Section 8
Receiving Water Modeling

A receiving water may receive combined sewer overflows and stormwater runoff from point and non-point sources. The overflows and runoff may contain toxic chemical pollution as well as nutrients, suspended solids, and BOD_5. One of the objectives in the creation of the SWMM was coupling runoff, routing and receiving water models in a single package. A receiving water model (RECEIV) was part of the SWMM package from its conception (Metcalf & Eddy Inc. et al., 1971a; Huber et al., 1975).

RECEIV was dropped from the SWMM package in 1981 (Huber et al., 1981b) since it was felt better models (Dynamic Estuary Model and RECEIV derivatives) were currently being written at EPA but were not immediately available for inclusion in the 1981 version of SWMM. This did not reflect a lessening of the importance of the coupling of land and receiving water models. It was planned to link the new receiving water model with SWMM. However, Runoff, Transport, Storage-Treatment and Extran were never linked to the new EPA model DYNHYA (currently DYNHYD3) (Ambrose et al., 1986).

The current EPA receiving water models are: (1) DYNHYD3, a dynamic, branching one-dimensional link node model that simulates the flow, velocities, and depths of a lake, river, and estuary, and (2) WASP3, a water quality model that simulates nutrients (EUTROWSP3), and toxic chemicals (TOXIWSP3) in receiving waters (Ambrose et al., 1986).

SWMM is coupled to both models through the SWMM interface file. Overland flows, routed pipe and channel flows, and the effluent from storage and treatment facilities can be input into DYNHYD3 as a variable-flow input. DYNHYD3 reads the SWMM interface file (see Section 2) to find first the location of the requested nodes and secondly the time history of the node flow. The flows are converted to negative numbers since DYNHYD3 input is negative and withdrawals are positive.

The SUMRY2.OUT file created by DYNHYD3 is then read by either EUTROWSP3 or TOXIWSP3 during the simulation of water quality. The SWMM interface file may also be read by WASP3, except that only the loadings are input to model by subroutine SMWASP.

Section 9
Statistics Block*

Introduction

The Statistics Block performs simple statistical analyses on continuous event or single-event data, although the latter is seldom necessary. Both quantity and quality parameters may be analyzed. The options available include event separation with a table depicting the sequential series of events, a table of magnitude, return period and frequency of events, a graph of magnitude versus return period, a graph of magnitude versus frequency, and the first three moments of the event data.

Statistical analyses are performed on data read from an interface file arranged in the standard SWMM format (refer to Section 2). The Statistics Block may be called after any block thas generated such a file. In addition, the user may create an interface file of rainfall or other data and, through an understanding and alteration of various conversion factors, use the Statistics Block to analyze rainfall, rather than stormwater events.

Separation of the data into events depends on the unique series of zero and non-zero instantaneous flow values found at each location within the system being simulated. The results of the analyses would be expected to vary from location to location. The Statistics Block can analyze only one location at a time. Multiple locations can be analyzed by making multiple calls to the Statistics Block from the Executive Block of SWMM using the same JIN interface file.

This section describes the program operation of the Statistics Block, identifies output options, provides instructions for preparing input data groups, defines program variables, presents the equations utilized within the block and explains the messages and labels that may be printed.

Program Operation

The Statistics Block is a FORTRAN program of approximately 1700 Fortran statements and consists of nine subroutines. The relationships among the Statistics Block, the rest of SWMM and the various subroutines are shown in Figure 9-1.

Subroutine STATS comprises the major portion of the block. Input data and data from the interface file are read, and descriptive information from the file header is printed, followed by a summary of the input data. The flow/pollutant data are separated into events and this new data set is written into a scratch file. There is an internal program limit of 4000 events per location. This is sufficient to analyze 100 storm events per year for 40 years. The user must have sufficient disk space to store the scratch file. The unformatted scratch file at the limit of 4000 events will require less than 100 k bytes for total storage. The event limit can be modified

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* This block originally developed by Mr. Donald J. Polmann.

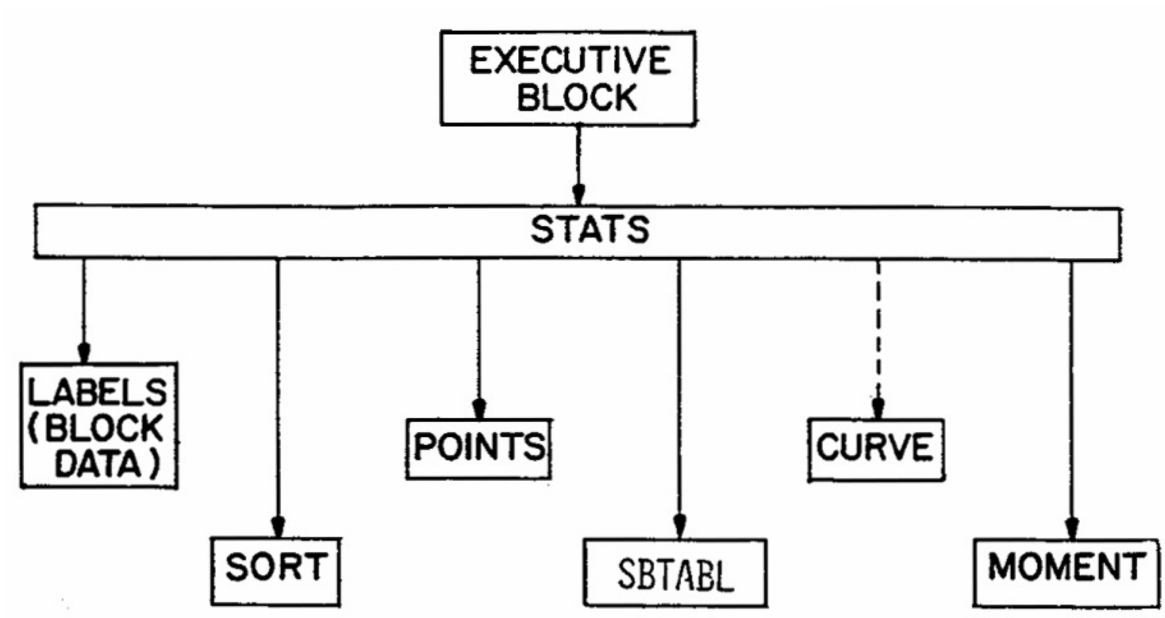

Figure 9-1. Structure of the Statistics Block subroutines.

by altering the parameter statement accompanying the INCLUDE file ‘TAPES.INC’ (see Section 2 for more detail).

After the entire simulation period has been examined, a table of the sequential series of events is printed (if requested). If a table of return period and frequency or a graph of either of these is requested, the series is sorted into descending order by Subroutine SORT. SBTABL generates and prints the tables of magnitude, return period and frequency. POINTS generates an array of (X,Y) pairs to be plotted as points on either the return period or frequency graphs. MOMENT calculates and prints the mean, variance, standard deviation, coefficient of variation and coefficient of skewness of the event data. LABELS is a Block Data subroutine that initializes the constants in labeled common blocks that are used for labeling graphs.

Output Options

Introduction

The table of sequential series of events depicts the original time series of flow data after the time steps have been grouped into events. The table includes the date and time of day that each event began, flow volume of each event, total rainfall during the <u>flow</u> event, duration of each event and interevent duration (time from the end of the previous event).

The table of magnitude, return period and frequency is a rank order table showing the data and time that each event began, the magnitude of the event being analyzed, the return period (in years or months) of that magnitude and the percent of occurrences that are less than or equal to the given magnitude.

The graph of magnitude versus return period is a plot of two columns of the table, except that return period is presented as the base ten logarithm. The graph of magnitude vs. frequency is a similar plot with frequency presented as a percent. Although the graphing routines plot information centered in the table, it is not necessary to select the table option in order to select the graph options. Any of these may be printed independently of the others. The last option available is a calculation of the mean, standard deviation, coefficient of variation and skewness of the event data.

The table of sequential series pertains only to the volume of the flow events. The remaining options can be requested for flow or pollutants. Any (or all) of these can be selected for any (or all) of the five flow parameters and for any (or all) of the five pollutant parameters. Different pollutant parameters can be analyzed for different pollutants. Events are identified on the basis of flows greater than or equal to a cutoff baseflow (user input), so that the duration of events and interevents will be identical for flow and any of the pollutants selected.

Sequential Series of Events

This option prints a table of the original series of events before any sorting has taken place. Printing of the table, which contains 120 events per page, may be accessed in several ways. First, the table may be printed directly as an option under normal program execution. Second, when the number of events in the time series exceeds the designated limit (4000) and termination of the program has not been requested, the table may be printed (ignoring the rest of the series). Third, in the case where termination has been selected, the option remains to print a table for that portion of the series that has been separated into events.

Table of Magnitude, Return Period and Frequency

For those parameters where this option is requested, one table will be printed for each parameter chosen for each constituent chosen. For example, if, for the constituent 'FLOW', two parameters are chosen (e.g., total flow and event duration), and for each of two pollutants two parameters are chosen (e.g., total load and peak concentration), then six separate tables are printed, each containing magnitude, return period and frequency for the appropriate parameter. Therefore, although it is unlikely that one would have reason to do so, up to 60 tables can be printed in one run (five flow parameters, five rainfall parameters and five pollutant parameters for ten pollutants). The length of each table depends on the number of events within the period of analysis (180 events are printed per page).

Graphs of Magnitude vs. Return Period or vs. Frequency

This paragraph applies to either type of graph. As with the tables above, one graph is printed for each parameter chosen of each constituent for which a graph is requested. Each graph comprises one page of out-put. Again, up to 55 graphs can be printed, although this would be an unlikely choice.

Moments

This option calculates and prints unbiased estimates for the mean, variance, standard deviation, coefficient of variation and coefficient of skewness. These values will be printed for each parameter chosen for each constituent chosen. The output incorporates approximately 15 lines and will appear in sequence where space is available (i.e., a new page is not printed for each set of moments).

Preparation of Input Data

Extent of Data

The Statistics Block requires a minimal amount of input data under normal use. The flow/pollutant data to be analyzed will be read from interface files generated by other blocks of SWMM. The input data required simply indicate what type of analysis should be performed on the interface data. Use of the block for rainfall data is discussed later.

Line by line instructions for preparing the input data will be presented. The user is referred to the table of Statistics Block Input Data later in this manual for input details. The general structure of the data groups is given in Table 9-1.

Table 9-1. Statistics Block Input Data

Data Group	Description
$STATS	Calls the Statistics Block
A1	Starting and Ending Dates
B1	General Data
B2	Print Control
B3	Pollutant Locations
C1	Table and Graph Requests for Flow
D1	Table and Graph Requests for Pollutants
E1	Table and Graph Requests for Rainfall

Flow, Pollutant and Rainfall Input Files

The Statistics Block reads the interface file JIN(1) for flow, pollutant, and rainfall information, It uses NSCRAT(1) as the temporary scratch file holding the event information it reads from JIN(1). The source of the interface file JIN(1) may be the output from the Runoff, Transport, or Storage/Treatment Block or the rainfall file created by the Rain Block. The Statistics Block can read flow, pollutants, and rainfall from the Runoff, Transport, or Storage/Treatment outputs. It can only read rainfall from the Rain Block output rainfall file.

Data Group A1

The variables ISTART and TSTART indicate the date and time, respectively, at which this block should begin searching for events. The variables IEND and TEND indicate the last point on the file that should read. In this manner, the user may choose any period within the record (e.g., one particular year, five sequential years, etc.) on which to perform statistical analyses. Default values of zero for both data and time can be chosen for starting and/or ending. Zero starting values indicate that analyses should commence with the first value on the interface file. Zero ending values indicate that analyses should continue to the end of the available record. Formats for data and time correspond to the standard interface format (Section 2).

Data Group B1

Minimum Interevent Time

The minimum interevent time (MIT) indicates the minimum number of dry hours (or fractional hours) that will constitute an interevent. In other words, the number of consecutive dry hours encountered in the search must be equal to or greater than MIT in order that the preceding wet period (made up of at least one non-zero flow value) be considered a separate event. Dry periods of duration less than MIT may exist within an event preceded and followed by wet time steps. The number of events in a given period of analysis is directly dependent on the value of MIT. If a value of zero is chosen for MIT, every wet time step will be viewed as a separate event.

No "correct" value of MIT can be suggested, although a value of 3 to 30 hours is often used to separate <u>rainfall</u> events (Hydroscience, 1979). Various event definitions for rainfall time series are available in the literature, e.g., Tavares (1975), Heaney et al. (1977), Hydroscience (1979), Restrepo-Posade and Eagleson (1982). Several urban runoff studies (e.g., EPA, 1983b) have evaluated MIT for rainfall events on the basis of the coefficient of variation (CV) of interevent times, where the CV is the ratio of the standard deviation to the mean. The MIT that gives a CV near 1.0 is usually chosen as the gage MIT. This assumes that the interevent times have an exponential distribution for which the mean equals the standard deviation (hence, CV = 1.0). Thus, the MIT is chosen to make the empirical date fit the theory. If this method is selected, two trial values of MIT are used and the corresponding CV values for interevent times determined through two runs of the Statistics Block. A plot (or linear extrapolation) of MIT versus CV will generally give a good estimate of the MIT value for which CV is approximately 1.0. Depending upon the site, this definition applied to the runoff time series can yield large values of MIT, on the order of 100 hours.

Baseflow

The events are separated using a baseflow or cutoff flow (BASE on Data Group B1). Flows greater than BASE are part of the event, conversely flows less than or equal to BASE are part of the interevent period. This parameter may be set equal to 0.0 cfs [m^3].

Location

The analyses are performed at one location (LOCRQ) within the system. The interface file may contain data for up to 100 locations, each identified in the array LOCNOS(K). The LOCRQ must be specified in one of the elements in the array LOCNOS(K).

Rainfall statistics can be calculated for one raingage (LOCRN) on the interface file. Rainfall may be analyzed in conjunction with flow and pollutants or separately by using an LOCRQ of 0 for the flow inlet.

Number of Pollutants

The number of pollutants requested for statistical analysis (NPR) must be less than or equal to the number of pollutants on the interface file (NPOLL). If NPR equals 0 then Data Group D1 is not read by STATS.

Number of Events Printed

The user can limit the number of events printed by setting NPOINT greater than 0. A value of 0 will print every event in the simulation. Otherwise, a maximum of NPOINT values will be printed.

Units

The variable METRIC indicates the system of units in which output should be reported. To implement U.S. customary units, use METRIC = 0. For metric units, use METRIC = 1.

Return Period Units and Plotting Position Parameter

Return periods will be calculated using either months or years as the basic time unit. The user decides by picking LRET = 0 (years) or LRET = 1 (months). The plotting position is adjusted by selecting parameter A on data group B1. This parameter is discussed in more detail later in the description of computations.

Data Group B2

Table of Events

The variable KSEQ indicates whether or not a table of the sequential series of events should be printed.

Limit on Number of Events

The variable KTERM indicates whether or not to terminate analyses in the case where the number of events exceeds the allowable computer memory space. The number of events that can be sorted and analyzed has been set within the program to 4000. This value corresponds to 200 events per year for a 20 year period. As noted, the user may alter this value. If the number of events exceeds the limit set, the program will either (a) perform the analyses on the events already identified, ignoring the remainder of the record (KTERM = 0), or (b) terminate execution of the block, performing no event analysis (KTERM = 1). If the analyses are being performed, a table of the sequential series will be printed if KSEQ = 1. If the analyses are not performed, the option still exists to print the table of sequential series before termination. The variable KTSEQS indicates that the table should or should not be printed in this case.

Data Group B3

The variable array IPOLRQ will contain up to ten elements, corresponding to the maximum value of NPR (and NPOLL, the number of pollutants on the interface file). The pollutants requested for analysis must be identified by their position on the interface file (not by name). Therefore, the elements of IPOLRQ will contain integer values from 1 to 10. For example, if the first pollutant to be analyzed is BOD, and BOD is the third pollutant on the interface file, then IPOLRQ(1) would have the value 3. Similarly, if the second pollutant to be analyzed is TSS, and TSS is the fifth pollutant on the interface file, then IPOLRQ(2) would have the value 5.

Data Group C1

Data group C1 indicates the statistical options requested for flow. There are five input variables in each line of input, one for each of the five flow parameters. The five parameters are (1) total flow for the event, measured as a volume and reported as inches [mm], (2) average flow for the event, measured as a rate and reported as in./hr [mm/hr], (3) peak flow for the event, measured as an instantaneous rate and reported as in./hr [mm/hr], (4) duration of the event, measured as the number of time steps making up the event and reported as hours, and (5) duration of the interevent, measured as the number of dry hours preceding the event and reported as hours. Two tables and two plots may be generated for each of the five parameters: (1) a table of event magnitude, return period and frequency (column 1), (2) a graph of magnitude vs. return period (column 2), (3) a graph of magnitude vs. frequency (column 3), and (4) a table of the first three moments of the event date (column 4).

The user selects the tables and graphs to be printed by entering a four digit number containing either a 0 or a 1 in each column. The columns pertain to the columns described in the previous paragraph. For a given group, those fields containing a 1 indicate the flow parameters for which that option has been selected. Values of zero indicate that the analyses should not be performed. For example, entering 1111 in parameter one’s field means two tables and two plots are generated for total flow. Entering 0000 or 0 means no tables or graphs are generated. See Table 9-3 for more details.

Data Group D1

Data group D1 is identical in format to group C1. The four statistical options available for flow are also available for pollutants. One D1 data line must be included for each of the NPR pollutants requested, indicating which options for which parameters should be performed for each pollutant. The D1 lines should be arranged in a sequence corresponding to the order in which the pollutants were requested. Again, there are five input fields on each D1 line, one field for each of the five pollutant parameters. The four-digit entry for each field indicates which of the two tables and two graphs are requested. The five parameters are: (1) total load, measured as a sum of the concentration times the flow rate and reported as pounds [kg], (2) average load, measured as a rate of pollutant loading and reported as lbs/hr [kg/hr], (3) peak load, measured as an instantaneous rate of pollutant loading and reported as lbs/hr [kg/hr], (4) flow-weighted average concentration (event mean concentration), reported as mg/l, and (5) peak concentration, reported as mg/l.

Data Group E1

Data Group E1 is also identical in format to group C1. The four statistical options available for flow are also available for rainfall. Again, there are five input fields, one field for each of the five rainfall parameters. The five parameters are (1) total event volume reported as inches [mm], (2) average intensity reported as in./hr [mm/hr], (3) peak intensity, reported as in./hr [mm/hour], (4) duration of the event, measured as the number of time steps making up the event and reported as hours, and (5) duration of the interevent, measured as the number of dry hours preceding the event.

Computations

Return Period and Frequency

In Subroutine STATS, variables T1 and T2 indicate the beginning and end, respectively, of the period of analysis, measured as elapsed time from the beginning of the simulation, in hours. The return period of an event may be reported in either months or years. If years are chosen, the simulation duration is rounded to the nearest number of years (NYRS). If months are chosen, it is necessary to calculate the number of months (NOMOS) within the period of analysis. The average number of hours per month in a year of 365.25 days is 730.5. This value is used to find a value for NOMOS, rounded to the nearest month, by the equation

$$\text{NOMOS} = \text{Integer}\left[(\text{T2}-\text{T1})/730.5 + 0.5\right] \tag{9-1}$$

For short periods of analysis (e.g., of the order of one year) NOMOS may be in error by one month depending on which months of the year are included in the period. This should pose little difficulty as a return period analysis for such a short period is generally not undertaken (or at best is of questionable worth).

Empirical return period (plotting position) is calculated by the general equation first proposed by Gringorten (1963) and analyzed by Cunnane (1978):

$$T = (\text{NMY} + 1 - 2A)/(M - A) \tag{9-2}$$

where

T	=	return period in months or years (depending on the option selected in data group B1 (LRET),
NMY	=	number or months, NOMOS, or number of years, NYRS,
M	=	rank of event (ranked in descending order), and
A	=	parameter of the equation (data group B1).

A value of A = 0 gives the familiar Weibull plotting position (Gumbel, 1958),

$$T = (\text{NMY} + 1)/M \tag{9-3}$$

The Weibull formule is often used in hydrology but has been criticized by Cunnane (1978) who suggested a value of A = 0.4 as a good compromise for the customary situation in which the underlying frequency distribution of the parameter is unknown. (The references only analyze return periods in years. No guidance is available for units of months.)

Large uncertainties exist in return periods computed in this manner (Gumbel, 1958)! A refined analysis would compute return periods and exceedance probabilities by fitting an assumed probability density function, as in flood-frequency analysis, for which confidence intervals may be established.

The discussion of return period assumes the events are independent, on the basis of the event separation criterion discussed earlier. However, the frequency, FREQ, computed for each event is merely the percent of total events less than or equal to the given magnitude

$$FREQ = 100\,[1 - (M-1)/N] \qquad (9\text{-}4)$$

where

M = rank, and
N = total number of events within the period of analysis.

The largest event is assigned a frequency of 100 percent, etc.

Moments

Calculations are made of estimates for the mean ($\bar{x}$), variance (S^2), standard deviation (S), coefficient of variation (CV) and coefficient of skewness (C_s). The equations utilized for these calculations are:

$$\bar{x} = \sum x / N \qquad (9\text{-}5)$$

$$S^2 = \left[\sum x^2 - N\bar{x}^2\right] \Big/ (N-1) \qquad (9\text{-}6)$$

$$S = \left(S^2\right)^{1/2} \qquad (9\text{-}7)$$

$$CV = S \Big/ \bar{x} \qquad (9\text{-}8)$$

$$C_s = (\text{Numer} \cdot \text{Factor})/\text{Denom} \qquad (9\text{-}9)$$

where

Numer = $\sum x^3 / N - 3\bar{x} \sum x^2 / N + 2\bar{x}^3$

Denom = $\left[\sum x^2 / N - \bar{x}^2\right]^{1.5}$

Factor = $\left[N(N-1)\right]^{1/2} / (N-2)$

The forms given above for Numer and Denom are for computational convenience and correspond to the more usual forms,

$$\text{Numer} = \sum \left(x - \bar{x}\right)^3 / N$$

$$\text{Denom} = \left[\sum \left(x - \bar{x}\right)^2 / N\right]^{1.5}$$

For the above equations, x is the magnitude of the event parameter, and N is the total number of events within the period of analysis. All summations are from 1 to N. Equations 9-6 and 9-9 are unbiased estimates for the variance and skewness, respectively.

Messages and Labels

Most of the messages printed as part of the block execution are self-explanatory and do not require discussion here. A notable exception to this involves the units printed for pollutants. As a prelude to this discussion, an explanation of the units provided in the tables and graphs is called for. Table 9-2 summarizes the units printed for flow and three types of pollutants. The labels printed for the ordinate of the graphs are also presented.

All flow parameters are normalized to depth or depth/hr (i.e., in. or mm or in./hr or mm/hr). Should true volumes be desired, they may be obtained by multiplying by the catchment area, printed after reading the interface file.

When NDIM = 2, a special message is printed on the graph or table. Rather than printing the units described in The Statistics Block Input data later, the output contains "SEE NOTE" and the note "Magnitude has units of .… See user manual for explanation." The explanation referred to is included in the following discussion.

The user is referred to Sections 2 and 4 for an introduction to the variable NDIM. For NDIM = 0, pollutant concentration is given in mg/l. In this case, a direct conversion is possible for loading rates and concentrations. For NDIM = 1, pollutant concentration is given in "other quantity" per liter (e.g., MPN/l). Here, no conversion is possible to mass loading or mass per unit volume. "Mass" must be presented as "quantity" and the user must be aware of what "quantity" refers to for the pollutant involved. The units printed for flow weighted average concentration and peak concentration will correspond to the variable PUNIT found on the interface file for the particular pollutant. For NDIM = 2, pollutant concentration is given in some other units, not on a "per liter" basis (e.g., JTU). Therefore, no units conversion can be made. Magnitudes reported for total load will have units of a volume multiplied by the appropriate PUNIT. The magnitude is obtained by summing the pollutant values found on the interface file (which are in units of an instantaneous flow rate multiplied by a concentration) and multiplying this value by the time step size (DTSEC) of the event. Interpretation of the significance of these magnitudes is left strictly to the user, who should exercise caution in selecting this statistical option. A similar caution applies to average load and peak load. These magnitudes will have units of a flow rate multiplied by the appropriate PUNIT. The average load is the mean of the values found on the interface file for a given event, with a units conversion for flow rate. The peak load is the largest of the values within an event, with a similar units conversion for flow rate. Flow weighted average concentration and peak concentration will have units corresponding to PUNIT for the particular pollutant and an interpretation of these magnitudes may be simpler than the above parameters. The calculation of these two parameters is self-evident.

Table 9-2. Labels and Units

	Parameters	Ordinate Label	U.S. Customary Units	Metric Units
Flow	Total Flow	Total Q	inches	mm
	Average Flow	Aver Q	inches/hr	mm/hr
	Peak Flow	Peak Q	inches/hr	mm/hr
	Event Duration	Duration	hours	hours
	Interevent Duration	Interevt	hours	hours
Rainfall	Volume	Total V	inches	mm
	Average Intensity	Aver In	inches/hr	mm/hr
	Peak Intensity	Peak In	inches/hr	mm/hr
	Event Duration	Duration	hours	hours
	Interevent Duration	Interevt	hours	hours
Pollutant with NDIM = 0	Total Load	Tot Load	pounds	kilogram
	Average Load	Ave Load	lbs/hr	kg/hr
	Peak Load	Peakload	lbs/hr	kg/hr
	Flow Weighted Average Concentration	Ave Conc	mg/l	mg/l
	Peak Concentration	PeakConc	mg/l	mg/l
Pollutant with NDIM = 1	Total Load	Tot Load	Quantity	Quantity
	Average Load	Ave Load	Quan/hr	Quan/hr
	Peak Load	Peakload	Quan/hr	Quan/hr
	Flow Weighted Average Concentration	Ave Conc	PUNIT	PUNIT
	Peak Concentration	PeakConc	PUNIT	PUNIT
Pollutant with NDIM = 2	Total Load	Tot Load	ft^3*PUNIT	Liter*PUNIT
	Average Load	Ave Load	cfs PUNIT	Liter/S*PUNIT
	Peak Load	Peakload	cfs PUNIT	Liter/S*PUNIT
	Flow Weighted Average Concentration	Ave Conc	PUNIT	PUNIT
	Peak Concentration	PeakConc	PUNIT	PUNIT

Analysis of Rainfall Data

The Statistics Block now has the capability of analyzing rainfall either directly from a SWMM interface file or a rainfall file from the Rain Block. It performs the analysis on raingage LOCRN (from data group B1) for the rainfall parameters selected on the E1 data line.

The Runoff Block places all raingage information on its output interface file. Thus, there may be up to 10 raingages on the interface file. The raingage name is a negative number from 1 to 6 digits long that is either the user designated raingage number or a National Weather Service precipitation station. It has units of inches/hour and is located in the same position as inlet flows on the interface file. Its distinguishing characteristic is its negativity. This information is carried through to following blocks such as Transport and Storage/Treatment and placed on their output interface file. Extran does not carry rainfall information to its output interface file. (It is unlikely anyone would use the Statistics Block to analyze Extran output.)

