Table 6-6. Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			Flow routing data for new shapes.		
A1	2X	1-2	Card identifier = A1.	--	Blank
	I3	5	Number of sewer cross-sectional shapes, in addition to the 13 program-supplied for which element routing parameters are to follow (maximum value = 2).	NKLASS	0
	I5	10	Control parameter for printing out flow routing parameters for all shapes, (about 500 lines). = 0, Suppress printing. = 1, To allow printing (for all shapes, program-supplied and additional)	KPRINT	0
			DELETE CARD GROUPS B1 TO B9 IF NKLASS = 0		
B1	2X	1-2	Card identifier = B1.	--	Blank
	8A4	3-18	16-letter name of shape 1.	NAME(I,14)	None
		19-34	16-letter name of shape 2.	NAME(I,15)	None
			Number of values of DNORM to be supplied (maximum value = 51, minimum value = 2).		
B2	2X	1-2	Card identifier = B2.	--	Blank
	I3	4-5	Number of values for shape 1.	NN(14)	None
	I5	9-10	Number of values for shape 2.	NN(15)	None

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			Number of values of QNORM to be read (maximum value = 51, minimum value = 2).		
B3	2X	1-2	Card identifier = B3.	--	Blank
	I3	4-5	Number of values for shape 1.	MM(14)	None
	I5	9-10	Number of values for shape 2.	MM(15)	None
			Value of A/A_f [1] corresponding to the maximum Q/Q_f [2] value for each shape.		
B4	2X	1-2	Card identifier = B4.	--	Blank
	F8.0	3-10	A/A_f value for shape 1.	ALFMAX(14)	None
	F10.0	11-20	A/A_f value for shape 2.	ALFMAX(15)	None
			Maximum Q/Q_f [2] value for each shape.		
B5	2X	1-2	Card identifier = B5.	--	Blank
	F8.0	3-10	Maximum Q/Q_f value for shape 1.	PSIMAX(14)	None
	F10.0	11-20	Maximum Q/Q_f value for shape 2.	PSIMAX(15)	None
			Factor used to determine full flow area for each shape, i.e., for use in AFULL = AFACT(GEOM1)^2.	AFACT	
B6	2X	1-2	Card identifier = B6.	--	Blank
	F8.0	3-10	Factor for shape 1.	AFACT(14)	None
	F10.0	11-20	Factor for shape 2.	AFACT(15)	None

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			Factor used to determine full flow hydraulic radius for each shape, i.e., for use in equation RADH = RFACT(GEOM1).		
B7	2X	1-2	Card identifier = B7.	--	Blank
	F8.0	3-10	Factor for shape 1.	RFACT(14)	None
	F10.0	11-20	Factor for shape 2.	RFACT(15)	None
			REPEAT CARD GROUP B8 FOR EACH ADDED SHAPE.		
			Input of tabular data (depth of flow, y, divided by total depth of conduit, y_f (y/y_f)) for each added shape corresponding to the NN-1 equal divisions of A/A_f of the conduit as given by NN on card group B2.[3]		
B8	2X	1-2	Card identifier[4] = B8.	--	Blank
	F8.0	3-10	First value for y/y_f for shape 1.	DNORM(I,1)	None
	7F10.0	11-20	Second value of y/y_f for shape 1.	DNORM(I,2)	None
		.	.	.	
		.	.	.	
		.	Last value of y/y_f for shape 1.	DNORM(I,NN(I))	None
			(Total of NN(14)/8 + NN(15)/8 data cards)		
			REPEAT CARD GROUP [illegible] FOR EACH ADDED SHAPE		
			Input of tabular data (flow rate, Q, divided by the flow rate of the conduit running full, Q_f (Q/Q_f)) for each added shape corresponding to the MM-1 equal divisions of A/A_f of the conduit as given by MM on card group B3.		

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
B9	2X	1-2	Card identifier[4] = B9.	--	Blank
	F8.0	10	First value of Q/Q_f for shape 1.	QNORM(I,1)	None
	7F10.0	11-20	Second value of Q/Q_f for shape 1.	QNORM(I,2)	None
		.	.	.	
		.	.	.	
		.	Last value of Q/Q_f for shape 1.	QNORM(I,MM(I))	None
			(Total of MM(14)/8 + MM(15)/8 data cards)		
			Two title cards.		
C1	2X	1-2	Card identifier = C1.	--	Blank
	19A4	3-78	Title, two cards with heading to be printed on output.[5]	TITLE	Blank
			Execution control data.		
D1	2X	1-2	Card identifier = D1.	--	Blank
	I8	3-10	Total number of time-steps, no limit.	NDT	None
	7I5	14-15	Total number of non-conduits elements into which there will be card input of hydrographs and pollutographs in card group R1 (maximum = 80).[7]	NINPUT	None
		19-20	Total number of non-conduit elements at which input hydrographs and pollutographs are to be printed out (maximum = 80, minimum = 0).	NNYN	None
		24-25	Total number of non-conduit elements at which routed hydrographs and pollutographs are to be printed out (maximum = 80, minimum = 0).	NNPE	None
		26-30	Total number of non-conduit elements at which flow is to be transferred to a subsequent block by tape or disk (maximum = 80).[8]	NOUTS	None

