1}	Not Used
2	0	$lb \cdot (100\ ft\ curb)^{-1}$	Not Used	day
	1	$lb \cdot ac^{-1}$	Not Used	day
	2	lb	Not Used	day

Parameters DDLIM, DDPOW, and DDFACT are single subscripted by land use, J.

Table 4-16. Buildup Equations for Constituents.

Enter Parameters on Card Group J3.

PSHED = Constituent quantity. t = time, days.

For parameter units, see Table 4-17.

KALC (Card Group J3)	Type	Equation	Equation Number
1	Power-Linear	$PSHED = QFACT(3) \cdot t^{QFACT(2)}$	(4-26)
		$PSHED \le QFACT(1)$	
2	Exponential	$PSHED = QFACT(1) \cdot (1-e^{-QFACT(2) \cdot t})$	(4-27)
3	Michaelis-Menton	$PSHED = \frac{QFACT(1) \cdot t}{(QFACT(3)+t)}$	(4-28)

Parameters QFACT are doubly subscripted. Second subscript is constituent number, K.

Table 4-17. Units for Card Input of Constituent Parameters, Card Group J3.

Define Q_1 and Q_2 ≡ Constituent quantity as follows:

NDIM	Q
0	Q_1 = lb, Q_2 = mg
1	$Q_1 = Q_2 = 10^6$ · Other quantity, e.g., 10^6·MPN
2	$Q_1 = Q_2$ = Concentration x ft^3, e.g., JTU · ft^3

For metric input substitute kg for lb, m^3 for ft^3, ha for ac and km for 100-ft.

For KALC = 4, buildup parameters are not required.

For KALC = 0, QFACT(J,K) = Q_2/g_{DD} for J = 1 to JLAND and g_{DD} = grams dust and dirt. (E.g., see Table 4-14)

Otherwise:

KALC	KACGUT	QFACT(1,K)	QFACT(2,K)	QFACT(3,K)
1	0	Q_1·(100 ft-curb)$^{-1}$	Dimensionless	Q_1·(100 ft-curb)$^{-1}$·day$^{-QFACT(2,K)}$
	1	Q_1·ac^{-1}	Dimensionless	Q_1·ac^{-1}·day$^{-QFACT(2,K)}$
	2	Q_1	Dimensionless	Q_1·day$^{-QFACT(2,K)}$
2	0	Q_1·(100 ft-curb)$^{-1}$	day^{-1}	Not Used
	1	Q_1·ac^{-1}	day^{-1}	Not Used
	2	Q_1	day^{-1}	Not Used
3	0	Q_1·(100 ft-curb)$^{-1}$	Not Used	day
	1	Q_1·ac^{-1}	Not Used	day
	2	Q_1	Not Used	day

QFACT(4,K) and QFACT(5,K) not required for KALC ≠ 0.

1. power-linear,
2. exponential, or
3. Michaelis-Menton.

Linear buildup is simply a subset of a power function buildup. The shapes of the three functions are compared in Figure 4-29 using the dust and dirt parameters (card group J2) as examples, and a strictly arbitrary assignment of numerical values to the parameters. Exponential and Michaelis-Menton functions have clearly defined asymptotes or upper limits. Upper limits for linear or power function buildup may be imposed if desired. "Instantaneous buildup" may be easily achieved using any of the formulations with appropriate parameter choices. For instance, if it were desired to always have a fixed amount of dust and dirt available, DDLIM, at the beginning of any storm event (i.e., after any dry time step during continuous simulation), then linear buildup could be used with DDPOW = 1.0 and DDFACT equal to a large number ≧ DDLIM/DELT. Linear buildup is "cheapest" to run in terms of computer time.

It is apparent in Figure 4-29 that different options may be used to accomplish the same objective (e.g., nonlinear buildup); the choice may well be made on the basis of available data to which one or the other functional forms have been fit. If an asymptotic form is desired, either the exponential or Michaelis-Menton option may be used depending upon ease of comprehension of the parameters. For instance, for exponential buildup the exponent (i.e., DDPOW for dust and dirt or QFACT(2,K) for a constituent) is the familiar exponential decay constant. It may be obtained from the slope of a semi-log plot of buildup versus time. As a numerical example, if its value were 0.4 day^{-1}, then it would take 5.76 days to reach 90 percent of the maximum buildup (see Figure 4-29).

For Michaelis-Menton buildup the parameter DDFACT for dust and dirt (or QFACT(3,K) for a constituent) has the interpretation of the half-time constant, that is, the time at which buildup is half of the maximum (asymptotic) value. For instance, DD = 50 lb at t = 0.9 days for curve 4 in Figure 4-29. If the asymptotic value is known or estimated, the half-time constant may be obtained from buildup data from the slope of a plot of DD versus t·(DDLIM-DD), using dust and dirt as an example. Generally, the Michaelis-Menton formulation will rise steeply (in fact, linearly for small t) and then approach the asymptote slowly.

The power function may be easily adjusted to resemble asymptotic behavior, but it must always ultimately exceed the maximum value (if used). The parameters are readily found from a log-log plot of buildup versus time. This is a common way of analyzing data, (e.g., Miller et al., 1978, Ammon, 1979, Smolenyak, 1979, Jewell et al., 1980, Wallace, 1980).

Prior to the beginning of the simulation, buildup occurs over DRYDAY days for both single event and continuous simulation. During the simulation, buildup will occur during dry time steps (runoff less than 0.0005 in./hr or 0.013 mm/hr) only for continuous simulation.

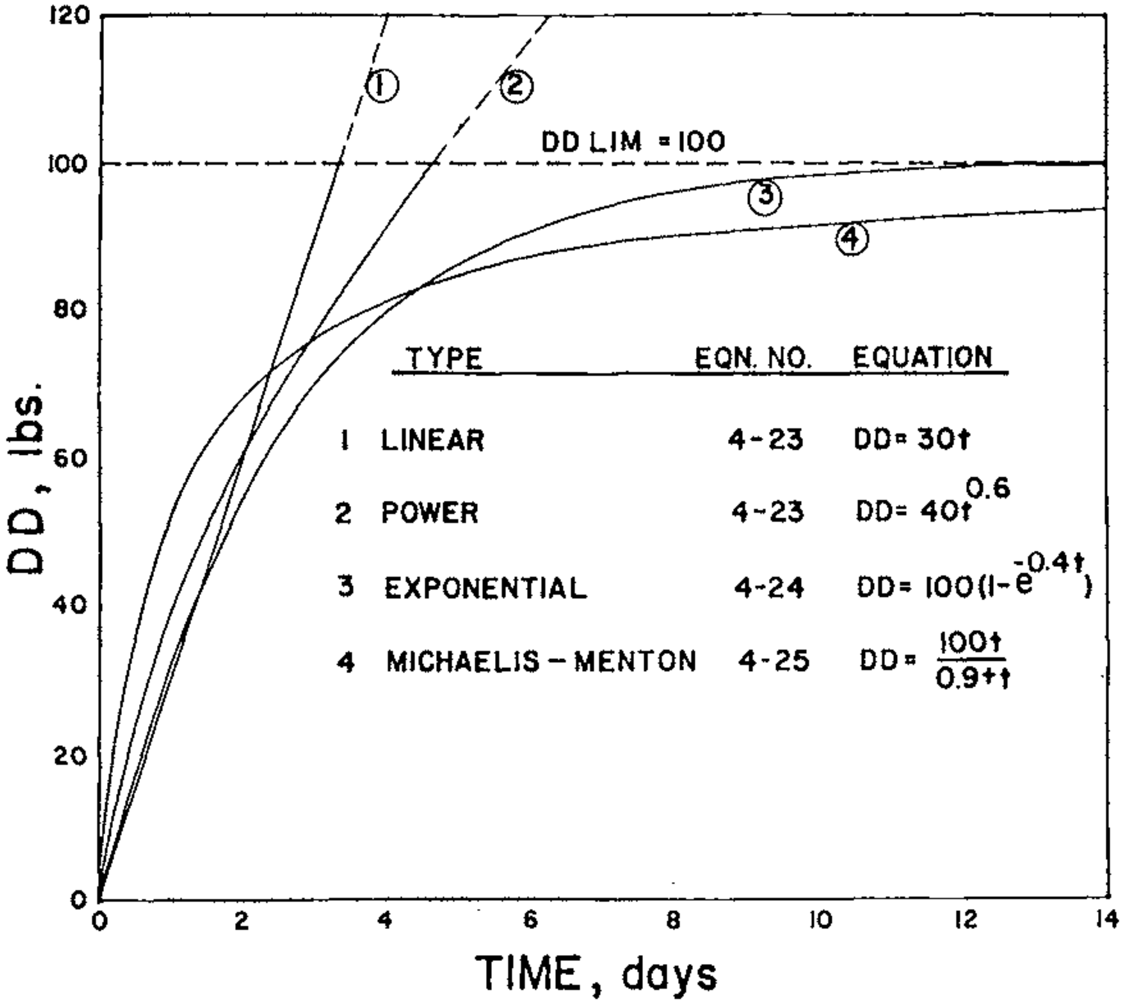


Figure 4-29. Comparison of Linear and Three Non-linear Buildup Equations. "Dust and dirt," DD, is used as an example. Numerical values have been chosen arbitrarily.

For a given constituent, buildup may be computed 1) as a fraction of dust and dirt, or 2) individually for the constituent. If the first option is used (KALC=0 on card group J3) then the rate of buildup will depend upon the fraction and the functional form used for a given land use. In other words, the functional form could vary with land use for a given constituent. If the second option is used (1 ≦ KALC ≦ 3 on card group J3) the buildup function will be the same for all land uses (and subcatchments) for a given constituent. Of course, each constituent may use any of the options. Catchment characteristics (i.e., area or gutter length) may be included through the use of parameters JACGUT (card group J2) or KACGUT (card group J3), as described in Tables 4-15 and 4-17.

Units for dust and dirt buildup parameters are reasonably straightforward and explained in Table 4-15. For example, if linear buildup was assumed using the Chicago APWA data (APWA, 1969), values for DDFACT could be taken directly from Table 4-13 for different land uses. Parameters JACGUT would equal zero. A limiting buildup (DDLIM) of so many lb/100 ft-curb could be entered if desired, and for linear buildup, DDPOW = 1.0.

Units for constituent buildup parameters depend upon parameter NDIM, that is, the units for the buildup parameters depend upon the units of the constituent. When NDIM = 0 and the constituent concentration is simply mg/l (mass per volume), then buildup units are straightforward and given as pounds. When NDIM = 1, concentrations are given as some other quantity per volume, usually a bacteria count such as MPN/l. In this case buildup is simply in millions of MPN. The scaling is included to facilitate entry of large numbers.

When NDIM = 2, constituent concentrations are given in specialized units such as pH, JTU, PCU, °C, etc. "Buildup" of such parameters is rarely referred to; instead, a much more viable option is the use of a rating curve that gives load (i.e., concentration times flow) directly as a function of flow (discussed subsequently). However, the buildup option may be used with such constituents if desired. Within the Runoff Block, concentrations are ultimately computed in subroutine GUTTER by dividing a load (quantity per second) by a flow rate (cubic feet per second). Thus, if the quantity has units of concentration times cubic feet, the proper conversion will be made. This is the reason for the peculiar units requested in Table 4-17. The authors of this report have not seen data placed in this form, but such an analysis would be straightforward and analogous to computations of total mass in pounds (obtained by summing flow rate times concentration) for constituents measured in mg/l.

Buildup Data -- Data with which to evaluate buildup parameters are available in most of the references cited earlier under "available studies." Manning et al. (1977) have perhaps the best summary of linear buildup rates; these are presented in Table 4-18. It may be noted that dust and dirt buildup varies considerably among three different studies. Individual constituent buildup may be taken conveniently as a fraction of dust and dirt from the entries in Table 4-18, or they may be computed explicitly. It is apparent that although a large number of constituents have been sampled, little distinction can be made on the basis of land uses for most of them.

Table 4-18. Nationwide Data on Linear Dust and Dirt Buildup Rates and on Pollutant Fractions. (After Manning et al., 1977, pp. 138-140.)

Pollutant		Land Use Categories				
		Single Family Residential	Multiple Family Residential	Commercial	Industrial	All Data
Dust and Dirt Accumulation lb/curb-mi/day kg/curb-km/day						
Chicago[1]	Mean	35(10)	109(31)	181(51)	325(92)	158(44)
	Range	19-96(5-27)	62-153(17-43)	71-326(80-151)	284-536(80-151)	19-536(5-15)
	No. of Obs	60	93	126	55	334
Washington[2]	Mean	--	--	134(38)	--	134(38)
	Range	--	--	35-365(10-103)	–	35-365(10-103)
	No. of Obs	--	--	22	--	22
Multi-City[3]	Mean	182(51)	157(44)	45(13)	288(81)	175(49)
	Range	3-950(1-268)	8-770(2-217)	3-260(1-73)	4-1,500(1-423)	3-1,500(1-423)
	No. of Obs	14	8	10	12	44
All Data	Mean	62(17)	113(32)	116(47)	319(90)	159(45)
	Range	3-950(1-268)	8-770(2-217)	3-365(1-103)	4-1,500(1-423)	3-1,500(1-423)
	No. of Obs	74	101	158	67	400
BOD mg/kg	Mean	5,260	3,370	7,190	2,920	5,030
	Range	1,720-9,430	2,030-6320	1,280-14,540	2,820-2,950	1,288-14,540
	No. of Obs	59	93	102	56	292
COD mg/kg	Mean	39,250	41,970	61,730	25,080	46,120
	Range	18,300-72,800	24,600-61,300	24,800-49 8,410	23,000-31,800	18,300-498,410
	No. of Obs	59	93	102	38	292
Total N-N (mg/kg)	Mean	460	550	420	430	480
	Range	325-525	356-961	323-480	410-431	323-480
	No. of Obs	59	93	80	38	270
Kjeldahl N (mg/kg)	Mean	--	--	640	--	640
	Range	--	.	230-1,790	--	230-1,790
	No. of Obs	--	--	22	--	22
NO_3 (mg/kg)	Mean	--	--	24	--	24
	Range	--	--	10-35	--	10-35
	No. of Obs	--	--	21	--	21
NO_2-N (mg/kg)	Mean	--	--	0	--	15
	Range	--	--	0	--	0
	No. of Obs.	--	--	15	--	15
Total PO_4 (mg/kg)	Mean	--	--	170	--	170
	Range	--	--	90-340	--	90-340
	No. of Obs	--	--	21	--	21

Table 4-18. (Continued)

Pollutant:		Land Use Categories				
		Single Family Residential	Multiple Family Residential	Commercial	Industrial	All Data
PO_4-P (mg/kg)	Mean	49	58	60	26	53
	Range	20-109	20-73	0-142	14-30	0-142
	No. of Obs	59	93	101	38	291
Chlorides (mg/kg)	Mean	--	--	220	--	220
	Range	--	--	100-370	--	100-370
	No. of Obs	--	--	22	--	22
Asbestos fibers/lb (fibers/kg)	Mean	--	--	57.2×10^6 (126×10^6)	--	57.2×10^6 (126×10^6)
	Range	--	--	$0-172.5\times10^6$ ($0-380\times10^6$)	--	$0-172.5\times10^6$ ($0-380\times10^6$)
	No. of Obs	--	--	16	--	16
Ag (mg/kg)	Mean	--	--	200	--	200
	Range	--	--	0-600	--	0-600
	No. of Obs	--	--	3	--	3
As (mg/kg)	Mean	--	--	0	--	0
	Range	--	--	0	--	0
	No. of Obs	--	--	3	--	3
Ba (mg/kg)	Mean	--	--	38	--	38
	Range	--	--	0-80	--	0-80
	No. of Obs	--	--	8	--	8
CD (mg/kg)	Mean	3.3	2.7	2.9	3.6	3.1
	Range	0-8.8	0.3-6.0	0-9.3	0.3-11.0	0-11.0
	No. of Obs	14	8	22	13	57
Cr (mg/kg)	Mean	200	180	140	240	180
	Range	111-325	75-325	10-430	159-335	10-430
	No. of Obs	14	8	30	13	65
Cu (mg/kg)	Mean	91	73	95	87	90
	Range	33-150	34-170	25-810	32-170	25-810
	No. of Obs	14	8	30	13	65
Fe (mg/kg)	Mean	21,280	18,500	21,580	22,540	21,220
	Range	11,000-48,000	11,000-25,000	5,000-44,000	14,000-43,000	5,000-48,000
	No. of Obs	14	8	10	13	45
Hg (mg/kg)	Mean	--	--	0.02	--	0.02
	Range	--	--	0-0.1	--	0-0.1
	No. of Obs	--	--	6	--	6
Mn (mg/kg)	Mean	450	340	380	430	410
	Range	250-700	230-450	160-540	240-620	160-700
	No. of Obs	14	8	10	13	45
Ni (mg/kg)	Mean	38	18	94	44	62
	Range	0-120	0-80	6-170	1-120	1-170
	No. of Obs	14	8	30	13	65

Table 4-18. (Concluded)

Pollutant		Land Use Categories				
		Single Family Residential	Multiple Family Residential	Commercial	Industrial	All Data
Pb	Mean	1,570	1,980	2,330	1,590	1,970
(mg/kg)	Range	220-5,700	470-3,700	0-7,600	260-3,500	0-7,600
	No. of Obs	14	8	29	13	64
Sb	Mean	--	--	54	--	54
(mg/kg)	Range	--	--	50-60	--	50-60
	No. of Obs	--	--	3	--	3
Se	Mean	--	--	0	--	0
(mg/kg)	Range	--	--	0	--	0
	No. of Obs	--	--	3	--	3
Sn	Mean	--	--	17	--	17
(mg/kg)	Range	--	--	0-50	--	0-50
	No. of Obs	--	--	3	-	3
Sr	Mean	32	18	17	13	21
(mg/kg)	Range	5-110	12-24	7-38	0-24	0-110
	No. of Obs	14	8	10	13	45
Zn	Mean	310	280	690	280	470
(mg/kg)	Range	110-810	210-490	90-3,040	140-450	90-3,040
	No. of Obs	14	8	30	13	65
Fecal Strep	Geo. Mean	--	--	370	--	370
No./gram	Range	--	--	44-2,420	--	44-2,420
	No. of Obs	--	--	17	--	17
Fecal Coli	Geo. Mean	82,500	38,800	36,900	30,700	94,700
No./gram	Range	26-130,000	1,500-1,000,000	140-970,000	67-530,000	26-1,000,000
	No. of Obs	65	96	84	42	287
Total Coli	Geo. Mean	891,000	1,900,000	1,000,000	419,000	1,070,000
No./gram	Range	25,000-3,000,000	80,000-5,600,000	18,000-3,500,000	27,000-2,600,000	18,000-5,600,000
	No. of Obs	65	97	85	43	290

As an example, suppose options METHOD = 0 and KALC = 0 are chosen in card groups J2 and J3 and "all data" are used from Table 4-18 to compute dust and dirt parameters. Since the data are given as $lb \cdot curb\ mile^{-1} \cdot day^{-1}$, linear buildup is assumed, and commercial land use DD buildup would be DDFACT = $2.2\ lb \cdot (100\ ft\ curb)^{-1} \cdot day^{-1}$ (i.e., 116/52.8, where 52.8 is the number of hundreds of feet in a mile). DDPOW would equal 1.0 and no data are available to set an upper limt, DDLIM. Parameter JACGUT = 0 so that the loading rate will be multiplied by the curb length for each subcatchment. Constituent fractions are available from the table. For instance, QFACT values for commercial land use would be 7.19 mg/g for BOD_5, 0.06 mg/g for total phosphorus, 0.00002 mg/g for Hg, and 0.0369 10^6 MPN/g for fecal coliforms. Direct loading rates could be computed for each constituent as an alternative. For instance, with KALC = 1 for BOD_5 and KACGUT = 0, parameter QFACT(3,K) would equal $2.2 \times 0.00719 = 0.0158\ lb \cdot (100\ ft\ curb)^{-1} \cdot day^{-1}$.

It must be stressed once again that the generalized buildup data of Table 4-18 are merely informational, and are never a substitute for local sampling or even a calibration using measured concentrations. They may serve as a first trial value for a calibration, however. In this respect it is important to point out that concentrations and loads computed by the Runoff Block are usually linearly proportional to buildup rates. If twice the quantity is available at the beginning of a storm, then concentrations and loads will be doubled. Calibration is probably easiest with linear buildup parameters, but it depends on the rate at which the limiting buildup, i.e., DDLIM or QFACT(1,K), is approached. If the limiting value is reached during the interval between most storms, then calibration using it will also have almost a linear effect on concentrations and loads. It is apparent that the interaction between the interevent time of storms (i.e., dry days) and the effect of buildup is accomplished using the rate constants, DDPOW and DDFACT for dust and dirt and QFACT(2,K) and QFACT(3,K) for constituents. This is discussed further subsequently under "Overall Sensitivity to Quality Parameters."

Almost all of the above loading data are from samples of storm water, not combined sewage. Although some loadings may be inferred from concentration measurements of combined sewage (e.g., Huber et al., 1979, 1980, Wallace, 1980), they are not directly related to most surface accumulation measurements. Thus, if buildup data alone are used in combined sewer areas, buildup rates will probably be multiples of the values listed, for example, in Table 4-18. The proper factor will most easily be found by calibration with local concentration measurements. Alternatively the dry-weather flow mixing and scour routines in the Transport Block may be used to increase combined sewer concentrations. However, mixing of dry-weather flow with storm water has a negligible effect on concentrations during high flows, and the scour routine is highly empirical and adds a second calibration step. Hence, the easiest option for combined sewers is probably to calibrate as described earlier. Calibration may also be achieved using the rating curve approach.

When snowmelt is simulated, some of the ten constituents may be used to represent deicing chemicals; several common roadway "salts" are listed in Figure 4-24. Application of such chemicals varies depending upon depth of snowfall and local practice. Loading rates are discussed in Appendix II and other references (Proctor and Redfern and J.F. MacLaren, 1976a, 1976b, Field et al., 1973, Richardson et al., 1974, Ontario Ministry of the Environment, 1974). For instance, guidelines of the type proposed by Richardson et al. (1974) are used in many cities and are given in Table 4-19. Summaries are also given by Manning et al. (1977) and Lager et al. (1977a).

Since for most deicing chemicals the principal source is direct application during snow events, there is little or no buildup during snow-free periods. Parameter LINKUP (card group J3) may be used to simulate this effect for continuous simulation. Of course, for single event simulation, buildup may be computed directly by the user and input in card group L1 or computed by any of the equations just discussed. Since there is only one storm simulated (ordinarily) there is no need for inter-storm buildup.

Washoff --

Definition -- Washoff is the process of erosion or solution of constituents from a subcatchment surface during a period of runoff. If the water depth is more than a few millimeters, processes of erosion may be described by sediment transport theory in which the mass flow rate of sediment is proportional to flow and bottom shear stress, and a critical shear stress can be used to determine incipient motion of a particle resting on the bottom of a stream channel, e.g., Graf (1971), Vanoni (1975). Such a mechanism might apply in street gutters and larger channels. For thin overland flow, however, rainfall energy can also cause particle detachment and motion. This effect is often incorporated into predictive methods for erosion from pervious areas (Wischmeier and Smith, 1958) and may also apply to washoff from impervious surfaces, although in this latter case, the effect of a limited supply (buildup) of the material must be considered.

Washoff Formulation -- Ammon (1979) reviews several theoretical approaches for urban runoff washoff and concludes that although the sediment transport based theory is attractive, it is often insufficient in practice because of lack of data for parameter (e.g., shear stress) evaluation, sensitivity to time step and discretization and because simpler methods usually work as well (still with some theoretical basis) and are usually able to duplicate observed washoff phenomena. Among the latter, the most oft-cited results are those of Sartor and Boyd (1972), shown in Figure 4-30, in which constituents were flushed from streets using a sprinkler system. From the figure it would appear that an exponential relationship could be developed to describe washoff of the form

$$POFF(t) = PSHED_o(1-e^{-kt}) \quad (4\text{-}29)$$

where $POFF$ = cumulative amount washed off at time, t,
$PSHED_o$ = initial amount of quantity on surface at t=0, and
k = coefficient.

Table 4-19. Guidelines for Chemical Application Rates for Snow Control. (Richardson et al., 1974.)

WEATHER CONDITIONS			APPLICATION RATE (Pounds of material per mile of 2-lane road or 2-lanes of divided)			
Temperature	Pavement Conditions	Precipitation	Low-and High-Speed Multilane Divided	Two and Three-Lane Primary	Two-Lane Secondary	INSTRUCTIONS
30°F and above	Wet	Snow	300 salt	300 salt	300 salt	- wait at least 0.5 hour before plowing
		Sleet or Freezing Rain	200 salt	200 salt	200 salt	- reapply as necessary
25-30°F	Wet	Snow or Sleet	initial at 400 salt repeat at 200 salt	initial at 400 salt repeat at 200 salt	initial at 400 salt repeat at 200 salt	- wait at least 0.5 hour before plowing; repeat
		Freezing Rain	initial at 300 salt repeat at 200 salt	initial at 300 salt repeat at 200 salt	initial at 300 salt repeat at 200 salt	- repeat as necessary
20-25°F	Wet	Snow or Sleet	initial at 500 salt repeat at 250 salt	initial at 500 salt repeat at 250 salt	1200 of 5:1 Sand/Salt; repeat same	- wait about 0.75 hour before plowing; repeat
		Freezing Rain	initial at 400 salt repeat at 300 salt	initial at 400 salt repeat at 300 salt		- repeat as necessary
15-20°F	Dry	Dry Snow	plow	plow	plow	- treat hazardous areas with 1200 of 20:1 Sand/Salt
	Wet	Wet Snow or Sleet	500 of 3:1 Salt/ Calcium Chloride	500 of 3:1 Salt/ Calcium Chloride	1200 of 5:1 Sand	- wait about one hour before plowing; continue plowing until storm ends; then repeat application
below 15°F	Dry	Dry Snow	plow	plow	plow	- treat hazardous area with 1200 of 20:1 Sand/Salt

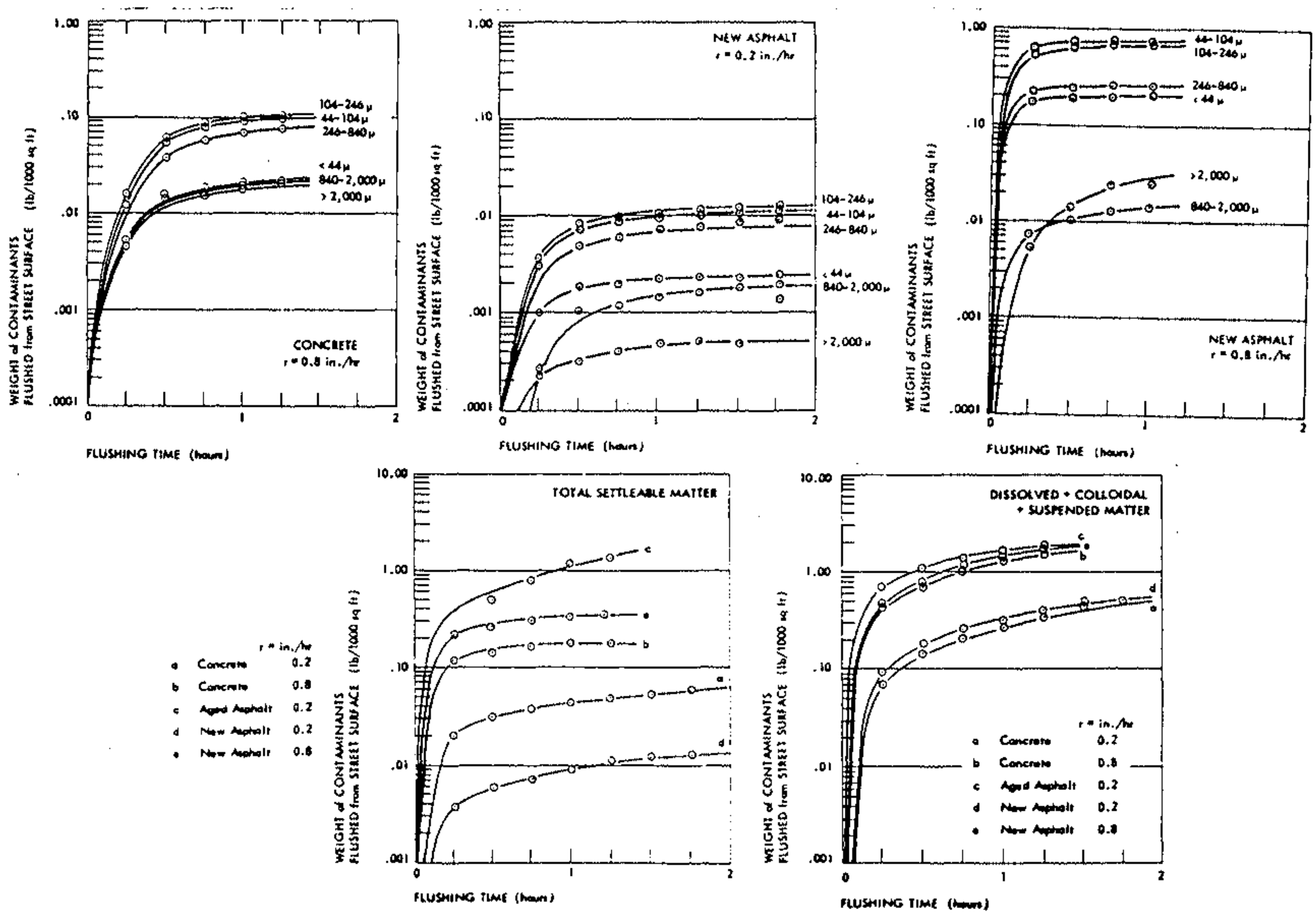


Figure 4-30. Washoff of Street Solids by Flushing with a Sprinkler System. (After Sartor and Boyd, 1972, pp. 86-87.)

POFF is shown as the ordinate of Figure 4-30. Alternatively, since the amount remaining, PSHED(t), equals $PSHED_o$-POFF, then

$$PSHED(t) = PSHED_o e^{-kt} \tag{4-30}$$

where PSHED(t) = quantity remaining on surface at time, t,
$PSHED_o$ = initial amount of quantity, and
k = coefficient.

It is clear that the coefficient, k, is a function of both particle size and runoff rate. An analysis of the Sartor and Boyd (1972) data by Ammon (1979) indicates that k increases with runoff rate, as would be expected, and decreases with particle size.

The Sartor and Boyd data lend credibility to the washoff assumption included in the original SWMM release (and all versions to date), that the rate of washoff (e.g., mg/sec) at any time is proportional to the remaining quantity,

$$\frac{d\ PSHED}{dt} = -k \cdot PSHED \tag{4-31}$$

The solution of equation 4-31 is equation 4-30. This was first proposed by Mr. Allen J. Burdoin, a consultant to Metcalf and Eddy, during the original SWMM development. The coefficient k may be evaluated by assuming it is proportional to runoff rate, r:

$$k = RCOEF \cdot r \tag{4-32}$$

where RCOEF = washoff coefficient, in^{-1}, and
r = runoff rate over subcatchment, in/hr.

Burdoin assumed that one-half inch of total runoff in one hour would wash off 90 percent of the initial surface load, leading to the now familiar value of RCOEF of 4.6 in^{-1}. (The actual time distribution of intensity does not affect the calculation of RCOEF.)

Even in the original SWMM release, this formulation did not adequately fit some data, and as a "correction," availability factors of the form

$$AV = a + br^c \tag{4-33}$$

where AV = availability factor, and
a,b,c = coefficients,

were multiplied by equation 4-29 in order to match measured suspended solids concentrations in Cincinnati and San Francisco (Metcalf and Eddy et al., 1971a, Section 11). The primary difficulty is that use of equations 4-31 and 4-32 will always produce decreasing concentrations as a function of time regardless of the time distribution of runoff. This is counter-intuitive, since it is expected that high runoff rates during the middle of a storm might indeed produce higher concentrations than those preceding. This may be explained by observing that concentrations are calculated by dividing the load rate (e.g., mg/sec.) to obtain the quantity per volume (e.g., mg/l). Thus,

$$C = \frac{1}{Q} \frac{d\ PSHED}{dt} = \text{const.} \cdot \frac{RCOEF \cdot r \cdot PSHED}{A \cdot r} \qquad (4\text{-}34)$$

where C = concentration, quantity/volume,
Q = A·r = flow rate, cfs,
A = subcatchment area, ac,
r = runoff rate, in/hr.,

and the constant incorporates conversion factors. Clearly, the concentration will always decrease with time since the runoff rate, r, divides out of the equation and the quantity remaining, PSHED, continues to decrease. This problem is overcome in the present version of SWMM by making washoff at each time step, POFF, proportional to runoff rate to a power, WASHPO,

$$-POFF(t) = \frac{d\ PSHED}{dt} = -RCOEFX \cdot r^{WASHPO} \cdot PSHED \qquad (4\text{-}35)$$

where POFF = constituent load washed off at time, t, quantity/sec (e.g., mg/sec),
PSHED = quantity of constituent available for washoff at time, t, (e.g., mg),
RCOEFX = washoff coefficient = RCOEF/3600, $(\text{in/hr})^{-WASHPO} \cdot \sec^{-1}$, and
r = runoff rate, in/hr.

It may be seen that if equation 4-35 is divided by runoff rate to obtain concentration, then concentration is now proportional to $r^{WASHPO-1}$. Hence, if the increase in runoff rate is sufficient, concentrations can increase during the middle of a storm even if PSHED is diminished. (Equation 4-35 was first suggested in a 1974 report to the Boston District Corps of Engineers, authorship unknown).

There are two parameters to be determined, RCOEF and WASHPO. Availability factors of the form of equation 4-33 are no longer used since there is sufficient flexibility for calibration using only equation 4-35. Of course, the original SWMM methodology can be recovered using WASHPO = 1.0.

Effects of Parameters -- The effect of different values for RCOEF and WASHPO on PSHED and concentration is shown for four temporal distributions of runoff (Figure 4-31) in Figures 4-32 to 4-35. The basis for the calculations and plotted values is given in Table 4-20. It may be seen that concentrations may be made to increase with increasing runoff rate during the middle of a storm by increasing the value of WASHPO. However, perhaps counter intuitively, a larger value of WASHPO generally yields lower concentrations and higher values of PSHED. This is because the runoff rates used for the

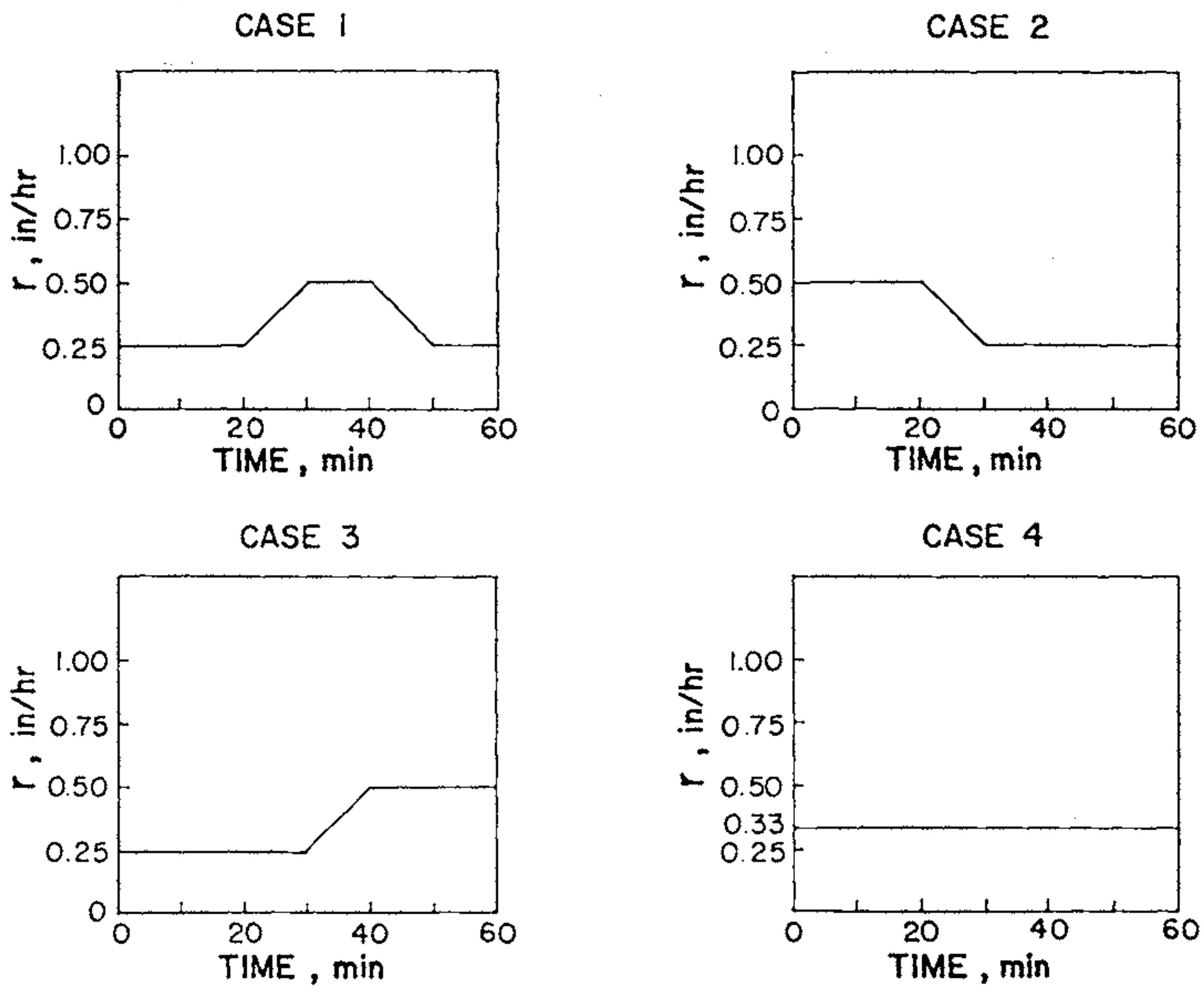


Figure 4-31. Time Variation of Runoff Rate Used in Example of Table 4-20 and Figures 4-32 to 4-35

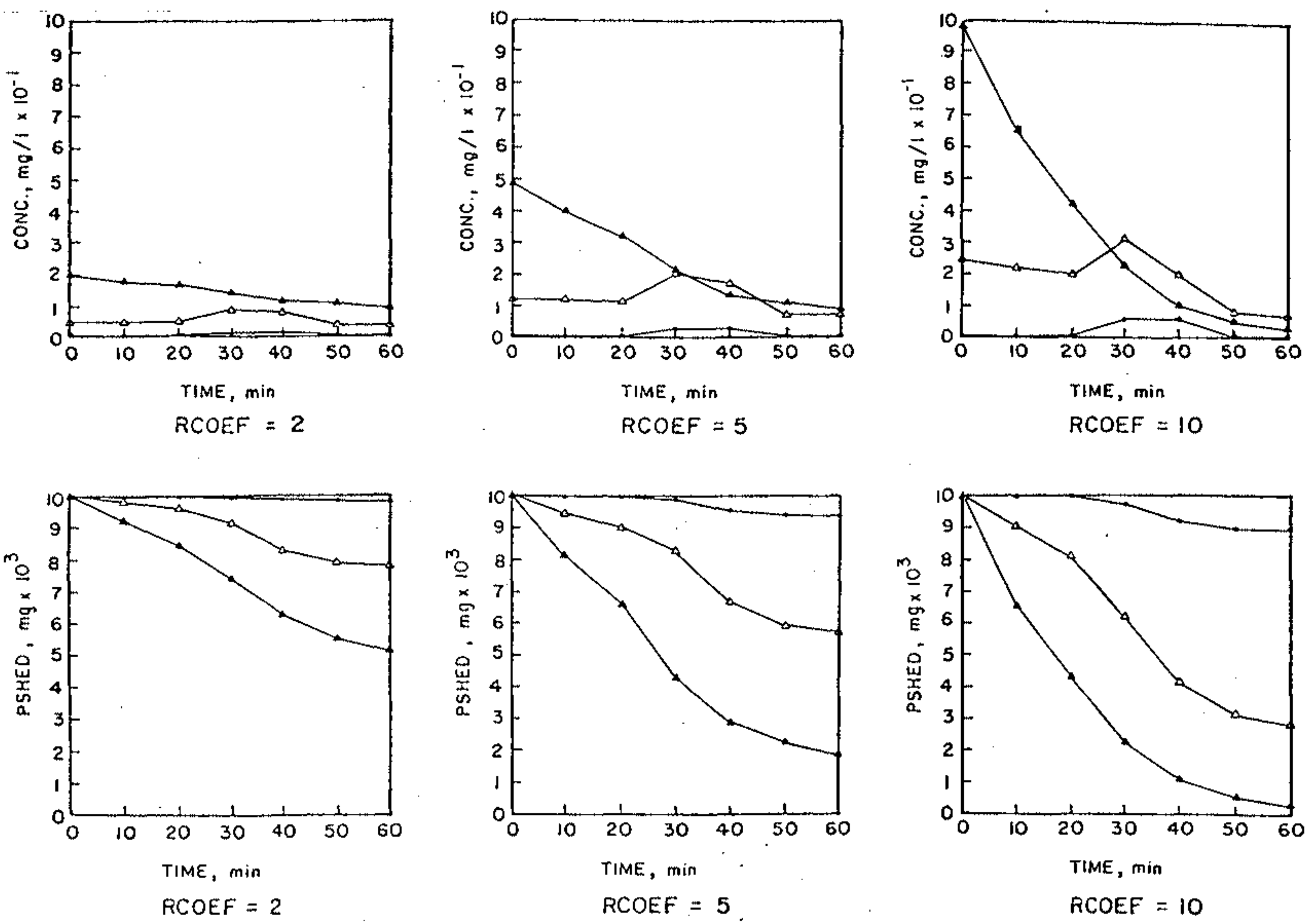


Figure 4-32. Time History of Concentration and Subcatchment Load (PSHED) for Case 1 Runoff (Figure 4-31).

