may be gleaned, somewhat less directly, from references on loading functions that include McElroy et al. (1976), Heaney et al. (1977) and Huber et al. (1981a).

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

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

Buildup Formulations

Most data, as will be seen, imply linear buildup since they are given in units such as lb/ac-day or lb/100 ft curb-day. As stated earlier, the Chicago data that were used in the original SWMM formulation assumed a linear buildup. However, there is ample evidence that buildup can be nonlinear; Sartor and Boyd’s (1972) data are most often cited as examples (Figure 4-27). More recent data from Pitt (Figure 4-28) for San Jose indicate almost linear accumulation, although some of the best fit lines indicated in the figure had very poor correlation coefficients, ranging from 0.35 ⦸ r ⦸ 0.9. Even in data collected as carefully as in the San Jose study, the scatter (not shown in the report) is considerable. Thus, the choice of the best functional form is not obvious. Whipple et al. (1977) have criticized the linear buildup formulation included in the original SWMM, although it is somewhat irrelevant since the user may insert his/her own desired initial loads, calculated by whatever procedure desired, in data group L1. However, this is a useful option only for single-event simulation.

The proper choice of the proper functional form must ultimately be the responsibility of the user. The program provides three options for dust and dirt buildup (Table 4-16) and three for individual constituents (Table 4-17), namely:

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

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

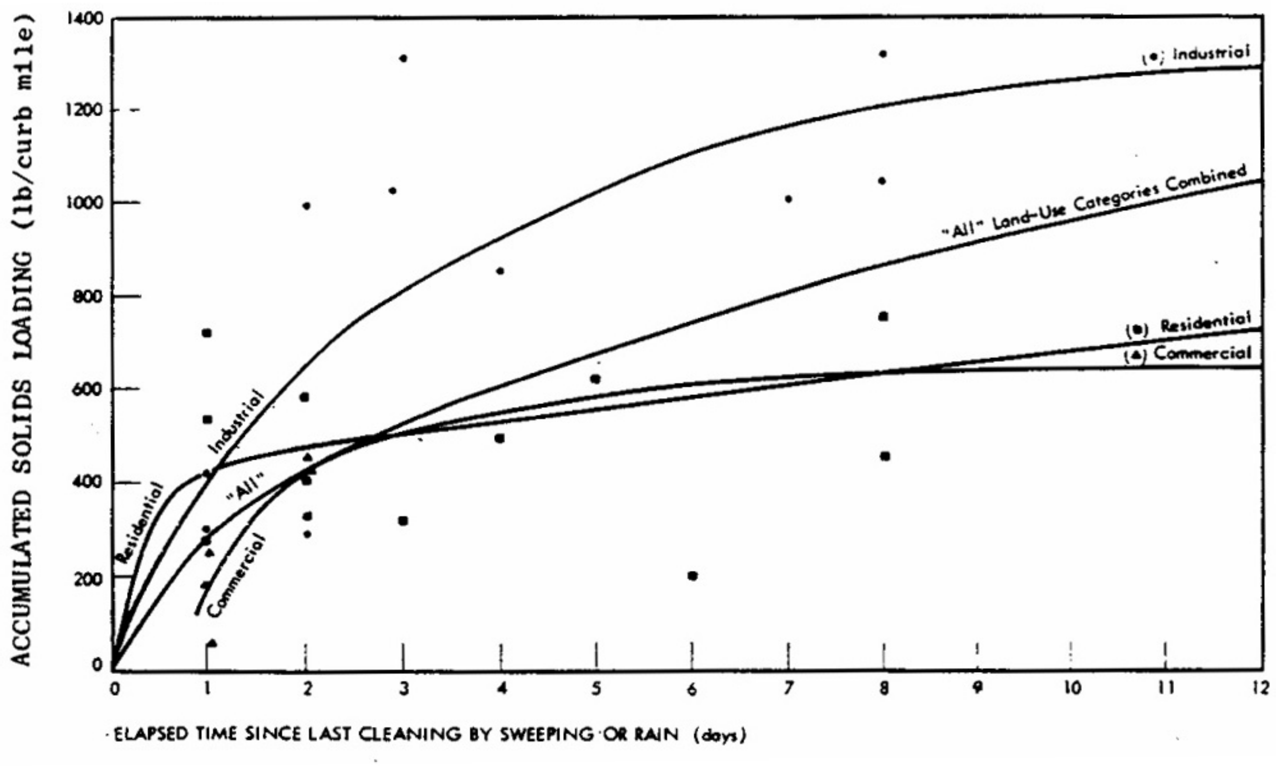

Figure 4-27. Nonlinear buildup of street solids (after Sartor and Boyd, 1972, p. 206).

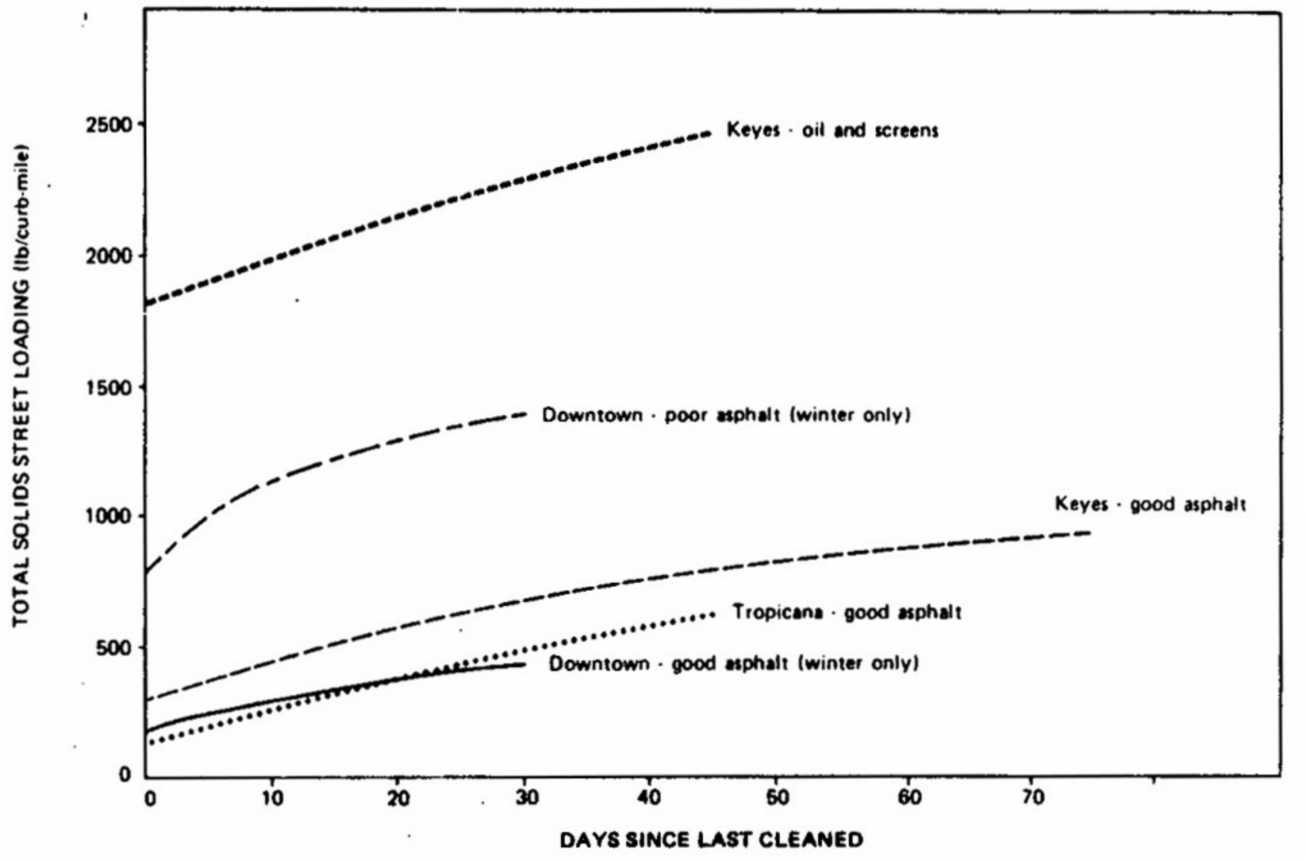

Figure 4-28. Buildup of street solids in San Jose (after Pitt, 1979, p. 29).

Table 4-16. Buildup Equations and Units for Dust and Dirt

Enter parameters on Card Group J2.
DD = Dust and Dirt, lb.   t = time, days.

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

Units for Card Input of:

Method	JACGUT	DDLIM	DDPOW	DDFACT
0	0	lb ⟐ (100 ft curb)$^{-1}$	Dimensionless	lb ⟐ (100 ft-curb)$^{-1}$ ⟐ day^{-DDPOW}
	1	lb ⟐ ac^{-1}	Dimensionless	lb ⟐ ac^{-1} ⟐ day^{-DDPOW}
	2	lb	Dimensionless	lb ⟐ day^{-DDPOW}
1	0	lb ⟐ (100 ft curb)$^{-1}$	day^{-1}	Not Used
	1	lb ⟐ ac^{-1}	day^{-1}	Not Used
	2	lb	day^{-1}	Not Used
2	0	lb ⟐ (100 ft curb)$^{-1}$	Not Used	day
	1	lb ⟐ ac^{-1}	Not Used	day
	2	lb	Not Used	day

Parameters DDLIM, DDPOW, and DDFACT are single subscripted by land use, J.
For metric input substitute kg for lb, Ha for ac and km for 100-ft.

Table 4-17. Buildup Equations for Constituents

Enter Parameters on Card Group J3.
PSHED = Constituent quantity.   t = time, days.
For parameter units, see Table 4-17.

KALC (Card Group J2)	Type	Equation	Equation Number
1	Power-Linear	PSHED = QFACT(3) ⟐ $t^{QFACT(2)}$ PSHED ⦸ QFACT(1)	4-26
2	Exponential	PSHED = QFACT(1) ⟐ (1-$e^{-QFACT(2)⟐t}$)	4-27
3	Michaelis-Menton	PSHED = ((QFACT(1) ⟐ t) / (QFACT(3) + t)	4-28

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

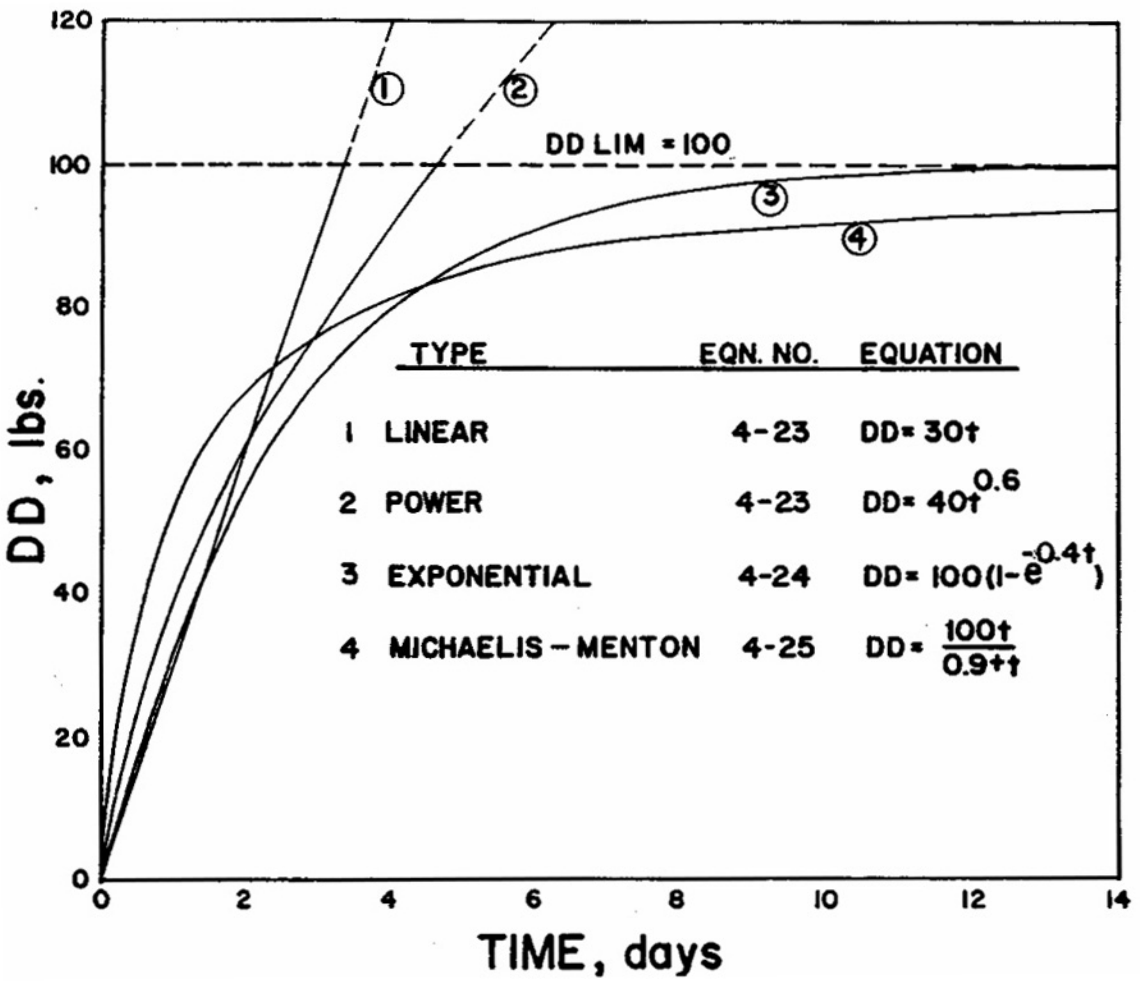

Figure 4-29. Comparison of linear and three nonlinear buildup equations. “Dust and dirt,” DD, is used as an example. Numerical values have been chosen arbitrarily.

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

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

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

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

For a given constituent, buildup may be computed 1) as a fraction of dust and dirt, or 2) individually for the constituent. If the first option is used (KALC = 0 in data group J3) then the rate of buildup will depend upon the fraction and the functional form used for a given land use. In other words, the functional form could vary with land use for a given constituent. If the second option is used (1 ⦸ KALC ⦸ 3 in data group J3) the buildup function will be the same for all land uses (and subcatchments) for a given constituent. Of course, each constituent may use any of the options. Catchment characteristics (i.e., area or gutter length) may be included through the use of parameters JACGUT (group J2) or KACGUT (group J3), as described in Tables 4-16 and 4-18.

Units for dust and dirt buildup parameters are reasonably straightforward and explained in Table 4-16. For example, if linear buildup was assumed using the Chicago APWA data (APWA, 1969), values for DDFACT could be taken directly from Table 4-13 for different land uses. Parameters JACGUT would equal zero. A limiting buildup (DDLIM) of so many lb/100 ft-curb could be entered if desired, and for linear buildup, DDPOW = 1.0.

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

When NDIM = 2, constituent concentrations are given in specialized units such as pH, JTU, PCU, °C, etc. “Buildup” of such parameters is rarely referred to; instead, a much more viable option is the use of a rating curve that gives load (i.e., concentration times flow) directly as a function of

Table 4-18. Units for Card Input of Constituent Parameters, Card Group J3

Define Q_1 and $Q_2 \equiv$ Constituent quantity as follows:

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

For KALC = 4, buildup parameters are not required.

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

Otherwise:

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

QFACT(4,K) and QFACT(5,K) are not required for KALC $\neq$ 0.

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

flow (discussed subsequently). However, the buildup option may be used with such constituents if desired. Within the Runoff Block, concentrations are ultimately computed in subroutine GUTTER by dividing a load (quantity per second) by a flow rate (cubic feet per second). Thus, if the quantity has units of concentration times cubic feet, the proper conversion will be made. This is the reason for the peculiar units requested in Table 4-18. Such an analysis is straightforward and analogous to computations of total mass in pounds (obtained by summing flow rate times concentration) for constituents measured in mg/l.

Buildup Data

Data with which to evaluate buildup parameters are available in most of the references cited earlier under “available studies.” Manning et al. (1977) have perhaps the best summary of linear buildup rates; these are presented in Table 4-19. It may be noted that dust and dirt buildup varies considerably among three different studies. Individual constituent buildup may be taken conveniently as a fraction of dust and dirt from the entries in Table 4-18, or they may be computed explicitly. It is apparent that although a large number of constituents have been sampled, little distinction can be made on the basis of land uses for most of them.

As an example, suppose options METHOD = 0 and KALC = 0 are chosen in groups J2 and J3 and “all data” are used from Table 4-19 to compute dust and dirt parameters. Since the data are given as lb ❸ curb-mile^{-1} ❸ day^{-1}, linear buildup is assumed and commercial land use DD buildup (average for all data) would be DDFACT = 2.2 lb / (100-ft curb - day) (i.e., 2.2 = 116/52.8, where 52.8 is the number of hundreds of feet in a mile). DDPOW would equal 1.0 and no data are available to set an upper limit, DDLIM. Parameter JACGUT = 0 so that the loading rate will be multiplied by the curb length for each subcatchment. Constituent fractions are available from the table. For instance, QFACT values for commercial land use would be 7.19 mg/g for BOD5, 0.06 mg/g for total phosphorus, 0.00002 mg/g for Hg, and 0.0369 106 MPN/g for fecal coliforms. Direct loading rates could be computed for each constituent as an alternative. For instance, with KALC = 1 for BOD5 and KACGUT = 0, parameter QFACT(3,K) would equal 2.2 ❸ 0.00719 = 0.0158 lb / (100-ft curb - day).

It must be stressed once again that the generalized buildup data of Table 4-19 are merely informational and are never a substitute for local sampling or even a calibration using measured concentrations. They may serve as a first trial value for a calibration, however. In this respect it is important to point out that concentrations and loads computed by the Runoff Block are usually linearly proportional to buildup rates. If twice the quantity is available at the beginning of a storm, the concentrations and loads will be doubled. Calibration is probably easiest with linear buildup parameters, but it depends on the rate at which the limiting buildup, i.e., DDLIM or QFACT(1,K), is approached. If the limiting value is reached during the interval between most storms, then calibration using it will also have almost a linear effect on concentrations and loads. If is apparent that the interaction between the interevent time of storms (i.e., dry days) and the effect of buildup is accomplished using the rate constants DDPOW and DDFACT for dust and dirt and QFACT(2,K) and QFACT(3,K) for constituents. This is discussed further subsequently under “Overall Sensitivity to Quality Parameters.”

Almost all of the above loading data are from samples of storm water, not combined sewage. Although some loadings may be inferred from concentration measurements of combined sewage (e.g., Huber et al., 1981a; Wallace, 1980), they are not directly related to most surface accumulation measurements. Thus, if buildup data alone are used in combined sewer areas, buildup rates will

Table 4-19. Nationwide Data on Linear Dust and Dirt Buildup Rates and on Pollutant Fractions (after Manning et al., 1977, pp. 138-140)

Pollutant		Land Use Categories				All Data
		Single Family Residential	Multiple Family Residential	Commercial	Industrial	
Dust and Dirt Accumulation lb/curb-mi/day kg/cub-km/day Chicago(1)	Mean	35(10)	109(31)	181(51)	325(92)	158(44)
	Range	19-96(5-27)	62-153(17-43)	71-326(80-151)	284-536(80-151)	19-536(5-15)
	No. of Obs	60	93	126	55	334
Washington(2)	Mean	—	—	134(38)	—	134(38)
	Range	—	—	35-365(10-103)	—	35-365(10-103)
	No. of Obs	—	—	22	—	22
Multi-City(3)	Mean	182(51)	157(44)	45(13)	288(81)	175(49)
	Range	3-950(1-268)	8-770(2-217)	3-260(1-73)	4-1,500(1-423)	3-1,500(1-423)
	No. of Obs	14	8	10	12	44
All Data	Mean	62(17)	113(32)	116(47)	319(90)	159(45)
	Range	3-950(1-268)	8-770(2-217)	3-365(1-103)	4-1,500(1-423)	3-1,500(1-423)
	No. of Obs	74	101	158	67	400
BOD mg/kg	Mean	5,260	3,370	7,190	2,920	5,030
	Range	1,720-9,430	2,030-6,320	1,280-14,540	2,820-2,950	1,288-14,540
	No. of Obs	59	93	102	56	292
COD mg/kg	Mean	39,250	41,970	61,730	25,080	46,120
	Range	18,300-72,800	24,600-61,300	24,800-498,410	23,000-31,800	18,300-498,410
	No. of Obs	59	93	102	38	292
Total N-N (mg/kg)	Mean	460	550	420	430	480
	Range	325-525	356-961	323-480	410-431	323-480
	No. of Obs	59	93	80	38	270
Kjeldahl N (mg/kg)	Mean	—	—	640	—	640
	Range	—	—	230-1,790	—	230-1,790
	No. of Obs	—	—	22	—	22
NO_3 (mg/kg)	Mean	—	—	24	—	24
	Range	—	—	10-35	—	10-35
	No. of Obs	—	—	21	—	21
NO_2-N (mg/kg)	Mean	—	—	0	—	15
	Range	—	—	0	—	0
	No. of Obs	—	—	15	—	15
Total PO_4 (mg/kg)	Mean	—	—	170	—	170
	Range	—	—	90-340	—	90-340
	No. of Obs	—	—	21	—	21
PO_4-P (mg/kg)	Mean	49	58	60	26	53
	Range	20-109	20-73	0-142	14-30	0-142
	No. of Obs	59	93	101	38	291
Chlorides (mg/kg)	Mean	—	—	220	—	220
	Range	—	—	100-370	—	100-370
	No. of Obs	—	—	22	—	22
Asbestos fibers/lb	Mean	—	—	$57.2\times10^{6}(126\times10^{6})$	—	$57.2\times10^{6}(126\times10^{6})$
	Range	—	—	$0\text{-}172.5\times10^{6}(0\text{-}380\times10^{6})$	—	$0\text{-}172.5\times10^{6}(0\text{-}380\times10^{6})$

(fibers/kg)	No. of Obs	—	—	16	—	16
Ag (mg/kg)	Mean	—	—	200	—	200
	Range	—	—	0-600	—	0-600
	No. of Obs	—	—	3	—	3
As (mg/kg)	Mean	—	—	0	—	0
	Range	—	—	0	—	0
	No. of Obs	—	—	3	—	3
Ba (mg/kg)	Mean	—	—	38	—	38
	Range	—	—	0-80	—	0-80
	No. of Obs	—	—	8	—	8

Table 4-19. Continued

Pollutant		Land Use Categories				All Data
		Single Family Residential	Multiple Family Residential	Commercial	Industrial	
Cd	Mean	3.3	2.7	2.9	3.6	3.1
(mg/kd)	Range	0-8.8	0.3-6.0	0-9.3	0.3-11.0	0-11.0
	No. of Obs	14	8	22	13	57
Cr	Mean	200	180	140	240	180
(mg/kg)	Range	111-325	75-325	10-430	159-335	10-430
	No. of Obs	14	8	30	13	65
Cu	Mean	91	73	95	87	90
(mg/kg)	Range	33–150	34-170	25-810	32-170	25-810
	No. of Obs	14	8	30	13	65
Fe	Mean	21,280	18,500	21,580	22,540	21,220
(mg/kg)	Range	11,000-48,000	11,000-25,000	5,000-44,000	14,000-43,000	5,000-48,000
	No. of Obs	14	8	10	13	45
Hg	Mean	—	—	0.02	—	0.02
(mg/kg)	Range	—	—	0-0.1	—	0-0.1
	No. of Obs	—	—	6	—	6
Mn	Mean	450	340	380	430	410
(mg/kg)	Range	250-700	230-450	160-540	240-620	160-700
	No. of Obs	14	8	10	13	45
Ni	Mean	38	18	94	44	62
(mg/kg)	Range	0-120	0-80	6-170	1-120	1-170
	No. of Obs	14	8	30	13	75
Pb	Mean	1,570	1,980	2,330	1,590	1,970
(mg/kg)	Range	220-5,700	470-3,700	0-7,600	260-3,500	0-7,600
	No. of Obs	14	8	29	13	64
Sb	Mean	—	—	54	—	54
(mg/kg)	Range	—	—	50-60	—	50-60
	No. of Obs	—	—	3	—	3
Se	Mean	—	—	0	—	0
(mg/kg)	Range	—	—	0	—	0
	No. of Obs	—	—	3	—	3
Sn	Mean	—	—	17	—	17
(mg/kg)	Range	—	—	0-50	—	0-50
	No. of Obs	—	—	3	—	3
Sr	Mean	32	18	17	13	21
(mg/kg)	Range	5-110	12-24	7-38	0-24	0-110
	No. of Obs	14	8	10	13	45
Zn	Mean	310	280	690	280	470
(mg/kg)	Range	110-810	210-490	90-3,040	140-450	90-3,040
	No. of Obs	14	8	30	13	65
Fecal	Geo. Mean	—	—	370	—	370
Strep	Range	—	—	44-2,420	—	44-2,420
No./gram	No. of Obs	—	—	17	—	17
Fecal Coli	Geo. Mean	82,500	38,800	36,900	30,700	94,700
No./gram	Range	26-130,000	1,500-1,000,000	140-970,000	67-530,000	26-1,000,000
	No. of Obs	65	96	84	42	287
Total Coli	Geo. Mean	891,000	1,900,000	1,000,000	419,000	1,070,000
No./gram	Range	25,000-3,000,000	80,000-5,600,000	18,000-3,500,000	27,000-2,600,000	18,000-5,600,000
	No. of Obs	65	97	85	43	290

probably be multiples of the values listed, for example in Table 4-18. The proper factor will most easily be found by calibration with local concentration measurements. Alternatively, the dry-weather flow mixing and scour routines in the Transport Block may be used to increase combined sewer concentrations. However, mixing of dry-weather flow with storm water has a negligible effect on concentrations during high flows, and the scour routine is highly empirical and adds a second calibration step. Hence, the easiest option for combined sewers is probably to calibrate as described earlier. Calibration may also be achieved using the rating curve approach.