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
		35	Control parameter for program-generated error messages occurring in the execution of the flow routing scheme. These errors do not normally[9] affect the program execution. = 0, messages suppressed. = 1, messages printed.	NPRINT	0
		40	Total number of pollutants being routed (maximum = 4, minimum = 0). When NPOLL = 0, program will route flows only and all quality operations will be bypassed.	NPOLL	0
		45	Total number of iterations to be used in routing subroutine (4 recommended).	NITER	4
	4X,I6	50-55	Starting date of storm, year-month-day, e.g., July 20, 1979 = 790720. Superseded by value on interface file from previous block, if accessed.	IDATEZ	0
	2I5	56-60	Metric input/output. = 0, U.S. customary units. = 1, Metric units, indicated in brackets [ ] among input variables.	METRIC	0
		61-65	Print interval for input and output elements. Use 1 for printing at each time step. Value of zero will result in printing of total loads and moments only.	INTPRT	0
			Execution control data.		
D2	2X	1-2	Card identifier = D2.	--	Blank
	F8.0	3-10	Size of[6,10] time-step for computation, sec.	DT	None
	5F10.0	11-20	Allowable error for convergence of iterative methods in routing routine (0.0001 recommended).	EPSIL	0.0001

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
		21-30	Total number of days (dry-weather days) prior to simulation during which solids were not flushed from the sewers.	DWDAYS	0
		31-40	Starting time of day of storm, hours and fraction, e.g., 5:30 PM is 17.5. Superseded by value on interface file from previous block, if accessed.	TZERO	0
		41-50	Kinematic viscosity of water, ft^2/sec [cm^2/sec]. Required only if SPG > 1.0 for any of pollutants in card group F1.	GNU	10^{-5} [10^{-2}]
		51-55	Total catchment area, ac [ha]. Superseded by value on interface file from previous block, if accessed.	TRIBA	0.0
			Execution control data.		
D3	2X	1-2	Card identifier = D3.	--	Blank
	I3	5	Control parameter specifying means to be used in transferring inlet hydrographs. = 0, Input from a preceding block using interface file (tape/disk), JIN (card input optional).[11] = 1, Input from cards only.	NCNTRL	0
	3I5	10	Control parameter in estimating groundwater infiltration inflows.[12] = 0, Infiltration not estimated (INFIL not called and corresponding data omitted). = 1, Infiltration to be estimated (subroutine INFIL called).	NINFIL	0

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
		15	Control parameter in estimating sanitary sewage inflow.[12] If used with quality simulation, the first three pollutants must be BOD_5, SS and Total Coliforms. = 0, Sewage inflows not estimated (FILTH not called and corresponding data omitted). = 1, Sewage inflows to be estimated (subroutine FILTH called).	NFILTH	0
		20	Control parameter for hydraulic design routine. (See pp. 6-4, 6-5.) = 0, Hydraulic design routine is not called. = 1, Hydraulic design routine is to be called.	NDESN	0
			REPEAT CARD GROUP E1 FOR EACH NUMBERED SEWER ELEMENT (maximum number of elements = 159). THESE CARDS MAY BE READ IN ANY ORDER. TERMINATE WITH A BLANK CARD. Sewer element data.		
E1	2X	1-2	Card group identifier = E1.	--	Blank
	5I4	3-6	External element number.[13] No element may be labeled with a number greater than 1000, and it must be a positive numeral. However, numbering need not be consecutive or continuous. = + number, element number. = -1, new ratios,[14] or = -2, new default values for values with*.[15]	NOE	None

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			EXTERNAL NUMBER(S) OF UPSTREAM ELEMENT(S). UP TO THREE ARE ALLOWED. A ZERO DENOTES NO UPSTREAM ELEMENT (maximum value = 1000).		
		7-10	First of three possible upstream elements.	NUE(1)	None
		11-14	Second of three possible upstream elements.	NUE(2)	None
		15-18	Third of three possible elements.	NUE(3)	None
		19-22	Classification of element type. Obtain value from Table 6-1 or 6-3.	NTYPE*	None
			THE FOLLOWING VARIABLES ARE DEFINED BELOW FOR CONDUITS ONLY. REFER TO TABLE 6-3 FOR REQUIRED INPUT FOR NON-CONDUITS.		
	7F8.3	23-30	Element length for conduit, ft. (For manhole: constant inflow into system, cfs [m^3/sec].)	DIST*	0.0
		31-38	First, characteristic dimension of conduit, ft[m]. See Figure 6-4 and Table 6-2 for definition. (For manhole: Constant concentration of pollutant 1 in the inflow if simulated. Units according to NDIM, card group F1.)	GEOM1*	0.0
		39-46	Invert slope of conduit, ft/100 ft (i.e., percent). (For manhole: constant concentration of pollutant 2 in the inflow, if simulated. Units according to NDIM, card group F1.)	SLOPE*	0.0
		47-54	Manning's roughness of conduit. (For manhole: constant concentration of pollutant 3 in the inflow, if simulated. Units according to NDIM, card group F1.)	ROUGH*	0.0