The output file from the Rain Block contains only rainfall. The raingage number (LOCRN) is the NWS, AES, or user defined raingage number in the Rain Block input data. Subroutine SREAD is sophisticated enough to decide the source of data on the JIN(1) interface file. The data to be analyzed by Subroutine STATS must be on file JIN(1).

Table 9-3. Statistics Block Input Data

SWMM INPUT GUIDELINES

There have been many changes made to the input format of SWMM. Following is a short list of the major changes along with explanations and guidelines.

1. Free format input. Input is no longer restricted to fixed columns. Free format has the requirement, however, that at least one space separate each data field. Free format input also has the following strictures on real, integer, and character data.
   a. No decimal points are allowed in integer fields. A variable is integer if it has a 0 in the default column. A variable is real if it has a 0.0 in the default column.
   b. Character data must be enclosed by single quotation marks, including both of the two title lines.
2. Data group identifiers are a requirement and <u>must</u> be entered in columns 1 and 2. These aid the program in line and input error identification and are an aid to the SWMM user. Also blank lines no longer are required to signal the end of sets of data group lines; the data group identifiers are used to identify one data group from another.
3. The data lines may be up to 230 columns long.
4. Input lines can wrap around. For example, a line that requires 10 numbers may have 6 on the first line and 4 on the second line. The FORTRAN READ statement will continue reading until it finds 10 numbers, e.g.,

   ```
   Z1   1  2   3  4  5  6
          7  8   9 10
   ```

   Notice that the line identifier is <u>not</u> used on the second line.
5. An entry must be made for <u>every</u> parameter in a data group, even if it is not used or zero and even if it is the last required field on a line. Trailing blanks are not assumed to be zero. Rather, the program will continue to search on subsequent lines for the "last" required parameter. Zeros can be used to enter and "mark" unused parameters on a line. This requirement also applies to character data. A set of quotes must be found for each character entry field. For instance, if the two run title lines (data group A1) are to consist of one line followed by a blank line, the entry would be:

   A1 'This is line 1.'
   A1 ''
6. See Section 2 for use of comment lines (indicated by an asterisk in column 1) and additional information.

Variable	Description	Default
	Starting and Ending Date/Time	
A1	Group identifier	None
ISTART	Starting date, yr/mo/day	000000
TSTART	Starting time, decimal hours	00.00
IEND	Ending date, yr/mo/day	000000
TEND	Ending time, decimal hours	00.00
	General Data	
B1	Group identifier	None
MIT	Minimum intervent time, decimal hours.	0.0
BASE	Cutoff flow (baseflow), cfs [m^3/s]. Flow used to separate events.	0.0
LOCRQ	Flow location requested.	0
LOCRN	Rainfall gage for analysis.	0
NPR	Number of pollutants requested.	0
NPOINT	Number of events printed in tables. Print only the top NPOINT flows etc. IF NPOINT is 0 then all events are printed.	0

Table 9-3. Continued

Variable	Description	Default
METRIC	Requests type of units for output = 0, U.S. customary, = 1, Metric.	0
LRET	Units of return period, = 0, Return period in years, = 1, Return period in months.	0
A	Plotting position parameter (see text for explanation).	0.0
	Print Control	
B2	Group identifier	None
KSEQ	Request to print sequential series of flow events? No = 0, Yes = 1	0
KTERM	Code for terminating program if number of events exceeds allowable memory space. = 0, Do not terminate (perform analyses on those events already identified). = 1, Terminate program (no event analysis performed).	0
KTSEQS	Code for printing sequential series if the number of events exceed limit and KTERM = 1. = 0, Do not print sequential series. = 1, Print sequential series of those events already identified.	0
	* * * Required only if NPR > 0 on Data Group B1 * * * * * * If NPR = 0 then skip to Data Group C1 * * *	
B3	Group identifier	None
IPOLRQ(1)	First pollutant requested, identified by position on interface file.	None
■	■	
IPOLRQ(NPR)	Last pollutant requested, identified by position on interface file.	None

* * * Required only if LOCRQ on Data Group B1 is > 0 * * *

Stat Options for Flow

This data group controls the printing or plotting of information on magnitude, return period and frequency for each of the five flow parameters. In all cases, No = 0, Yes = 1. The control information is entered as a four digit integer number with each column controlling a different table or graph.

First column	- table of magnitude, return period and frequency.
Second column	- print graph of magnitude versus return period.
Third column	- print graph of magnitude versus frequency.
Fourth column	- print moments.

For example, enter 1111 to print/plot all tables/graphs, 1000 to print the table only, 1100 to print the table and the graph of magnitude versus return period only, and 0000 to bypass printing/plotting of the flow parameter.

C1	Group identifier	None
ISFLOW(1,1)	Request for total flow?	0
ISFLOW(1,2)	Request for average flow?	0
ISFLOW(1,3)	Request for peak flow?	0
ISFLOW(1,4)	Request for event duration?	0
ISFLOW(1,5)	Request for interevent duration?	0

Table 9-3. Continued

Variable	Description	Default
	* * * Data Group D1 is only required if NPR > 0 on Data Group B1 * * *	
	Stat Options for Pollutants	
If NPR > 0 use one D1 Data Group for each pollutant requested, up to ten sets of D1 lines, in the order defined by Group B2. The first index of ISPOLL(K,I,J) identifies the pollutant. Follow the instructions for Data Group C1 in entering data for Data Group D1.		
D1	Group identifier	Blank
ISPOLL(1,1,1)	Request for total load?	0
ISPOLL(1,1,2)	Request for average load?	0
ISPOLL(1,1,3)	Request for peak load?	0
ISPOLL(1,1,4)	Request for flow weighted average concentration?	0
ISPOLL(1,1,5)	Request for peak concentration?	0
	* * * Required only if LOCRN on Data Group B1 is > 0 * * *	
	Stat Options for Rainfall Analysis	
	Follow the instructions for Data Group C1 in entering data for Data Group E1.	
E1	Group identifier	None
ISFLOW(2,1)	Request for total volume?	0
ISFLOW(2,2)	Request for average intensity?	0
ISFLOW(2,3)	Request for peak intensity?	0
ISFLOW(2,4)	Request for event duration?	0
ISFLOW(2,5)	Request for interevent duration?	0
	END OF STATISTICS BLOCK DATA.	
	Data lines following these will be read by the Executive Block.	

Section 10
Rain Block

Block Description

Introduction

Precipitation is the one of the principal driving forces in the SWMM package. The Runoff Block reads precipitation data and generates overland flows for input into the Transport or Extran Blocks. The purpose of the Rain Block is to read long time series of precipitation records, perform an optional storm event analysis, and generate a precipitation interface file for input into Runoff.

The Rain Block takes the place of Subroutine CTRAIN in SWMM 3 (Huber et al., 1981b). It incorporates the rainfall analysis capability of the SYNOP program (Hydroscience, 1979). It is able to read two National Weather Service (NWS) precipitation input formats and a simple user-generated precipitation time series.

This section describes the program operation of the Rain Block, its statistical capabilities, the program variables, how the user can modify the program, and provides instructions for preparing input data lines.

Program Operation

The Rain Block consists of seven Fortran subroutines. The main subroutine (RAIN) reads the input data, performs the statistical analysis, and prints the precipitation echo, storm event summary, statistical summary, and output tables. Subroutine GTRAIN reads the NWS precipitation input tapes or files. SETIA, IDATE, and INTCHR are utility functions used by RAIN. Subroutines SHELL and SHELR use the shell sort routine for integer and real data, respectively.

Input Options

The program is designed to read (NWS) precipitation Card Deck 48¸ (old format) and Tape Deck 3240 (new format) hourly precipitation data. A simple user-defined time series can also be read by Subroutine GTRAIN. This may be inadequate, however, for complicated formats with special codes and messages. GTRAIN can be easily modified by a person familiar with Fortran to read any input file (see Figure 10-1).

```
      SUBROUTINE GTRAIN(IDO,IGO)

C                                        THIS PROGRAM READS TWO VERSIONS OF
C                                        THE NWS PRECIPITATION TAPES
C                                        IFORM = 0 MEANS POST 1980 FORMAT
C                                        IFORM = 1 MEANS PRE  1980 FORMAT
C
      COMMON/PRECIP/HOUR(366,27),IYEND(3),IYBEG(3),
     *       X(2000,7),IFORM,IO,NEWYR,ISTA,SUM(2)
1000 FORMAT(3X,A6,10X,I2,I2,I4,3X,I2,3X,I5,A1)
1040 FORMAT(A6,3I2,I1,12A3)
C
C    IFORM 0 - SHOWS INPUT FORMAT FOR 1 RAINFALL VALUE PER LINE
C    IFORM 1 - SHOWS INPUT FORMAT FOR MULTIPLE RAINFALL VALUES PER LINE
C              IF YOU WANT TO MODIFY GTRAIN FOR YOUR TIME SERIES OF  RAINFALL
C              USE THE APPROPRIATE FORMAT AND THEN INSERT THE RAINFALL INTO
C              ARRAY HOUR AS SHOWN IN THE NEXT SECTION.
C
10    IF(IFORM.EQ.0)    THEN
                        READ(IO,1000,ERR=10,END=40) STA,YEAR,MONTH,
     *                  DAY,IHR,IRAIN,ICODE
                        ELSE
                        READ(IO,1040,ERR=10,END=40) STA,YEAR,MONTH,
     *                  DAY,ICARD,XRA
                        ENDIF
C
C       INSERT RAINFALL INTO ARRAY HOUR
C              AT THE END OF EVERY YEAR HOUR WILL BE PROCESSED BY
C             SUBROUTINE RAIN
C                                                    NEW FORMAT
        IF(IFORM.EQ.0) THEN
          HOUR(IDAY,IHR) = IRAIN
C                                         OLD FORMAT
                        ELSE
                        IF(ICARD.EQ.1) J1 =  0
                        IF(ICARD.EQ.2) J1 = 12
                        DO 35 J = 1,12
35                       HOUR(IDAY,J+J1) = INTCHR(XRA(J))
```

Figure 10-1. Guide for modifying Subroutine GTRAIN.

Output Options

The output of Rain potentially may be voluminous depending on the output options chosen on data group B1. If the user selects to echo the precipitation data, 1-3 pages per year are generated. A storm event summary is printed by year, generating an additional 1-2 pages. The statistical summary is contained on only two pages. Return period tables are generated for storm volume, average intensity, duration, and interevent time. Each return period table may be 10 to 20 pages long for a 30-year rainfall record.

Input and Output Files

File Identification

The Rain Block uses the JIN series as the precipitation input file. This applies to both the NWS data and the user-created data. The JOUT file will contain the rainfall interface file for the Runoff or Statistics Block. The user has the option of saving the storm event summary table in a formatted file. NSCRAT(1) is used to save the file. The formatted file then can be read by a spreadsheet, database, or statistical program for further analysis.

A JIN value is always required since it contains the input rainfall. JOUT and NSCRAT(1) are optional depending on the parameters chosen on data group B1.

National Weather Service Precipitation Data

Hourly precipitation values (including water equivalent of snowfall depths) are available for most first-order NWS stations around the U.S., with the periods of record usually beginning in the 1940s. (Similar data are available in Canada from the Atmospheric Environment Service.) Magnetic tapes containing card images of NWS Tape Deck (TD) 3240, “Hourly Precipitation Data” are available from the NOAA National Climatic Data Center (NCDC) in Asheville, NC (phone (704) 259-0682). The cost for the entire state of Florida was $154 in 1984. Similarly, for 15-min rainfall data, TD-3260 should be requested; the cost for the State of Florida for the period of record (approximately 1971 to 1986) was $531 in 1988. (Part of the reason for higher cost is the extra charge for combining recent years with the archive file.) Typically, purchasing the entire state record is actually cheaper than purchasing a single station due to extra processing costs for a one station retrieval.

The NWS sells fixed format and variable block/length precipitation tapes. This version of RAIN is written to read both fixed format and variable block/length tapes. However, the IBM mainframe at the University of Florida cannot read variable block/length records. Hence, <u>the variable block/length code is obviously unverified. User beware.</u> It is recommended that the user purchase fixed format (record length of 43, block size of 6300), ASCII tapes from the NWS.

The NWS NCDC has recently made hourly and 15-min rainfall data available in ASCII files on floppy disks, five years per disk. These may be read one disk at a time following on-screen prompts during execution on a PC. (TD-3200 “Summary of Day” for use in the Temp Block is also available on floppy disks. This option is not included in SWMM4.)

Special Considerations

Long precipitation records are subject to meter malfunctions and missing data (any reason). The NWS has special codes on its old Card Deck 48¸ and new Tape Decks 3240 and 3260 denoting these conditions. The Rain Block reads the special codes and the date, and the total number of missing hours is printed in the storm event summary table. Subroutine Rain lists the estimated total missing rainfall by multiplying the total rainfall for the year times the missing hours divided by the total number of hours in a year. This information is printed only for the user's benefit. The rainfall interface file contains only good non-zero precipitation data.

If the codes for missing data or meter malfunction are present during the time between storm events that interevent duration is not used in the analysis of interevent duration. The number of interevent durations analyzed may be substantially less than the number for volume, average intensity, and storm duration. Some raingages (especially during the 1940s and 1950s) have long periods of missing data. The user should not use these data in a continuous simulation.

Rainfall Interval

When ordering the rainfall tape from the NCDC, either hourly (TD-3240, Hourly Precipitation) or 15-minute (TD-3260, 15-min Precipitation) rainfall must be specified. The program automatically detects the rainfall interval from the input tape or file. Hourly rainfall is available at most stations for 40 to 45 years, typically beginning in the 1940s. Fifteen minute rainfall is available for a shorter period of record, typically beginning in the 1970s.

Preparation of Input Data

Extent of Data

There are only three data groups in the input of the Rain Block. Table 10-1 presents the general structure of the data input. The input data formats for the Rain Block are shown in Table 10-2 at the end of this section.

Table 10-1. Rain Block Input Data Sequence

Data Group	Description
$RAIN	Calls the Rain Block
A1	Two Title Lines
B1	General Control Data
B2	General Data for User-Defined Time Series

Data Group A1

Data group A1 consists of two 80-column lines of character data. These descriptive titles will be printed at the top of each page of output.

Data Group B1

Rainfall Format

Parameter IFORM indicates the format of the rainfall data. The Rain Block supports four rainfall formats, including NWS TD-3240 or TD-3260, the new NWS precipitation format (actually two formats since the data are obtainable with fixed length or variable length records), and NWS Card Deck 488, which is the old (pre-1980) format. An indication of whether hourly or 15-min NWS data are being entered is found among the data and does not need to be indicated by the user. A rainfall time series created by the user may also be read by the Rain Block if IFORM = 3. NWS-format floppy disk input is indicated by IFORM = 4.

Station Number

ISTA is the precipitation station number. These are 6-digit numbers for NWS stations. Alternatively, for a user-generated time series, this is the number used to identify the rainfall time series when the Runoff Block reads the rainfall input file.

Program Purpose

The Rain Block has three modes of operation: (1) it can simply generate a rainfall interface file, (2) it can generate an interface file and perform the synoptic rainfall analysis, or (3) it can analyze the rainfall data and not create an interface file. The value of IDECID determines the program mode.

Starting Date

Parameter IYBEG is the starting date to begin reading the rainfall data. This is a six-digit number in format of YR/MO/DY. If this number is 0 then the program will start at the first rainfall record of station ISTA.

Ending Date

Parameter IYEND is the ending date to stop reading the rainfall data. This is a six-digit number in format of YR/MO/DY. If this number is 0 then the program will stop at the last rainfall record of station ISTA.

Echo Print of Rainfall

The actual rainfall read by the program may be echoed back to the Rain Block output file (or printer) using the parameter IYEAR. The month/day/year and hour/rain-fall are printed, five across a line, for each non-zero rainfall. This may generate one to three pages of printout per year.

Storm Summary Printout

A storm event summary table by year may be generated if ISUM is 1 on data group B1. The table has the storm volume, average intensity, average intensity, storm duration, beginning storm date, previous seven days rainfall, missing data, and number of meter malfunctions. One to two pages will be printed depending on the average number of storms per year.

Minimum Interevent Time

The minimum interevent time (MIT, integer only) indicates the minimum number of zero-rainfall hours that will constitute an interevent period. In other words, the number of consecutive dry hours encountered in the search must be equal to or greater than MIT in order that the preceding wet period (made up of at least one non-zero rainfall value) be considered a separate event. Dry periods of duration less than MIT may exist within an event preceded and followed by wet periods. The number of events in a given period of analysis is directly dependent on the value of MIT. If a value of 1 (the minimum) is chosen for MIT, every contiguous rainfall sequence will be viewed as a separate event.

No “correct” value of MIT can be suggested, although a value of 3 to 30 hours is often used to separate rainfall events (Hydroscience, 1979). Various event definitions for rainfall time series are available in the literature, e.g., Tavares (1975), Heaney et al. (1977), Hydroscience (1979), Restrepo-Posada and Eagleson (1982). Several urban runoff studies (e.g., EPA, 1983b) have evaluated MIT for rainfall events on the basis of the coefficient of variation (CV) of interevent times, where the CV is the ratio of the standard deviation to the mean. The MIT that gives a CV near 1.0 is usually chosen as the station MIT. This assumes that the interevent times have an exponential distribution for which the mean equals the standard deviation (hence, CV = 1.0). Thus, the MIT is chosen to make the empirical data fit the theory. If this method is selected, two trial values of MIT are used and the corresponding CV values for interevent times determined through two runs of the Rain Block. A plot (or linear extrapolation) of MIT versus CV will generally give a good estimate of the MIT value for which CV is approximately 1.0.

An MIT value is necessary only if storm event data are to be analyzed. Users who simply want to generate an input rainfall file for Runoff need not be concerned with this parameter.

Number of Events Printed

Parameter NPTS controls the number of points printed in the return period tables for volume, average intensity, storm duration, and interevent duration. If NPTS is 0 then all events will printed, ranked from highest to lowest.

Formatted Output File

The rainfall interface file saved on JOUT is unformatted and thus unreadable by most programs. The user has an option (parameter IFILE) of saving the storm event summary table as a formatted ASCII file on NSCRAT(1). This file then can be read by spreadsheet, database or statistical programs. The output file has the same appearance as the printed storm event summary. Also at the head of each column of numbers, on the first line, is a short one or two word description of the variable.

Plotting Position Parameter

See equation 10-1 and the discussion of "Return Period" below.

Storm Event Tables

The sorted events from largest to smallest may be printed for storm volume, average intensity, storm duration, and interevent duration (i.e., time between storm event midpoints). Parameter NOSTAT governs which tables are printed. No tables are printed if NOSTAT = 0. If NOSTAT > 0 then either all the events are printed or only the largest NPTS, depending on NPTS.

Data Group B2

The Rain Block has a rudimentary ability to read a user-generated precipitation file. It reads only files that are similar to the fixed format NWS Tape Deck 488. The input file is always the JIN interface file.

Rainfall Interval

THISTO is the duration of each rainfall interval for the time series, in minutes. Each rainfall value is assumed to be constant for THISTO minutes. Only non-zero rainfall need be entered when creating the JIN input file.

Rainfall Units

The type and units of rainfall are defined by parameters METRIC, KUNIT and CONV on data group B2. “Standard” units are in./hr or mm/hr for intensity and inch [mm] for volume (depth).

Rainfall Format and Date Positions

FIRMAT is the format of the input data. Enough fields should be included to account for the site, date, time, and rainfall variables. Example formats are:

‘(I6,5I2,F10.0)’ -- I6 field for site, 5I2 for yr/mo/dy/hr/mn, and F10.0 for rainfall
’(5I3,F10.0,I6)’ -- 5I3 for yr/mo/dy/hr/mn, F10.0 for rainfall, and I6 for the site

The exact position of each field is user defined. The parameters F1-F7 on data group B2 communicate the correct field position for year, months, days, hours, minutes, and rainfall.

Computations

Return Period

The return period of an event is reported in years. The simulation duration is rounded to the nearest number of years (NYRS).

Empirical return period (plotting position) is calculated by the general equation first proposed by Gringorten (1963) and analyzed by Cunnane (1978):

$$T = (NYRS + 1 - 2A)/(M - A) \qquad (10\text{-}1)$$

where

T = return period in years,
M = rank of event (ranked in descending order), and
A = parameter of the equation (data group B1).

A value of A = 0 gives the familiar Weibull plotting position (Gumbel, 1958),

$$T = (NYRS + 1)/M \qquad (10\text{-}2)$$

The Weibull formula is often used in hydrology but has been criticized by Cunnane (1978) who suggested a value of A = 0.4 as a good compromise for the customary situation in which the underlying frequency distribution of the parameter is unknown.

Moments

Calculations are made of estimates for the mean ($\bar{x}$), variance (S^2), standard deviation (S), coefficient of variation (CV) and coefficient of skewness (C_s). The equations utilized for these calculations are

$$\bar{x} = \sum x / N \qquad (10\text{-}3)$$

$$S^2 = \left[\sum x^2 - N\bar{x}^2\right] \Big/ (N-1) \qquad (10\text{-}4)$$

$$S = \left(S^2\right)^{1/2} \tag{10-5}$$

$$CV = S \Big/ \bar{x} \tag{10-6}$$

C_s = (Numer ⟐ Factor)/Denom
(10-7)

where

$$\text{Numer} \quad = \quad \sum x^3 \Big/ N - 3\bar{x} \sum x^2 \Big/ N + 2\bar{x}^3$$

$$\text{Denom} \quad = \quad \left[\sum x^2 \Big/ N - \bar{x}^2\right]^{1.5}$$

$$\text{Factor} \quad = \quad \left[N(N-1)\right]^{1/2} \Big/ (N-2)$$

The forms given above for Numer and Denom are for computational convenience and correspond to the more usual forms,

$$\text{Numer} \quad = \quad \sum \left(x - \bar{x}\right)^3 \Big/ N$$

$$\text{Denom} \quad = \quad \left[\sum \left(x - \bar{x}\right)^2 \Big/ N\right]^{1.5}$$

For the above equations, X is the magnitude of the event parameter, and N is the total number of events within the period of analysis. All summations are from 1 to N. Equations 10-4 and 10-7 are unbiased estimates for the variance and skewness, respectively.

Table 10-2. Rain Block Input Data

SWMM INPUT GUIDELINES

There have been many changes made to the input format of SWMM. Following is a short list of the major changes along with explanations and guidelines.

1. Free format input. Input is no longer restricted to fixed columns. Free format has the requirement, however, that at least one space separate each data field. Free format input also has the following strictures on real, integer, and character data.
   a. No decimal points are allowed in integer fields. A variable is integer if it has a 0 in the default column. A variable is real if it has a 0.0 in the default column.
   b. Character data must be enclosed by single quotation marks, including both of the two title lines.
2. Data group identifiers are a requirement and must be entered in columns 1 and 2. These aid the program in line and input error identification and are an aid to the SWMM user. Also blank lines no longer are required to signal the end of sets of data group lines; the data group identifiers are used to identify one data group from another.
3. The data lines may be up to 230 columns long.
4. Input lines can wrap around. For example, a line that requires 10 numbers may have 6 on the first line and 4 on the second line. The FORTRAN READ statement will continue reading until it finds 10 numbers, e.g.,
   ```
   Z1  1 2  3 4 5 6
       7 8  9 10
   ```
   Notice that the line identifier is not used on the second line.
5. An entry must be made for every parameter in a data group, even if it is not used or zero and even if it is the last required field on a line. Trailing blanks are not assumed to be zero. Rather, the program will continue to search on subsequent lines for the "last" required parameter. Zeros can be used to enter and "mark" unused parameters on a line. This requirement also applies to character data. A set of quotes must be found for each character entry field. For instance, if the two run title lines (data group A1) are to consist of one line followed by a blank line, the entry would be:
   ```
   A1 'This is line 1.'
   A1 ''
   ```
6. See Section 2 for use of comment lines (indicated by an asterisk in column 1) and additional information.

Variable	Description	Default
	Two Title Lines	
A1	Group Identifier	None
SITE	Two 80-column descriptive titles.	'Blank'

Table 10-2. Continued

Variable	Description	Default
	Control Information	
B1	Group identifier	None
IFORM	Format of precipitation (rainfall) data. = 0, Post-1980 NWS format (NWS Tape Deck 3240 or 3260), fixed length records. = 1, Post-1980 NWS format (NWS Tape Deck 3240 or 3260), variable length records. = 2, NWS Card Deck 488. = 3, User-defined rainfall format. = 4, NWS diskette rainfall format ("Release B, condensed"). Provide first 5-yr diskette on unit JIN and provide other input files (if any) in the input data file. = 5, Canadian AES precipitation data format. = 6, NWS diskette rainfall format ("Release B, condensed"). Provide first 5-yr diskette file on unit JIN and provide other input files (if any) in the input data file. Quotation marks have been changed to apostrophes in this file by RBFIX.EXE program. = 7, Earth Info NCDC rainfall format. = 8, Earth Info ASCII rainfall format.	0
ISTA	NWS station number, or alternatively for user defined data, an arbitrary integer station number.	0
IDECID	Controls the program purpose and output. = 0, Create a rainfall interface file on JOUT. =1, Create a rainfall interface file on JOUT, and perform the synoptic rainfall analysis. = 2, Only do the synoptic rainfall analysis.	0
IYBEG	Starting date, six digits, yr/mo/dy. If zero the program searches for beginning year.	0
IYEND	Ending date, six digits, yr/mo/dy. If zero the program reads all the station data.	0
IYEAR	Echo print of the rainfall values read. = 0, Do not print and rainfall data. = 1, Print <u>all</u> the data.	0
ISUM	Indicator for storm event summary printout. = 0, Do not print storm event summary, and = 1, Do print the storm event summary (1-2 pages per year).	0
	*** The following fields are not required if IDECID is 0 ***	
MIT	Minimum interevent time to separate storm events, number of hours (≥1). Only used if storm event statistics are printed. (See text.)	1
NPTS	NPTS highest events are printed in rainfall analysis tables. If zero, all events are printed.	0
IFILE	Indicator for storm event formatted file creation. = 0, Do not save storm event data on a file, and = 1, Save the storm event data on a formatted NSCRAT(1). User must insure that this file will be permanently saved by appropriate JCL or by using the @ function as described in Section 2.	0
A	Plotting position parameter (see text for explanation).	0.0

Table 10-2. Continued

Variable	Description	Default
NOSTAT	Indicator for storm event statistics printout.	0

NOSTAT controls the printing of the event tables for volume, average intensity, storm duration, and interevent duration. In all cases, No = 0, Yes = 1. The control information is entered as a four digit integer number with each column controlling a different table.

First column	- table of storm volume by return period.
Second column	- table of average intensity by return period.
Third column	- table of storm duration by return period.
Fourth column	- table of interevent duration by return period.

For example, enter 1111 to print all four tables, 1000 to print the first table only, 1100 to print the first two tables, and 0000 or 0 to bypass all table printing. In all cases only the top NPTS events are printed.

User-Defined Rainfall Time Series

Required only if IFORM = 3 on data group B1.