When snowmelt is simulated, some of the ten constituents may be used to represent deicing chemicals; several common roadway "salts" are listed in Figure 4-24. Applications of such chemicals varies depending upon depth of snowfall and local practice. Loading rates are discussed in Appendix II and in other references (Proctor and Redfern and J.F. MacLaren, 1976a, 1976b; Field et al., 1973; Richardson et al., 1974; Ontario Ministry of the Environment, 1974). For instance, guidelines of the type proposed by Richardson et al. (1974) are used in many cities and are given in Table 4-20. Summaries are also given by Manning et al. (1977) and Lager et al. (1977a).

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

Washoff

Definition

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

Washoff Formulation

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

Table 4-20. Guidelines for Chemical Application Rates for Snow Control (Richardson et al., 1974)

Weather Conditions			Application Rate (pounds of material per mile of 2-lane road or 2 lanes of divided)			
Temperature	Pavement Conditions	Precipitation	Low- and High-Speed Multilane Divided	Two- and Three-Lane Primary	Two-Lane Secondary	Instructions
30°F and above	Wet	Snow	300 salt	300 salt	300 salt	wait at least 0.5 hour before plowing
		Sleet or Freezing Rain	200 salt	200 salt	200 salt	reapply as necessary
25-30°F	Wet	Snow or Sleet	initial at 400 salt repeat at 200 salt	initial at 400 salt repeat at 200 salt	initial at 400 salt repeat at 200 salt	wait at least 0.5 hour before plowing; repeat
		Freezing Rain	initial at 300 salt repeat at 200 salt	initial at 300 salt repeat at 200 salt	initial at 300 salt repeat at 200 salt	repeat as necessary
20-25°F	Wet	Snow or Sleet	initial at 500 salt repeat at 250 salt	initial at 500 salt repeat at 250 salt	1200 of 5:1 sand/salt; repeat same	wait about 0.75 hour before plowing; repeat
		Freezing Rain	initial at 400 salt repeat at 300 salt	initial at 400 salt repeat at 300 salt		repeat as necessary
15-20°F	Dry	Dry Snow	plow	plow	plow	treat hazardous areas with 1200 of 20:1 sand/silt
	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/silt

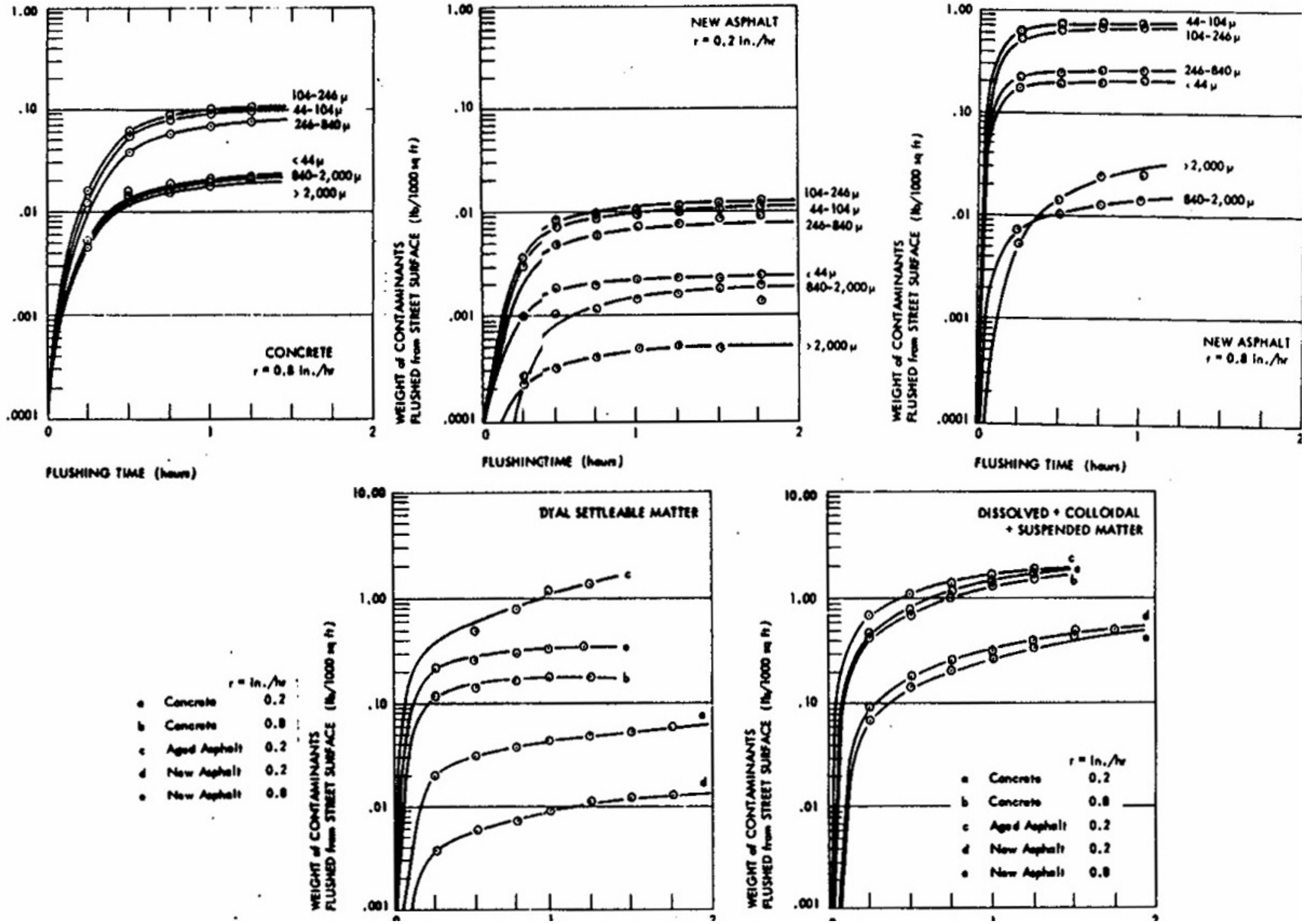

Figure 4-30. Washoff of street solids by flushing with a sprinkler system (after Sartor and Boyd, 1972, pp. 86-87).

$$POFF(t) = PSHED_o\,(1 - e^{-kt}) \qquad (4\text{-}32)$$

where

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

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

$$PSHED(t) = PSHED_o\, e^{-kt} \qquad (4\text{-}33)$$

where

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

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

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

$$dPSHED/dt = -k \diamond PSHED \qquad (4\text{-}34)$$

The solution of equation 4-34 is equation 4-33. This was first proposed by Mr. Allen J. Burdoin, a consultant to Metcalf and Eddy, during the original SWMM development. The coefficient k may be evaluated by assuming it is proportional to runoff rate, r:

$$k = RCOEF \diamond r$$
(4-35)

where

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

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

Sonnen (1980) estimated values for RCOEF from sediment transport theory ranging from 0.052 to 6.6 in.$^{-1}$, increasing as particle diameter decreases, rainfall intensity decreases, and as catchment area decreases. He pointed out that 4.6 in.$^{-1}$ is relatively large compared to most of his calculated values. Although the exponential washoff formulation of equations 4-34 and 4-35 is not completely satisfactory as explained below, it has been verified experimentally by Nakamura (1984a, 1984b), who also showed the dependence of the coefficient k on slope, runoff rate and cumulative runoff volume.

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

$$AV = a + br^{c} \qquad (4\text{-}36)$$

where

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

were multiplied by equation 4-32 in order to match measured suspended solids concentrations in Cincinnati and San Francisco (Metcalf and Eddy et al., 1971a, Section 11). The primary difficulty is that use of equations 4-34 and 4-35 will always produce decreasing concentrations as a function of time regardless of the time distribution of runoff. This is counter-intuitive, since it is expected that high rates during the middle of a storm <u>might</u> indeed produce higher concentrations than those preceding. This may be explained by observing that concentrations are calculated by dividing the load rate (e.g., mg/sec) to obtain the quantity per volume (e.g., mg/l). Thus,

$$C = \frac{1 dPSHED}{Q\, dt} = const \cdot \frac{RCOEF \cdot r \cdot PSHED}{A \cdot r} \qquad (4\text{-}37)$$

where

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

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

-POFF(t) = dPSHED/dt = -RCOEFX ⟐ r^{WASPO} ⟐ PSHED (4-38)

where

POFF = constituent load washed off at time, t, quantity/sec (e.g., mg/sec),

PSHED = uantity of constituent available for washoff at time, t, (e.g., mg),
RCOEFX = washoff coefficient = RCOEF/3600, (in/hr)$^{-WASHPO}$ ⟐ sec^{-1}, and
r = runoff rate, in./hr.

It may be seen that if equation 4-38 is divided by runoff rate to obtain concentration, then concentration is now proportional to $r^{WASHPO-1}$. Hence, if the increase in runoff rate is sufficient, concentrations can increase during the middle of a storm even if PSHED is diminished. (Equation 4-38 was first suggested in a 1974 report to the Boston District Corps of Engineers, authorship unknown).

There are two parameters to be determined, RCOEF and WASHPO. Availability factors of the form of equation 4-36 are no longer used since there is sufficient flexibility for calibration using only equation 4-38. Of course, the original SWMM methodology can be recovered by using WASHPO = 1.0.

Effects of Parameters

The effect of different values for RCOEF and WASHPO on PSHED and concentration is shown for four temporal distributions of runoff (Figure 4-31) in Figures 4-32 to 4-35. The basis for the calculations and plotted values is given in Table 4-21. It may be seen that concentrations may be made to increase with increasing runoff rate during the middle of a storm by increasing the value of WASHPO. However, perhaps counter intuitively, a larger value of WASHPO generally yields lower concentrations and higher values of PSHED. This is because the runoff rates used for the example are all less than 1.0 in./hr. (25.4 mm/hr) and decrease in magnitude when raised to a power. The reverse will be true for values of r > 1.0. But most storms will have r < 1.0 throughout their durations. Increasing the value of RCOEF always increases concentrations. (See also the subsequent discussion under “Overall Sensitivity to Quality Parameters.”)

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

$$\mathrm{PSHED}(t+\Delta t)=\mathrm{PSHED}(t)\cdot e^{-\mathrm{RCOEF}\cdot\frac{r(T)^{\mathrm{WASHPO}}+r(t+\Delta t)^{\mathrm{WASHPO}}}{2}}\cdot\Delta t \tag{4-39}$$

This calculation is done prior to application of equation 4-38. The average (trapezoidal rule) approximates the integral of r^{WASHPO} over the time step.

That the load rate of sediment is proportional to flow rate as in equation 4-38 is supported by both theory and data. For instance, sediment data from streams can usually be described by a sediment rating curve of the form

$$G = aQ^b \tag{4-40}$$

where

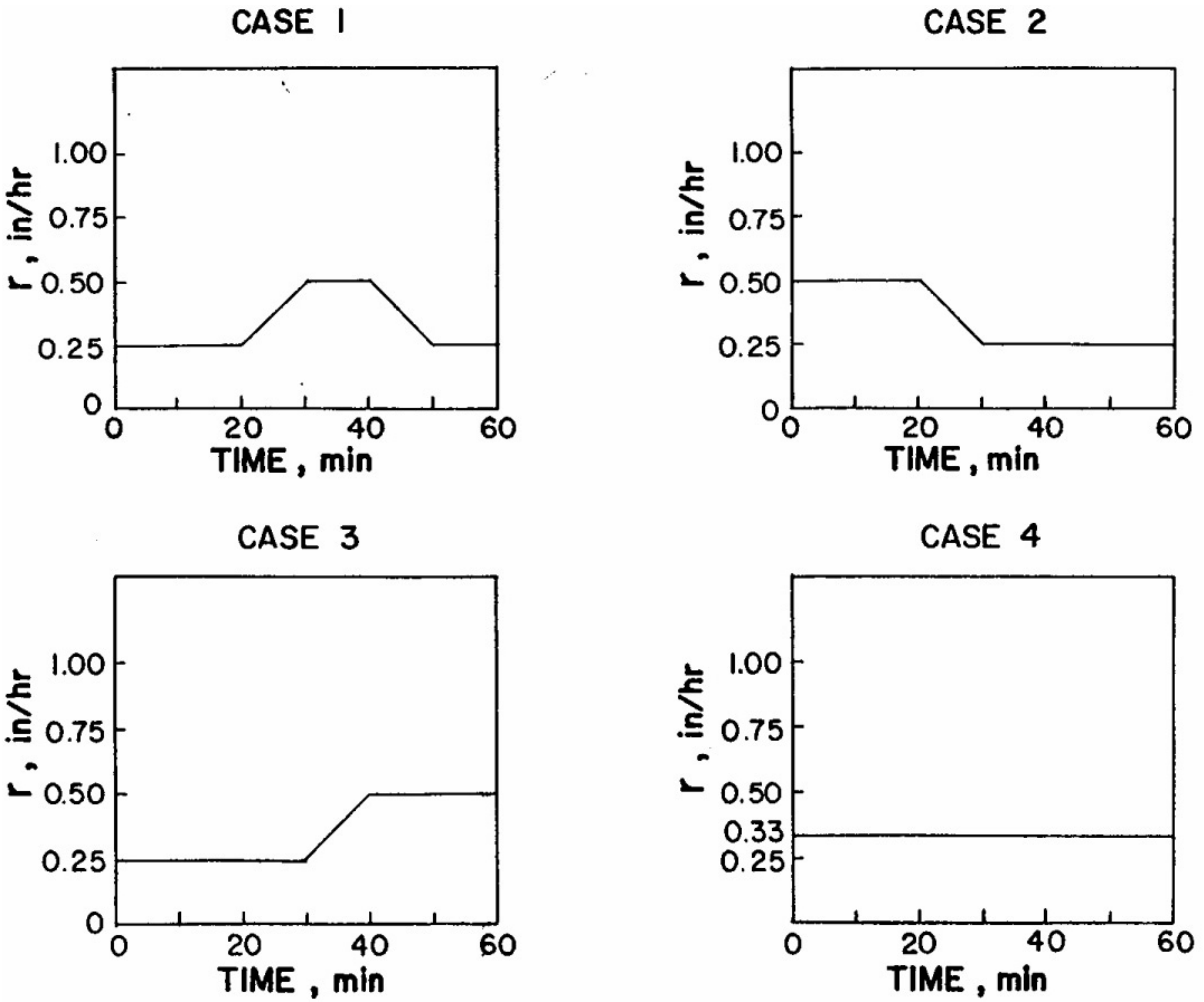

Figure 4-31. Time variation of runoff rate used in example of Table 4-21 and Figures 4-32 to 4-35.

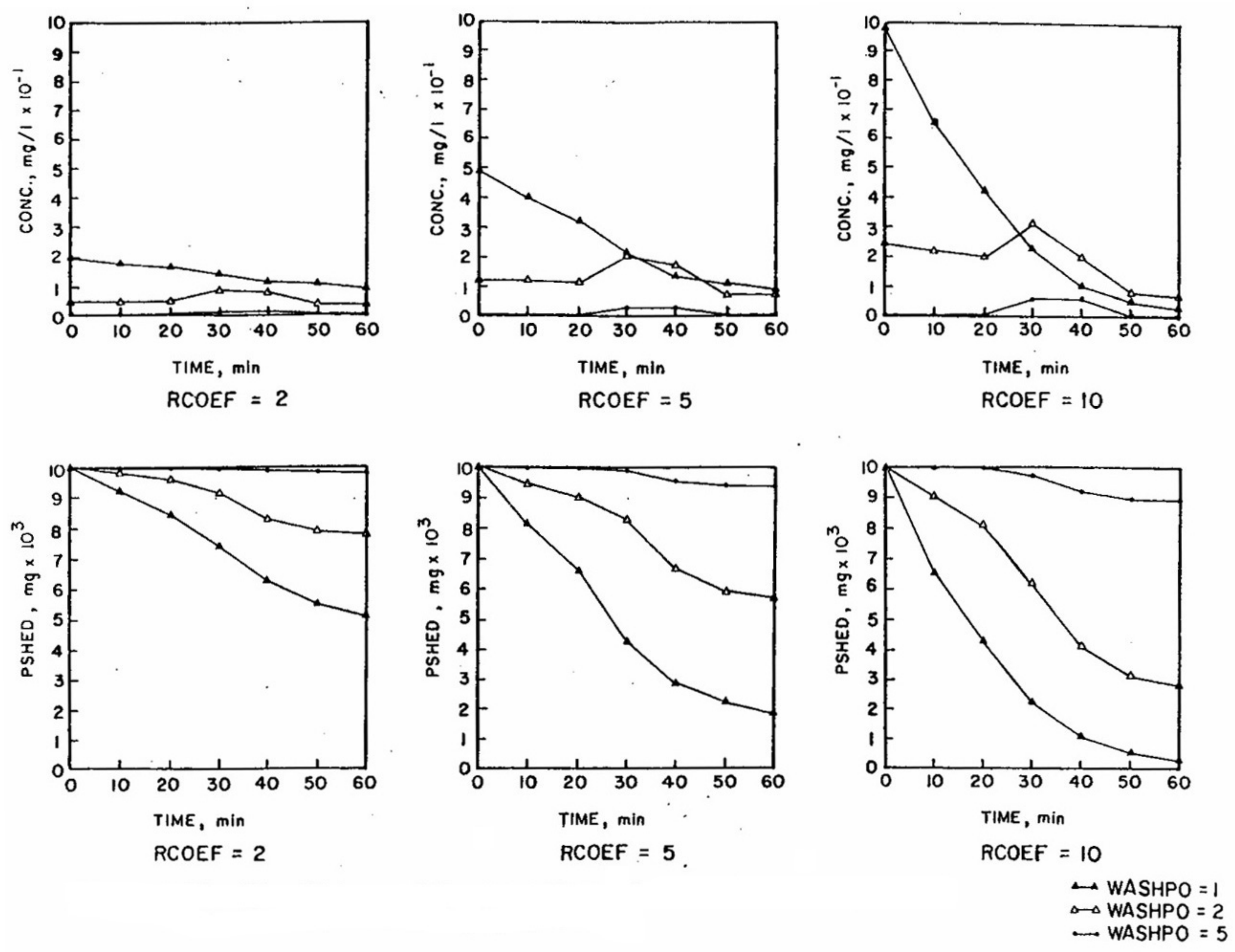

Figure 4-32. Time history of concentration and subcatchment load (PSHED) for case 1 runoff (Figure 4-31).