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
		55-62	Second characteristic dimension of conduit, ft[m]. See Figure 6-4 and Table 6-2 for definition. (Not required for some conduit shapes.) (For manhole: constant concentration of pollutant 4 in the inflow, if simulated. Units according to NDIM, card group F1.)	GEOM2*	None
		63-70	Number of barrels for this element. The barrels are assumed to be identical in shape and flow characteristics.[16] (Must be integer ≥ 1.)	BARREL*	1.0
		71-78	Third characteristic dimension of conduit, ft[m]. See Figure 6-4 and Table 6-2 for definition. (Not required for some conduit shapes.)	GEOM3*	None
E2			Blank card (except for identifier) to end card group E1. (Test is whether NOE = 0.)		
			SKIP TO CARD G1 IF NPOLL = 0 (card D1)		
			Quality input data.		
			READ NPOLL CARDS (NPOLL ≤ 4). POLLUTANT NUMBERS ASSIGNED BY THE ORDER OF THESE CARDS.		
F1	2X	1-2	Card group identifier = F1.	--	Blank
	I3	3-5	Pollutant selector from interface file. E.g., if KPOL = 7, seventh constituent on interface file will be this pollutant. User must know contents of interface file from running preceding block. If KPOL = 0, this pollutant is defined below and not taken from interface file.[17]	KPOL	0

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			*** The following three parameters, *** PNAME, PUNIT, NDIM not required if KPOL ≠ 0.		
	2A4	6-13	Pollutant name.[18]	PNAME	Blank
	2A4	14-21	Pollutant units.[18]	PUNIT	Blank
	I4	22-25	Type of units.[18] = 0, mg/l. = 1, "other" per liter, e.g., MPN/l. = 2, other concentration units, e.g., pH, JTU.	NDIM	0
	10F5.0	26-30	First order decay coefficient, day^{-1}	DECAY	0.0
		31-35	Specific gravity. If SPG > 1.0, pollutant will be subject to scour-deposition calculations.	SPG	0.0
			*** The following parameters not *** required if SPG ≤ 1.0.		
			Particle size distribution. First point, PSIZE(1) = 0.0 mm, PGR(1) = 100.0 is automatically included. See Figure 6-6.[19]		
		36-40	Particle size, mm.	PSIZE(2)	0.0
		41-45	Percent greater than, %.	PGR(2)	0.0
		46-50	Particle size, mm.	PSIZE(3)	0.0
		51-55	Percent greater than, %.	PGR(3)	0.0
		56-60	Particle size, mm.	PSIZE(4)	0.0
		61-65	Percent greater than, %.	PGR(4)	0.0
		66-70	Particle size, mm.	PSIZE(5)	0.0
		71-75	Percent greater than, %.	PGR(5)	0.0
		76-80	Maximum particle size contained in dry-weather flow input (either through manholes or using subroutine FILTH). Must be ≤ PSIZE(5).	PSDWF	0.0

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			CARD GROUPS G1 THROUGH G5 ARE FOR INTERNAL STORAGE (NTYPE = 19). OMIT IF INTERNAL STORAGE IS NOT DESIRED AND SKIP TO CARD H1. REPEAT CARD GROUPS G1-G5 FOR EACH INTERNAL STORAGE ELEMENT, IS (maximum of 2).		
G1	2X	1-2	Card identifier = G1.	--	Blank
	I8	3-10	Outflow routing parameter. = 0, The depth-outflow relationship is described by as many as sixteen data pairs on the G2 cards. = 1, The depth-outflow relationship is described by a single power equation on card G3. = 2, The depth-outflow relationship is governed by two power equations on card G3. = 3, The depth-outflow relationship is controlled by the pumps described on card G4.	LOUT(IS)	0

Depth-surface area-volume-outflow data cards. Each card contains a column for a unit depth and the corresponding values of area, volume and treated outflow. The column for outflow may be left blank depending on the value of LOUT(IS) on card G1. If no values for volume are entered the program estimates volume from the depth-surface area relationship. Order the cards from the bottom of the unit (TSDEP(IS,1) = 0.0) to the maximum depth (including as many as sixteen cards. End the card series with a blank card.