WASHPO = 1
WASHPO = 2
WASHPO = 5

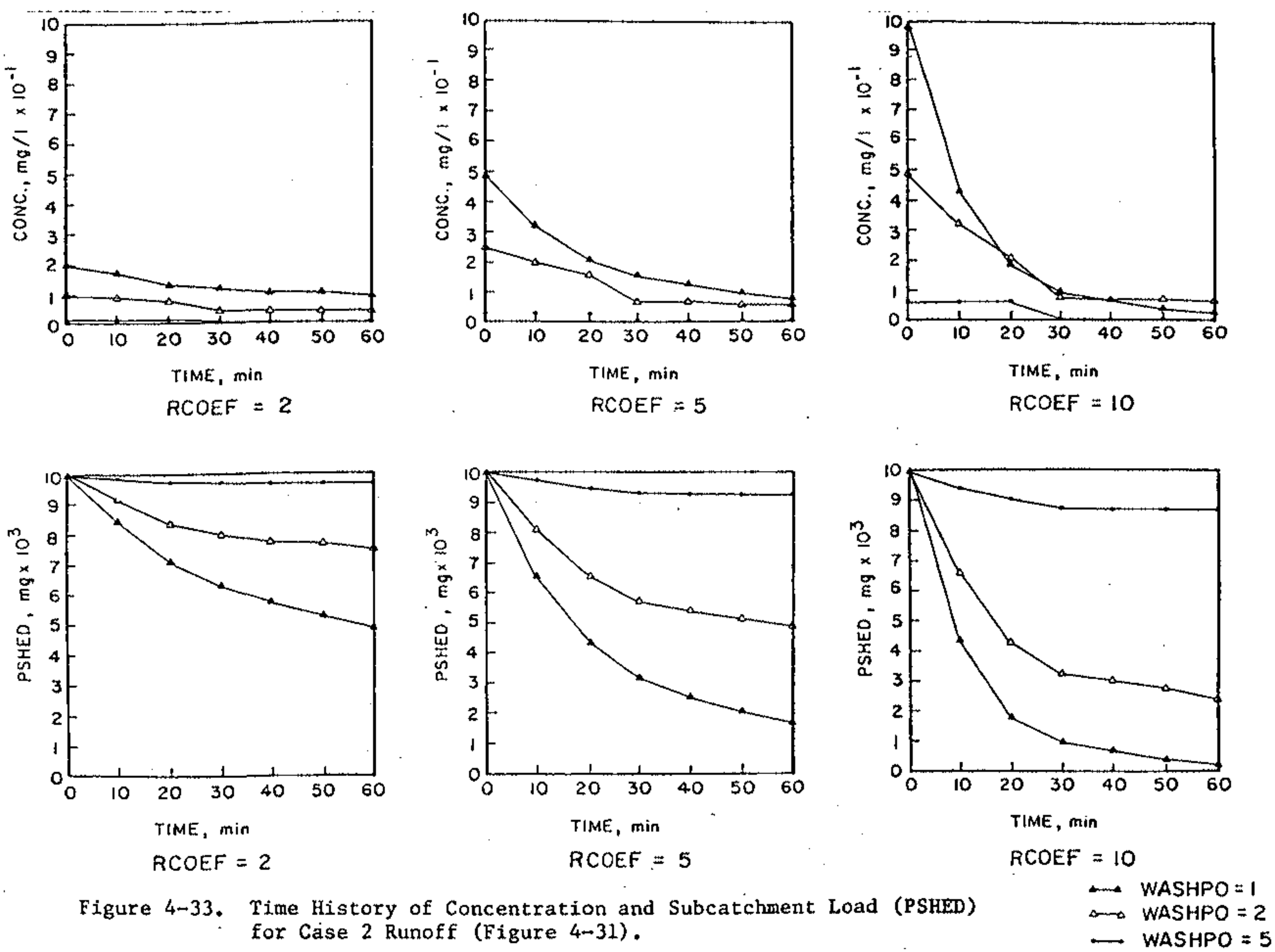


Figure 4-33. Time History of Concentration and Subcatchment Load (PSHED) for Case 2 Runoff (Figure 4-31).

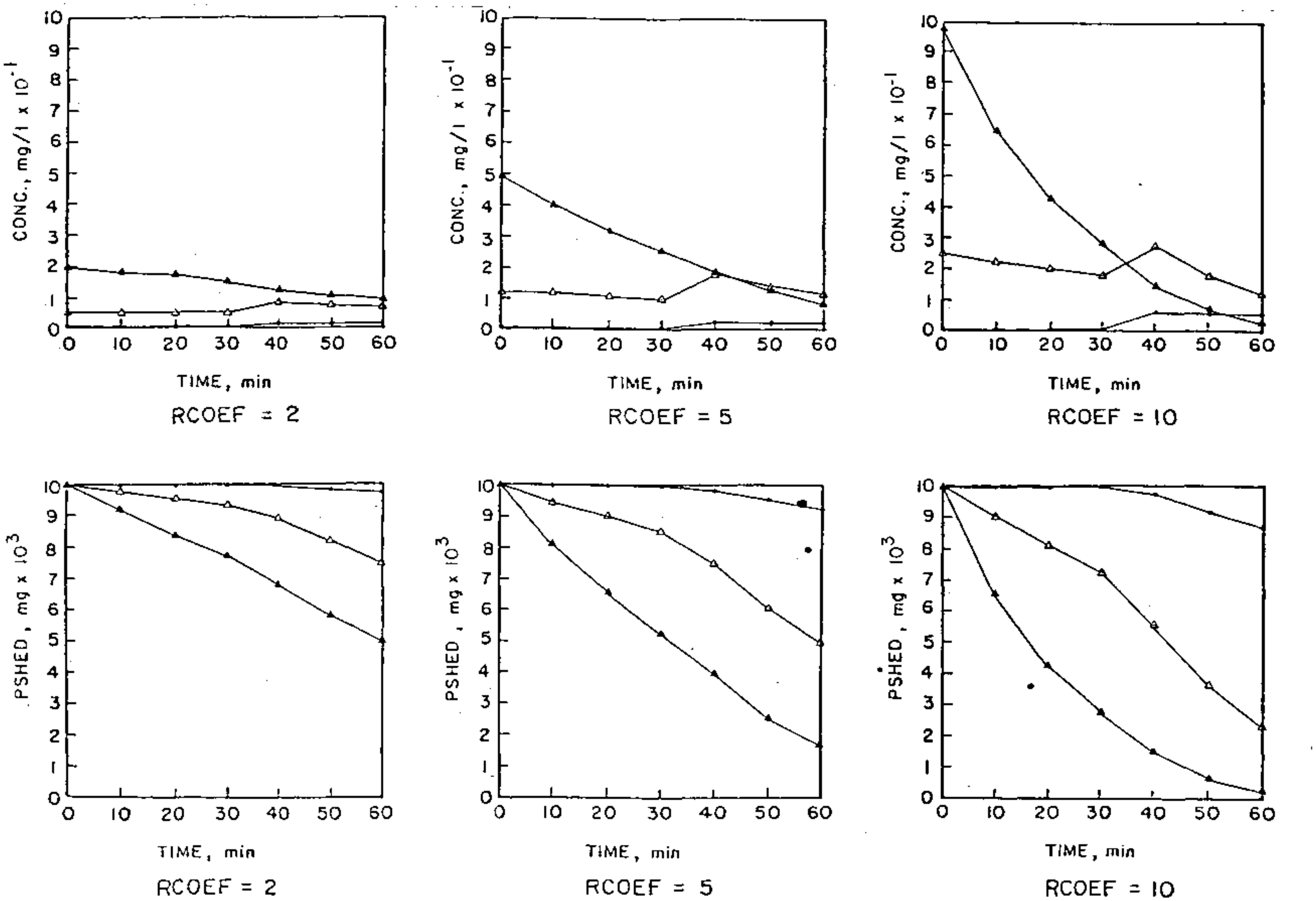


Figure 4-34. Time History of Concentration and Subcatchment Load (PSHED) for Case 3 Runoff (Figure 4-31).

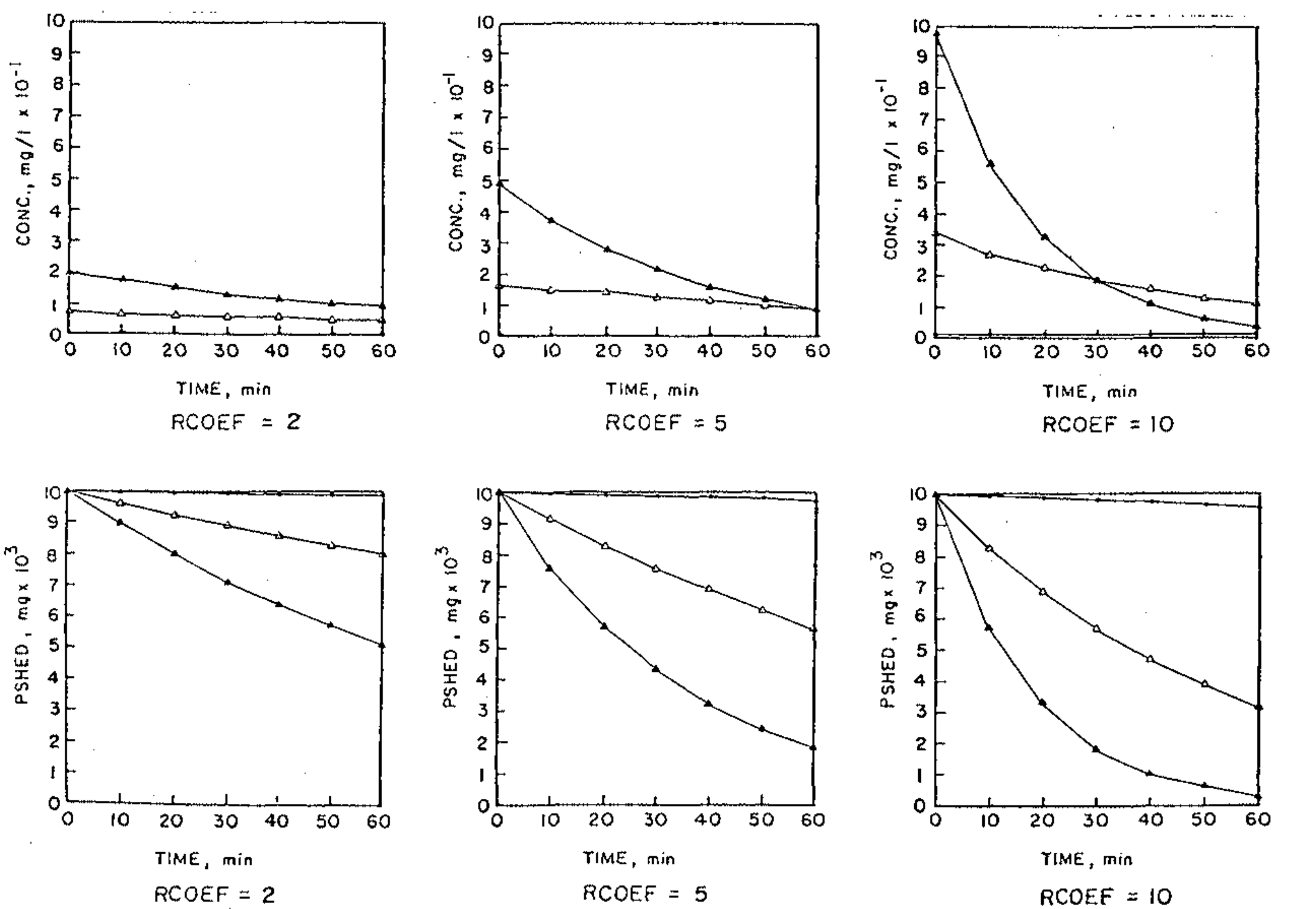


Figure 4-35. Time History of Concentration and Subcatchment Load (PSHED) for Case 4 Runoff (Figure 4-31).

example are all less than 1.0 in/hr. (25.4 mm/hr.) and decrease in magnitude when raised to a power. The reverse will be true for values of $r < 1.0$. But many storms will have $r > 1.0$ throughout their durations. Increasing the value of RCOEF always increases concentrations. (See also the subsequent discussion under "Overall Sensitivity to Quality Parameters".)

In subroutine QSHED of the Runoff Block, washoff load rates (e.g., mg/sec) are computed instantaneously at the end of a time step using equation 4-35. They are subsequently combined with other possible inflow loads to a gutter/pipe or inlet before dividing by the total inflow rate to obtain a concentration. The remaining constituent load on the subcatchment at the end of a time step is determined by using the average power of the runoff rate over the time step,

$$PSHED(t+\Delta t) = PSHED(t) \cdot e^{-RCOEF \cdot \frac{r(t)^{WASHPO} + r(t+\Delta t)^{WASHPO}}{2} \cdot \Delta t} \quad (4\text{-}36)$$

Table 4-20 Parameters Used for Washoff Equation Example

Equations Used:

$$PSHED(t+\Delta t) = PSHED(t) \cdot e^{-RCOEF \cdot \Delta t \cdot 0.5 \cdot [r(t+\Delta t)^{WASHPO} + r(t)^{WASHPO}]}$$

$$C(t+\Delta t) = \frac{Const. \cdot RCOEFX}{A} \cdot r(t+\Delta t)^{WASHPO-1} \cdot PSHED(t+\Delta t)$$

where PSHED(t) = mg on catchment,
PSHED(0) = 1000 mg,
C(t) = concentration, mg/l,
RCOEFX = RCOEF/3600,
Const. = 0.0353 ft^3/l, (utilizing 1 ac-in/hr ~ 1 cfs),
A = 1 ac,
Δt = 0.16667 hr. (10 min),
r(t) = runoff rate in in/hr. (Figure 4-31).

Evaluate for 36 combinations of four runoff rate distributions (Figure 4-31), three values of RCOEF and three values of WASHPO given below:

RCOEF, $(in/hr.)^{-WASHPO} \cdot hr^{-1}$	WASHPO
2	1
5	2
10	5

This calculation is done prior to application of equation 4-35. The average (trapezoidal rule) approximates the integral of r^{WASHPO} over the time step.

That the load rate of sediment is proportional to flow rate as in equation 4-35 is supported by both theory and data. For instance, sediment data from streams can usually be described by a sediment rating curve of the form

$$G = aQ^b \tag{4-37}$$

where G = sediment load rate, mg/sec,
Q = flow rate, cfs, and,
a,b = coefficients.

Due to a hysteresis effect, such relationships may vary during the passing of a flood wave, but the functional form is evident in many rivers, e.g., Vanoni (1975), pp. 220-225, Graf (1971), pp. 234-241, and Simons and Senturk (1977), p. 602. Of particular relevance to overland flow washoff is the appearance of similar relationships describing sediment yield from a catchment e.g., Vanoni (1975), pp. 472-481. The exponent b in equation 4-37 corresponds to the exponent WASHPO in equation 4-35, and the presence of the quantity PSHED in equations 4-35 reflects the fact that the total quantity of sediment washed off of a largely impervious urban area is likely to be limited to the amount built up during dry weather. Natural catchments and rivers from which equation 4-37 is derived generally have no source limitation.

The use of rating curves in their own right is an option in the Runoff Block which will be discussed subsequently. At this point, however, results from sediment transport theory can be used to provide guidance for the magnitude of parameters WASHPO and RCOEF in equation 4-35. Values of the exponent b in equation 4-37 range between 1.1 and 2.6 for rivers and sediment yield from catchments, with most values near 2.0. Typically, the exponent tends to decrease (approach 1.0) at high flow rates (Vanoni, 1975, p. 476). In the Runoff Block, constituent concentrations will follow runoff rates better if WASHPO is higher (see Figures 4-32 to 4-35). A reasonable first guess for WASHPO would appear to be in the range of 1.5-2.5.

Values of RCOEF are much harder to infer from the sediment rating curve data since they vary in nature by almost five orders of magnitude. The issue is further complicated by the fact that equation 4-35 includes the quantity remaining to be washed off, PSHED, which decreases steadily during an event. At this point it will suffice to say that values of RCOEF between 1.0 and 10 appear to give concentrations in the range of most observed values in urban runoff. Both RCOEF and WASHPO may be varied in order to calibrate the model to observed data.

The preceding discussion assumes that urban runoff quality constituents will behave in some manner similar to "sediment" of sediment transport theory. Since many constituents are in particulate form the assumption may not be too bad. If the concentration of a dissolved constituent is observed to decrease strongly with increasing flow rate, a value of WASHPO $<$ 1.0 could be used.

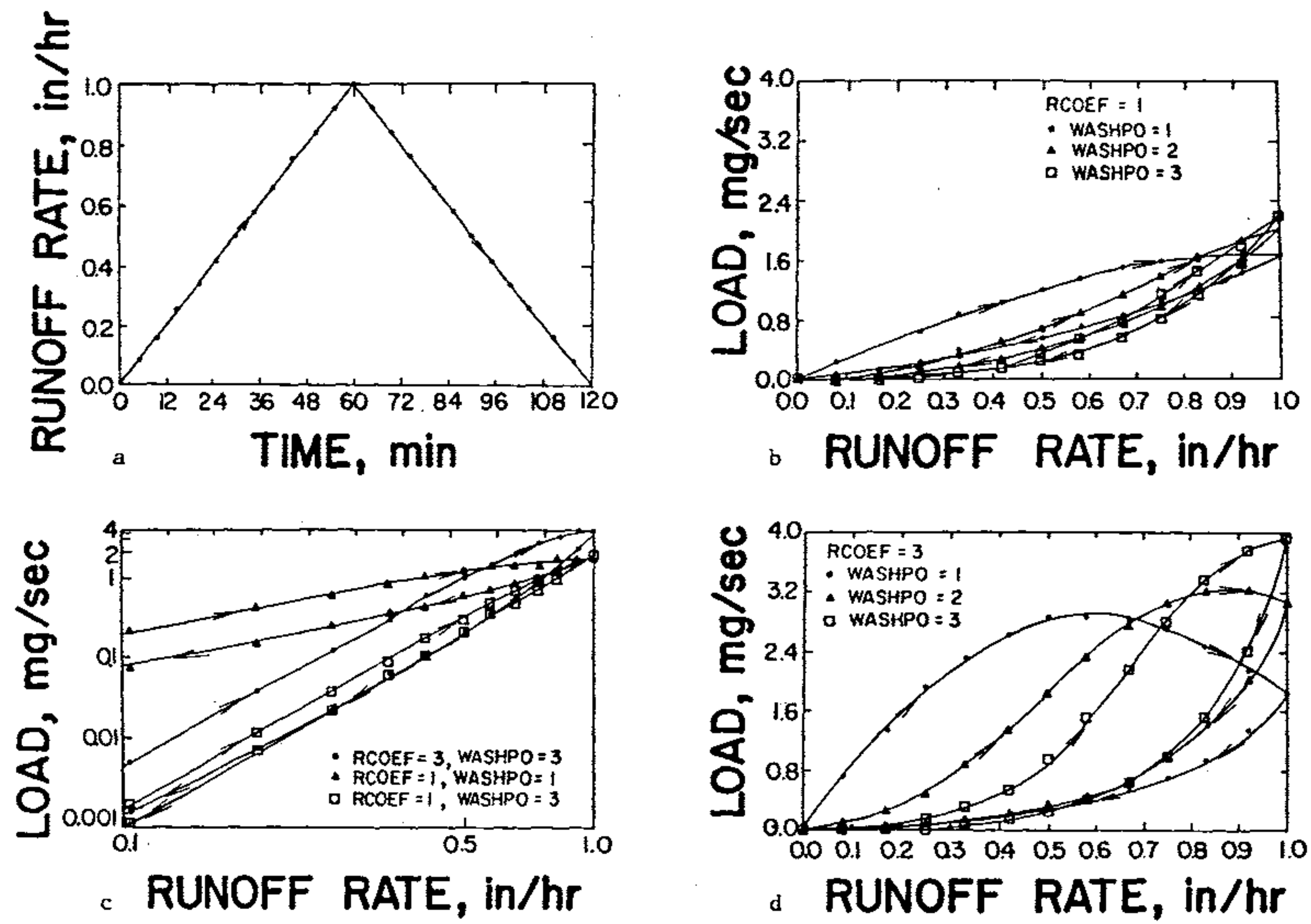


Figure 4-36. Simulated Load Variations within a Storm as a Function of Runoff Rate. The initial surface load is 1000 mg on a 1 ac catchment, and the time step is 5 min. The loop effect is exagerated as RCOEF is increased (Figures b vs. d). The loops are flattened when using a log-log scale (Figure c).

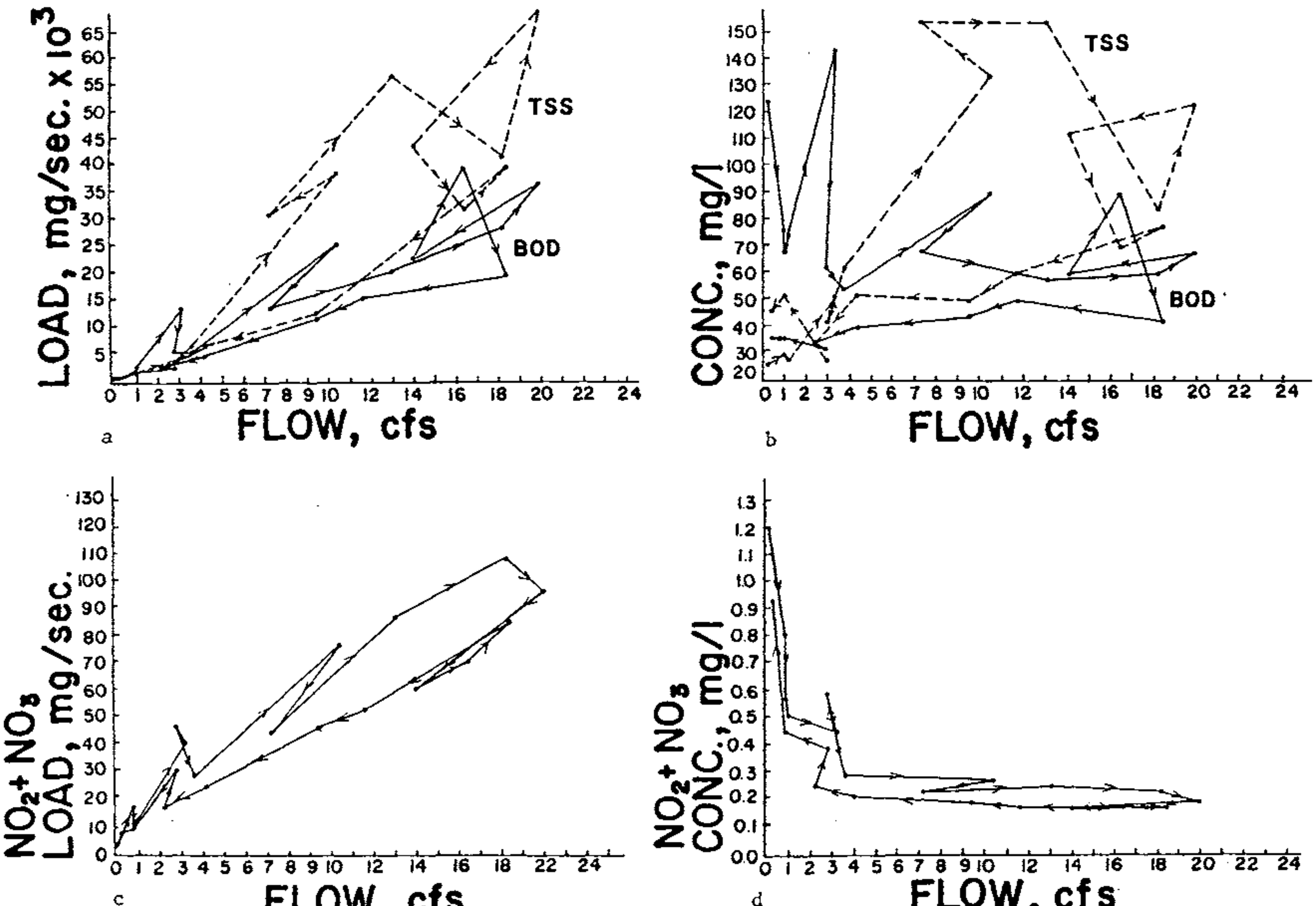
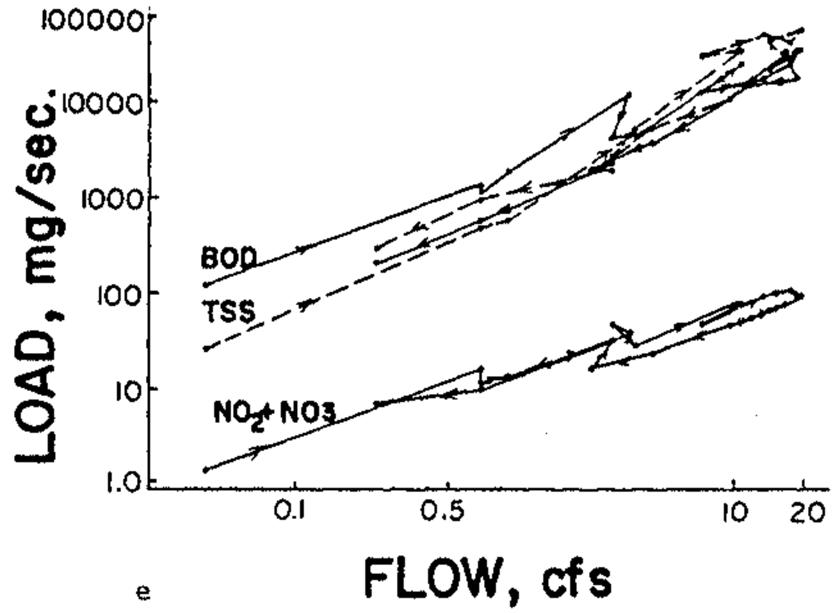


Figure 4-37. Variation of BOD_5, TSS and NO_2+NO_3-N Load and Concentration for Storm of 11/17/74 for View Ridge 1 Catchment, Seattle (from Huber et al., 1979). Connected points trace time history. (Figure continued, next page.)



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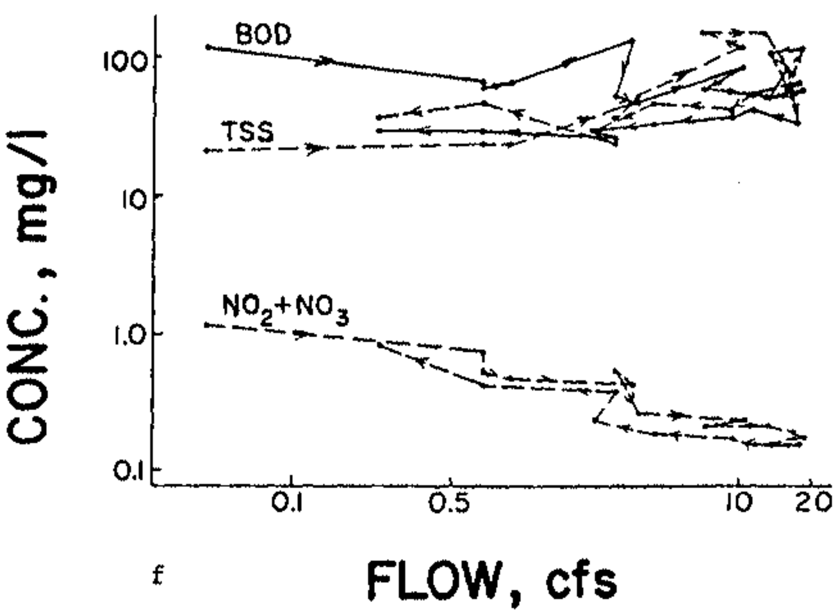

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Figure 4-37 (Continued). The log-log plots could form the basis for rating curves, although the loop effect may only be simulated using a washoff calculation. Compare with Figure 4-36 b and d. Several more plots are shown in Appendix VII.

Although the development has ignored the physics of rainfall energy in eroding particles, the runoff rate, r, in equation 4-35 closely follows rainfall intensity. Hence to some degree at least, greater washoff will be experienced with greater rainfall rates. As an option, soil erosion literature could be surveyed to infer a value of WASHPO if erosion is proportional to rainfall intensity to a power.

An idea of the relative effect of parameters RCOEF and WASHPO has been shown in Figures 4-32 to 4-35. Another view is presented in Figure 4-36 in which the time history of washoff is presented as a function of flow for various parameter values and for a more realistic runoff hydrograph. By variation of WASHPO especially, the shape of the curve may be varied to match local data. A plot using such data (Figure 4-37) is illustrated under the discussion of rating curves, and several such plots are given in Appendix VII.

Related Buildup-Washoff Studies --

Several recent studies are directly related to the preceding discussions of the SWMM Runoff Block water quality routines. Some of these have been mentioned previously in the text, but it is worthwhile pointing out those that are particularly relevant to SWMM modeling as opposed to data collection and analysis (although most of the studies do, of course, utilize data as well). The following discussion is by no means exhaustive but does include several studies that have simulated water quality using buildup-washoff mechanisms, rating curves or both.

The U.S. Geological Survey (USGS) has performed comprehensive urban hydrologic studies from both a data collection and modeling point of view. For example, their South Florida urban runoff data are described and referenced in the EPA Urban Rainfall-Runoff-Quality Data Base (Huber et al., 1979, 1980). Urban rainfall-runoff quantity may be simulated with the USGS distributed Routing Rainfall-Runoff Model (Dawdy et al., 1978, Alley et al., 1980a) which is presently being appended to include simulation of water quality. This will be accomplished using a separate program that uses the quantity model results as input. These efforts are described by Alley (1980) and Alley et al. (1980b). Alley (1981) also provides a method for optimal estimation of washoff parameters using measured data. The USGS procedures are based in part upon earlier work of Ellis and Sutherland (1979). These four references all discuss the use of the original SWMM buildup-washoff equations. An application of SWMM Runoff and Transport Blocks to two Denver catchments during which buildup-washoff parameters were calibrated is described by Ellis (1978) and Alley and Ellis (1979).

Work at the University of Massachusetts has developed procedures for calibration of SWMM Runoff Block quality (Jewell et al., 1978a) and for determination of appropriate washoff relationships for use in the Version II SWMM release (Jewell et al., 1978b). Recently Jewell et al. (1980) and Jewell and Adrian (1981) reviewed the supporting data base for buildup-washoff relationships and advocate using local data to develop site specific equations for buildup and washoff. Most of their suggested forms could be simulated using the available functional forms in SWMM.

Since several other models use quality formulations similar to those of SWMM, their documentation provides insight into choosing proper SWMM parameters. In particular, most of the STORM calibration procedures (Roesner et al., 1974, HEC, 1977a,b) can be applied also to SWMM (with WASHPO=1). Recent inclusion of water quality simulation in ILLUDAS (Terstriep et al., 1978, Han and Delleur, 1979) also is based on SWMM procedures. Finally, modified SWMM routines have been used to simulate water quality in Houston (Diniz, 1978, Bedient et al., 1978).

Rating Curve --

As discussed above, the washoff calculations may be avoided and load rates computed for each subcatchment at each time step by a rating curve method, analogous to equation 4-37,

$$POFF = RCOEF \cdot WFLOW^{WASHPO} \tag{4-38}$$

where WFLOW = subcatchment runoff, cfs, (or m^3/sec for metric input),
POFF = constituent load washed off at time, t, quantity/sec (e.g., mg/sec),
RCOEF = coefficient that includes correct units conversion, and
WASHPO = exponent.

Parameters RCOEF and WASHPO are entered for a particular constituent on card J3. That these parameters apply to a rating curve is indicated by parameter KWASH on card J3. Although used on a time step basis, the parameters for equation 4-38 are customarily determined on a storm event basis, by plotting total load versus total flow (Huber, 1980, Wallace, 1980).

Two differences are apparent between equations 4-35 and 4-38. First, the former includes the quantity remaining on the surface, PSHED, in the right-hand side of the equation, leading to an exponential-type decay of the quantity in addition to being a function of runoff rate.

Second, the form of the runoff rate is different in the equations. The power-exponential washoff, equation 4-35, uses a normalized runoff rate, r, in in./hr over the total subcatchment surface (not just the impervious part). The rating curve, equation 4-38, also uses the total runoff, but in an unnormalized form, WFLOW, in cfs. Since data for a particular catchment are often analyzed as a log-log plot of load versus flow, equation 4-38 facilitates use of the best fit line. For example, data for Seattle are plotted in Figure 4-37. In addition, Appendix VII contains several other similar plots for three Seattle catchments and for Lancaster, Pennsylvania.

Clearly, the rating curve will work better for some storms and parameters than for others. If the data plot primarily as a loop (Figure 4-37), the power-exponential washoff formulation will work better since it tends to produce lower loads at the end of storm events. But if the load versus flow data tend to plot as a straight line on log-log paper, the rating curve method should work better. On the basis of the previous discussion of rating curves based on sediment data, it is expected that the exponent, WASHPO, would be in the range of 1.5-3.0 for constituents that behave like particulates. For dissolved constituents, the exponent will tend to be less than 1.0 since concentration often decreases as flow increases, and concentration is proportional to flow to the power WASHPO-1. (Constant concentration would use WASHPO = 1.0.) Much more variability is expected for RCOEF. Should a value need to be entered for RCOEF that exceeds the field width of five available using the F5.0 format, an E-format may still be used with three place accuracy. For instance, the entry 243E3 will be read as 243,000 using an F5.0 format. This may often be necessary, since for constituents measured in mg/l (NDIM=0), load rates in mg/sec will usually be quite large.

The rating curve approach may be combined with constituent buildup if desired. If KWASH=1 on card J3, constituents are generated according to the rating curve with no upper limit. There is no buildup between storms during continuous simulation, nor will measures like street sweeping have any effect. Constituents will be generated solely on the basis of flow rate.

Alternatively, with KWASH=2, the rating curve is still used, but the maximum amount that can be removed is the amount built up prior to the storm. It will have an effect only if this limit is reached, at which time loads and concentrations will suddenly drop to zero. They will not assume non-zero values again until dry-weather time steps occur to allow buildup (during continuous simulation). Street sweeping will have an effect if the buildup limit is reached.

Street Cleaning --

Street cleaning is performed in most urban areas for control of solids and trash deposited along street gutters. Although it has long been assumed that street cleaning has a beneficial effect upon the quality of urban runoff, until recently, few data have been available to quantify this effect. The best current study is probably that of Pitt (1979) in which street surface loadings were carefully monitored along with runoff quality in order to determine the effectiveness of street cleaning. According to Pitt, frequent street cleaning on smooth asphalt surfaces (once or twice per day) can remove up to 50 percent of the total solids and heavy metal yields of urban runoff. Under more typical cleaning programs (once or twice a month), less than 5 percent of the total solids and heavy metals in the runoff are removed. Organics and nutrients in the runoff cannot be effectively controlled by intensive street cleaning -- typically much less than 10 percent removal, even for daily cleaning. This is because the latter originate primarily in runoff and erosion from off-street areas during storms.

The removal effectiveness of street cleaning depends upon many factors such as the type of sweeper, whether flushing is included, the presence of parked cars, the quantity of total solids, and constituent being considered. Data from which an analysis of most of these efforts can be performed are available in Pitt (1979). For example, removal efficiencies for several constituents are shown in Table 4-21. Clearly, efficiencies are greater for constituents that behave as particulates.

Within the Runoff Block, street cleaning (usually assumed to be sweeping) is performed (if desired) prior to the beginning of the first storm event and in between storm events (for continuous simulation). Unless initial constituent loads are input in card group L1 (or unless a rating curve is used) a "mini-simulation" is performed for each constituent during the dry days prior to a storm during which buildup and sweeping are modeled. Starting with zero initial load, buildup occurs according to the method chosen in card groups J2 and J3. Street sweeping occurs at intervals of CLFREQ days (card J2). (During continuous simulation, sweeping occurs between storms based on intervals calculated using dry time steps only. A dry time step does not have runoff greater than 0.0005 in/hr (0.013 mm/hr), nor is snow present on the impervious area of the catchment.) Removal occurs such that the fraction of constituent surface load, PSHED, remaining on the surface is

$$\text{REMAIN} = 1.0 - \text{AVSWP(J)} \cdot \text{REFF(K)} \quad (4\text{-}39)$$

where REMAIN = fraction of constituent (or dust and dirt) load remaining on catchment surface,
AVSWP = availability factor (fraction) for land use J, and
REFF = removal efficiency (fraction) for constituent K.