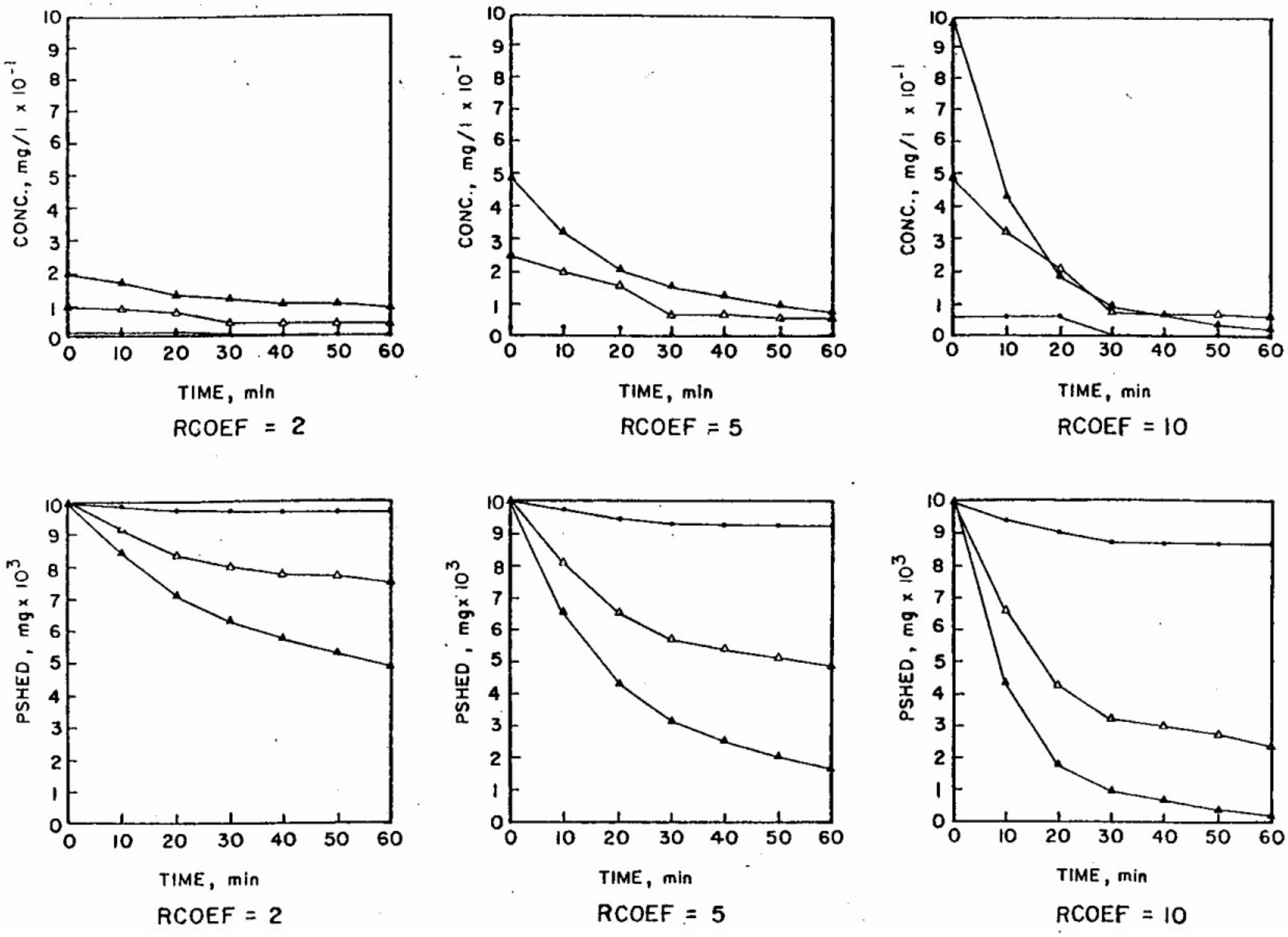

Figure 4-33. Time history of concentration and subcatchment load (PSHED) for case 2 runoff (Figure 4-31).

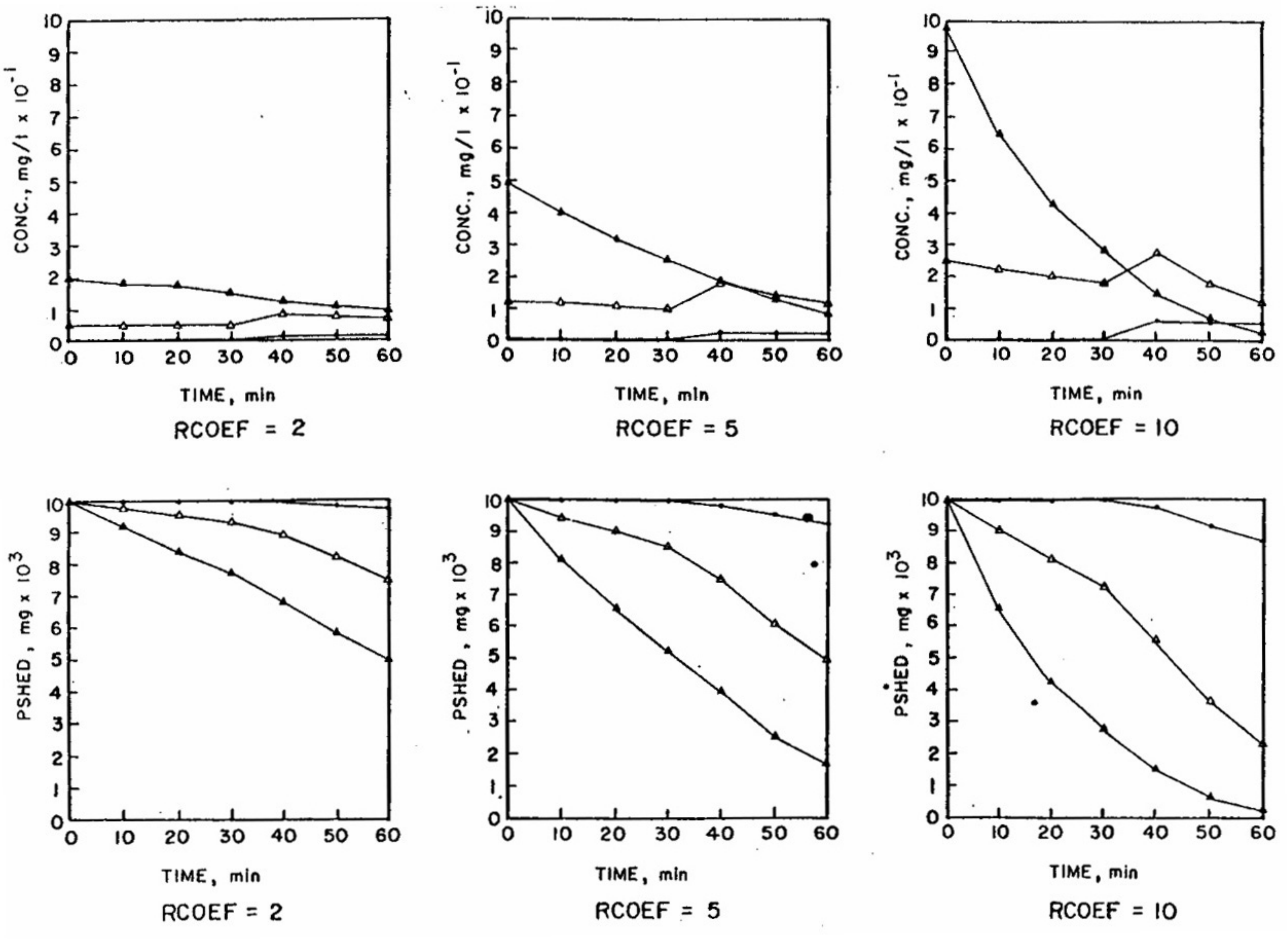

Figure 4-34. Time history of concentration and subcatchment load (PSHED) for case 3 runoff (Figure 4-31).

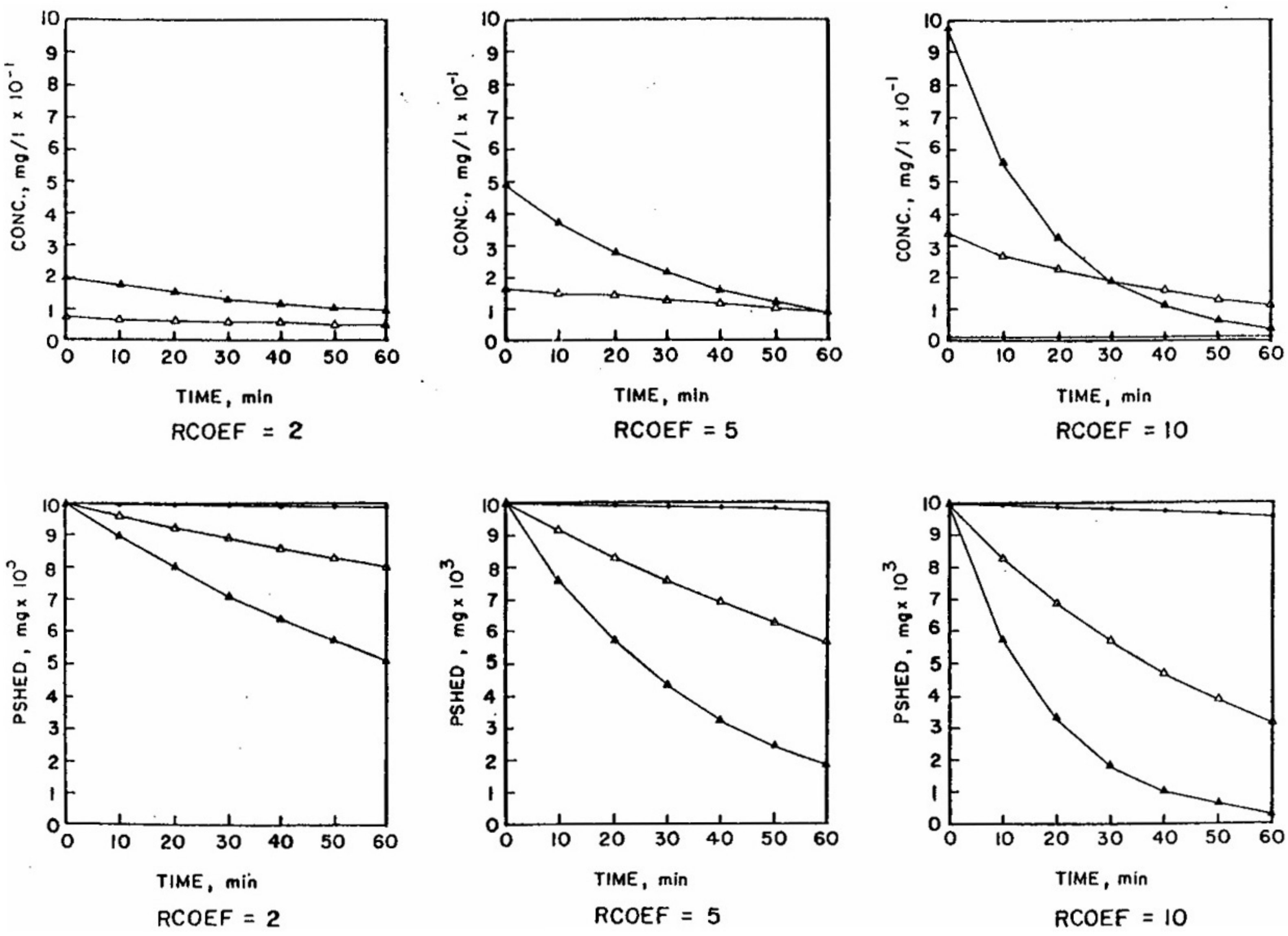

Figure 4-35. Time history of concentration and subcatchment load (PSHED) for case 4 runoff (Figure 4-31).

Table 4-21. Parameters Used for Washoff Equation Example

Equations Used:

Equation 4-39 and

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

where

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

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

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

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

Due to a hysteresis effect, such relationships may vary during the passing of a flood wave, but the functional form is evident in many rivers, e.g., Vanoni (1975), pp. 220-225, Graf (1971), pp. 234-241, and Simons and Senturk (1977), p. 602. Of particular relevance to overland flow washoff is the appearance of similar relationships describing sediment yield from a catchment e.g., Vanoni (1975), pp. 472-481. The exponent b in equation 4-40 corresponds to the exponent WASHPO in equation 4-38, and the presence of the quantity PSHED in equations 4-38 reflects the fact that the total quantity of sediment washed off a largely impervious urban area is likely to be limited to the amount built up during dry weather. Natural catchments and rivers from which equation 4-40 is derived generally have no source limitation.

The use of rating curves in their own right is an option in the Runoff Block which will be discussed subsequently. At this point, however, results from sediment transport theory can be used to provide guidance for the magnitude of parameters WASHPO and RCOEF in equation 4-38. Values of the exponent b in equation 4-40 range between 1.1 and 2.6 for rivers and sediment yield from catchments, with most values near 2.0. Typically, the exponent tends to decrease (approach 1.0) at high flow rates (Vanoni, 1975, p. 476). In the Runoff Block, constituent concentrations will follow runoff rates better if WASHPO is higher (see Figures 4-32 to 4-35). A reasonable first guess for WASHPO would appear to be in the range of 1.5-2.5.

Values of RCOEF are much harder to infer from the sediment rating curve data since they vary in nature by almost five orders of magnitude. The issue is further complicated by the fact that equation 4-38 includes the quantity remaining to be washed off, PSHED, which decreases steadily during an event. At this point it will suffice to say that values of RCOEF between 1.0 and 10 appear to give concentrations in the range of most observed values in urban runoff. Both RCOEF and WASHPO may be varied in order to calibrate the model to observed data.

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

Although the development has ignored the physics of rainfall energy in eroding particles, the runoff rate, r, in equation 4-38 closely follows rainfall intensity. Hence, to some degree at least, greater washoff will be experienced with greater rainfall rates. As an option, soil erosion literature could be surveyed to infer a value of WASHPO if erosion is proportional to rainfall intensity to a power.

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

Related Buildup-Washoff Studies

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

The U.S. Geological Survey (USGS) has performed comprehensive urban hydrologic studies from both a data collection and modeling point of view. For example, their South Florida urban runoff data are described and referenced in the EPA Urban Rainfall-Runoff Quality Data Base (Huber et al., 1981a). Urban rainfall-runoff quantity may be simulated with the USGS distributed Routing Rainfall-Runoff Model (Dawdy et al., 1978; Alley et al., 1980a) which includes simulation of water quality. This is accomplished using a separate program that uses the quantity model results as input. These efforts are described by Alley (1980) and Alley et al. (1980b). Alley (1981) also provides a method for optimal estimation of washoff parameters using measured data. The USGS procedures

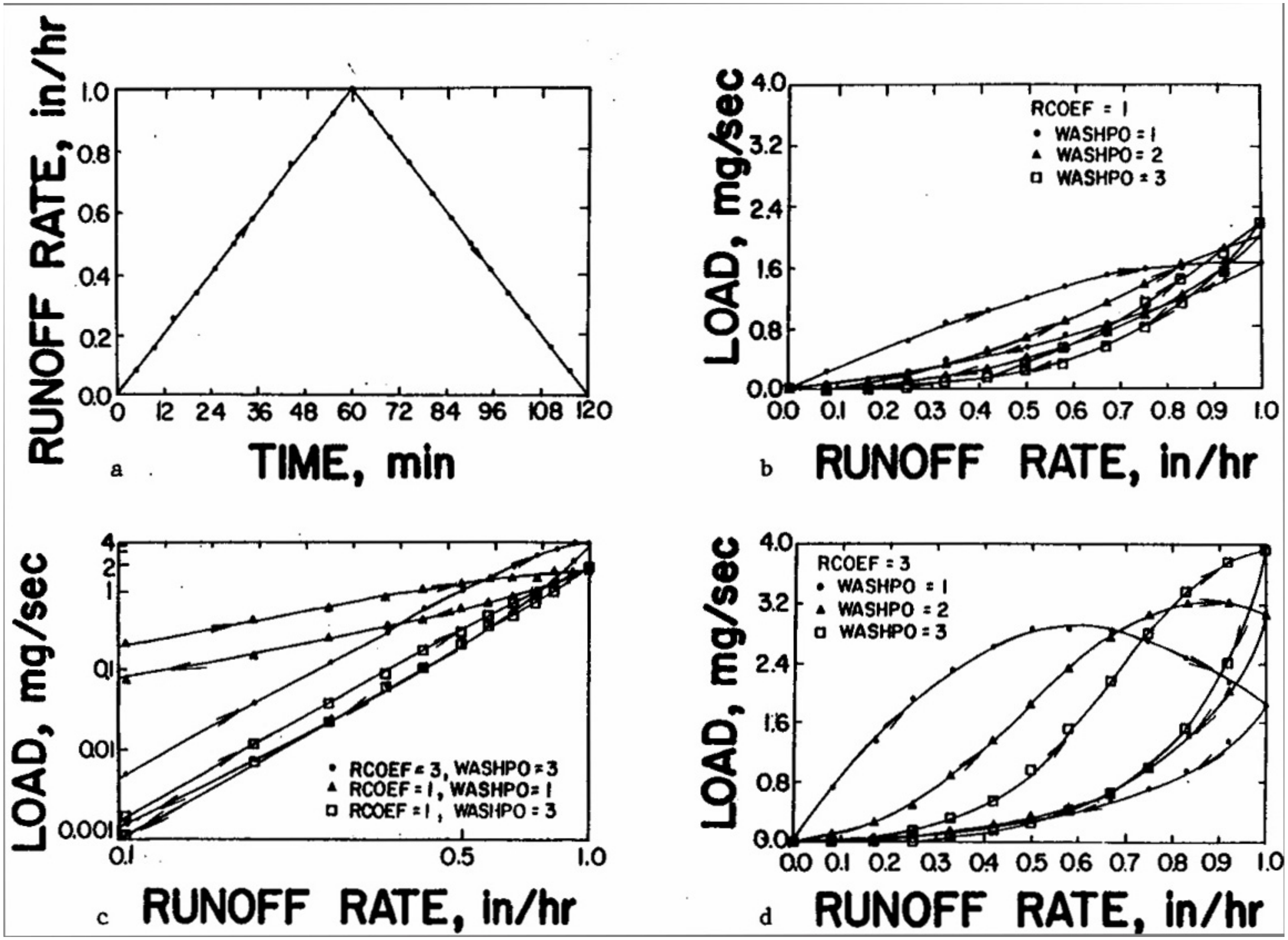

Figure 4-36. Simulated load variations within a storm as a function of runoff rate. The initial surface load is 1000 mg on a 1 ac catchment, and the time step is 5 min. The loop effect is exaggerated as RCOEF is increased (Figures b vs d). The loops are flattened when using a log-log scale (Figure c).

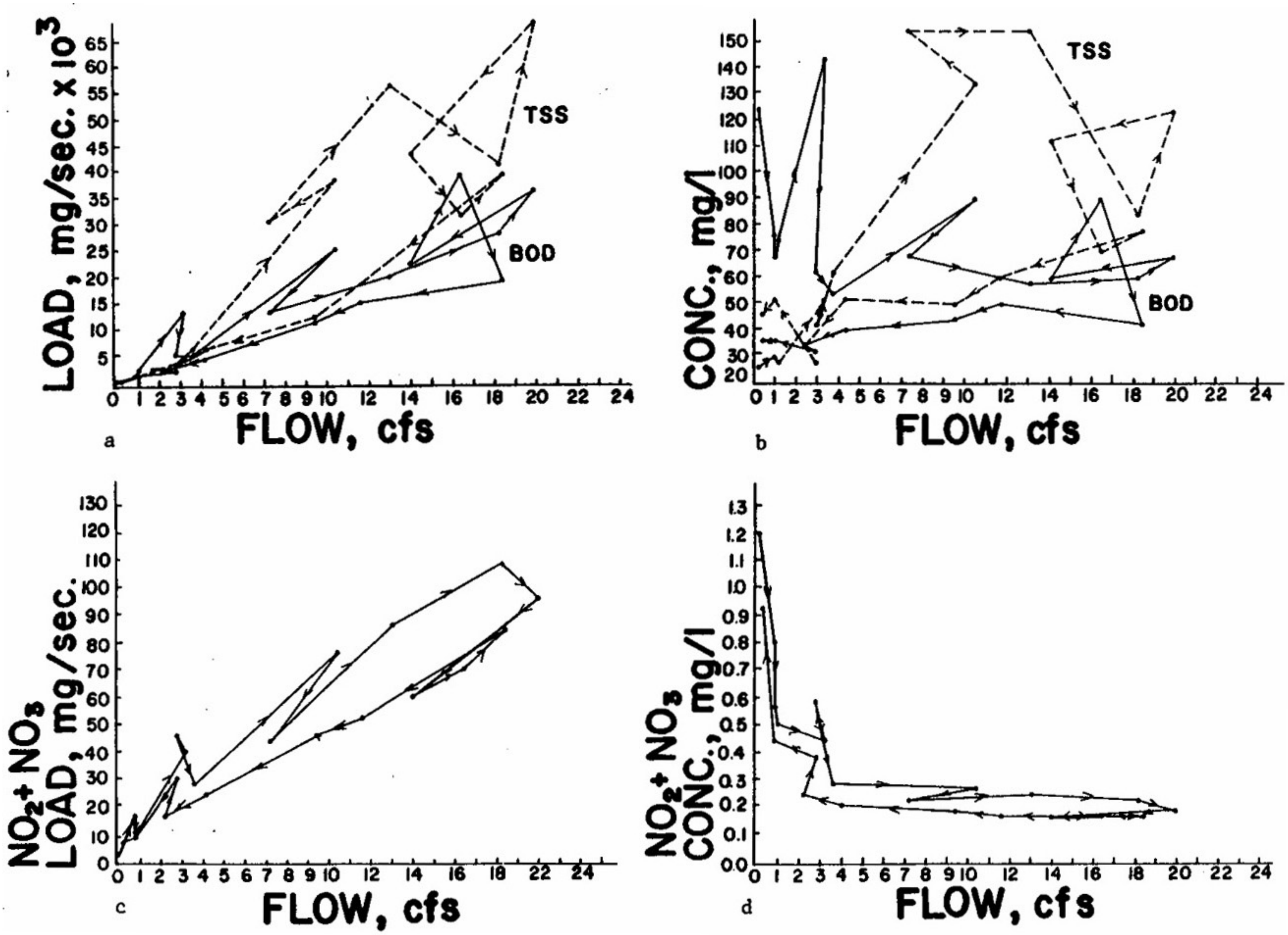

Figure 4-37. Variation of BOD_5, TSS and NO_2+NO_3-N load and concentration for storm of 11/17/74 for View Ridge 1 Catchment, Seattle (from Huber et al., 1979). Connected points trace time history. (Figure continued, next page.)