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
G2	2X	1-2	Card identifier = G2.	--	Blank
	F8.0	3-10	A unit depth, ft [m].	TSDEP(IS,MM)	None
	4F10.0	11-20	Surface area corresponding to the above depth, ft^2 [m^2].	TSAREA(IS,MM)	None
		21-30	Volume corresponding to the above depth, ft^3 [m^3].	TSTORE(IS,MM)	None
		31-40	Outflow at the above depth, ft^3/sec [m^3/sec].	TSQOU(IS,MM)	None
			Follow the last card (maximum depth) with a blank card.		
			Depth-outflow power equation card. Required only if LOUT(IS) = 1 or 2 (card G1). (See Equation 7-3)		
G3	2X	1-2	Card identifier = G3.	--	Blank
	F8.0	3-10	Depth-outflow equation coefficient, A_1.	A1(1)	0.0
	6F10.0	11-20	Depth-outflow equation minimum flow depth, D_0.	DO(1)	0.0
		21-30	Depth-outflow equation exponent, A_2.	A2(1)	0.0
			*** The following parameters required *** only if LOUT(IS) = 2 (card G1).		
		31-40	Depth-outflow equation coefficient for second outlet.	A1(2)	0.0
		41-50	Depth-outflow equation minimum flow depth for second outlet.	DO(2)	0.0
		51-60	Depth-outflow equation exponent for second outlet.	A2(2)	0.0
		61-70	External element number into which flows the outflow from the second outlet. (Include decimal point.)	GEOM3	0.0

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			Outflow pumping card. Required <u>only</u> if LOUT(IS) = 3 (card G1).		
G4	2X	1-2	Card identifier = G4.	--	Blank
	F8.0	3-10	Depth at which pumping rate TQPUMP(IS,1), ft [m].	TDSTAR(IS,1)	None
	4F10.0	11-20	Depth at which pumping rate TQPUMP(IS,2) begins, ft [m]. Must be greater than or equal to TDSTAR(IS,1).	TDSTAR(IS,2)	None
		21-30	Pumping rate when depth is greater than or equal to TDSTAR(IS,1), ft^3/sec [m^3/sec].	TQPUMP(IS,1)	None
		31-40	Pumping rate when depth is greater than or equal to TDSTAR(IS,2), ft^3/sec [m^3/sec].	TQPUMP(IS,2)	None
		41-50	Depth below which all pumping stops, ft [m]. Must be less than or equal to TDSTAR(IS,1).	TDSTOP(IS)	None
			Initial conditions in internal storage element IS.		
G5	2X	1-2	Card identifier = G5.	--	Blank
	F8.0	3-10	Total volume of water in unit at the start of the simulation, ft^3 [m^3].	STORL(IS)	0.0
			The initial pollutant concentration are required only if STORL(IS) > 0.0. The concentrations must be given with dimensions consistent with those entered in card group F1.		
	4F10.0	11-20	Concentration of pollutant in the storage unit at the start of the simulation. Required only if NPOLL ≥ 1.	PTCO(IS,1)	0.0
		21-30	Concentration of pollutant 2 in the storage unit at the start of the simulation. Required only if NPOLL ≥ 2.	PTCO(IS,2)	0.0

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
		31-40	Concentration of pollutant 3 in the storage unit at the start of the simulation. Required only if NPOLL ≥ 3.	PTCO(IS,3)	0.0
		41-50	Concentration of pollutant 4 in the storage unit at the start of the simulation. Required only if NPOLL = 4.	PTCO(IS,4)	0.0
			SKIP TO CARD I1 IF NOUTS = 0 ON CARD D1.		
			List of external non-conduit element numbers at which outflows are to be transferred to subsequent blocks for a total of NOUTS (Card D1) non-conduit elements.[20]		
H1	2X	1-2	Card identifier = H1.	--	Blank
	I3	3-5	First element number.[21]	JN(1)	None
	15I5	6-10	Second element number.	JN(2)	None
		. . . . .	Last element number.	JN(NOUTS)	None
			SKIP TO CARD J1 IF NINPUT = 0 (card D1).		
			Non-conduit element numbers into which hydrographs and pollutographs (from card input using card group R1) enter the sewer system. These must be in the order in which hydrograph and pollutograph ordinates appear at each time step.[20] A total of NINPUT values required.		
I1	2X	1-2	Card identifier = I1.	--	Blank

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
	I3	3-5	First element number.	NORDER(1)	None
	15I5	6-10	Second element number.	NORDER(2)	None
		.			
		.			
		.			
		.			
		.	Last element number.	NORDER(NINPUT)	None
			SKIP TO CARD J2 IF NNYN = 0 (card D1).		
			List of external non-conduit element numbers at which input hydrographs and pollutographs are to be stored and printed out for a total of NNYN$_{20}$ (card D1) non-conduit elements.		
J1	2X	1-2	Card identifier = J1.	--	Blank
	I3	3-5	First input location number.	NYN(1)	None
	15I5	6-10	Second input location number.	NYN(2)	None
		.		.	
		.		.	
		.		.	
		.		.	
		.	Last input location number.	NYN(NNYN)	None
			SKIP TO CARD K1 IF NNPE = 0 (card D1).		
			List of external non-conduit element numbers at which output hydrographs and pollutographs are to be stored and printed out for a total of$_{20}$NNPE (card D1) non-conduit elements.		
J2	2X	1-2	Card identifier = J2.	--	Blank
	I3	3-5	First output location number.	NPE(1)	None