The removal efficiency differs for each constituent as seen in Table 4-21, from which estimates of REFF may be obtained. The effect of multiple passes must be included in the value of REFF. During the mini-simulation that occurs prior to the initial storm or start of simulation "dust and dirt" is also removed during sweeping using an efficiency REFFDD (card J2). It is probably reasonable to assume that dust and dirt is removed similarly to the total solids of Table 4-21. A non-linear effect is exhibited in Table 4-21, in which efficiencies tend to increase as the total solids on the street surface increase. The Runoff Block algorithm does not duplicate this effect. Rather, the same fraction is removed during each sweeping.

The availability factor, AVSWP, is intended to account for the fraction of the catchment area that is actually sweepable. For instance, Heaney and Nix (1977) demonstrate that total imperviousness increases faster as a function of population density than does imperviousness due to streets only. Thus, the ratio of street surface to total imperviousness is one measure of the availability factor, and their relationship is

$$\text{AVSWP} = 0.6 \cdot PD_d^{-0.2}, \; PD_d > 0.1 \quad (4.40)$$

where AVSWP = availability factor, fraction, and
PD_d = population density over developed area, persons/ac.

Such a relationship is reasonably a function of land use. Although a value of AVSWP must be entered for each land use (card J2), the equation of Heaney and Nix (1977) was developed only for an overall urban area. Thus, extra-

Table 4-21. Removal Efficiencies from Street Cleaner Path for Various Street Cleaning Programs.* (Pitt, 1979)

Sreet Cleaning Program and Street Surface Loading Conditions	Total Solids	BOD_5	COD	KN	PO_4	Pesti- cides	Cd	Sr	Cu	Ni	Cr	Zn	Mn	Pb	Fe
Vacuum Street Cleaner 1 pass; 20 → 200 lb/curb mile total solids	31	24	16	26	8	33	23	27	30	37	34	34	37	40	40
2 passes	45	35	22	37	12	50	34	35	45	54	53	52	56	59	59
3 passes	53	41	27	45	14	59	40	48	52	63	60	59	65	70	68
Vacuum Street Cleaner 1 pass; 200 → 1,000 lb/curb mile total solids	37	29	21	31	12	40	30	34	36	43	42	41	45	49	59
2 passes	51	42	29	46	17	59	43	48	49	59	60	59	63	68	68
3 passes	58	47	35	51	20	67	50	53	59	68	66	67	70	76	75
Vacuum Street Cleaner 1 pass; 1000 → 10,000 lb/curb mile total solids	48	38	33	43	20	57	45	44	49	55	53	55	58	62	63
2 passes	60	50	42	54	25	72	57	55	63	70	68	69	72	79	77
3 passes	63	52	44	57	26	75	60	58	66	73	72	73	76	83	82
Mechanical Street Cleaner 1 pass; 180 → 1800 lb/curb mile total solids	54	40	31	40	20	40	28	40	38	45	44	43	47	44	49
2 passes	75	58	48	58	35	60	45	59	58	65	64	64	64	65	71
3 passes	85	69	59	69	46	72	57	70	69	76	75	75	79	77	82
Flusher	30	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
Mechanical Street Cleaner followed by a flusher	80	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)

(a) 15 → 40 percent estimated
(b) 35 → 100 percent estimated

*These removal values assume all the pollutants would lie within the cleaner path (0 to 8 ft. from the curb) polation to specific land uses should be done only with caution, but equation 4-40 is probably suitable for use on a large, aggregated catchment, such as might be used for continuous simulation.

An alternative approach may be found in Pitt (1979) in which the issue of parked cars is dealt with directly. Pitt shows that the percentage of curb left uncleaned is essentially equal to the percentage of curb occupied by parked cars. Thus, if typically 40 percent of the curb (length) is occupied by parked cars, the availability factor would be about 0.60. In many cities, parking restrictions on street cleaning days limit the length of curb occupied during sweeping.

Parameter DSLCL (card J2) merely establishes the proper time sequence for the "mini-simulation" prior to the start of the storm (or continuous simulation). A hypothetical sequence of linear buildup and street sweeping prior to a storm is sketched in Figure 4-38. Eventually an equilibrium between buildup and sweeping will occur. For the example shown in Figure 4-38, this is when the removal, 0.32 · PSHED, equals the weekly buildup, $0.3 \times 10^6 \cdot 7$, or PSHED = 6.56×10^6 mg. If sweeping is scheduled for the day of the start of the storm (DSCL = CLFREQ) it does <u>not</u> occur. (An exception would be when the first day of a continuous simulation is a dry day. Sweeping would then occur during the first time step.)

The SWMM user should bear in mind that although the model assumes constituents to build up over the entire subcatchment surface, the surface load, PSHED, is simply a lumped total in, say, mg (for NDIM = 0), and there are no spatial effects on buildup or washoff. Hence, if it is assumed that a particular constituent originates only on the impervious portion of the catchment, loading rates and parameters can be scaled accordingly. Likewise, AVSWP can be determined based on the characterization of only the impervious areas described above. However, if a constituent originates over both the pervious and impervious area of the subcatchment (e.g., nutrients and organics) the removal efficiency, REFF, should be reduced by the average ratio of impervious to total area since it is independent of land type. The availability factor, AVSWP, differs for individual land uses but has the same effect on all constituents.

<u>Catchbasins</u> --

<u>Background</u> -- Catchbasins are found in a large number of cities. They were originally installed at storm water inlets to combined sewers to prevent sewer clogging by trapping coarse debris and solids and to prevent emanation of odors from the sewer by providing a water seal. There is no standard design for catchbasins; representative designs are shown in Figure 4-39. The purpose of the deep well or sump is to trap solids by sedimentation prior to stormwater entry into the sewer, which distinguishes catchbasins from stormwater inlets. The volume of the sump varies considerably with design, ranging from 2.8 to 78 ft^3 (0.08 - 2.21 m^3). The volume is typically reduced by a large quantity of solids trapped in the sump, often by more than 50 percent.

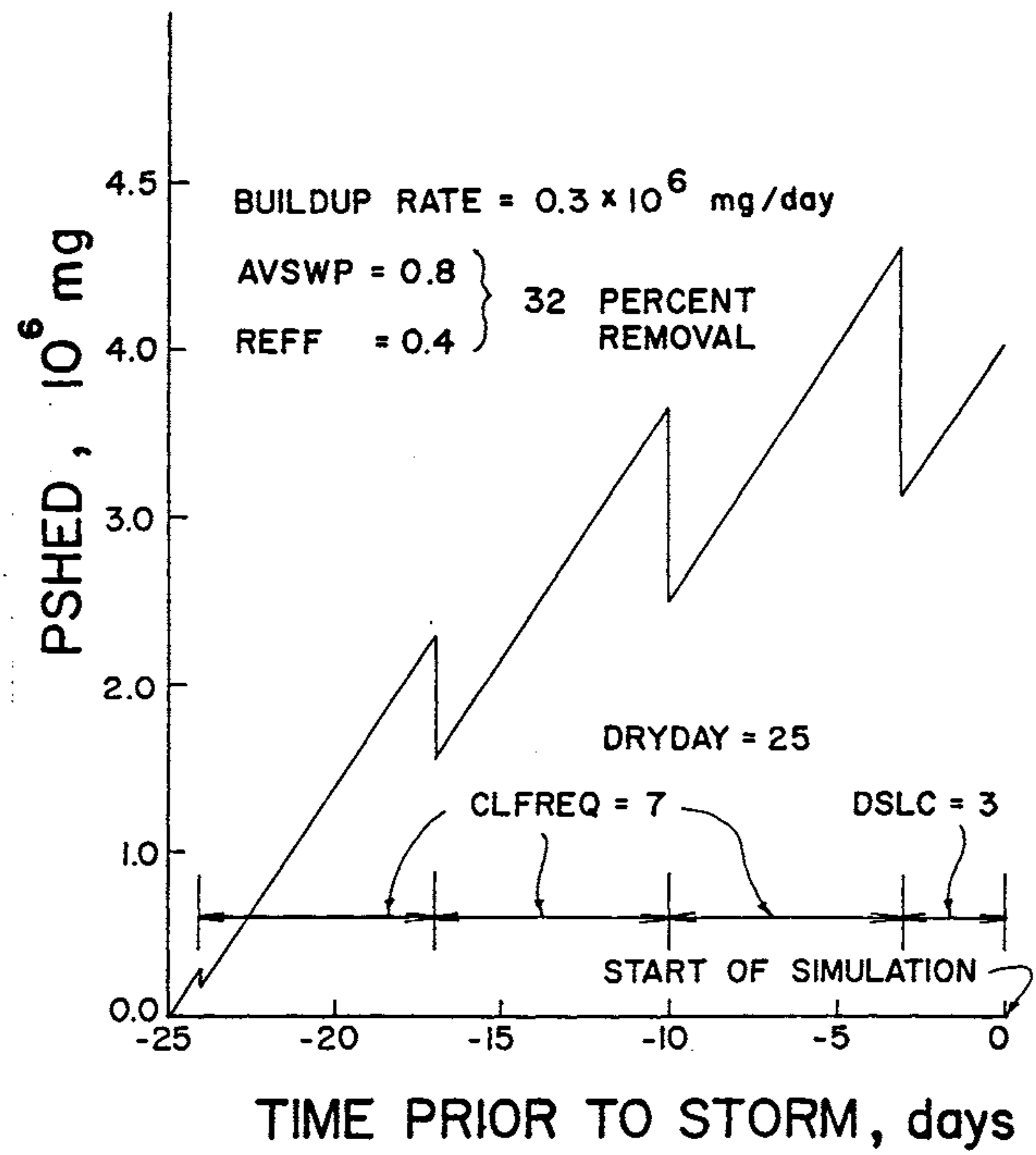

Figure 4-38. Hypothetical Time Sequence of Linear Buildup and Street Sweeping.

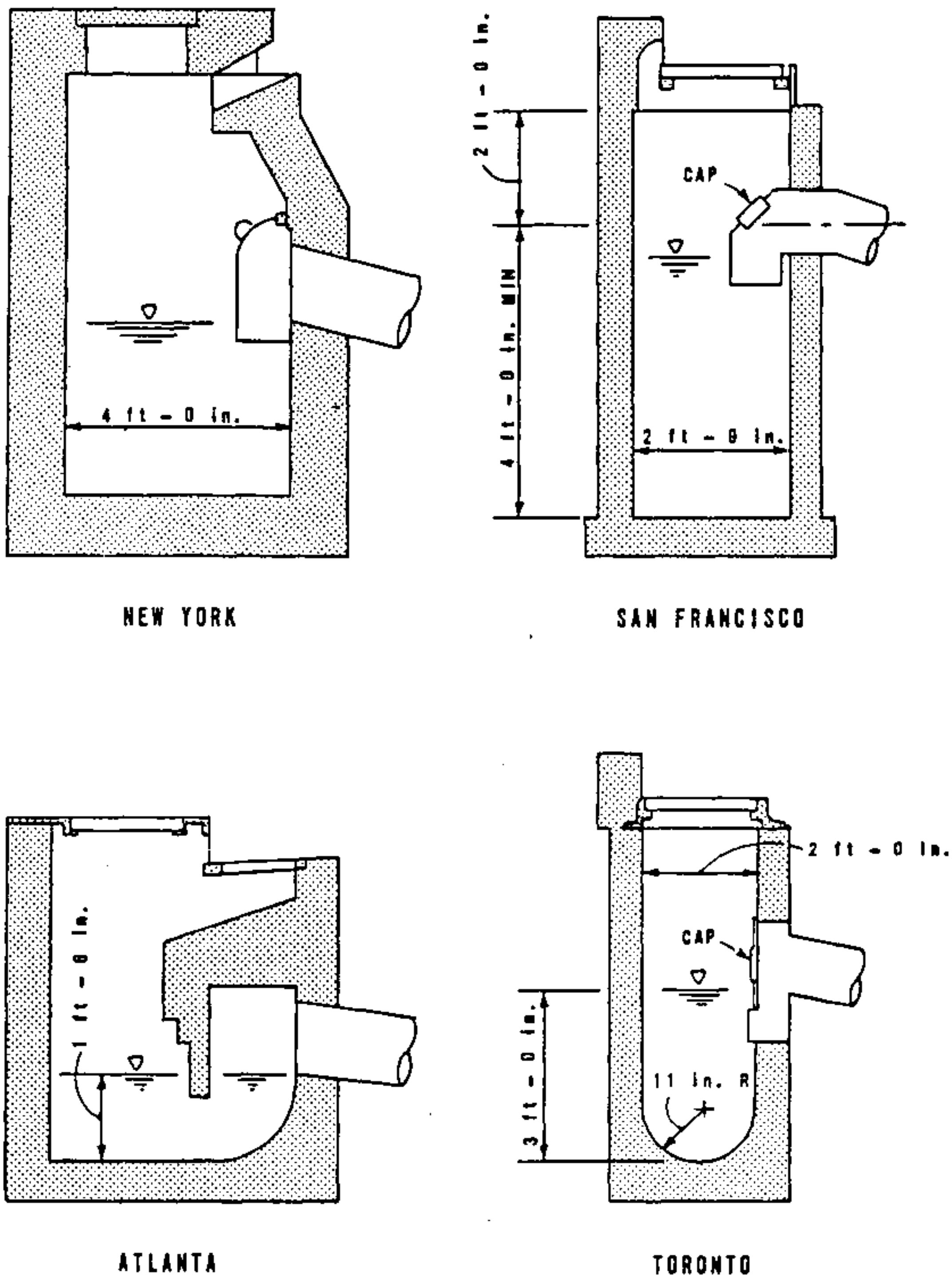

Figure 4-39. Representative Catchbasin Designs. (After Lager et al., 1977b, p. 12.)

A comprehensive examination of catchbasins and their effectiveness for pollutant control is presented by Lager et al. (1977b). They conclude that:

> "Existing catchbasins exhibit mixed performance with respect to pollution control. The trapped liquid purged from catchbasins to the sewers during each storm generally has a high pollution content that contributes to the intensification of first-flush loadings. Countering this negative impact is the removal of pollutants associated with the solids retained in, and subsequently cleaned from, the basin."

In fact according to their data, there is unlikely to be much removal (treatment) at all in most cities because of infrequent maintenance; the median cleaning frequency in 1973 was once per year. Without such maintenance, solids accumulate in the sump until there is little removal effectiveness, even for large particles. Lager et al. (1977b) conclude that, with the possible exception of total solids and heavy metals, catchbasins are of limited usefulness for pollution abatement, both because of their ineffectiveness and because of their high maintenance costs. Hence, their treatment potential is not modeled in SWMM. (If it is significant in a given city, surface loadings could be correspondingly reduced.)

Modeling Approach -- The potential for a first flush of catchbasin material is simulated by assuming that the sump contains at the beginning of a storm a constituent load (e.g., mass, in mg, for NDIM = 0) given by

$$\text{PBASIN} = \text{CBVOL} \cdot \text{BASINS} \cdot \text{CBFACT} \cdot \text{FACT3} \tag{4-41}$$

where PBASIN = subcatchment constituent load in catchbasins at beginning of storm, mg for NDIM = 0,
CBVOL = individual catchbasin volume of sump, reduced by quantity of stored solids, if know, ft^3,
BASINS = number of basins in subcatchment,
CBFACT = constituent concentration in basin at beginning of storm, mg/l for NDIM = 0, and
FACT3 = conversion factor, equals 28.3 l/ft^3 for NDIM = 0.

Parameter CBVOL is entered on card J1 as an average for the entire catchment. The number of basins in each subcatchment, BASINS, is entered in card group L1. Numbers can be obtained knowing the general basin density for the catchment in lieu of the more tedious method of counting every one. Constituent concentrations, CBFACT, are entered in card group J3 and should, of course, be measured in the catchment under study. Literature values are few. Samples from 12 San Francisco catchbasins (Sartor and Boyd, 1972) were characterized by Lager et al. (1977b) by "casting out the extremes and averaging," resulting in the values shown in Table 4-22.

Table 4-22 Constituent Concentrations in San Francisco Catchbasins (Sartor and Boyd, 1972)

Constituent	Concentration, mg/l Average	Range
COD	6,400	153 - 143,000
BOD_5	110	5 - 1,500
Total-N	8	0.5 - 33
Total-P	0.2	<0.2 - 0.3

The values for COD and Total-N are consistent with a few samples reported by Sartor and Boyd (1972) for Baltimore and Milwaukee, although the "phosphates" concentration in these two cities was somewhat higher, 1.1 - 2.2 mg/l. The concentration of BOD_5 in seven Chicago catchbasins was measured by APWA (1969). The average concentration for five commercial area basins was 126 mg/l, ranging from 35 to 225 mg/l. Two residential area basins yielded BOD_5 concentrations of 50 and 85 mg/l.

No data have been found to characterize other constituents within the catchbasins themselves. In particular, suspended solids (SS) concentrations can be expected to be high for particle sizes less than about 0.25 mm, on the basis of flushing tests (Sartor and Boyd, 1972, Lager et al., 1977b). Initial suspended and total solids concentrations of several thousand mg/l are probably justified, although measurements by Waller (1971) <u>during</u> storms in four residential catchbasins in Halifax indicate SS concentrations in a range of 42 to 305 mg/l.

Flushing of stored constituents from catchbasin sumps is based on tests conducted by APWA (1969) in which salt was used as a tracer and its rate of flushing observed. Data and fitted equations are shown in Figure 4-40. The basin behaves approximately as a completely mixed tank in which

$$\frac{d\ PBASIN}{dt} = -\frac{WFLOW}{k \cdot BASINS} \cdot PBASIN \qquad (4\text{-}42)$$

where PBASIN = constituent load remaining in the catchbasin as a function of time, e.g., mg for NDIM = 0,
WFLOW = flow through the basin (runoff from the subcatchment), cfs,
BASINS = volume of catchbasin sump, ft^3, and
k = constant to be determined from flushing tests.

When the flow rate is constant, equation 4-42 integrates to

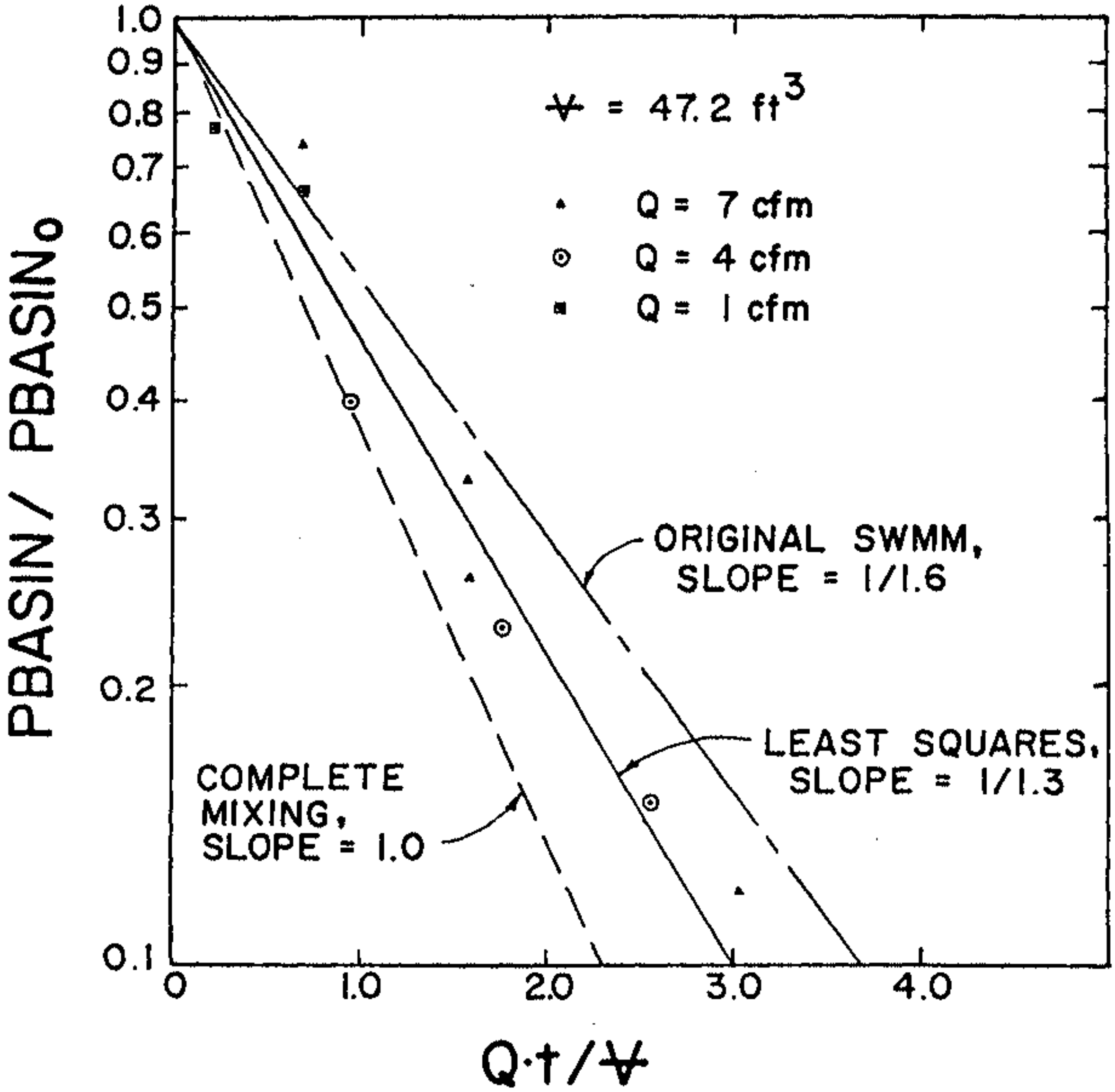

Figure 4-40. Catchbasin Flushing Characteristics. Data are from APWA (1969).

$$PBASIN = PBASIN_o \cdot e^{-\frac{WFLOW}{k \cdot BASINS} \cdot t} \tag{4-43}$$

where $PBASIN_o$ = initial catchbasin load.

If complete mixing occurs, k=1. For the Chicago tests this did not quite occur, as seen in Figure 4-40. The original SWMM version used k=1.6, but this does not give the best-fit line. Rather, a k value of 1.3 is consistent with a least squares fit through the data points and is used in this version of SWMM. (However, the difference is probably undetectable in a simulation.)

During a runoff event, equation 4-42 is used to calculate the load rate, dPBASIN/dt, at each time step. (Parameter BASINS represents the total catchbasin volume for the subcatchment.) The remaining catchbasin load is then computed by multiplying the load rate by DELT and subtracting from PBASIN. This crude Euler integration is justified because of 1) the weakness of field data and mixing assumptions, 2) the necessity for an additional array and computation time for a more sophisticated approximation, and 3) insensitivity of most simulations to catchbasin flushing. The latter point will be discussed further subsequently.

Regeneration of Catchbasin Loads -- During continuous simulation, catchbasin loads are regenerated to their original values, $PBASIN_o$ at a rate $PBASIN_o$/ DRYBSN (e.g., mg/day) where DRYBSN is entered on card J1 and is the time required for complete regeneration from a zero load. No data are available herein to establish a value for DRYBSN, but it is likely that catchbasins are at "full strength" after only few days of dry weather.

Effect on Simulation -- It is the experience of the authors of this report that catchbasins have a negligible effect on most simulation results. Typical drainage areas served by catchbasins range from 2.15 to 5.05 ac/basin (0.85 to 2.05 ha/basin) in the U.S. (Lager et al., 1977b). Unless the area served is low, surface loadings tend to overwhelm those from catchbasins. Although they do contribute to a first flush effect, the most important task in most simulations is to obtain a proper total storm load, to which catchbasins are seldom strong contributors. Hence, excessive effort to pin down catchbasin simulation parameters is seldom justified.

Constituent Fractions --

Background -- As previously discussed, the original SWMM Runoff Block quality routines were based on the 1969 APWA study in Chicago (APWA, 1969). A particular aspect of that study that led to modifications to the first buildup-washoff formulation was that the Chicago quality data (e.g., Table 4-14) were reported for the soluble fraction only, i.e., the samples were filtered prior to chemical analysis. Hence, they could not represent the total content of, say, BOD_5, in the stormwater. In calibration of SWMM in San Francisco and Cincinnati, five percent of predicted suspended solids was added to BOD_5 to account for the insoluble fraction. This provided a reasonable BOD_5 calibration in both cities.

The Version II release of SWMM (Huber et al., 1975) followed the STORM model (Roesner et al., 1974) and added to BOD_5, N and PO_4 fractions of both suspended solids and settleable solids. Adding a fraction from settleable solids is double counting however, since it is no more than a fraction of suspended solids itself. Furthermore, all the fractions in SWMM and STORM were basically just assumed from calibration exercises as opposed to being measured from field samples.

Agricultural models, such as NPS (Donigian and Crawford, 1976) and ARM (Donigian et al., 1977) also relate other constituent mass load rates and concentrations to that of "solids," usually "sediment" predicted by an erosion equation. The ratio of constituent to "solids" is then called a "potency factor" and for some constituents is the only means by which their concentrations are predicted. The approach works well when constituents are transported in solid form, either as particulates or by adsorption onto soil particles. This approach can also be used in SWMM. For instance, one constituent could represent "solids" and be predicted by any of the means available (i.e., buildup-washoff, rating curve, Universal Soil Loss Equation). Other constituents could then be treated simply as a fraction, F1, of "solids." The fractions (potency factors) are entered in card group J4. As a refinement, two or more constituents could represent "solids" in different particle size ranges, and fractions of each summed to predict other constituents. Again, this approach will not work well for constituents that are transported primarily in a dissolved state (e.g., NO_3).

Available Information -- In an effort to evaluate potency factors for various constituents in both urban and agricultural runoff, Zison (1980) examined available data and developed regression relationships as a function of suspended solids and other parameters. His only urban catchments were three from Seattle, taken from the Urban Rainfall-Runoff-Quality Data Base (Huber et al., 1979), for which several water quality and storm event parameters were available. Unfortunately, statistically meaningful results could only be obtained using log-transformed data, and simple fractions of the type required for input in card group J4 are seldom reported. Zison (1980) acknowledged this and suggested that model modifications might be made or piecewise-linear approximation made to the power function relationship. In any event, Zison related the total constituent concentration (not just the nonsoluble portion) to other parameters. Hence, for their use in SWMM, the buildup-washoff portion would need to be "zeroed out," (easily accomplished), as suggested earlier.

Other reports also provide some insight as to potential values for the constituent fractions. For instance, Sartor and Boyd (1972), Shaheen (1975) and Manning et al. (1977), report particle size distributions for several constituents. However, the distributions refer principally to fractions of constituents appearing as "dust and dirt," not to fractions of total concentration, soluble plus nonsoluble. Finally, Pitt and Amy (1973) give fractions (and surface loadings) for heavy metals.

If constituent fractions are used in SWMM, local samples should identify the soluble (filtrable) and nonsoluble fractions for the constituents of interest. Alternatively, the fractions may be avoided altogether by treating the buildup-washoff or rating curve approach as one for the total concentration, thus eliminating the need to break constituents into more than one form.

Effect in Runoff Block -- The fractions entered in card group J4 act only in "one direction." That is, nothing is subtracted from, say, suspended solids if it is a constituent that contributes to others. When the fractions are used, they can contribute significantly to the concentration of a constituent. For instance, if five percent of suspended solids is added to BOD_5, high SS concentrations will insure somewhat high BOD_5 concentrations, even if BOD_5 loadings are small.

Units conversions must be accounted for in the fractions. For instance, if a fraction of SS is added to total coliforms, units for F1 would be MPN per mg of SS. In general, F1 has units of the "quantity" of KTO (e.g., MPN) per "quantity" of constituent KFROM (e.g., mg).

The contributions from other constituents are the penultimate step in subroutine QSHED. They occur after the Universal Soil Loss Equation calculation, and the to-from constituents can include the contribution from erosion if desired. Only the contribution from precipitation comes later and thus cannot be included in the constituent fractions. Rather it is added to the constituent load at the end of the chain of calculations, as described below.

Precipitation Contributions --

Precipitation Chemistry -- There is now considerable public awareness of the fact that precipitation is by no means "pure" and does not have characteristics of distilled water. Low pH (acid rain) is the best known parameter but many substances can also be found in precipitation, including organics, solids, nutrients, metals and pesticides. Compared to surface sources, rainfall is probably an important contributor mainly of some nutrients, although it may contribute sustantially to other constituents as well. In particular, Kluesener and Lee (1974) found ammonia levels in rainfall higher than in runoff in a residential catchment in Madison, Wisconsin; rainfall nitrate accounted for 20 to 90 percent of the nitrate in stormwater runoff to Lake Wingra. Mattraw and Sherwood (1977) report similar findings for nitrate and total nitrogen for a residential area near Fort Lauderdale, Florida. Data from the latter study are presented in Table 4-23 in which rainfall may be seen to be an important contributor to all nitrogen forms, plus COD, although the instance of a higher COD value in rainfall than in runoff is probably anomalous.

In addition to the two references first cited, Weibel et al. (1964, 1966) report concentrations of constituents in Cincinnati rainfall (Table 4-24), and a summary is also given by Manning et al. (1977). A comprehensive summary is presented by Brezonik (1975) from which it may be seen in Table 4-24 that there is a wide range of concentrations observed in rainfall. Again, the most important parameters relative to urban runoff are probably the various nitrogen forms.

Uttormark et al. (1974) provide annual nitrogen (and phosphorus) precipitation loading values (kg/ha-yr) for many cities regionally for the U.S. and Canada. Their nitrogen loadings are shown in Figure 4-41

Table 4-23 Rainfall and Runoff Concentrations For A Residential Area Near Fort Lauderdale, Florida (After Mattraw and Sherwood, 1977).

	Storm		
	8/23/75	9/17/75	9/26/75
Rainfall, in.	1.01	0.55	0.77
Runoff, in.	0.060	0.012	0.072
Concentrations (mg/l):			
Total N, rainfall	0.30	0.84	0.29
Total N, runoff	0.52	0.74	1.50
NO_3-N, rainfall	0.14	0.73	0.12
NO_3-N, runoff	0.16	0.19	0.26
Org.-N, rainfall	0.15	0.09	0.12
Org.-N, runoff	0.34	0.49	1.10
NH_3-N, rainfall	0.01	0.01	0.04
NH_3-N, runoff	0.02	0.04	0.13
Total P, rainfall	0.01	0.02	0.05
Total P, runoff	0.12	0.20	0.30
COD, rainfall	22	12	4
COD, runoff	16	21	17

Table 4-24 Representative Concentrations in Rainfall

Parameter	Ft. Lauderdale[a] (Mattraw and Sherwood, 1977)	Cincinnati[b] (Weibel et al., 1966)	"Typical Range" (Brezonik, 1975)
Acidity (pH)			3-6
Organics			
BOD_5, mg/l			1-13
COD, mg/l	4-22	16	9-16
TOC, mg/l	1-3		Few
Inorg. C, mg/l	0-2		
Color, PCU	5-10		
Solids			
Total Solids, mg/l	18-24		
Suspended Solids, mg/l	2-10	13	
Turbidity, JTU	4-7		
Nutrients			
Org. N, mg/l	0.09-0.15	0.58	0.05-1.0
NH_3-N, mg/l	0.01-0.04		
NO_2-N, mg/l	0.00-0.01		
NO_3-N, mg/l	0.12-0.73	1.27[c]	0.05-1.0
Total N, mg/l	0.29-0.84		0.2 -1.5
Orthophosphorus, mg/l	0.01-0.03	0.08	0.0 -0.05
Total P, mg/l	0.01-0.05		0.02-0.15
Pesticides, µg/l		3-600	Few
Heavy metals, µg/l			Few
Lead, µg/l			30-70

[a]Range for three storms [b]Average of 35 storms [c]Sum of NH_3-N, NO_2-N, NO_3-N

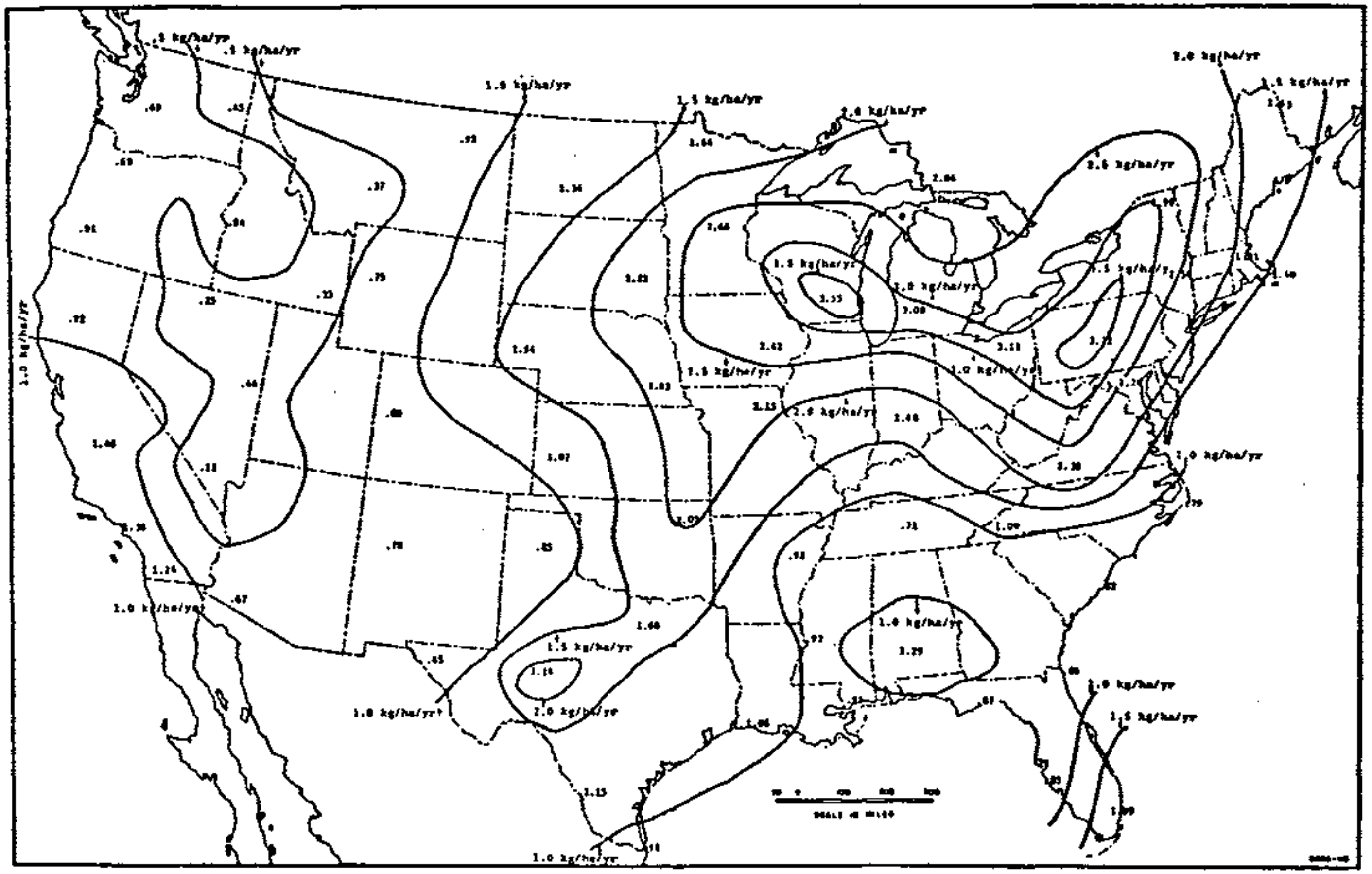

Figure 4-41. Nationwide Annual Loadings of NH_4^+-N + NO_3-N in Precipitation (after Uttormark et al., 1974, p. 87). Dry fallout is not included.

although it should be remembered that considerable seasonal variability may exist. These may be easily converted to precipitation concentrations required for SWMM input if the local rainfall is known, since kg/ha-yr ÷ cm/yr x 10 = mg/l. For instance, annual NH_3-N + NO_3-N loadings at Miami are almost 2 kg/ha-yr from Figure 4-41, and annual rainfall is 60 in (152 cm). From the above, the inorganic nitrogen concentration is 10 x 2/152 = 0.13 mg/l which compares quite favorably with the sum of NH_3-N and NO_3-N concentrations for two of the three Ft. Lauderdale storms given in Table 4-23. For a better breakdown of nitrogen forms, see Table 17 of Uttormark et al. (1974).

Effect in Runoff Block -- Constituent concentrations in precipitation are entered in card group J3. All runoff, including snowmelt, is assumed to have at least this concentration, and the precipitation load (e.g., mg/sec) is calculated by multiplying by the runoff rate and adding to the load already generated by other mechanisms. It may be inappropriate to add a precipitation load to loads generated by a calibration of buildup-washoff or rating curve parameters against measured runoff concentrations, since the latter already reflect the sum of all contributions, land surface and otherwise. But precipitation loads might well be included if starting with buildup-washoff data from other sources.

For single event simulation, use of precipitation concentrations is a simple way in which to account for the high concentrations of several constituents found in snowpacks (Proctor and Redfern and James F. MacLaren, 1976b). It would be inappropriate for continuous simulation, however, since such high concentrations in runoff would not be expected to persist over the whole year. If this is the only method used to simulate melt quality, however, a constant predicted concentration will result. Also, caution should be used if simulating particulates (e.g., suspended solids) or heavy metals since high concentrations in a snowpack do not necessarily mean high concentrations in runoff, since the material may rapidly settle during overland flow. For instance, the very high lead concentrations (2 - 100 mg/l) found in snow windrows in urban areas are greatly reduced in the melt runoff (0.05 - 0.95 mg/l), (Proctor and Redfern and James F. MacLaren, 1976b).

Urban Erosion --

Background -- Erosion and sedimentation are often cited as a major problem related to urban runoff. They not only contribute to degradation of land surfaces and soil loss but also to adverse receiving water quality and sedimentation in channels and sewer networks. Several ways exist to analyze erosion from the land surface (e.g., Vanoni, 1975), the most sophisticated of which include calculations of the shear stress exerted on soil particles by overland flow and/or the influence of rainfall energy in dislodging them. In keeping with the simplified quality procedures included in the rest of the Runoff Block, a widely-used empirical approach, the Universal Soil Loss Equation (USLE), has been adapted for use in SWMM. Full details and further information on the USLE are given by Heaney et al. (1975).