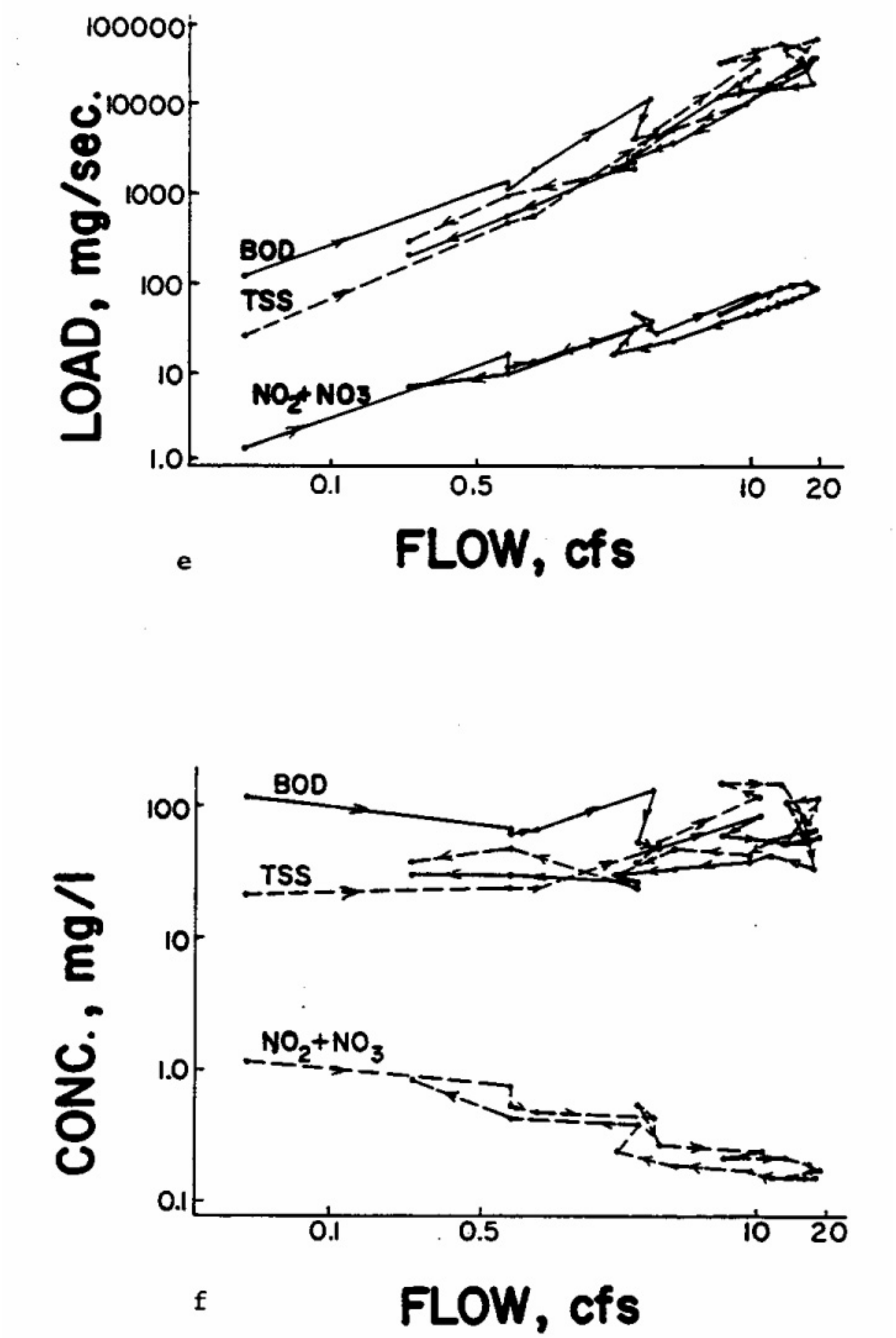

Figure 4-37 (continued). The log-log plots could form the basis for rating curves, although the loop effect may only be simulated using a washoff calculation. Compare with Figure 4-36 b and d. Several more plots are shown in Appendix VII.

are based in part upon earlier work of Ellis and Sutherland (1979). These four references all discuss the use of the original SWMM buildup-washoff equations. An application of SWMM Runoff and Transport Blocks to two Denver catchments during which buildup-washoff parameters were calibrated is described by Ellis (1978) and Alley and Ellis (1979).

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

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

Rating Curve

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

$$\mathrm{POFF} = \mathrm{RCOEF} \diamond \mathrm{WFLOW}^{\mathrm{WASHPO}} \tag{4-41}$$

where

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

Parameters RCOEF and WASHPO are entered for a particular constituent in group J3. That these parameters apply to a rating curve is indicated by parameter KWASH in group J3. Although used on a time step basis, the parameters for equation 4-41 are customarily determined on a storm event basis, by plotting total load versus total flow (Huber, 1980; Wallace, 1980).

Two differences are apparent between equations 4-38 and 4-41. First, the former includes the quantity remaining on the surface, PSHED, in the right-hand side of the equation, leading to an exponential-type decay of the quantity in addition to being a function of runoff rate.

Second, the form of the runoff rate is different in the equations. The power-exponential washoff, equation 4-38, uses a normalized runoff rate, r, in in./hr over the total subcatchment surface (not just the impervious part). The rating curve, equation 4-41, also uses the total runoff, but in an unnormalized form, WFLOW, in cfs. Since data for a particular catchment are often analyzed as a log-log plot of load versus flow, equation 4-41 facilitates use of the best fit line. For example, data for Seattle are plotted in Figure 4-37. In addition, Appendix VII contains several other similar plots for three Seattle catchments and for Lancaster, Pennsylvania.

Clearly, the rating curve will work better for some storms and parameters than for others. If the data plot primarily as a loop (Figure 4-37), the power-exponential washoff formulation will work better since it tends to produce lower loads at the end of storm events. But if the load versus flow data tend to plot as a straight line on log-log paper, the rating curve method should work better. On the basis of the previous discussion of rating curves based on sediment data, it is expected that the exponent, WASHPO, would be in the range of 1.5-3.0 for constituents that behave like particulates. For dissolved constituents, the exponent will tend to be less than 1.0 since concentration often decreases as flow increases, and concentration is proportional to flow to the power WASHPO-1. (Constant concentration would use WASHPO = 1.0.) Much more variability is expected for RCOEF.

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

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

The rating curve method is generally easiest to use when only total runoff volumes and pollutant loads are available for calibration. In this case a pure regression approach should suffice to determine parameters RCOEF and WASHPO in equation 4-41.

Street Cleaning

Street cleaning is performed in most urban areas for control of solids and trash deposited along street gutters. Although it has long been assumed that street cleaning has a beneficial effect upon the quality of urban runoff, until recently, few data have been available to quantify this effect. Unless performed on a daily basis, EPA Nationwide Urban Runoff Program (NURP) studies generally found little improvement of runoff quality by street sweeping (EPA, 1983b).

The most elaborate studies are probably those of Pitt (1979, 1985) in which street surface loadings were carefully monitored along with runoff quality in order to determine the effectiveness of street cleaning. In San Jose, California (Pitt, 1979) frequent street cleaning on smooth asphalt surfaces (once or twice per day) can remove up to 50 percent of the total solids and heavy metal yields of urban runoff. Under more typical cleaning programs (once or twice a month), less than 5 percent of the total solids and heavy metals in the runoff are removed. Organics and nutrients in the runoff cannot be effectively controlled by intensive street cleaning -- typically much less than 10 percent removal, even for daily cleaning. This is because the latter originate primarily in runoff and erosion from off-street areas during storms. In Bellevue, Washington (Pitt, 1985) similar conclusions were reached, with a maximum projected effectiveness for pollutant removal from runoff of about 10 percent.

The removal effectiveness of street cleaning depends upon many factors such as the type of sweeper, whether flushing is included, the presence of parked cars, the quantity of total solids, the constituent being considered, and the relative frequency of rainfall events. Obviously, if street sweeping is performed infrequently in relation to rainfall events, it will not be effective. Removal efficiencies for several constituents are shown in Table 4-21 (Pitt, 1979). Clearly, efficiencies are greater for constituents that behave as particulates.

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

$$\text{REMAIN} = 1.0 - \text{AVSWP}(J) \diamond \text{REFF}(K) \qquad (4\text{-}42)$$

where

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

The removal efficiency differs for each constituent as seen in Table 4-22, from which estimates of REFF may be obtained. The effect of multiple passes must be included in the value of REFF. During the mini-simulation that occurs prior to the initial storm or start of simulation "dust and dirt" is also removed during sweeping using an efficiency REFFDD (group J2). It is probably reasonable to assume that dust and dirt is removed similarly to the total solids of Table 4-22. A non-linear effect is exhibited in Table 4-22, in which efficiencies tend to increase as the total solids on the street surface increase. The Runoff Block algorithm does not duplicate this effect. Rather, the same fraction is removed during each sweeping.

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

$$\text{AVSWP} = 0.6 \cdot \text{PD}_d^{-0.2},\ \text{P}_d > 0.1 \qquad (4\text{-}43)$$

where

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

Table 4-22. Removal Efficiencies from Street Cleaner Path for Various Street Cleaning Programs* (Pitt, 1979)

Street Cleaning Program and Street Surface Loading Conditions	Total Solids	BOD_5	COD	KN	PO_4	Pesticides	Cd	Sr	Cu	Ni	Cr	Zn	Mn	Pb	Fe
Vacuum Street Cleaner 20 ◖ 200 lb/curb mile total solids															
1 pass	31	24	16	26	8	33	23	27	30	37	34	34	37	40	40
2 passes	45	35	22	37	12	50	34	35	45	54	53	52	56	59	59
3 passes	53	41	27	45	14	59	40	48	52	63	60	59	65	70	68
Vacuum Street Cleaner 200 ◖ 1,000 lb/curb mile total solids															
1 pass	37	29	21	31	12	40	30	34	36	43	42	41	45	49	59
2 passes	51	42	29	46	17	59	43	48	49	59	60	59	63	68	68
3 passes	58	47	35	51	20	67	50	53	59	68	66	67	70	76	75
Vacuum Street Cleaner 1,000 ◖ 10,000 lb/curb mile total solids															
1 pass	48	38	33	43	20	57	45	44	49	55	53	55	58	62	63
2 passes	60	50	42	54	25	72	57	55	63	70	68	69	72	79	77
3 passes	63	52	44	57	26	75	60	58	66	73	72	73	76	83	82
Mechanical Street Cleaner 180 ◖ 1,800 lb/curb mile total solids															
1 pass	54	40	31	40	20	40	28	40	38	45	44	43	47	44	49
2 passes	75	58	48	58	35	60	45	59	58	65	64	64	64	65	71
3 passes	85	69	59	69	46	72	57	70	69	76	75	75	79	77	82
Flusher	30	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
Mechanical Street Cleaner followed by a Flusher	80	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)

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

*These removal values assume all the pollutants would lie within the cleaner path (0 to 8 ft. from the curb)

Such a relationship is reasonably a function of land use. Although a value of AVSWP must be entered for each land use (group J2), the equation of Heaney and Nix (1977) was developed only for an overall urban area. Thus, extrapolation to specific land uses should be done only with caution, but equation 4-43 is probably suitable for use on a large, aggregated catchment, such as might be used for continuous simulation.

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

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

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

Catchbasins

Background

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

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

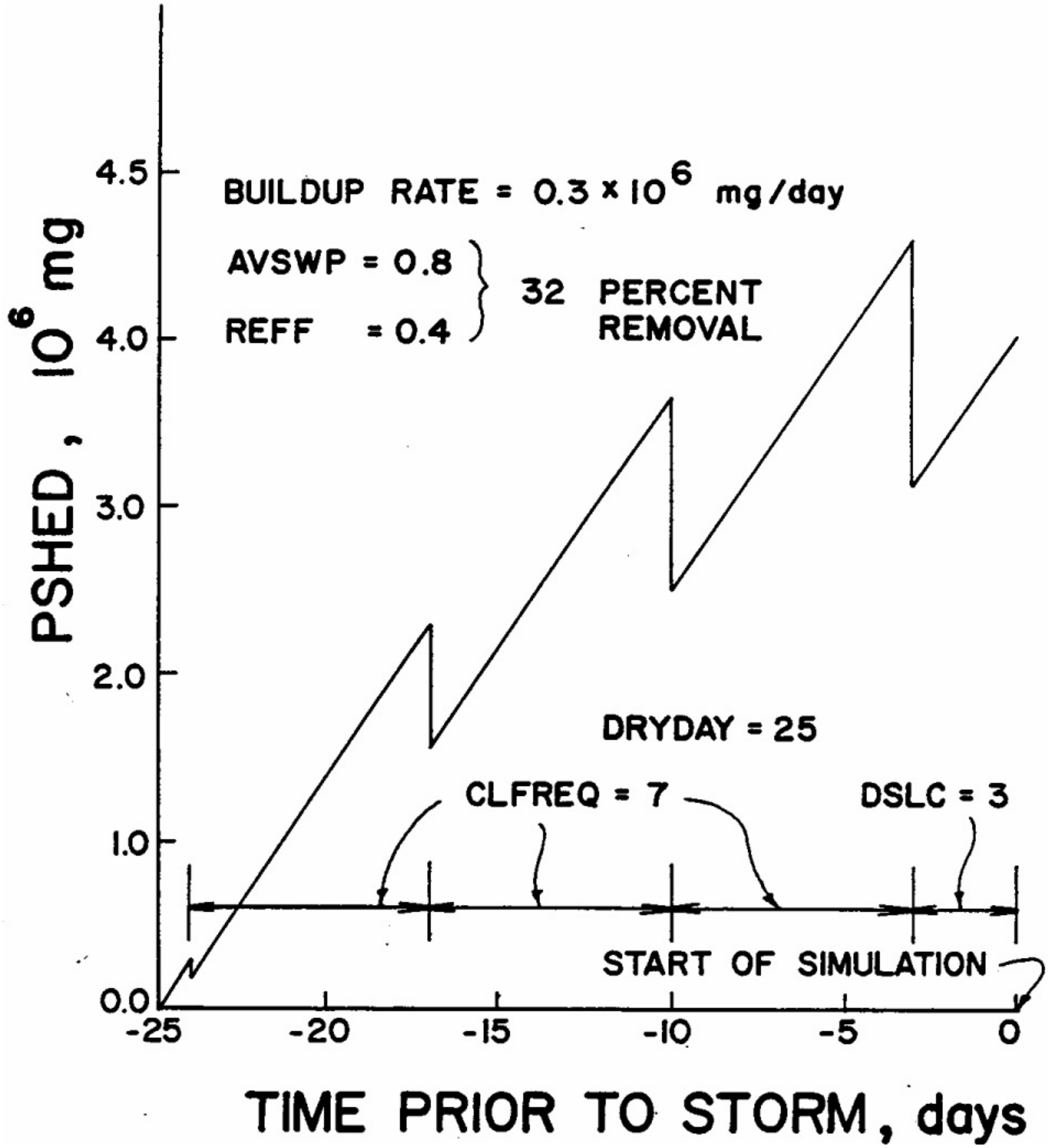

Figure 4-38. Hypothetical time sequence of linear buildup and street sweeping.

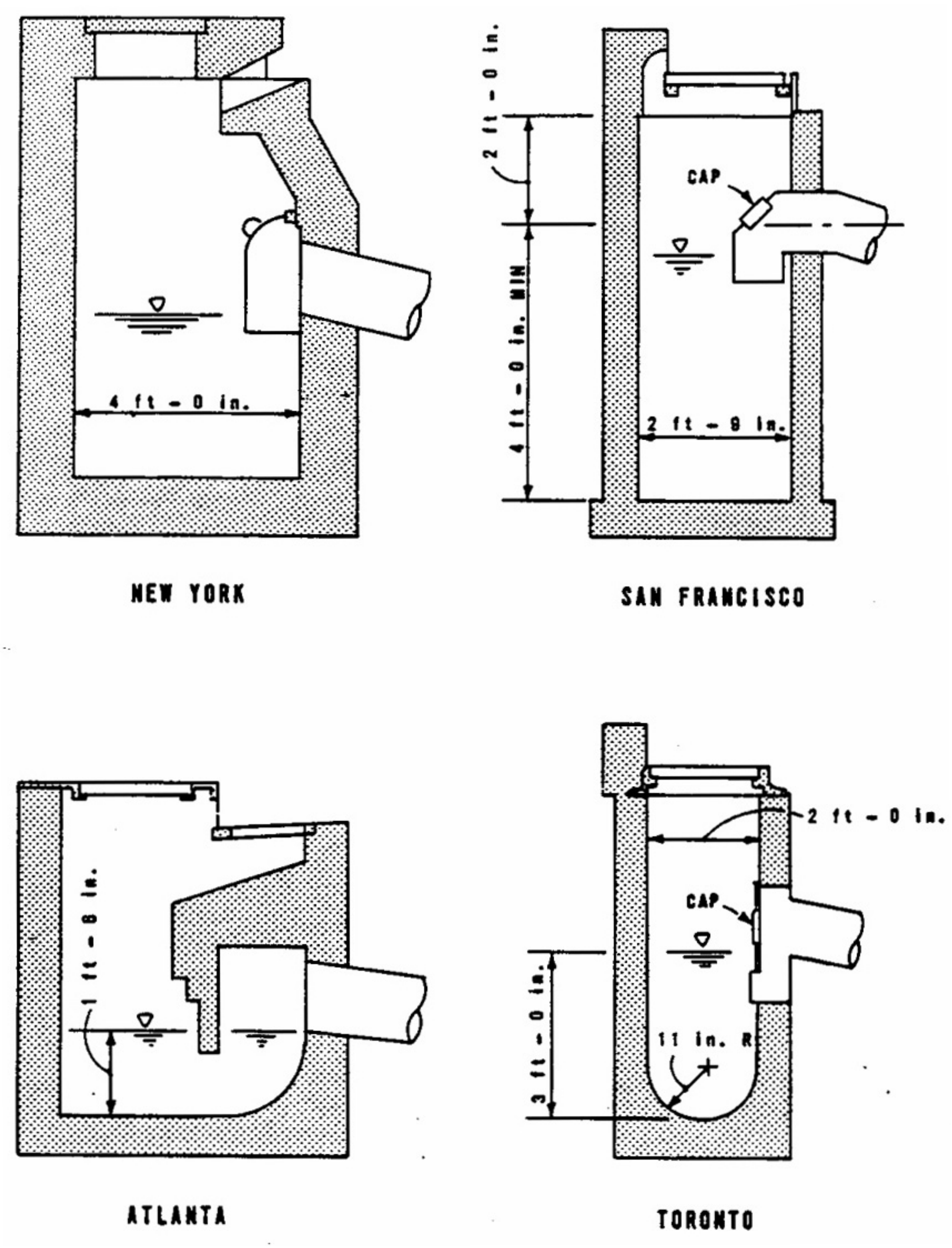

Figure 4-39. Representative catchbasin designs (after Lager et al., 1977b, p. 12).

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

In fact according to their data, there is unlikely to be much removal (treatment) at all in most cities because of infrequent maintenance; the median cleaning frequency in 1973 was once per year. Without such maintenance, solids accumulate in the sump until there is little removal effectiveness, even for large particles. Lager et al. (1977b) conclude that, with the possible exception of total solids and heavy metals, catchbasins are of limited usefulness for pollution abatement, both because of their ineffectiveness and because of their high maintenance costs. More recently, Pitt (1985) found that semi-annual catchbasin cleaning could reduce solids loads by up to 25 percent. However, their treatment potential is not modeled in SWMM. (If it is significant in a given city, surface loadings could be correspondingly reduced.)

Modeling Approach

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

$$\text{PBASIN} = \text{CBVOL} ⟐ \text{BASINS} ⟐ \text{CBFACT} ⟐ \text{FACT3} \qquad (4\text{-}44)$$

where

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

Parameter CBVOL is entered in group J1 as an average for the entire catchment. The number of basins in each subcatchment, BASINS, is entered in group L1. Numbers can be obtained knowing the general basin density for the catchment in lieu of the more tedious method of counting every one. Constituent concentrations, CBFACT, are entered in group J3 and should, of course, be measured in the catchment under study. Literature values are few. Samples from 12 San Francisco catchbasins (Sartor and Boyd, 1972) were characterized by Lager et al. (1977b) by "casting out the extremes and averaging," resulting in the values shown in Table 4-23. Concentrations from ten catchbasins in a residential catchment in Bellevue, Washington, are also shown (Pitt, 1985). The values for COD and Total-N are consistent with a few samples reported by Sartor and Boyd (1972) for Baltimore and Milwaukee, although the "phosphates" concentration in those two cities was somewhat higher, 1.1-

2.2 mg/l. The concentration of BOD5 in seven Chicago catchbasins was measured by APWA (1969).

Table 4-23. Constituent Concentrations in Catchbasins

City	Constituent	Concentration, mg/l	
		Average	Range
San Francisco (Sartor and Boyd, 1972)	COD	6,400	153-143,000
	BOD5	110	5-1,500
	Total-N	8	0.5-33
	Total-P	0.2	< 0.2-0.3
Bellevue (Pitt, 1985)	COD	59	20-244
	Total Solids	67	34-272
	TKN	2.1	< 0.5-5.6
	Total-P	0.95	0.078-6.9
	Pb	0.14	0.05 - 0.45
	Zn	0.19	0.033-1.19

The average concentration for five commercial area basins was 126 mg/l, ranging from 35 to 225 mg/l. Two residential area basins yielded BOD5 concentrations of 50 and 85 mg/l.

Suspended solids (SS) concentrations can be expected to be high for particle sizes less than about 0.25 mm, on the basis of flushing tests (Sartor and Boyd, 1972; Lager et al., 1977b). Initial suspended and total solids concentrations of several thousand mg/l are probably justified, although measurements by Waller (1971) during storms in four residential catchbasins in Halifax indicate SS concentrations in a range of 42 to 305 mg/l. Pitt (1985) provides a particle size distribution for the constituents listed in Table 4-23.