A maximum of 3000 precipitation values per year may be input in file JIN (no limit on number of years), one value per line, each value with a date and time (and optional station ID). Note, 24 precipitation values per line may be entered according to special criteria through the use of optional line B3, explained below.

Variable	Description	Default
B2	Group identifier	0
THISTO	Rainfall time interval, minutes.	60.0
METRIC	Metric input/output. = 0, Use U.S. customary units. = 1, Use metric units, denoted by brackets [ ].	0
KUNIT	Standard rainfall units. = 0, intensity, in./hr [mm/hr], or = 1, volume, in. [mm]. (Note: other units, e.g., hundredths of an inch, may be used by using CONV below.)	0
FIRMAT	Rainfall format (character data). Should include integer fields for station number, year, month, day, hour, minute and an F, E or G field for rainfall. Rainfall may not be read as integer (I-format).	'None'
CONV	Multiply by CONV to convert non-standard rainfall units to in./hr [mm/hr] (KUNIT = 0) or in. [mm] (KUNIT = 1). (Conversion is to mm if METRIC = 1.)	1.0
F1	Field position for station number. If F1 is zero a station number will not be read.	0
F2	Field position for year. Required.	0
F3	Field position for month. Required.	0
F4	Field position for day. Required.	0
F5	Field position for hour. Required.	0
F6	Field position for minute. Required.	0
F7	Field position for precipitation. Required. Rainfall must be either first (1) or last (6 or 7) field. SWMM considers positive numbers to be rainfall and negative numbers to be snowfall. ***Note, if NUVAL=24 is entered in group B3, F7 is ignored, and precipitation entries are read last on each line.	0

Table 10-2. Continued

Variable	Description	Default
Optional data group for entry of 24 precipitation values per line. This line may be omitted. If used, this line should follow the B2 line.		
B3	Group identifier	None
NUVAL	= 24 = number of precipitation values entered on each B2 line for variable F7. If this option is used, the year, month and day are entered (in the sequence defined by F2, F3 and F4 on line B2 and in the fields specified by FIRMAT on line B2), followed by 24 (hourly) precipitation values in 100th's of an inch (METRIC=0) or mm $\times$ 100 (METRIC=1). For example, an intensity of 0.2 in./hr should be entered as 20 (METRIC=0), and an intensity of 30 mm/hr should be entered as 3000 (METRIC=1). *** Rainfall is read in integer format.*** The integer format (e.g., 24I5) is included in parameter FIRMAT on line B2. There is no multiplication by parameter CONV of these data entries. Note that by manipulation of the format specified in parameter FIRMAT, the data can be arranged in groups of 12 values on two lines. For instance, if year, month and day occupy the first three fields of each line as real values, followed by 12 precipitation values as integers, the following FIRMAT is an example: ‘'(3F5.0, 12I5,/,15X,12I5)’ Of course, a field position may be left for a station number if need be.	None

End of Rain Block Data

At this point the program seeks new input from the Executive Block.

Section 11
Temp Block

Block Description

Introduction

The purpose of the Temp Block is to input temperature, evaporation, and wind speed data and make a file accessible to the Runoff Block of SWMM.

The Temp Block replaces Subroutine CTRAIN in SWMM 3 (Huber et al., 1981b). It is able to read the NWS temperature, evaporation, and wind speed input formats and a simple user-generated precipitation time series.

Program Operation

The Temp Block consists of a single FORTRAN subroutine (TEMP). TEMP reads the input data, translates the temperature, evaporation, and/or wind speed data into the required SWMM format, and prints raw data or summary tables.

Input Options

The program is designed to read the National Weather Service (NWS) TD-3200 "Summary of Day Co-Operative" containing daily maximum and minimum temperatures, pan evaporation, and daily wind movement, among other variables. A simple user-defined time series can also be input. These data may be purchased from the National Climatic Data Center in Asheville, North Carolina. This program does not read the NWS format used by SWMM 3 ("Card Deck 345"). Hopefully, this will not inconvenience SWMM 4 users.

Output Options

The output of the Temp Block consists of a SWMM interface file containing daily maximum and minimum temperatures, evaporation estimates, and wind speed, either singly or in combination. The raw data, summary statistics, or both may be printed by the Temp Block depending on the value of IYEAR on data group B1.

Input and Output Files

File Identification

The Temp Block uses the JIN series (specified in the Executive Block) as the temperature, evaporation and wind speed input file. This applies to both the NWS data and the user-created data. The JOUT file will contain the temperature, evaporation and wind speed interface file for the Runoff Block.

The JOUT file may be an existing file from a previous run of the Temp Block. A user who wants to create an interface file containing non-NWS temperature, evaporation and wind speed will have to run the Temp Block three times. During the first run, for example, only temperature data will be on the interface file. The second run will add evaporation data to the already existing interface file containing temperature data. The third run will add wind speed data to the temperature and evaporation data. Only one interface file will be read by the Runoff Block. This also applies to users who want to mix temperature, evaporation, and wind speed data from more than one NWS station. If the NWS station contains all forms of data, however, only one run of the Temp Block is required.

JIN and JOUT values are always required by the Temp Block. An NSCRAT(1) scratch file is required when evaporation or wind speed data are added to temperature data during multiple runs of the Temp Block.

Special Considerations

Long time series records are subject to periods of invalid data (for any reason, including broken gages). The NWS has special codes for invalid or suspect data. These suspect data are summarized by the Temp Block and not placed on the interface file. An interpolation scheme is used to replace invalid or missing data in the time series for use in the Runoff Block. The interpolation scheme will not be activated, however, for missing data periods longer than two weeks. In such an instance, the interface file will contain a gap of data that the Runoff Block will skip over and not simulate. For example, if snowmelt is simulated in the Runoff Block and there are no temperature data for January, January will not be simulated. The simulation period will resume when the temperature time series resumes.

Data Interval

The NWS data potentially utilized consist of daily maximum and minimum temperature, pan evaporation, and wind movement. Longer (but not shorter) periods may be input by the user by specifying the time unit parameter TUNIT on data group B2. For example, monthly estimates of evaporation for a multiple-year simulation may be entered using the user-defined time series option. Summaries of monthly pan evaporation for many U.S. stations are provided by Farnsworth and Thompson (1982).

Preparation of Input Data

Extent of Data

There are only three data groups in the input of the Temp Block. Table 11-1 presents the general structure of the input data. The input formats for the Temp Block are shown in Table 11-2 at the end of this section.

Table 11-1. Temp Block Input Data Sequence

Data Group	Description
$TEMP	Calls the Temp Block
A1	Two Title Lines
B1	General Control Data
B2	General Data for User-Defined Time Series

Data Group A1

Data group A1 consists of two 80-column lines of character data. These descriptive titles will be printed at the top of each page of output.

Data Group B1

Data group B1 contains information on program control. The parameters of data group B1 are:

Data Format

Parameter IFORM specifies the format of the input data on the JIN file. This is restricted to NWS Tape Deck 3200 fixed-length or variable-length records, or a fixed-length user-defined format. The authors recommend that the SWMM user purchase NWS fixed-length data tapes.

Station Number

ISTA is the station number of the principal climatological station operated by the NWS. These 8-digit numbers identify one of the 9000 stations currently being processed by the NWS, or one of the 23000 stations with recorded observations since 1945. The primary emphasis is on the recording of daily rainfall but 55 percent of the stations also record maximum and minimum temperature.

Type of Time Series Data

Parameter KTYPE defines the type of data input. Daily maximum and minimum temperatures, daily pan evaporation, and daily wind speed may be input either singly or in combination to the Temp Block -- if the NWS data tapes are being used. A user-defined time series must consist of a single input parameter (maximum and minimum temperatures are herewith defined as a single input parameter).

Starting Date

Parameter IYBEG is the starting date to begin reading the data. This is a six-digit number in format of YR/MO/DY. If this number is 0 then the program will start at the first record of station ISTA.

Ending Date

Parameter IYEND is the ending date to stop reading the data. This is a six-digit number in format of YR/MO/DY. If this number is 0 then the program will stop at the last record of station ISTA.

Echo Print of the Input Data

Parameter IYEAR determines the extent to which the input data will be echoed back on the output file. Setting IYEAR equal to 0 will eliminate the echo of the raw data input and the summary tables. Setting IYEAR equal to 1 will result in a voluminous output containing all the input data and the summary tables. It is recommended that the user set IYEAR = 2 to print only the monthly/yearly summary tables. These tables will contain the minimum, mean, and maximum values read by month and/or year.

Pan Evaporation Coefficients

If pan evaporation data are read by the Temp Block, then pan coefficients are required to convert the pan evaporation estimates to free-water-surface evaporation estimates used by the Runoff Block. (The pan data are multiplied by the pan coefficients to obtain the free-water-surface estimates.) Twelve monthly coefficients must be entered only if evaporation data are read, otherwise leave blank. Pan coefficient summaries may be found in hydrology textbooks (e.g., Linsley et al., 1983).

Data Group B2

File Identification

The Temp Block has a rudimentary ability to read a user-generated data file. It reads only files that are similar to the fixed-format NWS Tape Deck 3200. The input file is always the JIN interface file.

Data Units

The type and units of data are defined by parameters METRIC, KUNIT and CONV on data group B2.

Input Format and Date Positions

FIRMAT is the format of the input data. Enough fields should be included to account for the site, date and meteorological variables. Example formats are:

'(I6,3I2,F10.0)'	-- I6 field for the site ID, 3I2 for yr/mo/dy, and F10.0 for evaporation
'(3I3,F10.0,I6)'	-- 3I3 for yr/mo/dy, F10.0 for evaporation, and I6 for the site ID

The exact position of each field is user-defined. The parameters F1-F6 on data group B2 communicate the correct field position for year, month, day and either: (1) evaporation; (2) temperature, or (3) wind speed. For example, for the second format listed just above, required parameters F1 - F5 would be 5, 1, 2, 3, 4, respectively. See the above section on "Input and Output Files" for the procedure used for mixing the various types of data. The year may be entered either as a four-digit number (e.g., 1971) or two-digit number (e.g., 71). The program will determine which form is being used.

The program adopts the following convention for missing data, or data intentionally left missing. Temperature data are always interpolated by the Runoff Block using a polynomial method. The interpolation scheme will not be activated, however, for missing data periods longer than two weeks. Evaporation and wind speed data are not interpolated. The last value read is assumed to be the constant evaporation rate or wind speed until a new evaporation rate or wind speed is read. This allows the user to create, for example, a monthly time series of evaporation rates for continuous simulation by specifying a new evaporation rate for the first day of every month for every year simulated.

Table 11-2. Temp Block Input Data

SWMM INPUT GUIDELINES

There have been many changes made to the input format of SWMM. Following is a short list of the major changes along with explanations and guidelines.

1. Free format input. Input is no longer restricted to fixed columns. Free format has the requirement, however, that at least one space separate each data field. Free format input also has the following strictures on real, integer, and character data.
   a. No decimal points are allowed in integer fields. A variable is integer if it has a 0 in the default column. A variable is real if it has a 0.0 in the default column.
   b. Character data must be enclosed by single quotation marks, including both of the two title lines.
2. Data group identifiers are a requirement and must be entered in columns 1 and 2. These aid the program in line and input error identification and are an aid to the SWMM user. Also blank lines no longer are required to signal the end of sets of data group lines; the data group identifiers are used to identify one data group from another.
3. The data lines may be up to 230 columns long.
4. Input lines can wrap around. For example, a line that requires 10 numbers may have 6 on the first line and 4 on the second line. The FORTRAN READ statement will continue reading until it finds 10 numbers, e.g.,

   ```
   Z1   1  2   3  4  5  6
          7  8   9 10
   ```

   Notice that the line identifier is not used on the second line.
5. An entry must be made for every parameter in a data group, even if it is not used or zero and even if it is the last required field on a line. Trailing blanks are not assumed to be zero. Rather, the program will continue to search on subsequent lines for the "last" required parameter. Zeros can be used to enter and "mark" unused parameters on a line. This requirement also applies to character data. A set of quotes must be found for each character entry field. For instance, if the two run title lines (data group A1) are to consist of one line followed by a blank line, the entry would be:

   ```
   A1 'This is line 1.'
   A1 ''
   ```
6. See Section 2 for use of comment lines (indicated by an asterisk in column 1) and additional information.

Variable	Description	Default
	Two Title Lines	
A1	Group Identifier	None
SITE	Two 80-column descriptive titles.	'Blank'
	Control Information	
B1	Group Identifier	None
IFORM	Format of data, = 0, NWS Tape Deck 3200, fixed length records, = 1, NWS Tape Deck 3200, variable length records, = 2, User defined format.	0
ISTA	NWS Station Number, or alternatively for user-defined data, an arbitrary station number.	0
KTYPE	Type of time series data. = 0, Daily maximum and minimum temperature. = 1, Daily evaporation. = 2, Daily wind speed. = 3, Daily temperature and evaporation. = 4, Daily temperature and wind speed. = 5, Daily evaporation and wind speed. = 6, Daily temperature, evaporation and wind speed.	0

Table 11-2. Continued

Variable	Description	Default
IYBEG	Starting date (six digits). If zero the program searches for beginning year.	0
IYEND	Ending date (six digits). If zero the program reads all the station data.	0
IYEAR	Echo print of the KTYPE values read. = 0, Do not print raw data or summary tables, = 1, Print <u>all</u> the data and summary tables, and = 2, Print only monthly/yearly summary tables.	0
PAN(1)	January pan evaporation coefficient. Required only if evaporation data are read by the Temp Block.	0.7
■	■	
PAN(12)	December pan evaporation coefficient. Required only if evaporation data are read by the Temp Block.	0.7
	User-defined temperature/evaporation/wind speed time series Required only if IFORM = 2 on data group B1.	
B2	Group Identifier	0
FIRMAT	Format (character data). Should include a field for station number, year, month, day, and daily max-min temperature, evaporation, or wind speed.	'None'
METRIC	Metric input-output. = 0, Use U.S. customary units. = 1, Use metric units.	0
KUNIT	Units of temperature. Required field. = 0, Degrees F. = 1, Degrees C.	0
CONV	Conversion factor used to convert input units to internal SWMM units for evaporation (in./day or mm/day) and wind speed (miles/hr or km/hr), depending on the value of METRIC.	1.0
F1	Field position for station number. If F1 is zero a station number will not be read.	0
F2	Field position for year. Required.	0
F3	Field position for month. Required.	0
F4	Field position for day. Required.	0
F5	Field position for daily maximum temperature, or Field position for daily evaporation estimate, or Field position for wind speed.	0
F6	Field position for daily minimum temperature.	0
	End of Temp Block Data At this point the program seeks new input from the Executive Block.	

Section 12
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Appendix I
Continuous Simulation

Continuous and Single Event Simulation

The original (1971 and 1975 versions) Storm Water Management Model was designed for single-event simulation, and produced detailed (i.e., short time increment) hydrographs and pollutographs for individual storm events. SWMM may also be run for an unlimited number of time steps, for multiple events. In this mode an overall assessment of urban runoff problems and estimates of the effectiveness and costs of abatement procedures can be performed. Trade-offs among various control options, such as storage, treatment and street sweeping, may be evaluated. Complex interactions between the meteorology, e.g., precipitation patterns, and the hydrology of an area may be simulated without resorting to average values or very simplified methods. In this manner, critical events from the long period of simulation may be selected for detailed analysis. In addition, return periods for intensity, duration and volume (mass) of runoff (pollutant loads) may be assigned on the basis of the simulated record using the SWMM Statistics Block. In this manner, the critical events chosen for study may be substituted for synthetic design storms (e.g., “SCS Type-II”) the latter often being synthesized from intensity-duration-frequency curves on the basis of questionable statistical assumptions (Huber et al., 1986). Linsley and Crawford (1974) present a useful discussion of continuous simulation in urban hydrology.

Several continuous simulation models are available for urban runoff analysis. Among the earliest was the Stanford Watershed Model (Crawford and Linsley, 1966), out of which evolved the HSPF Model (Johanson et al., 1980), a versatile program for natural and agricultural as well as urban areas. It uses a 15 minute time step whereas a 5 minute time step is used by the Dorsch QQS model (Geiger et al., 1974; Geiger and Dorsch, 1980). A widely used continuous simulation model for urban areas is STORM (Hydrologic Engineering Center, 1977; Roesner et al., 1974), developed by Water Resources Engineers, the City of San Francisco and the Hydrologic Engineering Center of the Corps of Engineers. It utilizes one hour time steps coupled with simplified runoff and pollutant estimation procedures and has been extensively used for planning (Roesner et al., 1974) and overall urban runoff evaluation (Heaney et al., 1977). A similar, but even simpler model, still producing useful statistics of long-term urban runoff, is the Simplified Storm Water Management Model developed by Metcalf and Eddy, Inc. (Lager et al., 1976). Finally, several “first cut” procedures have been developed, based in part upon continuous simulation, but avoiding any computer usage at all (Hydroscience, Inc., 1976; Howard, 1976; Heaney et al., 1976; Chan and Bras, 1979).

Continuous SWMM Overview

SWMM may be run continuously using any (or all) of the blocks, although the most convenient output summaries are in the Runoff and Storage/Treatment Blocks. The Statistics Block is almost always used to analyze the continuous time series produced during a continuous simulation. A "Level III" receiving water model that will couple with either SWMM or STORM has been developed based upon earlier work (Heaney et al., 1977) and is documented (Medina, 1979). There is no functional distinction between single-event and continuous simulation. In general, any time step and any number of time steps may be used for any simulation.

Input Data

Continuous SWMM requires the same data entries as for the event mode. A coarse schematization greatly reduces the amount of entries required for subcatchments and channels (see below). The key data need is a long-term precipitation record for the area. SWMM is keyed to the use of magnetic tapes available from the National Climatic Data Center of the NWS at Asheville, North Carolina. These tapes contain at least 25 years of hourly data for most stations and cost up to a few hundred dollars depending on the amount of processing required. A tape will ordinarily contain data for all the stations in one or more states. (Similar tapes are supplied in Canada by the Atmospheric Environment Service.) When snowmelt is simulated, a record of daily temperature data is also required; see the snowmelt documentation in Appendix II and Chapter 4. These data are processed in by the Rain and Temp Blocks for later use by the other blocks. Optionally, the processed data, including a tabulation of the 50 highest values, may be examined prior to proceeding with the remainder of the simulation. When snowmelt is simulated, rainfall or snowfall is determined from hourly air temperatures synthesized from the daily max-min values for the station. Snowfall values are keyed as negative precipitation for internal use in the program. Other input data unique to continuous simulation consist mainly of dates for starting and stopping, printing, etc.

Catchment Schematization

Guidelines for subcatchment "lumping" or aggregation as described by Smith (1975) and Proctor and Redfern, Ltd. and James F. MacLaren, Ltd. (1976a, 1976b) are given in Section 4. In general, almost identical outlet hydrographs may be produced using only one subcatchment and one or no channel/pipes as for a detailed schematization, using several subcatchments and channel/pipes. A key parameter to be adjusted is the subcatchment width. Quality comparisons may be more variable depending upon how the several land uses and/or pollutant loading rates are aggregated.

Output

Runoff Block

Output from single-event simulation consists basically of hydrographs and pollutographs printed over the whole event at a specified interval of time steps (e.g., every time step). Continuous SWMM retains this option for up to five user-specified date intervals. In addition, daily, monthly, annual and grand total values for runoff, precipitation and pollutant loads are provided. Daily totals are printed whenever there is runoff and/or precipitation.

In addition, the 50 highest hourly totals are listed, by both runoff volume and BOD load. These may be compared to the 50 highest hourly rainfall depths and used in selecting critical time periods for more detailed study. For example, a two-year simulation of a 312 ac (126 ha) catchment tributary to Lake Calhoun in Minneapolis was made, and the ten highest rainfall, runoff and BOD loads (from the output of the 50 highest) are shown in Table I-1. The comparisons indicate that the rankings differ according to the antecedent conditions, etc. affecting each parameter. For example, the highest rainfall depth corresponds to the third highest runoff depth and second highest BOD load. The table adds further justification to the contention that it is necessary to treat rainfall, runoff and pollutant loads separately in terms of statistical analyses.

Table I-1. Hourly Event Ranking by Rain Flow and BOD for Two Year Simulation of Lake Calhoun Catchment, Minneapolis. Ten highest values are taken from the tabulated output of 50 highest given by SWMM.

Rank	Date	Hr	Rain (in./hr)	Date	Hr	Flow (in./hr)	Date	Hr	BOD (lb/min)
1	7/29/51	22	0.98	7/21/51	2	0.543	5/15/51	22	16.78
2	7/21/51	1	0.80	7/20/51	23	0.429	7/20/51	22	12.88
3	7/22/50	15	0.79	7/20/51	22	0.392	7/16/51	2	9.62
4	7/30/51	8	0.65	5/15/51	22	0.383	7/20/51	23	7.64
5	5/15/51	21	0.63	7/21/51	1	0.320	5/15/51	21	6.19
6	7/21/51	2	0.56	7/30/51	8	0.295	9/08/51	20	5.70
7	9/11/51	23	0.55	7/16/51	2	0.254	7/22/51	15	5.43
8	8/07/51	18	0.54	7/22/51	16	0.253	7/30/51	8	5.42
9	5/05/50	10	0.49	5/18/51	16	0.238	5/05/50	10	5.25
10	6/25/51	24	0.49	7/22/50	15	0.221	7/22/50	16	5.11

Statistics Block

The most useful review of continuous SWMM output is probably accomplished using the Statistics Block where a frequency analysis of many storm quantity and quality parameters (e.g., depth, duration, interevent time, load, peak concentration, etc.) may be performed. Output is available in both tabular and graphical forms. Analysis by the Statistics Block may follow any other block whether or not a long-term (continuous) simulation was run.

Other Blocks

There is no distinction made between output for a single-event or continuous simulation in the Transport, Extran or Storage/Treatment Blocks.

Dry-Period Regeneration

Quantity

Infiltration capacity is regenerated during dry periods assuming an exponential "drying curve" analogous to the "wetting curve" of Horton's equation (see Appendix V). Monthly evaporation totals are used to regenerate depression storage on both pervious and impervious areas and are also considered an initial "loss" for each time step with rainfall. Computations are bypassed during dry periods if infiltration and depression storage regeneration is complete.

Quality

Pollutant loadings on the subcatchment surfaces are generated during dry time steps (i.e., no runoff) depending upon how they are input initially. Linear or non-linear buildup may be used, with or without an upper limit. If desired, a rating curve (load versus flow) may be used instead of a washoff equation.

Street sweeping occurs at intervals specified for each land use. The intervals are computed on the basis of intervening dry time steps. A dry time step is one in which the subcatchment receives no precipitation and has no water remaining in impervious area depression storage or as snow. When snowmelt is simulated, street sweeping may be bypassed for a specified interval of the year (e.g., the winter months). Runoff simulates any ten quality parameters with arbitrary units, plus, optionally, erosion using the Universal Soil Loss Equation. As a user option, regeneration of selected constituents (e.g., chlorides) during dry periods will occur only when snow is present.

Continuous SWMM Compared to STORM

Comparisons of SWMM and STORM, without S/T simulation, indicate that the two outputs are comparable and STORM is approximately 50 percent faster. Why, then, might SWMM be used over STORM or other existing continuous models? When just the Runoff Block is required, STORM could be the choice because of its simplicity, good documentation, useful output or inclusion of the SCS method for rural runoff generation. SWMM might be preferred if smaller time-steps than one hour were needed, or if flow routing in channel/pipes were desired, or if particular features of runoff or quality generation were needed. In addition, SWMM couples both the single-event and continuous simulation capability into one model. Finally, the Statistics Block of SWMM is a very flexible routine for a large variety of post-processing of continuous time series, including separation into independent events and frequency analysis.

Appendix II
SWMM Snowmelt Routines

Introduction

Snowmelt is an additional mechanism by which urban runoff may be generated. Although flow rates are typically low, they may be sustained over several days and remove a significant fraction of pollutants deposited during the winter. Rainfall events superimposed upon snowmelt baseflow may produce higher runoff peaks and volumes as well as add to the melt rate of the snow.

In the context of long term continuous simulation, runoff and pollutant loads are distributed quite differently in time between the cases when snowmelt is and is not simulated. The water and pollutant storage that occurs during winter months in colder estimates cannot be simulated without including snowmelt.

Several hydrologic models include snowmelt computations, e.g., Stanford Watershed Model (Crawford and Linsley, 1966), HSPF (Johanson et al., 1980), NWS (Anderson, 1973, 1976), STORM (Hydrologic Engineering Center, 1977; Roesner et al., 1974) and SSARR (Corps of Engineers, 1971). Of these examples, only HSPF and STORM include pollutant routing options. Useful summaries of snowmelt modeling techniques are available in texts by Fleming (1975), Eagleson (1970), Linsley et al. (1975), Viessman et al. (1977), and Gray (1970). All of these draw upon the classic work, *Snow Hydrology*, of the Corps of Engineers (1956).

As part of a broad program of testing and adaptation to Canadian conditions, a snowmelt routine was placed in SWMM for single event simulation by Proctor and Redfern, Ltd. and James F. MacLaren, Ltd., abbreviated PR-JFM (1976a, 1976b, 1977), during 1974-1976. The basic melt computations were based on routines developed by the U.S. National Weather Service, NWS (Anderson, 1973). The work herein has utilized the Canadian SWMM snowmelt routines as a starting point and has considerably augmented their capabilities as well as added the facility for snowmelt computations while running continuous SWMM. In addition, features have been added which aid in adapting the snowmelt process to urban conditions since most efforts in the past, except for STORM, have been aimed at simulation of spring melt in large river basins. The work of the National Weather Service (Anderson, 1973) has also been heavily utilized, especially for the extension to continuous simulation and the resulting inclusion of cold content, variable melt coefficients and areal depletion.

The following sections describe the methodology presently programmed in the SWMM Runoff Block. It is intended to aid in understanding the various input parameters required, computations performed, and the output produced.

Overview

Snow Depth

Throughout the program, all snow depths are treated as "depth of water equivalent" to avoid specification of the specific gravity of the snow pack which is highly variable with time. The specific gravity of new snow is of the order of 0.09; an 11:1 or 10:1 ratio of snow pack depth to water equivalent depth is often used as a rule of thumb. With time, the pack compresses until the specific gravity can be considerably greater, to 0.5 and above. In urban areas, lingering snow piles may resemble ice more than snow with specific gravities approaching 1.0. Although snow pack heat conduction and storage depend on specific gravity, sufficient accuracy may be obtained without using it. It is adequate to maintain continuity through the use of depth of water equivalent.

Most input parameters are in units of inches of water equivalent (in. w.e.). For all computations, conversions are made to feet of water equivalent.

Single Event Simulation

For most SWMM calculations, there is no functional distinction between single event and continuous simulation. However, for snowmelt calculations, the user can specify (through parameter ISNOW in Runoff Block data group B1) whether melt is to be treated in a single event or continuous form. For single event simulation, it is unnecessary to generate a long record of precipitation and temperature data. Snow quantities are input as initial depths (water equivalent) on subcatchments and as negative rainfall intensities on rainfall input data groups. Snowfall is generally keyed as negative precipitation on input files. Temperature data are read for each time step from line input. The air temperature time step is defined by parameter DTAIR on data group C5. (Other parameters are explained subsequently.)