Universal Soil Loss Equation -- The USLE was derived from statistical analyses of soil loss and associated data obtained in 40 years of research by the Agricultural Research Service (ARS) and assembled at the ARS runoff and soil loss data center at Purdue University. The data include more than 250,000 runoff events at 48 research stations in 26 states, representing about 10,000 plot-years of erosion studies under natural rain. It was developed by Wischmeier and Smith (1958) as an estimate of the average annual soil erosion from rainstorms for a given upland area, L, expressed as the average annual soil loss per unit area, (tons per acre per year):

$$L = R \cdot K \cdot LS \cdot C \cdot P \tag{4-44}$$

where R = the rainfall factor,
K = the soil erodibility factor,
LS = the slope length gradient ratio,
C = the cropping management factor or cover index factor, and
P = the erosion control practice factor.

This equation represents a comprehensive attempt at relating the major factors in soil erosion. It is used in SWMM to predict the average soil loss for a given storm or time period. It is recognized that the USLE was not developed for making predictions based on specific rainfall events. There are many random variables which tend to cancel out when predicting individual storm yields. For example, the initial soil moisture condition, or antecedent moisture condition, is a parameter which cannot be determined directly and used reliably. It should be understood by the SWMM user that equation 4-44 enables land management planners to estimate gross erosion rates for a wide range of rainfall, soil, slope, crop, and management conditions.

Input Parameters -- If erosion is to be simulated, it is so indicated by parameter IROS on card J1. Note that at least one other (arbitrary) quality constituent must be simulated along with "erosion." No particular soil characteristics (e.g., particle size distribution) are assigned to the erosion parameter, and its title is "EROSION," with units of mg/l, in the output. Erosion may be added to another constituent, e.g., suspended solids, if desired using parameter IROSAD on card J1. However, the erosion parameter will also always be maintained as an individual parameter throughout the Runoff Block.

Other input parameters are:

1) the maximum 30-minute rainfall intensity of the storm (single-event) or of the simulation period (continuous), RAINIT, (card J1),

2) the area of each subcatchment subject to erosion, ERODAR, (card K1),

3) the flow distance in feet from the point of origin of overland flow over the erodible area to the point at which runoff enters the gutter or inlet, ERLEN, (card K1),

4) the soil factor K, SOILF, (card K1),

5) the cropping management factor C, CROPMF, (card K1), and

6) the control practice factor P, CONTPF, (card K1).

The source and use of these parameters is described below.

Rainfall Factor and Maximum Thirty Minute Intensity -- The rainfall factor, R, of equation 4-44 is the product of the maximum thirty minute intensity and the sum of the rainfall energy for the time of simulation. Rainfall energy, E, is given by an empirical expression by Wischmeier and Smith (1958),

$$E = \Sigma(9.16 + 3.31 \log_{10} \cdot RNINHR_j) \cdot RNINHR_j \cdot DELT \qquad (4\text{-}45)$$

where E = total rainfall energy for time period of summation, 100-ft-ton/ac, $RNINHR_j$ = rainfall intensity at time interval j, in/hr, and

DELT = time interval, hr, such that the product RNINHR · DELT = rainfall depth during the time interval.

The summation was performed over all time intervals with rainfall for a year for the original USLE development; contours of R over the U.S. are given by Wischmeier and Smith (1965). However, it can also be performed for an individual storm. In SWMM this is performed on a time step basis; that is, E is evaluated at each time step using the rainfall intensity at that time step (no summation). The rainfall factor, R, is then

$$R = E \cdot RAINIT \qquad (4\text{-}46)$$

where RAINIT = maximum average 30-minute rainfall intensity for the storm (single event) or the period of simulation (continuous), in/hr.

RAINIT must be found from an inspection of the input hyetograph prior to simulation. Computed in this manner, the rainfall factor does not account for soil losses due to snowmelt or wind erosion. The units of R (100-ft-ton-in/ac-hr) are generally meaningless since the soil factor, K, is designed to cancel them. But the indicated units for RAINIT and RNINHR (in/hr) must be used.

Erosion Area -- Parameter ERODAR (card K1) represents the acres of the subcatchment subject to erosion. This would ordinarily be less than or equal to the pervious area of the subcatchment and could indicate land that is barren or under construction.

Soil Factor -- The soil factor, K, is a measure of the potential erodibility of a soil and has units of tons per unit of rainfall factor, R. The soil erodibility nomograph shown in Figure 4-42 (Wischmeier et al., 1971) may be used to find the value of the soil factor once five soil parameters have

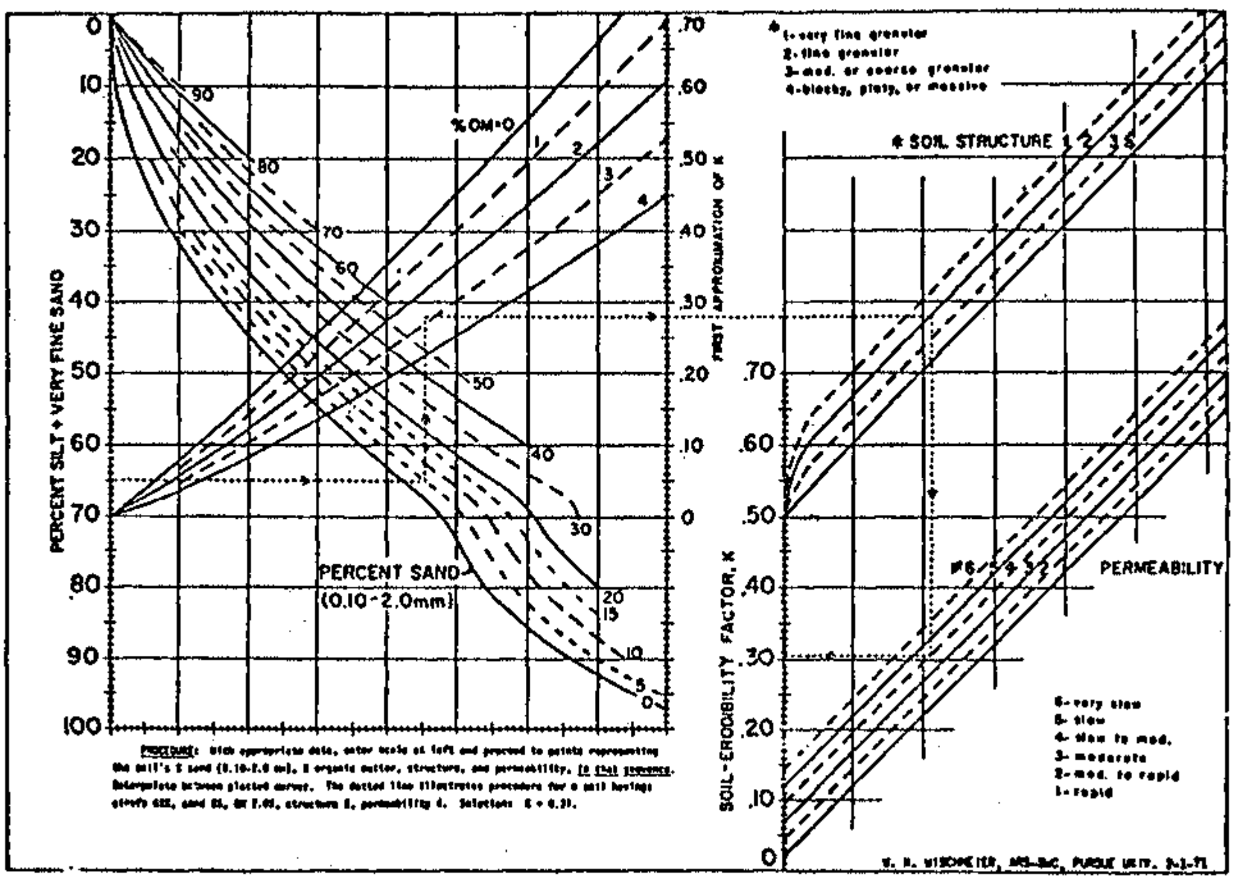

Figure 4-42. Nomograph for Calculation of Soil Erodability Factor, K. (After Wischmeier et al., 1971.)

been estimated. These parameters are: percent silt plus very fine sand (0.05-0.10 mm), percent sand greater than 0.10 mm, organic matter (O.M.) content, structure, and permeability. To use the nomograph, enter on the left vertical scale with the appropriate percent silt plus very fine sand. Proceed horizontally to the correct percent sand curve, then move vertically to correct organic matter curve. Moving horizontally to the right from this point, the first approximation of K is given on the vertical scale. For soils of fine granular structure and moderate permeability, this first approximation value corresponds to the final K value and the procedure is terminated. If the soil structure and permeability is different than this, it is necessary to continue the horizontal path to interact the correct structure curve, proceed vertically downward to the correct permeability curve, and move left to the soil erodibility scale to find K. This procedure is illustrated by the dotted line on the nomograph. For a more complete discussion of this topic, see Wischmeier et al. (1971).

A preferable and often simpler alternative to the use of the nomograph of Figure 4-42 is to refer directly to the soil survey interpretation sheet for the soil in question, on which may be found the value of the soil factor. This is illustrated in Figure 4-19 for Conestoga Silt Loam whereupon the K value is given as 0.43. Since this is site-specific local information, it is highly recommended. Local Agricultural Research Service and Soil Conservation Service offices are available to obtain the soil survey interpretation sheets and to provide much other useful information.

Slope Length Gradient Ratio -- This parameter is an empirical function of runoff length and slope and is given by

$$LS = ERLEN^{0.5} \cdot (0.0076 + 0.53 \cdot WSLOPE + 7.6 \cdot WSLOPE^2) \quad (4\text{-}47)$$

where LS = slope length gradient ratio,
ERLEN = the length in feet from the point of origin of overland flow to the point where the slope decreases to the extent that deposition begins or to the point at which runoff enters a defined channel, e.g., gutter/pipe or inlet, and
WSLOPE = the average slope over the given runoff length, ft/ft.

Parameter ERLEN is entered with the erosion parameters in card group K1. The slope, WSLOPE, is the same as for runoff calculations and will already have been entered in card group H1.

In using the average slope in calculating the LS factor, the predicted erosion will be different from the actual erosion when the slope is not uniform. Meyer and Kramer (1969) show that when the actual slope is convex, the average slope prediction will underestimate the total erosion whereas for a concave slope, the prediction equation will overestimate the actual erosion. If possible, to minimize these errors, large eroding sites should be broken up into areas of fairly uniform slope.

Cropping Management Factor -- This factor is dependent upon the type of ground cover, the general management practice and the condition of the soil over the area of concern. The C factor (CROPMF in card group K1) is set equal to 1.0 for continuous fallow ground which is defined as land that has been tilled and kept free of vegetation and surface crusting. Values for the cropping management factor are given in Table 4-25 (Maryland Dept. of Natural Resources, 1973). Again consultation with local soils experts is recommended.

Control Practice Factor -- This is similar to the C factor except that P (CONTPF in card group K1) accounts for the erosion-control effectiveness of superimposed practices such as contouring, terracing, compacting, sediment basins and control structures. Values for the control practice factor for construction sites are given in Table 4-26 (Ports, 1973). Agricultural land use P factor values are given by Wischmeier and Smith (1965).

The C and P factors are the subject of much controversy among erosion and sedimentation experts of the US Department of Agriculture (USDA) and the Soil Conservation Service (SCS). These factors are estimates and many have no theoretical or experimental justification. It has been suggested that upper and lower limits be placed on these factors by local experts to increase the flexibility of the USLE for local conditions.

The P factors in the upper portion of Table 4-26 were designated as estimates when they were originally published. SCS scientists have found no theoretical or experimental justification for factors significantly greater than 1.0. Surface conditions 4, 6, 7 and 8 ($P \leq 1.0$) of Table 4-26 also are estimates with no experimental verification.

Subcatchment Quality Data (Card Group L1) --

Introduction -- As discussed earlier while describing buildup and washoff mechanisms, certain quality parameters are unique to each subcatchment and are entered in this card group. These parameters are independent of the quantity parameters entered in card group H1 (except for subcatchment number, of course) and are not required if no quality simulation is performed.

Land Use -- Each subcatchment is assigned one of up to five land uses defined in card group J2. Parameters entered for an individual land use will then be used on the corresponding subcatchments.

Catchbasins -- The total number is entered for parameter BASINS. (See earlier discussion of catchbasins.) In lieu of counting every one, BASINS may be computed if the general catchbasin density is known, e.g., 0.2 - 0.5 per ac (0.5 - 1.2 per ha) for most cities (Lager et al., 1977b). When BASINS = 0, no catchbasin computations are performed for the subcatchment.

Gutter Length -- Gutter or curb length, GQLEN, is used only for quality calculations for which buildup parameters are normalized as lb/100-ft curb, etc. (i.e., only when parameters JACGUT or KACGUT equal zero in card groups J2 and J3). This parameter may be measured directly by scaling the total length of streets off of maps and multiplying by two. As for other parameters, this is most economically achieved by measurements in a few representative areas and extrapolation to others.

Table 4-25 Cropping Management Factor, C
(Maryland Dept. of Natural Resources, 1973)

Type of cover	C Value	Mulch	Rate of Application (tons/acre)	C Value	Maximum Allowable Slope Length
None (fallow)	1.00	Hay or straw	0.5	0.35	20 feet
			1.0	0.20	30
Temporary seedings:			1.5	0.10	40
First sixty days	0.40		2.0	0.05	50
After sixty days	0.05				
		Stone or gravel	15.0	0.80	15
Permanent seedings:			60.0	0.20	80
First sixty days	0.40		135.0	0.10	175
After sixty days	0.05		240.0	0.05	200
		Chemical mulches			
Sod (laid immediately)	0.01	First ninety days	[a]	0.50	50
		After ninety days	[a]	1.00	50
		Woodchips	2.0	0.80	25
			4.0	0.30	50
			12.0	0.10	100
			20.0	0.06	150
			25.0	0.05	200

[a]As recommended by manufacturer

Table 4-26 Erosion Control Practice Factor, P, for Construction Sites (Ports, 1973)

Surface Condition With no Cover	Factor P
1. Compact, smooth, scraped with bulldozer or scraper up and down hill	1.30
2. Same as above, except raked with bulldozer root, raked up and down hill	1.20
3. Compact, smooth, scraped with bulldozer or scraper across the slope	1.20
4. Same as above, except raked with bulldozer root, raked across the slope	0.90
5. Loose, as in a disked plow layer	1.00
6. Rough irregular surface, equipment tracks in all directions	0.90
7. Loose with rough surface greater than 12" depth	0.80
8. Loose with smooth surface greater than 12" depth	0.90
Structures	
1. Small sediment basins:	
0.04 basin/acre	0.50
0.06 basin/acre	0.30
2. Downstream sediment basins:	
with chemical flocculants	0.10
without chemical flocculants	0.20
3. Erosion control structures:	
normal rate usage	0.50
high rate usage	0.40
4. Strip building	0.75

Curb length has been measured in several cities as a function of land use. Results for Tulsa and for ten Ontario cities are shown in Table 4-27. The Ontario results were compiled from aerial photographs. On a broad, total urbanized area basis, curb length has been related to population density, e.g., Graham et al. (1974) for the Washington, D.C. area. Manning et al. (1977) augmented the Washington, D.C. data with data from six other U.S. cities to develop the equation

$$GD = 413 - 353 \cdot 0.839^{PD} \tag{4-48}$$

where GD = curb length density, ft/ac, and
PD = population density, persons/ac.

Subcatchment gutter length may then be obtained simply by

$$GQLEN = GD \cdot WAREA/100. \tag{4-49}$$

where GQLEN = gutter (curb) length, 100-ft, and
WAREA = subcatchment area, ac.

Equation 4-48 should only be used for large areas, such as an aggregated subcatchment used for continuous simulation. Site specific data are always preferred in any event.

Table 4-27. Measured Curb Length Density for Various Land Uses. (Heaney et al., 1977, Sullivan et al., 1978)

	Tulsa			10 Ontario Cities		
	mile/acre	km/ha	100ft/acre	mile/acre	km/ha	100ft/acre
Residential	0.076	0.30	4.0	0.042	0.17	2.2
Commercial	0.081	0.32	4.3	0.057	0.23	3.0
Industrial	0.042	0.17	2.2	0.025	0.099	1.3
Park	0.042	0.17	2.2	-	-	-
Open	0.016	0.063	0.85	0.015	0.059	0.79
Institutional	-	-	-	0.030	0.12	1.60

Constituent Loadings -- As an alternative to the several buildup options available in card groups J2 and J3, initial desired constituent loads may be entered on a per acre basis for each subcatchment. Total initial loads are then computed simply by multiplication by the subcatchment area,

$$PSHED = pshed \cdot WAREA \cdot FACT1 \qquad (4\text{-}50)$$

where PSHED = initial surface constituent load, e.g., mg for NDIM=0,
pshed = loading entered on card group L1, e.g., lb/ac for NDIM=0,
WAREA = subcatchment area, ac, and
FACT1 = conversion factor, e.g., 453600 mg/lb for NDIM=0.

Loadings may be entered for any number of constituents. A loading entered for one subcatchment does not affect buildup calculations on another for which a zero loading is used.

For continuous simulation, constituents will buildup between storms, (unless the rating curve option is used). These buildup parameters must be entered in card groups J2 and J3. The initial loading will have no effect after the first storm has ended except for a possible residual load (PSHED) remaining on the surface. The loading parameters on card group L1 are thus most easily adapted to single event simulation. They also provide one method of avoiding computation of an equivalent gutter length for land uses such as parking lots (if that type of normalized loading rate is being used).

Overall Sensitivity to Quality Parameters --

One of the advantages of computer simulation is that it permits examination of the interactions between the complex precipitation time series and the various quantity and quality process of the catchment. It should be borne in mind that quality buildup processes in the model occur only during dry weather, and quality washoff processes occur only during storms (or during runoff due to snowmelt). For the moment it will be assumed that the rating curve approach is not being used.

As a general rule, predicted concentrations and total loads are most sensitive to buildup rates. Twice the initial surface load usually means that about twice the load in the runoff will occur. (An obvious qualification is if washoff parameters are such that not all the material is washed from the surface during most storm events.) For instance, if linear buildup is used for dust and dirt, parameter DDFACT in card group J2 is a very important parameter. But the upper limit to buildup also enters the picture.

Consider the sketch in Figure 4-43. If the limiting buildup quantity is reached before a storm occurs, the results will be sensitive to the buildup limit (i.e., DDLIM or QFACT(1)) but not the rate. On the other hand, if the limit is not reached before a storm occurs, the results will be sensitive to the buildup rate (i.e., DDFACT or QFACT(3)) but not the limit. During continuous simulation the interevent time between storms varies, typically with an exponential probability density function. But

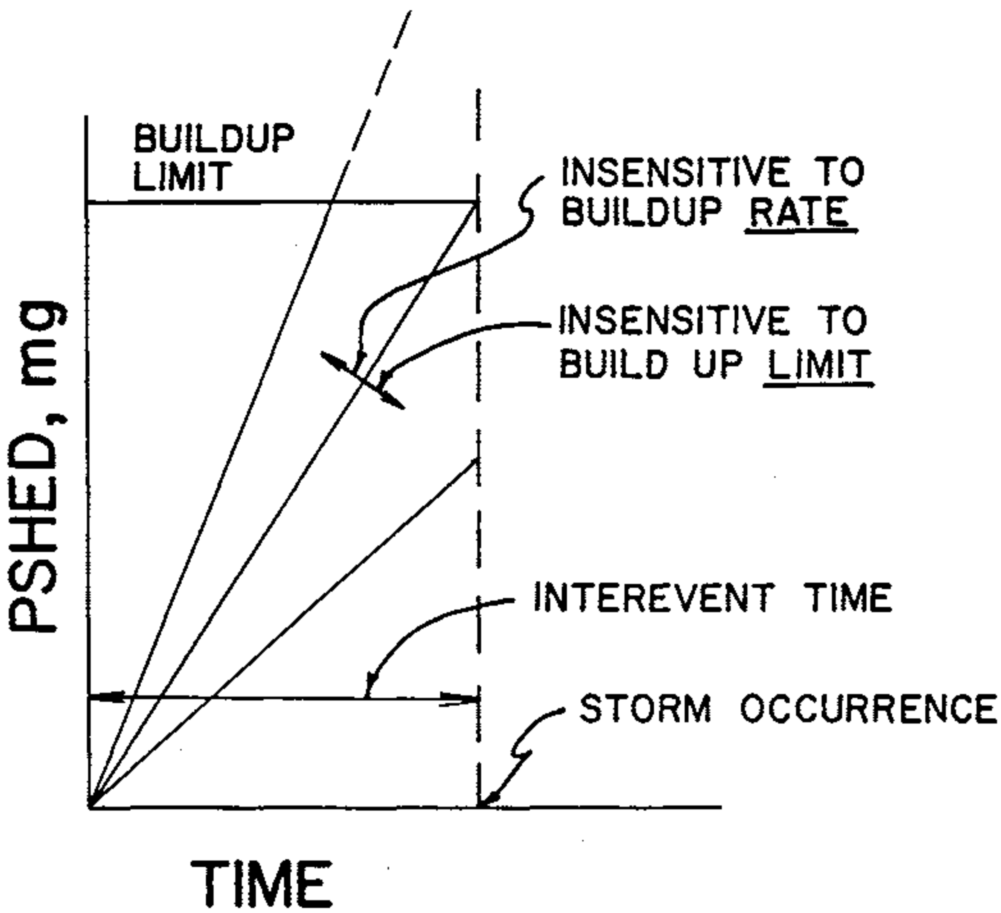

Figure 4-43. Interaction of Buildup Parameters and Storm Interevent Time.

examination of the average interevent item should permit a sensitivity analysis of the type sketched in Figure 4-43. A similar argument could be made using power, exponential or Michaelis-Menton buildup functions

The effect of street cleaning is also obviously related to average interevent time. Clearly if the interval, CLFREQ, exceeds the storm interevent time, cleaning will have a decreasing effect. For example, for a continuous simulation of Des Moines, Iowa, street cleaning had essentially no effect for intervals greater than 20 days (Heaney et al., 1977). The average interevent time for Des Moines is about 4 days.

Should it be desired to evaluate the average interevent time for precipitation, the computer program SYNOP may be used to process the National Weather Service precipitation tapes. This is described in the EPA Area-wide Assessment Procedures Manual (EPA, 1976). Alternatively the SWMM Statistics Block may be used.

Total storm loads will be sensitive to washoff parameters as long as they do not already produce 100 percent washoff during most storms. For examples, in many SWMM applications in the past, parameters RCOEF and WASHPO (equation 4-51) were set to 4.6 in^{-1} and 1.0, respectively. This resulted in 90 percent washoff after 0.5 in (13 mm) of runoff (independent of the time, as discussed earlier). Since most applications of single event SWMM simulated storm events for which runoff was greater than 0.5 in (13 mm), total loads were insensitive to increases in RCOEF and relatively insensitive to decreases.

This may still be true for single event simulations of "large" storms (i.e., depths greater than 0.5 in or 13 mm). But during continuous simulation the median runoff depth is likely to be considerably less than 0.5 in (13 mm), more on the order of 0.2 in (5 mm). Hence washoff coefficients will be relatively more important for continuous simulation. As an indication of relative sensitivity, equation 4-36 can be rearranged for constant runoff rate, r, and for 90 percent washoff ($PSHED/PSHED_o = 0.1$) to give

$$RCOEF \cdot r^{WASHPO} \cdot t = RCOEF \cdot r^{WASHPO-1} \cdot d = -\ln 0.1 = 2.303 \quad (4\text{-}51)$$

where RCOEF = washoff coefficient, $in^{-WASHPO} \cdot hr^{WASHPO-1}$,
WASHPO = washoff power,
t = time (runoff duration), hr,
r = runoff rate, in/hr, and
d = storm runoff depth, in.

This relationship between RCOEF and WASHPO (linear on semi-log paper) is shown for d = 0.2 and 0.5 in (5 and 13 mm) on Figure 4-44 for various values of r. Note that for a half-inch of runoff, the familiar value for RCOEF of 4.6 is found for r = 1.0 in/hr or WASHPO = 1.0. The figure shows that for runoff rates less that 1.0 in/hr (25 mm/hr) RCOEF must be increased as WASHPO is increased to achieve the same percent washoff. The relationship is reversed for r > 1.0 in/hr, but runoff rates this high occur only over

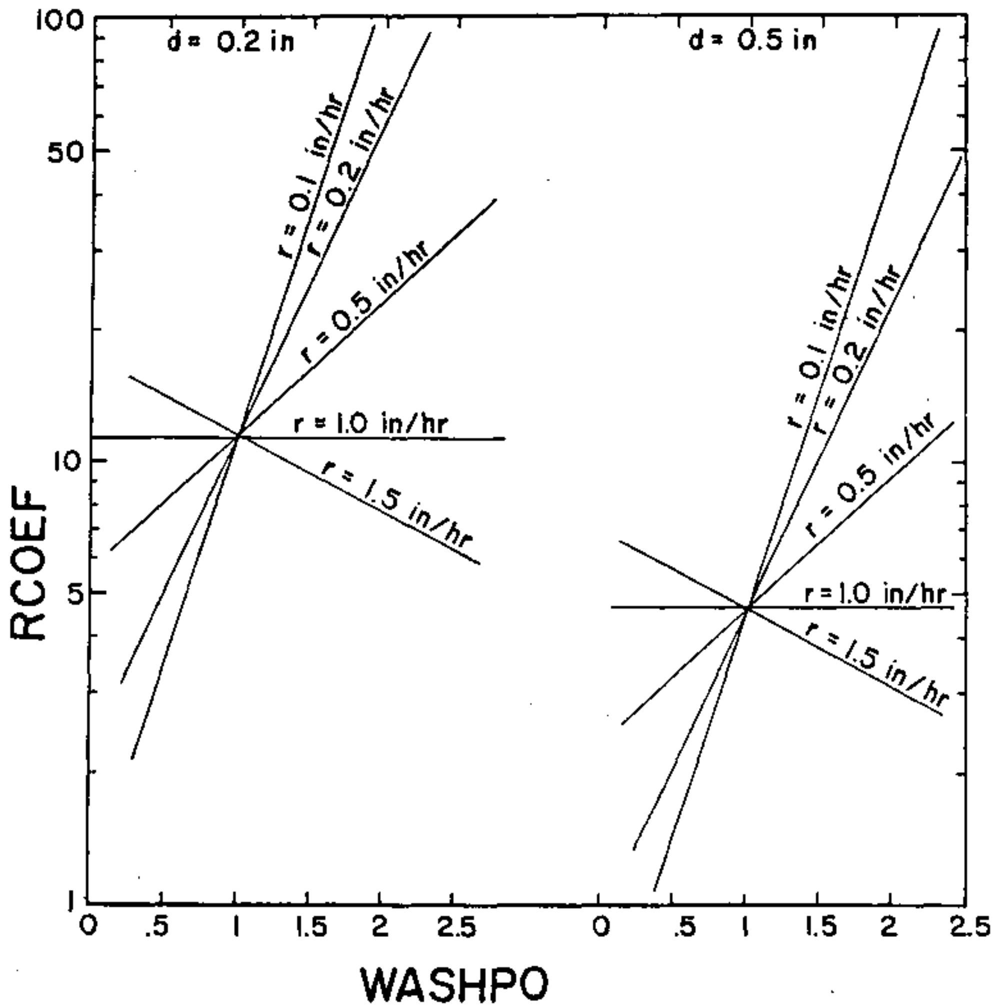

Figure 4-44. Relationship Between RCOEF and WASHPO for 90 Percent Washoff During a Storm Event of Runoff Depth d. The runoff rate is r.

brief intervals during a year. In fact, average hourly rainfall intensities greater than 1.0 in/hr are rarely found in precipitation records. Hence, during continuous simulation, if RCOEF or WASHPO is changed, the other parameter should be increased if the same percentage total washoff is desired. Manipulations similar to equation 4-51 may be performed if a different percentage washoff is being considered.

During single event simulation it may occasionally be important to match the pollutograph (concentration versus time) shape to measured data, as well as the total storm load. The effect of RCOEF and WASHPO on pollutographs has already been discussed and illustrated in Figures 4-32 to 4-36. Generally, if the data show that concentrations tend to increase with flow rate, especially late in the storm, then WASHPO should be greater than one.

If a rating curve approach is being used buildup parameters will have no effect (KWASH = 1) or little effect (KWASH = 2). In general, as WASHPO increases beyond 1.0, the predicted loads and concentrations will closely follow flow variations. If WASHPO is less than 1.0, concentration will be inversely proportional to flow.

As has been discussed, catchbasins have only a small effect on total storm load and affect pollutographs only during the first several time steps of a storm. Their main effect is to enhance the first flush, if there is one.

The constituent fractions (card group J4) are capable of having a large effect on a few constituents if those constituents have added to them a large loading. Thus, if suspended solids (SS) are high and five percent of SS is added to BOD, BOD can also be high without any surface loading. Since the fractions interrelate the constituents, it is often easier to calibrate the model without them, although it may be more physically realistic to include them.

Print Control (Card Groups M1 and M2)

Two types of printed output are available from the Runoff Block. Examples may be found subsequently in the section on case studies. Summary tables listing total flow volumes and quality loads by source are always printed. For continuous simulation options exist for the frequency of summaries (daily or monthly and annual) as indicated by parameter IPRDAY on card B1. Caution should be used in order not to produce excessive lines and pages of output.

The continuity check for quantity will ordinarily have an error of less than 1 percent, due to roundoff and the method of summing (numerically integrating) instantaneous flow rates. Should non-convergence messages be encountered, the continuity error could be somewhat higher.

The second type of output available is on a time step basis. Single event SWMM (ICRAIN = 0) will print output for desired locations for the total event duration. Since there is no limit on time steps, it is possible for this output to be lengthy. However, the number of time steps between printing may be varied using parameter INTERV on card M1.

For continuous simulation, time step print out is available for up to five specified time periods. The choice of these time periods must be made in advance and can be most reasonably accomplished by examination of the precipitation record prior to running the total continuous simulation. Recall that this is done by using ICRAIN = 4 for preprocessing of the precipitation (and temperature) records.

For single event simulation (ICRAIN = 0) all time step flows and concentrations are <u>instantaneous</u> values at the indicated time. (In previous SWMM versions they were averages over the preceding time step.) In addition to the time step values, the total load, and flow-weighted averages and standard deviations are printed for flow and each quality parameter.

For continuous simulation (ICRAIN > 0), <u>flows</u> are <u>time averages</u> over the previous time step. It was necessary to adopt this scheme to reduce large continuity errors that resulted when using a one hour time step for periods of a year or more. Computationally, the procedure is the same as outlined in Appendix V except that the average flow, Q, is found by insertion of the end-of-time-step depth, d_2, found by equation V-37 into the continuity equation V-33. This is the way the Runoff Block formerly computed all flows and results in very low continuity errors at the expense of other computational inconveniences.

The print control cards mark the end of Runoff Block input. A schematic of all required card input is given in Figure 4-45. Control is now returned to the Executive Block. For review of hydrographs and pollutographs and for ease of calibration, use of the graph routines described in Section 2 is highly recommended. Finally, continuous SWMM output may most conveniently be summarized using the Statistics Block.

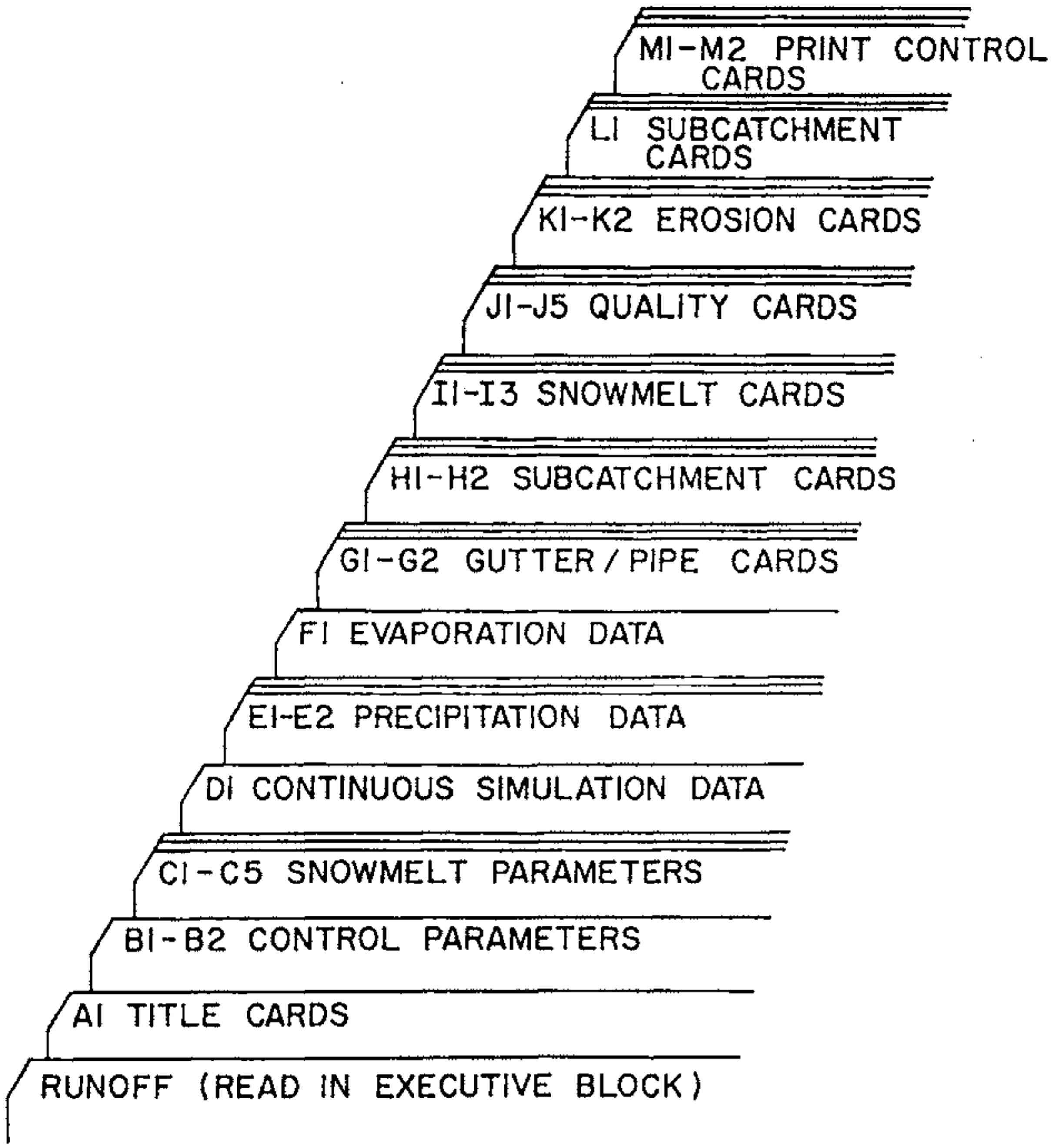

Figure 4-45. Data Deck for the Runoff Block

Table 4-28. Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			Two Title Cards		
A1	2X	1-2	Card group identifier = A1.	--	Blank
	19A4	3-78	Title, heading to be printed on output and carried to subsequent SWMM blocks (two cards.)	TITLE	Blanks
			First Control Card		
B1	2X	1-2	Card identifier = B1.	--	Blank
	I3	3-5	Continuous SWMM parameter.[1]	ICRAIN	0
			= 0, Single event SWMM, continuous SWMM not used.		
			Values greater than zero indicate continuous SWMM		
			= 1, Hourly precipitation values read as card images from National Weather Service (NWS) tape. Input unit is JIN(1) for NWS tape.		
			= 2, Processed hourly precipitation values (and temperatures if ISNOW = 2) are read from unit NSCRAT(2). These values were generated and saved from earlier run when ICRAIN = 1 or 4.		
			= 3, Read precipitation values from cards, using card groups E1 and E2. Not useable with snowmelt, i.e., ISNOW must equal zero.		
			= 4, Same as ICRAIN = 1, except that program stops after processing precipitation (and temperature) data. The only Runoff Block input parameters required are those needed for this processing.[2] Card input ceases after card D1.		

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
	I2	6-7	Metric input-output. = 0, Use U.S. customary units. = 1, Use metric units. Metric input indicated in brackets [ ] in remainder of Table 4-28.	METRIC	0
B1	I3	8-10	Snowmelt parameter[3] = 0, Snowmelt not simulated. = 1, Snowmelt simulation for single event SWMM. ICRAIN must equal zero. = 2, Snowmelt simulation for continuous SWMM, ICRAIN ≠ 0 or 3. When ICRAIN = 1 or 4, NWS temperature tape is input on unit NSCRAT(3). When ICRAIN = 2, use already processed precipitation and temperature data saved on NSCRAT(2).	ISNOW	0
	6I5	11-15	Number of hyetographs (rain gages) (maximum = 6, must be equal to only one for continuous SWMM).	NRGAG	1
		16-20	Choice of infiltration equation. = 0, Horton equation used. = 1, Green-Ampt equation used.	INFILM	0
		21-25	Quality (or erosion) simulated? = 0, No. = 1, Yes.	KWALTY	0
		26-30	Evaporation parameter.[4] = 0, Evaporation data not read in, default rate used of 0.1 in./day [3 mm/day].	IVAP	0

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			= 1, Read monthly evaporation data on Card F1.		
		31-35	Hour of day of start of storm (24-hour clock, midnight = 0). N.R. for ICRAIN ≠ 0.	NHR	0
		36-40	Minute of hour of start of storm. N.R. for ICRAIN ≠ 0.	NMN	0
	3(3X,I2)	41-45	Day of month of start of simulation.[5]	NDAY	1
		46-50	Month of start of simulation.[6]	MONTH	1
		51-55	Year of start of simulation.[5]	IYRSTR	None
	3I5	56-60	Print control parameter for NWS precipitation and temperature data, (continuous SWMM). Used (and useable) when ICRAIN = 1 or 4 only.	IRPRNT	0
			= 0, No print of any precipitation or temperature data.		
			= 1, All hourly precipitation data printed.[7] When snowmelt is run, prints only daily maximum and minimum temperatures, one year per page, 6 days per line.		
			= 2, All hourly precipitation data printed.[7] When snowmelt is run, all generated hourly temperatures are printed (including summer values), two lines per day, 29 days per page (See also Card D1).		
		61-65	Data set print control parameter. Used to print data sets generated while processing NWS precipitation and temperature data. Used only for possible debugging, and only for ICRAIN ≠ 1 or 4.	ICNTNS	0
			= 0, Not used.		
			= 1, Prints data set, NSCRAT(2), with hourly precipitation and temperature values on it. Prints 4 lines per day.		