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

$$\mathrm{dPBASIN} / \mathrm{dt} = -\frac{\mathrm{WFLOW}}{\mathrm{k \ BASINS}} \cdot \mathrm{PBASIN} \tag{4-45}$$

where

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

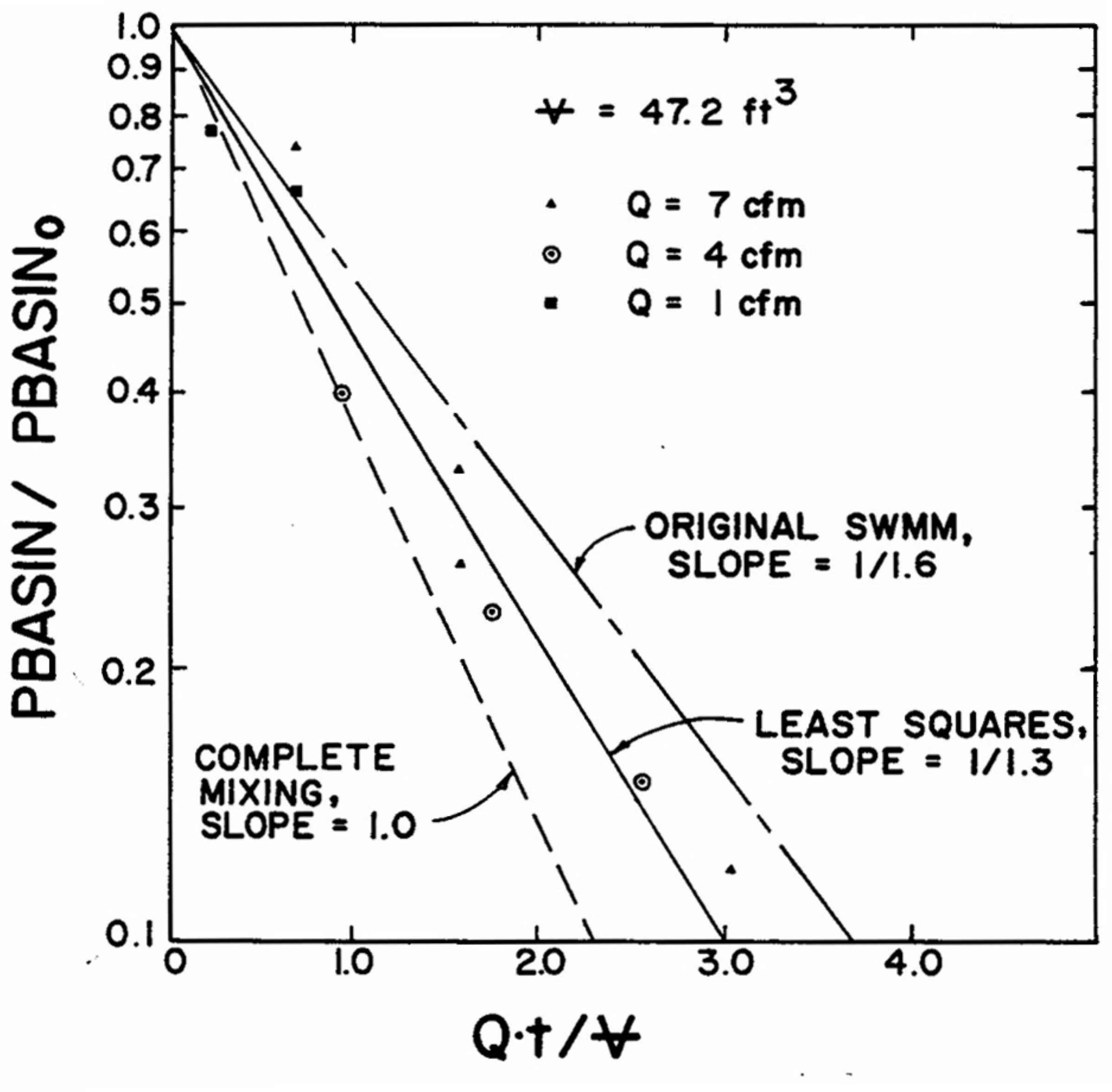

Figure 4-40. Catchbasin flushing characteristics (from APWA, 1969).

When the flow rate is constant, equation 4-45 integrates to

$$\mathrm{PBASIN} = \mathrm{PBASIN}_o \cdot e^{-\frac{\mathrm{WFLOW}}{\mathrm{K\ BASINS}} \cdot t} \qquad (4\text{-}46)$$

where

PBASIN_o = initial catchbasin load.

If complete mixing occurs, k = 1. For the Chicago tests this did not quite occur, as seen in Figure 4-40. The original SWMM version (Metcalf and Eddy et al., 19761a) used k = 1.6, but this does not give the best-fit line. Rather, a k value of 1.3 is consistent with a least squares fit through the data points and is used in this version of SWMM. (However, the difference is probably undetectable in a simulation.)

During a runoff event, equation 4-45 is used to calculate the load rate, dPBASIN/dt, at each time step. (Parameter BASINS represents the total catchbasin volume for the subcatchment.) The remaining catchbasin load is then computed by multiplying the load rate by DELT and subtracting from PBASIN. This crude Euler integrations is justified because of 1) the weakness of field data and mixing assumptions, 2) the necessity for an additional array and computation time for a more sophisticated approximation, and 3) insensitivity of most simulations to catchbasin flushing. The latter point will be discussed further subsequently.

Regeneration of Catchbasin Loads

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

Effect on Simulation

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

Constituent Fractions

Background

As previously discussed, the original SWMM Runoff Block quality routines were based on the 1969 APWA study in Chicago (APWA, 1969). A particular aspect of that study that led to modifications to the first buildup-washoff formulation was that the Chicago quality data (e.g., Table 4-15) were reported for the soluble fraction only, i.e., the samples were filtered prior to chemical analysis. Hence, they could not represent the total content of, say, BOD5 in the stormwater. In calibration of SWMM in San Francisco and Cincinnati, 5 percent of predicted suspended solids was added to BOD5 to account for the insoluble fraction. This provided a reasonable BOD5 calibration in both cities.

The Version II release of SWMM (Huber et al., 1975) followed the STORM model (Roesner et al., 1974) and added to BOD5, N and PO_4 fractions of both suspended solids and settleable solids. Adding a fraction from settleable solids is double counting, however, since it is no more than a fraction of suspended solids itself. Furthermore, all the fractions in SWMM and STORM were basically just assumed from calibration exercises as opposed to being measured from field samples.

Agricultural models, such as NPS (Donigian and Crawford, 1976), ARM (Donigian et al., 1977) and HSPF (Johanson et al., 1980) also relate other constituent mass load rates and concentrations to that of “solids,” usually “sediment" predicted by an erosion equation. The ratio of constituent to “solids” is then called a “potency factor” and for some constituents is the only means by which their concentrations are predicted. The approach works well when constituents are transported in solid form, either as particulates or by adsorption onto soil particles. this approach can also be used in SWMM. For instance, one constituent could represent “solids” and be predicted by any of the means available (i.e., buildup-washoff, rating curve, Universal Soil Loss Equation). Other constituents could then be treated simply as a fraction, F1, of “solids.” The fractions (potency factors) are entered in data group J4. As a refinement, two or more constituents could represent “solids” in different particle size ranges, and fractions of each summed to predict other constituents. Again, this approach will not work well for constituents that are transported primarily in a dissolved state, e.g., NO_3.

Available Information

In an effort to evaluate potency factors for various constituents in both urban and agricultural runoff, Zison (1980) examined available data and developed regression relationships as a function of suspended solids and other parameters. His only urban catchments were three from Seattle, taken from the Urban Rainfall-Runoff-Quality Data Base (Huber et al., 1981a), for which several water quality and storm event parameters were available. Unfortunately, statistically meaningful results could only be obtained using log-transformed data, and simple fractions of the type required for input in group J4 are seldom reported. Zison (1980) acknowledged this and suggested that model modifications might be made or piecewise-linear approximations made to the power function relationship. In any event, Zison related the total constituent concentration (not just the nonsoluble portion) to other parameters. Hence, for their use in SWMM< the buildup-washoff portion would need to be “zeroed out” (easily accomplished), as suggested earlier.

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

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

Effect in Runoff Block

The fractions entered in group J4 act only in "one direction." That is, nothing is subtracted from, say, suspended solids if it is a constituent that contributes to others. When the fractions are used, they can contribute significantly to the concentration of a constituent. For instance, if 5 percent of suspended solids is added to BOD5, high SS concentrations will insure somewhat high BOD5 concentrations, event if BOD5 loadings are small.

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

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

Precipitation Contributions

Precipitation Chemistry

There is now considerable public awareness of the fact that precipitation is by no means "pure" and does not have characteristics of distilled water. Low pH (acid rain) is the best known parameter but many substances can also be found in precipitation, including organics, solids, nutrients, metals and pesticides. Compared to surface sources, rainfall is probably an important contributor mainly of some nutrients, although it may contribute substantially to other constituents as well. In particular, Kluesener and Lee (1974) found ammonia levels in rainfall higher than in runoff in a residential catchment in Madison, Wisconsin; rainfall nitrate accounted for 20 to 90 percent of the nitrate in stormwater runoff to Lake Wingra. Mattraw and Sherwood (1977) report similar findings for nitrate and total nitrogen for a residential area near Fort Lauderdale, Florida. Data from the latter study are presented in Table 4-24 in which rainfall may be seen to be an important contributor to all nitrogen forms, plus COD, although the instance of a higher COD value in rainfall than in runoff is probably anomalous.

In addition to the two references first cited, Weibel et al. (1964, 1966) report concentrations of constituents in Cincinnati rainfall (Table 4-25), and a summary is also given by Manning et al. (1977). Other data on rainfall chemistry and loadings is given by Betson (1977), Hendry and Brezonik (1980), Novotny and Kincaid (1981) and Randall et al. (1981). A comprehensive summary is presented by Brezonik (1975) from which it may be seen in Table 4-25 that there is a wide range of concentrations observed in rainfall. Again, the most important parameters relative to urban runoff are probably the various nitrogen forms.

Uttormark et al. (1974) provide annual nitrogen (and phosphorus) precipitation loading values (kg/ha-yr) for many cities regionally for the U.S. and Canada. Their nitrogen loadings are shown in Figure 4-41 although it should be remembered that considerable seasonal variability may exist. These may be easily converted to precipitation <u>concentrations</u> required for SWMM input if the local rainfall is known, since 10 ❸ kg/ha-yr / cm/yr = mg/l. For instance, annual NH_3-N + NO_3-N loadings at Miami are almost 2 kg/ha-yr from Figure 4-41, and annual rainfall is 60 in. (152 cm). From the above, the inorganic nitrogen concentration is 10 ❸ 2/152 = 0.13 mg/l which compares quite favorably with the sum of NH_3-N and NO_3-N concentrations for two of the three Ft. Lauderdale storms given in Table 4-24. For a better breakdown of nitrogen forms, see Table 17 of Uttormark et al. (1974).

Table 4-24. Rainfall and Runoff Concentrations for a Residential Area Near Fort Lauderdale, Florida (after Mattraw and Sherwood, 1977)

	Storm		
	8/23/75	9/17/75	9/26/75
Rainfall, in.	1.01	0.55	0.77
Runoff, in.	0.060	0.012	0.072
Concentration (mg/l):			
Total N, rainfall	0.30	0.84	0.29
Total N, runoff	0.52	0.74	1.50
NO3-N, rainfall	0.14	0.73	0.12
NO3-N, runoff	0.16	0.19	0.26
Org.-N, rainfall	0.15	0.09	0.12
Org.-N, runoff	0.34	0.49	1.10
NH3-N, rainfall	0.01	0.01	0.04
NH3-N, runoff	0.02	0.04	0.13
Total P, rainfall	0.01	0.02	0.05
Total P, runoff	0.12	0.20	0.30
COD, rainfall	22	12	4
COD, runoff	16	21	17

Effect in Runoff Block

Constituent concentrations in precipitation are entered in group J3. All runoff, including snowmelt, is assumed to have at least this concentration, and the precipitation load is calculated by multiplying this concentration by the runoff rate and adding to the load already generated by other mechanisms. It may be inappropriate to add a precipitation load to loads generated by a calibration of buildup-washoff or rating curve parameters against measured runoff concentrations, since the latter already reflect the sum of all contributions, land surface and otherwise. But precipitation loads might well be included if starting with buildup-washoff data from other sources. They also provide a simple means for imposing a constant concentration on any Runoff Block constituent.

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

Table 4-25. Representative Concentrations in Rainfall

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

[a] Range for three storms (Mattraw and Sherwood, 1977)

[b] Average of 35 storms (Weibel et al., 1966)

[c] Brezonik, 1975

[d] Sum of NH_3-N, NO_2-N, NO_3-N

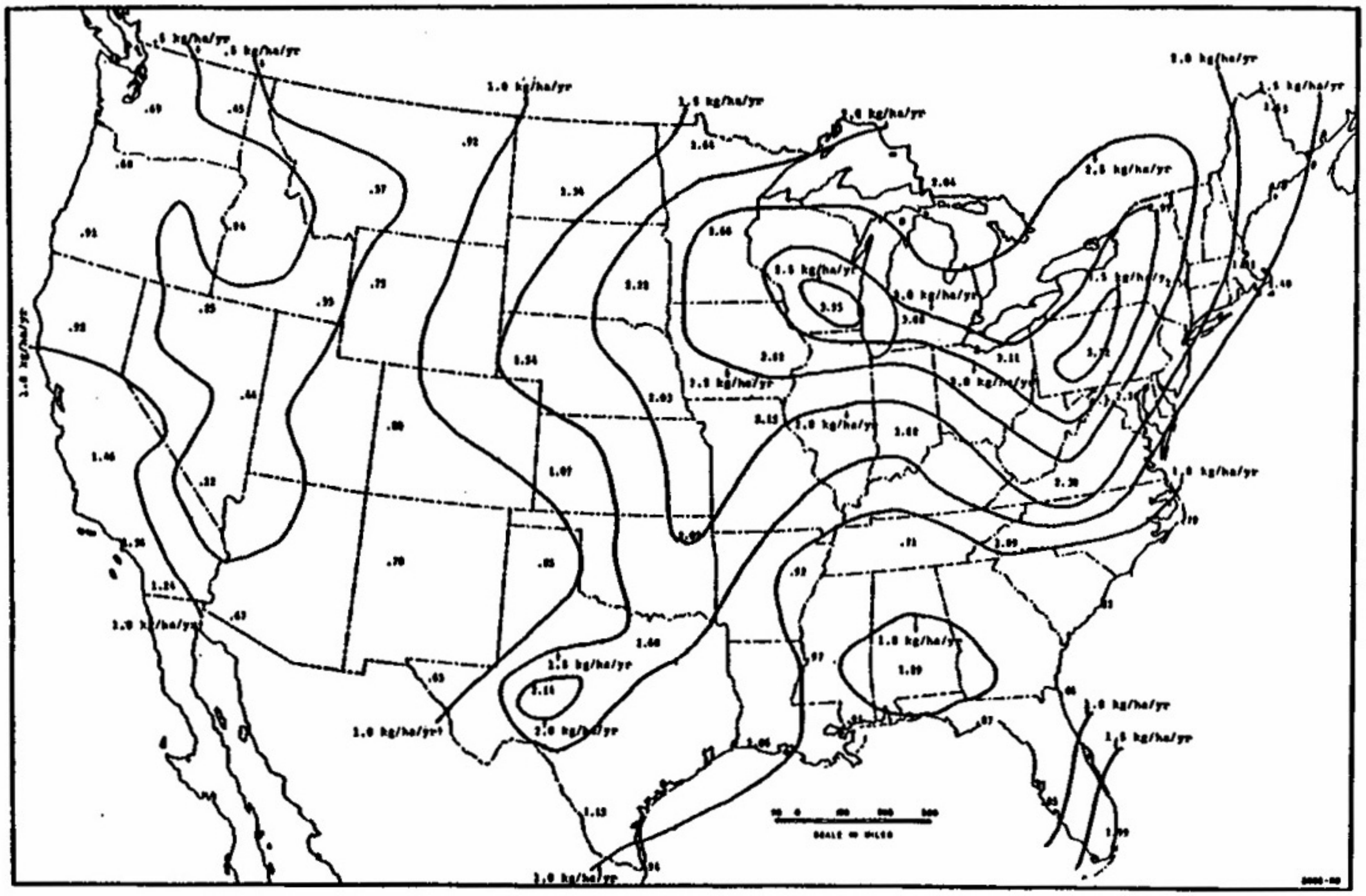

Figure 4-41. Nationwide annual loadings of NH_4^+-N + NO_3-N in precipitation (after Uttormark et al., 1974, p. 87). Dry fallout is not included.

Urban Erosion

Background

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

Universal Soil Loss Equation

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

$$L = R \text{ ⟐ } K \text{ ⟐ } LS \text{ ⟐ } C \text{ ⟐ } P$$

where

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

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

Input Parameters

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

Other input parameters are:

1) the maximum 30-minute rainfall intensity of the storm (single-event) or of the simulation period (continuous), RAINIT, (group J1),
2) the area of each subcatchment subject to erosion, ERODAR, (group K1),
3) the flow distance in feet from the point of origin of overland flow over the erodible area to the point at which runoff enters the gutter or inlet, ERLEN, (group K1),
4) the soil factor K, SOILF, (group K1),
5) the cropping management factor C, CROPMF, (group K1), and
6) the control practice factor P, CONTPF, (group K1).

The source and use of these parameters is described below.

Rainfall Factor and Maximum Thirty Minute Intensity. The rainfall factor, R, of the equation 4-47 is the product of the maximum thirty minute intensity and the sum of the rainfall energy for the time of simulation. Rainfall energy, E, is given by an empirical expression by Wischmeier and Smith (1958):

$$E = \sum [9.16 + 3.31 ⟐ \log_{10}(RNINHR_j)] ⟐ RNINHR_j ⟐ DELT$$

where

E = total rainfall energy for time period of summation, 00-ft-ton/ac,
$RNINHR_j$ = rainfall intensity at time interval j, in./hr, and
$DELT$ = time interval, hr, such that the product RNINHR ❸ DELT equals the rainfall depth during the time interval.

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

$$R = E ⟐ RAINIT \qquad (4\text{-}49)$$

where

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

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

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

Soil Factor. The soil factor, K, is a measure of the potential erodibility of a soil and has units of tons per unit of rainfall factor, R. The soil erodibility nomograph shown in Figure 4-42 (Wischmeier et al., 1971) may be used to find the value of the soil factor once five soil parameters have been estimated. These parameters are: percent silt plus very fine sand (0.05-0.10 mm), percent sand greater than 0.10 mm, organic matter (O.M.) content, structure, and permeability. To use the nomograph, enter on the left vertical scale with the appropriate percent silt plus very fine sand. Proceed horizontally to the correct percent sand curve, then move vertically to correct organic matter curve. Moving horizontally to the right from this point, the first approximation of K is given on the vertical scale. For soils of fine granular structure and moderate permeability, this first approximation value corresponds to the final K value and the procedure is terminated. If the soil structure and permeability is different than this, it is necessary to continue the horizontal path to intersect the correct structure curve, proceed vertically downward to the correct permeability curve, and move left to the soil erodibility scale to find K. This procedure is illustrated by the dotted line on the nomograph. For a more complete discussion of this topic, see Wischmeier et al. (1971).

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

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

$$LS = ERLEN^{0.5} \diamond (0.0076 + 0.5 \diamond WSLOPE + 7.6 \diamond WSLOPE^2)$$

where

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

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

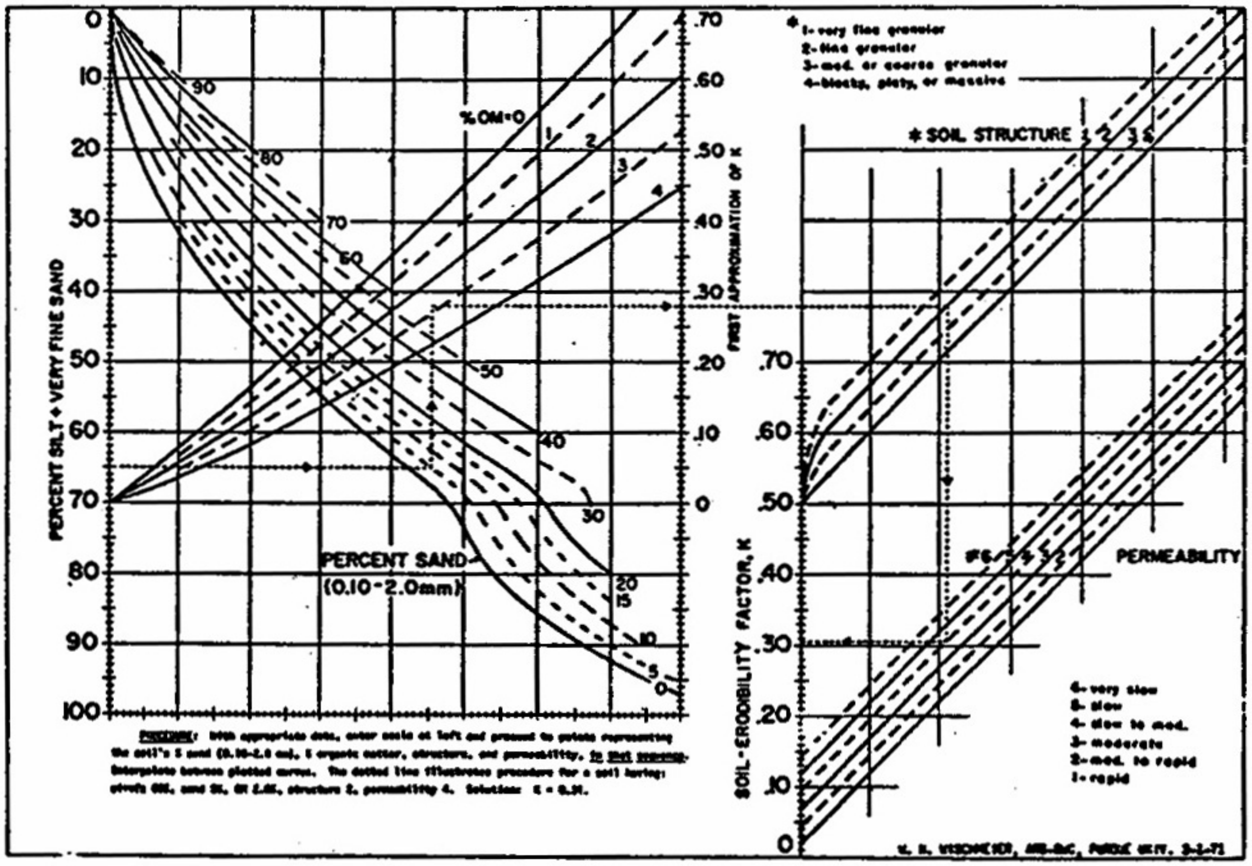

Figure 4-42. Nomograph for calculation of soil erodability factor, K (after Wischmeier et al., 1971).

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

Cropping Management Factor. This factor is dependent upon the type of ground cover, the general management practice and the condition of the soil over the area of concern. The C factor (CROPMF in group K1) is set equal to 1.0 for continuous fallow ground which is defined as land that has been tilled and kept free of vegetation and surface crusting. Values for the cropping management factor are given in Table 4-26 (Maryland Dept. of Natural Resources, 1973). Again consultation with local soils experts is recommended.

Table 4-26. Cropping Management Factor, C (Maryland Dept. of Natural Resources, 1973)

Type of Cover	C Value	Mulch	Rate of Application (tons/acre)	C Value	Maximum Allowable Slope Length (ft)
None (fallow)	1.00	Hay or straw	0.5	0.35	20
			1.0	0.20	30
Temporary seedlings:			1.5	0.10	40
First 60 days	0.40		2.0	0.05	50
After 60 days	0.05				
		Stone or gravel	15.0	0.80	15
Permanent seedlings:			60.0	0.20	80
First 60 days	0.40		135.0	0.10	175
After 60 days	0.05		240.0	0.05	200
		Chemical mulches			
Sod (laid immediately)	0.01	First 90 days	a	0.50	50
		After 90 days	a	1.00	50
		Woodchips	2.0	0.80	25
			4.0	0.30	50
			12.0	0.10	100
			20.0	0.06	150
			25.0	0.05	200

[a] As recommended by manufacturer

Control Practice Factor. This is similar to the C factor except that P (CONTPF in group K1) accounts for the erosion-control effectiveness of superimposed practices such as contouring, terracing, compacting, sediment basins and control structures. Values for the control practice factor for construction sites are given in Table 4-27 (Ports, 1973). Agricultural land use P factor values are given by Wischmeier and Smith (1965).