During the simulation, melt is generated at each time step using a degree-day type equation during dry weather and Anderson's NWS equation (1973) during rainfall periods. Specified, constant areas of each subcatchment are designated as snow covered. Melt, after routing through the remaining snow pack, is combined with rainfall to form the spatially weighted "effective rainfall" for overland flow routing.

Continuous Simulation

For continuous simulation, hourly precipitation depths from NWS magnetic tapes are utilized along with daily max-min temperatures from other NWS tapes. The latter are interpolated sinusoidally to produce the temperature value at the beginning of a time step, as explained in detail in the next subsection. If temperatures are below a dividing value (e.g., 32°F), precipitation values are treated as snow and keyed with a negative sign. The interpolated temperatures are also used in the melt computations.

Melt is again generated using a degree-day type equation during dry weather and Anderson's NWS equation during rainfall periods. In addition, a record of the cold content of the snow is maintained. Thus, before melt can occur, the pack must be "ripened," that is, heated to a specified base temperature.

One partition of the urban subcatchment is the "normally bare impervious area." This is intended to represent surfaces such as streets, parking lots and sidewalks which are subject to plowing or snow "redistribution". The program includes this feature.

Following the practice of melt computations in natural basins, “areal depletion curves” describe the spatial extent of snow cover as the pack melts. For instance, shaded areas would be expected to retain a snow cover longer than exposed areas. Thus, the snow covered area of each subcatchment changes with time during continuous simulation.

Melt computations themselves proceed as in the single event simulation, except that the degree-day melt coefficients vary sinusoidally, from a maximum on June 21 to a minimum on December 21.

Pollutant Simulation

Pollutant washoff is simulated using combined runoff from snowmelt and/or rainfall. For continuous SWMM, regeneration of any pollutant may depend upon whether snow cover is present if, for example, chlorides are to be simulated.

Snow and Temperature Generation from NWS Tapes

National Weather Service (NWS) Data

Continuous SWMM utilizes long-term precipitation and temperature data obtained from the National Climatic Data Center (NCDC) at Asheville, North Carolina, for the nearest NWS or airport weather station of record. (Similar data, but with a different format, are available in Canada from the Atmospheric Environment Service.) If snowmelt is not simulated only the precipitation tape is needed; hourly precipitation totals are included on it for every day with measurable precipitation. For continuous SWMM without snowmelt, all such hourly values are treated as rainfall.

Maximum and minimum temperatures as well as several other meteorological parameters are given for every day of the year on the NCDC’s “Surface Land Daily Cooperative, Summary of Day, TD-3200.” For snowmelt, only the ID number, date and max-min temperatures are used although other data (e.g., evaporation) may be used for other purposes. Note that the ID number for TD-3200 is not necessarily the same as for the hourly precipitation data. The data are accessed in the Rain and Temp Blocks, usually directly from the magnetic tape. The unit number of the tape is input in the Executive Block as NSCRAT(1). As explained in the description of continuous SWMM, a magnetic tape containing card images of hourly precipitation values is accessed similarly using unit number JIN(1).

Temperature data are input and processed for every day of the year, including summer months. Should an entry (date) be missing, the max-min values for the previous day are used.

Creation of Hourly Temperatures

The “Summary of Day” or temperature tape does not list the time of day at which the minimum and maximum temperatures occur. Hence, the minimum temperature is assumed to occur at sunrise each day, and the maxi-mum is assumed to occur three hours prior to sunset. All times are rounded to the nearest hour. This scheme obviously cannot account for many meteorological phenomena that would create other temperature-time distributions but is apparently the most appropriate one under the circumstances. Given the max-min temperatures and their assumed hours of occurrence, the other 22 hourly temperatures are readily created by sinusoidal interpolation, as sketched in Figure II-1. The interpolation is performed, using three different periods: 1) between the maximum of the previous day and the minimum of the present, 2) between the minimum and maximum of the present, and 3) between the maximum of the present and minimum of the following.

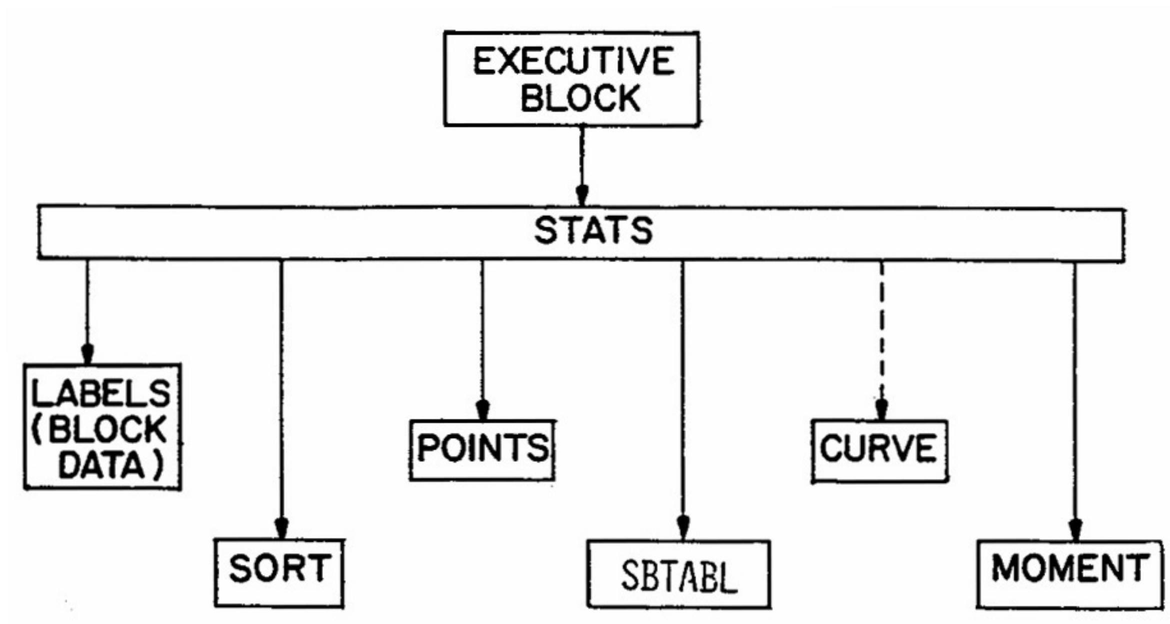

Figure II-1. Sinusoidal interpolation of hourly temperatures.

The time of day of sunrise and sunset are easily obtained as a function of latitude and longitude of the catchment and the date. Techniques for these computations are explained, for example, by List (1966) and by the TVA (1972). The Runoff Block utilizes approximate (but sufficiently accurate) formulas given in the latter reference. Their use is explained briefly below.

The hour angle of the sun, h, is the angular distance between the instantaneous meridian of the sun (i.e., the meridian through which passes a line from the center of the earth to the sun) and the meridian of the observer (i.e., the meridian of the catchment). It may be measured in degrees or radians or readily converted to hours, since 24 hours is equivalent to 360 degrees or 2 pi radians. The hour angle is a function of latitude, declination of the earth and time of day and is zero at noon, true solar time, and positive in the afternoon. However, at sunrise and sunset, the solar altitude of the sun (vertical angle of the sun measured from the earth's surface) is zero, and the hour angle is computed only as a function of latitude and declination,

$$\cos h = -\tan\delta \cdot \tan\phi$$

(II-1)

where

h	=	hour angle, radians,
δ	=	earth's declination, a function of season (date), radians, and
ϕ	=	latitude of observer, radians.

The earth's declination is provided in tables (e.g., List, 1966), but for programming purposes an approximate formula is used (TVA, 1972):

$$\delta = \left(\frac{23.45\ \text{pi}}{180}\right)\cos\left[\frac{2\ \text{pi}}{365}(172 - D)\right] \qquad \text{(II-2)}$$

where D is number of the day of the year (no leap year correction is warranted) and d is in radians. Having the latitude as an input parameter, the hour angle is thus computed in <u>hours</u>, positive for sunset, negative for sunrise, as

$$h = (12/\text{pi})\cos^{-1}(-\tan\delta \cdot \tan\phi) \qquad \text{(II-3)}$$

The computation is valid for any latitude between the arctic and Antarctic circles, and no correction is made for obstruction of the horizon.

The hour of sunrise and sunset is symmetric about noon, true solar time. True solar noon occurs when the sun is at its highest elevation for the day. It differs from standard zone time, i.e., the time on clocks) because of a longitude effect and because of the "equation of time". The latter is of astronomical origin and causes a correction that varies seasonally between approximately ± 15 minutes.; it is neglected here. The longitude correction accounts for the time difference due to the separation of the meridian of the observer and the meridian of the standard time zone. These are listed in Table II-1. It is readily computed as

Table II-1. Time Zones and Standard Meridians

Time Zone	Example Cities	Standard Meridian
Newfoundland Std. Time	St. Johns's, Newfoundland	52.5[a]
Atlantic Std. Time	Halifax, Nova Scotia San Juan, Puerto Rico	60
Eastern Std. Time	New York, New York	75
Central Std. Time	Chicago, Illinois	90
Mountain Std. Time	Denver, Colorado	105
Pacific Std. Time	San Francisco, California	120
Yukon Std. Time	Yakutat, Alaska[b]	135
Alaska Std. Time Hawaiian Std. Time	Anchorage, Alaska Honolulu, Hawaii	150
Bering Std. Time	Nome, Alaska	165

[a]The time zone of the island of Newfoundland is offset one half hour from other zones.
[b]All of the Yukon Territory is on Pacific Standard Time.

$$\text{DTLONG} = 4\ \frac{\text{minutes}}{\text{degree}} \times (\Theta - \text{SM}) \qquad \text{(II-4)}$$

where

DTLONG	=	longitude correction, minutes (of time),
Θ	=	longitude of the observer, degrees, and
SM	=	standard meridian of the time zone, degrees, from Table II-1.

Note that DTLONG can be either positive or negative, and the sign should be retained. For instance, Boston at approximately 71°W has DTLONG = -16 minutes, meaning that mean solar noon precedes EST noon by 16 minutes. (Mean solar time differs from true solar time by the neglected "equation of time.")

The time of day of sunrise is then

$$\text{HSR} = 12 - h + \text{DTLONG}/60 \qquad \text{(II-5)}$$

and the time of day of sunset is

$$\text{HSS} = 12 + h + \text{DTLONG}/60 \qquad \text{(II-6)}$$

These times are rounded to the nearest hour for use in continuous SWMM. As stated earlier, the maximum temperature is assumed to occur at hour HSS - 3.

Standard time is used in all calculations and in NWS tapes. There is no input or output that includes allowance for daylight savings time.

Generation of Snowfall Intensities

The estimated hourly temperatures, T, in °F, are compared to a dividing temperature, SNOTMP, for each hour with precipitation. Then if

$$
\begin{aligned}
&T > \text{SNOTMP, precipitation = rain;} \\
&T \geq \text{SNOTMP, precipitation = snow.}
\end{aligned}
\tag{II-7}
$$

Snowfall depths are tagged as negative quantities for identification by later components of the program.

Gage Catch Deficiency Correction

Precipitation gages tend to produce inaccurate snowfall measurements because of the complicated aerodynamics of snow flakes falling into the gage. Snowfall totals are generally underestimated as a result, by a factor that varies considerably depending upon gage exposure, wind velocity and whether or not the gage has a wind shield. The program includes a parameter, SCF, which multiplies snow depths only.

Although it will vary considerable from storm to storm, SCF acts as a mean correction factor over a season in the model. Anderson (1973) provides typical values of SCF as a function of wind speed, as shown in Figure II-2, that may be helpful in establishing an initial estimate. The value of SCF can also be used to account for other factors, such as losses of snow due to interception and sublimation not accounted for in the model. Anderson (1973) states that both losses are usually small compared to the gage catch deficiency.

Structure of Precipitation - Temperature Data Set

The Rain and Temp Blocks create output files from the NWS precipitation and temperature data tapes that are subsequently read as input by the Runoff Block. The interested user can find descriptions of the output file format used by the Rain and Temp Blocks in Sections 10 and 11, respectively.

Single Event SWMM

NWS tapes are not used in single event simulation. Precipitation is entered on Runoff Block data group E1-E3. However, snowfall can be included, if desired, as a negative precipitation value at any time step.

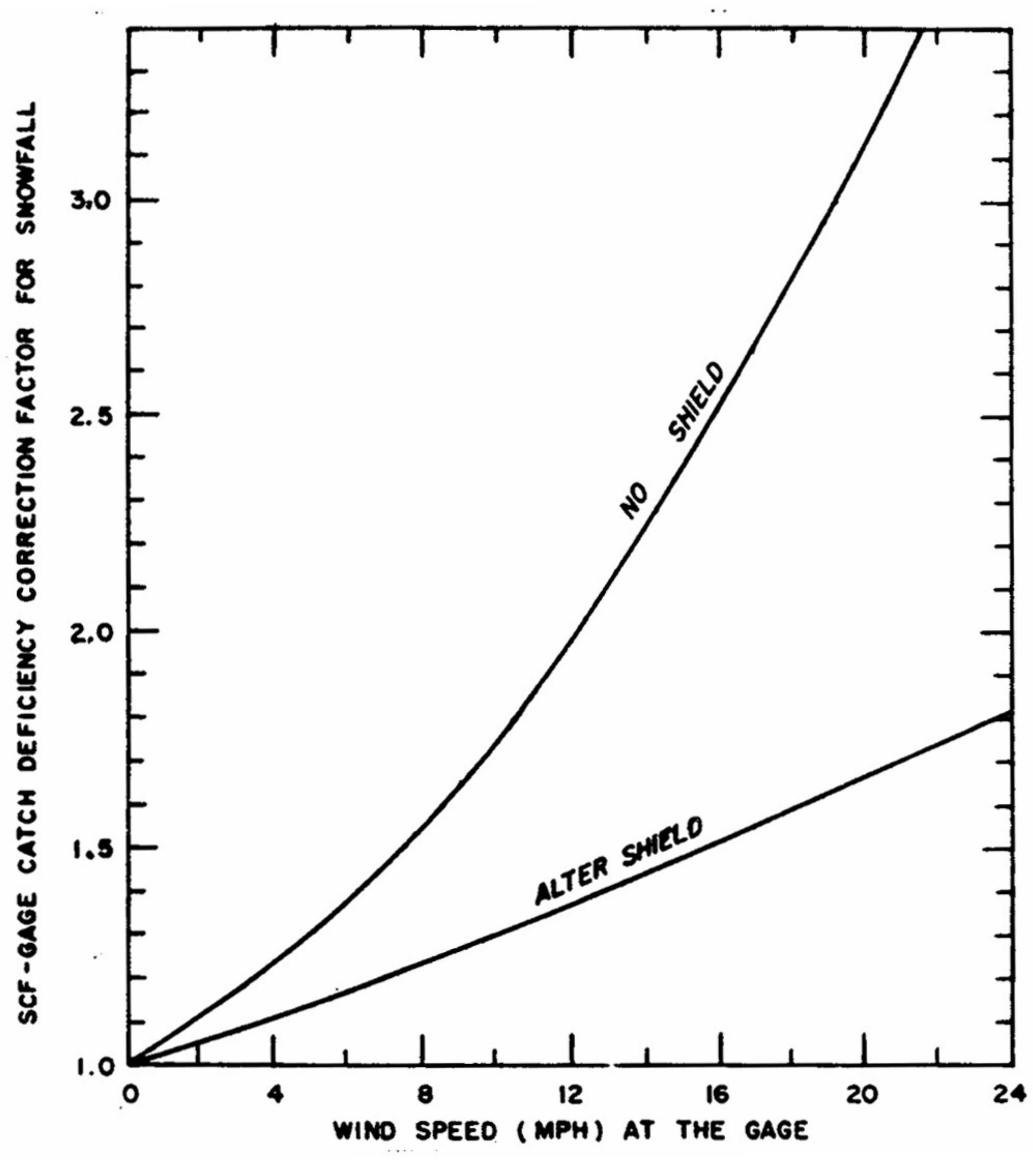

Figure II-2. Typical gage catch deficiency correction (Anderson, 1973, p. 5-20).

Subcatchment Schematization

Land Surface - Snow Cover Combinations

In order to have flexibility in treating different combinations of snow cover and ground surface types, four such combinations are provided, as described in Table II-2 and illustrated in Figure II-3. When snowmelt is not simulated, only the first three are used, as in the past. (Type 3, impervious area with no depression storage, is specified in Runoff by the parameter PCTZER, percent of impervious area with immediate runoff.) Snow cover is treated identically on types 1 and 3 since these surfaces are likely to be of similar nature, e.g., streets, sidewalks, parking lots, etc. For continuous simulations, these surfaces are considered “normally bare” because of probable plowing, salting or other rapid snow removal, but are subject to snow cover also, as described subsequently. For single event simulation, these surfaces are always bare; all snow on impervious areas is handled in type 4.

In Runoff, especially subroutine WSHED, the “types” are subscripts for the parameter WDEPTH, the water depth on each surface type. Since snow cover is the same for types 1 and 3, snow depths, WSNOW, are only triply subscripted.

For single event simulation, the fraction of snow-covered pervious area is constant; for continuous simulation the fraction varies according to an areal depletion curve (as for type 4 impervious). The depletion curves are explained later.

Apportionment of impervious area is different when simulating with and without snowmelt. For the latter situation, the area with zero depression storage (type 3) is taken to be a percentage, PCTZER, of the total impervious area. For the former situation (with snowmelt), it is taken as a percentage, the “normally bare” impervious area (continuous simulation). Thus, the type 3 area will vary according to whether snowmelt is simulated or not, as shown in Figure II-3. The effect on outflow is very minor. The fraction of impervious area with 100 percent snow cover (single event) or subject to an areal depletion curve (continuous) is an input parameter, SNN1, for each subcatchment.

Table II-2. Subcatchment Surface Classification

Type	Perviousness	Depression Storage	Snow Cover and Extent: Single Event*	Snow Cover and Extent: Continuous*
1	Impervious	Yes	Bare	Normally bare, but may have snow cover over 100% of type 1 plus type 3 area.
2	Pervious	Yes	Constant fraction, SNCP, of area is snow covered.	Snow covered subject to areal depletion curve.
3	Impervious	No	Bare	Same as type 1.
4	Impervious	Yes	100% covered.	Snow covered subject to areal depletion curve.

*Single event or continuous is determined by parameter ISNOW in Runoff Block input.

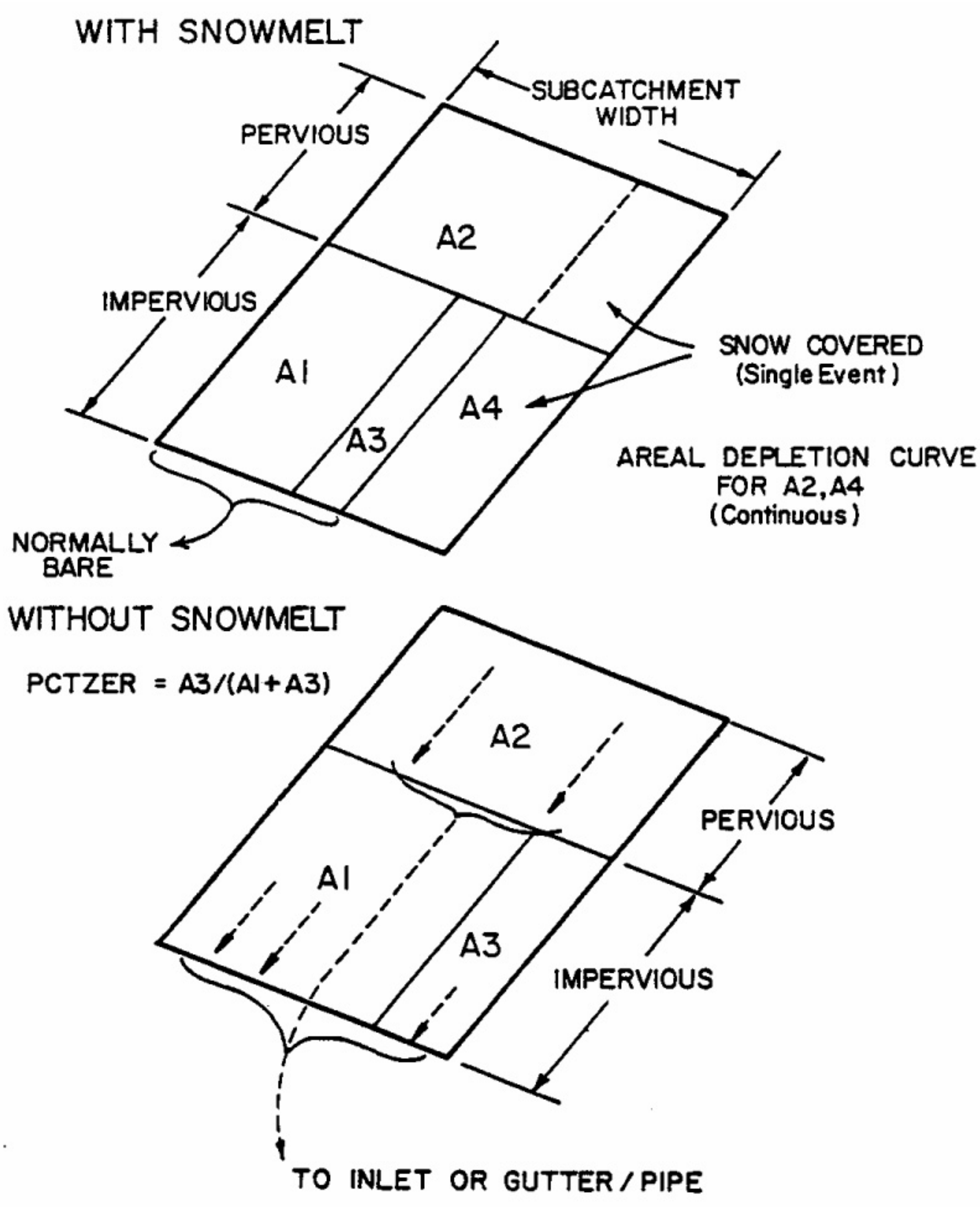

Figure II-3. Subcatchment schematization with and without snowmelt simulation. See also Table II-2.

Redistribution and Simulation of Snow Removal

Snow removal practices form a major difference between the snow hydrology of urban and rural areas. Much of the snow cover may be completely removed from heavily urbanized areas, or plowed into windrows or piles, with melt characteristics that differ markedly from those of undisturbed snow. Management practices in cities vary according to location, climate, topography and the storm itself; they are summarized in a study by APWA (1974). It is probably not possible to treat them all in a simulation model. See Table R-20. However, in continuous SWMM, provision is made to approximate simulation of some practices.

It is assumed that all snow subject to "redistribution", (e.g. plowing) resides on the "normally bare" category, type 1 plus 3 above, (see Figure II-3), that might consist of streets, sidewalks, parking lots, etc. (The desired degree of definition may be obtained by using several subcatchments, although a coarse schematization, e.g., one or two subcatchments, may be sufficient for some continuous simulations.) For each subcatchment, a depth of snow, WEPLOW, is input for this area, above which redistribution occurs as indicated in Figure II-4. All snow in excess of this depth, say 0.1 - 0.2 in. water equivalent (2.5 - 5.1 mm), is redistributed to other areas according to five fractions, SFRAC, input for each subcatchment. These are described on Figure II-4. For instance, if snow is usually windrowed onto adjacent impervious or pervious areas, SFRAC(1) or SFRAC(2) may be used. If it is trucked to another subcatchment (the last one input is used for this purpose), a fraction SFRAC(3) will so indicate, or SFRAC(4) if the snow is removed entirely from the simulated watershed. In the latter case, such removals are tabulated and included in the final continuity check. Finally, excess snow may be immediately "melted" (i.e., treated as rainfall), using SFRAC(5). The transfers are area weighted, of course, and the five fractions should sum to 1.0. A depth of snow WEPLOW remains on the normally bare area and is subject to melting as on the other areas. See Table II-3 for guidelines as to typical levels of service for snow and ice control (Richardson et al., 1974).

No pollutants are transferred with the snow. The transfers are assumed to have no effect on pollutant washoff and regeneration. In addition, all the parameters of this process remain constant throughout the simulation and can only represent averages over a snow season.

The redistribution simulation does not account for snow management practices using chemicals, e.g., roadway salting. This is handled using the melt equations, as described subsequently.

Array Restrictions

Continuous snowmelt and single event snowmelt are limited to the number of subcatchments defined by the variable NW in the parameter statement of the /Tapes/ Common. The NOW parameter is 100 in the default version of SWMM. This should be more than adequate for continuous simulation, with or without snowmelt, since only a coarse catchment discretization should be sufficient.

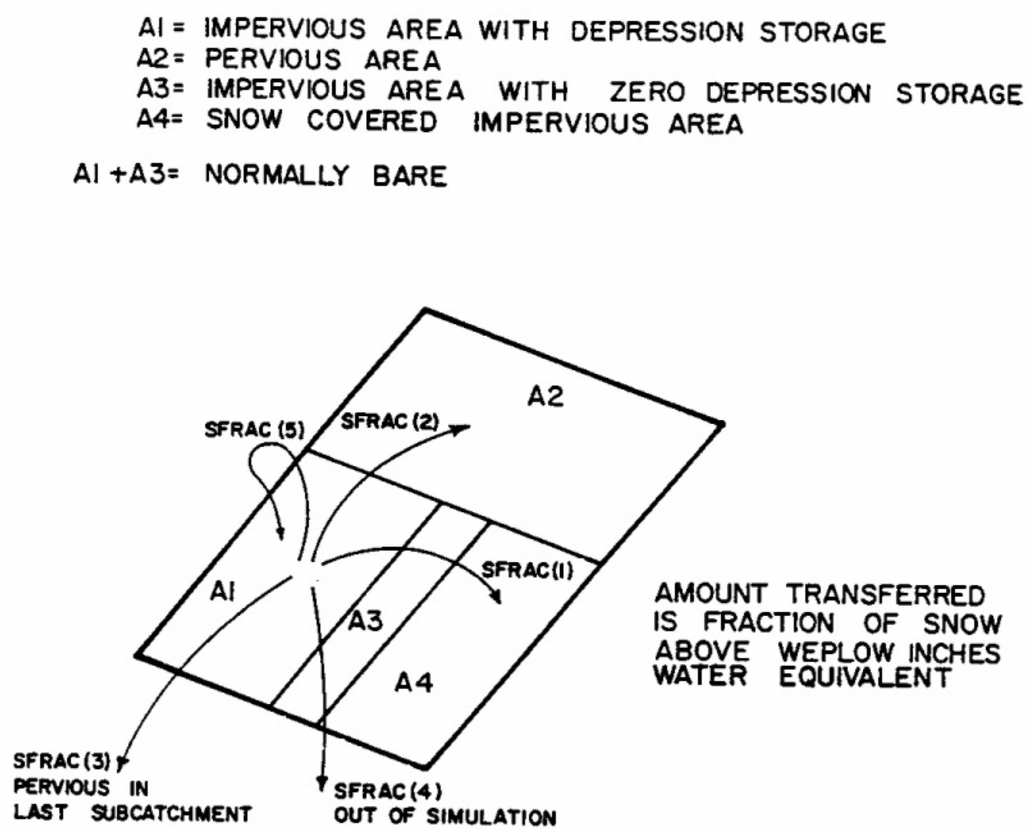

Figure II-4. Redistribution of snow during continuous simulation.