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			= 2, Prints scratch data set of hourly temperatures only, 3 lines per day.		
		66-70	Print control for output of continuous SWMM,[8] (ICRAIN ≠ 0). "Totals" below refer to precipitation, runoff and all quality parameters, for each inlet, to a maximum of 30 inlets.	IPRDAY	0
			= 0, Monthly and annual totals only, one year per page.		
			= 1, Daily, monthly and annual totals, two months per page. Daily totals are printed whenever there is non-zero precipitation and/or runoff.		
			Second Control Card		
B2	2X	1-2	Card identifier = B2.	--	Blank
	I8	3-10	Number of time steps in simulation. No maximum.[9] Required when ICRAIN = 0. Optional for ICRAIN >0. If given as zero for ICRAIN >0, NSTEP will be computed using beginning and ending simulation dates.	NSTEP	0
	4F5.0	11-15	Integration period (time step), min. Must be 60 min for ICRAIN = 1,2, or 4.[10]	DELT	None
		16-20	Percent of impervious area with zero detention (immediate runoff).[11]	PCTZER	25.0
		21-25	For continuous SWMM, infiltration capacity is regenerated using a Horton type exponential rate constant equal to REGEN·DECAY, where DECAY is the Horton rate constant read in for each subcatchment in card group H1. N.R. if ICRAIN = 0 or INFILM = 1.	REGEN	0.01
	*** The following two parameters required only for ISNOW = 1. ***				
		26-30	Time interval between input of air temperatures in card group C5.	DTAIR	0.0
	I5	31-35	Number of air temperatures read in on card group C5.	NAIRT	0

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			General Snow Input Data		
			IF ISNOW = 0 ON CARD B1, SKIP TO CARD D1.		
C1	2X	1-2	Card identifier = C1.	--	Blank
	F8.0	3-10	Average watershed elevation, ft. [m] MSL.	ELEV	0.0
	9F5.0	11-15	Ratio of free water holding capacity to snow depth (in. or mm w.e.)[12] on snow covered impervious area.	FWFRAC(1)	0.0
		16-20	Ratio of free water holding capacity to snow depth (in. or mm w.e.) on snow covered pervious area.	FWFRAC(2)	0.0
			*** The following parameters are required only for *** ISNOW = 2 (continuous SWMM).		
		21-25	Ratio of free water holding capacity to snow depth (in. or mm w.e.) for snow on normally bare impervious area.	FWFRAC(3)	0.0
		26-30	Dividing temperature between snow and rain, °F [°C]. Precipitation occurring at air temperatures above this value will be rain, at or below will be snow.	SNOTMP	0.0
		31-35	Snow gage catch correction factor. Snow depths computed from NWS precipitation tape will be multiplied by this value.[13]	SCF	1.0
		36-40	Weight used to compute antecedent temperature index, 0 ≤ TIPM ≤ 1.0. Low values (e.g., 0.1) give more weight to past temperatures. Values ≧ 0.5 essentially give weight to temperatures only during the past day.	TIPM	0.0
		41-45	Ratio of negative melt coefficient to melt coefficient. "Negative melt coefficient" is used when snow is warming or cooling below the base melt temperature without producing liquid melt. RNM is usually ≦ 1.0 with a typical value of 0.6.	RNM	0.6

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
		46-50	Average latitude of watershed, degrees north.	ANGLAT	0.0
		51-55	Longitude correction, standard time minus mean solar time, minutes (of time).[15]	DTLONG	0.0
		The following parameter is not required if ICRAIN = 2 (precipitation/temperature data set has been already computed).			
	I5	56-60	National Weather Service (NWS) Station ID number for temperature tape, read in on NSCRAT(3). Program must find a match for this ID number.[15]	LOCAT3	None
			Monthly Wind Speeds		
		If ISNOW = 2, values are required for all months with potential snow melt.			
		If ISNOW = 1, value is required only for month of the event being simulated.			
C2	2X	1-2	Card identifier = C2.	--	Blank
	F8.0	3-10	Average wind speed in January, miles/hr [m/hr].	WIND(1)	0.0
	11F5.0	11-15	Average wind speed in February, miles/hr [m/hr].	WIND(2)	0.0
		. . .		. . .	
		61-65	Average wind speed in December, miles/hr [m/hr].	WIND(12)	0.0

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			IF ISNOW = 1, ON CARD B1, SKIP TO CARD GROUP C5		
			REQUIRED ONLY FOR ISNOW = 2		
			Areal Depletion Curve for Impervious Area[16]		
C3	2X	1-2	Card identifier = C3.	--	Blank
	F8.0	3-10	Fraction of area covered by snow (ASC) at "zero+"[17] ratio of snow depth to depth at 100 percent cover (AWESI).[18]	ADCI(1)	0.0
	9F5.0	11-15	Value of ASC for AWESI = 0.1.	ADCI(2)	0.0
		16-20	Value of ASC for AWESI = 0.2.	ADCI(3)	0.0
		. . .		. . .	
		46-50	Value of ASC for AWESI = 0.8	ADCI(9)	0.0
		51-55	Value of ASC for AWESI = 0.9.	ADCI(10)	0.0

Note: Program automatically assigns value of ADCI = 1.0 when AWESI = 1.0.

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			Areal Depletion Curve for Pervious Area[16]		
C4	2X	1-2	Card identifier = C4.	--	Blank
	F8.0	3-10	Fraction of area covered by snow (ASC) at "zero+"[17] ratio of snow depth to depth at 100 percent cover (AWESI).[18]	ADCP(1)	0.0
	9F5.0	11-15	Value of ASC for AWESI = 0.1	ADCP(2)	0.0
		16-20	Value of ASC for AWESI = 0.2	ADCP(3)	0.0
		. .		. .	
		46-50	Value of ASC for AWESI = 0.8	ADCP(9)	0.0
		51-55	Value of ASC for AWESI = 0.9	ADCP(10)	0.0

Note: Program automatically assigns value of ADCP = 1.0 when AWESI = 1.0.

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			Air Temperatures		
			READ CARD C5 ONLY IF ISNOW = 1. SKIP TO CARD D1 IF ISNOW = 2.		
			(For ISNOW = 2, (continuous SWMM) air temperatures are computed using NWS tapes). Read an air temperature for each time interval, ten values per card, for a total of NAIRT values. (Maximum number of values = 200.)		
C5	2X	1-2	Card group identifier = C5.	--	Blank
	F8.0	3-10	Air temperature during time interval 1, °F [°C].	TAIR(1)	0.0
	9F5.0	11-15	Air temperature during time interval 2, °F [°C].	TAIR(2)	0.0
		. . .		. . .	
		51-55	Air temperature during time interval 10, °F [°C].	TAIR(10)	0.0
			Repeat card C5 until NAIRT values are read in.		
			IF ICRAIN = 0 ON CARD B1, SKIP TO CARD E1		
D1	2X	1-2	Card identifier = D1.	--	Blank
	I3	3-5	Day simulation ends.[19]	DAYSTP	last day of month
	I5	6-10	Month simulation ends.[19]	MONSTP	12
	3X,I2	14-15	Year simulation ends.[19]	IYRSTP	IYRSTR
	I10	16-25	NWS station identification number.[15,19] Program must find a match for this ID number on JIN(1) (precipitation tape). Required only for ICRAIN = 1 or 4.	LOCAT1	None
	8A4	26-57	Station name.	RTITLE	Blank
			The following parameters required only to control print out of continuous temperature data, ICRAIN = 1 or 4, ISNOW = 2, IRPRNT = 2 or 3 (card B1).		

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			No temperature data printed during a year between these dates. (Use equal dates to print for all dates.)		
D1	3X,I3	61-63	Month to end print of temperature data.	MOT1	4
	I2	64-65	Day of month to end print of temperature data.	MDAY1	1
	I3	66-68	Month to resume print of temperature data.	MOT2	10
	I2	69-70	Day of month to resume print of temperature data.	MDAY2	1
			End of Runoff Block input if ICRAIN = 4		
			IF ICRAIN = 1 OR 2 ON CARD B1, SKIP CARDS E1 & E2		
			Rainfall Control Card		
E1	2X	1-2	Card identifier = E1	--	Blank
	I8	3-10	Number of data points for each hyetograph (Maximum = 200 for ICRAIN = 0 and NSCRAT(4) = 0, no limit for ICRAIN = 3 or NSCRAT(4) ≠ 0.)[20]	NHISTO	None
	F5.0	11-15	Time interval between values, min.[21]	THISTO	None
			REPEAT CARD GROUP E2 FOR EACH HYETOGRAPH, UP TO NRGAG TIMES		
			Rainfall hyetograph cards: Read 10 intensities per card, up to NHISTO values.		
E2	2X	1-2	Card group identifier = E2	—	Blank
	F8.0	3-10	Rainfall intensity, first interval, in./hr [mm/hr].	RAIN(1)	0.0
	9F5.0	11-15	Rainfall intensity, second interval, in./hr [mm/hr].	RAIN(2)	0.0
		16-20	Rainfall intensity, third interval, in./hr [mm/hr].	RAIN(3)	0.0

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
E2		. . .		. . .	
		51-55	Rainfall intensity, tenth interval, in./hr [mm/hr].	RAIN(10)	0.0
	Note:	IF ISNOW = 1, snowfall during a time step may be entered as a negative value. Units are in. [mm] water equivalent/hr.			
			SKIP THIS CARD IF IVAP ≠ 1 ON CARD B1		
F1	2X	1-2	Card identifier = F1.	--	Blank
	F8.0	3-10	Evaporation rate for month 1 (January), in./day [mm/day].	VAP(1)	0.0[22]
	11F5.0	11-15	Evaporation rate for month 2 (February), in./day [mm/day].	VAP(2)	0.0
		. . .		. . .	
		61-56	Evaporation rate for month 12 (December), in./day [mm/day].	VAP(12)	0.0
			REPEAT CARD G1 FOR EACH GUTTER/PIPE		
			Gutter/pipe cards: one card per gutter/pipe (if none, leave out). Maximum number of gutter/pipes plus inlets = 200.		
G1	2X	1-2	Card group identifier = G1	--	Blank
	I8	3-10	Gutter/pipe number. = +number, gutter/pipe ID number.[25] = -1, new ratios, or = -2, new default values for values with*.[24]	NAMEG[25]	None
	2I5	11-15	Gutter or inlet number for drainage. (Max. of 30 different inlets for continuous SWMM.)	NGTO[25,26]	None
		16-20	Gutter/pipe shape. = 1 for gutter, (trapezoidal channel). = 2 for circular pipe, = 3 for dummy gutter, inflow=outflow.[27]	NPG = NP	

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			The following parameters are N.R. if NP = 3		
G1	7F8.0	21-28	Bottom width of gutter[28], or pipe diameter, ft [m].	GWIDTH=G1*	0.0
		29-36	Length of gutter, ft [m].	GLEN=G2*	0.0
		37-44	Invert slope, ft/ft [dimensionless].	G3*	None
		45-52	Left-hand side slope, ft/ft [dimensionless]. } Horizontal/vertical.[29] N.R. if NP ≠ 1.	GS1 = G4*	None
		53-60	Right-hand side slope, ft/ft [dimensionless].	GS2 = G5*	None
		61-68	Manning's roughness coefficient.	G6*	None
		69-76	Depth of gutter when full, ft [m]. N.R. if NP ≠ 1.	DFULL=G7*	None
G2			Blank card (except for identifier) to terminate gutter cards: one card (must always be included).[30]		
			REPEAT CARD H1 FOR EACH SUBCATCHMENT		
			Subcatchment Data: (Maximum of 200 different subcatchments for single event SWMM, ICRAIN = 0, and 30 for continuous SWMM, ICRAIN ≠ 0).		
H1	2X	1-2	Card group identifier = H1.	--	Blank
	I3	3-5	Hyetograph number (based on the order in which they are input, in card group E2).	JK	1
	2I5	6-10	Subcatchment number = + number, subcatchment ID number, = -1, new ratio, or = -2, new default for values with *[24].	NAMEW[31]	None
		11-15	Gutter or inlet (manhole) number for drainage (max. 30 different inlets for continuous SWMM).	NGTO[25,32]	None

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
H1	8F5.0	16-20	Width of subcatchment, ft [m]. This term actually refers to the physical width of <u>overland flow</u> in the subcatchment and may be obtained as illustrated in the text.[33]	WW(1)*	None
		21-25	Area of subcatchment, acres [ha].	WAREA=WW(2)*	None
		26-30	Percent imperviousness of subcatchment, %.	WW(3)*	None
		31-35	Ground slope, ft/ft [dimensionless].	WSLOPE=WW(4)*	None
		36-40	Impervious area. } Roughness factor. (Manning's n)	WW(5)*	None
		41-45	Pervious area. } Roughness factor. (Manning's n)	WW(6)*	None
		46-50	Impervious area. } Depression storage, in. [mm].	WSTORE=WW(7)*	None
		51-55	Pervious area. } Depression storage, in. [mm].	WSTORE=WW(8)*	None
	*** Horton equation parameters if INFILM = 0 (Card B1) ***				
		56-60	Maximum (initial) infiltration rate, in./hr [mm/hr].	WLMAX=WW(9)*	None
		61-65	Minimum (asymptotic) infiltration rate, in./hr [mm/hr].	WLMIN=WW(10)*	None
	F10.5	66-75	Decay rate of infiltration in Horton's equation, 1/sec.	DECAY=WW(11)*	None
	*** Green-Ampt equation parameters if INFILM = 1 (Card B1) ***				
	2F5.0	56-60	Capillary suction, inches [mm] of water.	SUCT=WW(9)*	None
		61-65	Hydraulic conductivity of soil, in./hr [mm/hr].	HYDCON=WW(10)*	None
	F10.5	66-75	Initial moisture deficit for soil, volume air/volume voids.	SMDMAX=WW(11)*	None
H2			Blank card (except for identifier) to terminate subcatchment cards: one card.[30]		

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			IF ISNOW = 0, SKIP TO CARD J1. IF ISNOW = 1, READ ONLY CARD I1 AND TERMINATE WITH A BLANK CARD (CARD I3). IF ISNOW = 2, READ BOTH CARDS I1 AND I2, IN PAIRS, AND TERMINATE WITH ONE BLANK CARD (CARD I3). ORDER OF SUBCATCHMENTS MUST BE SAME AS IN CARD GROUP H1, AND THERE MUST BE SNOW DATA CARD(S) FOR EACH ONE. CAUTION - THERE IS A LIMIT OF 30 SUBCATCHMENTS WHEN ISNOW = 2.		
			NOTE THAT ALL SNOW DEPTH RELATED PARAMETERS REFER TO DEPTH OF SNOW WATER EQUIVALENT (in. w.e.)[12].		
			Subcatchment Snow Input Data		
I1	2X	1-2	Card group identifier = I1.	--	Blank
	I3	3-5	Subcatchment number.[34]	JK1[35](=NAMEW(N))[36]	None
			= + number, subcatchment ID number.[23] = -1, new ratio. = -2, new default value[24] for parameter with *.[37]		
	15F5.0	6-10	Fraction of impervious area with 100 percent snow cover (ISNOW = 1) or subject to areal depletion curve (ISNOW = 2).	SNN1	0.0
		11-15	Fraction of pervious area subject to 100 percent snow cover (ISNOW = 1). N.R. if ISNOW = 2.	SNN2=SNCP(N)	0.0
		16-20	Initial snow depth on impervious area that is normally snow covered, in. [mm] water equivalent (in. or mm w.e.)[12].	SNN3=WSNOW(N,1)	0.0
		21-25	Initial snow depth on pervious area, in. [mm] w.e.	SNN4=WSNOW(N,2)	0.0
		26-30	Initial free water on snow covered impervious area, in. [mm].	SNN5=FW(N,1)	0.0
		31-35	Initial free water on snow covered pervious area, in. [mm].	SNN6=FW(N,2)	0.0
		36-40	Melt coefficient (ISNOW = 1) or maximum melt coefficient, occurring June 21 (ISNOW = 2) for snow covered impervious area, in. w.e./hr-°F [mm w.e./hr-°C].	SN(1)*=DHMAX(N,1)	0.0

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
I1		41-45	Melt coefficient (ISNOW = 1) or maximum melt coefficient, occuring on June 21 (ISNOW = 2) for snow covered pervious area, in. w.e./hr-°F [mm w.e./hr-°C].	SN(2)*=DHMAX(N,2)	0.0
		46-50	Snowmelt base temperature for snow covered impervious area, °F [°C].	SN(3)*=TBASE(N,1)	0.0
		51-55	Snowmelt base temperature for snow covered pervious area, °F [°C].	SN(4)*=TBASE(N,2)	0.0
			READ CARD I2 ONLY FOR ISNOW = 2		
I2	2X	1-2	Card group identifier = I2.	--	Blank
	I3	3-5	Subcatchment number.[34] If JK2 =+ number, then JK2 = subcatchment number. If JK2 = -1, new ratio[23] or if JK2 -2, new default value for parameters with *[37].	JK2[35](=NAMEW(N))	None
	15F5.0	6-10	Initial snow depth on impervious[38] area that is normally bare,[12] in. [mm] w.e.	SNN7=WSNOW(N,3)	0.0
		11-15	Initial free water on impervious area that is normally bare, in. [mm].	SNN8=FW(N,3)	0.0
		16-20	Maximum melt coefficient, occurring on June 21 for snow on normally bare impervious area, in. w.e./hr-°F [mm w.e./hr-°C].	SN(5)*=DHMAX(N,3)	0.0
		21-25	Snowmelt base temperature for normally bare impervious area, °F [°C].	SN(6)*=TBASE(N,3)	0.0
		26-30	Minimum melt coefficient occuring on Dec. 21 for snow covered impervious area, in. w.e./hr.-°F [mm/w.e./hr-°C].	SN(7)*=DHMIN(N,1)	0.0
		31-35	Minimum melt coefficient, occurring on Dec. 21 for snow covered pervious area, in. w.e./hr-°F [mm w.e./hr-°C].	SN(8)*=DHMIN(N,2)	0.0
		36-40	Minimum melt coefficient, occurring on Dec. 21 for snow on normally bare impervious area, in. w.e./hr-°F [mm w.e./hr-°C].	SN(9)*=DHMIN(N,3)	0.0

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
I2		41-45	Snow depth above which there is 100 percent cover on snow covered impervious areas, in.[mm] w.e.[12].	SN(10)*=SI(N,1)	0.0
		46-50	Snow depth above which there is 100 percent cover on snow covered pervious areas, in.[mm] w.e.	SN(11)*=SI(N,2)	0.0
		51-55	Redistribution (plowing) depth on normally bare impervious area, in. w.e. Snow above this depth redistributed according to fractions below.	SNN9=WEPLOW(N)	0.0
			Redistribution (plowing) fractions. (See Figure 4-25.) Snow[38] above WEPLOW in. w.e. on normally bare impervious area will be transferred to area(s) indicated below. The five fractions should sum to 1.0.		
		56-60	Fraction transferred to snow covered impervious area.	SNN10=SFRAC(N,1)	0.0
		61-65	Fraction transferred to snow covered pervious area.	SNN11=SFRAC(N,2)	0.0
		66-70	Fraction transferred to snow covered[39] pervious area in last subcatchment.	SNN12=SFRAC(N,3)	0.0
		71-75	Fraction transferred out of watershed.	SNN13=SFRAC(N,4)	0.0
		76-80	Fraction converted to immediate melt on normally bare impervious area.	SNN14=SFRAC(N,5)	0.0
I3			Terminate card group I1 (or I1 and I2) with one blank card (except for identifier).[40]		

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			IF KWALTY ≠ 1 (CARD B1) SKIP TO CARD M1		
			General Quality Control Card		
J1	2X	1-2	Card identifier = J1.	--	Blank
	I3	3-5	Number of quality constituents, maximum = 10. Must have 1≤ NQS ≤ 9 if erosion is simulated (IROS =1).[41]	NQS	None
	3I5	6-10	Number of land uses, 1 ≤ JLAND ≤ 5.	JLAND	None
		11-15	Erosion simulation parameter.	IROS	0
			= 0, Erosion not simulated.		
			= 1, Erosion of suspended solids simulated using the Universal Soil Loss Equation. Parameters input in card group K1. Output will be last quality constituent (i.e., constituent NQS+1).[41]		
		16-20	Option to add erosion constituent to constituent number IROSAD. E.g., if IROSAD = 3, erosion will be added to constituent 3 (perhaps suspended solids). No addition if IROSAD = 0. N.R. if IROS = 0.[42]	IROSAD	0
	5F5.0	21-25	Number of dry days prior to start of storm. Must be >0 for ICRAIN >0 (continuous simulation).[43]	DRYDAY	0.0
		26-30	Average, individual catchbasin storage volume, ft^3 [m^3].	CBVOL	0.0
		31-35	Dry days required to recharge catch-basin concentrations to initial values (CBFACT, card group J3). N.R. if ICRAIN = 0. Must be > 0.	DRYBSN	1.0
		36-40	For erosion, highest average 30-minute rainfall intensity during the year (continuous SWMM) or during the storm (single event), in./hr. [mm/hr]. N.R. if IROS = 0.	RAINIT	0.0

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			*** Street Sweeping Parameters ***		
		41-45	Street sweeping efficiency (removal), for "dust and dirt" fraction.	REFFDD	0.0
			*** The following two variables are required only *** for ICRAIN ≠ 0 (continuous SWMM)		
	2I5	46-50	Day of year on which street sweeping begins (e.g., March 1 = 60)[44]	KLNBGN	0
		51-55	Day of year on which street sweeping stops (e.g., Nov. 30 = 334).[44]	KLNEND	367
			Land Use Cards		
			REPEAT FOR EACH LAND USE, TOTAL OF JLAND CARDS. (MINIMUM =1, MAXIMUM =5.) LAND USE 1 WILL BE THAT AT FIRST CARD, LAND USE 2 WILL BE THAT OF SECOND CARD, ETC.		
J2	2X	1-2	Card group identifier = J2.	--	Blank
	2A4	3-10	Name of land use.	LNAME(1,J) LNAME(2,J)	Blank
	2I5	11-15	Buildup equation type for "dust and dirt"[45] (see text). = -2, New default value,[23] or = -1, new ratio for parameters with *.[24] = 0, Power-linear. = 1, Exponential. = 2, Michaelis - Menton.	METHOD(J)	0
		16-20	Functional dependence of buildup parameters.[46] = 0, Function of subcatchment gutter length. = 1, Function of subcatchment area. = 2, Constant.	JACGUT(J)	0

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			*** Following are up to three buildup parameters.[45] *** (See Table 4-15)		
	3F10.0	21-30	Limiting buildup quantity.	DDLIM(J)*	10^{50}
		31-40	Power or exponent.	DDPOW(J)*	0.0
		41-50	Coefficient.	DDFACT(J)*	0.0
			Street Sweeping Parameters[47]		
	3F5.0	51-55	Cleaning interval, days.	CLFREQ(J)*	0.0
		56-60	Availability factor, fraction.	AVSWP(J)*	0.0
		61-65	Days since last cleaning, DSLCL $\leq$ CLFREQ.	DSLCL(J)*	0.0
			Constituent Cards		
			REPEAT FOR EACH CONSTITUENT, TOTAL OF NQS CARDS. (MAXIMUM =10.) CONSTITUENT 1 WILL BE THAT OF FIRST CARD, CONSTITUENT 2 THAT OF SECOND CARD, ETC.		
J3	2X	1-2	Card group identifier = J3.	--	Blank
	2A4	3-10	Constituent name.[48]	PNAME(1,K) PNAME(2,K)	Blank
	2A4	11-18	Constituent units.	PUNIT(1,K) PUNIT(2,K)	Blank
	I2	19-20	Type of units.[49]	NDIM(K)	0
			= 0, mg/l. = 1, "other"per liter, e.g., MPN/l. = 2, other concentration units, e.g., pH, JTU.		
	I3	21-23	Type of buildup calculation.[50]	KALC(K)	0
			=-2, New default value[24], or =-1, New ratio for paramters with *.[23] = 0, Buildup is fraction of "dust and dirt" for each land use.		

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			= 1, Power-linear constituent buildup. = 2, Exponential constituent buildup. = 3, Michaelis-Menton constituent buildup. = 4, No buildup required (with KWASH = 1).		
	I2	24-25	Type of washoff calculation.[50]	KWASH(K)	0
			= 0, Power-exponential. = 1, Rating curve, no upper limit. = 2, Rating curve, upper limit by buildup equation.		
	I3	26-28	Functional dependence of buildup parameters.[51] N.R. for KALC = 0 or 4.	KACGUT(K)	0
			= 0, Function of subcatchment gutter length. = 1, Function of subcatchment area. = 2, Constant.		
	I2	29-30	Linkage to snowmelt. N.R. if ICRAIN = 0 or ISNOW = 0 or KALC = 4.	LINKUP(K)	0
			= 0, Linkage to snow parameters. = 1, Constituent buildup during dry weather only when snow is present on impervious surface of subcatchment.[52]		
	Following are up to five buildup parameters (see text and Tables 4-16 & 4-17)				
	5F5.0	31-35	First buildup parameter, e.g., limit.	QFACT(1,K)*	0.0
		36-40	Second buildup parameter, e.g. power or exponent.	QFACT(2,K)*	0.0
		41-45	Third buildup parameter, e.g. coefficient.	QFACT(3,K)*	0.0
		46-50	Fourth buildup parameter, N.R. if KALC ≠ 0.	QFACT(4,K)*	0.0
		51-55	Fifth buildup parameter, N.R. if KALC ≠ 0.	QFACT(5,K)*	0.0
			Following are two washoff or rating curve parameters.		
	4F5.0	56-60	Power (exponent) for runoff rate.	WASHPO(K)*	0.0
		61-65	Coefficient, $(in/hr)^{-WASHPO} \cdot hr^{-1}$ $[(mm/hr)^{-WASHPO} \cdot hr^{-1}]$. For washoff, see Table 4-20 and equation 4-35. For rating curve see equation 4-38.	RCOEF(K)*	0.0

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			Miscellaneous parameters.		
		66-70	Initial catchbasin concentration.[53] (Units according to NDIM.)	CBFACT(K)*	0.0
		71-75	Concentration in precipitation.[54] (Units according to NDIM.)	CONCRN(K)*	0.0
		76-80	Street sweeping efficiency (removal) for this constituent, fraction.	REFF(K)*	0.0
			Fractions For Contributions From Other Constituents[55]		
			REPEAT THIS CARD UNTIL ALL DESIRED FRACTIONS ARE ENTERED. END WITH A BLANK CARD.		
J4	2X	1-2	Card group identifier = J4.	--	Blank
	I3	3-5	Number (from order in card group J3) of constituent <u>to</u> which fraction will be added.	KTO	0
	I5	6-10	Number of constitutent <u>from</u> which fraction is computed.	KFROM	0
	F10.0	11-20	Fraction of constitutent KFROM to be added to constituent KTO.	F1(KTO, KFROM)	0.0
J5			End this card group with a blank card (except for identifier).		
			Erosion Cards[56]		
			IF IROS = 0 ON CARD J1, SKIP TO CARD GROUP L1		
			REPEAT CARD K1 ONLY FOR EACH SUBCATCHMENT THAT IS SUBJECT TO EROSION COMPUTATIONS. ORDER OF CARDS IS ARBITRARY, BUT A MATCH MUST BE FOUND OF SUBCATCHMENT NUMBER WITH A VALUE OF NAMEW USED IN CARD GROUP H1.		
K1	2X	1-2	Card group identifier = K1.	--	Blank

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
	I8	3-10	Subcatchment number. = + number, subcatchment ID number. =-1, New ratio[23], or =-2, new default value[24] for values with*.	N=NAMEW	None
	5F5.0	11-15	Area of subcatchment subject to erosion, acres [ha].	ERODAR*	0.0
		16-20	Flow distance in feet [m] from point of origin of overland flow over erodible area to point at which runoff enters gutter or inlet.	ERLEN*	0.0
		21-25	Soil factor 'K'.	SOILF*	0.0
		26-30	Cropping management factor 'C'.	CROPMF*	0.0
		31-35	Control practice factor 'P'.	CONTPF*	0.0
K2			Terminate erosion input data with one blank card (except for identifier).[30]		
			Subcatchment Surface Quality Data Cards IF NQS = 0, SKIP TO CARD M1. ONE CARD FOR EACH SUBCATCHMENT IS REQUIRED. ORDER IS ARBITRARY, BUT A MATCH MUST BE FOUND FOR EACH SUBCATCHMENT NUMBER (NAMEW) USED EARLIER IN CARD GROUP H1.		
L1	2X	1-2	Card group identifier = L1	--	Blank
	I8	3-10	Subcatchment number = +number, subcatchment ID number. = -1, New ratio.[23] = -2, New default[24] for values with *.	N=NAMEW	None
	I5	11-15	Land use classification. Must have 1 ≤ KL ≤ 5. Numbers correspond to input sequence of card group J2.	KL	1

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
	F5.0	16-20	Number of catchbasins in subcatchment.	BA*=BASINS(N)	0.0
	F10.0	21-30	**Total curb length within subcatchments, hundreds of feet [km].** May not be required, depending on method used to calculate constituent loadings (card groups J2 and J3).[57] The following constituent loading values may be input as an alternative to computation of loadings via methods specified in card groups J2 and J3. For any non-zero values read in, initial constituent loadings will be calculated simply by multiplication of the value by the subcatchment area. "Load" has units depending on value of NDIM (card group J3), according to following table: NDIM — Load 0 — pounds [kg] 1 — 10^6 x quantity, e.g., 10^6 MPN 2 — 10^6 quantity x ft^3, e.g., 10^6 pH·ft^3	GQ*=GQLEN(N)	0.0
	10F5.0	31-35	Initial loading, first constituent, load/acre [load/ha].	PSHED(1,N)*	0.0
		36-40	Initial loading, second constituent, load/acre [load/ha].	PSHED(2,N)*	0.0
			. . .	. . .	
		76-80	Initial loading, tenth constituent (if used), load/acre [load/ha].	PSHED(10,N)*	0.0

Gutter/Inlet Print Control

Card Group	Format	Card Columns	Description	Variable Name	Default Value
M1	2X	1-2	Card identifier = M1.	--	Blank
	I3	3-5	Total number of gutters/inlets for which non-zero flows (and concentrations) are to be printed (maximum = 200).[58]	NPRNT	0

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
	I5	6-10	Number of time-steps between printings. (Use INTERV = 1 for printing at each time step.)	INTERV	None
			*** For continuous SWMM (ICRAIN = 1, 2, 3), detailed (time *** step) printing may be obtained for up to five different time periods. The following parameters N.R. if ICRAIN = 0, (printing will occur for the total simulation), or if NPRNT = 0.		
	10I6	11-16	For starting printout date, year, month day, e.g., October 2, 1949 = 491002.	STARTP(1)[59]	None
		17-22	First stopping printout date.	STOPPR(1)[59]	None
		23-28	Second starting date.	STARTP(2)	0
		29-34	Second stopping date.	STOPPR(2)	0
		35-40	Third starting date.	STARTP(3)	0
		41-46	Third stopping date.	STOPPR(3)	0
		47-52	Fourth starting date.	STARTP(4)	0
		53-58	Fourth stopping date.	STOPPR(4)	0
		59-64	Fifth starting date.	STARTP(5)	0
		65-70	Fifth stopping date.	STOPPR(5)	0
			IF NPRNT = 0, SKIP CARD M2		
			Gutter/Inlet Print Cards: 16 Values/Card (Same format for all cards)		
M2	2X	1-2	Card group identifier = M2.	--	Blank
	I3	3-5	Gutter/inlet numbers for which flows and concentrations are to be printed.	IPRNT(1)[60]	None
	15I5	6-10		IPRNT(2)	None

Table 4-28 (continued). Runoff Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
		11-15		IPRNT(3)	None
		.		.	
		.		.	
		.		.	
				IPRNT(NPRNT)	None

END OF RUNOFF BLOCK DATA CARDS

At this point, program will seek new input data from the Executive Block.

Footnotes to Table 4-28

1. The main difference between "single event" and "continuous" SWMM is basically that the latter uses data sets or offline storage (e.g., disks) for storage of precipitation (and temperature) input data instead of dimensioned arrays, thus eliminating any restriction on the number of time steps. With the slight exception of snowmelt, all computations are done identically for the two cases. In addition, continuous SWMM produces extra daily, monthly and annual summary output which single event SWMM does not. See also footnotes 9, 10, and 20.

2. This option may be used, for example, if it is desired to review the precipitation/temperature data prior to the simulation, perhaps for location of critical time periods for detailed output using card group M1. To avoid the expense of reprocessing the NWS tapes, output stored on unit NSCRAT(2) should be permanently saved for later use when ICRAIN = 2. This is done using appropriate job control language instructions. When ICRAIN = 4, only the following parameters are required on card groups A1 - D1; others may be left blank (zero), although the print out of zeros may be misleading. Required parameters (allowing for some default values) are: card A1, TITLE; card B1, ICRAIN (=4), ISNOW, INFILM, KWALTY, NDAY, MONTH, IYRSTR, IRPRNT, ICNTNS; card B2, DELT (=60.); card C1, ELEV, SNOTMP, SCF, ANGLAT, DTLONG, LOCAT3; card C2, none; card C3, none; card C4, none; card C5, none; card D1, DAYSTP, MONSTP, LYRSTP, LOCAT1, RTITLE. Input data end after card D1. The usual instructions for skipping card groups should be followed, e.g., if ISNOW = 0, skip card groups C1-C5.

3. The main differences between single event and continuous snowmelt simulation follow. For single event SWMM, snow covered areas are constant (areal depletion curves are used for continuous SWMM) and input parameters are fewer. In addition, snowfall quantities are not computed on the basis of air temperatures but may only be input, if desired, as negative precipitation intensities on card group E2. Melt coefficients are constant and there is no maintenance of the cold content of the snow pack, nor is there redistribution (e.g., plowing) from normally bare areas. For continuous SWMM, melt coefficients vary daily, from a maximum on June 21 to a minimum on December 21. Both modes use the same melt equations and melt routing procedures.

4. Evaporation is used to renew surface depression storage and is also subtracted from rainfall and/or snowmelt at each time step. It has a negligible effect on single event simulation, but is important for continuous simulation. Evaporation is <u>not</u> used to deplete the snow pack, i.e., it does not also act as sublimation, nor does it affect regeneration of infiltration capacity.

5. Used for information only for single event SWMM (ICRAIN = 0). This parameter does not affect computations, but it is passed to subsequent blocks.

6. Used as subscript for monthly wind speed and evaporation data (card groups C2 and F1).

7. Precipitation values printed one line per day, 57 days per page. A line is printed only for days with measureable precipitation and for the first day of each month.

8. Conventional output from card groups M1 and M2 may also be used with continuous SWMM.

9. There is now no limit on the number of time steps for any SWMM block. However, the allowable number of input values for precipitation and temperature data may provide an effective limit of 200 time steps in some cases. See card groups C5 and E2. When ICRAIN =1 or 4, (optional for ICRAIN = 3) NSTEP will be calculated by program on the basis of nearest precipitation (and temperature) data to specified beginning and ending dates. (Ending date will always be reached, using zeroes for missing precipitation and temperatures at end of record, if required.) Note that continuous SWMM will always start and stop at midnight, such that computations are done for groups of whole days. If ICRAIN = 2, (use previously processed and saved precipitation and, possibly, temperature values), NSTEP must still be input and must be less than or equal to value printed in output from prior run using ICRAIN = 1 or 4.

10. A 60 minute time step must be used when accessing National Weather Service (NWS) tapes (ICRAIN = 1, 2, or 4) since they provide hourly data, and the program is not equipped to average over longer time steps or to treat the hourly values as a step function for shorter time steps. This restriction, however, is due only to I/O complexity; all computations use DELT as a variable.

    When ICRAIN = 3, no use is made of NWS tapes. DELT is arbitrary for this case.

    The nonlinear reservoir routing procedures used for subcatchment overland flows and gutter/pipe flows is unconditionally stable and independent of the time step. However, problems of convergence arise occasionally for gutter/pipe routing when too large a time step is used. These take the form of error messages printed from subroutine GUTTER, and usually mean that flow values computed at one or a few time steps are slightly in error. It may also result from an attempt to produce a negative outflow, necessary to satisfy continuity, but not allowed by the program. These problems can usually be eliminated by shortening the time step (e.g. reduce DELT from, say, five minutes to two and one-half minutes), or, by increasing the volume of the offending gutter/pipe (i.e., increase the length and/or the width/diameter). The latter option would be the only recourse when using continuous SWMM with a 60 minute time step; however, gutter/pipes will seldom be used at all with continuous SWMM, thus avoiding any such problem.

Convergence problems almost never occur in the subcatchment overland flow routing. If nonconvergence messages are encountered from subroutine WSHED, however, the time step could be shortened or subcatchment area increased.

See also footnotes 1, 9 and 21.

11. This parameter allows immediate runoff, prior to filling depression storage on impervious areas. As PCTZER is increased, the rising limb of the hydrograph steepens.

12. All snow depths are in inches [or mm] of water equivalent, "in. [mm] w.e." One inch of snow water equivalent equals a depth of approximately 11 inches of new snow on the ground surface.

13. Values of SCF are usually > 1.0 and increase as a function of wind speed. See Figure 4-2. The value of SCF can also be used to account for snow losses, such as interception and sublimation, not included in program computations.

14. Compute DTLONG as follows: Determine standard meridian (SM) for time zone of catchment (e.g., EST = 75°W, CST = 90°W, MST = 105°W, PST = 120°W). Let Θ = average longitude of catchment and $\Delta = \Theta - SM$. Then DTLONG = 4 min/deg x Δ. Example: Minneapolis at Θ = 93°W has DTLONG = +12 min.

15. The NWS station ID for the temperature tape is not necessarily the same as for the precipitation tape.

16. See Figures 4-4 and 4-5 for description of areal depletion curve.

17. Value of ADC may = zero, but curve need not pass through (0,0); see Figure 4-4. Thus ADC can take on an arbitrary value for a small departure of AWESI from zero.

18. In program, AWESI is the ratio of actual snow depth (WSNOW) to depth at 100 percent cover (SI, read in card group I2).

19. Values are used computationally only for ICRAIN = 1 or 4. When ICRAIN = 2 or 3, ending date may be optionally determined from value of NSTEP. Card is required for continuous SWMM for these cases only to be able to print out values on card.

20. Scratch file number 2, NSCRAT(2), is used for storage of processed rainfall data for continuous simulation. NSCRAT(4) may also be used for this purpose for single event simulation, thus eliminating the restriction of 200 rainfall values imposed by the rainfall array dimension.

21. THISTO must be the same or an integer multiple of DELT (card B2) or vice versa. (If DELT is an integer multiple of THISTO, the rainfall values are averaged over the time step, DELT.)

22. If this card is read, the default value of 0.1 in./day [3 mm/day] indicated on card B1 no longer applies, i.e., the default value becomes zero.

23. Input values on this card indicated with asterisks are multiplied by ratios, initially set equal to 1.0. If the ID number = -1, non-zero data entries for parameters with asterisks will replace old values of the ratios. Ratios may be altered or reset to 1.0 any number of times. The intention of the use of ratios is to simplify sensitivity analyses, etc., by allowing easy changes of data values without repunching data cards. Ratios may be reset any number of times and alter the indicated ratios to be applied to all following data cards (until another ratio card is encountered).

24. Input parameters on this card indicated with asterisks will take on default values if input values are zero. If the ID number = -2, non-zero data entries for parameters with asterisks will become new default values for all future entries of these parameters. Default values may be altered or reset to their original values (except zero) any number of times. The indicated default values apply to all following data cards (until another default card is encountered).