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

The P factors in the upper portion of Table 4-27 were designated as estimates when they were originally published. SCS scientists have found no theoretical or experimental justification for factors significantly greater than 1.0. Surface conditions 4, 6, 7 and 8 (P ⦸ 1.0) of Table 4-26 also are estimates with no experimental verification.

Table 4-27. Erosion Control Practice Factor, P, for Construction Sites (Ports, 1973)

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

Subcatchment Quality Data (Group L1)

Introduction

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

Land Use

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

Catchbasins

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

Gutter Length

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

Curb length has been measured in several cities as a function of land use. Results for Tulsa and for ten Ontario cities are shown in Table 4-28. The Ontario results were compiled from aerial photographs. On a broad, totally urbanized area basis, curb length has been related to population density, e.g., Graham et al. (1974) for the Washington, D.C. area. Manning et al. (1977) augmented the Washington, D.C. data with data from six other U.S. cities to develop the equation:

$$GD = 413 - 353 ⟐ 0.839^{PD} \qquad (4\text{-}51)$$

where

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

Subcatchment gutter length may then be obtained simply by

$$GQLEN = GD ⟐ AREA/100$$

where

GQLEN = gutter (curb) length, 100-ft, and
WAREA = subcatchment area, ac.

Equation 4-51 should be used for large areas, such as an aggregated subcatchment used for continuous simulation. Site specific data are always preferred in any event.

Table 4-28. Measured Curb Length Density for Various Land Uses (Heaney et al., 1977; Sullivan et al., 1978)

	Tulsa, Oklahoma			10 Ontario Cities		
Land Use	mi/ac	km/ha	100-ft/ac	mi/ac	km/ha	100-ft/ac
Residential	0.076	0.30	4.0	0.042	0.17	2.2
Commercial	0.081	0.32	4.3	0.057	0.23	3.0
Industrial	0.042	0.17	2.2	0.025	0.099	1.3
Park	0.042	0.17	2.2	—	—	—
Open	0.016	0.063	0.85	0.015	0.059	0.79
Institutional	—	—	—	0.030	0.12	1.6

Constituent Loadings

As an alternative to the several buildup options available in groups J2 and J3, initial desired constituent loads may be entered on a per acre basis for each subcatchment. Total initial loads are then computed simply by multiplication by the subcatchment area,

$$\text{PSHED} = \text{pshed} ⟐ \text{WAREA} ⟐ \text{FACT1} \tag{4-53}$$

where

PSHED = initial surface constituent load, e.g., mg for NDIM = 0,
pshed = loading entered on data group L1, e.g., lb/ac for NDIM = 0,
WAREA = subcatchment area, ac, and
FACT1 = conversion factor, e.g., 453600 mg/lb for NDIM = 0.

Loadings may be entered for any number of constituents. A loading entered for one subcatchment does not affect buildup calculations on another for which a zero loading is used.

For continuous simulation, constituents will buildup between storms, (unless the rating curve option is used). These buildup parameters must be entered in groups J2 and J3. The initial loading will have no effect after the first storm has ended except for a possible residual load (PSHED) remaining on the surface. The loading parameters on group L1 are thus most easily adapted to single event simulation. They also provide one method of avoiding computation of an equivalent gutter length for land uses such as parking lots (if that type of normalized loading rate is being used).

Overall Sensitivity to Quality Parameters

One of the advantages of computer simulation is that it permits examination of the interactions between the complex precipitation time series and the various quantity and quality process of the catchment. It should be borne in mind that quality buildup processes in the model occur only during storms (or during runoff due to snow melt). For the moment it will be assumed that the rating curve approach is not being used.

As a general rule, predicted concentrations and total loads are most sensitive to buildup rates. Twice the initial surface load usually means that about twice the load in the runoff will occur. (An obvious qualification is if washoff parameters are such that not all the material is washed from the surface during most storm events.) For instance, if linear buildup is used for dust and dirt, parameter DDFACT in group J2 is a very important parameter. But the upper limit to buildup also enters the picture.

Consider the sketch in Figure 4-43. If the limiting buildup quantity is reached before a storm occurs, the results will be sensitive to the buildup limit (i.e., DDLIM or QFACT(1)) but not the rate. On the other hand, if the limit is not reached before a storm occurs, the results will be sensitive to the buildup rate (i.e., DDFACT or QFACT(3)) but not the limit. During continuous simulation the interevent time between storms varies, typically with an exponential probability density function. But examination of the average interevent time should permit a sensitivity analysis of the type sketched in Figure 4-43. A similar argument could be made using power, exponential or Michaelis-Menton buildup functions.

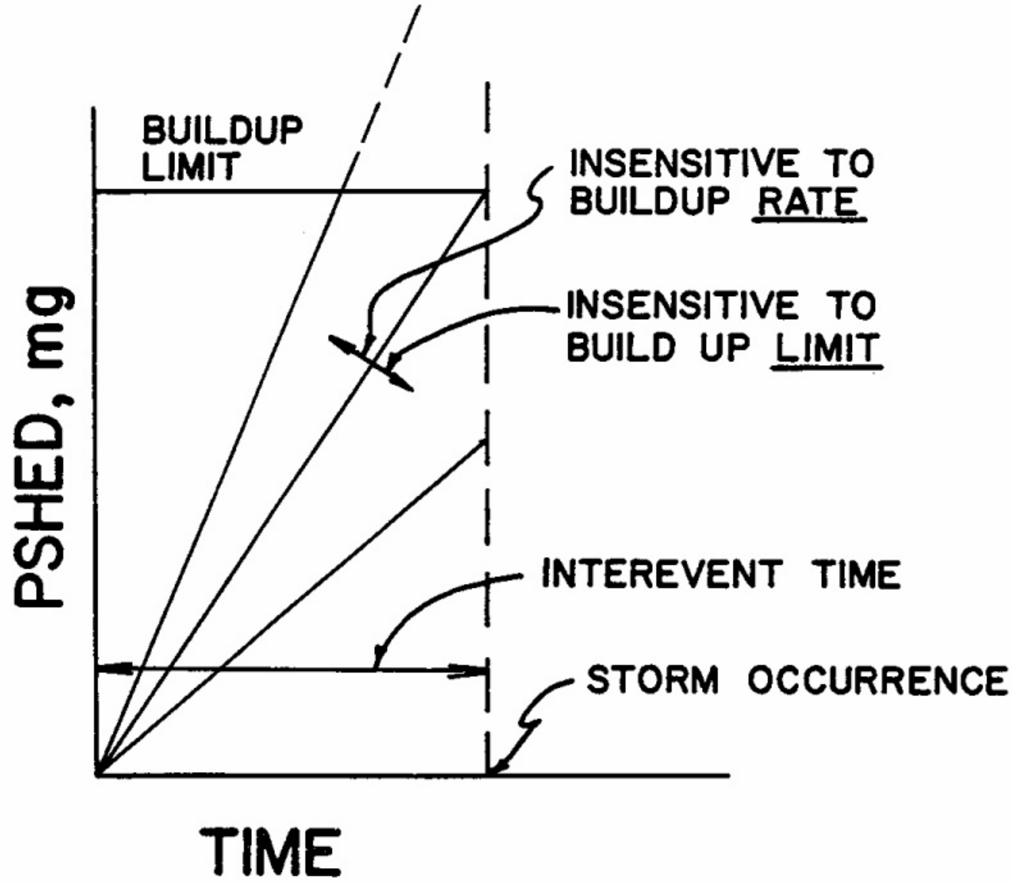

Figure 4-43. Interaction of buildup parameters and storm interevent time.

The effect of street cleaning is also obviously related to average interevent time. Clearly if the interval, CLFREQ, exceeds the storm interevent time, cleaning will have a decreasing effect. For example, for a continuous simulation of Des Moines, Iowa, street cleaning had essentially no effect for intervals greater that 20 days (Heaney et al., 1977). The average interevent time for Des Moines is about 4 days.

Should it be desired to evaluate the average interevent time for precipitation, the computer program SYNOP may be used to process the National Weather Service precipitation tapes. This is described in the EPA Area-wide Assessment Procedures Manual (EPA, 1976). Alternatively, the SWMM Statistics Block may be used.

Total storm loads will be sensitive to washoff parameters as long as they do not already produce 100 percent washoff during most storms. For example, in many past SWMM applications, parameters RCOEF and WASHPO (Equation 4-38) were set to 4.6 in.^{-1} and 1.0, respectively. This resulted in 90 percent washoff after 0.5 in. (13 mm) of runoff (independent of the time, as discussed earlier). Since most applications of single event SWMM simulated storm events for which runoff was greater than 0.5 in. (13 mm), total loads were insensitive to increases in RCOEF and relatively insensitive to decreases.

This may still be true for single event simulations of “large” storms (i.e., depths greater that 0.5 in. or 13 mm). But during continuous simulation the median runoff depth is likely to be considerably less than 0.5 in. (13 mm), more on the order of 0.2 in. (5 mm). Hence, washoff coefficients will be relatively more important for continuous simulation. As an indication of relative sensitivity, equation 4-38 can be rearranged for constant runoff rate, r, and for 90 percent washoff ($\mathrm{PSHED}/\mathrm{PSHED}_o = 0.1$) to give

$$\mathrm{RCOEF} \text{ ⟐ } R^{\mathrm{WASHPO}} \text{ ⟐ } t = \mathrm{RCOEF} \text{ ⟐ } R^{\mathrm{WASHPO-1}} \text{ ⟐ } d = -\ln 0.1 = 2.303$$

where

RCOEF = washoff coefficient, in.$^{-\mathrm{WASHPO}}$ ⟐ hr$^{\mathrm{WASHPO-1}}$,
WASHPO = washoff power,
t = time (runoff duration), hr,
r = runoff rate, in/hr, and
d = storm runoff depth = r ⟐ t, in.

This relationship between RCOEF and WASHPO (linear on semi-log paper) is shown for d = 0.2 and 0.5 in. (5 and 13 mm) on Figure 4-44 for various values of r. Note that for a half-inch of runoff, the familiar value for RCOEF of 4.6 is found for r = 1.0 in./hr or WASHPO = 1.0. The figure shows that for runoff rates less that 1.0 in./hr (25 mm/hr) RCOEF must be increased as WASHPO is increased to achieve the same percent washoff. (This is because an increase in WASHPO results in a decrease in washoff for $r < 1.0$ in./hr.) The relationship is reversed for $r > 1.0$ in./hr, but runoff rates this high occur only over brief intervals during a year. In fact, average hourly rainfall intensities greater than 1.0 in./hr are rarely found in precipitation records. Hence, during continuous simulation, if RCOEF or WASHPO is changed, the other parameter should be increased if the same percentage total washoff is desired. Manipulations similar to equation 4-54 may be performed if a different percentage washoff is being considered.

During single event simulation it may occasionally be important to match the pollutograph (concentration versus time) shape to measured data, as well as the total storm load. The effect of RCOEF and WASHPO on pollutographs has already been discussed and illustrated in Figures 4-32 to 4-36. Generally, if the data show that concentrations tend to increase with flow rate, especially late in the storm, then WASHPO should be greater than one.

If a rating curve approach is being used, buildup parameters will have no effect (KWASH = 1) or little effect (KWASH=2). In general, as WASHPO increases beyond 1.0, the predicted loads and concentrations will closely follow flow variations. If WASHPO is less than 1.0, concentration will be inversely proportional to flow.

As has been discussed, catchbasins have only a small effect on total storm load and affect pollutographs only during the first several time steps of a storm. Their main effect is to enhance the first flush, if there is one.

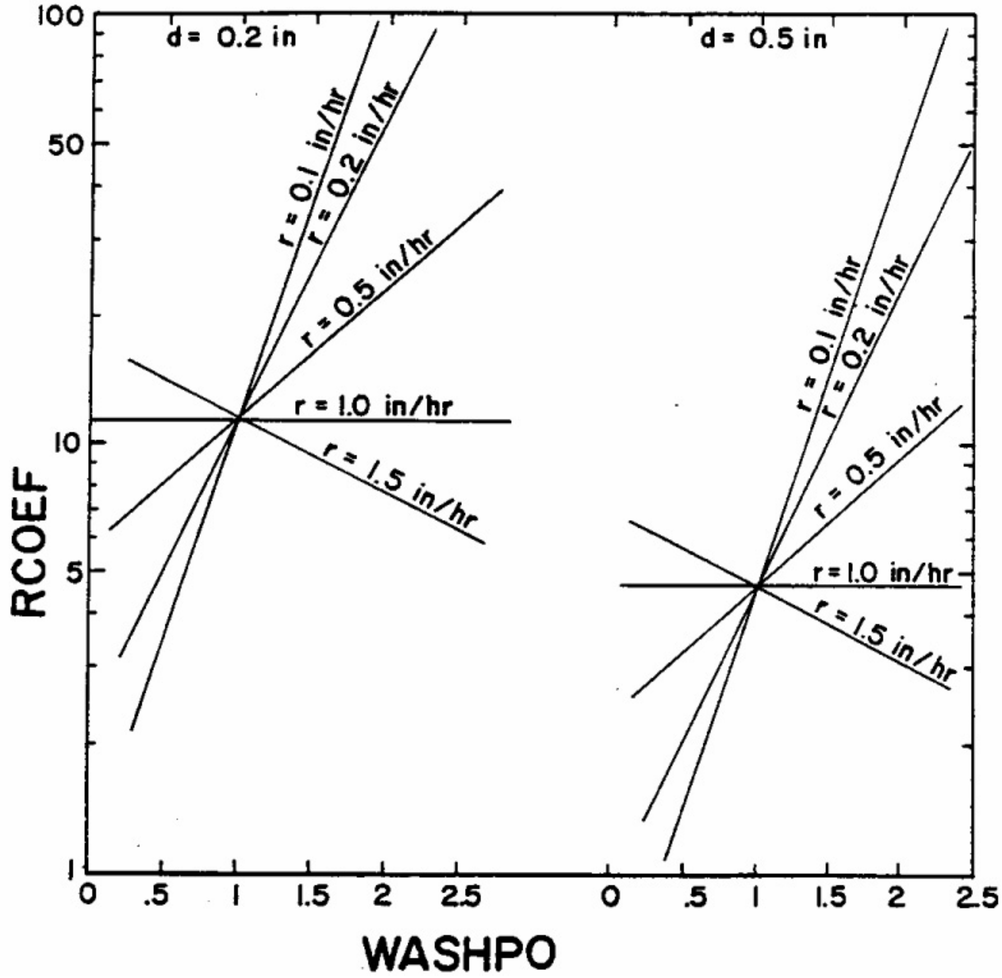

Figure 4-44. Relationship between RCOEF and WASHPO for 90 percent washoff during a storm event of runoff depth d. The runoff rate is r.

The constituent fractions (group J4) are capable of having a large effect on a few constituents if those constituents are added to a large loading. Thus, if suspended solids (SS) are high and 5 percent of SS is added to BOD, BOD can also be high without any surface loading. Since the fractions interrelate the constituents, it is often easier to calibrate the model without them, although it may be more physically realistic to include them.

Print Control (Groups M1-M3)

Runoff Output

The output tables and graphs generated by the Runoff Block are briefly described in Table 4-29. Possible outputs include: continuity checks for quantity and quality; daily, monthly, annual and simulation summaries of surface water flow; groundwater soil moisture, stage, and flow; hyetographs; inlet hydrographs; and graphs of soil moisture content and groundwater stage and flow.

Subroutine HYDRO prints a continuity check for quantity. The error will ordinarily be less than 1 percent due to round-off and the method of summing (numerically integrating) instantaneous flow rates. Should non-convergence messages be encountered, the continuity error could be somewhat higher.

Subroutine PRINTR generates a summary quality table that concisely summarizes the sources, concentrations, and losses of surface water quality simulation. Groundwater output by subcatchment is controlled by parameters ISFPF and ISFGF on the individual H2 data lines.

Print Options

Data groups M1-M3 control two types of printed output from subroutine PRINTR of the Runoff Block: (1) summary flows and concentrations, and (2) detailed time step printouts. The channels/inlets to be printed are selected using data groups M1 and M3. Summary tables listing total flow volumes and quality loads for each selected channel/inlet are always printed.

Table 4-29. Output from the Runoff Block

Description	Comments
Continuity Check	Quantity check from HYDRO that is always printed.
Continuity Check	Quality continuity check from PRINTR that is only if quality is simulated.
Daily, Monthly, and Annual Summaries	Select channel/inlet with M1 and M3 data groups. Control printout with parameter IPRN(3) on data group B2. Printed by Subroutine PRINTR.
Detailed time step printout every INTERV times	Select channel/inlet with M1 and M3 data groups. Control printout with INTERV parameter on data M1. INTERV=0 prints only simulation summary.
Detailed time step printout of groundwater	Select using parameter ISFPF on data group H2. The stage, soil moisture, and flow are printed by Subroutine PRINTR.
Graph of stage, flow and soil moisture from groundwater storage	Select using parameter ISFGF on data group H2. The stage, flow and soil moisture are graphed by Subroutine HCURVE, called from the Runoff Block.
Graph of the inlet hydrograph, hyetograph, and infiltration	Control graph using parameter IPRN(2) on data group B2.

The first possible output is summary output for daily, monthly, or annual periods. For any simulation, options exist for the frequency of summaries (daily, monthly and annual) as indicated by parameter IPRN(3) on data group B1. Caution should be used in order not to produce excessive lines and pages of output.

The second type of output available is on a time step basis. Single event SWMM will print output for desired locations for the total event duration. Since there is no limit on time steps, it is possible for this output to be lengthy. However, the number of time steps between printing may be varied using parameter INTERV in group M1.

For longer (continuous) simulation, time step print out is available for up to ten specified time periods. The parameters are entered on data group M2. The choice of these time periods must be made in advance and can be most reasonably accomplished by examination of the precipitation record prior to running the total continuous simulation, using the Rain Block.

All time step flows and concentrations are <u>instantaneous</u> values at the indicated time. In addition to the time step values, the total load, and flow-weighted averages and standard deviations are printed for flow and each quality parameter.

The SWMM user can use IPRN(3) on data group B2, INTERV on data group M1, and NDET on data group M2 to control the amount of printout. At a minimum for each selected channel/inlet a simulation summary will be generated. At the most a detailed time step printout for every time step, plus daily, monthly, annual, and simulation summaries will be generated. Judicious usage of the print controls is strongly recommended.

The print control groups mark the end of Runoff Block input. The sequence of all required input data is given in Table 4-30, followed by detailed instructions for data entry in Table 4-31. Control is now returned to the Executive Block. For review of hydrographs and pollutographs and for ease of calibration, use of the Graph Block is highly recommended. Finally, continuous SWMM output may most conveniently be summarized using the Statistics Block.

Table 4-30. Input Data Sequence for the Runoff Block.

Data Group	Description
$Runoff	Read in Executive Block - Starts Runoff Simulation
A1	Descriptive Titles - 2 lines
B1-B4	Control Parameters
C1-C5	Snowmelt Parameters
D1	Precipitation Control
E1-E3	Precipitation Data
F1	Evaporation Data
G1	Channel/Pipe Data
G2	Weir, Orifice Data
H1	Subcatchment Surface Data
H2-H4	Subcatchment Soil Moisture and Groundwater Data
I1-I3	Subcatchment Snowmelt Data
J1-J4	Quality Data
K1	Erosion Data
L1	Subcatchment Quality Data
M1-M3	Print Control Input

Table 4-31. Runoff 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
TITLE	Title lines: two lines with heading to be printed on output. Each line has format A76.	Blank
	First Control Data Group	
B1	Group identifier	None
METRIC	Metric input-output. = 0, Use U.S. customary units = 1, Use metric units. Metric input indicated in brackets [ ] in remainder of this table.	0
ISNOW	Snowmelt parameter[1] = 0, Snowmelt not simulated. = 1, Single event snowmelt simulation. = 2, Continuous snowmelt simulation.	0
NRGAG	Number of hyetographs (rain gages), maximum of 10 hyetographs.	1

Table 4-31. Continued.

Variable	Description	Default
INFILM	Choice of infiltration equation = 0, Horton equation used = 1, Green-Ampt equation used.	0
KWALTY	Quality (or erosion) simulated? = 0, No. = 1, Yes.	0
IVAP	Evaporation parameter[2] = 0, Evaporation data not read in, default rate used of 0.1 in/day [3 mm/day]. = 1, Read monthly evaporation data in Group F1. = 2, Read evaporation data from NSCRAT(3). Created by the Temp Block.	0
NHR	Hour of day of start of storm (24 hour clock, midnight = 0.0).	0
NMN	Minute of hour of start of storm.	0
NDAY	Day of month of start of simulation.[3]	2
MONTH	Month of start of simulation.[4]	8
IYRSTR	Year of start of simulation	41
	Second Control Data Group	
B2	Group identifier	None
IPRN(1)	Print control for SWMM input. = 0, Print all input data. = 1, Do not print channel/pipe, snowmelt, subcatchment, or quality data, only control information is printed. = K, where K equals possible combinations of channel/pipe (2), snowmelt (3), subcatchment (4), or water quality (5). Channel/pipe + subcatchment would be 24. Channel/pipe + subcatchment + quality would be 245, etc.	0
IPRN(2)	Print control for Runoff Block graphs. = 0, Plot all graphs. = 1, Do not plot hyetograph(s) (for each gage), or inlet hydrograph (sum of all inlets).	0
IPRN(3)	Print control for output of SWMM. 'Totals' below refer to precipitation, runoff and all quality parameters. Done for each inlet. Daily, monthly, and yearly printouts only function if simulation is long enough. = 0, Do not print daily, monthly, or yearly totals. = 1, Monthly and annual totals only, one year per page. = 2, Daily, monthly and annual totals, two months per page. Daily totals are printed whenever there is non-zero precipitation and/or runoff.	0
	Third Control Data Group	
B3	Group identifier	None
WET	Wet time step (seconds). WET must be ☚ 1 second.	3600.0

WETDRY	Transition between wet and dry time step in seconds. WETDRY should be greater than WET and less than DRY.	7200.0

Table 4-31. Continued.