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
	15I5	6-10	Second output location number.	NPE(2)	None
		.		.	
		.		.	
		.		.	
		.	Last output location number.	NPE(NNPE)	None
			IF SUBROUTINE INFIL IS TO BE CALLED (NINFIL = 1), INSERT CARDS K1 THROUGH K2, OTHERWISE OMIT.		
			Estimated infiltration.		
K1	2X	1-2	Card identifier = K1.	--	Blank
	F8.0	3-10	Base dry weather infiltration, cfs, [m^3/sec].	DINFIL	0.0
	7F10.0	11-20	Groundwater infiltration, cfs [m^3/sec].	GINFIL	0.0
		21-30	Rainwater infiltration, cfs [m^3/sec].	RINFIL	0.0
		31-40	Peak residual moisture, cfs [m^3/sec].	RSMAX	0.0
			Constant concentrations of pollutants in infiltration. Not required if NPOLL = 0. Units of each according to NDIM, card group F1.		
		41-50	Concentration of pollutant 1.	CPINF(1)	0.0
		51-60	Concentration of polutant 2.	CPINF(2)	0.0
		61-70	Concentration of pollutant 3.	CPINF(3)	0.0
		71-80	Concentration of pollutant 4.	CPINF(4)	0.0
			Monthly degree-days.[22]		
K2	2X	1-2	Card identifier = K2.	--	Blank
	I3	3-5	July degree-days.	NDD(1)	0.0

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
	11I5	6-10	August degree-days.	NDD(2)	0.0
		.		.	.
		.		.	.
		.		.	.
		56-60	June degree-days.	NDD(12)	0.0
			IF SUBROUTINE FILTH IS TO BE CALLED (NFILTH = 1), INSERT CARD GROUPS L1 THROUGH Q1, OTHERWISE OMIT.		
			Factors to correct yearly average sewage flows to daily average by accounting for daily variations throughout a typical week.		
L1	2X	1-2	Card identifier = L1.	--	Blank
	F8.0	3-10	Flow correction for Sunday.	DVDWF(1)	1.0
	6F10.0	11-20	Flow correction for Monday.	DVDWF(2)	1.0
		.		.	
		.		.	
		.		.	
		61-70	Flow correction for Saturday.	DVDWF(7)	1.0
			IF NPOLL = 0 SKIP TO CARD GROUP M1. (NOTE: IF POLLUTANTS ARE SIMULATED AND FILTH IS CALLED, FIRST THREE POLLUTANTS MUST BE BOD_5, SUSPENDED SOLIDS AND TOTAL COLIFORMS.		
			Factors to correct BOD yearly averages to daily averages.		
L2	2X	1-2	Card identifier = L2.	--	Blank
	F8.0 6F10.0	3-10	BOD correction for Sunday.	DVBOD(1)	1.0
		.			.
		.			.
		.			.
		61-70	BOD correction for Saturday.	DVBOD(7)	1.0

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			Factors for correction of yearly SS averages to daily averages.		
L3	2X	1-2	Card identifier = L3.	--	Blank
	F8.0 6F10.0	3-10	SS correction for Sunday.	DVSS(1)	1.0 . . . .
		61-70	SS correction for Saturday.	DVSS(7)	1.0
			(No daily correction factors for coliforms)		
			Factors to correct daily average sewage flow to hourly averages by accounting for hourly variations throughout a typical day (3 cards needed).		
M1	2X	1-2	Card identifier = M1.	--	Blank
	F8.0 7F10.0	3-10	Midnight to 1 a.m. factor (first card).	HVDWF(1)	1.0 . . . .
		1-10	8 a.m. to 9 a.m. factor (second card).	HVDWF(9)	1.0 . . . .
		1-10	4 p.m. to 5 p.m. factor (third card).	HVDWF(17)	1.0
			IF NPOLL = 0 SKIP TO CARD GROUP N1.		
			Factors for BOD hourly corrections (3 cards needed).		
M2	2X	1-2	Card group identifier = M2.	--	Blank

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
	F8.0 7F10.0	3-10 71-80	Midnight to 1 a.m. factor (first card). 11 p.m. to midnight factor (third card).	HVBOD(1) HVBOD(24)	1.0 . . . . 1.0
			Factors for SS hourly corrections (3 cards needed).		
M3	2X	1-2	Card group identifier = M3.	--	Blank
	F8.0 7F10.0	3-10 71-80	Midnight to 1 a.m. factor (first card). 11 p.m. to midnight factor (third card).	HVSS(1) HVSS(24)	1.0 . . . . 1.0
			Factors for total coliform hourly corrections (3 cards needed).		
M4	2X	1-2	Card group identifier = M4.	--	Blank
	F8.0 7F10.0	3-10 71-80	Midnight to 1 a.m. factor (first card). 11 p.m. to midnight factor (third card).	HVCOLI(1) HVCOLI(24)	1.0 . . . . 1.0
			Study area data.		
N1	2X	1-2	Card group identifier = N1.	--	Blank
	I3	3-5	Total number of subareas within a given study area in which sewage flow and quality are to be estimated.	KTNUM	None
	3I5	6-10	Indicator as to whether study area data, such as treatment plant records, are to be used to estimate sewage quality, i.e., = 1, Yes. = 2, No.	KASE	1