Table II-3. 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[a]	• 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[a]	• 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[a]	• 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

[a]ADT – average daily traffic

Melt Calculations

Theory of Snowmelt

Introduction

Excellent descriptions of the processes of snowmelt and accumulation are available in several texts and simulation model reports and in the well known 1956 Snow Hydrology report by the Corps of Engineers (1956). The important heat budget and melt components are first mentioned briefly here; any of the above sources may be consulted for detailed explanations. A brief justification for the techniques adopted for snowmelt calculations in SWMM is presented below.

Snowpack Heat Budget

Heat may be added or removed from a snowpack by the following processes:

1. Absorbed solar radiation (addition).
2. Net longwave radiation exchange with the surrounding environment (addition or removal).
3. Convective transfer of sensible heat from air (addition or removal).
4. Release of latent heat of vaporization by condensate (addition) or, the opposite, its removal by sublimation (removing the latent heat of vaporization plus the latent heat of fusion).
5. Advection of heat by rain (addition) plus addition of the heat of fusion if the rain freezes.
6. Conduction of heat from underlying ground (removal or addition).

The terms may be summed, with appropriate signs, and equated to the change of heat stored in the snowpack to form a conservation of heat equation. All of the processes listed above vary in relative importance with topography, season, climate, local meteorological conditions, etc., but items 1-4 are the most important. Item 5 is of less importance on a seasonal basis, and item 6 is often neglected.

A snow pack is termed “ripe” when any additional heat will produce liquid runoff. Rainfall (item 5) will rapidly ripen a snowpack by release of its latent heat of fusion as it freezes in subfreezing snow, followed by quickly filling the free water holding capacity of the snow.

Melt Prediction Techniques

Prediction of melt follows from prediction of the heat storage of the snow pack. Energy budget techniques are the most exact formulation since they evaluate each of the heat budget terms individually, requiring as meteorologic input quantities such as solar radiation, air temperature, dew point or relative humidity, wind speed, and precipitation. Assumptions must be made about the density, surface roughness and heat and water storage (mass balance) of the snow pack as well as on related topographical and vegetative parameters. Further complications arise in dealing with heat conduction and roughness of the underlying ground and whether or not it is permeable.

Several models individually treat some or all of these effects. One of the more recent was developed for the NWS river forecast system by Anderson (1976). Interestingly, under many conditions he found that results obtained using his energy balance model were not significantly better than those obtained using simpler (e.g., degree-day or temperature-index) techniques in his earlier model (1973). The more open and variable the conditions, the better is the energy balance technique. Closest agreement between his two models was for heavily forested watersheds.

Minimal data needed to apply an energy balance model are a good estimate of incoming solar radiation, plus measurements of air temperature, vapor pressure (or dew point or relative humidity) and wind speed. All of these data, except possibly solar radiation, are available at at least one location (e.g., the airport) for almost all reasonably sized cities. Even solar radiation measurements are taken at several locations in most states. Predictive techniques are also available, for solar radiation and other parameters, based on available measurements (TVA, 1972; Franz, 1974).

Choice of Predictive Method

Two major reasons suggest that simpler, e.g., temperature-index, techniques should be used for simulation of snowmelt and accumulation in urban areas. First, even though required meteorologic data for energy balance models are likely to be available, there is a large local variation in the magnitude of these parameters due to the urbanization itself. For example, radiation melt will be influenced heavily by shading of buildings and albedo reduced by urban pollutants. In view of the many unknown properties of the snowpack itself in urban areas, it may be overly ambitious to attempt to predict melt at all! But at the least, simpler techniques are probably all that are warranted. They have the added advantage of considerably reducing the already extensive input data to a model such as SWMM.

Second, the objective of the modeling should be examined. Although it may contribute, snowmelt seldom causes flooding or hydrologic extremes in an urban area itself. Hence, exact prediction of flow magnitudes does not assume nearly the importance it has in the models of, say, the NWS, in which river flood forecasting for large mountainous catchments is of paramount importance. For planning purposes in urban areas, exact quantity (or quality) prediction is not the objective in any event; rather, these efforts produce a statistical evaluation of a complex system and help identify critical time periods for more detailed analysis.

For these and other reasons, simple snowmelt prediction techniques have been incorporated into SWMM. Anderson's NWS (1973) temperature-index method is also well documented and tested, and has been incorporated into SWMM. As described subsequently, the snowmelt modeling follows Anderson's work in several areas, not just in the melt equations. The energy budget technique is illustrated later to show how it reduces to a temperature-index equation under certain assumptions. It may be noted that the STORM model (Hydrologic Engineering Center, 1977; Roesner et al., 1974) also uses the temperature-index method for snowmelt prediction, in a considerably less complex manner than is now programmed in SWMM.

SWMM Melt Equations

Anderson's NWS model (1973) treats two different melt situations: with and without rainfall. When there is rainfall (greater than 0.1 in./6 hr or 2.5 mm/6 hr in the NWS model; greater than 0.02 in./hr or 0.51 mm/hr in SWMM), accurate assumptions may be made about several energy budget terms. These are: zero solar radiation, incoming longwave radiation equals blackbody radiation at the ambient air temperature, the snow surface temperature is 32°F (0°C), and the dew point and rain water temperatures equal the ambient air temperature. Anderson combines the appropriate terms for each heat budget component into one equation for the melt rate. As used in subroutine MELT in SWMM, it is:

$$SMELT = (TA - 32) \diamond (0.001167 + SGAMMA \diamond UADJ + 0.007 \diamond PREC) + 8.5 \diamond UADJ \diamond (EA - 0.18) \quad \text{(II-8)}$$

where

SMELT	=	melt rate, in./hr,
TA	=	air temperature, °F,
SGAMMA	=	$7.5 \diamond$ GAMMA, in. Hg/°F,
GAMMA	=	psychometric constant, in. Hg/°F,
UADJ	=	wind speed function, in. /in. Hg - hr,
PREC	=	rainfall intensity, in./hr, and
EA	=	saturation vapor pressure at air temperature, in. Hg.

The psychometric constant, GAMMA, is calculated as:

$$GAMMA = 0.000359 \diamond PA \quad \text{(II-9)}$$

where PA = atmospheric pressure, in. Hg.

Average atmospheric pressure is in turn calculated as a function of elevation, z:

$$PA = 29.9 - 1.02 (z/1000) + 0.0032 \diamond (z/1000)^{2.4} \quad \text{(II-10)}$$

where z = average catchment elevation, ft.

The elevation, z, is an input parameter, ELEV. The wind function, UADJ, accounts for turbulent transport of sensible heat and water vapor. Anderson (1973) gives:

$$UADJ = 0.006 \diamond u \quad \text{(II-11)}$$

where

UADJ	=	wind speed function, in./in. Hg - hr, and
u	=	average wind speed 1.64 ft (0.5 m) above the snow surface, mi/hr.

In practice, available wind data are used and are seldom corrected for the actual elevation of the anemometer. For SWMM, average wind speeds are input for each month. Finally, the saturation vapor pressure, EA, is given accurately by the convenient exponential approximation,

$$EA = 8.1175 \times 10^6 \exp[-7701.544/(TA + 405.0265)] \quad \text{(II-12)}$$

where

EA	=	saturation vapor pressure, in. Hg, and
TA	=	air temperature, °F.

The origin of numerical constants found in equation II-8 for SMELT is given by Anderson (1973), and reflects units conversions as well as U.S. customary units for physical properties. Note that equation II-13 of Appendix III may be reduced to equation II-8.

During non-rain periods, melt is calculated as a linear function of the difference between the air temperature, TA, and a base temperature, TBASE, using a degree-day or temperature-index type equation:

$$\text{SMELT} = \text{DHM} \diamond (\text{TA} - \text{TBASE}) \qquad \text{(II-13)}$$

where

SMELT	=	snowmelt, in./hr (internally as ft/sec,)
TA	=	air temperature, °F,
TBASE	=	base melt temperature, °F, and
DHM	=	melt factor, in./hr-°F (internally ft/sec-°F).

Different values of TBASE and DHM may be input for three area classifications for each subcatchment (see Table II-2 and Figure II-3). For instance, these parameters may be used to account for street salting which lowers the base melt temperature. If desired, rooftops could be simulated as a separate subcatchment using a lower value of TBASE to reflect heat transfer vertically through the roof. Values of TBASE will probably range between 25 and 32 °F (-4 and 0 °C). Unfortunately, few urban area data exist to define adequately appropriate modified values for TBASE and DHM, and they may be considered calibration parameters.

In rural areas, the melt coefficient ranges from 0.03 - 0.15 in./day-°F (1.4 - 6.9 mm/day-°C) or from 0.001 - 0.006 in./hr-°F (0.057 - 0.29 mm/hr-°C). In urban areas, values may tend toward the higher part of the range due to compression of the pack by vehicles, pedestrians, etc. Again there appear to be few data available to produce accurate estimates. However, Bengtsson (1981) and Westerstrom (1981) do describe preliminary results of urban snowmelt studies in Sweden, including degree-day coefficients which range from 3 to 8 mm/°C-day (0.07 - 0.17 in./°F-day). Additional data for snowmelt on an asphalt surface (Westerstrom, 1984) gave degree-day coefficients of 1.7 - 6.5 mm/°C-day (0.04 - 0.14 in./°F-day).

It is important to realize that a degree-day equation may be derived from the complete energy budget equation if parameters other than air temperature are held constant. The equation is simply linearized about a desired air temperature range, and numerical values for DHM and TBASE computed. The values are accurate for the assumed values of other parameters, but may not appear to make sense physically, e.g., it is not difficult to use parameters that produce negative values of TBASE. An example of this procedure is given in Appendix III. It also serves to illustrate the energy budget computation method.

For single event SWMM, parameters DHM and TBASE are constant throughout the simulation. For continuous SWMM, TBASE remains constant, but DHM is allowed a seasonal variation, as illustrated in Figure II-5. Following Anderson (1973), the minimum melt coefficient is assumed to occur on December 21 and the maximum of June 21. Parameters

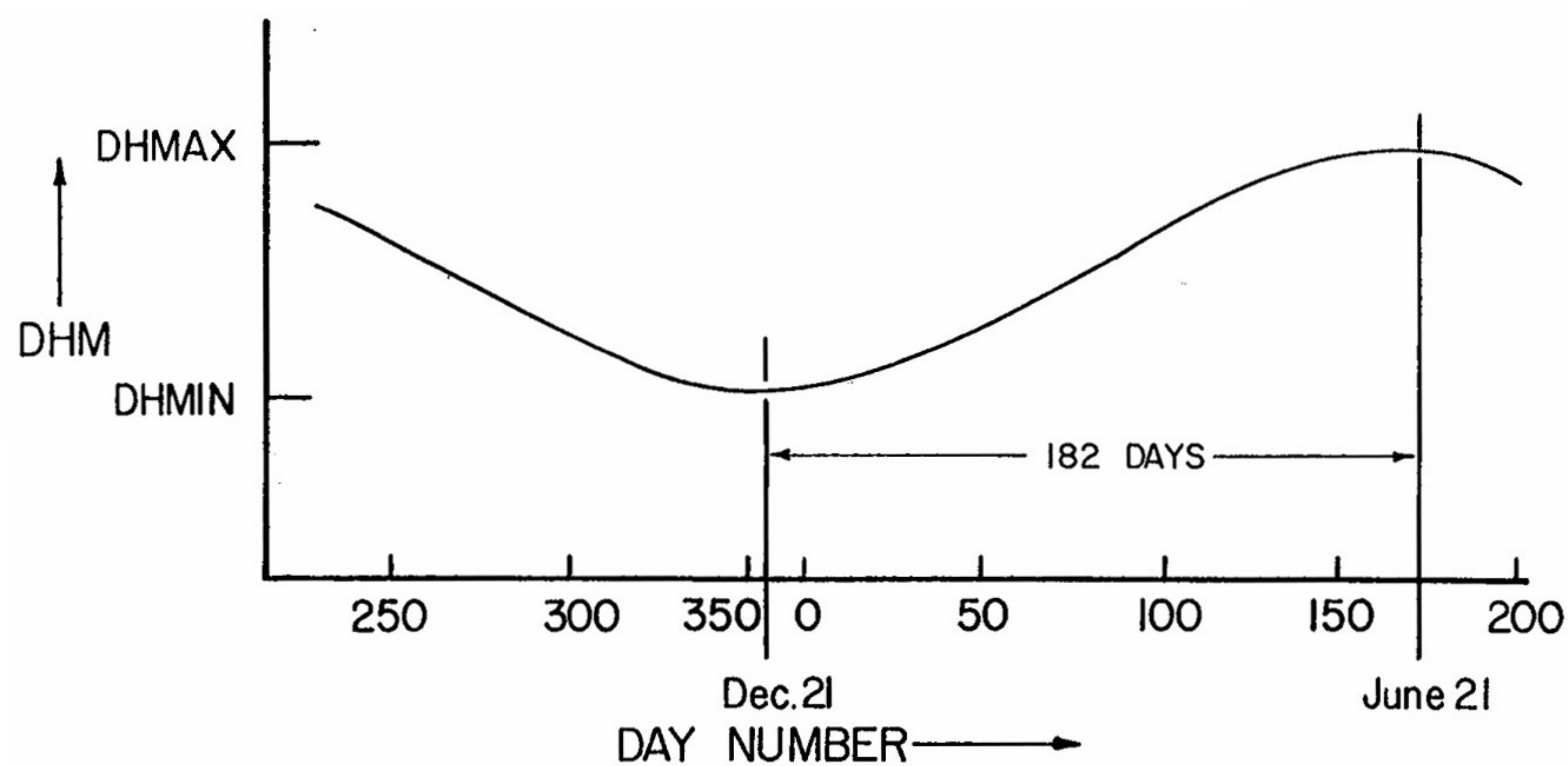

Figure II-5. Seasonal variation of melt coefficients

DHMIN and DHMAX are input for the three areas of each subcatchment, and sinusoidal interpolation is used to produce a value of DHM, constant over each day,

$$DHM = (DHMAX + DHMIN)/2 + (DHMAX - DHMIN)\Big/ 2 \cdot \sin\left[\frac{pi}{182}(D - 81)\right] \quad \text{(II-14)}$$

where

DHMIN	=	minimum melt coefficient, occurring Dec. 21, in./hr-°F,
DHMAX	=	maximum melt coefficient, occurring June 21, in./hr-°F, and
D	=	number of the day of the year.

No special allowance is made for leap year. However, the correct date (and day number, D) is maintained.

Heat Exchange During Non-Melt Periods

During subfreezing weather, the snow pack does not melt, and heat exchange with the atmosphere can either warm or cool the pack. The difference between the heat content of the subfreezing pack and the (higher) base melt temperature is taken as positive and termed the “cold content” of the pack. No melt will occur until this quantity, COLDC, is reduced to zero. It is maintained in inches (or feet) of water equivalent. That is, a cold content of 0.1 in. (2.5 mm) is equivalent to the heat required to melt 0.1 in. (2.5 m) of snow. Following Anderson (1973), the heat exchange altering the cold content is proportional to the difference between the air temperature, TA, and an antecedent temperature index, ATI, indicative of the temperature of the surface layer of the snow pack. The revised value of ATI at time step 2 is calculated as

$$ATI_2 = ATI_1 + TIPM \cdot (TA_2 - ATI_1) \quad \text{(II-15)}$$

where

ATI	=	antecedent temperature index, °F,
TA	=	air temperature, °F,
TIPM	=	antecedent temperature index parameter, $0 \le TIPM \le 1.0$, and

subscripts 1 and 2 refer to time steps 1 and 2, respectively. The value of ATI is not allowed to exceed TBASE, and when snowfall is occurring, ATI takes on the current air temperature.

The weighting factor, TIPM, is an indication of the thickness of the “surface” layer of snow. Values of TIPM less than 0.1 give significant weight to temperatures over the past week or more and would thus indicate a deeper layer than TIPM values greater than, say, 0.5, which would essentially only give weight to temperatures during the past day. In other words, the pack will both warm and cool more slowly with low values of TIPM. Anderson states that TIPM = 0.5 has given reasonable results in natural watersheds, although there is some evidence that a lower value may be more appropriate. No calibration has been attempted on urban water-sheds.

Following computation of the antecedent temperature index, the cold content is changed by an amount

$$DCOLDC = RNM \diamond DHM \diamond (ATI - TA) \diamond DELT \quad \text{(II-16)}$$

where

DCOLDC	=	change in cold content, ft water equivalent,
RNM	=	ratio of negative melt coefficient to melt coefficient,
DHM	=	melt coefficient, ft/sec-°F,
TA	=	air temperature, °F,
ATI	=	antecedent temperature index, °F, and
DELT	=	time step, sec.

Note that the cold content is increased, (DCOLDC is positive) when the air temperature is less (colder) than the antecedent temperature index. Since heat transfer during non-melt periods is less than during melt periods, Anderson uses a "negative melt coefficient" in the heat exchange computation. SWMM computes this simply as a fraction, RNM, of the melt coefficient, DHM. Hence, the negative melt coefficient, i.e., the product RNM × DHM, also varies seasonally. A typical value of RNM is 0.6.

When heat is added to a snow pack with zero cold content, liquid melt is produced, but runoff does not occur, until the "free water holding capacity" of the snow pack is filled. This is discussed subsequently. For single event SWMM no cold content calculations are performed; values of COLDC are assumed to equal zero throughout the simulation. The value of COLDC is in units of feet of water equivalent over the area in question. The cold content "volume," equivalent to calories or BTUs, is obtained by multiplying by the area. Finally, an adjustment is made to equation II-16 depending on the areal extent of snow cover. This is discussed below.

Areal Extent of Snow Cover

Introduction

The snow pack on a catchment rarely melts uniformly over the total area. Rather, due to shading, drifting, topography, etc., certain portions of the catchment will become bare before others, and only a fraction, ASC, will be snow covered. This fraction must be known in order to compute the snow covered area available for heat exchange and melt, and to know how much rain falls on bare ground. Because of year to year similarities in topography, vegetation, drift patterns, etc., the fraction, ASC, is primarily only a function of the amount of snow on the catchment at a given time; this function, called an "areal depletion curve", is discussed below. These functions are used only for continuous SWMM to describe the seasonal growth and recession of the snow pack. For single event simulation, fractions of snow covered area are fixed for the pervious and impervious areas of each subcatchment.

Areal Depletion Curves

As used in most snowmelt models, it is assumed that there is a depth, SI, above which there will always be 100 percent cover. 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 each of the three possible snow covered areas of each subcatchment (see Figure II-3). This depth is nondimensionalized by SI for use in calculating ASC. Thus, an areal depletion curve is a plot of WSNOW/SI versus ASC; a typical ADC for a natural catchment is shown in Figure II-6. 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 II-7. Since the program maintains snow quantities, WSNOW, as the depth over the total area, AT, the actual snow depth, WS, and actual area covered, AS, are related by continuity:

WSNOW ⟐ AT = WS ⟐ AS
(II-17)

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, this equation may be rearranged to read

AWESI = WSNOW/SI = (WS/SI) ⟐ (AS/AT) = (WS/SI) ⟐ ASC (II-18)

This equation 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 II-7. Thus:

WS = (AWESI/ASC) ⟐ SI (II-19)

Consider the three ADC curves B, C and D. For curve B, AWESI is always less than ASC; hence WS is always less than SI as shown in Figure II-7d. For curve C, AWESI = ASC, hence WS = SI, as shown in Figure II-7e. Finally, for curve D, AWESI is always greater than ASC; hence, WS is always greater than SI, as shown in Figure II-7f. Constant values of ASC at 100 percent cover and 40 percent cover are illustrated in Figure II-7c, curve A, and Figure II-7g, curve E, respectively. At a given time (e.g., t_1 in Figure II-7), the area of each snow depth versus area curve is the same and equal to AWESI ⟐ SI, (e.g., 0.¸ SI for time t_1).

Curve B on Figure II-7a is the most common type of ADC occurring in nature, as shown in Figure II-6. 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. A complex curve could be generated to represent specific snow removal practices in a city. However, the program utilizes only on ADC curve for all impervious areas (e.g., area A4 of Figure II-3 for all subcatchments) and only one ADC curve for all per-vious areas (e.g., area A2 of Figure II-3 for all subcatchments). This limitation should not hinder an adequate simulation since the effects of variations in individual locations are averaged out in the city-wide scope of most continuous simulations.

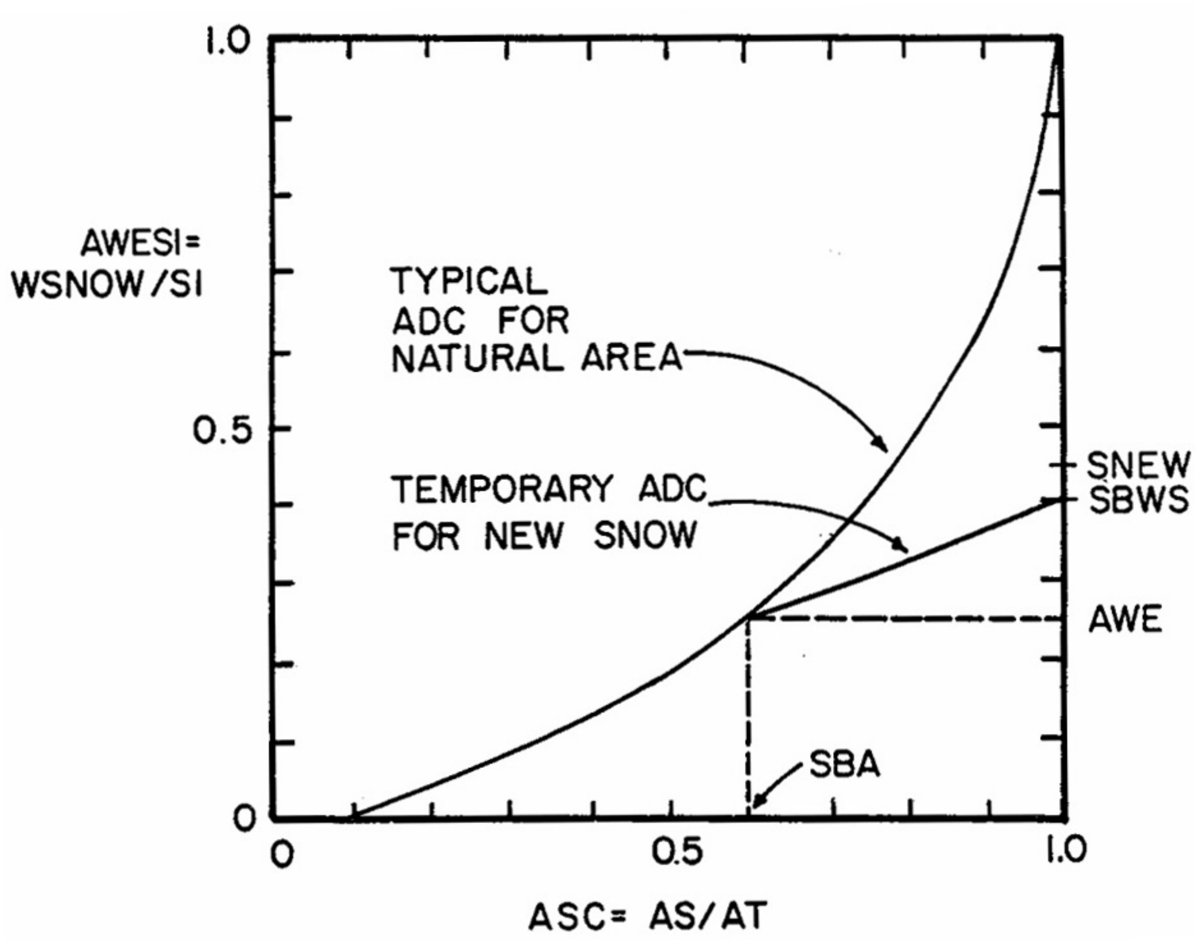

Figure II-6. Typical areal depletion curve for natural area (Anderson, 1973, p. 3-15) and temporary curve for new snow.

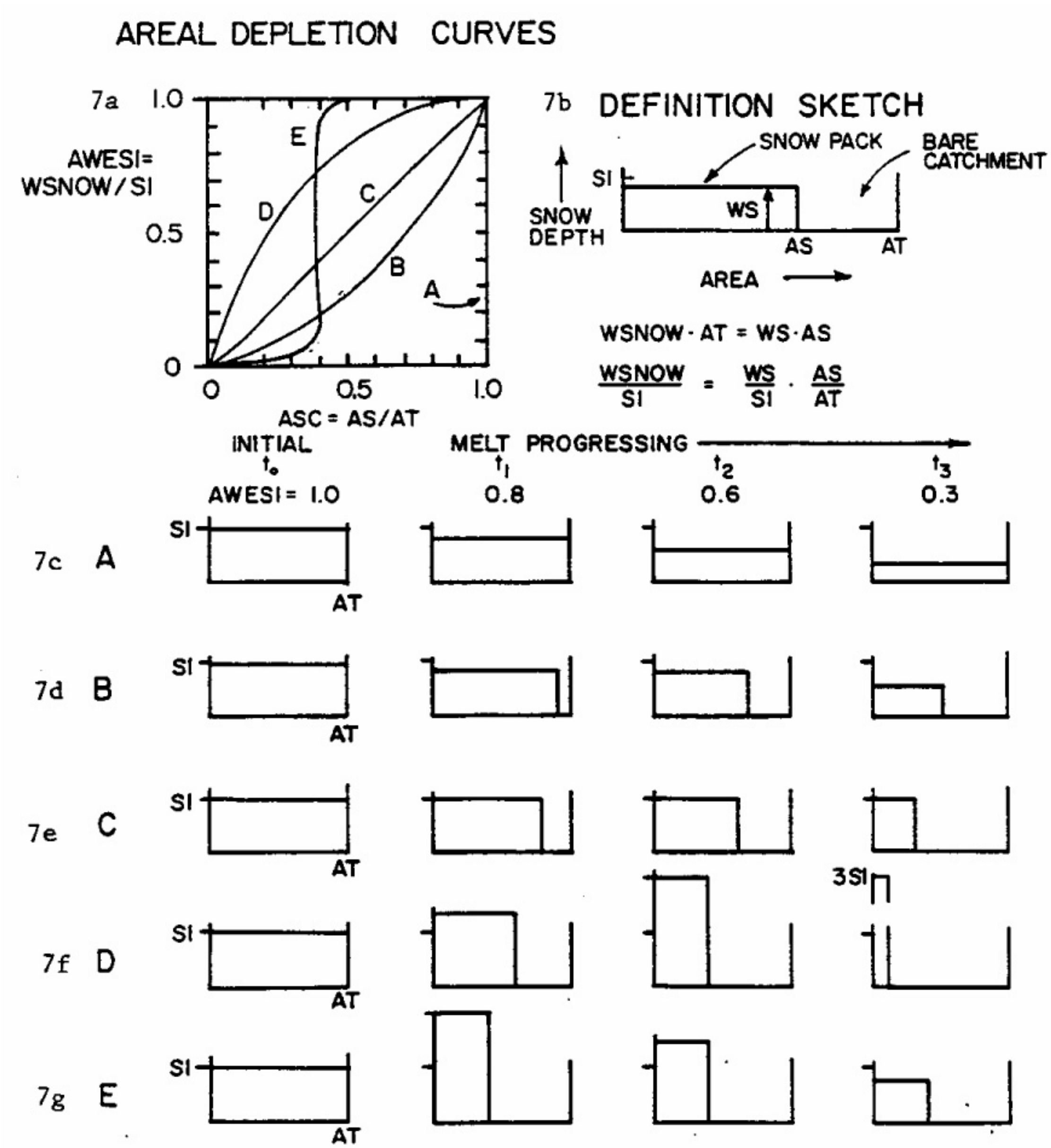

Figure II-7. Effect of snow cover on areal depletion curves.