Variable	Description	Default
DRY	Dry time step (seconds). DRY must be greater than or equal to WET.	86400.0
LUNIT	Units of LONG (simulation length) = 0, seconds. = 1, minutes. = 2, hours. = 3, days. = 4, ending date, a six figure number (yr/mo/dy), e.g. ,870730	0
LONG	Simulation length (units from LUNIT)	1.0
	Optional Subcatchment Data	
	Optional data group. The B4 data group is used only if the user desires to modify one of SWMM's subcatchment default parameters.	
B4	Group identifier	None
PCTZER	Percent of impervious area with zero detention (immediate runoff)[5]	25.0
REGEN	For continuous SWMM, infiltration capacity is regenerated using Horton type exponential rate constant equal to REGEN·DECAY, where DECAY is the Horton rate constant read in for each subcatchment in Group H1. N.R. (not required) if using Green-Ampt infiltration.	0.01
	General Snow Input Data	
	*** IF ISNOW = 0 IN GROUP B1, SKIP TO GROUP D1 ***	
C1	Group identifier	None
ELEV	Average watershed elevation, ft, msl [m, msl]	0.0
FWFRAC(1)	Ratio of free water holding capacity to snow depth (in. or mm w.e.)[6] on snow covered impervious area.	0.0
FWFRAC(2)	Ratio of free water holding capacity to snow depth (in. or mm w.e.) on snow covered pervious area.	0.0
	*** The following parameters are required only for ISNOW=2. ***	
FWFRAC(3)	Ratio of free water holding capacity to snow depth (in. or mm w.e.) for snow on normally bare impervious area.	0.0
SNOTMP	Dividing temperature between snow and rain, °F [°C]. Precipitation occurring at air temperatures above this value will be rain, at or below will be snow.	0.0
SCF	Snow gage catch correction factor. Snow depths computed from NWS precipitation tape will be multiplied by this value.[7]	1.0
TIPM	Weight used to compute antecedent temperature index, 0° $\leq$ TIPM $\leq$ 1.0. Low values (e.g., 0.1) give more weight to past temperatures. Values $\geq$ 0.5 essentially give weight to temperatures only during the past day.	0.0

RNM	Ratio of negative melt coefficient to melt coefficient. “Negative melt coefficient” is used when snow is warming or cooling below the base melt temperature without producing liquid melt. RNM is usually ≤ 1.0 with a typical value of 0.6.	0.6

Table 4-31. Continued

Variable	Description	Default
ANGLAT	Average latitude of watershed, degrees north.	0.0
DTLONG	Longitude correction, standard time minus mean solar time, minutes (of time).[8]	0.0
	Monthly Wind Speeds	
	Enter values only for months with potential snow melt. Enter values for months in any order.	
C2	Group identifier	None
NUMB	Enter number of months with wind speed data.	0
MONTH	Integer number of first month.	1
WIND(MONTH)	Average wind speed for first month, mi/hr [km/hr].	0.0
■	■	
MONTH	Integer number of last month.	12
WIND(MONTH)	Average wind speed for last month, mi/hr [km/hr].	0.0
	Areal Depletion Curve for Impervious Area[9]	
	IF ISNOW=1 IN GROUP B1, SKIP TO DATA GROUP C5	
C3	Group identifier	None
ADCI(1)	Fraction of area covered by snow (ASC) at “zero+”[10] ratio of snow depth to depth at 100 percent cover (AWESI).[11]	0.0
ADCI(2)	Value of ASC for AWESI = 0.1.	0.0
ADCI(3)	Value of ASC for AWESI = 0.2.	0.0
■	■	
ADCI(9)	Value of ASC for AWESI = 0.8.	0.0
ADCI(10)	Value of ASC for AWESI=0.9.	0.0
	Note: Program automatically assigns value of ADCI=1.0 when AWESI=1.0.	
	Areal Depletion Curve for Pervious Area[9]	
C4	Group identifier	None
ADCP(1)	Fraction of area covered by snow (ASC) at “zero+”[10] ratio of snow depth to depth at 100 percent cover (AWESI).[11]	0.0
ADCP(2)	Value of ASC for AWESI = 0.1.	0.0
ADCP(3)	Value of ASC for AWESI = 0.2.	0.0
■	■	
ADCP(9)	Value of ASC for AWESI = 0.8.	0.0
ADCP(10)	Value of ASC for AWESI = 0.9.	0.0
	Note: Program automatically assigns value of ADCP = 1.0 when AWESI = 1.0.	

Table 4-31. Continued

Variable	Description	Default
	Air Temperatures	
	READ GROUP C5 ONLY IF ISNOW = 1. SKIP TO GROUP D1 IF ISNOW = 2.	
	For ISNOW = 2 (continuous SWMM), air temperatures are entered in the Temp Block. For ISNOW = 1, read an air temperature for each time interval DTAIR, for a total of NAIRT values. (Maximum number of values = 200. If more are needed, use ISNOW = 2 option.) DTAIR, the time step of air temperatures, is not necessarily equal to the time steps entered on data group B1. Air temperatures are considered constant over the air time step.	
C5	Group identifier	None
DTAIR	Time interval for input of air temperatures, hours. First line only.	0.0
NAIRT	Number of air temperatures read. First line only.	0
TAIR(1)	Air temperature during time interval 1, °F [°C].	0.0
■	■	
TAIR(NAIRT)	Air temperature during time interval NAIRT, °F [°C].	0.0
	First Rainfall Control Card	
D1	Group identifier	None
ROPT	Precipitation input option. = 0, Read NRGAG hyetographs on E1, E2 and E3 data groups. (Rain data can be saved permanently on NSCRAT(1) using the @ function.) = 1, Read processed precipitation file on JIN file. This file is either from the Rain Block (earlier saved JOUT file) or from a previous run of the Runoff Block (earlier saved NSCRAT(1) file). Unless blocks are run as part of a single overall SWMM run, access to earlier saved files is through the @ function described in Section 2.	0
	Second Rainfall Control Card	
E1	Group identifier	None
KTYPE	Type of precipitation input. Precipitation is in units of in./hr [mm/hr] for THISTO minutes or hours. Use variable KTIME to select units of time. = 0, Read KINC precipitation values per line. = 1, Read KINC time and precipitation pairs per line. = 2, Read time and NRGAG precipitation values per line.	0
KINC	Number of precipitation or time/precipitation pairs per line. Enter any number if KTYPE=2.	0
KPRINT	Print control for precipitation input. = 0, Print all precipitation input. = 1, Suppress all but summary of precipitation input.	0
KTHIS	Variable THISTO option. Data input on E2 lines. = 0, rainfall interval (THISTO) is constant. = K, where K is the number of variable rainfall intervals entered on the E2 data group lines. Precipitation values outside the time frame of any variable rainfall interval uses THISTO as the rainfall interval.	0

Table 4-31. Continued

Variable	Description	Default
KTIME	Precipitation time units. = 0, time in minutes. = 1, time in hours.	0
KPREP	Precipitation unit type. = 0, intensity, in./hr [mm/hr]. = 1, total precipitation volume over the interval, in. [mm]	0
NHISTO	Number of data points for each hyetograph.	None
THISTO	Time interval between values, units of KTIME.	None
TZRAIN	Initial time of day of rainfall input, units of KTIME. Added to times entered in groups E2 and E3. (If first time entered in groups E2 and/or E3 is 0.0, TZRAIN will ordinarily correspond to time of start of storm entered on group B1.)	0.0

Variable Rainfall Interval Information

Required only if KTHIS > 0. Enter variable precipitation intervals, 10 per line for a total of KTHIS intervals. This data group is used to collate rainfall records of differing intervals, for example, a period of 5 minute rainfall between periods of 15 minute rainfall. See text.

Variable	Description	Default
E2	Group identifier	None
WTHIS(1,1)	Start time for first variable precipitation interval. Units of KTIME.	0.0
WTHIS(1,2)	End time for first variable precipitation interval. Units of KTIME.	0.0
WTHIS(1,3)	Length of THISTO for the first precipitation interval. Units of KTIME.	1.0
■	■	
WTHIS(KTHIS,1)	Start time for last variable precipitation interval. Units of KTIME.	0.0
WTHIS(KTHIS,2)	End time for last variable precipitation interval. Units of KTIME.	0.0
WTHIS(KTHIS,3)	Length of THISTO for the last precipitation interval. Units of KTIME.	1.0

Rainfall input if KTYPE = 0

Rainfall hyetograph lines: read KINC intervals per line, up to NHISTO values. Repeat group E3 for each hyetograph, up to NRGAG times.

Variable	Description	Default
E3	Group identifier	None
RAIN(1)	Rainfall intensity, first interval, in./hr [mm/hr].	0.0
■	■	0.0
RAIN(KINC)	Rainfall intensity, last interval per line, in./hr [mm/hr].	

Note: If ISNOW=1, snowfall during a time step may be entered as a negative value. Units are in. [mm] water equivalent/hr.

Table 4-31. Continued

Variable	Description	Default
Rainfall input if KTYPE = 1		
Rainfall hyetograph lines: read KINC pairs per line, up to NHISTO values. Repeat group E3 for each hyetograph, up to NRGAG times.		
E3	Group identifier	None
REIN(1)	Time of first precipitation. Units of KTIME.	0.0
REIN(2)	Precipitation in./hr [mm/hr], for first interval.	0.0
■	■	
REIN(2*KINC-1)	Time of last precipitation. Units of KTIME.	0.0
REIN(2*KINC)	Precipitation for last interval, in./hr [mm/hr].	0.0
Note: If ISNOW=1, snowfall during a time step may be entered as a negative value. Units are in. [mm] water equivalent/hr.		
Rainfall input if KTYPE = 2		
Rainfall hyetograph lines: read NRGAG precipitation values per line. Repeat NHISTO times.		
E3	Group identifier	None
REIN(1)	Time of precipitation. Units of KTIME.	0.0
REIN(2)	Precipitation, first raingage, in./hr [mm/hr].	0.0
■	■	
REIN(NRGAG+1)	Precipitation, last raingage, in./hr [mm/hr].	0.0
Note: If ISNOW=1, snowfall during a time step may be entered as a negative value. Units are in. [mm] water equivalent/hr.		
* * * INCLUDE THIS GROUP ONLY IF IVAP=1 ON GROUP B1 * * *		
Evaporation data[12]		
F1	Group identifier	None
VAP(1)	Evaporation rate for month 1 (January) in./day [mm/day].	0.0
■	■	
VAP(12)	Evaporation rate for month 12 (December) in./day [mm/day].	0.0
Channel/Pipe Data		
Channel/pipe data: one line per channel/pipe (if none, leave out). Maximum number of channels or pipes plus inlets is 200. An inlet is any location identified by NGTO (groups G1 and H1) that is not listed in group G1 as a channel or pipe. All inlets are saved on interface file, if JOUT $\neq$ 0.		
	Variables with asterisks can be modified using the Default/Ratio option.[13,14]	
G1	Group identifier	None
NAMEG[15]	Channel/pipe number.	None
NGTO[15,16]	Channel/pipe or inlet number for drainage.	None

Table 4-31. Continued

Variable	Description	Default
NPG=NP	Type of channel or pipe. = 1 for channel (trapezoidal channel), = 2 for circular pipe, = 3 for dummy channel/pipe, inflow=outflow,[17] = 4 for parabolic channel, = 5 for trapezoidal channel with weir or orifice (follow with G2 data group), = 6 for circular pipe with weir or orifice (follow with G2 data group), and = 7 for parabolic channel with weir or orifice (follow with G2 data group).	None
	*** The following parameters are N.R. if NP=3 ***	
GWIDTH=G1*	Bottom width of trapezoidal channel[18], diameter of pipe, or top width of parabolic channel, ft [m].	0.0
GLEN=G2*	Length of channel/pipe, ft [m].	0.0
G3*	Invert slope, ft/ft.	None
GS1=G4	Left-hand side slope, ft/ft.[19] (Slope = horiz./vert.)	None
GS2=G5	Right-hand side slope, ft/ft.	None
G6*	Manning's roughness coefficient.	None
DFULL=G7*	Depth of channel when full, ft [m]. (N.R. if NP equals 2, 3, or 6)	None
GDEPTH=G8*	Starting depth of pipe/channel, ft [m].	0.0
	Control Structure Description	
	A G2 data group must follow a G1 line if NPG is greater than 4.	
G2	Group identifier	None
WTYPE	Type of weir/orifice, = 0, Broad or narrow crested weir, = 1, V-notched weir, or = 2, Orifice.	0
WELEV	Elevation of weir (bottom of notch for V-notch) or of orifice centerline, referenced to bottom of channel/pipe, ft [m].	0.0
WDIS	Discharge coefficient of the weir or orifice (parameter C in equations 4-5, 4-6, 4-7). Units for equations 4-5 or 4-6: $ft^{1/2}$/sec [$m^{1/2}$/sec]. Parameter C_d in equation 4-7 is dimensionless.	3.3
SPILL	Weir length (e.g., width of spillway) for a broad or narrow crested weir, ft [m]. The angle (degrees) of the notch for a V-notch weir. The cross sectional area of the outflow orifice, ft^2 [m^2].	1.0

Table 4-31. Continued

Variable	Description	Default
Subcatchment Data		
REPEAT GROUP H1 FOR EACH SUBCATCHMENT (MAXIMUM of 200)		
Maximum of 200 different subcatchments. Variables with asterisks can be modified using the Default/Ratio option.[13,14]		
H1	Group identifier	None
JK	Hyetograph number (based on the order in which they are input, in Group E3).	1
NAMEW[20]	Subcatchment number	None
NGTO[15,21]	Channel/pipe or inlet (manhole) number for drainage.	None
WW(1)*	Width of subcatchment, ft. This term actually refers to the physical width of overland flow in the subcatchment and may be estimated as illustrated in the text.[22]	None
WAREA=WW(2)*	Area of subcatchment, acres [ha].	None
WW(3)*	Percent imperviousness of subcatchment, (percent hydraulically effective impervious area).	None
WSLOPE=WW(4)*	Ground slope, ft/ft (dimensionless).	None
WW(5)*	Impervious area Manning’s roughness.	None
WW(6)*	Pervious area Manning’s roughness.	None
WSTORE=WW(7)*	Impervious area depression storage, in. [mm].	None
WSTORE=WW(8)*	Pervious area depression storage, in. [mm].	None
*** Horton equation parameters if INFILM=0 (Group B1) ***		
WLMAX=WW(9)*	Maximum initial infiltration rate, in./hr [mm/hr].	None
WLMIN=WW(10)*	Minimum (asymptotic) infiltration rate, in./hr [mm/hr].	None
DECAY=WW(11)*	Decay rate of infiltration in Horton’s equation, 1/sec.	None
*** Green-Ampt equation parameters if INFILM=1 (Group B1) ***		
SUCT=WW(9)*	Average capillary suction, in. (mm) of water.	None
HYDCON=WW(10)*	Saturated hydraulic conductivity of soil, in./hr (mm/hr).	None
SMDMAX=WW(11)*	Initial moisture deficit for soil, volume air/volume voids (fraction).	None

Table 4-31. Continued

Variable	Description	Default
	Groundwater Subcatchment Data	
	Data groups H2, H3, and H4 describe the groundwater portion of the subcatchment. They should follow the correct H1 data group line. There are a maximum of (any) 100 subcatchments with groundwater simulation allowed.	
H2	Group identifier	None
NMSUB	Subsurface subcatchment indicator variable, must be same as preceding NAMEW.[13,14]	None
NGWGW	Number of inlet, channel or pipe for subsurface drainage. Does not have to be the same as preceding NGTO for surface runoff.	None
ISFPF	Indicator variable for saving soil moisture, water table elevation and outflow for printing out. = 0, do not save subsurface information, or = 1, save subsurface information for printout.	0
ISFGF	Indicator variable for saving soil moisture, water table elevation and outflow for graphing. = 0, do not save subsurface information, or = 1, save subsurface information for graphing.	0
	*** See Figure X-1 for definition of elevation variables. ***	
BELEV	Elevation of bottom of water table aquifer, ft [m].	0.0
GRELEV	Elevation of ground surface, ft [m].	0.0
STG	Elevation of initial water table stage, ft [m].	0.0
BC	Elevation of channel bottom or threshold stage for groundwater flow, ft [m].	0.0
TW	Channel water influence parameter ≥ BC, average elevation of water in channel or pipe over run, ft [m] or, < 0, (e.g., -1) channel water influence will be determined by depth in channel or pipe at the end of the previous time step.	0.0
	Groundwater Flow Coefficients And Exponents (Equations X-24 and X-25)	
	Variables with asterisks can be modified using the Default/Ratio option.[13,14] Indicator is NMSUB on data group H2.	
H3	Group identifier	None
A1*	Groundwater flow coefficient, in/hr-ft^{B1} [mm/hr-m^{B1}].	0.0
B1*	Groundwater flow exponent, dimensionless.	0.0
A2*	Coefficient for channel water influence in/hr-ft^{B2} [mm/hr-m^{B2}].	0.0
B2*	Exponent for channel water influence, dimensionless.	0.0
A3*	Coefficient for the cross product between groundwater flow and channel water, in/hr-ft^2 [mm/hr-m^2].	0.0
POR*	Porosity expressed as a fraction.	0.0
WP*	Wilting point expressed as a fraction.	0.0

Table 4-31. Continued

Variable	Description	Default
FC*	Field capacity expressed as a fraction.	0.0
HKSAT*	Saturated hydraulic conductivity, in./hr [mm/hr].	0.0
TH1*	Initial upper zone moisture expressed as a fraction.	0.0
More Groundwater Parameters		
Variables with asterisks can be modified using the Default/Ratio option.[13,14] Indicator is NMSUB on data group H2.		
H4	Group identifier	None
HCO*	Hydraulic conductivity vs. moisture content curve-fitting parameter (Eqn. X-21), dimensionless.	0.0
PCO*	Average slope of tension versus soil soil moisture curve (see Figs. X-2, X-3 X-4), ft/fraction [m/fraction].	0.0
CET*	Fraction of maximum ET rate assigned to the upper zone.	0.0
DP*	Coefficient for unquantified losses, (Eqn. X-23), in./hr [mm/hr].	0.0
DET*	Maximum depth over which significant lower zone transpiration occurs, ft [m].	0.0
IF ISNOW=0, SKIP TO GROUP J1. IF ISNOW=1, READ ONLY GROUP I1. IF ISNOW=2, READ BOTH GROUPS I1 AND I2, IN PAIRS. ORDER OF SUBCATCHMENTS MUST BE SAME AS IN GROUP H1, AND THERE MUST BE SNOW DATA GROUP(S) FOR EACH ONE. NOTE THAT ALL SNOW-DEPTH RELATED PARAMETERS REFER TO DEPTH OF SNOW WATER EQUIVALENT (w.e.)[6]		
Subcatchment Snow Input Data		
Variables with asterisks can be modified using the Default/Ratio option·[13,14]		
I1	Group identifier	None
JK1 (=NAMEW(N))	Subcatchment number.[23,24,25] Must correspond to NAMEW entered in Group H1.	None
SNN1	Fraction of impervious area with 100 percent snow cover (ISNOW=1) or subject to areal depletion curve (ISNOW=2).	0.0
SNN2=SNCP(N)	Fraction of pervious area subject to 00 percent snow cover (ISNOW=1). N.R. if ISNOW=2.	0.0
SNN3=WSNOW(N,1)	Initial snow depth of impervious area that is normally snow covered, in water equivalent (in. or mm w.e.)[6]	0.0
SNN4=WSNOW(N,2)	Initial snow depth on pervious area, in. w.e. [mm w.e.].	0.0
SNN5=FW(N,1)	Initial free water on snow covered impervious area, in. [mm].	0.0
SNN6=FW(N,2)	Initial free water on snow covered pervious area, in. [mm].	0.0
SN(1)*=DHMAX(N,1)	Melt coefficient (ISNOW=1) or maximum melt coefficient, occurring on June 21 (ISNOW=2) for snow covered impervious area, in. w.e./hr-°F [mm w.e./hr-°C].	0.0
SN(2)*=DHMAX(N,2)	Melt coefficient (ISNOW=1) or maximum melt coefficient, occurring on June 21 (ISNOW=2) for snow covered pervious area, in. w.e./hr-°F [mm w.e./hr-°C].	0.0

Table 4-31. Continued

Variable	Description	Default
SN(3)*=TBASE(N,1)	Snow melt base temperature for snow covered impervious area, °F [°C].	32.0
SN(4)*=TBASE N,2)	Snow melt base temperature for snow covered pervious area, °F [°C].	32.0
	Subcatchment Snow Input Data if ISNOW=2. Variables with asterisks can be modified using the Default/Ratio option.[13,14]	
I2	Group identifier	None
JK2 (=NAMEW(N))	Subcatchment number.[23,24,25] Must correspond to JK1 (Group I1) and NAMEW (Group H1).	None
SNN7=WSNOW(N,3)	Initial snow depth on impervious area that is normally bare, in. [mm].	0.0
SNN8=FW(N,3)	Initial free water on impervious area that is normally bare, in. [mm].	0.0
SN(5)*=DHMAX(N,3)	Maximum melt coefficient occurring on June 21, for snow on normally bare impervious area, in. w.e./hr-°F [mm w.e./hr-°C].	0.0
SN(6)*=TBASE(N,3)	Snow melt base temperature for normally bare impervious area, °F [°C].	32.0
SN(7)*=DHMIN(N,1)	Minimum melt coefficient occurring on December 21 for snow covered impervious area, in. w.e./hr-°F [mm w.e./hr-°C].	0.0
SN(8)*=DHMIN(N,2)	Minimum melt coefficient occurring on December 21 for snow covered pervious area, in. w.e./hr-°F [mm w.e./hr-°C].	0.0
SN(9)*=DHMIN(N,3)	Minimum melt coefficient occurring on December 21 for snow on normally bare impervious area, in. w.e./hr-°F [mm w.e./hr-°C].	0.0
SN(10)*=SI(N,1)	Snow depth above which there is 100 percent cover on snow covered impervious areas, in. [mm] w.e.[6]	0.0
SN(11)*=SI(N,2)	Snow depth above which there is 100 percent cover on snow covered pervious areas, in. [mm] w.e.	0.0
SNN9=WEPLOW(N)	Redistribution (plowing) depth on normally bare impervious area, in. [mm] w.e. Snow above this depth redistributed according to fractions below.	0.0
	Redistribution (plowing) fractions (see Figure 4-25). Snow above WEPLOW in. [mm] w.e. on normally bare[26] impervious area will be transferred to area(s) indicated below. The five fractions should sum to 1.0.	
SNN10=SFRAC(N,1)	Fraction transferred to snow covered impervious area.	0.0
SNN11=SFRAC(N,2)	Fraction transferred to snow covered pervious area.	0.0
SNN12=SFRAC(N,3)	Fraction transferred to snow covered pervious area in last catchment.[27]	0.0
SNN13=SFRAC(N,4)	Fraction transferred out of watershed.	0.0
SNN14=SFRAC(N,5)	Fraction converted to immediate melt on normally bare impervious area.	0.0

Table 4-31. Continued

Variable	Description	Default
	IF KWALTY $\neq$ 1 (GROUP B1) SKIP TO GROUP M1	
	General Quality Control Group	
J1	Group identifier	None
NQS	Number of quality constituents maximum = 10. Must have $1 < NQS \leq 9$ if erosion is simulated (IROS=1).[28]	None
JLAND	Number of land uses (Max of 5).	None
IROS	Erosion simulation parameter = 0, Erosion not simulated. = 1, Erosion of suspended solids simulated using the Universal Soil Loss Equation. Parameters input in Group K1. Output will be last quality constituent (i.e., constituent NQS+1).[28]	0
IROSAD	Option to add erosion constituent to constituent number IROSAD. E.g., if IROSAD=3, erosion will be added to constituent 3 (perhaps suspended solids). No addition if IROSAD=0. N.R. if IROS=0.[29]	0
DRYDAY	Number of dry days prior to start of storm.[30]	0.0
CBVOL	Average individual catchbasin storage volume, ft^3 [m^3].	0.0
DRYBSN	Dry days required to recharge catchbasin concentrations to initial values (CBFACT, Group J3). Must be > 0.	1.0
RAINIT	For erosion, highest average 30-minute rainfall intensity during the year (continuous SWMM) or during the storm (single event), in./hr [mm/hr]. N.R. if IROS = 0.	0.0
	*** Street Sweeping Parameters ***	
REFFDD	Street sweeping efficiency (removal) fraction) for “dust and dirt.”	0.0
	*** The following two variables are required only for simulations longer than one month. ***	
KLNBGN	Day of year on which street sweeping begins (e.g. March 1 = 60).[31]	0
KLNEND	Day of year on which street sweeping stops (e.g. Nov. 30 = 334)[31]	367
	Land Use Groups	
	REPEAT FOR EACH LAND USE, TOTAL OF JLAND GROUPS. (MINIMUM = 1, MAXIMUM = 5) LAND USE 1 WILL BE THAT OF FIRST GROUP, LAND USE WILL BE THAT OF SECOND GROUP, ETC.	
J2	Group identifier	None
LNAME(J)	Name of Land use	‘Blank’
METHOD(J)	Buildup equation type for ‘dust and dirt’ (see text).[32] = -2, New default values,[14] = -1, New ratios,[13] = 0, Power-linear, = 1, Exponential, = 2, Michaelis - Menton.	0

Table 4-31. Continued

Variable	Description	Default
JACGUT(J)	Functional dependence of buildup parameters.[33] = 0, Function of subcatchment gutter length, = 1, Function of subcatchment area, = 2, Constant.	0
	*** Following are up to three buildup parameters.[32] (See Table 4-16) ***	
	Variables with asterisks can be modified using the Default/Ratio option·[13,14]	
DDLIM(J)*	Limiting buildup quantity	10
DDPOW(J)*	Power or exponent	0.0
DDFACT(J)*	Coefficient	0.0
	*** Street Sweeping Parameters[34] ***	
CLFREQ(J)*	Cleaning interval, days	0.0
AVSWP(J)*	Availability factor, fraction	0.0
DSLCL(J)*	Days since last cleaning, DSLCL ≤ CLFREQ	0.0

Constituent Groups

REPEAT FOR EACH CONSTITUENT, TOTAL OF NQS GROUPS. (MAXIMUM = 10) CONSTITUENT 1 WILL BE THAT OF FIRST GROUP, CONSTITUENT 2 THAT OF SECOND GROUP, ETC.