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
		11-15	Total number of process flows within the study area for which data are included in one of the following card groups.	NPF	0
		16-20	Number indicating the day of the week during which simulation begins (Sunday = 1).	KDAY	1
	2F5.0	21-25	Consumer Price Index.	CPI	109.5
		26-30	Composite Construction Cost Index.	CCCI	103.0
	F10.0	31-40	Total population in all areas, thousands.	POPULA	None
			IF KASE = 1, INCLUDE CARD GROUPS 01, 02 AND P1.		
			Average study area data.[24]		
01	2X	1-2	Card identifier = 01.	--	Blank
	F8.0	3-10	Total study area average sewage flow, e.g., from treatment plant records, cfs [m^3/sec].	ADWF	0.0
	2F10.0	11-20	Total study area average BOD, mg/l.	ABOD	0.0
		21-30	Total study area average SS, mg/l.	ASUSO	0.0
	E10.2	31-40	Study area average total coliforms, MPN/100 ml.	ACOLI	0.0
			Categorized study area data.		
02	2X	1-2	Card group identifier = 02.	--	Blank
	F8.0	3-10	Total study area from which ABOD and ASUSO were taken, acres [ha].	TOTA	None
	7F10.0	11-20	Total contributing industrial area, acres [ha].	TINA	None

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
		21-30	Total contributing commercial area, acres [ha].	TCA	None
			*** Valuations for the following three *** parameters are for 1963 dollars!		
		31-40	Total contributing high income (above $15,000) residential area, acres [ha].	TRHA	None
		41-50	Total contributing average income (above $7,000 but below $15,000) residential area, acres [ha].	TRAA	None
		51-60	Total contributing low income (below $4,000) residential area, acres [ha].	TRLA	None
		61-70	Total area from the above three residential areas that contribute additional waste from garbage grinders, acres [ha].	TRGGA	None
		71-80	Total park and open area within the study area, acres [ha].	TPOA	None
			IF PROCESS FLOW DATA ARE AVAILABLE (NPF NOT EQUAL 0 AND KASE = 1), REPEAT CARD GROUP P1 FOR EACH PROCESS FLOW (NPF cards). OTHERWISE, SKIP TO CARD GROUP Q1.		
			Process flow characteristics.		
P1	2X	1-2	Card group identifier = P1.	--	Blank
	I3	3-5	External manhole number into which flow is assumed to enter (maximum value = 1000, minimum value = 1).	INPUT	None
	3F10.3	6-15	Average daily process flow entering the study area system, cfs [m^3/sec]. 25	QPF	None
		16-25	Average daily BOD of process flow, mg/l.	BODPF	0.0
		26-35	Average daily SS of process flow, mg/l.	SUSPF	0.0

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			REPEAT CARD GROUP Q1 FOR EACH OF THE KTNUM SUBAREAS. THESE SUBAREAS DO NOT NECESSARILY HAVE TO CORRESPOND TO RUNOFF SUBCATCHMENTS.		
			Subarea data.		
Q1	2X	1-2	Card group identifier = Q1.	--	Blank
	I3	3-5	Subarea number.	KNUM	None
	I5	6-10	External number of the manhole into which flow is assumed to enter for subareas KNUM (maximum value = 1000, minimum value = 1).	INPUT	None
	I2	11-12	Predominant land use within subarea.	KLAND	5
			= 1, Single-family residential.		
			= 2, Multi-family residential.		
			= 3, Commercial.		
			= 4, Industrial.		
			= 5, Undeveloped or park lands.		
	3I1	13	Parameter indicating whether or not water usage within subarea KNUM is metered.	METHOD	2
			= 1, Metered water use.		
			= 2, Incomplete or no metering.		
		14	Parameter indicating units in which water usage estimates (WATER) are tabulated.	KUNIT	0
			= 0, thousand gal/mo [$10^3 m^3$/mo].		
			= 1, thousand ft^3/mo [$10^3 m^3$/mo].		