    It is not possible to reset a default value exactly to zero since only non-zero values are changed. However, the value may be made arbitrarily small by using E-format data entries. For example, 1E-50 will be read as 10^{-50} in an F5.0 format.

25. Numbers may be arbitrarily chosen, such that 1 $\leq$ NAMEG or NGTO $\leq$ 9999. However, if an inlet number is to correspond to an inlet manhole in the Transport Block, it must be $\leq$ 1000. The maximum total number of inlets must be $\leq$ 80 for input to Transport, $\leq$ 180 for input to Extended Transport, $\leq$ 50 for input to Receive. There is no restriction for input to Storage/Treatment except that the block will select only one of the inlets on the interface file for input. Others will be saved but ignored. Gutter/pipe numbers and inlet numbers are contained in the same array and thus must be distinct from one another; however, they may duplicate subcatchment numbers if desired. Each inlet is assigned a dummy gutter/pipe to receive upstream flows. Hence, the total number of gutter/pipes plus

inlets must be $\leq$ 200. Internal subscripts in the program for gutter/pipe data are assigned in the order in which cards in card group G1 are read in.

Of course it makes no sense to indicate a gutter/pipe with nothing entering it. Thus, each one should have flow entering, either from other gutter/pipe(s) or from subcatchment(s).

26. A maximum of five different gutter/pipes may feed to a single gutter/pipe or to a single inlet. If more are desired, a dummy gutter/pipe may be used to provide five additional "feeds". See footnote 27.

27. Dummy gutters may be used for two purposes: 1) to provide five additional "feeds" to a given gutter/pipe or inlet (see footnote 26) by placing it in series with the gutter/pipe or inlet (although, of course, by placing it in series with the original gutter/pipe or inlet, it uses one of the original five "feeds"), or 2) to provide a location for print out of data. The latter situation arises because outflows from subcatchments may not be printed directly (using card groups M1 and M2), only inflows or outflows to gutter/pipes or inflows to inlets. Hence, if a dummy gutter/pipe is placed immediately downstream from a subcatchment, the inflow (or outflow) to the dummy gutter/pipe is the outflow from the subcatchment, (provided that that is the only subcatchment feeding the dummy gutter/pipe).

28. A bottom width of zero for a gutter corresponds to a triangular cross section.

29. A side slope of zero indicates a vertical wall.

30. Check for blank card is to see if ID number equals zero.

31. Numbers may be arbitrarily chosen such that 1 $\leq$ NAMEW $\leq$ 9999 except that when snow melt is simulated (ISNOW > 0), numbers must be $\leq$ 999 since they are read by an I3 format in card groups I1 and I2. Numbers may duplicate gutter/pipe and inlet numbers if desired. Internal subscripts in the program for subcatchment data are assigned in the order in which cards in card group H1 are read in.

32. A maximum of five different subcatchments may feed to a single gutter/pipe or to a single inlet, (in addition to gutter/pipes feeding the gutter/pipe or inlet). If more "feeds" are desired, a dummy gutter/pipe may be used to provide additional feeds. See footnote 27.

33. The subcatchment width is a key calibration parameter, one of the few that can significantly alter the shape of the hydrograph,

rather than just the runoff volume. One way to think of the width is the area of the subcatchment divided by the average path length of overland flow (see Figure 4-13). The effect upon output hydrographs is illustrated in Figure 4-15 and is approximately as follows. For rainfall durations less than the time of concentration, (i.e., less than the equilibrium time of an impervious subcatchment, at which inflow equals outflow), increasing the width effectively provides a greater cross sectional area for outflow from the subcatchment, thus increasing the magnitude of the peak flow and decreasing the time to peak. Decreasing the width has the opposite effect, and the subcatchment surface acts more as a reservoir, reducing and delaying the peak. For rainfall durations greater than the time of concentration, the magnitude of the peak is affected only minutely. The time to equilibrium conditions, that is, the time of concentration, is reduced slightly for larger widths.

The subcatchment width can thus be used to incorporate storage lost when pipes are removed from the simulation. For instance, if only a coarse discretization of the total catchment is desired, only a few or no pipes need be modeled. To account for this lost storage in the system, the overall subcatchment width is correspondingly reduced (see Figure 4-20). Whether for one aggregated catchment or for a small individual subcatchment, a reasonable approximation for determining the width is to use twice the length of the <u>main</u> drainage channel in the catchment (see Figure 4-20).

The same subcatchment width entered here is used for the pervious area of the subcatchment and the total impervious area of the subcatchment (see Figure 4-11).

34. Subcatchment number(s) entered on cards I1 and I2 must correspond exactly to numbers and order of card group H1.

35. Numbers JK1 and JK2 must be the same.

36. Subscript N is the internal subcatchment number (subscript) determined from the order in which subcatchment data are entered in card group H1.

37. Default value/ratio test is on parameter JK1. If JK1 = -1 or -2, then <u>both</u> cards I1 and I2 will be treated as changes of default values/ratios.

38. "Normally bare" implies surfaces such as roadways and sidewalks that receive snowfall, but are subject to early snow removal.

39. "Last subcatchment" is last one entered in card group H1.

40. Test for blank card (zero) is on parameter JK1.

41. The 10 or fewer constituents may be arbitrarily chosen (see text). When erosion is simulated it is stored as the last constituent. Hence, no more than 9 constituents may be simulated while using the erosion routine. Furthermore, at least one constituent must be simulated in addition to erosion in order to proceed correctly through program loops.

42. This addition is performed before constituent fractions are added (card group J4).

43. A "dry day" is not well defined, but may be considered as the number of days prior to start of simulation, in which the cumulative rainfall is less than a specified value, e.g., 0.1 in. (3 mm).

44. Not required for ICRAIN = 0. For year-round sweeping, let KLNBGN = 0 and KLNEND = 367. Leap years are not treated separately, other than in maintaining the proper number of days in February and in total annual days.

45. See the text for explanation and illustration of the various options for buildup of dust and dirt. Depending on the form of buildup chosen for each constituent (card group J3), the land use buildup parameters may not be required.

46. If JACGUT = 0, parameters DDLIM and DDFACT will be multiplied by GQLEN (card group L1) in 100-ft. If JACGUT = 1, parameters DDLIM and DDFACT will be multiplied by WAREA (card group H1) in acres.

47. For continuous simulation, street sweeping occurs at intervals of CLFREQ days, computed during the simulation using dry time steps only (no runoff and no unmelted snow on normally bare impervious areas). When cleaning occurs, a fraction of each pollutant, REFF·AVSWP, is removed from each subcatchment. The availability factor AVSWP, is intended to account for the relative amount of subcatchment surface that consists of streets, and therefore may be swept. See text.

    At start of single-event and continuous simulations, streets are swept approximately DRYDAY/CLFREQ times, each time removing a fraction REFF·AVSWP. Parameter DSLCL establishes proper backwards time sequence.

48. The constituent names and units established in this card group will be carried through to subsequent SWMM blocks. See Figure 4-26 for illustration of how the A-format names and units will appear as headings.

49. Since most constituents are measurable in mass units, NDIM = 0 will be the most common. Since concentrations will be printed using an F10.3 format, NDIM = 0 should suffice also for constituents whose concentrations are usually given in µg/l. The value of NDIM basically affects conversion factors used in the program.

50. See the text for full explanation of buildup-washoff equation options and interpretation of parameters.

51. If KACGUT = 0, parameters QFACT(1,K) and QFACT(3,K) will be multiplied by GQLEN (card group L1) in 100-ft [km]. If KACGUT = 1, parameters QFACT(1,K) and QFACT(3,K) will be multiplied by WAREA (card group H1) in acres [ha].

52. For instance, if chlorides are simulated, they might be only applied for street salting when snow is present. The rate of buildup will not be a function of the amount of snow, however.

53. For continuous SWMM, concentrations will be regenerated to this value during dry time steps over a period of DRYBSN days, (DRYBSN entered on card J1).

54. This concentration is assumed to be that of the runoff (and snowmelt) before adding washoff loads. The precipitation load is always added regardless of the washoff mechanism utilized, unless of course, CONCRN = 0.

55. After computing and summing all loads except rainfall, a fraction of any constituent may be added to any other. (No fractions are removed, however.) This is intended to account for insoluble BOD etc. if surface loadings are based only on insoluble portions, as is true, for instance, for 1969 APWA data from Chicago. For instance, 5 percent of suspended solids could be added to BOD. Alternatively, different particle size ranges could be generated as different constituents, and other constituents could consist of fractions of the first group of different particle sizes. When these fractions are used, concentrations can be drastically (and subtly) increased if, for instance, suspended solids are high, soluble BOD is low and a fraction of 0.05 is used. The choice of whether or not any fractions should be entered depends upon how constituent data are being reported (e.g. total BOD or only the soluble fraction) and on how it is desired to simulate each constituent in SWMM.

56. See text for explanation of method of computation, parameters and typical values. Also, there may be a need to consult with local Soil Conservation Service or Agricultural Research Service or state agricultural extension service experts for knowledge of parameter values for particular areas.

    A value of the "sediment delivery ratio" is sometimes included in the U.S.L.E. computation. Since it is merely another multiplier, if desired, it may be incorporated into the "K" or "C" or "P" factors.

57. See footnotes 46 and 51. This is the only use of parameter GQLEN.

58. Zero flows are not printed to avoid voluminous output with continuous SWMM. (There are no quality loads when flows are zero). Thus, some care should be taken in examining the output, since if a zero flow occurs in the middle of a single-event simulation, for instance, it will not be listed. This can be determined by inspecting the sequential time of day printed with each set of values.

    Care should still be taken when running continuous SWMM, since one line of output will be generated for each hourly value of non-zero flow, for each indicated location, within the indicated time span. Hence, the potential exists for thousands of lines of output.

59. All printed values are instantaneous (flows and concentrations) at the end of the preceding time step.

60. These numbers correspond to numbers NAMEG and NGTO used in card groups G1 and H1. They may be either positive or negative. A positive number will cause the total inflows to the indicated gutter/pipe or inlet to be printed. A negative number will cause the outflow to be printed. (Both a positive and negative value for the same location may be used). Regardless of the sign, only outflow concentrations are printed, however, since it is computationally inconvenient to calculate the average inflow concentration. Of course, for an inlet (or dummy gutter/pipe), inflow values equal outflow values.

SECTION 5

EXTENDED TRANSPORT BLOCK

Following development of the original SWMM model, Water Resources Engineers (now, Camp, Dresser and McKee) participated in a study of the proposed master plan for control of combined sewer overflows in San Francisco. In order to analyze the complex hydraulics of that system, they developed the WRE Transport Model (Shubinski and Roesner, 1973), one that solves the coupled complete St. Venant equations and accounts for phenomena such as backwater, looped connections, surcharging and pressure flow that were either not considered or treated in a very simplified manner in the original Transport Model (Section 6). Through subsequent work for EPA in other cities the WRE Transport Model was acquired for the SWMM package and became known as the Extended Transport Model or Extran. This model has few peers in its capacity for simulation of the hydraulics of urban drainage system and is probably the most sophisticated such model that is non-proprietary and available in the public domain. (Similar proprietary models do exist.) Extran capabilities are compared with those of Runoff and Transport in Table 4-3.

Extran has been part of the SWMM package since 1976. However, it has been rather poorly documented and the quality portion has never been used. In fact, the only (but very extensive) use for the model has been for hydraulic analysis, and the quality routing has been formally removed from the program. The state of the art in urban runoff quality modeling is such that adequate simulation of pollutographs may be performed using the simpler hydraulics of the Runoff and Transport Blocks.

Comprehensive new documentation of Extran for this Version III of SWMM has been prepared by Camp, Dresser and McKee and is included as a separate addendum to this User's Manual (Roesner et al., 1981). Full details of the model are available therein. Interfacing between Extran and the remainder of SWMM is performed as described in Section 2.

SECTION 6

TRANSPORT BLOCK

BLOCK DESCRIPTION

Introduction

Flow routing through the sewer system may be accomplished in the Storm Water Management Model (SWMM) by subroutine TRANS which is called from the Executive Block program. TRANS has the responsibility of coordinating not only routing of sewage quantities but also such functions as routing of quality parameters (subrouting QUAL), estimating dry-weather flow (DWF) (subrouting FILTH), estimating infiltration (subroutine INFIL), and calling internal storage (subroutine TSTRDT). The relationships among the subroutines which make up the Transport Block are shown in Figure 6-1. The program is about 5,000 cards long, consisting of 24 subroutines and functions.

This section describes the Transport Block, provides instructions on data preparation, and furnishes examples of program usage. Instructions are provided for these subroutines requiring card input data, namely: transport, internal storage, infiltration, and DWF. Examples, with sample I/O data, are given for transport, infiltration, and DWF computations.

Broad Description of Flow Routing

Differences in flow routing techniques among the Runoff, Transport and Extended Transort Blocks were described in Section 4 (e.g., Table 4-3); the techniques increase in complexity in the order just listed. A brief description of techniques used in the Transport Block follows.

To categorize a sewer system conveniently prior to flow routing, each component of the system is classified as a certain type of "element." All elements in combination form a conceptual representation of the system in a manner similar to that of links and nodes. Elements may be conduits, manholes, lift stations, overflow structures, or any other component of a real system. Conduits themselves may be of different element types depending upon their geometrical cross-section (e.g., circular, rectangular, horseshoe). A sequencing is first performed (in subroutine SLOP) to order the numbered elements for computations. Flow routing then proceeds downstream through all elements during each increment in time until the storm hydrographs have been passed through the system.

The solution procedure is described in detail in the original SWMM documentation (Metcalf and Eddy et al., 1971a) and basically follows a kinematic wave approach in which disturbances are allowed to propagate only

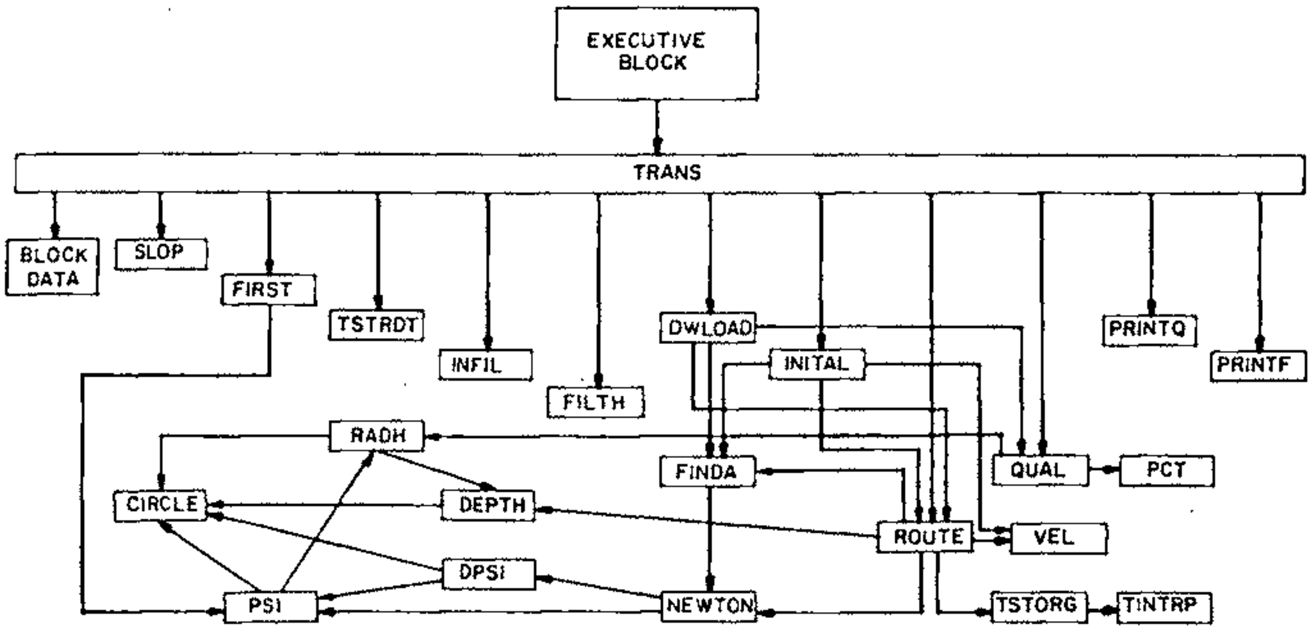

Figure 6-1. Structure of Transport Block Subroutines

in the downstream direction. As a consequence, backwater effects are not modeled beyond the realm of a single conduit, and downstream conditions (e.g., tide gates, diversion structures) will not affect upstream computations. Systems that branch in the downstream direction can be modeled using "flow divider" elements to the extent that overflows, etc., are not affected by backwater conditions. Surcharging is modeled simply by storing excess flows (over and above the fullflow conduit capacity) at the upstream manhole until capacity exists to accept the stored volume. Pressure-flow conditions are not explicitly modeled and no attempt is made to determine if ground surface flooding exists. However, a message is printed at each time step for each location at which surcharging occurs. The Transport Block has proven its ability to model accurately flows in most sewer systems, within the limitations discussed above, and as such it should be adequate for most applications. However, it will not accurately simulate systems with extensive interconnections or loops, systems that exhibit flow reversals or significant backwater effects, or systems in which surcharging must be treated as a pressure-flow phenomenon; the Extended Transport Block should be used for this purpose (Section 5).

An option in the program is the use of the internal storage model which acts as a transport element. It is a scaled-down version of the Storage/Treatment Block (Section 7) and provides the possibility of storagerouting of the storm at one or two separate points within the sewer system (restricted by computer core capacity). The program routes the flow through the storage unit for each time step based on the continuity equation in a manner analogous to flood routing through a reservoir. Extensive backwater conditions may thus be modeled by treating portions of the sewer system as a storage unit with a horizontal water surface.

Broad Description of Quality Routing

Up to four contaminants are also handled by the Transport Block. Constituents may be introduced to the sewer system by any combination of four means:

1) Storm-generated pollutographs computed by an upstream block[a] are transferred on tape/disk devices (the interface file of Section 2) to enter the system at designated inlet manholes.

2) Storm-generated pollutographs may be entered on cards at designated inlet manholes.

3) Residual bottom sediment in the pipes may be resuspended due to the flushing action of the storm flows (subroutine DWLOAD).

4) For combined systems, dry-weather flow pollutographs (subroutine FILTH) may be entered at designated inlet manholes.

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[a]The Transport Block can receive inputs from the Runoff, Storage/Treatment, Extran, and Transport Block itself.

The routing of the pollutants is then done for each time step by subroutine QUAL. The maximum number of contaminants that can be routed is four. These may be selected arbitrarily from the input file, except that the FILTH routine can only be used to generate suspended solids, BOD_5 and total coliforms. The scour/deposition routines may be used for any constituent.

Program Operation

Most of the input to TRANS is related to data needed to describe the particular sewer system being modeled (e.g., dimensions, slopes, roughnesses, etc.) and parameters needed to solve the governing flow routing equations.

Following input of these data, the sewer elements are sequenced for computations in subroutine SLOP. Certain geometric and flow parameters are then initialized in subroutine FIRST while others are initialized in TRANS. The various program parameters and initialized variables describing the elements are then printed. Parameters relating to the amount of data to be stored and printed out are also read (from cards).

If indicated, infiltration values will be calculated in subroutine INFIL and DWF quantity and quality parameters will be calculated in subroutine FILTH. Alternatively, user supplied values may simply be input at any manhole location. If desired, subroutine DWLOAD then initializes constituent depositions, and subroutine INITAL initializes flows and pollutant concentrations in each element to values corresponding to a condition of dry-weather flow and infiltration only.

The main iterations of the program consist of an outer loop on time steps and an inner loop on element numbers in order to calculate flows and concentrations in all elements at each time step. Inlet hydrographs and pollutograph ordinates are read from the interface file and/or cards to permit linear interpolation for values at each time step prior to entering the loop of element numbers.

When in the loop on element numbers (with index I), the current sewer element through which flows are to be routed, indicated by the variable M, is determined from the vector JR(I). This array is calculated in subroutine SLOP in a manner to insure that prior to flow routing in a given element, all flows upstream will have been calculated.

When calculating flows in each element, the upstream flows are summed and added to surface runoff, DWF, and infiltration entering at that element. These latter three quantities are allowed to enter the system only at non-conduits (e.g., manholes, flow dividers). If the element is a conduit, a check for surcharging is made. If the inflow exceeds the conduit capacity, excess flow is stored at the element just upstream (usually a manhole) and the conduit is assumed to operate at full-flow capacity until the excess flow can be transmitted. A message indicating surcharging is printed.

A simple hydraulic design routine is available at this point. If desired (NDESN = 1), when a surcharge condition is encountered, the conduit will be increased in size in standard increments (for circular pipes) or in six-inch width increments for rectangular conduits until capacity exists to accept the flow. (Conduits that are neither circular nor rectangular will be converted to circular if they need to be resized.) A message is printed indicating the resizing, and a table of final conduit dimensions is printed at the end of the simulation. This design operation will effectively eliminate surcharging but will also minimize in-system storage within manholes, etc. The net effect is to increase hydrograph peaks at the downstream end of the system. An obvious conflict can thus exist between controls aimed at curing in-system hydraulic problems and controls intended for pollution abatement procedures at the outfall.

Flows are routed through each element in subroutine ROUTE and quality parameters are routed in subroutine QUAL. When routing flows in conduits, ROUTE may be entered more than once depending upon the value of ITER, the number of iterations. It is necessary to iterate upon the solution in certain cases because of the implicit nature of calculating the energy grade line in ROUTE.

Upon completion of flow and quality routing at all time steps for all elements, TRANS then performs the task of outputting the various data. Hydrograph and pollutograph ordinates for any specified outfall point(s) may be written onto an interface file for further use by the Executive Block, and subroutine PRINTQ (or PRINTF for flows only) is then called for printing outflows for any of up to 80 desired elements.

Off-Line Files

The Transport Block uses two scratch data sts, NSCRAT(1) and NSCRAT(2), for storage of input and output hydrographs and pollutographs prior to printing. These are specified in the Executive Block using job control language (JCL) appropriate to the computer system. No input data will be sought from the interface file (Section 2) if JIN = 0, and no output will be placed on the file if JOUT = 0.

INSTRUCTIONS FOR DATA PREPARATION

Introduction

Instructions for data preparation for the Transport Block have been divided along the lines of the major components for clarity of the presentation. These components are: (1) Transport, (2) Quality, (3) Internal Storage, (4) Infiltration and (5) Dry-Weather Flow. All data input card and tape/disk sources enter the Transport Block through one of these components. The typical data deck setup for the complete Transport Block is shown in Figure 6-2. Transport data describe the physical characteristics of the conveyance system. Quality data identify pollutants to be routed and their characteristics. Internal Storage data describe a particular type of Transport element. Infiltration and DWF data describe the necessary drainage area characteristics to permit the computation of the respective inflow quantities and qualities. Data card preparation and sequencing instructions for the complete Transport Block are given at the end of these instructions in Table 6-6.

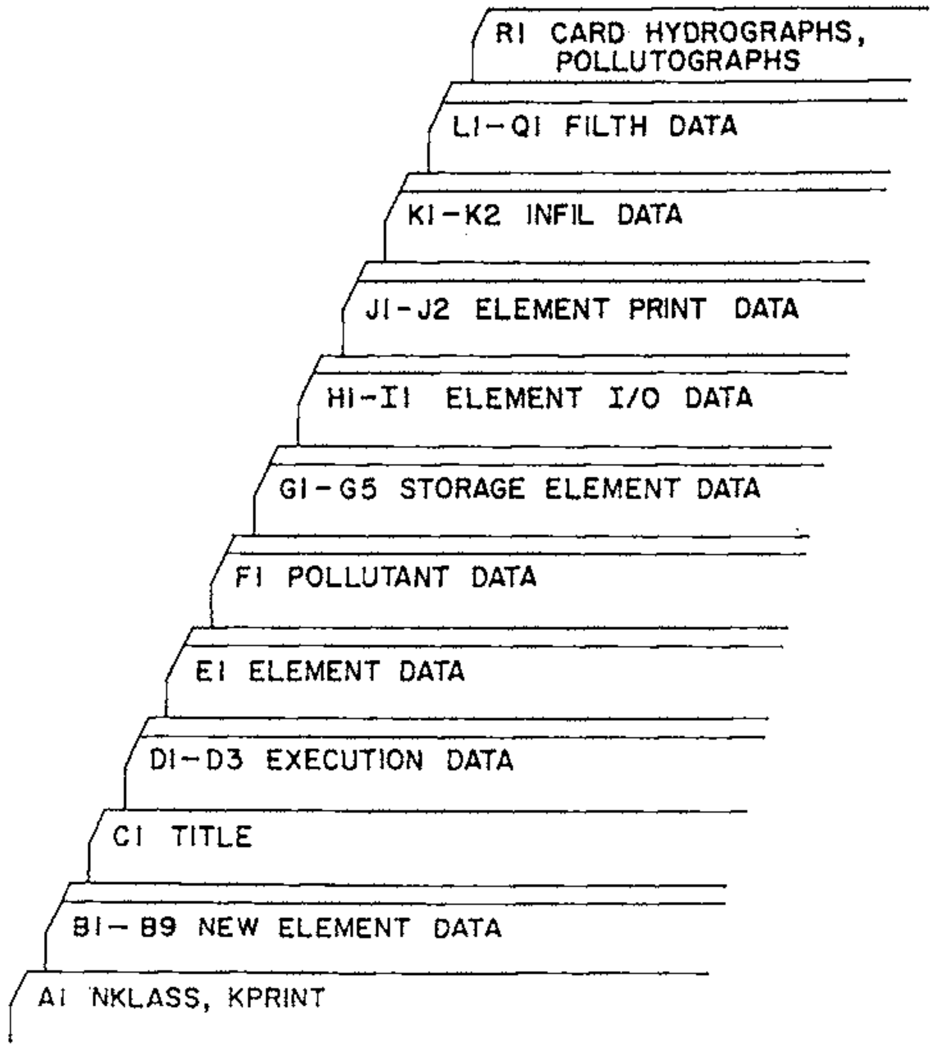


Figure 6-2. Data Deck for the Transport Block

Transport

Categories of Data --

Use of the Transport program involves three primary steps:

1) Preparation of theoretical data for use by subroutines engaged in hydraulic calculations in the program.

2) Preparation of physical data describing the combined sewer system.

3) Generation of inlet hydrographs and pollutographs required as input to the Transport Block and computational controls.

Data for Step 1 are supplied with the SWMM program for 13 different conduit shapes, and it will only be necessary for the user to generate supplemental data in special instances. These instances will occur only when conduit sections of very unusual geometry are incorporated into the sewer system. Generation of such data will be discussed below.

The primary data requirements for the user are for Step 2, the physical description of the combined sewer system, i.e., the tabulation of shape, dimension, slope, and roughness parameters, which will be discussed in detail below.

The data for Step 3 may be generated by cards, by an external block and by subroutines INFIL and FILTH.

Step 1. Theoretical Data --

The first data read by TRANS describe the number and types of different conduit shapes found in the system. Only in the case of a very unusual shape should it become necessary to generate theoretical data to supplement the data supplied by the program. The required data describe flow-area relationships of conduits, as shown in Figure 6-3 through the parameters ANORM and QNORM described below. A similar depth-area relationship is also required using the parameter DNORM.

The flow-area data are generated from Manning's equation, normalized by dividing by the corresponding equation for the conduit flowing full, denoted by the subscript f. Thus,

$$Q/Q_f = \frac{A \cdot R^{2/3}}{A_f \cdot R_f^{2/3}} = f(A/A_f) \qquad (6\text{-}1)$$

where Q = flow, cfs,
A = flow area, ft^2, and
R = hydraulic radius, ft.

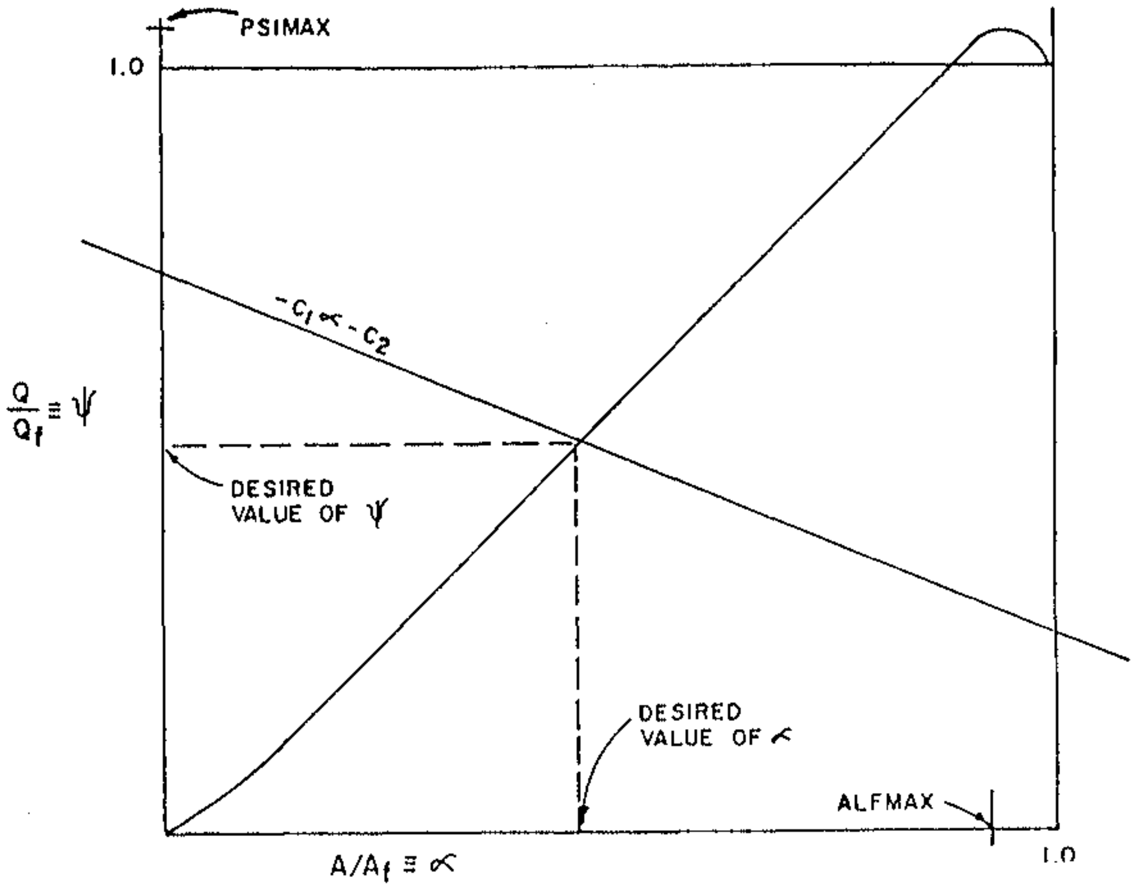


Figure 6-3. The Intersection of the Straight Line and the Normalized Flow-Area Curve as Determined in Route. The ψ-$\propto$ Curve is Formed by Straight Line Segments Delineated by the Variables ANORM and QNORM, for Conduits with a Tabular Q-A Relationship. Q Denotes Flow, A Denotes Area, and the Subscript f Denotes Values at Full-Flow. The Line $-C_1 \propto -C_2$ is Formed by the Program from the Continuity Equation.

For a given conduit shape (e.g., circular, rectangular, horseshoe), the hydraulic radius is a unique function of the area of flow; hence, Q/Q_f (interpolated between values of QNORM) is a function only of A/A_f (interpolated between values of ANORM). This function is tabulated for circular conduits in Appendix A of Chow (1959), for example, and on page 443 of Davis (1952) for a Boston horseshoe section. It is shown in graphical form for several conduit shapes in Chapter XI of Metcalf and Eddy (1914) from which some data supplied with this program have been generated. A list of the conduit shapes supplied with the Transport Block as well as all other element types is given in Table 6-1. The conduits are illustrated in Figure 6-4. If y = depth of flow, values of y/y_f corresponding to A/A_f (ANORM) are tabulated as the variable DNORM.

It will often be satisfactory to represent a shape not included in Table 6-1 by one of similar geometry. This use of "equivalent" sewer sections will avoid the problem of generating flow-area and depth-area data. An equivalent section is defined as a conduit shape from Table 6-1 whose dimensions are such that its cross-sectional area and the area of the actual conduit are equal. Only very small errors should result from the flow routing when this is done.

If it is desired to have the exact flow-area and depth-area relationships, then the product $AR^{2/3}$ must be found as a function of area. In general, the mathematical description of the shape will be complex and the task is most easily carried out graphically. Areas may be planimetered, and the wetted perimeter measured to determine R. In addition, the depth may be measured with a scale. The required flow-area relationship of Equation 6-1 may then be tabulated as can the depth-area relationship. The number of points on the flow-area and depth-area curves required to describe the curves is an input variable (MM and NN, respectively). Note that the normalized flows (QNORM) and depths (DNORM) must be tabulated at points corresponding to MM-1 and NN-1, respectively, equal divisions of the normalized area axis (ANORM). If desired, the routing parameters stored in the program may be listed by specifying KPRINT = 1 on card A1. The four pages of output are seldom necessary during the simulations, however.

Step 2. The Physical Representation of the Sewer System --

General -- These data are the different element types of the sewer system and their physical descriptions. The system must first be as a network of conduit lengths, joined at manholes (or other nonconduits). In addition, either real or hypothetical manholes should delineate significant changes in conduit geometry, dimensions, slope, or roughness. Finally, inflows to the system (i.e., stormwater, wastewater, and infiltration) are allowed to enter only at manholes (or other non-conduits). Thus, manholes must be located at points corresponding to inlet points for hydrographs generated by an external block and input points specified in subroutines FILTH and INFIL. In general, the task of identifying elements of the sewer system will be done most conveniently in conjunction with the preparation of data for these other subroutines, especially the Runoff Block.

Table 6-1. Different Element Types Supplied with the Storm Water Management Model

NTYPE	
	<u>Conduits</u>
1	Circular
2	Rectangular
3	Phillips standard egg shape
4	Boston horseshoe
5	Gothic
6	Catenary
7	Louisville semielliptic
8	Basket-handle
9	Semi-circular
10	Modified basket-handle
11	Rectangular, triangular bottom
12	Rectangular, round bottom
13	Trapezoid
14,15	User supplied
	<u>Non-conduits</u>
16	Manhole
17	Lift station
18	Flow divider
19	Storage unit
20	Flow divider - weir
21	Flow divider
22	Backwater element

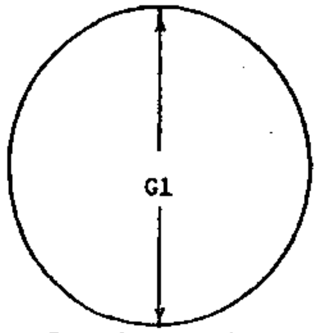
Each element (conduit or non-conduit) must be identified with a number which may range from 1 to 1000. They need not be sequential or continuous. Experience has shown that a schematic map showing the complete sewer network and the numbering system will be very useful for debugging and identification purposes. It is difficult to rely upon detailed (and often cluttered) sewer plans alone.

Description of Conduits -- The 16 conduit shapes supplied with the SWMM are shown in Figure 6-4. For each shape, the required dimensions are illustrated in the figure and specified in Table 6-2. In addition, Table 6-2 gives the formula for calculating the total cross-sectional area of the conduit.

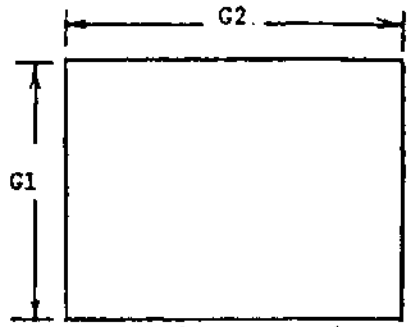
Usually, the shape and dimensions of the conduit will be indicated on plans. It is then a simple matter to refer to Figure 6-4 for the proper conduit type and dimensions. If the shape does not correspond to any supplied by the program, it will ordinarily suffice to choose a shape corresponding most nearly to the one in question. For example, an inverted egg can be reasonably approximated by a catenary section. The dimensions of the substitute shape should be chosen so that the area of the substitute conduit and that of the actual conduit are the same. This is facilitated by Table 6-2, in which the area is given as a function of conduit dimensions. If desired, the flow-depth area parameters for up to two additional conduit shapes may be read in at the beginning of the program as discussed previously. (See also Card Groups B1-B9, Table 6-6.)

Occasionally, the conduit dimensions and area may be given, but the shape not specified. It will sometimes be possible to deduce the shape from the given information. For example, a conduit may have an area of 4.58 ft^2. (0.425 m^2) and dimensions of 2 ft by 3 ft (0.6 by 1.0 m). First, assume that the 2 foot dimension is the width and the 3 foot dimension is the depth of the conduit. Second, note from Figure 6-4 that the ratio of depth to width for an egg-shaped conduit is 1.5:1. Finally, the area of an egg-shaped conduit of 3 foot depth is 0.5105 x 9 = 4.59 ft^2 (0.426 m^2). It is concluded that the conduit should be type 3 with GEOM1 = 3 ft.

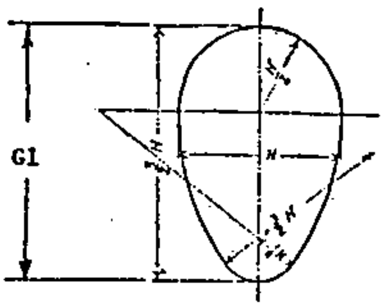
Because of the limits on the size of the computer program, it will usually not be possible to model every conduit in the drainage basin. Consequently, aggregation of individual conduits into longer ones will usually be the rule. Average slopes and sizes may be used provided that the flow capacity of the aggregate conduit is not significantly less than that of any portion of the real system. This is to avoid simulated surcharge conditions that would not occur in reality. In general, flow calculations are relatively insensitive to conduit lengths although with conduits over 4000 to 5000 ft (1200 m and 1500 m) long some loss of routing accuracy will result. This is caused primarily when a large inflow enters a dry or nearly dry pipe, often at the beginning of the simulation. A non-convergence error message will be printed, but the resultant error is seldom significant. Conduit lengths should always be separated by manholes (or other non-conduit type elements). The conduit length should be measured from the center of the adjacent manholes. A further means of simulating large systems lies in simulating different portions with separate Transport runs and combining the results using the Combine Block (see Section 3).