Variables with asterisks can be modified using the Default/Ratio option·[13,14]

J3	Group identifier	None
PNAME(K)	Constituent name.[35]	‘Blank’
PUNIT(K)	Constituent units.	‘Blank’
NDIM(K)	Type of units.[36] = 0, mg/l = 1, “Other” per liter, e.g., MPN/l = 2, Other concentration units, e.g., pH, JTU	0
KALC(K)	Type of buildup calculation[37] = 0, Buildup is fraction of “dust and dirt” for each land use = 1, Power-linear constituent buildup = 2, Exponential constituent buildup = 3, Michaelis-Menton constituent buildup = 4, No buildup required (with KWASH=1)	0
KWASH(K)	Type of washoff calculation[37] = 0, Power-exponential = 1, Rating curve, no upper limit = 2, Rating curve, upper limit by buildup equation	0
KACGUT(K)	Functional dependence of buildup parameters.[38] N.R. for KALC = 0 or 4 = 0, Function of subcatchment gutter length = 1, Function of subcatchment area = 2, Constant	0

Table 4-31. Continued

Variable	Description	Default
LINKUP(K)	Linkage to snowmelt. N.R. if ISNOW = 0 or KALC = 4. = 0, No linkage to snow parameters = 1, Constituent buildup during dry weather only when snow is present on impervious surface of subcatchment[39]	0
Following are up to five buildup parameters (see text and Tables 4-16, 4-17). Variables with asterisks can be modified using the Default/Ratio option·[13,14]		
QFACT(1,K)*	First buildup parameter, e.g., limit.	0.0
QFACT(2,K)*	Second buildup parameter, e.g., power or exponent.	0.0
QFACT(3,K)*	Third buildup parameter, e.g. coefficient.	0.0
QFACT(4,K)*	Fourth buildup parameter, N.R. if KALC ≠ 0.	0.0
QFACT(5,K)*	Fifth buildup parameter, N.R., if KALC ≠ 0.	0.0
	*** Following are two washoff or rating curve parameters. ***	
WASHPO(K)*	Power (exponent) for runoff rate.	0.0
RCOEF(K)*	Coefficient	0.0
	*** Miscellaneous parameters ***	
CBFACT(K)*	Initial catchbasin concentration[40] (units according to NDIM).	0.0
CONCRN(K)*	Concentration in precipitation[41] (units according to NDIM).	0.0
REFF(K)*	Street sweeping efficiency (removal fraction) for this constituent.	0.0
	Fractions for contributions from other constituents·[42]	
	REPEAT UNTIL ALL DESIRED FRACTIONS ARE ENTERED.	
J4	Group identifier	None
KTO	Number (from order in Group J3) of constituent to which fraction will be added.	0
KFROM	Number of constituent from which fraction is computed.	0
F1(KTO,KFROM)	Fraction of constituent KFROM to be added to constituent KTO.	0.0
	Erosion Data[43]	
	IF IROS=0 ON GROUP J1, SKIP TO GROUP L1	
	REPEAT GROUP K1 ONLY FOR EACH SUBCATCHMENT THAT IS SUBJECT TO EROSION COMPUTATIONS. ORDER OF GROUPS IS ARBITRARY, BUT A MATCH MUST BE FOUND OF SUBCATCHMENT NUMBER WITH A VALUE OF NAMEW USED IN GROUP H1.	
	Variables with asterisks can be modified using the Default/Ratio option·[13,14]	
K1	Group identifier	None
N=NAMEW	Subcatchment number.	None
ERODAR*	Area of subcatchment subject to erosion, acres [ha].	0.0

Table 4-31. Continued

Variable	Description	Default
ERLEN*	Flow distance in feet [meters] from point of origin of overland flow over erodible area to point at which runoff enters channel/pipe or inlet	0.0
SOILF*	Soil factor ‘K’.	0.0
CROPMF*	Cropping management factor ‘C’.	0.0
CONTPF*	Control practice factor ‘P’.	0.0

Subcatchment Surface Quality Data

IF NQS=0, SKIP TO GROUP M1

ONE LINE FOR EACH SUBCATCHMENT IS REQUIRED. ORDER IS ARBITRARY, BUT A MATCH MUST BE FOUND FOR EACH SUBCATCHMENT NUMBER (NAMEW) USED EARLIER IN GROUP H1.

Variables with asterisks can be modified using the Default/Ratio option·[13,14]

L1	Group identifier	None
N=NAMEW	Subcatchment number.	None
KL	Land use classification. 1 ≤ KL ≤ 5. Numbers correspond to input sequence of Group J2.	1
BA*=BASINS(N)	Number of catchbasins in subcatchment.	0
GQ*=GQLEN (N)	Total curb length within subcatchment hundreds of feet [km]. May not be required depending on method used to calculate constituent loadings (Groups J2 and J3).[44]	0
	The following constituent loading values may be input as an alternative to computation of loadings via methods specified groups J2 and J3 (for initial conditions only). For any non-zero values read in, initial constituent loadings will be calculated simply by multiplication of the value by the subcatchment area. ”Load” has units depending on value of NDIM (Group J3), according to the following table:	

NDIM	LOAD
0	pounds [kg]
1	$10^6 \times$ quantity, e.g. 10^6 MPN
2	$10^6 \times$ quantity $\times$ ft^3, e.g. 10^6 pH-ft^3.

PSHED(1,N)	Initial loading, first constituent, load/acre (load/ha).	0.0
■	■	
PSHED(10,N)	Initial loading, tenth constituent, load/acre (load/ha).	0.0

Channel/Inlet Print Control

M1	Group identifier	None
NPRNT	Total number of channels/pipes/inlets for which non-zero flows[46] (and concentrations) are to be printed (maximum = 200).[45]	0
INTERV	Print Control. = 0, Print statistical summary only. = 1, Print every time step. = K, Print every K time steps.	None

Table 4-31. Continued

Variable	Description	Default
	* * * IF NPRNT=0, SKIP GROUPS M2 and M3 * * *	
	Print Periods	
M2	Group identifier	None
NDET	Number of detailed printout periods. (Maximum of 10 periods.)	0
	** If NDET = 1 and STARTP(1) = 0 and STOPPR(1) = 0 then total simulation period will be printed as default. **	
STARTP(1)	First starting printout date, year, month, day, e.g., October 2, 1949 = 491002.	None
STOPPR(1)	First stopping printout date.	None
■	■	
STARTP(NDET)	Last starting date.	0
STOPPR(NDET)	Last stopping date.	0
	Channel/Inlet Print Groups: 16 Values per Line	
M3	Group identifier	None
IPRNT(1)[47]	Channel/inlet numbers for which flows and concentrations are to be printed.	None
■	■	
IPRNT(NPRNT)		None
	***** END OF RUNOFF BLOCK INPUT DATA *****	
	At this point, program will seek new input data from the Executive Block.	

Footnotes to Table 4-31

1. The main difference between single event and continuous snowmelt simulation follow. For single event SWMM, snow covered areas are constant (areal depletion curves are used for continuous SWMM) and input parameters are fewer. In addition, snowfall quantities are not computed on the basis of air temperatures but may only be input, if desired, as negative precipitation intensities on group E2. Melt coefficients are constant and there is no maintenance of the cold content of the snow pack, nor is there redistribution (e.g., plowing) from normally bare areas. For continuous SWMM, melt coefficients vary daily, from a maximum on June 21 to a minimum on December 21. Both modes use the same melt equations and melt routing procedures.
2. Evaporation is used to renew surface depression storage and is also subtracted from rainfall and/or snowmelt at each time step. It has a negligible effect on single event simulation, but is important for continuous simulation. Evaporation is not used to deplete the snow pack, i.e., it does not also act as sublimation, nor does it affect regeneration of infiltration capacity. However, the evaporation input to Runoff acts as an upper bound for ET losses from groundwater and soil moisture. Evaporation now also occurs from trapezoidal and parabolic channels.
3. Used for information only for single event SWMM. This parameter does not affect computations, but it is passed to subsequent blocks.
4. Used as subscript for monthly wind speed and evaporation data (Groups C2 and F1).
5. Immediate runoff occurs from impervious areas without depression storage, whereas runoff from areas with depression storage may be delayed. As PCTZER is increased, the rising limb of the hydrograph begins earlier.
6. All snow depths are in inches (or mm) of water equivalent, “in. [mm] w.e.” One inch of snow water equivalent equals a depth of approximately 11 inches of new snow on the ground surface.

7. Values of SCF are usually > 1.0 and increase as a function of wind speed. See Figure 4-2. The value of SCF can also be used to account for snow losses, such as interception and sublimation, not included in program computations.

8. Compute DTLONG as follows: Determine standard meridian (SM) for time zone of catchment (e.g., EST=75°W, CST=90°W, MST=105°W, PST=120°W). Let theta = average longitude of catchment, and delta = theta - SM. Then DTLONG = 4 (min/deg) × delta. Example: Minneapolis at theta = 93°W has DTLONG = +12 min (of time).

9. See Figures 4-3 and 4-4 for description of areal depletion curve.

10. Value of ADC may = zero, but curve need not pass through (0,0); see Figure 4-3. Thus ADC can take an arbitrary value for a small departure of AWESI from zero.

11. In the program, AWESI is the ratio of actual snow depth (WSNOW) to depth at 100 percent cover (SI, read in Group I2).

12. If this group is read, the default value of 0.1 in./day [3 mm/day] indicated in Group B1 no longer applies, i.e., the default value becomes zero.

13. Input values in this group indicated with asterisks are multiplied by ratios, initially set equal to 1.0. If the ID number = -1, non-zero data entries for parameters with asterisks will replace old values of the ratios. Ratios may be altered or reset to 1.0 any number of times. The intention of the use of ratios is to simplify sensitivity analyses, etc., by allowing easy changes of data values without re-entering data. Ratios may be reset any number of times and alter the indicated ratios to be applied to all following entries in this data group (until another ratio group is encountered).

14. Input parameters in this group indicated with asterisks will take on default values if input values are zero. If the ID number = -2, non-zero data entries for parameters with asterisks will become new default values for all future entries of these parameters. Default values may be altered or reset to their original values (except zero) any number of times. The indicated default values apply to all following entries in this data group (until another default group is encountered).

    It is not possible to reset a default value exactly to zero since only non-zero values are changed. However, the value may be made arbitrarily small by using E-format data entries. For example, 10^{-50} may be entered as 10E-50.

15. Numbers may be arbitrarily chosen, such that 1 ≤ NAMEG or NGTO ≤ 99999. However, if an inlet number is to correspond to an inlet manhole in the Transport Block, it must be ≤ 10,000. The maximum total number of inlets must be ≤ 200 for input to Transport and ≤ 200 for input to Extended Transport. There is no restriction for input to Storage/Treatment except that that block will select only one of the inlets on the interface file for input. Others will be saved but ignored. Channel/pipe numbers and inlet numbers are contained in the same array and thus must be distinct from one another; however, they may duplicate subcatchment numbers if desired. Each inlet is assigned a dummy channel/pipe to receive upstream flows. Hence the total number of channel/pipes plus inlets must be ≤ 200. Internal subscripts in the program for channel/pipe data are assigned in the order in which data in group G1 are read in.

    Of course, it makes no sense to indicate a channel/pipe with nothing entering it. Thus, each one should have flow entering, either from other channel/pipe(s) or from subcatchment(s).

16. A maximum of five different channel/pipes may feed to a single channel/pipe or to a single inlet. If more are desired, a dummy channel/pipe may be used to provide five additional “feeds.” See footnote 17.

17. Dummy channels may be used for two purposes: 1) to provide five additional "feeds" to a given channel/pipe or inlet (see footnote 16) by placing it in series with the channel/pipe or inlet (although, of course, by placing it in series with the original channel/pipe or inlet, it uses one of the original five “feeds”), or 2) to provide a location for print out of data. The latter situation arises because outflows from subcatchments may not be printed directly (using groups M1 - M3), only inflows or outflows to channel/pipes or inflows to inlets. Hence, if a dummy channel/pipe is placed immediately downstream from a subcatchment, the inflow (or outflow) to the dummy channel/pipe is the outflow from the subcatchment, (provided that that is the only subcatchment feeding the dummy channel/pipe).

18. A bottom width of zero for a channel corresponds to a triangular cross section.

19. A side slope of zero indicates a vertical wall, or a rectangular cross section.

20. Numbers may be arbitrarily chosen such that 1 ≤ NAMEW ≤ 99999. Numbers may duplicate channel/pipe and inlet numbers if desired. Internal subscripts in the program for subcatchment data are assigned in the order in which data in group H1 are read in.

21. A maximum of five different subcatchments may feed to a single inlet, (in addition to channel/pipes feeding the channel/pipe or inlet). If more "feeds" are desired, a dummy channel/pipe may be used to provide additional feeds. See footnote 17.

22. The subcatchment width is a key calibration parameter, one of the few that can significantly alter the shape of the hydrograph, rather than just the runoff volume. One way to think of the width is the area of the subcatchment divided by the average path length of overland flow (see Figure 4-13). The effect upon output hydrographs is illustrated in Figure 4-15 and is approximately as follows. For rainfall durations less than the time of concentration, (i.e., less than the equilibrium time of an impervious subcatchment at which inflow equal overflow), increasing the width effectively provides a greater cross sectional area for outflow from the subcatchment, thus increasing the magnitude of the peak flow and decreasing the time to peak. Decreasing the width has the opposite effect, and the subcatchment surface acts more as a reservoir, reducing and delaying the peak. For rainfall durations greater than the time of concentration, the magnitude of the peak is affected only minutely. The time to equilibrium conditions, that is the time of concentration, is reduced slightly for larger widths.

    The subcatchment width can thus be used to incorporate storage lost when pipes are removed from the simulation. For instance, if only a coarse discretization of the total catchment is desired, only a few or no pipes need be modeled. To account for this lost storage in the system, the overall subcatchment width is correspondingly reduced (see Figure 4-20). Whether for one aggregated catchment, or for a small individual subcatchment, a reasonable first approximation for determining the width is to use twice the length of the main drainage channel in the catchment (see Figure 4-20).

    The same subcatchment width entered here is used for the pervious area of the subcatchment and the total impervious area of the subcatchment (see Figure 4-11).

23. Subcatchment number(s) entered in Groups I1 and I2 must correspond exactly to numbers and order of group H1.

24. Numbers JK1 and JK2 must be the same.

25. Subscript N is the internal subcatchment number (subscript) determined from the order in which subcatchment data are entered in group H1.

26. "Normally bare" implies surfaces such as roadways and sidewalks that receive snowfall but are subject to early snow removal.

27. "Last subcatchment" is last one entered in group H1.

28. The 10 or fewer constituents may be arbitrarily chosen (see text). When erosion is simulated it is stored as the last constituent. Hence, no more than 9 other constituents may be simulated while using the erosion routine. Furthermore, at least one constituent must be simulated in addition to erosion in order to proceed correctly through program loops.

29. This addition is performed before constituent fractions are added (group J4).

30. A "dry day" is not well defined, but may be considered as the number of days prior to start of simulation, in which the cumulative rainfall is less than a specified value, e.g. 0.1 in (3 mm).

31. For year-round sweeping, let KLNBGN=0 and KLNEND=367. Leap years are not treated separately, other than in maintaining the proper number of days in February and in total annual days.

32. See the text for explanation and illustration of the various options for buildup of dust and dirt. Depending on the form of buildup chosen for each constituent (group J3), the land use buildup parameters may not be required.

33. If JACGUT=0, parameters DDLIM and DDFACT will be multiplied by GQLEN (group L1) in 100-ft (or km for metric input). If JACGUT=1, parameters DDLIM and DDFACT will be multiplied by WAREA (group H1) in acres [ha].

34. For continuous simulation street sweeping occurs at intervals of CLFREQ days, computed during the simulation using dry time steps only (no runoff and no unmelted snow on normally bare impervious areas). When cleaning

occurs, a fraction of each pollutant REFF·AVSWP is removed from each subcatchment. The availability factor, AVSWP, is intended to account for the relative amount of subcatchment surface that consists of streets, and therefore may be swept. See the text.

At start of single-event and continuous simulations, streets are swept approximately DRYDAY/CLFREQ times, each time removing a fraction REFF·AVSWP. Parameter DSLCL establishes proper backwards time sequence.

35. The constituent names and units established in this group will be carried through to subsequent SWMM blocks. See Figure 4-26 for illustration of how the character-format names and units will appear as headings.

36. Since most constituents are measurable in mass units, NDIM=0 will be the most common. Since concentrations will be printed using an F10.3 format, NDIM=0 should suffice also for constituents whose concentrations are usually given in ug/1. The value of NDIM basically affects conversion factors used in the program.

37. See the text for full explanation of buildup-washoff equation options and interpretation of parameters.

38. If KACGUT = 0, parameters QFACT(1,K) and QFACT(3,K) will be multiplied by GQLEN (group L1) in 100-ft [km]. If KACGUT=1, parameters QFACT(1,K) and QFACT(3,K) will be multiplied by WAREA (group H1) in acres [ha].

39. For instance, if chlorides are simulated, they might only be applied for street salting when snow is present. The rate of buildup will not be a function of the amount of snow, however.

40. For continuous SWMM, concentrations will be regenerated to this value during dry time steps over a period of DRYBSN days, (DRYBSN entered in group J1).

41. This concentration is assumed to be that of the runoff (and snowmelt) before adding washoff loads. The precipitation load is always added regardless of the washoff mechanism utilized, unless of course, CONCRN = 0.

42. After computing and summing all loads except rainfall, a fraction of any constituent may be added to any other. (No fractions are removed, however). This is intended to account for insoluble BOD etc. if surface loadings are based only on insoluble portions, as is true for instance for 1969 APWA data from Chicago. For example, 5 percent of suspended solids could be added to BOD. Alternatively, different particle size ranges could be simulated as different constituents, and other constituents could consist of fractions of the first group of different particle sizes. When these fractions are used, concentrations can be drastically (and subtly) increased if, for instance, suspended solids are high, soluble BOD is low and a fraction of 0.05 is used. The choice of whether or not any fractions should be entered depends upon how constituent data are being reported (e.g. total BOD or only the soluble fraction) and on how it is desired to simulate each constituent in SWMM.

43. See the text for explanation of method of computation, parameters and typical values. Also, there may be a need to consult with local soils experts (e.g., Soil Conservation Service or Agricultural Research Service or State Agricultural Extension Service experts in the U.S.) for knowledge of parameter values for particular areas.

    A value of the “sediment delivery ratio” is sometimes included in the U.S.L.E. computation. Since it is merely another multiplier, if desired it may incorporated into the “K” or “C” or “P” factors.

44. See footnotes 33 and 38. This is the only use of parameter GQLEN.

45. Zero flows are not printed to avoid voluminous output with continuous SWMM. (There are no quality loads when flows are zero). Thus, some care should be taken in examining the output, since if a zero flow occurs in the middle of a single-event simulation, for instance, it will not be listed. This can be determined by inspecting the sequential time of day printed with each set of values.

    Care should still be taken when running continuous SWMM, since one line of output will be generated for each hourly value of non-zero flow, for each indicated location, within the indicated time span. Hence, the potential exists for thousands of lines of output.

46. All printed values are instantaneous (flows and concentrations) at the end of the preceding time step.

47. These numbers correspond to numbers NAMEG and NGTO used in groups G1 and H1. They may be either positive or negative. A positive number will cause total inflows to the indicated channel/pipe or inlet to be printed. A negative number will cause the outflow to be printed. (Both a positive and negative value for the same location may be used). Regardless of the sign, only outflow concentrations are printed, however, since it is computationally in-

convenient to calculate the average inflow concentration. Of course, for an inlet (or dummy channel/pipe), inflow values equal outflow values.