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
		15	Subtotals printed after each subarea input?	MSUBT	0
			= 0, No.		
			= 1, Yes.		
		***	Several of the following parameters *** are optional. See text.		
	13F5.1	16-20	Measured <u>winter</u> water use for subarea KNUM in the units specified by KUNIT.[25]	WATER	None
		21-25	Cost of the last thousand gal [$10^3 m^3$] of water per billing period for an average consumer within subarea KNUM, cents/1,000 gal [cents/$10^3 m^3$].	PRICE	None
		26-30	Measured average sewage flow from entire subarea KNUM, cfs [m^3/sec], but not including process flows (SAQPF).[25]	SEWAGE	None
		31-35	Total area within subarea KNUM, acres [ha].	ASUB	None
		***	The next six parameters are not re- *** required if KLAND > 2.		
		36-40	Population density within subarea KNUM, persons/acre [pers/ha].[26]	POPDEN	None
		41-45	Total number of dwelling units within subarea KNUM.[27]	DWLNGS	10.0/ac.
		46-50	Number of people living in average dwelling unit within subarea KNUM.[27]	FAMILY	3.0
		51-55	Market value of average dwelling unit within subarea KNUM, thousands of dollars.	VALUE	20.0
		56-60	Percentage of dwelling units possessing garbage grinders within subarea KNUM.	PCGG	0.0
		61-65	Income of average family living within subarea KNUM, thousands of dollars per year.	XINCOM	VALUE/2.5

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
		66-70	Total industrial process flow originating within subarea KNUM, cfs [m^3/sec].[28]	SAQPF	0.0
		71-75	BOD contributed from industrial process flow originating within subarea KNUM, mg/l.	SABPF	0.0
		76-80	SS contributed from industrial process flow originating within subarea KNUM, mg/l.	SASPF	0.0
			END OF FILTH DATA CARDS.		
			Include card group R1 only if NINPUT ≠ 0 (Card D1).		
			REPEAT CARD R1 FOR EACH INLET FOR FIRST TIME AND THEN REPEAT CARD R1 FOR EACH INLET FOR SECOND TIME, ETC. REPEAT THIS COMBINATION FOR ALL INPUT TIMES. ORDER OF INLET CARDS MUST BE THE SAME AS INDICATED IN CARD GROUP I1.		
			Hydrograph and pollutograph input ordinates.		
R1	2X	1-2	Card group identifier = R1	--	Blank
	F8.0	3-10	Time of day, decimal hours, e.g., 6:30 p.m. = 18.5. The <u>first</u> time must equal time TZERO. The program will automatically set TEO = TZERO for entries for the first time.[29]	TE2	0.0 or TZERO
	5F10.0	11-20	Input flow for this time step at first inlet, cfs [m^3/sec].	QE2	0.0
		21-30	Pollutant 1 for this time at first inlet, concentration according to NDIM (card F1).	PE2(1)	0.0
		31-40	Pollutant 2 for this time at first inlet, concentration according to NDIM (card F1).	PE2(2)	0.0

Table 6-6 (continued). Transport Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
		41-50	Pollutant 3 for this time at first inlet, concentration according to NDIM (card F1).	PE2(3)	0.0
		51-60	Pollutant 4 for this time at first inlet, concentration according to NDIM (card F1).	PE2(4)	0.0

END OF TRANSPORT BLOCK DATA CARDS.

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

Footnotes to Table 6-6

1. A/A_f = ANORM is the cross-sectional flow area divided by the cross-sectional flow area of the pipe running full. Tabular values of ANORM are generated in the program by dividing the ANORM axis (0.0 1.0) into NN1 or MM1 equal divisions.

2. Q/Q_f = QNORM is the flow rate divided by the flow rate of the conduit flowing full.

3. y/y_f = DNORM is the depth of flow, y, divided by the maximum flow depth, y_f (e.g., diameter of a circular conduit).

4. Repeated cards have same format, i.e., 2X, F8.0, 7F10.0.

5. The title from the first of any preceding blocks run will also be printed.

6. The Transport Block time step does not have to equal that of a preceding block. The total simulation time is NDT · DT. If this is greater than that of an input file, the simulation will end earlier. Although there is no limit on the simulation time (number of time steps), output is geared toward single events only. That is, daily or monthly totals are not printed, and zeroes are not suppressed. Hence, output is inconvenient for continuous simulation, although the Transport Block can be run that way.

7. Inlet hydrographs from a preceding block will automatically be accepted, but a match must be found for each inlet (element) number on the interface file with an element number entered in Transport.

8. These locations should include any elements for which graphical output is desired since only locations on the interface file may be plotted using the Executive Block.

9. Except in unusual cases, these errors will only indicate that a small continuity violation will occur. These errors can usually be cured by shortening the time step or increasing the length of the conduit.

10. If the time step for Transport is different than that for a preceding block, input hydrograph and pollutograph ordinates will be found by linear interpolation at the required time.

11. If both card and interface file input is used, hydrographs and pollutograph loads entered at common locations will be summed. Transport can be run without card hydrograph input if it were desired to route only dry-weather flows (base flows).

12. Constant base flows and concentrations may be entered at manhole elements (Type 16) in card group E1 if desired, thus eliminating the need to call FILTH or INFIL. They may still be called if desired;

infiltration, dry-weather flow and base flow will be summed for entry at non-conduits. Base flows and concentrations entered in card group E1 will not be subject to daily and hourly correction factors.

13. "External" numbers are those assigned by the user to the various sewer system components. "Internal" numbers are assigned within the program in the order in which elements in card group E1 are read in. All input to the Transport Model is in terms of external numbers.