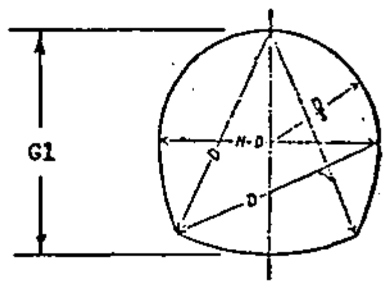
Type 1: Circular



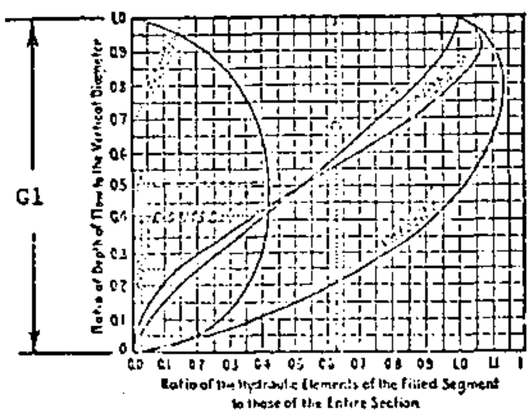
Type 2: Rectangular



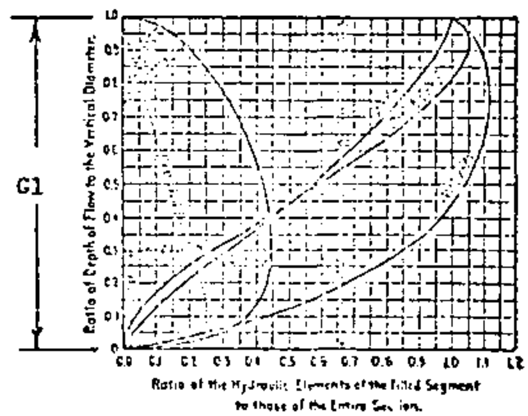
Type 3: Phillips Standard
Egg Shape



Type 4: Boston Horseshoe

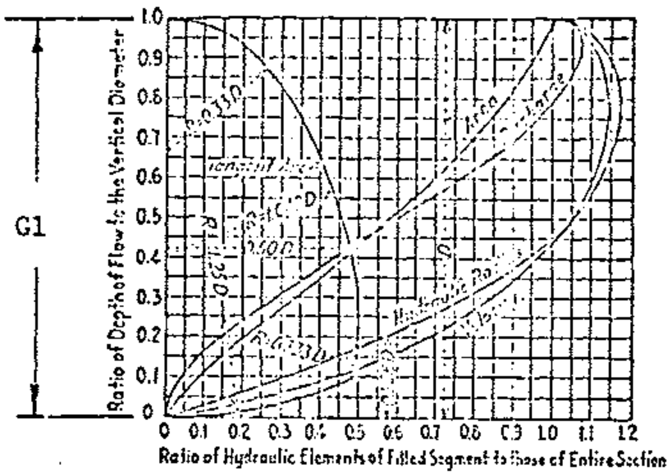


Type 5: Gothic

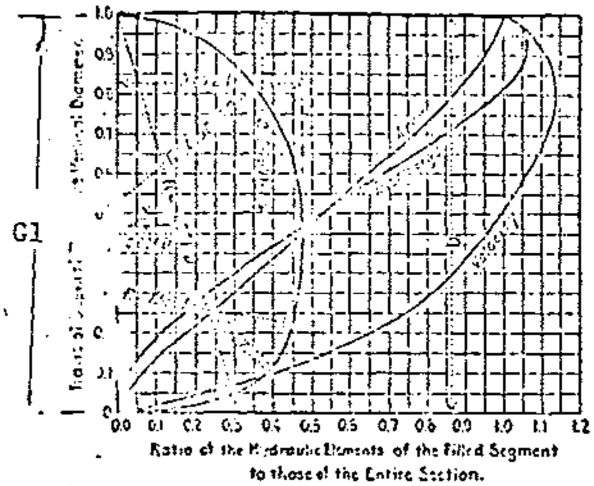


Type 6: Catenary

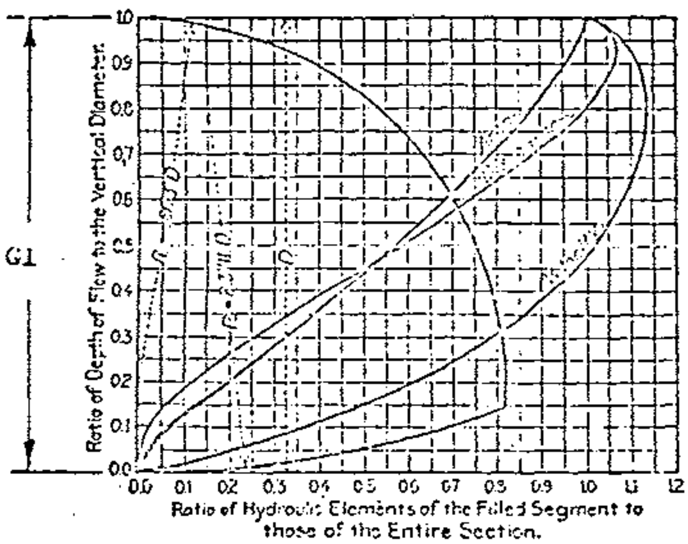
Figure 6-4. Sewer Cross-Sections



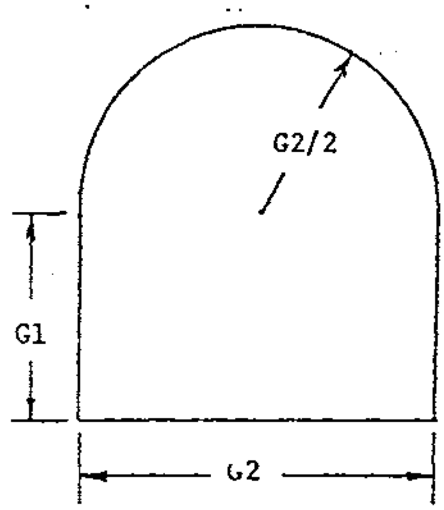
Type 7: Louisville Semielliptic



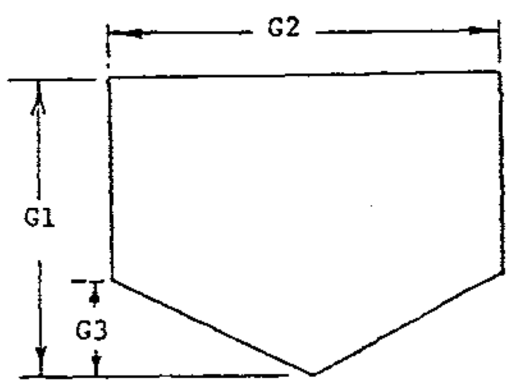
Type 8: Basket-handle



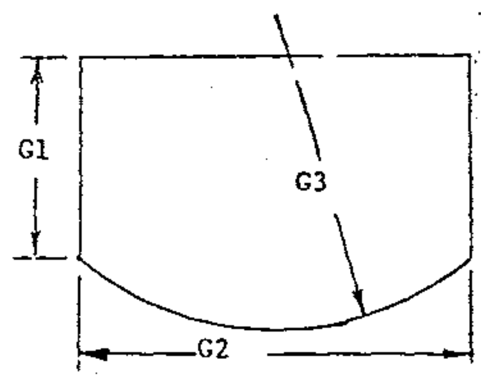
Type 9: Semi-circular



Type 10: Modified Basket-handle

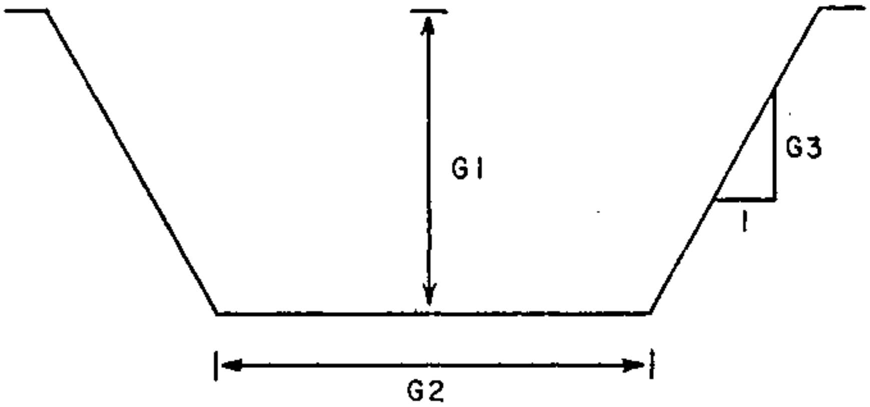


Type 11: Rectangular, Triangular Bottom



Type 12: Rectangular, Round Bottom

Figure 6-4 (continued). Sewer Cross-Sections



TYPE 13: TRAPEZOID

Figure 6-4 (continued). Sewer Cross-Section

Table 6-2. Summary of Area Relationships and Required Conduit Dimensions.[a]

NTYPE	Shape	Area	Required dimensions (ft)
1	Circular	$(\pi/4)(G1)^2$	GEOM1 = Diameter
2	Rectangular	$G1 \cdot G2$	GEOM1 = Height GEOM2 = Width
3	Egg-shaped	$0.5105 \cdot (G1)^2$	GEOM1 = Height
4	Horseshoe	$0.829 \cdot (G1)^2$	GEOM1 = Height
5	Gothic	$0.655 \cdot (G1)^2$	GEOM1 = Height
6	Catenary	$0.703 \cdot (G1)^2$	GEOM1 = Height
7	Semielliptic	$0.785 \cdot (G1)^2$	GEOM1 = Height
8	Basket-handle	$0.786 \cdot (G1)^2$	GEOM1 = Height
9	Semi-circular	$1.27 \cdot (G1)^2$	GEOM1 = Height
10	Modified basket-handle	$G2(G1+(\pi/8)G2)$	GEOM1 = Side height GEOM2 = Width
11	Rectangular, triangular bottom	$G2(G1-G3/2)$	GEOM1 = Height GEOM2 = Width GEOM3 = Invert height
12	Rectangular, round bottom	$\theta = 2 \cdot ARSIN \cdot (G2/(2G3))$ $Area = G1 \cdot G2 + (G3)^2/2 \cdot (\theta - SIN(\theta))$	GEOM1 = Side height GEOM2 = Width GEOM3 = Invert radius
13	Trapezoidal channel	$G1(G2+G/G3)$	GEOM1 = Depth GEOM2 = Bottom width GEOM3 = Side slope (vertical/horizontal)

[a]Refer to Figure 6-4 for definition of dimensions, G1, G2, and G3. Note that G1 = GEOM1, G2 = GEOM3, G3 = GEOM3.

Values of Manning's roughness may be known by engineers familiar with the sewer system. Otherwise, they may be estimated from tables in many engineering references (e.g., Chow, 1959, ASCE-WPCF, 1969) as a function of the construction material and sewer conditions. The value may be adjusted to account for losses not considered in the routing procedure (e.g., head losses in manholes or other structures, roots, obstructions). However, the flow routing is relatively insensitive to small changes in Manning's n.

Description of Non-Conduits -- The sewer system consists of many different structures, each with its own hydraulic properties. Elements 16 through 22 are designed to simulate such structures. Data requirements for these elements are given in Table 6-3. Brief descriptions of these elements follow.

Manholes (NTYPE = 16) -- No physical data are required for manholes except their numbers and upstream element numbers. Note that the number of upstream elements is limited to three. If more than three branches of the system should join at a point, two manholes could be placed in series, allowing a total of five branches to joint at that point, etc. Flow routing is accomplished in manholes by specifying that the outflow equals the sum of the inflows.

As an alternative to the use of the more detailed infiltration (INFIL) and dry-weather flow (FILTH) routines described later, flow and quality constituents may be input at manholes to simulate baseflow conditions. This input is constant over time and is allowed only at manholes and at no other element types.

Lift Stations (NTYPE = 17) -- The data requirements for lift stations are given in Table 6-3. It is assumed that the force main will remain full when the pump is not operating, resulting in no time delay in the flow routing (i.e., no time is required to fill the force main when the pump starts). When the volume of sewage in the wet well reaches its specified capacity, the pumps begin to operate at a constant rate. This continues until the wet well volume equals zero. (Two-stage pumping may be simulated using a storage element.)

Flow Dividers (NTYPE = 18 and 21) -- The routing procedure through these elements is explained in the discussion below. Typical uses are given below.

1) Simple diversion structure - A type 18 flow divider may be used to model a diversion structure in which none of the flow is diverted until it reaches a specified value (GEOM1). When the inflow is above this value, the non-diverted flow (QO1) remains constant at its capacity, GEOM1, and the surplus flow (QO2) is diverted.

2) Cunnette section - A type 21 flow divider may be used to model a downstream cunnette section. The cunnette section is considered as a separate circular conduit to be placed parallel to the primary conduit as shown in Figure 6-5. In order to model the cunnette as a semi-circle, the separate circular conduit is given a diameter (GEOM1) so that

Table 6-3. Parameters Required for Non-Conduits.

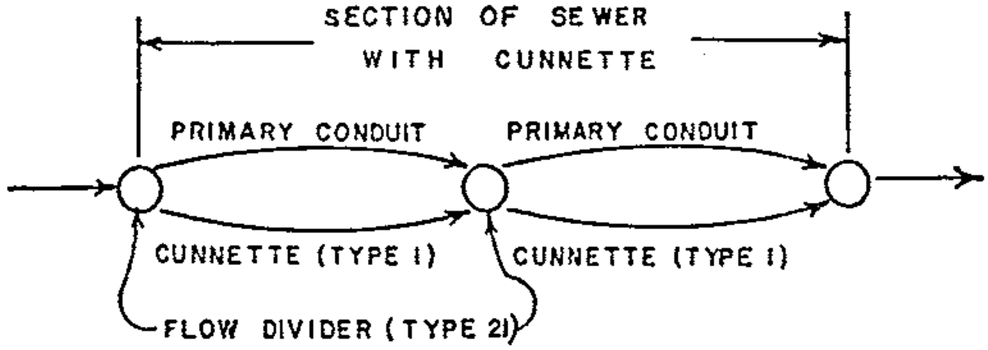
NTYPE	Description	DIST	GEOM1	SLOPE	ROUGH	GEOM2	BARREL	GEOM3
16	Manhole	Constant Inflow, cfs, [m^3/sec].	Const. inflow concen. of pollutant 1.[a]	Const. inflow concen. of pollutant 2.[a]	Const. inflow concen. of pollutant 3.[a]	Const. inflow concen. of pollutant 4.[a]	N.R.[b]	N.R.
17	Lift station	Pumping rate, assumed constant, cfs, [m^3/sec].	Volume in wet well at which pumps will start, ft^3, [m^3].	N.R.	N.R.	N.R.	N.R.	N.R.
18	Flow divider	N.R.	Maximum undiverted flow. Inflow in excess of this value is diverted, cfs, [m^3/sec].	N.R.	N.R.	N.R.	N.R.	Number of element into which flows the undiverted flow (include decimal point).
19	Storage unit[c]	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.
20	Flow divider	Maximum inflow without flow over the weir, cfs, [m^3/sec].	Weir height, above zero flow depth, ft, [m].	Maximum inflow through whole structure, cfs, [m^3/sec].	Weir constant times weir length, ft, [m].	Depth in structure at time of maximum inflow, ft, [m].	N.R.	Number of element into which flows the undiverted flow (weir flow is the diverted flow).
21	Flow divider	N.R.	N.R. (assigned in program)	N.R.	N.R.	N.R.	N.R.	Number of element into which flows the undiverted flow.
22	Backwater element	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	Element number of downstream storage unit.

[a]Units according to NDIM, Card group F1.

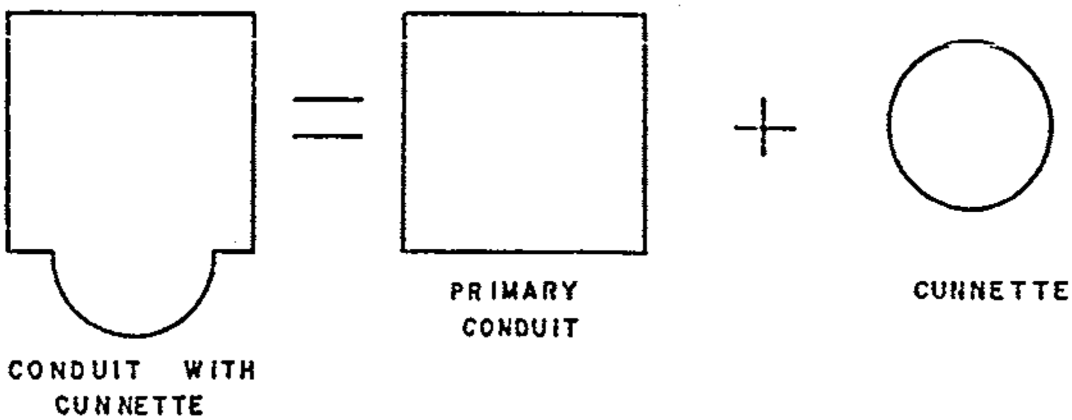
[b]N.R. = Not Required.

[c]Additional parameters are read in subsequently in Card groups G1 – G5.

NOTE: All elements require an element number (NOE), three upstream element numbers (NUE), and type (NTYPE). Parameters for conduits are defined in Table 6-2.



a. SCHEMATIC OF HYPOTHETICAL FLOW DIVISION



b. SPLIT OF CONDUIT INTO PRIMARY CONDUIT AND CUNNETTE

Figure 6-5. Cunnette Section

its area will be twice that of the actual total cunnette flow area. (The distance, slope and roughness will be the same as for the primary conduit.) A type 21 flow divider is then the upstream element common to both conduits, as shown in Figure 6-5. (The program assigns a value of GEOM1 of the flow divider equal to half the full flow capacity of the circular pipe simulating the cunnette so that it has the hydraulic characteristics of a semi-circle.) Any flow higher than GEOM1 will be diverted to the primary conduit. Note that the parameter GEOM3 of the flow divider will be the element number assigned to the cunnette section. Note further that the element downstream from the two parallel conduits must list them both as upstream elements.

3) Overbank flow - A type 18 flow divider can be used to simulate flow into a main channel (undiverted flow) and into a parallel overbank channel for simulation of flooded conditions. Parameter GEOM1 would be set equal to the main channel capacity. The channels could be of any shape although two trapezoidal channels might be most appropriate for many natural configurations.

Routing at Flow Dividers (NTYPE = 18 and 21) -- Both types will divide the inflow, QI, into two outflows, QO1 and QO2. The divider then acts as follows:

$$
\begin{aligned}
&\text{For } 0 \leq QI \leq GEOM1, && QO1 = QI \\
& && QO2 = 0.0 \\
&\text{For } GEOM1 \leq QI, && QO1 = GEOM1 \\
& && QO2 = QI - GEOM1
\end{aligned}
\qquad (6\text{-}2)
$$

The undiverted outflow, QO1, will flow into the downstream element denoted by GEOM3. (The element into which QO2 flows does not need to be specified).

Flow Divider (NTYPE = 20) -- This element is used to model a weir-type diversion strucutre in which a linear relationship can adequately relate the flow rate and the depth of flow into the weir structure. Input parameters are defined in Table 6-3. The weir constant, incorporated into the variable ROUGH, can be varied to account for the type of weir. Typical values of the weir constant are 3.3 for a broad crested weir and 4.1 for a side weir.

The flow divider behaves as a function of the inflow, QI, as follows:

$$
\begin{aligned}
&\text{For } Q \leq QI \leq DIST, && QO1 = QI \\
& && QO2 = 0.0
\end{aligned}
\qquad (6\text{-}3)
$$

For DIST ≦ QI, QO1 and QO2 are computed as follows:

1) Compute depth of flow above the weir, DH, assuming a linear flow-depth relationship:

$$DH = (QI-DIST)\cdot(GEOM2-GEOM1)/(SLOPE-DIST)$$

2) Compute the diverted flow from the weir formula:

$$QO2 = ROUGH \cdot DH^{1.5}$$

3) Compute the undiverted flow:

$$QO1 = QI - QO2$$

Storage Unit (NTYPE 19) -- This element is specified only when internal storage computations are required. Internal storage is modeled in a manner similar to the detention unit of the Storage/Treatment Block. (See Section 7 and Appendix IV.) Internal storage is modeled as a completely-mixed unit with a variety of outlet structures. However, as opposed to the detention unit in the S/T Block, pollutant removal is not simulated other than by decay. The storage unit must be described on card groups G1 to G5.

A storage unit may be placed anywhere in the sewer system where appreciable storage may exist, such as at an outflow or diversion structure. The required data inputs are described later. It should be noted that the storage area or "reservoir" may consist of a portion of the sewer system itself, and area-depth relationships must be worked out accordingly.

Backwater Element (NTYPE = 22) -- This element may be used to model backwater conditions in a series of conduits due to a flow control structure downstream. The situation is modeled in a manner analogous to reservoir flood routing as follows:

1) A storage element (NTYPE 19) is placed at the location of the control structure. The type of storage element will depend upon the structure (e.g., weir, orifice). One inflow to this storage element is then from the conduit just upstream.

2) If the water surface is extended horizontally upstream from the flow control structure at the time of maximum depth at the structure, it will intersect the invert slope of the sewer at a point corresponding to the assumed maximum length of backwater. The reach between this point and the structure may encompass several conduit lengths. A backwater element (NTYPE 22) is placed at this point of maximum backwater, in place of a manhole, for instance.

3) The backwater element then diverts flow directly into the storage element depending upon the volume of water (and hence, the length of backwater) in the storage element. If the backwater extends all the way to the backwater element, the total flow is diverted to the storage element; none is diverted to the conduits.

4) The amount of diverted flow (QO1) is assumed directly proportional to the length of the backwater. The storage area in reality consists of the conduits. Since most conduits

can be assumed to have a constant width, on the average, the backwater length is assumed proportional to the square root of the current storage volume, obtained from the storage routine.

5) The parameter GEOM3 of the backwater element must contain the element number of the downstream storage unit.

6) Parameters for the storage element are read in as usual. Note that the depth-area values will correspond to the storage area of the upstream conduits. Note also that the storage unit must list the backwater element as one of its upstream elements, as well as the conduit immediately upstream.

7) At each time step, the backwater element computes the ratio of current to maximum storage volume in the downstream storage element. Call this ratio r. Then

$$QO1 = QI\sqrt{r}$$

and (6-4)

$$QO2 = OI - QO1$$

where QO1 = flow directly into storage unit,
QO2 = flow into intermediate conduits, and
Q1 = inflow to backwater element.

<u>Step 3. Input Data and Computational Controls</u> --

<u>Options</u> -- The basic input data, hydrographs and pollutographs are generated outside of the Transport Block. However, certain operational controls are available within Transport.

<u>Choice of Time Step (DT)</u> -- The size of the time step must be an integer multiple or integer fraction of the time step used in the preceding block. In tests of sensitivity (Metcalf and Eddy et al., 1971a), it was found that except for very small values of DT (10 seconds), the output from Transport is insensitive to the length of the time step. Between values of two minutes and 30 minutes, hydrograph ordinates varied by less than one percent. For extremely short time step values, the peak flow moved downstream faster and never attained the maximum value that it had with a DT of two minutes and longer. Within the range commonly needed by SWMM users (two minutes to 30 minutes), the choice of time step will not significantly affect results. However, continuity errors can occasionally arise if the time step is "appreciably" longer than the travel time through any conduit. "Appreciably" longer means about factor of two.

<u>Choice of Number of Time Steps (NDT)</u> -- The number of time steps is not restricted. The program will use the number input in Transport (NDT) or the number used by the preceding block, whichever gives the shorter simulation time.

Choice of Number of Iterations (NITER) -- The purpose of iterations in the computations is to eliminate flow oscillations in the output. The flatter pipe slopes (less than 0.001 ft/ft) require iterations of the flow routing portion of the Transport Model to help dampen these oscillations. Four iterations have proven to be sufficient in most cases.

Choice of Allowable Convergence Error (EPSIL) -- Convergence of the flow routing procedure should not be any problem, and the default value of EPSIL, 0.0001, may be used. It will provide sufficient accuracy and result in only a very minimal increase in computer time over larger values. The only convergence problems that may exist can occur when flow enters a dry conduit. For instance, this could occur at the beginning of a storm in a sewer with little or no base flow. Messages to this effect will be printed if parameter NPRINT $\neq 0$. These may almost always be ignored since the default options in subroutine ROUTE will continue program execution and only result in a very small error in continuity (a fraction of a percent).

Alternate Hydrograph and Pollutograph Inputs -- Hydrograph and pollutographs may be entered from a tape/disk file (e.g., as generated in the Runoff Block) and/or entered from cards, using card groups I1 and R1 in Table 6-6. Parameters NCNTRL and NINPUT are set accordingly. Note that input from both cards and tape/disk may be performed simultaneously. If, for some reason, input from cards is not desired, a tape/disk file containing the specified input values could be created and specified as an input file to Transport in place of, say, a file generated by the Runoff Block. The format of such a file is described in Section 2.

Quality

Constituents --

Up to four pollutants may be arbitrarily chosen for input and routing by the Transport Block. Although these would often be chosen from the group (up to ten) supplied by the Runoff Block (or another preceding block), they do not have to be since card input may be used in addition to the interface file. If the same pollutant is entered from both the interface file and from cards, the description (name, name of units, type of units) from the interface file must be used. If the pollutant is entered only from cards, this description must be supplied on card group F1. Further information on pollutant description is contained in Section 4.

Decay --

Each pollutant may be subjected to a first order decay during the routing process by supplying a first order decay coefficient, DECAY (based on natural logarithms or base e). Although travel time through most sewer systems is short enough so that decay is seldom important, the user could supply, for example, a deoxygenation coefficient, K_1, for BOD if desired. Nonconservative pollutants are not linked. The decay of one has no effect on any other.

Routing --

Routing of quality parameters is performed by using the integral solution for the output from a completely mixed conduit volume (Medina et al., 1981). See Appendix IX for a derivation. Although this tends to introduce artificial dispersion of concentration profiles, it is the most convenient way in which to introduce new loadings at manholes along the system, as well as to facilitate scour and deposition calculations. The quality routing procedure is not subject to calibration directly. However, the routing becomes closer to pure advection (plug flow) as the number of elements is increased.

Scour and Deposition --

The basis for these procedures is described in Appendix VI. Each pollutant is assigned a specific gravity (SPG) and particle size distribution, assumed to apply throughout the drainage system regardless of the source of the pollutant, e.g., stormwater or dry-weather flow. If the specific gravity is less than or equal to 1.0, the pollutant is considered to be entirely suspended (or dissolved) and not subject to scour and deposition. If all calibration is to be performed using Runoff Block buildup-washoff parameters, for instance, it may be desirable to avoid the complexity of simulating a second real but largely unknown source.

Typical particle size distributions (and interpretation of input parameters PSIZE and PGR) are illustrated in Figure 6-6. Such information should be collected first hand at each catchment; secondary sources such as Sartor and Boyd (1972), Shaheen (1975), Manning et al. (1977) and Pisano et al. (1979) should be used only if local data are not available. During the simulation scour and deposition are simulated using Shield's criterion to determine the critical diameter for incipient motion and deposition (see Appendix VI). The kinematic velocity of water (GNU on Card D2) is a function of temperature and used to calculate the boundary Reynolds number on Shield's diagram (Graf, 1971, Vanoni, 1975). For each conduit, the critical diameter is determined as a function of velocity, roughness and specific gravity. At the same time, the <u>maximum</u> diameter of the <u>suspended</u> fraction and the <u>minimum</u> diameter of the <u>settled</u> fraction is maintained. If the critical diameter is less than the maximum of the suspended material, more is settled; the settled mass is determined by multiplying by a fraction determined from the particle size distribution (Appendix VI). Similarly, if the critical diameter is greater than the minimum of the settled material, more is suspended. The settled material is thus assumed to have the particle size distribution of the right hand tail of the total distribution (Figure 6-6), and the suspended material has the distribution of the left hand side.

Decreasing the specific gravity (downwards toward 1.0) increases the amount suspended and vice versa. As SPG approaches 1.0 closely the procedure becomes very sensitive to SPG since there is a division by SPG-1.0. Typical values of specific gravities of particulate matter in sewers range from 1.1 for volatile material to 2.7 for sand and grit. The actual situation in which each particle size range may have its own specific gravity can be handled by the Storage/Treatment Block, but not the Transport Block

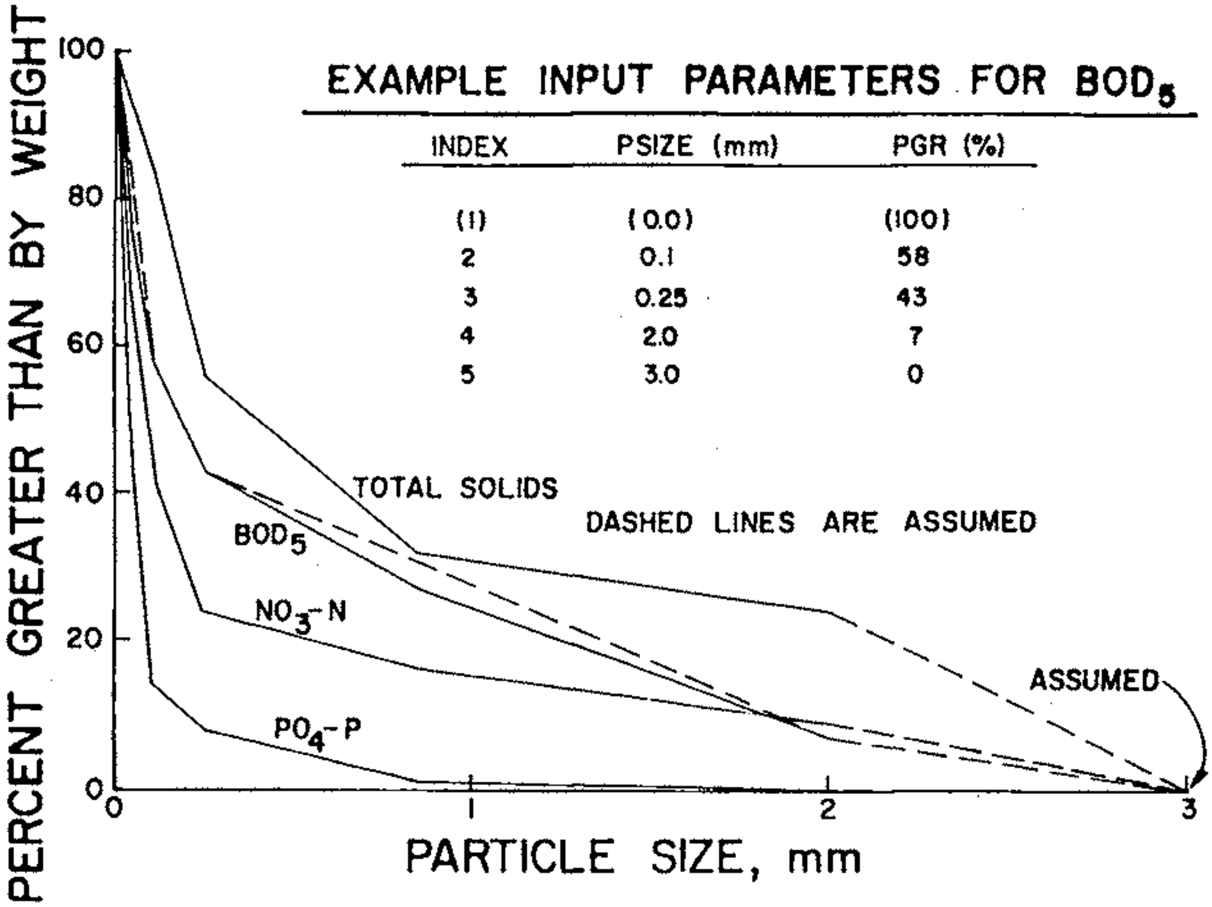


Figure 6-6. Example Particle Size Distributions for Pollutants found on Street Surfaces. (After Sartor and Boyd, 1972, p. 146.)

(except that up to four different pollutants may be simulated). Since it is only one parameter, calibration of the scour-deposition routine may be most easily calibrated using SPG. Alternatively, a greater percentage of large diameter material may be assigned a pollutant using the particle size distribution if, for instance, more deposition were desired.

Unlike the previous Transport Model, continuity of pollutant mass is now maintained during scour and deposition. In addition, larger particles can settle upstream in flat conduits and be unavailable for downstream settling. An initial settled mass in each conduit is computed prior to the start of the simulation by running the routine for DWDAYS days (card D2) prior to the storm event (or longer) simulation. This initial deposition is assumed to start with a clean bed.

Although this scour-deposition routine is a far cry from the detailed sewer sediment transport program developed by Sonnen (1977), it is reasonably simple, consistent and may be calibrated. And should the user desire, it may be bypassed (using SPG≦1.0), and all quality calibration performed in the Runoff Block.

Internal Storage Model

Use of the internal storage routine involves four basic steps. A somewhat more detailed data description may be found in Section 7.

Step 1. Call --

The internal storage routine is called by subroutine TRANS when element NTYPE 19 is specified. No more than two storage locations may be specified in a single run.

Step 2. Storage Description: Part 1 --

Describe the manner in which the outlet depth-discharge relationship is given (set of data pairs, power equation or pumps). See Appendix IV and Section 7 for a more detailed description of this technique.

Step 3. Storage Description: Part 2 --

Describe the geometry of the unit with a set of depth-surface area volume data triplets and the depth-discharge relationship with data pairs or a power equation. See Appendix IV and Section 7 for more details.

Step 4. Initial Conditions --

Describe the initial conditions of the unit with respect to volume and pollutant concentrations.

Infiltration Model

Description --

The infiltration program, INFIL, has been developed to estimate infiltration into a given sewer system based upon existing information about the sewer, its surrounding soil and groundwater, and precipitation. It should be borne in mind throughout that the accuracy of infiltration prediction is dependent upon the accuracy and extent of data descriptive of infiltration in the system being modeled.

Using these data, INFIL has been structured to accept estimates of average daily infiltration inflows at discrete locations along the trunk sewers of a given sewer system. A typical urban drainage basin in which infiltration might be estimated is shown in Figure 6-7.

Since the Storm Water Management Model's principal use has been mainly to simulate individual storms which cover a time period of less than a day, average daily estimates from INFIL are calculated only once prior to sewer flow routing. INFIL is called from subroutine TRANS by setting the variable, NINFIL equal to 1, thus signaling the computer to estimate infiltration. In fact, however, the user has most of the responsibility for infiltration estimation, optionally using techniques described below. The program does little more than apportion it properly.

For the purposes of analysis, infiltration is classified into four categories, i.e., miscellaneous sources causing a base dry weather inflow, frozen residual moisture, antecedent precipitation, and high groundwater. The cumulative effects of the first three sources can be seen in Figure 6-8 which excludes surface runoff. Figure 6-8 shows total infiltration QINF as the sum of dry weather infiltration DINFIL, wet weather infiltration RINFIL, and melting residual ice and frost infiltration SINFIL. However, in cases where the groundwater table rises about the sewer invert, it is assumed that groundwater inflow GINFIL alone will be the dominant source of infiltration. Thus, infiltration is defined as:

$$\text{QINF} = \begin{cases} \text{DINFIL} + \text{RINFIL} + \text{SINFIL} \\ \qquad\qquad \text{or} \\ \text{GINFIL for high groundwater table} \end{cases} \tag{6-5}$$

Throughout the procedure for determining input variables, observations and estimates based upon local data given preference over generalized estimates for infiltration described below. Thus, the hierarchy for basing estimates should be:

1) Use historical data for the study area under consideration.

2) Use historical data for a nearby study area and adjust results accordingly.

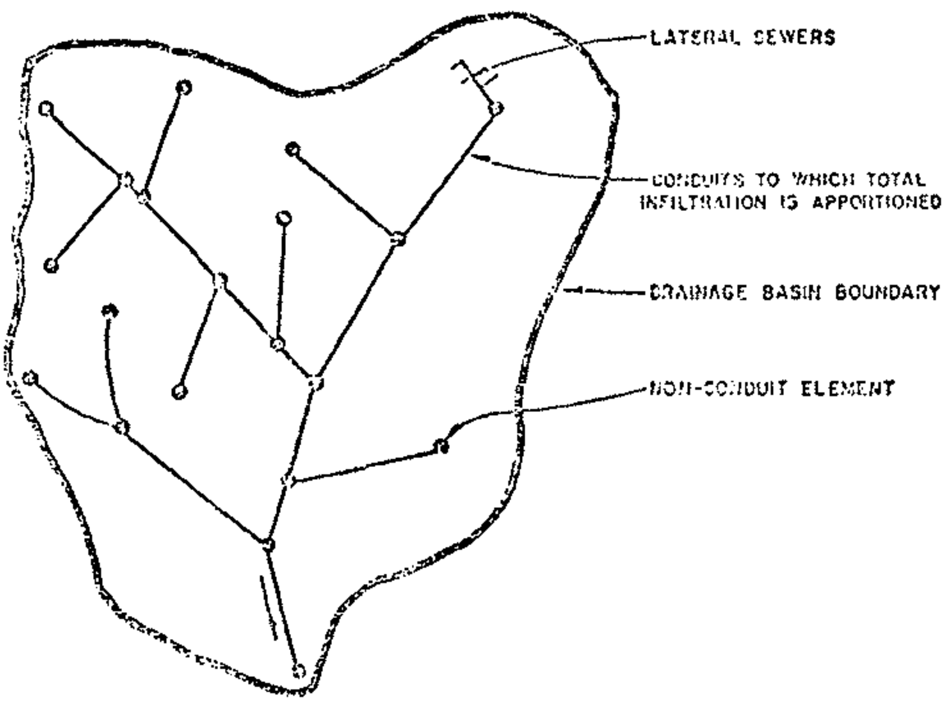
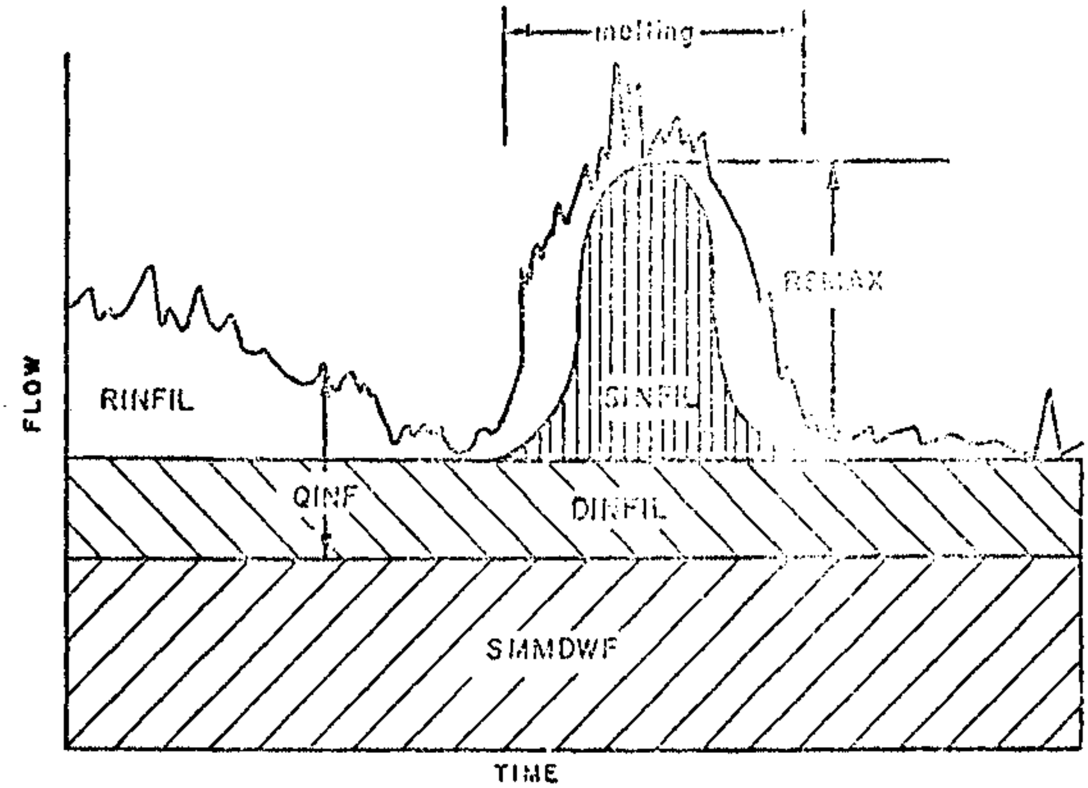


Figure 6-7. Typical Drainage Basin in which Infiltration is to be Estimated



QINF = Total infiltration
DINFIL = Dry weather infiltration
RINFIL = Wet weather infiltration
SINFIL = Melting residual ice and snow infiltration
RSMAX = Residual moisture peak contribution
SMMDWF = Accounted for sewage flow

Figure 6-8. Components of Infiltration

3) Use estimates of local professionals.