The two ADC curves for pervious and impervious areas are input by the user, as are values of SI for each subcatchment. 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 in order to maintain some snow covered area up until the instant that all snow disappears (see Figure II-6). However, the curves may not intersect the ordinate, AWESI > 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 needs to be discussed, starting from both zero or non-zero initial cover. The SWMM procedure again follows Anderson's NWS method (1973).

When there is new snow and WSNOW is already greater than or equal to SI, them ASC remains unchanged at 1.0. However, when there is new snow on bare or partially bare ground, it is assumed that the total area is 100 percent covered for a period of time, and a "temporary" ADC is established as shown in Figure II-6. This temporary curve returns to the same point on the ADC as the snow melts. Let the depth of new snow be SNO, measured in equivalent feet of water. Then the value of AWESI will be changed from an initial value of AWE to a new value of SNEW by:

$$SNEW = AWE + SNO/SI \qquad \text{(II-20)}$$

It is assumed that the areal snow cover remains at 100 percent until 25 percent of the new snow melts. This defines the value of SBWS of Figure II-6 as:

$$SBWS = AWE + 0.75 \cdot SNO/SI \qquad \text{(II-21)}$$

Anderson (1973) reports low sensitivity of model results to the arbitrary 25 percent assumption. When melt produces a value of AWESI between SBWS and AWE, linear interpolation of the temporary curve is used to find ASC until the actual ADC curve is again reached. When new snow has fallen, the program thus maintains values of AWE, SBA and SBWS (Figure II-6).

The interactive nature of melt and fraction of snow cover is not accounted for <u>during</u> each time step. It is sufficient to use the value of ASC at the beginning of each time step, especially with a short (e.g., one-hour) time step for the simulation.

Use of Value of ASC

The fraction of area that is snow covered, ASC, is used to adjust 1) the volume of melt that occurs, and 2) the "volume" of cold content change, since it is assumed that heat transfer occurs only over the snow covered area. The melt rate is computed from either of the two equations for SMELT. The snow depth is then reduced from its value at time step 1 to time step 2 as:

$$WSNOW_2 = WSNOW_1 - SMELT \cdot ASC \qquad \text{(II-22)}$$

with variables as defined previously and including appropriate continuity checks in the program to avoid melting more snow than is there, etc.

Cold content changes are also adjusted by the value of ASC. Thus, using equation II-16, cold content at time step 2 is computed from the value at time step 1 by:

$$COLDC_2 = COLDC_1 + RNM \diamond DHM \diamond (ATI\text{-}TA) \diamond DELT \diamond ASC \qquad \text{(II-23)}$$

where variables are as previously defined. Again there are program checks for negative values of COLDC, etc.

Liquid Water Routing in Snow Pack

Production of melt does not necessarily mean that there will be liquid runoff at a given time step since a snow pack, acting as a porous medium with a "porosity," has a certain "free water holding capacity" at a given instant in time. Following PR-JFM (1976a, 1976b), this capacity is taken to be a constant fraction, FWFRAC, of the variable snow depth, WSNOW, at each time step. This volume (depth) must be filled before runoff from the snow pack occurs. The program maintains the depth of free water, FW, ft of water, for use in these computations. When FW = FWFRAC × WSNOW, the snow pack is fully ripe. The procedure is sketched in Figure II-8.

The inclusion of the free water holding capacity via this simple reservoir-type routing delays and somewhat attenuates the appearance of liquid runoff. The value of FWFRAC will normally be less than 0.10 and usually between 0.02 - 0.05 for deep snow packs (SWNOW > 10 in. or 254 mm water equivalent). However, Anderson (1973) reports that a value of 0.25 is not unreasonable for shallow snow packs that may form a slush layer. When rainfall occurs, it is added to the melt rate entering storage as free water. No free water is released when melt does not occur, but remains in storage, available for release when the pack is again ripe. This re-frozen free water is not included in subsequent cold content or melt computations.

Net Runoff

Melt from snow covered areas and rainfall on bare surfaces are area weighted and combined to produce net runoff <u>onto</u> the surface as follows:

$$RI = ASC \diamond SMELT + (1.0 - ASC) \diamond RINE \qquad \text{(II-24)}$$

where

RI	=	net runoff onto surface, ft/sec,
ASC	=	fraction of area that is snow covered,
SMELT	=	melt rate, including effect of attenuation due to free water holding capacity, ft/sec, and
RINE	=	rainfall intensity, ft/sec.

Thus, the net runoff acts just as rainfall would act alone in subsequent overland flow and infiltration calculations.

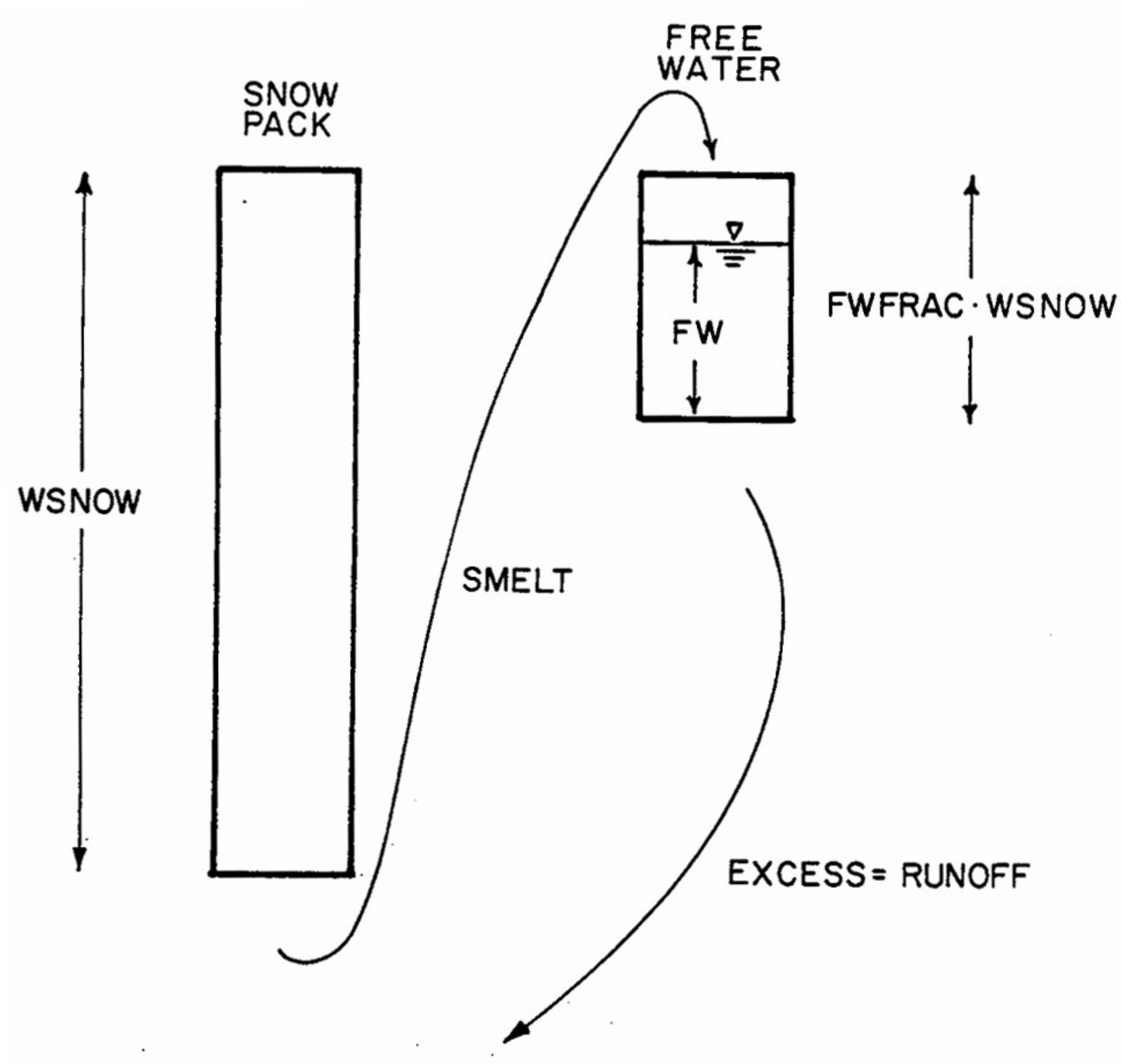

Figure II-8. Schematic of liquid water routing through snow pack.

If immediate melt is produced through the use of the snow redistribution fraction SFRAC(5) (see Figure II-4), it is added to the last equation. Furthermore, all melt calculations are ended when the depth of snow water equivalent becomes less than 0.001 in. (0.025 mm), and remaining snow and free water are converted to immediate melt and added to equation II-24.

Effect of Snow on Infiltration and Surface Parameters

A snow pack tends to insulate the surface beneath it. If ground has frozen prior to snowfall, it will tend to remain so, even as the snow begins to melt. Conversely, unfrozen ground is generally not frozen by subsequent snowfall. The infiltration characteristics of frozen versus unfrozen ground are not well understood and depend upon the moisture content at the time of freezing. For these and other reasons, SWMM assumes that snow has no effect on infiltration or other parameters, such as surface roughness or detention storage (although the latter is altered in a sense through the use of the free water holding capacity of the snow). In addition, all heat transfer calculations cease when the water becomes "net runoff." Thus, water in temporary surface storage during the overland flow routing will not refreeze as the temperature drops and is also subject to evaporation beneath the snow pack.

Quality Interactions

Pollutant Accumulation

Snowmelt Quality

A detailed review of literature related to snowmelt quality is given by PR-JFM (1976a, 1976b). Among the various contaminants found in deposited snow and melt water, chlorides and lead appear to be the most serious and potentially hazardous. Chloride concentrations in runoff along major highways can be higher than 20,000 mg/l, with typical values of from 1,000 to 10,000 mg/l. Several other studies also document chloride contamination and discuss street salting practices (Field et al., 1973; Richardson et al., 1974; Ontario Ministry of the Environment, 1974). Lead concentrations in snow windrows have been as high as 100 mg/l with typical values of from 1 to 10 mg/l. However, most deposited lead results from automobile combustion and is insoluble. Hence, melt runoff concentrations are lower than snow pack values and are mostly associated with suspended solids.

Pollutant Loadings

Mechanisms and modeling alternatives for pollutant buildup and washoff are described extensively in Section 4 (Runoff Block). Any parameter related to snowmelt may be generated using linear or non-linear buildup, or else a rating curve (load proportional to flow). Specifically, street salting chemicals may be simulated, such as sodium chloride or calcium chloride.

Adjustments for Presence of Snow

As a user option, regeneration of any quality constituent may be performed only when snow is present. This option is indicated by parameter LINKUP. Thus, if chlorides are simulated, for example, they will not be regenerated from bare ground, during the summer months for instance. However, regeneration when it does occur is a function only of snow presence, not the actual amount (depth).

Possible Loading Rates

Pollutant loading rates are best determined from local data. The literature review of PR-JFM (1976a, 1976b) may also be consulted for tables that may be used to estimate loading rate parameters for snow-associated pollutants. Other references will also be useful (e.g., Field et al., 1973; Richardson et al., 1974; Ontario Ministry of the Environment, 1974).

Table II-4 (Richardson et al., 1974) lists recommended deicing chemical application rates for roadways. In general, PR-JFM show that observed loading rates are functions of population density with suburban rates lower than arterial highway rates, as indicated in Table II-5. This is also true for other pollutants.

Street Sweeping

The effect of snow is included in two minor ways. First, beginning and ending dates, parameters KLNBGN and KLNEND respectively, may be input for continuous SWMM to indicate the interval during the year subject to street sweeping. If sweeping normally is not done between, say, December 1 and March 1, because of high snow volumes, this may be so indicated.

Second, the presence of snow can alter the street sweeping interval. These intervals are specified for each of the five land uses. Each subcatchment is swept when the number of dry time steps for that subcatchment exceeds the interval for the given land use. A dry time step, in subroutine QSHED, is one in which there is no precipitation and no water or snow on areas A1 and A3 (Figure II-3). Thus, subcatchments will not be swept until there is no snow or water on "normally bare" impervious areas.

Other Considerations

The snow itself is assumed to be "pure" and contain no pollutants. Thus, the redistribution or transfers of snow described earlier (Figure II-4) will not remove accumulated pollutants. This is partially justified on the basis of the assumption that such transfers would occur soon after fresh snow has fallen. They occur during the same time step in the model.

Although not well tested, it is assumed that the principal effect of inclusion of snowmelt upon runoff quality predictions of continuous SWMM will be to shift the season and magnitude of pollutant washoff. There will tend to be fewer periods of washoff during the winter. As snowmelt, equivalent melt rates are likely to be less than the usual magnitude of rainfall intensities experienced. Hence, concentrations may tend to be more uniform during the melt washoff events.

Data Requirements

Input Parameters

For single event simulation, input parameters include watershed elevation, free water holding capacities, air temperatures and wind speeds, and for each subcatchment, snow covered fractions, initial snow and free water, melt coefficients and base temperatures. Continuous simulation requires the same data as above, except that air temperatures are computed using other input parameters. In addition, it requires the snow gage correction factor, negative heat exchange parameter, areal depletion curves, and, for each subcatchment, the redistribution parameters. Of course, for continuous simulation, the required parameters can be kept to a minimum by keeping the number of subcatchments used to a minimum. Also required are pollutant loading data that may or may not be related to snow.

Table II-4. Guidelines for Chemical Application Rates (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 areas with 1200 of 20:1 sand/salt

Table II-5. Salting Rates Used in Ontario (Proctor and Redfern Ltd. and James F. MacLaren, Ltd., Vol. II, 1976b)

Population Density (person per sq mile)	Salting Rate per Application (lb per lane-mile)
Less than 1,000	75 - 800
1,000 to 5,000	350 - 1,800
More than 5,000	400 - 1,200

Sensitivity

The melt routines have not been sufficiently tested to date to quantify the sensitivity of results to various input parameters. It is expected that melt volumes will be most related to the precipitation record, of course, and to the gage correction factor, which influences the amount of snow that falls. Melt rates will be influenced by the melt coefficients and base temperatures, and, to some degree, by the areal depletion curves which simulate the relative "piling" or "stacking" of the snow.

Output

Temperature and Snowfall Generation

Output consists of temperatures synthesized from daily max-min values, and hourly precipitation totals, in which snowfall is tagged as a negative value.

Runoff Simulation Output

Snowmelt events are not indicated in a special manner for output by either continuous or single event SWMM. If daily output is used, snowmelt may be discerned to some degree by observing whether precipitation accompanies the runoff for that day. Snowfall and initial snow depths are identified as separate items in the final continuity check for the total watershed.

Appendix III
Reduction Of Energy Balance Equation To Degree-Day Equation

Purpose

This appendix presents equations that can be used for each term in the energy balance equation discussed in Appendix II. The equation is then linearized and typical numerical values are used to reduce it to a degree-day or temperature-index type equation. The energy budget method will thus be better understood, and a physical basis for the simple prediction equations will be seen. Notation and equations used will follow Eagleson (1970), although an identical development could be based on several other references.

Energy Budget

The energy budget given in Appendix II is repeated and symbols are assigned to each term. Units for each energy budget term are energy/area-time, e.g., ly/day (one langley = one cal/cm^2). However, within this scope, there are mixtures of units used as convenient, e.g., minutes and days, °C and °F. The equation is ultimately converted to U.S. customary units.

The snow pack energy budget is (e.g., units of ly/day):

$$\Delta H = H_{rs} + H_g + H_{rl} + H_c + H_e + H_p \qquad \text{(III-1)}$$

where

ΔH	=	change in heat storage in snow pack,
H_{rs}	=	net short wave radiation entering the snow pack,
H_g	=	conduction of heat to snow pack from underlying ground,
H_{rl}	=	net (incoming minus outgoing) long wave radiation entering the snow pack,
H_c	=	convective transport of sensible heat from air to snow pack,
H_e	=	release of latent heat of vaporization by condensation of atmospheric water vapor, and
H_p	=	advection of heat to snow pack by rain.

All terms can be positive or negative except for H_e (sublimation will not be considered since it also involves the heat of fusion), H_{rs} and H_p (heat cannot be removed by rain).

It will be assumed that the snow pack is ripe, and all heat added will product liquid melt. Since inches of melt are desired, and it requires about 80 cal to melt one gram of water (the latent heat of fusion) or 80 ly per cm, it requires 2.54 cm/in. x 80 ly/cm = 203.2 ly per inch of melt.

The above equation is eventually linearized and put in the form of the simple degree-day equation:

$$SMELT = \Delta h/203.2 = DHM \cdot (T_a - T_b) \quad \text{(III-2)}$$

where

SMELT	=	melt rate, in./day,
DELH	=	change in heat storage, ly/day,
DHM	=	melt coefficient, in./day-°F,
T_a	=	air temperature, °F, and
T_b	=	base melt temperature, °F.

Other terms are defined where introduced. Caution should be used to insure that all terms eventually have the same units.

Short Wave Radiation, H_{rs}

Measured values from NWS stations are ordinarily used. The albedo (reflection coefficient) of new snow can be as high as 0.80 and is seldom lower than 0.4 in natural areas. Albedos of dirty urban snow surfaces are not documented, but probably lower than 0.4. Net shortwave radiation, H_{rs}, is incoming minus reflected. If measurements of incoming radiation are unavailable, predictive techniques may be used (TVA, 1972; Franz, 1974).

Heat Conduction Through Ground, H_g

Few data are available to quantify this term, and it is often determined as a residual in the energy budget equation. For urban areas, the intriguing possibility exists of predicting heat transfer through roofs based upon assumed temperature differences across the roof surface and thermal properties of the roofing material. In most cases, however, such calculations will be inaccurate and/or infeasible. Hence, this term is usually neglected.

Net Long Wave Radiation, H_{rl}

Incoming minus outgoing long wave radiation is given by the Stefan-Boltzman law:

$$H_{rl} = 0.97 \cdot \varepsilon_a \cdot \sigma \cdot T_a^4 - 0.97 \cdot \sigma \cdot T_s^4 \quad \text{(III-3)}$$

where

ε_a	=	atmospheric emissivity, a function of water vapor content,
σ	=	Stefan-Boltzman constant = 0.826×10^{-10} ly/min-°K^4,
T_a	=	air temperature at specified elevation, °K,
T_s	=	snow surface temperature, °K.

The first factor of 0.97 accounts for three percent reflection of incoming long wave radiation, and the second factor of 0.97 is the emissivity of the snow surface.

The key unknown is the atmospheric emissivity, for which several empirical formulas are available and in which the effect of clouds may also be included (TVA, 1972). For example, a simple formula due to Anderson (1973) for clear skies is:

$$\varepsilon_a = 0.74 + 0.0049e \qquad \text{(III-4)}$$

where e = ground level atmospheric vapor pressure, mb.

Clouds may be assumed to radiate with an emissivity of 0.97 at the cloud base temperature, if known.

The snow surface temperature may be taken to be 0°C. Hence, it is necessary to linearize only the air temperature term. This may be done by means of a Taylor series, under the assumption:

$$T_a = T_o + \Delta T \qquad \text{(III-5)}$$

The fourth-power term is then linearized about the reference temperature, T_o:

$$T_a^4 = (T_o + \Delta T)^4 = T_o^4 + \Delta T \cdot 4 \cdot T_o^3 + \ldots = T_o^3(4T_a - 3T_o) \qquad \text{(III-6)}$$

The reference temperature, T_o will be a constant in the equation and is chosen near the midpoint of the expected temperature range at the time of evaluation of the heat budget. Equation III-6 may be substituted into equation III-3,

$$H_{rl} = 0.97 \cdot \varepsilon_a \cdot \sigma \cdot T_o^3(4T_a - 3T_o) - 0.97 \cdot \sigma \cdot T_s^4 \qquad \text{(III-7)}$$

which is linear in T_a, in °K. Later, temperatures are converted to °F for consistency.

Convective Heat Transfer, H_c

Equations for this process (and for condensation melt) vary according to the assumptions made about surface roughness, wind speed profiles and turbulent transfer coefficients. A common equation is (Eagleson, 1970):

$$H_c = 203.2 \cdot k_c \cdot p_s / p_o \cdot (z_a \cdot z_b)^{-1/6} \cdot \bar{u}_b \cdot (T_a - T_s) \qquad \text{(III-8)}$$

where

p_s	=	surface atmospheric pressure (consistent units with p_o),
p_o	=	sea level atmospheric pressure (consistent units with p_s),
z_a	=	height above surface of air temperature (and humidity) measurement, ft,
z_b	=	height above surface of wind speed measurement, ft,
$\bar{u}_b$	=	wind speed at height z_b, mph,
T_a	=	air temperature, °F,

T_s = snow surface temperature, °F, and
H_c = heat transfer in ly/day.

The factor 203.2 converts inches to langleys and the coefficient k_c has been measured in the Sierra Nevada mountains as:

$$k_c = 0.00629 \text{ in.ft}^{1/3}\text{hr/day-°F-mi} \quad \text{(III-9)}$$

Condensation Heat Transfer, H_e

Since both this and convective heat transfer are diffusive type processes, the same introductory remarks hold as for the latter. A common equation is (Eagleson, 1970):

$$H_e = 203.2 \cdot 8.5 \cdot k_e \cdot (z_a \cdot z_b)^{-1/6} \cdot \bar{u}_b \cdot (e_a - e_s) \quad \text{(III-10)}$$

where

e_a = vapor pressure of atmosphere at temperature and relative humidity at height za, mb,

e_s = saturation vapor pressure at the snow surface temperature, mb

and other variables are defined as for equation III-8. The coefficient k_e has been measured for the Sierras as

$$K_e = 0.00635 \text{ in.ft}^{1/3} \text{ hr/day-mb-mile.} \quad \text{(III-11)}$$

The factor of 8.5 in equation III-10 accounts for the fact that when the snow pack is ripe, the latent heat of condensation will supply the latent heat of fusion to melt the snow. Because of the ratio of these latent heats, 600/80 = 7.5, each inch of condensate will cause 7.5 + 1 = 8.5 inches of "melt".

Heat Advection by Rain, H_p

Heat is advected by rain in proportion to the rainfall depth and temperature of the rain (assumed to be equal to the air temperature). Then:

$$H_p = 1.41 \, d \, (T_a - T_s) \quad \text{(III-12)}$$

where

H_p = heat advected in ly/day, and
d = daily rainfall depth, in./day, and

the temperatures are in °F.

Combined Equations

When equations for each component are substituted into the equation III-1 and using equation III-2 to generate inches of melt, all equations may be combined into:

$$\begin{aligned}\text{SMELT} = \frac{\Delta H}{203.2} = &\frac{0.97\varepsilon_a \sigma 4T_o^3}{203.2}\left(265.2 + 5/9\,T_a\right) \\ &+ \left(z_a \cdot z_b\right)^{-1/6} \bar{u}_b \cdot k_c \cdot p_s/p_o \cdot T_a + \frac{H_{rs} + H_g}{203.2} - \frac{0.97\sigma T_s^4}{203.2}\Bigg|\,{}^\circ K \\ &+ \left(z_a \cdot z_b\right)^{-1/6} \bar{u}_b \left[8.5 \cdot k_e\left(e_a - e_s\right) - k_c p_s/p_o T_s\right] \\ &- \frac{0.97\varepsilon_a \sigma 3T_o^4}{203.2} + \frac{1.41 \cdot d \cdot \left(T_a - T_s\right)}{203.2}\end{aligned} \qquad \text{(III-13)}$$

where terms have been defined previously, and temperature units are:

T_o = reference temperature, °K,
T_s = snow surface temperature, °F, (except °K in term 4), and
T_a = air temperature, °F.

The units of SMELT are inches/day. The equation is linear in the air temperature, T_a, which will be the only variable when the others are assigned numerical values. Note also the conversion from °K to °F in term 1. A further refinement would make saturation atmospheric vapor pressure a linear function of air temperature, which is valid over say, 10°F ranges. Then,

$$e_a = r \cdot e_{a_s} = r \cdot f\left(T_a\right) \qquad \text{(III-14)}$$

where

r = relative humidity, fraction, and
e_{a_s} = saturation vapor pressure at air temperature, T_a.

This modification would then add another term in T_a to equation III-13; it is pursued no further here. Note that equation II-8 in Appendix II is only a simplification of equation III-13 under suitable assumptions for rainfall conditions and with units conversions.

Numerical Example

The following meteorological parameters are assumed:

H_{rs} = 288 ly/day,
T_o = 35°F = 274.7°K
T_s = 32°F = 273°K

z_a = 6 ft
z_b = 20 ft
$\bar{u}_b$ = 9 mph
e_s = $e_s(32°F)$ = 6.11 mb
r = 0.6
e_a = $0.6 \diamond e_s(35°F) = 0.6 \diamond 6.87 = 4.12$ mb
ε_a = 0.90
p_o = 1013.2 mb
p_s = 950 mb (about 2000 ft elevation),
rainfall = zero
H_g = zero

Each of the terms in the long equation is now evaluated, with units of inches/day:

Term	Constant	Temperature Term
1	+11.24	$+ 0.0235\ T_a$
2	+1.24	$+ 0.0239\ T_a$
3	+1.417	
‘	- 3.154	
5	-1.200	
6	-8.729	
	-0.426	$+ 0.0474\ T_a$

Then the degree-day or temperature-index equation becomes, with T_a in °F:

$$\begin{aligned} SMELT &= DHM \diamond (T_a - T_b) \\ &= 0.0474\ T_a - 0.426 \quad \text{in./day} \\ &= 0.0474\ (T_a - 8.99) \quad \text{in./day} \\ &= 0.00198\ (T_a - 8.99) \quad \text{in./hr} \end{aligned}$$

The low value of T_b of about 9°F implies sufficient energy input (via solar radiation and condensation) to cause melt even at low temperatures. This is not really true, however, since the melt equation was linearized about a temperature of 35°F and should only be used in that range. The exercise serves to indicate the range of values that may be found when substituting actual meteorological data into the equations. Although seemingly wrong values may result, e.g., base melt temperatures less than zero, the equation with such values is still valid for the input parameters used and over the range of the linearization.

Appendix IV
Storage/Treatment Simulation

Objectives

The primary objectives of the Storage/Treatment Block are to:

1. provide the capability of modeling a larger number of processes in both the single event and continuous modes;
2. simulate the quality improvement provided by each process;
3. simulate the handling of sludges; and
4. provide estimates of capital, operation and maintenance costs.

Although the objectives of the Storage/Treatment Block have not changed appreciably from earlier versions (Metcalf and Eddy et al., 1971a), the model has been virtually rewritten. The earlier versions were more limited in use and scope. This version is much more flexible in terms of the control units available, pollutant routing and cost estimating. However, the user is advised that increased flexibility implies increased user input and knowledge of the processes to be modeled. In other words, the model does not provide several dozen specialized designs, but provides the tools necessary to simulate the desired processes. Naturally, flexibility precludes ultrasophistication.

Several precautions should be noted before setting up the S/T Block.

1. Local waste characterization data are essential to appraise realistically the performance of treatment units.
2. Lab or pilot plant performance data should be used whenever possible to derive performance functions.
3. Dry-weather treatment performance functions should be applied cautiously to wet-weather units.

Program Development and Overview

Development

Past versions of the Storage/Treatment Block simulated various processes on the basis of limited empirical data and operating experience. Often the data were localized and/or specialized. Thus, they were of questionable applicability to a wide variety of situations. Additionally, the model did not account for the physical characteristics of the incoming waste stream or the handling of residuals (sludges).

To improve the storage/treatment modeling capabilities of SWMM the following considerations were instrumental in creating a new model.

1. There should be a high degree of flexibility in the simulation of individual units and the interaction among units.

2. In addition to simulating the mass of pollutants, it is important to account for the physical characteristics (i.e., particle size and specific gravity distribution) of each pollutant.
3. Residual (sludge) handling is an important part of any wastewater treatment scheme and should be simulated.
4. All costing routines should be as flexible as the performance algorithms.
5. The model should be capable of modeling wet- and dry-weather facilities.

Overview

The present Storage/Treatment Block is approximately 2000 Fortran statements in length and consists of eight subroutines. The routing of flow and pollutants through the entire block is controlled by subroutine STRT which is called from the Executive Block. STRT also provides the main driving loop for the model and generally acts as the central coordinating subroutine. Subroutine STRDAT is called in STRT and is responsible for reading the input data provided by the user. Subroutine CONTRL is called each time-step from the main driving loop in STRT. CONTRL directs flow and pollutants from one unit to another as prescribed by the desired scheme and coordinates the majority of the printed output. Subroutine UNIT is called from CONTRL for each unit modeled and is the heart of the Storage/Treatment block. It contains the necessary flexibility and capability to model most storage/treatment processes (units). Subroutine EQUATE is used by UNIT to provide several forms of pollutant removal equations. Subroutine INTERP is employed by UNIT for linear interpolation. Subroutine PLUGS is used by UNIT to model perfect plug flow through a detention unit. Subroutine STCOST is called from STRT to determine capital and operation and maintenance costs.

The model has become user-intensive rather than program-intensive. The user is responsible for providing the program with the desired storage/treatment scheme and operating characteristics of each unit (along with other information). However, input guidelines are provided in the User's Manual for several types of units. Again, the strength of this approach is to maximize flexibility and applicability to local conditions and design criteria.

Simulation Techniques

Introduction

Flow and pollutants are routed through one or more storage/treatment units by several techniques. The flows into, through and out of a unit are shown in Figure IV-1. The units may be arranged in any fashion, restricted only by the requirements that inflow to the plant enters at only one unit and that the products (treated outflow, residuals, and bypass flow) from each unit not be directed to more than three units. Treatment and sludge handling units are modeled by the same subroutine (UNIT). Additionally, both wet- and dry-weather facilities may be simulated by the proper selection of unit arrangement and characteristics. Units may be modeled as having a detention capability or instantaneous throughflow. Pollutants or sludges may be represented as mass only or further characterized by a particle size or settling velocity distribution. A unit may remove pollutants (or concentrate sludges) as a function of particle size and specific gravity, detention time, incoming concentration, the removal rate of another pollutant, or a constant percentage. The S/T Block can receive the flow and any three pollutants from any <u>one</u> outlet in any other block of SWMM. Also, flows and pollutants may be provided by the user and fed directly to the S/T Block. If both sources are present they are combined and treated as one input. For example, the user may enter directly dry-weather flows and enter wet-weather flows from

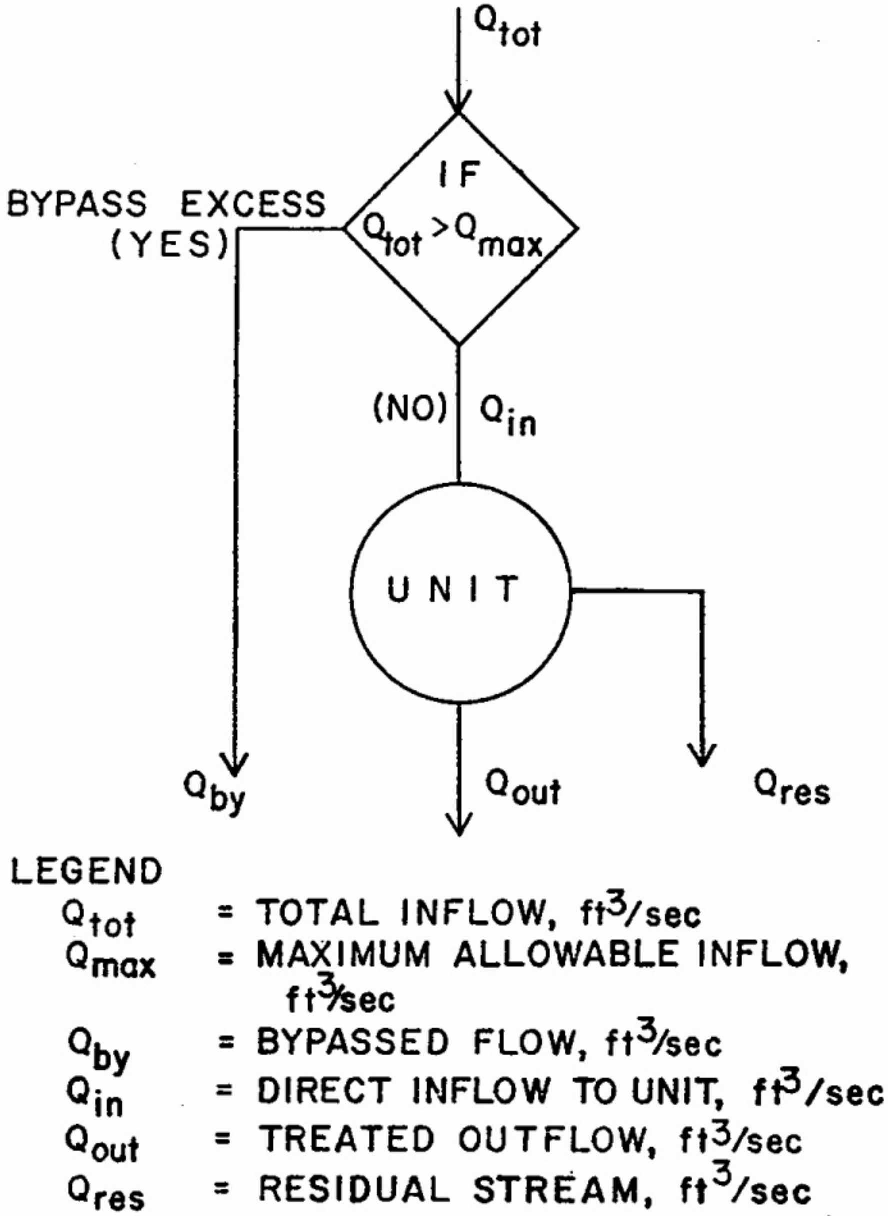

Figure IV-1. Flows into, through, and out of a storage/treatment unit.

the Runoff Block. All flows and pollutant concentrations reported by the S/T Block are average values over each time step. This is necessary for some of the algorithms in the S/T Block (in particular, the plug flow routines); it does not significantly affect the results.

The following sections describe the techniques available for flow and pollutant routing which allow the user to model several types of storage/treatment units.

Flow Routing

Detention vs. Instantaneous Throughflow

A unit may be modeled to handle flow in one of two ways; as a detention unit (reservoir) or a unit instantaneously passing all flow. The idea of a detention unit is not limited to storage basins and sedimentation tanks but also includes such processes as dissolved air flotation, activated sludge, and chlorination. Processes that may be modeled as having instantaneous throughflow include microscreens, fine screens and other forms of screening.

Detention Units

The rate of change of storage in a detention unit or reservoir is found by writing a mass balance equation for the system shown in Figure IV-2.

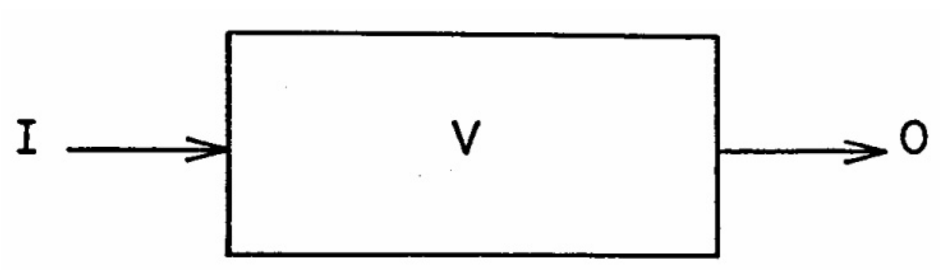

Figure IV-2. Time varying inflow and outflow rates for a reservoir.

The rate of change of storage equals inflow minus outflow, or

$$\Delta V / \Delta t = \bar{I} - \overline{O} \qquad \text{(IV-1)}$$

where

$\bar{I}$	=	average inflow rate during Δt, ft^3/sec,
$\overline{O}$	=	average outflow rate during Δt, ft^3/sec
V	=	reservoir volume, ft^3, and
Δt	=	time step, sec.

Let subscripts 1 and 2 denote the beginning and end of the time step, respectively. Then, the average inflow rate $\bar{I}$, is

$$\bar{I} = (I_1 + I_2)/2 \tag{IV-2}$$

The average outflow rate, $\overline{O}$, is

$$\overline{O} = (O_1 + O_2)/2 \tag{IV-3}$$

Also, the change in reservoir volume is

$$\Delta V = V_2 - V_1 \tag{IV-4}$$

Substituting equations IV-2, IV-3, and IV-4 into equation IV-1 and multiplying through by Δt yields the desired expression for the change in volume, i.e.,

$$V_2 - V_1 = \frac{I_1 + I_2}{2}\Delta t - \frac{O_1 + O_2}{2}\Delta t \tag{IV-5}$$

For a given time step, I_1, I_2, O_1, and V_1 are known and O_2 and V_2 need to be determined. Grouping the unknowns on the left hand side of the equation and rearranging yields one of two required equations:

$$0.5O_2\Delta t + V_2 = 0.5(I_1 + I_2)\Delta t + (V_1 - 0.5O_1\Delta t) \tag{IV-6}$$

The second required equation is found by relating O_2 and V_2, each of which is a function of reservoir depth. The procedure is illustrated in the following example.

Table IV-1 presents geometric and routing data for a hypothetical reservoir with a base elevation of 343.0 ft and a maximum pool elevation of 353.0 ft. The corresponding depths are shown in column 3. Surface area, as a function of depth, is presented in column 4. If the reservoir has an irregular geometry, the surface area is measured from a topographic map. The depth area data pairs shown in columns 3 and 4 of Table IV-1 are required input data. If the user desires, the depth-discharge relationship may be input directly by assigning values of O_2 to each depth or generated by a user-supplied depth-discharge equation (e.g., weir equation). Similarly, the user may specify the volume, V_2, associated with each depth or allow the model to calculate the depth-volume relationship. This is accomplished by averaging the surface area between adjacent values of depth, multiplying by the difference in depth, and adding the incremental volume to the accumulated total. The depth-area data pairs are also used to estimate the volume lost from the reservoir due to evaporation.

Recalling equation IV-6, the objective is to find

$$0.5O_2\Delta t = f(0.5O_2\Delta t + V_2). \tag{IV-7}$$

Table IV-1. Geometric and Hydraulic Data for Hypothetical Reservoir

n	Elevation h ft	Depth y ft	Surface Area A $1000\ ft^2$	Discharge O_2 ft^3/sec	Volume V_2 $1000\ ft^3$	O2DT2 $0.5O_2\Delta t$ $1000\ ft^3$	SATERM $0.5O_2\Delta t+V_2$ $1000\ ft^3$	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	343.0	0.0	0.	0.	0.	0.	0.	Base of reservoir
2	344.0	1.0	3.	0.	2.	0.	2.	
3	345.0	2.0	15.	0.	10.	0.	10.	
4	346.0	3.0	45.	0.	40.	0.	40.	
5	347.0	4.0	121.	0.	120.	0.	120.	
6	348.0	5.0	225.	0.	300.	0.	300.	
7	349.0	6.0	365.	0.	590.	0.	590.	
8	350.0	7.0	550.	0.	1050.	0.	1050.	
9	351.0	8.0	790.	0.	1720.	0.	1720.	Weir elevation
10	351.5	8.5	910.	30.	2140.	324.	2464.	
11	352.0	9.0	1080.	65.	2650.	702.	3352.	
12	352.2	9.2	1130.	80.	2900.	864.	3764.	
13	352.4	9.4	1190.	105.	3100.	1134.	4234.	
14	352.6	9.6	1270.	130.	3400.	1404.	4804.	
15	352.8	9.8	1350.	165.	3700.	1782.	5482.	
16	353.0	10.0	1440.	200.	3900.	2160.	6060.	Maximum pool

Column
- (1) Counter
- (2) Elevation from topographic map
- (3) Depth = h – 343.0
- (4) Measured from topographic map or may be calculated (by user) if geometry is regular
- (5) Measured data or calculated from discharge formulas
- (6) Measured data or calculated
- (7) Calculated from column 5, Δt = 21,600 sec.
- (8) Calculated from columns 6 and 7

The data in Table IV-1 give O_2 and V_2 as functions of depth. In this case, discharge or outflow occurs only if the reservoir depth exceeds 8.0 ft. The model uses these data to calculate the values of $0.5O_2\Delta t$ (column 7) and $0.50_2\Delta t + V_2$ (column 8) for each depth (defined in the model as O2DT2 and SATERM, respectively). Thus, the relationship required by equation IV-7 is indirectly generated. During the simulation, the value of $0.5O_2\Delta t + V_2$ is calculated by equation IV-6 and the corresponding value of $0.50_2\Delta t$ found by linear interpolation through the previously generated set of 02DT2 – SATERM values. The values O_2 and V_2 are subsequently calculated. This procedure is repeated each time step with the value of O_2 and V_2 becoming the values of O_1 and V_1 for use in equation IV-6 during the next time step. In a normal simulation the outflow, O_2, represents treated outflow, residual flow, and evaporation.

The computational procedure is summarized as follows:

1. Known values of I_1, I_2, O_1, Δt, and V_1 are substituted into the right hand side of equation IV-6. The result is the first value of $0.5O_2\Delta t + V_2$.
2. Knowing $(0.5O_2\Delta t + V_2)$ the value of $0.5O_2\Delta t$ is obtained by interpolating between adjacent values of 02DT2 and SATERM.
3. The values of V_2 and O_2 are determined and become the values of V_1 and O_1, respectively, in the next time step.
4. Add $0.5(I_1 + I_2)\Delta t$ to the new value of $V_1 - 0.5O_1\Delta t$ to get the new value of $0.5O_2\Delta t + V_2$.
5. Continue this process until all inflows have been routed.

To summarize the input alternatives, the earlier version of the storage model permitted the user to read in depth-area data and an outflow condition of a weir, orifice, or pumping. It could not handle the case of a natural reservoir with an irregular stage-discharge relationship. The updated model allows the user to input the required relationship between depth-surface area, treated outflow, residual flow, and storage volume through as many as 16 data sets. This approach permits the user to select the data points which best approximate the desired functional relationships. This approach is felt to be preferable to adding more complexity to the model to analyze automatically the wide variety of reservoir geometries and operating policies encountered in practice.

An excellent description of this level-surface routing procedure (the Puls Method) is presented in Viessman et al. (1977). Sound engineering judgement is essential in setting up this routing procedure. The input data and associated assumptions should be checked carefully.

Residual Flow

Residual flows occur only during dry periods (i.e., no inflow or treated outflow) and, thus, serve to drain the detention unit between storms. The user can direct the unit to be drained after a specified number of dry time steps or on a scheduled basis (every i^{th} time, depending on the inflow/outflow status). Residual flows are handled in the same manner as the outflow in the routing procedure outlined previously. These flows contain a mixture of the stored wastewater and removed pollutant quantities (see later discussion). The manner in which pollutants are removed and accumulated is discussed later. In detention units, the residual flow is suspended when wet weather occurs.

Evaporation

Evaporation losses are also accounted for in detention units. The loss rate is computed by

$$e_v = A \diamond e_d / k \quad \text{(IV-8)}$$

where

e_v	=	evaporation loss rate, ft^3/sec,
A	=	surface area at the water level in the unit, ft^2,
e_d	=	evaporation rate, in./day, and
k	=	1036800.0, conversion factor, in./day per ft/sec.

The user must supply the values of e_d for each month of the simulation period.

Instantaneous Throughflow

If the unit is specified to have no detention capability, then the model assumes that what arrives during a time step leaves as treated outflow that same time step less the residual flow. The residual flow is calculated as a constant fraction of the inflow.

Pollutant Routing

Complete Mixing

Pollutants are routed through a detention unit by one of two modes: complete mixing or plug flow. For complete mixing, the concentration of the pollutant in the unit is assumed to be equal to the effluent concentration. The mass balance equation for the assumed well-mixed, variable-volume reservoir shown in Figure IV-3 is (Medina, 1976):

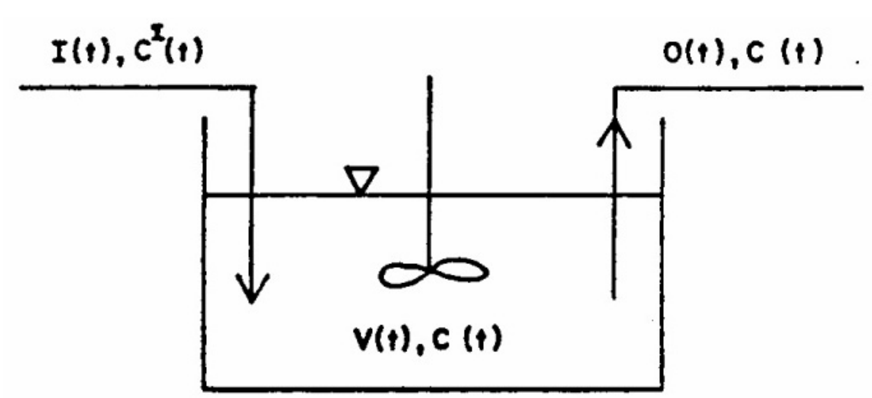

Figure IV-3. Well mixed, variable-volume reservoir (Rich, 1973).

$$\frac{d(VC)}{dt} = I(t)C^I(t) - O(t)C(t) - K\,C(t)V(t) \qquad \text{(IV-9)}$$

where

V	=	reservoir volume, ft^3
C^I	=	influent pollutant concentration, mg/l
C	=	effluent and reservoir pollutant concentration, mg/l
I	=	inflow rate, ft^3/sec
O	=	outflow rate, ft^3/sec
t	=	time, sec, and
K	=	decay coefficient, sec^{-1}.

Equation IV-9 is very difficult to work with directly. It may be approximated by writing the mass balance equation for the pollutant over the interval, Δt:

$$\begin{matrix}\text{Change in mass in basin during } \Delta t\end{matrix} = \text{Mass entering during } \Delta t - \text{Mass leaving during } \Delta t - \text{Decay during } \Delta t$$

$$C_2V_2 - C_1V_1 = \frac{C_1^I I_1 + C_2^I I_2}{2}\Delta t - \frac{C_1O_1 + C_2O_2}{2}\Delta t - K\frac{C_1V_1 + C_2V_2}{2}\Delta t \qquad \text{(IV-10)}$$

where subscripts 1 and 2 refer to the beginning and end of the time step, respectively.

From the flow routing procedure discussed earlier, I_1, I_2, O_1, O_2, V_1, and V_2 are known. The concentration in the reservoir at the beginning of the time step, C_1, and the influent concentrations, C_1^I and C_2^I, are also known as are the decay rate, K, and the time step, Δt. Thus, the only unknown, the end of time step concentration, C_2, can be found by rearranging equation IV-10 to yield

$$C_2 = \frac{C_1V_1 + \frac{(C_1^I I_1 + C_2^I I_2)}{2}\Delta t - \frac{C_1O_1}{2}\Delta t - \frac{K\,C_1V_1}{2}\Delta t}{V_2\left(1 + \frac{K\,\Delta t}{2}\right) + \frac{O_2}{2}\Delta t} \qquad \text{(IV-11)}$$

Equation IV-11 is the basis for the complete mixing model of pollutant routing through a detention unit.

Equations IV-9, IV-10, and IV-11 assume that pollutants are removed at a rate proportional to the concentration present in the unit. In other words, a first-order reaction is assumed. The coefficient K is the rate constant. The product of K and Δt is represented by the value of R in a user-supplied removal equation. (See Equation IV-14 and accompanying discussion).

Removed pollutant quantities are not allowed to accumulate in a completely-mixed detention unit. Strictly, pollutants cannot settle under such conditions. Therefore, the residual stream is effectively another route for treated outflow. All pollutant removal is assumed to occur by non-physical means (e.g., biological decomposition). Several processes such as flocculation and rapid-mix chlorination are essentially completely-mixed detention units.

Plug Flow

If the user selects the plug flow option, the inflow during each time step, herein called a plug, is labeled and queued through the detention unit. Transfer of pollutants between plugs is not permitted. The outflow for any time step is comprised of the oldest plugs, and/or fractions thereof, present in the unit. This is accomplished by satisfying continuity for the present outflow volume (which was calculated earlier):

$$\sum_{j=JP}^{LP} V_j \cdot f_j = V_o \qquad \text{(IV-12)}$$

where

V_o	=	volume leaving unit during the present time step, ft^3,
V_j	=	volume entering unit during j^{th} time step (plug j), ft^3,
f_j	=	fraction of plug j that must be removed to satisfy continuity with V_o, $0 \le f_j \le 1$,
JP	=	time step number of the oldest plug in the unit, and
LP	=	time step number of the youngest plug required to satisfy continuity with V_o.

As in a completely-mixed detention unit, detention time is the most important indicator of pollutant removal ability. Removal equations are specified by the user (see later discussion) and, in this case, should be written as a function of detention time (along with other possible parameters). The detention time for each plug j is calculated as

$$(t_d)_j = (KKDT - j)\Delta t \qquad \text{(IV-13)}$$

where KKDT = present time step number. The detention time is calculated in the same manner during dry- and wet-weather periods because the plugs always maintain their identity.

Removed pollutant quantities accumulate in a plug-flow unit until they are drawn off by residual flow. The accumulated pollutants do not affect the amount of available storage and are assumed to be conservative (i.e., no decay). When residual flow occurs the entire unit contents (including the removed pollutant quantities) are mixed and drawn off until the unit is empty or wet weather continues. If wet weather (i.e., inflow) occurs before the unit is empty, the contents are placed into one plug for further routing.

Instantaneous Throughflow

Pollutants are routed instantaneously through units modeled as having no detention capability. In other words, the pollutants arriving during a time step leave the same time step less the removed portion. The amount of removed pollutants is determined by user-supplied removal equations (see later discussion). The removed pollutants are routed with the residuals stream.

Pollutant Characterization

Pollutants are characterized by their magnitude (i.e., mass flow and concentration) and, if the user desires, by particle size/specific gravity or settling velocity distributions. Describing pollutants by their particle size distribution is especially appropriate where small or large particles dominate or where several storage/treatment units are operated in series. For example, if the influent is primarily sand and grit, then a sedimentation unit would be very effective; if clay and silt predominate, sedimentation may be of little use. Also, if several units are operated in series, the first units will remove a certain range of particle sizes thus affecting the performance of downstream units. Therefore, the need for describing pollutants in more detail is obvious for modeling purposes. The pollutant removal mechanism peculiar to each characterization is discussed below.

Pollutant Removal

Characterization by Magnitude

If pollutants are characterized only by their magnitude then the model improves the quality of the waste stream by removal equations. Removal of a pollutant may be simulated as a function of (1) detention time (detention units only), (2) time step size, (3) its influent concentration, (4) inflow rate, (5) the removal fractions of pollutants, and/or (6) the influent concentrations of other pollutants. This selection is left to the user but there are some restrictions (depending on the unit type). A single flexible equation is provided by the program to construct the desired removal equation:

$$R = \left(a_{12}e^{a_1x_1}x_2^{a_2} + a_{13}e^{a_3x_3}x_4^{a_4} + a_{14}e^{a_5x_5}x_6^{a_6} + a_{15}e^{(a_7x_7+a_8x_8)}x_9^{a_9}x_{10}^{a_{10}}x_{11}^{a_{11}}\right)^{a_{16}} \qquad \text{(IV-14)}$$

where

x_i = removal equation variables
a_j = coefficients, and
R = removal fraction, $0 \le R \le 1.0$

The user assigns the removal equation variables, x_i, to specific program variables (detention time, flow rate, etc.). If an equation variable is not assigned it is set equal to 1.0 for the duration of the simulation. The values of the coefficients, a_j, are directly specified by the users. There is considerable flexibility contained in equation IV-14 and, with a judicious selection of coefficients and assignment of variables, the user probably can create the desired equation. Three examples are given below.

An earlier version of the Storage/Treatment block employed the following removal equation for suspended solids in a sedimentation tank (Huber et al., 1975):

$$R_{SS} = R_{max}\left(1 - e^{-Kt_d}\right) \qquad \text{(IV-15)}$$

where

R_{SS} = suspended solids removal fraction, $0 \le R_{SS} \le R_{max}$,
R_{max} = maximum removal fraction,

t_d	=	detention time, sec, and
K	=	first order decay coefficient, sec^{-1}.

This same equation could be built from equation IV-14 by setting $a_{12} = R_{max}$, $a_{13} = -R_{max}$, $a_3 = -K$, $a_{16} = 1.0$, and letting x_3 = detention time, t_d. All other coefficients, a_j, would equal zero.

Another example is taken from a study by Lager et al. (1977a). Several curves for suspended solids removal from microstrainers with a variety of aperture sizes were derived. Fitting a power function to the curve representing a 35-micron microstrainer yields

$$R_{SS} = 0.0963\ SS^{0.286} \tag{IV-16}$$

where

R_{SS}	=	suspended solids removal fraction, and $0 \leq R_{SS} \leq 1.0$, and,
SS	=	influent suspended solids concentration, mg/l.