4) Use generalized estimates based upon country-wide observations.

Infiltration - inflow studies (e.g., EPA, 1975) have been performed in many cities and should provide much of the needed data.

Dry Weather Infiltration (DINFIL) --

If the study area under consideration has been gaged, base dry-weather infiltration can be taken by inspection from the flow data. In the absence of flow data, an estimate of the unit infiltration rate XLOCAL (gpm/inch-diameter per mile) for dry weather must be obtained from local professionals. From data in the form of calculated values of DIAM and PLEN, Equation 6-6 can then be used to determine DINFIL (gpm):

$$\text{DINFIL} = \text{XLOCAL} \cdot \text{DIAM} \cdot \text{PLEN} \tag{6-6}$$

where DIAM = average sewer diamater, in., and
PLEN = pipe length, mi.

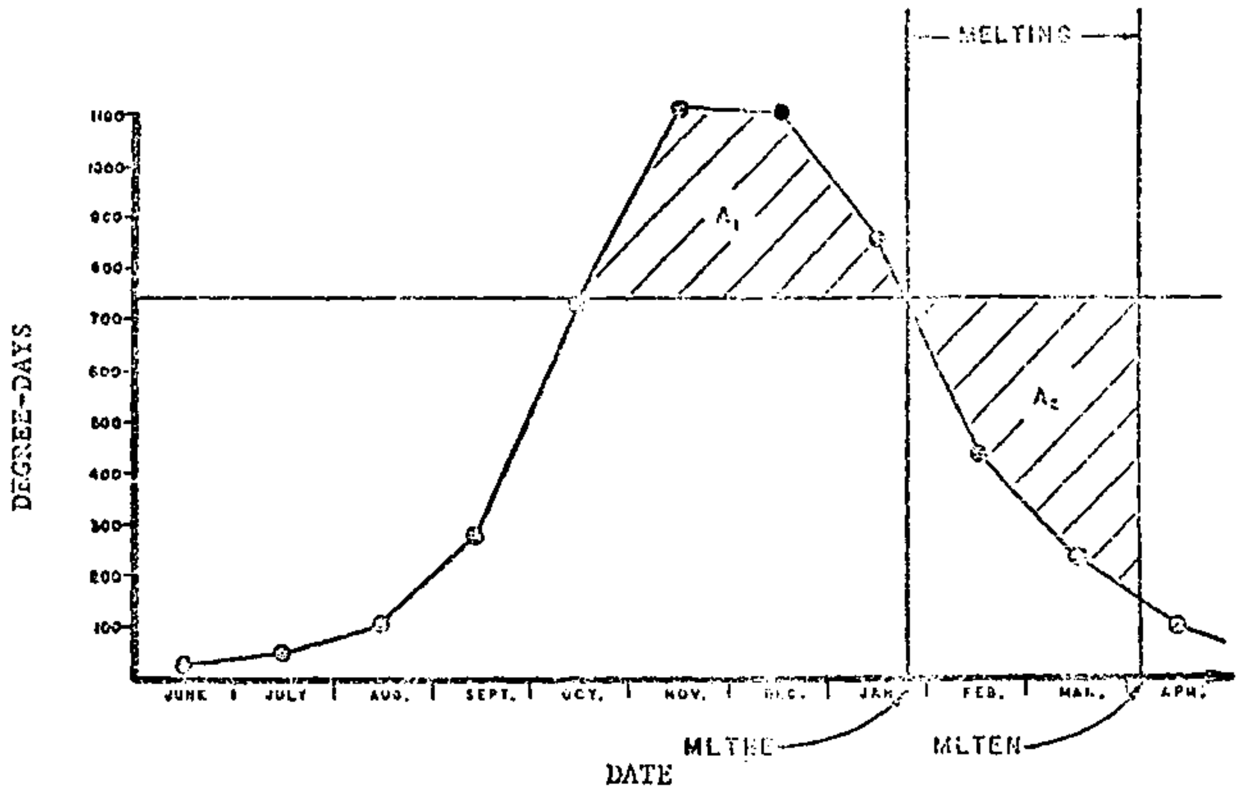
Values of XLOCAL range from 250 to 600 gpm/in-diameter per day (ASCE-WPCF, 1969) and may be even higher for laterals with many stubs and wyes. The importance of local data cannot be over-emphasized.

Residual Melting Ice and Frost Infiltration (SINFIL) --

SINFIL arises from residual precipitation such as snow as it melts following cold periods. Published data (American Soc. of Heating and Air Conditioning Engineers) in the form of monthly degree days (sum of deviations below 65°F) provide an excellent index as to the significance of SINFIL. Average monthly degree-days for cities in the United States are reproduced in Appendix VIII. The onset and duration of melting can be estimated by noting the degree days NDD above and immediately below a value of 750. Refer to Figure 6-9 for the following description.

Within subroutine INFIL, the beginning of melting, MLTBE, is taken as the day on which NDD drops below 750. Next, MLTEN is determined so that A_1 equals A_2. In the absence of evidence to the contrary, it is assumed that the melting rate is sinusoidal. The maximum contribution RSMAX from residual moisture can be determined from previous gaging of the study area or local estimates. In either case, SINFIL is determined within the program by the following equation:

$$\text{SINFIL} = \begin{cases} \text{RSMAX} \cdot \sin[180 \cdot (\text{NDYUD}-\text{MLTBE})/(\text{MLTEN}-\text{MLTBE})] \\ \\ \text{0.0 if NDYUD is not in melting period or if} \\ \text{NDD never exceeds 750.} \end{cases} \tag{6-7}$$



MLTBE = Day on which melting period begins
MLTEN = Day on which melting period ends

Figure 6-9. Prescribed Melting Period

where NDYUD = day on which infiltration estimate is desired,
RSMAX = residual moisture peak contribution, gpm,
MLTBE = beginning of melting period, day, and
MLTEN = end of melting period, day.

Note that RSMAX is a required input parameters, in addition to degree day information.

Antecedent Precipitation (RINFIL) --

RINFIL depends upon antecedent precipitation occurring within nine days prior to an estimate. If antecedent rainfall is unavailable or less than about 0.25 in (6.4 mm), the RINFIL contribution to QINFIL is usually small. For larger antecedent rainfall contributions, regression techniques offer one method of estimating RINFIL. For example, during development of the infiltration routine, available rainfall and infiltration data were examined (Metcalf and Eddy et al., 1971a). For three areas in which sewer flow data were not affected by melting, RINFIL was found to satisfy the following linear relationship:

$$RINFIL = ALF + ALF0 \cdot RN0 + ALF1 \cdot RN1 + \ldots + ALF9 \cdot RN9 \qquad (6\text{-}8)$$

where RINFIL = SWFLOW - DINFIL - SMMDWF, gpm,
ALFN = coefficient to rainfall for N days prior to estimate, gpm/in,
RNN = precipitation on N days prior to estimate, in,
SWFLOW = daily average sewer flow excluding surface runoff, gpm,
and
SMMDWF = otherwise accounted for sewage flow, gpm.

To determine the coefficients in Equation 6-8, a multiple linear regression should be run on existing flow and rainfall data. For comparative purposes, the results of regression analyses for study areas in three selected cities (Lentz, 1963, Metcalf and Eddy et al., 1971a) are given in Table 6-4.

High Groundwater Table (GINFIL) --

For locations and times of the year that cause the groundwater table to be above the sewer invert, groundwater infiltration GINFIL supersedes contributions from DINFIL, RINFIL, and SINFIL. GINFIN can be determined from historical sewer flow data by inspection or regression analysis. For example, a regression analysis could involve determination of the BETA coefficients in Equation 6-9, or an alternative formulation could be investigated.

$$GINFIL = BETA + BETA1 \cdot GWHD + BETA2 \cdot GWHD^2 + BETA3 \cdot GWHD^{0.5} \qquad (6\text{-}9)$$

where GWHD = groundwater table elevation above sewer invert, ft, and
BETAN = coefficient for term N.

Table 6-4 RINFIL Equations For Three Study Areas

Study Area	Equation
Bradenton, Florida	RINFIL = 4.1 + 2.9RNO + 17.5RN1 + 15.0RN2 + 12.8RN3 + 13.0RN4 + 10.4RN5 + 13.2RN6 + 10.1RN7 + 11.8RN8 + 9.5N9
Baltimore, Maryland	RINFIL = 2.4 + 11.3RNO + 11.6RN1 + 5.5RN2 + 6.4RN3 + 4.8RN4 + 3.6RN5 + 1.0RN6 + 1.5RN7 + 1.4RN8 + 1.8RN9
Springfield, Missouri	RINFIL = 2.0 + 18.3RNO + 13.9RN1 + 8.9RN2 + 5.5RN3 + 6.7RN4 + 16.RN5 + 5.2RN6 + 4.6RN7 + 4.4RN8 + 1.3RN9

Apportionment of Infiltration --

Once an estimate of the total local infiltration QINF has been obtained, this flow must be apportioned throughout the designated study area. The criterion chosen for apportionment is an opportunity factor OPINF which represents the relative number and length of openings susceptible to infiltration. Pipe joints constitute the primary avenue for entry of infiltration (Geyer and Lentz, 1963). The number and length of joints is assumed to be proportional to the relative surface area of each conduit. For each, an equivalent circular pipe diameter will be proportional to the square root of its known cross sectional area, ft. Then the fraction of total infiltration ("opportunity" for infiltration) allocated to each conduit, OPINF, is:

$$\mathrm{OPINF} = \frac{\sqrt{A_f} \cdot \mathrm{DIST}}{\Sigma \sqrt{A_f} \cdot \mathrm{DIST}} \tag{6-10}$$

where A_f = cross sectional area of conduit, ft^2, and
DIST = conduit length, ft,

and the summation in the denominator is over all conduits. Trapezoidal channels are treated the same as all others. The apportioned infiltration enters the system at the non-conduit element immediately upstream of the conduit.

This procedure allocates the most infiltration to the largest and longest conduits. Should local information dictate otherwise, infiltration may be apportioned by the user and entered at appropriate manholes in card group E1.

Infiltration developed using subroutine INFIL is held constant in time. Should hourly or daily corrections be desired, infiltration can be incorporated into dry-weather flow (described below).

Quality of Infiltration --

Although infiltration is often assumed to be "clean" due to its origin in the soil layers, in-conduit measurements usually indicate non-zero levels of most parameters. These concentrations may be entered on card K1.

Data Needs --

Hydrologic Data -- Concurrent historical rainfall, water table, and sewer flow data of several weeks' duration are needed to completely describe infiltration. In addition, rainfall for several days prior to the flow estimate is required for use in a regression equation for RINFIL. Of course, such data would be required for many different storms for development of such an equation.

Ideally, the rainfall record would be from a rain gage which is located near the center of the study area and which records daily rainfall in inches. If more than one rain gage is located within the study area, daily measurements from all gages should be averaged. Missing data (e.g., from a malfunctioning gage) or a total absence of measurements due to no gaging within the study area can sometimes be overcome with measurements taken from a rain gage located within a few miles. If National Weather Service (NWS) Climatological Data recorded at the nearest airport or federal installation are not available, contact the National Weather Records Center (Asheville, NC) for assistance.

Should some other form of precipitation, e.g., snowfall, be encountered, it will be necessary to convert this to equivalent rainfall. If estimates are unavailable from the NWS, the ratio of ten inches of snow to one inch of rain may be used.

Water table data should also be obtained from gaging within the study area. However, shallow-well data from the US Geological Survey or state geological office can be used to supplement missing data. Water table elevations are not required if they are below the sewer inverts for the day on which QINF is to be estimated.

Sewer Data -- Sewer flow data for regression analysis should be taken from a gage located at the downstream point within the study area. Upstream gaging may sometimes be used to estimate flows at the downstream point by simply adjusting flows based upon respective surface area. Physical sewer data (e.g., lengths, diameters) are taken from prior input used within TRANS to route sewer flow.

Summary of Infiltration Procedures --

Input -- Effective use of the Infiltration Model requires estimates of its component flows, namely:

DINFIL = dry weather infiltration,
RINFIL = wet weather infiltration,
SINFIL = melting residual ice and snow, and
GINFIL = groundwater infiltration.

Step 1. Determine Groundwater Condition - If the groundwater table is predominantly above the sewer invert, all infiltration is attributed to this source (GINFIL). In this case, an estimate of the total infiltration is made directly (in cfs for the total drainage basin) and read in card K1. This card followed by a blank card (card K2) would complete the infiltration data input. If the groundwater table is not predominantly above the sewer invert, proceed to Step 2.

Step 2. Build-Up Infiltration from Base Estimates -- From measurements, historical data, or judgment, provide estimates of DINFIL and RINFIL. In this case, GINFIL must be set equal to 0.0. Finally, if needed, provide the peak residual moisture (RSMAX), and the 12 monthly degree-day totals taken from Appendix VII or a local source.

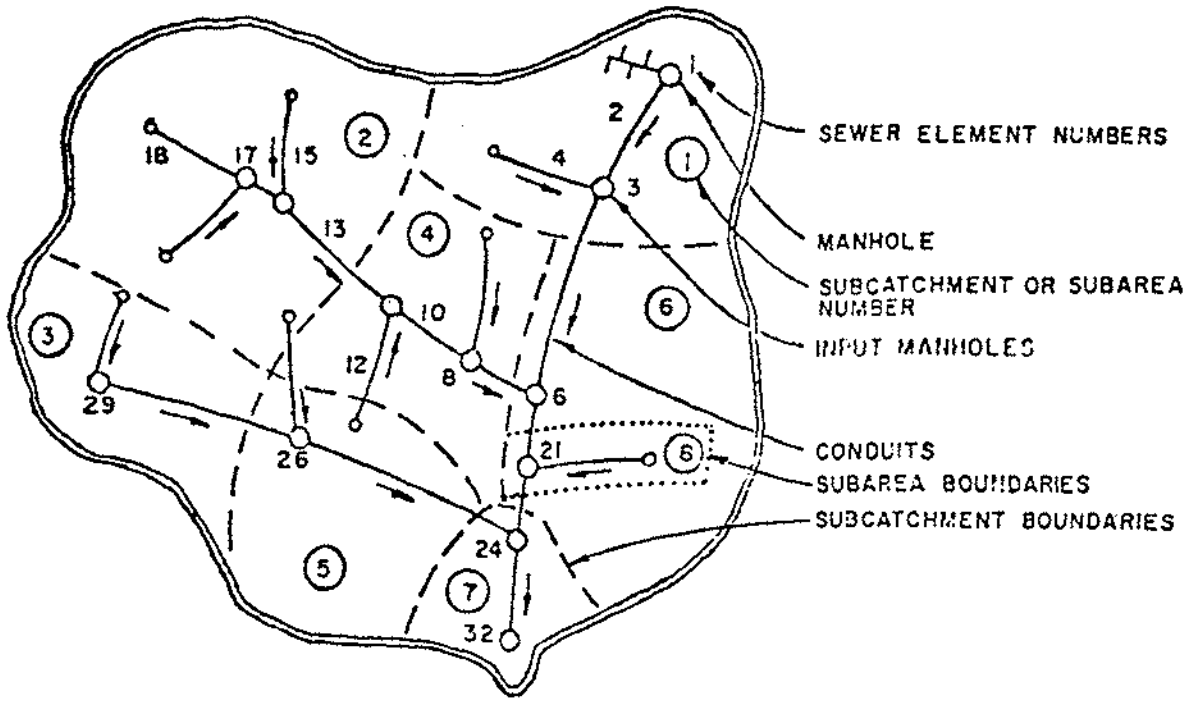
Dry Weather Flow Model

Methodology --

Subroutine FILTH has been developed as an option to estimate average sewage flow and quality from residential, commercial, and industrial urban areas. FILTH estimates sewage inputs at discrete locations along the trunk sewers of any specified urban drainage basin. These estimates are calculated from data describing drainage basin subsections (subcatchments and subareas) under which the trunk sewer passes. In this routine, dry-weather flow quantity and quality are developed from regression equations, as explained in the documentation (Metcalf and Eddy et al., 1971a). The estimates are for three specific quality parameters: BOD_5, suspended solids (SS) and total coliforms. Thus, if any different parameters are to be simulated, FILTH cannot be used. However, if a fourth parameter is to be routed in addition to BOD_5, SS and total coliforms, FILTH can be used to provide estimates for the first three but not the additional one. Also bear in mind that a constant base flow for any parameter may be input at manholes in card group E1.

When FILTH is not used, DWF estimates may be input at desired manholes, as discussed previously. In fact, this option may be routinely used in place of FILTH whenever reasonable estimates are available for instream DWF quantity and quality.

An example of a hypothetical sewer system and input situation for FILTH is given in Figure 6-10. To avoid confusion with Runoff Block subcatchments, all drainage basin subdivisions will be referred to as subareas in the following discussion. As shown in the figure, an input manhole near the center of each subarea is assumed to accept all sewage flow from that subarea. Criteria for establishing subarea boundaries and input locations are discussed later in the text.



Sewer and Subcatchment Data

1. Manhole 32 is the most downstream point.
2. Subcatchments 1,2,3, and 4 are single-family residential areas, each 100 acres in size and each with water metering.
3. Subcatchments 5 and 7 are 220-acre industrial areas.
4. Subarea 6 is a 250-acre park.
5. Subarea 8 is a 50-acre commercial area.

Subareas 6 and 8 constitute a subcatchment draining to input manhole number 21.

Resulting Data

8 sewage estimates
KTNUM, total subcatchments and subareas in drainage basin = 8.
TOTA, total acres in drainage basin = 1,140.

KNUM, subcatchment or subarea	INPUT, input manhole number	KLAND, land use category	ASUB, acres in subcatchment or subarea
1	3	1	100
2	17	1	100
3	29	1	100
4	8	1	100
5	26	4	220
6	21	5	250
7	24	4	220
8	21	3	50

Figure 6-10. Determination of Subcatchment and Identification to Estimate Sewage at 8 Points

In the context of the SWMM, FILTH calculates daily sewage flow (cfs) and characteristics (BOD_5, SS, and total coliforms) averaged over the entire year for each subarea. FILTH is called from subroutine TRANS by setting the parameter NFILTH equal to one. Flow and quality characteristics estimates and corresponding manhole input numbers are then returned to TRANS where the estimates undergo adjustment depending upon the day of the week and hour of the day during which simulation is proceeding.

The subroutine may be omitted when modeling separate storm sewers unless it is desired to generate a base flow with DWF characteristics. FILTH is designed to handle an unrestricted number of inlet areas and individual process flow contributors. As a safeguard against faulty data, however, a program interrupt is provided if the combined number exceeds 159, which is a limit set by the Transport Model.

Quantity Estimates --

Three data categories are used to estimate sewage flow: (1) drainage basin data, (2) subarea data, and (3) decision and adjustment parameters.

Study area data are TOTA, KTNUM and ADWF. KTNUM denotes the number of subareas into which a drainage basin, having a surface area TOTA (acres), is being divided. ADWF, which is optional depending upon its availability, gives the average sewage flow (cfs) originating from the entire drainage basin (e.g., average flow data from a treatment plant serving the study area). When it is included, the predicted basin flow will be adjusted to match this value.

Subarea data requirements consist of several options depending upon availability and choice of input. Discussion later in the text will assist in data tabulation by noting the order of preference where options exist. Subarea data can be broken into three categories as follows: (1) identification parameters, (2) flow data, and (3) estimating data.

1) Identification parameters -- Identification parameters are KNUM, INPUT, and KLAND. KNUM identifies each subarea by a number less than or equal to KTNUM. For each of the KTNUM subareas, INPUT indicates the number of the manhole into which DWF is assumed to enter. Land use within each subarea which approximately corresponds to zoning classification, is categorized according to Table 6-5. KLAND serves as an important factor in deciding subarea locations and sizes. Figure 6-10 will assist in describing how the above data are determined and tabulated.

Table 6-5. Land Use Classification

KLAND	
1	Single-family residential
2	Multi-family residential
3	Commercial
4	Industrial
5	Park and open area

2) Flow data -- Flow data are optional inputs that eliminate the need for using predictive equations. Two possible types of flow data are average sewage flow measurements, SEWAGE, and metered water use, WATER. Commercial or industrial sewage flow or water use measurements should be input using the variable SAQPF. Flows from commercial and industrial establishments located in residential or open subareas may be included using SAQPF, also. Metering at lift stations and other flow control structures within the study area is occasionally available and should be used whenever possible. Metered water use offers a more available source of subarea flow data. Unfortunately, considerable effort in locating, tabulating, and averaging these data is often required.

3) Estimating data -- For each subarea where SEWAGE or WATER measurements are not available estimated water use must be used as an estimate of sewage flow. In the case of a factory or commercial establishment, estimates can be made by multiplying the number of employees by an established coefficient (gpd per employee). In the case of a large factory or commercial establishment, one subarea may be established with estimated water use tabulated as SAQPF for that subarea. On the other hand, estimates of water use for established non-residential areas (e.g., industrial parks or shopping centers) may be summed and tabulated as SAQPF for one large subarea. A list of the above mentioned coefficients is given in Appendix VIII.

In the case of residential areas, estimating data for each subarea are METHOD, PRICE, ASUB, POPDEN, DWLINGS, FAMILY, and VALUE. Default values and definitions of each of these are given in the description of input data. Decision and adjustment parameters consist of DVDWF, HVDWF, KDAY, CPI, and

CCCI. DVDWF and HVDWF are daily and hourly correction factors, respectively, for DWF. DVDWF is comprised of seven numbers that are ratios of daily average sewage flows to weekly average flow. Likewise, HVDWF is comprised of 24 numbers that are ratios of hourly average sewage flows to daily average flow. Both groups of numbers may be derived from observed flow variation patterns throughout the country (e.g., Tucker, 1967, Portland Cement Association, 1968). Their use is to correct measured or estimated average sewage flow to more accurate estimates depending upon the day and hour. Typical sewage flow variations are shown in Figures 6-11 and 6-12. These flow patterns are only examples; locally observed patterns more accurately describe local variations and should be used when available.

KDAY denotes the day of the week at which simulation is to begin. As the simulation proceeds, this value is continually updated. By using the current day and hour, the appropriate values of DVDWF and HVDWF can be multiplied by average flow to determine the correct value. KDAY ranges from 1 to 7 with Sunday being day number 1.

Two cost indices are employed to adjust current house valuations and water prices to appropriate 1960 values and 1963 prices, respectively. This is done because estimating equations within FILTH are based upon 1960 values and 1963 prices. CPI, consumer price index, has been chosen to adjust water price by multiplying water price by 1960 CPI divided by the current CPI. CCCI, composite construction cost index, has been chosen to adjust house valuations similarly. Both indices can be found in most libraries in journals on economic affairs (e.g., U.S. Dept. of Commerce, Survey of Current Business and Statistical Abstracts of the United States).

Quality Estimates --

The purpose of the DWF quality computation is to apportion waste characteristics (such as would be measured at a sewage treatment plant before treatment) among the various subareas in the drainage basin under study, or in the event no measured data are available, to estimate and apportion usable average values. The apportionment is based upon the flow distribution, land use, measured or estimated industrial flows, average family income, the use or absence of garbage grinders, and infiltration.

Daily and hourly correction factors for concentrations of BOD_5, SS and total coliforms are input in conjunction with those for flow variations. All are expressed as ratios of instantaneous to annual or daily averages.

Card N1 includes the total number of subareas and process flow sources to be processed along with the type case (whether the total DWF characteristics are known or to be estimated), the number of process flow contributors, the cost indices, and the total drainage basin population. Depending upon the instructions given, computations proceed along the Case 1 or Case 2 channel.

> Case 1 -- In this instance, the total DWF quality characteristics are known at a point well downstream in the system. These characteristics may be obtained from treatment

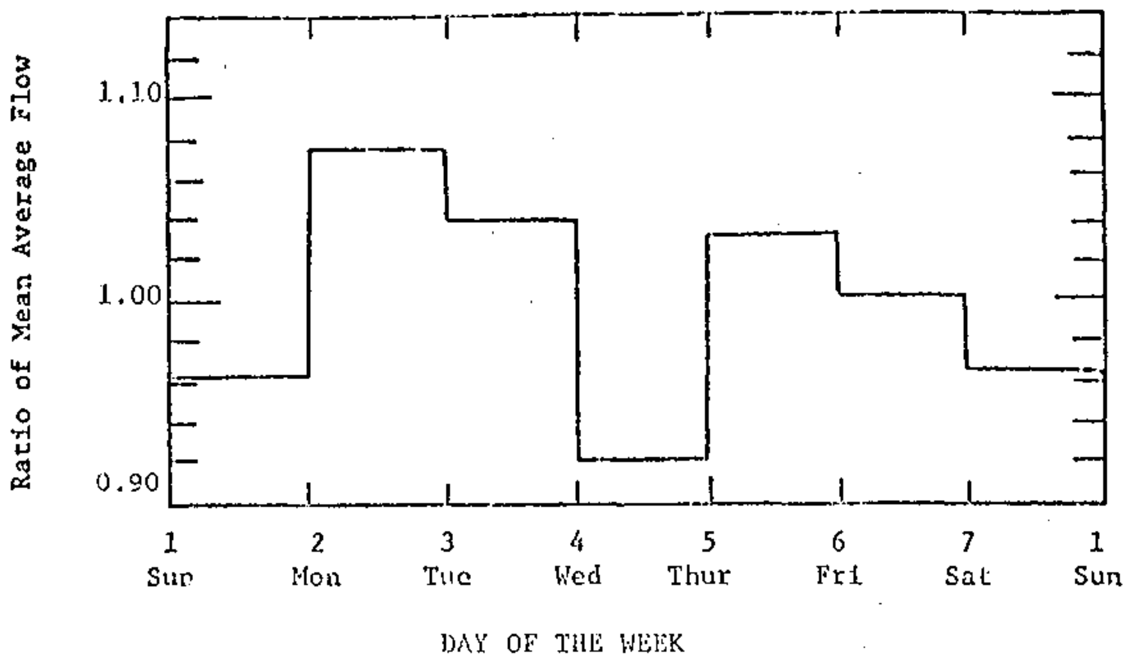


Figure 6-11. Representative Daily Flow Variation

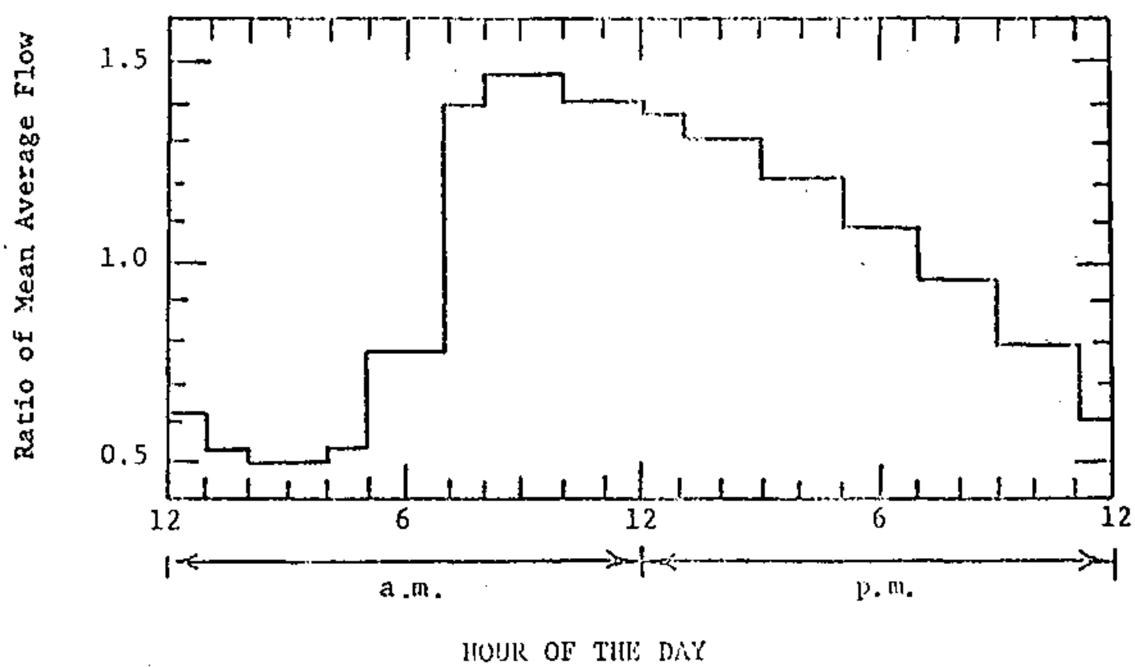


Figure 6-12. Representative Hourly Flow Variation

plant operating records (raw sewage) or by a direct sampling program. The average daily concentrations are read into the program for flow, BOD_5, SS, and total coliforms (card 01). The total pounds per day of BOD_5 and SS and the total MPN per day of coliforms are then calculated. Then, infiltration and base flow are subtracted from the average daily flow. Note that infiltration is computed in separate subroutine INFIL. If it is not executed a default of zero will be assumed.

Next, the known process flow contributions (card group P1) are summed and deducted from the daily totals, yielding a further corrected flow, C2DWF (cfs), and characteristics, C1BOD and C1SS (lb/day). This is the only use of the input from card group P1. Process flow information must be re-entered for each subarea, in card group Q1.

Finally, corrections based on regression equations, are made for personal income variations, degree of commercial use, and garbage grinder status (card 02). The DWF quantity does not change but the characteristics obtain new, average values, C2BOD and C2SS. Average concentrations of the residual flow, A1BOD, A1SS, and A1COLI are then computed.

Case 2 -- Here no direct measurements are available; thus, estimates must be made or default values will be assumed. A typical application of Case 2 would be in a situation where several catchments are to be modeled, yet funds will permit monitoring the DWF only in a single area. A1BOD, A1SS, and A1COLI would be computed via the Case 1 subroutine for the known area and the results could be transferred as Case 2 for the remaining catchments.

Default values of A1BOD, A1SS, and A1COLI are 1300 lb/day-cfs (241 mg/l), 1420 lb/day-cfs (263 mg/l) and 6.2×10^7 MPN/100 ml. These values assume 85 gal/capita-day (322 l/capita-day) domestic wastewater flow and 0.02 lb/capita-day (0.09 kg/capita-day) for BOD_5, 0.22 lb/capita-day (0.1 kg/capita-day) for SS and 200 billion MPN/capita-day for total coliforms. All values assume average income families. The default value for ADWF assumes 100 gal/capita-day (376 l/capita-day) which includes an extra 15 gal/capita-day (57 l/capita-day) for infiltration or other sources.

Following estimation of basin totals, average daily flow and quality values are computed for each of the KTNUM subareas. Data are input in card group Q1 for estimation of water use and sewage quality as well as process flow information for each subarea.

Dry weather flow quantity (DWF in cfs) is computed for each land use on the basics of the following priorities:

Priority	Method
1	Measured average sewage flow (SEWAGE ≠ 0.0).
2	Measured water use (WATER ≠ 0).
3	Regression equations, for single and multiple-family residential land use only.

The first two methods are really equivalent since DWF is simply equated to either SEWAGE or WATER, in this order, for all land uses. Regression equations are employed as a third choice for residential land uses. As explained in the documentation (Metcalf and Eddy et al., 1971a), DWF becomes a function of the number of dwelling units within the subarea (DWLNGS) and other parameters as will be listed below. DWLNGS is required for all regression equations and is computed on the following basis:

Priority	Method
1	Input on card Q1
2	DWLNGS = POPDEN·ASUB/FAMILY
3	Default to 10 units per acre.

DWF is then computed using DWLNGS and input parameters as listed below:

METHOD = 1		METHOD = 2
PRICE = 0	PRICE ≠ 0	
DWLNGS	DWLNGS	DWLNGS
VALUE	PRICE	FAMILY
	CPI	VALUE
	VALUE	

For each technique default values will be used where necessary. It may be inferred that parameters not used in a regression equation may be omitted from input. Note that VALUE is also used in each technique. It is adjusted to the 1960 Composite Construction Cost Index, CCCI, by

$$VALUE = VALUE \cdot 103/CCCI \tag{6-11}$$

Finally, the user is reminded that all inputs for the regression equations can be avoided if either SEWAGE or WATER is known.

For commercial, industrial or undeveloped land uses parameter SEWAGE or WATER is the only method used to input DWF, except that process flows are added to the value of DWF previously computed, for all land uses. Thus, they could constitute the only dry-weather flow source for non-residential land use.

Dry-weather flow quality starts with the average BOD_5 and SS concentrations (A1BOD and A1SS) previously computed for the entire subarea. These are used for the concentrations of non-process flows for all subareas, with two exceptions. First, for commercial and industrial areas, the average concentrations are multiplied by 0.9. Second, the strengths of residential flows are adjusted according to average family income, XINCOM, and percent garbage grinders, PCGG, as explained in the documentation.

The process flow load (i.e. flow times concentration) is then added to the loads just computed, for all land uses. For non-residential land use process flows could constitute the only quality loads.

Finally, for all subareas, total coliforms are computed solely on the basis of population using the average concentration, A1COLI, computed earlier along with the total basin populations, POPULA, (card N1) and subarea populations computed from POPDEN (card Q1). Thus, there will be a subarea contribution of total coliforms only if POPDEN ≠ 0.

For each of the KTNUM subareas, subtotals (cumulative up to this subarea) of computed flows and quality will be printed for each subarea if MSUBT ≠ 1. Otherwise, only basin totals will be printed. If measured basin averages have been input on card O1 (KASE = 1) all subarea loads are adjusted by a constant ratio such that the flow and concentrations computed from the data of card group Q1 will agree with the input averages.

Summary of Dry Weather Flow Requirements --

Step 1. Establishing Subareas -- Establishment of the subareas constitutes the initial step in applying subroutine FILTH. Both detail of input data and assumptions made in developing FILTH imply constraints on the type, size, and number of subareas. However, most important in subarea establishment is the type of estimating data available and the maintenance of homogenous land use.

Subareas should be located and sized to utilize existing sewer flow measurements taken within the drainage basin. These measurements should be recent and of sufficient duration to provide a current average sewage flow value for the period of time during which simulation is to proceed. Measured daily and hourly flow variation should be used in lieu of generalized values described earlier in the text. A gaging site with less than 200 ac (81 ha) contributing flow often provides a convenient data input situation. A subarea should be established upstream from the gage with average sewage flow tabulated as SEWAGE for that subarea. It is convenient, though not necessary, for the subareas to correspond to subcatchments in Runoff.

If metered water use is to be used to estimate sewage flow, subareas should be located to coincide with meter reading zones or other zones used by the water department that simplify data takeoff. Since water use would be used to estimate sewage flow, average winter readings should be used to minimize the effects of lawn sprinkling and other summer uses.

If neither gaging nor metered water use are input, sewage characteristics must be estimated. Subareas should then be established to yield appropriate input data for the residential estimating equations in FILTH. Zero sewage flow is assumed from commercial, industrial, and parkland subareas for which SEWAGE and WATER are zero and measurements of SAQPF are not given. Since KLAND and VALUE are the significant variables in estimating subarea sewage flow, subareas should be located and sized to include land with uniform land use and property valuation. To utilize existing census data, subarea boundaries should be made to coincide with census tract boundaries.

Criteria for establishing subareas are listed in the following summary:

1) Subareas in general should:

   a. be of homogenous land use;

   b. be less than or equal to 159 in number; and

   c. conform to the branched pipe network.

2) Subareas should be established to employ any existing sewer flow measurements.

3) Subareas for which metered water use is used to estimate sewage flow should be compatible with meter reading zones.

4) Residential subareas for which estimated water use is used to estimate sewage flow should:

   a. be uniform with respect to land use;

   b. be uniform with respect to dwelling unit valuation; and

   c. coincide with census tracts.

Step 2. Collection of Data -- Other than the establishment of measured data described earlier, the primary data source is the US Bureau of Census for census tract information. This source provides readily available data on population distribution, family income, and the number and relative age of dwelling units. City records, aerial photographs, and on-site inspection may be necessary to define land use activities, process flow, and dwelling density variations within tracts.

Step 3. Data Tabulation -- Once subareas have been established, several alternatives exist regarding data tabulation. An identification number KNUM should be given to each subarea prior to data takeoff. However, once KNUM's have been established, corresponding INPUT manhole numbers are selected from a previously numbered schematic diagram of the trunk sewer. This numbered schematic serves as the mechanism to coordinate runoff, infiltration, and sewage inputs. Refer to the Transport discussion for additional information about the numbered schematic. If water use estimates are necessary, land use should be determined from city zoning maps and the previously tabulated values for KLAND.

ADWF should be tabulated as average drainage basin sewage flow. As the ADWF, SEWAGE should be averaged from flow data for the appropriate month, season, or year. ADWF, SAQPF, or SEWAGE may be obtained from routine or specific gaging programs done by the city, consulting engineers, or other agencies. SAQPF may be estimated for commercial and industrial areas using water use coefficients (Appendix VIII). Also, SAQPF and WATER may be determined for all land use categories from water meter records.

Initialization

Following execution of subroutines INFIL and/or FILTH, flows and concentrations will be initialized to base flow values simply by summing flows and loads at all junctions (non-conduits) in subroutine INITAL. Base flow can thus originate from three sources: input at manholes, infiltration (subroutine INFIL), and/or dry-weather flow (subroutine FILTH). Inflows from FILTH are always subject to the hourly and daily adjustment factors; inflows from INFIL and manholes are not.

In addition, the buildup of settled pollutant fractions (if simulated) in the sewer system is estimated using subroutine DWLOAD. For the particle size distribution and specific gravity discussed earlier, daily "solids" deposition is computed for DWDAYS dry-weather days (card D2) prior to the simulation. The initial pounds of deposition are printed for each conduit. This material is then eligible for erosion during the simulation (computed in subroutine QUAL). Thus, if flows increase over their initial values, (as expected during a storm) a "first flush" will be provided.