Equation IV-14 can be used to duplicate this removal equation by setting $a_{12} = 0.0963$, $a_2 = 0.286$, $a_{16} = 1.0$, and x_2 = influent suspended solids concentration, SS. All other a_j are zero.

Sludge handling may also be modeled with equation IV-14. Figure IV-4 shows the reduction in volatile solids in raw sludge (suspended solids – see earlier discussion) by a digester as a function of percent volatile solids and detention time (Rich, 1973). These curves can be approximated by

$$R_{VS} = 1.31 \times 10^{-4} \left(\frac{t_d}{86400} \right)^{0.33} P_{VS}^{1.67} \tag{IV-17}$$

where

R_{VS}	=	volatile solids reduction, $0 \leq R_{VS} \leq 1.0$
t_d	=	detention time, sec,
P_{VS}	=	percent volatile solids in raw sludge,

$$P_{VS} = 100 \frac{VS}{SS} \tag{IV-18}$$

where

VS	=	influent volatile solids concentration, mg/l, and
SS	=	influent suspended solids (raw sludge) concentration, mg/l.

Equation IV-14 can be used to construction equation IV-17 by setting $a_{15} = (1.31 \times 10^{-4}) (1440)^{-0.33} (100)^{1.67}$, $a_9 = 0.33$, $a_{10} = 1.67$, $a_{11} = -1.67$, $a_{16} = 1.0$, x_9 = detention time, t_d, x_{10} = influent volatile solids concentration, VS, and x_{11} = influent suspended solids (raw sludge) concentration, SS. A current description of sludge handling can be found in several references (Gupta et al., 1977; Huibregtse, 1977; Osantowski et al., 1977).

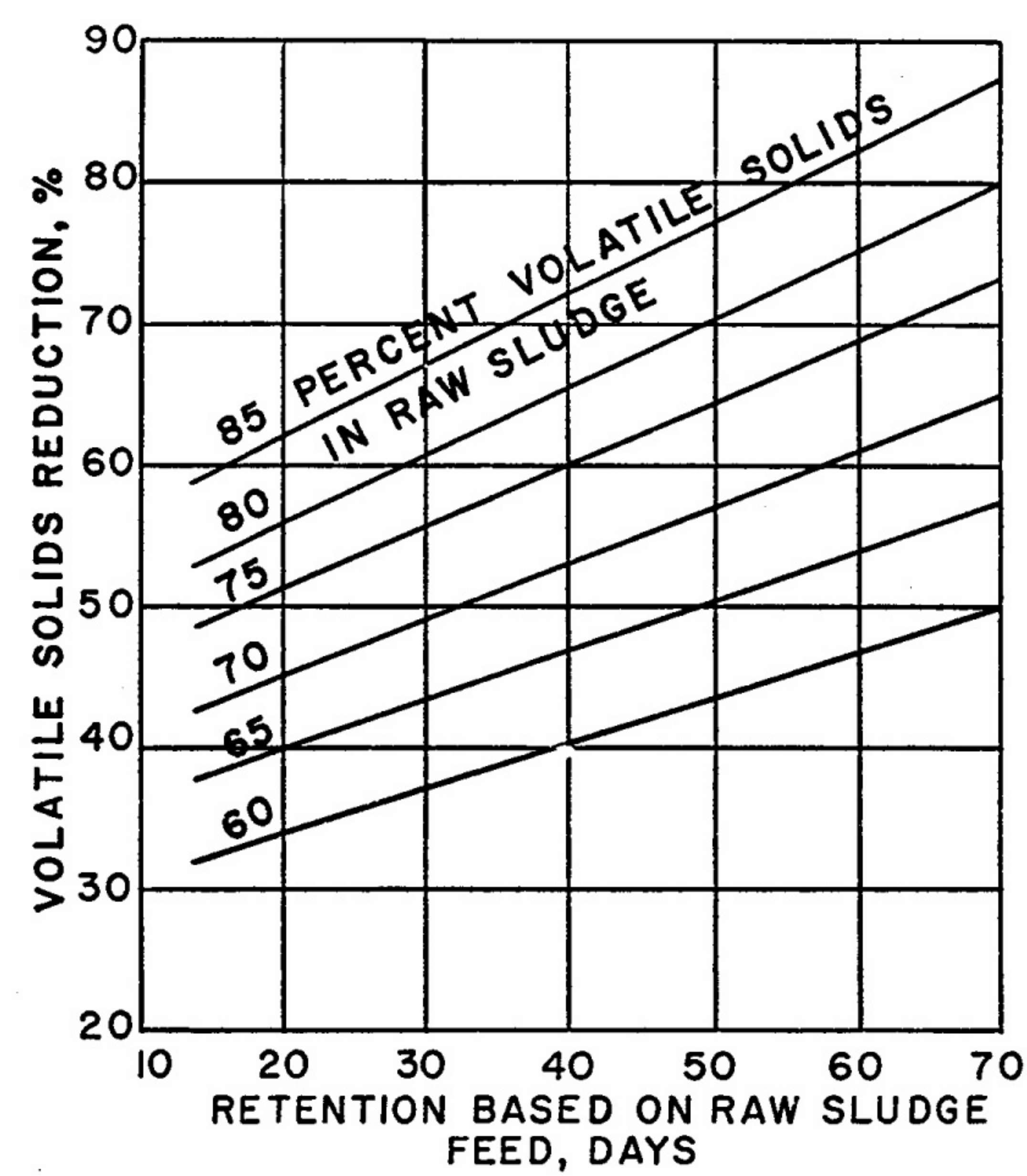

Figure IV-4. Reduction in volatile solids in raw sludge (Rich, 1973).

Characterized by Particle Size/Specific Gravity or Settling Velocity Distribution

Particle Sizes and Specific Gravities. If a pollutant is characterized by its particle size/specific gravity or settling velocity distribution, then it is removed from the waste stream by particle settling or obstruction. Many storage/treatment processes use these physical methods to treat wastewater; sedimentation and screening are among the most obvious examples.

In this mode, the pollutant is apportioned over several (up to 10) particle size/specific gravity ranges (e.g., ten percent of the BOD is found in the range from 10 to 50 microns) or settling velocities. Each of the ranges is preset by the user and assigned an upper and lower bound on the particle diameter and a value for specific gravity. If a size/specific gravity distribution is specified the model estimates the average settling velocity for each range. Alternatively, the user may specify a set of settling velocity ranges. The user also specifies the apportionment of the pollutant over the various ranges as it enters the first unit. This distribution is modified as it passes through the storage/treatment plant. Unfortunately, the distribution entered at the first unit must remain constant over time since the other blocks of SWMM do not provide a time-varying particle size or settling velocity distribution.

Each unit removes all or some portion of the particles in each range or velocity; the associated removal of the pollutant is easily determined. For example, if a sedimentation unit removes 50 percent of the particles in the 50 to 100 micron range and ten percent of the pollutant in question is found in this range, then five percent of the total pollutant load is removed. The total removal is determined by summing the effects of the several ranges or settling velocities passing through this unit. Once certain particles are removed, the distribution of particle sizes or settling velocities for the outflow can be determined and passed on to the next unit or receiving water. The removed particles constitute the size or settling velocity distribution for the sludge volume. The next several paragraphs describe the two mechanisms available to the user for pollutant removal when a pollutant is characterized by particle size or settling velocity.

Particle Settling. There are several forms of settling: unhindered settling by discrete particles, settling by flocculating particles, and hindered settling by closely spaced particles (Fair et al., 1968). For simplicity, the unhindered settling of discrete particles will be the removal mechanism simulated in this model. This procedure is <u>only</u> applicable to detention basins modeled as plug-flow reactors.

Discrete particles settling in a quiescent fluid accelerate to the point where the drag force exerted by the suspending fluid reaches equilibrium with the gravitational force exerted on the particle (Fair et al., 1968). At this point, the particle settles at a constant velocity known as the terminal velocity. By equating the forces acting on such a particle, the equation for the terminal or settling velocity of the particle is derived and approximated by

$$v_s = \sqrt{\frac{4}{3}\frac{gd}{C_D}\left(S_p - 1\right)} \qquad \text{(IV-19)}$$

where

v_s	=	terminal velocity of particle, ft/sec,
g	=	gravitational constant, 32 ft/sec^2,
C_D	=	drag coefficient,

S_p	=	specific gravity of particle, and
d	=	diameter of particle, ft.

Additionally,

$$C_D = \frac{24}{N_R}\text{, if } N_R < 0.5\text{, or} \qquad \text{(IV-20)}$$

$$C_D = \frac{24}{N_R} + \frac{3}{\sqrt{N_R}} + 0.34\text{, if } 0.5 \leq N_R < 10^4\text{, or} \qquad \text{(IV-21)}$$

$$C_D \cong 0.4\text{, if } N_R \geq 10^4. \qquad \text{(IV-22)}$$

where N_R = Reynolds number, dimensionless,

$$N_R = v_s\, d/\nu \qquad \text{(IV-23)}$$

and ν = kinematic viscosity, ft^2/sec. Kinematic viscosity is a function of temperature and is approximated by (Fair et al., 1969)

$$\nu \cong 8.46 \times 10^{-4} / (T + 10) \qquad \text{(IV-24)}$$

where T = water temperature, °F.

The procedure for finding v_s under any of the above conditions is demonstrated by Sonnen (1977). The average of the high and low ends of each particle size range is used as the representative particle size for use in the above calculations. If a settling velocity distribution is provided by the user these calculations are omitted.

A range of conditions may exist in an actual detention unit, from very quiescent to highly turbulent and nonquiescent. Camp's (1946) ideal removal efficiency, E_Q, will be used for quiescent conditions and an adaptation of his sedimentation trap efficiency curves (Camp, 1946; Dobbins, 1944; Brown, 1950) as described by Chen (1975) will be used to make the extension to nonquiescent conditions, as described below.

For quiescent conditions,

$$E_Q = \min\begin{cases} 1 \\ v_s/v_u \end{cases} \qquad \text{(IV-25)}$$

where

E_Q	=	particle removal efficiency as a fraction, $0 \oslash E_Q \oslash 1$,
v_s	=	terminal velocity of particle, ft/sec, and
v_u	=	overflow velocity, ft/sec.

Additionally,

$$v_u = Q/A = \frac{Ay/t_d}{A} = y/t_d \qquad \text{(IV-26)}$$

where

Q = flow rate, ft^3/sec,
A = surface area of detention unit, ft^2,
y = depth of water in unit, ft, and
t_d = detention time, sec.

Equation IV-26 assumes a rectangular detention unit with vertical sides. However, a circular unit (with vertical sides) may also be modeled when characterizing pollutants by particle size. In other words, equation IV-26 is restricted to units that allow the surface area to remain constant at any depth. Applying this equation (and, thus, the entire methodology) to other unit types should only be done when the surface area is independent of depth.

Equation IV-25 represents an ideal quiescent basin in which all particles with settling velocities greater than v_u will be removed. Deviations from quiescent conditions can be handled explicitly based on Camp's (1946) sedimentation trap efficiency curves, which were developed as a complex function of particle settling velocity, and several basin parameters, i.e.,

$$E = f\left(\frac{v_s y}{2\varepsilon}, \frac{v_s A}{Q} = \frac{v_s \ell}{v_t y} = \frac{v_s}{v_u}\right) \qquad \text{(IV-27)}$$

where

E = particle removal efficiency, $0 \le E \le 1$,
ε = vertical turbulent diffusivity or mixing coefficient, ft^2/sec,
v_t = flow through velocity of detention unit, ft/sec
ℓ = travel length of detention unit, ft, and
other terms are defined previously.

Camp (1946) solves for the functional form of equation IV-27 assuming a uniform horizontal velocity distribution and constant diffusivity, ε. A form of the advective-diffusion equation then results in which local changes in concentration at any vertical elevation are equal to the net effect of settling from above and diffusion from below. The diffusivity will be constant if the horizontal velocity is assumed to have a parabolic distribution (although this assumption is clearly at variance with the uniform velocity distribution assumption above). For the parabolic distribution, ε is then found from

$$\varepsilon = 0.075\, y \sqrt{\tau_o/\rho} \qquad \text{(IV-28)}$$

where

τ_o = boundary shear stress, lb/ft^2, and
ρ = density of water ≅ 1.94 slug/ft^3 (1.00 g/cm^3).

The term $\sqrt{\tau_o/\rho}$ is known as the shear velocity, u_*, and can be evaluated using Manning's equation for open channel flow (Brown, 1950),

$$u_* = \sqrt{\tau_o/\rho} = \frac{v_t n \sqrt{g}}{1.49\, y^{1/6}} \qquad \text{(IV-29)}$$

where n = Manning's roughness coefficient.

The flow through ("horizontal") velocity, v_t, is also given by

v_t = □/t_d
(IV-30)

where

□ = travel distance of detention unit, ft, and
t_d = detention time, sec.

Equations IV-27 and IV-28 are then used to convert $v_s y/2\varepsilon$ to a more usable form,

$$\alpha = 0.1\frac{v_s y}{2\varepsilon} = \frac{v_s}{1.5u_*} = \frac{v_s y^{1/6}}{v_t\, n\sqrt{g}} \qquad \text{(IV-31)}$$

where α = turbulence factor, dimensionless when all parameters are in units of feet and seconds.

Camp's sedimentation trap efficiency curves (Camp, 1946; Dobbins, 1944; Brown, 1950; Chen, 1975) are the solution to the advective-diffusion equation mentioned previously and are shown in Figure IV-5 as a function of α. Ideally, these curves could be included in the model in some manner, but their representation is not straightforward from a programming standpoint. Instead, a simplification is used, based on early work of Hazen (1904) and the Bureau of Reclamation as described by Chen (1975).

It is assumed that an upper limit on turbulent conditions is given by α = 0.01. Removal efficiency under these conditions is accurately represented by the function (fitted to the ordinate of Figure IV-5),

$$E_T = \left(1 - e^{-v_s/v_u}\right) \qquad \text{(IV-32)}$$

or

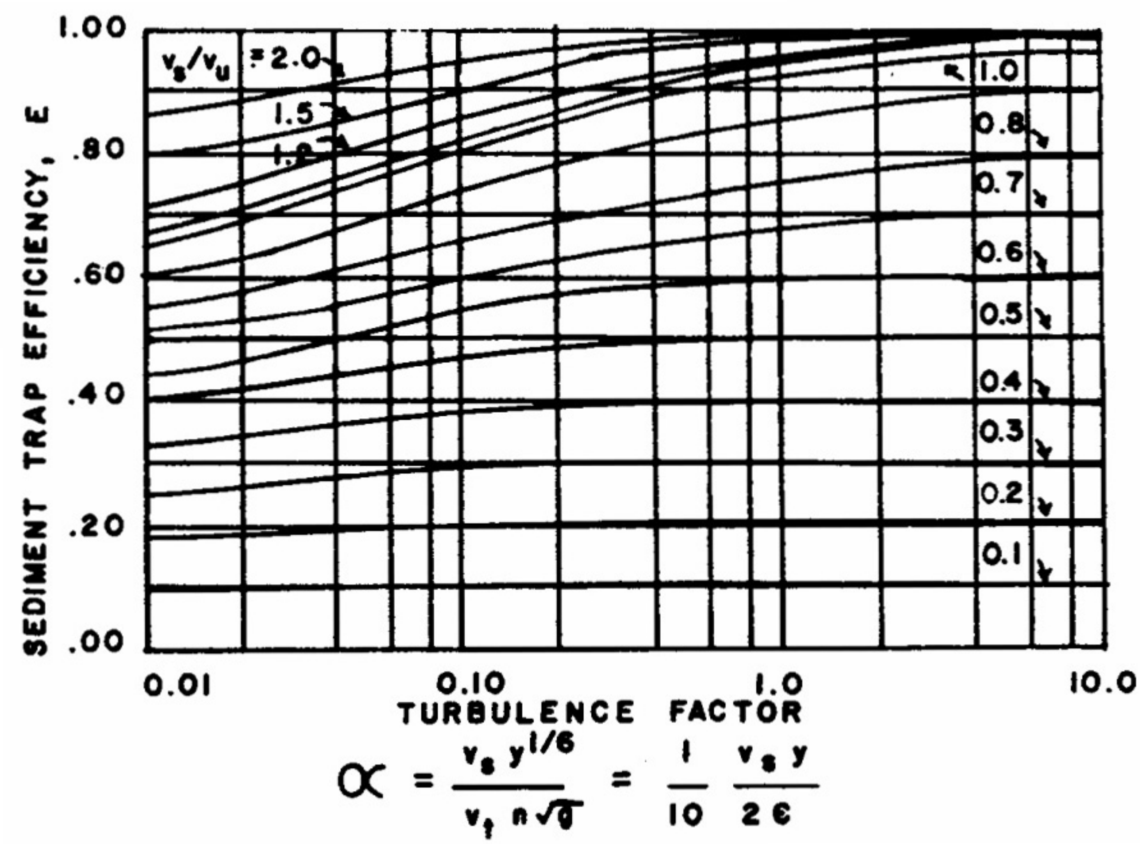

Figure IV-5. Camp's sediment trap efficiency curves (Camp, 1946; Dobbins, 1944; Brown, 1950; Chen, 1975).

$$E_T = \left(1 - e^{-v_s t_d / y}\right) \qquad \text{(IV-33)}$$

where E_T = particle removal efficiency under turbulent conditions, $0 \le E_T \le 1$.

Quiescent conditions are assumed to exist for α = 1.0 for which removal is given by equation IV-25. Equations IV-25 and IV-32 are shown in Figure IV-6. The parameter α may now be used as a weighting factor to obtain the overall removal efficiency, E,

$$E = E_T + \frac{\ln\alpha - \ln 0.01}{\ln 1 - \ln 0.01}\left(E_Q - E_T\right) = E_Q + \frac{\ln\alpha}{4.605}\left(E_Q - E_T\right) \qquad \text{(IV-34)}$$

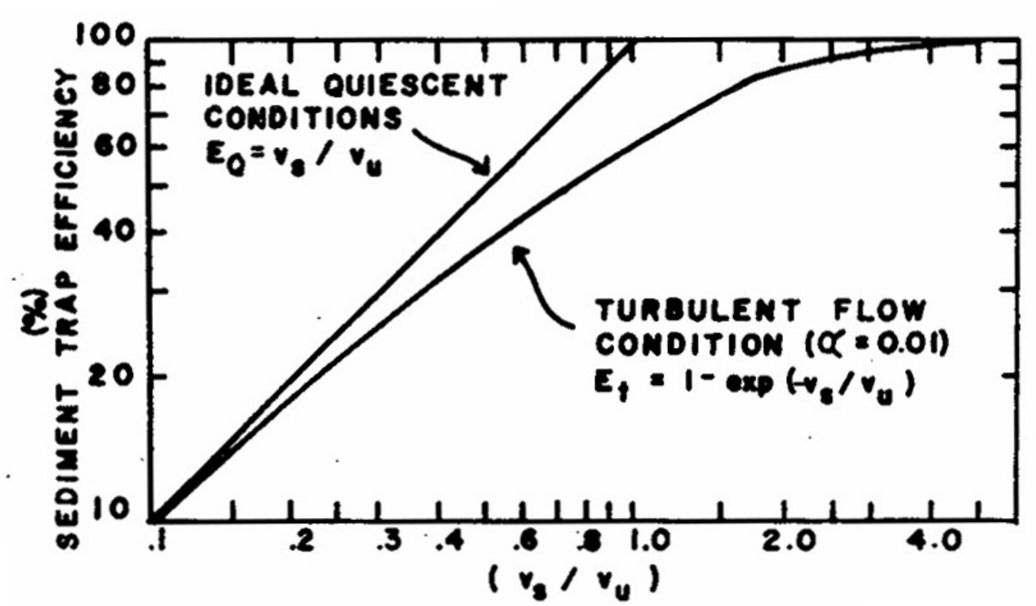

Figure IV-6. Limiting cases in sediment trap efficiency (Chen, 1975).

Thus, a linear approximation (with respect to ln α) is made of the curves shown in Figure IV-5. Within the program, values of the turbulence factor are limited to $0.01 \leq \alpha \leq 1.0$. If a value computed from equation IV-31 is less than 0.01 it is set equal to 0.01 and similarly for the quiescent boundary.

To summarize, the particle settling computations proceed as follows.

1. For each size and specific gravity range a settling velocity is computed using equations IV-19 to IV-24 or a distribution of settling velocities is provided by the user. If a settling velocity distribution is used the end points of each range are averaged to estimate the representative velocity. Then for each velocity (in each plug leaving the unit) all steps below are performed.
2. The turbulence factor, α, is computed from equation IV-31.
3. E_Q is computed using equation IV-25.
4. E_T is computed using equation IV-32 or IV-33.
5. Finally, the removal efficiency for the particular particle settling velocity is computed from equation IV-34.

In a normal simulation, several plugs leave the detention unit in any given time step. The effluent is all or part of a number of plugs depending on the required outflow as determined by the storage routing techniques discussed earlier. Thus, the effluent particle size or settling velocity distribution is a composite of several plugs. This composite distribution is determined by taking a weighted average (by pollutant weight in each plug) over the effluent plugs. This distribution is then routed downstream for release or further treatment. The particles that were removed from each plug are also composited and are used to characterize the sludge volume.

Paricle Obstruction. The second removal mechanism used when a pollutant is characterized by a particle size or settling velocity distribution is obstruction. The most obvious example of a storage/treatment process using this mechanism is screening. This mechanism is assumed by the model whenever a non-detention unit is encountered (and a pollutant is characterized by a size or settling velocity distribution). The user simply specifies a “critical” size or settling velocity and any particles with a greater size or settling velocity are removed (and, in turn, so are the associated pollutants). The program operation is simple but the interpretation of the “critical” size or settling velocity is more complex.

The primary intent of including this mechanism in the model is to simulate screens. Pollutant removal by screens is a result of two actions: the straining of the screens, and the additional filtration provided by the mat produced by the initial screening (Maher, 1974). Screens vary widely in the size of the aperture and the manner in which the waste water flows through them. To simplify the analysis, the removal of particles may be assumed to be a function of screen size only; i.e., the filtration by the mat is ignored. In other words, a particular screen size will remove only those particles larger than that size. If a settling velocity distribution is employed, the user must specify a settling velocity. This is not entirely accurate, of course, but the result is a conservative removal estimate that may be accurate in cases where backwashing is at a relatively high rate. In fact, a study by Maher indicates that this simplifying assumption is reasonable (Maher, 1974). In this case, a microstrainer with a Mark “0” screen (aperture of 23 microns) was installed in a residential area of Philadelphia, Pennsylvania. The analysis of the backwash material for two storms (one in which a coagulant was used) revealed that, by particle count, 88 to 96 percent of the particles were indeed smaller than 23 microns. However, by weight, over 99 percent of the material was found in particles greater than 23 microns. Although Maher did not report the distribution in terms of weight, it was a simple matter to convert by assuming a specific gravity.

During the simulation, a screen alters a particle size distribution for a particular time step without detention time. Again, only the particles larger than a specified or “critical” size are removed. The specific size may or may not correspond to the screen aperture, but such an assumption is probably valid given the preceding discussion. If the specified size falls between the high and low ends of any range, the pollutants are removed by simple linear interpolation. For example, if 20 percent of the suspended solids are found in the range from 10 to 50 microns and the “critical” size is 20 microns, then 75 percent of the suspended solids in that range will be removed or 15 percent of the total suspended solids load. Of course, if the entire range is larger than the specified size, then all pollutants in that range are removed. If a pollutant is characterized by a settling velocity distribution (in lieu of a size distribution) the user specifies a “critical” settling velocity. The portion associated with velocities greater than or equal to the “critical” value is removed.

Comment on Characterization by Particle Size Distribution. Pollutants characterized by a particle size or settling velocity distribution are restricted by the model to the two removal mechanisms discussed above. This limits the user somewhat if this characterization is chosen. The types of units that could be considered in this case would include sedimentation tanks and storage basins (operating as plug-flow reactors), bar racks, fine screens and microscreens. However, these units probably represent a large portion of the processes applied to the problem of combined sewer overflow and stormwater runoff. Thus, the limits of the applicability of the model using this model are probably not too severe.

Cost Calculations

Initial capital and operation and maintenance costs are calculated at the end of a simulation. These costs are computed using only the information processed for the simulation period. In other words, no attempt is made to derive costs for particular time intervals (e.g., annual). It is left for the user to interpret the results produced by the subroutine STCOST.

The capital cost for each unit is computed as a function of a design flow or volume specified by the user or is calculated by the model as a function of the maximum value recorded during the simulation.

$$C_{cap} = a\,Q_{max}^{b} \tag{IV-35}$$

or

$$C_{cap} = a\left(Q_{in}\right)_{max}^{b} \tag{IV-36}$$

or

$$C_{cap} = a\,V_{max}^{b} \tag{IV-37}$$

or

$$C_{cap} = a\left(V_{obs}\right)_{max}^{b} \tag{IV-38}$$

where

C_{cap}	=	initial capital cost, dollars
Q_{max}	=	maximum allowable inflow, ft^3/sec,
$(Q_{in})_{max}$	=	maximum inflow encountered during the simulation, ft^3/sec,
V_{max}	=	maximum allowable storage (detention units only), ft^3
$(V_{obs})_{max}$	=	maximum storage encountered during the simulation (detention units only), ft^3, and
a, b	=	coefficients (specified by the user)

Power functions are frequently used in wastewater treatment cost estimations. Therefore, the above equations should be widely applicable.

Operation and maintenance costs are calculated as functions of the variables listed above and the total operating time (calculated as the number of time steps with inflow to the unit).

$$C_{om} = d\,Q_{max}^{f} + hD_{op} \tag{IV-39}$$

or

$$C_{om} = d\left(Q_{in}\right)_{max}^{f} + hD_{op} \tag{IV-40}$$

or

$$C_{om} = d\,V_{max}^{f} + hD_{op} \qquad \text{(IV-41)}$$

or

$$C_{om} = d\left(V_{obs}\right)_{max}^{f} + hD_{op} \qquad \text{(IV-42)}$$

where

C_{om} = operation and maintenance costs, dollars,
D_{op} = total operating time during the simulation period, hours, and
d, f, h = coefficients (supplied by the user).

The user is cautioned not to misinterpret the cost calculated by the model. For example, in a single event simulation the calculated capital cost could only be considered an estimator of the true capital cost when the even simulated is a design event. Likewise, when operating time is a factor in computing operating and maintenance costs, the calculated costs can be a valid estimator of the true costs only when a long term simulation is performed. Recent EPA publications provide useful information for the proper selection of the coefficients required in equations IV-35 through IV-42 (EPA, 1976; Bejes, 1976).

Summary

A new Storage/Treatment Block has been developed that is somewhat different from its predecessor. The model requires greater user input and knowledge of the processes being modeled. Storage/Treatment units may be modeled as detention or non-detention units. Pollutants may be characterized by their magnitude alone or by magnitude and their particle size/specific gravity distribution. Any three of the pollutants available from other blocks may be routed through the S/T Block. A simple cost routine is also included.

In summary, the Storage/Treatment Block offers the user a flexible tool for modeling wet- and dry-weather facilities and evaluating their performance and costs.