14. Input values on this card indicated with asterisks are multiplied by ratios, initially set equal to 1.0. If the element number = 1, non-zero data entries for parameters with asterisks will replace old values of the ratios. Ratios may be altered or reset to 1.0 any number of times. The intention of the use of ratios is to simplify sensitivity analyses, etc., by allowing easy changes of data values without repunching data cards. The altered ratios apply to all subsequent input cards (until changed by another ratio card).

15. Input parameters on this card indicated with asterisks will take on default values if input values are zero. If the element 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. 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, 0.10E-50 will be read as 10^{-51} in an F8.3 format. The altered default values apply to all subsequent input cards (until changed by another default value card).

16. For example, a two-barrelled conduit would consist of two identical parallel conduits adjacent to each other, as in a double box culvert.

17. If NFILTH = 1 (card D3) it will be assumed that the first pollutant is BOD_5, the second is suspended solids and the third is total coliforms. Hence, the selection indicated by NPOL must be in this order. The fourth pollutant, if simulated, is unaffected by the value of NFILTH.

18. See the discussion in the Runoff Block.

19. Up to the five available points (including 0.0 mm, 100%) may be used to define the particle size distribution. For instance, if a triangular distribution were satisfactory with 0.1 mm being the largest particle size, then PSIZE(2) = 0.1, PGR(2) = 0.0 would be the only entries needed.

20. May require multiple cards.

21. Be careful in subsequent blocks to ensure that element numbers will correspond to those transferred in interface file. However, any element number may be placed on the interface file, e.g., for plotting purposes.

22. See Table VIII-1, Appendix VIII, for representative values. Degree-days are not needed if RSMAX = 0.0 on card K1, (but a blank card must still be included for card K2). Degree days are in °F-day and there is no metric input for this parameter.

23. When subroutine FILTH is used to generate dry-weather flow and pollutants, the only pollutants included are BOD_5, suspended solids (SS) and total coliforms (T.C.). NPOLL must be 3 or 4, and the three pollutants entered in the given order in card group F1. The fourth pollutant is arbitrary (if used) and is not affected by FILTH calculations.

24. Predicted total average daily dry-weather flow from downstream end(s) of system will be adjusted to these values.

25. If process flows are too large it is possible for ADWF - infiltration - ΣQPF < 0 in which case the program defaults to KASE = 2.

26. Either SEWAGE or else WATER is required to generate dry-weather flow from commercial areas. If both are zero, only process flows will be considered. SEWAGE and WATER should = 0 for industrial land use; for KLAND = 4, let entire flow be process flow.

27. DWLNGS and FAMILY can be used to calculate the population and then the population density. If both are given, the value of POPDEN will be overridden.

28. These industrial process flows described by SAQPF, SABPF and SASPF will be added to flows and quality already generated.

29. The program will interpolate linearly between entries of TE2 to obtain intermediate values of flow and concentrations. Hence, the difference between two time entries, TE2, should not be less than the time step, DT, unless a step function change is desired. Time entries need not be equally spaced, but the last time entered must extend past the end time of the run. Time TZERO is read from the interface file or else entered on card D2. If simulation extends beyond midnight (i.e., TE2 > 24), continue the running time into the next day or days (i.e., let TE2 be greater than 24). Note, the time TE2 must be the same for all inlets. (The program will use the value for TE2 entered on the last inlet card.)

SECTION 7

STORAGE/TREATMENT BLOCK

BLOCK DESCRIPTION

Introduction

The Storage/Treatment Block has been developed to simulate the routing of flows and pollutants through a dry- or wet-weather storage/treatment plant containing up to five units or processes. The model will accept any number of time steps; therefore, a single-event or a continuous simulation is possible. Each unit may be modeled as having detention or non-detention characteristics. The various units may be linked in a variety of configurations. Sludge handling may also be modeled using one or more units. Additionally, capital cost and operation and maintenance cost may be estimated for each unit.

The S/T Block will route, in addition to flow, up to three different pollutants. These pollutants may be input to the block from any external block via off-line storage, directly from cards, or a combination of both. Characterization of the pollutants may be by magnitude (i.e., concentration) or by magnitude and a particle size/specific gravity or settling velocity distribution. All input flows and pollutant concentrations are assumed to be instantanous values. However, the instantaneous values at the beginning and end of each time are used to compute average values for each time step. Thus, the user is cautioned that the output from the S/T Block consist of average values, not instantaneous values as in the rest of SWMM.

This section describes the program operations of the S/T Block, provides instructions for preparing input data cards, defines program variables, and presents test applications. The user is referred to Appendix IV for theoretical development and explanations.

Program Operation

The Storage/Treatment Block is a FORTRAN program of approximately 2000 statements in length and consists of eight subroutines. The relationships among the S/T Block, the rest of SWMM and the various subroutines are shown in Figure 7-1.

The subroutine STRT is called by the Executive Block to initiate the operation of the S/T Block. STRT provides the main driving loop for the block and generally acts as the central coordinating subroutine. Input flow and pollutants from any external block are read in this subroutine. Output

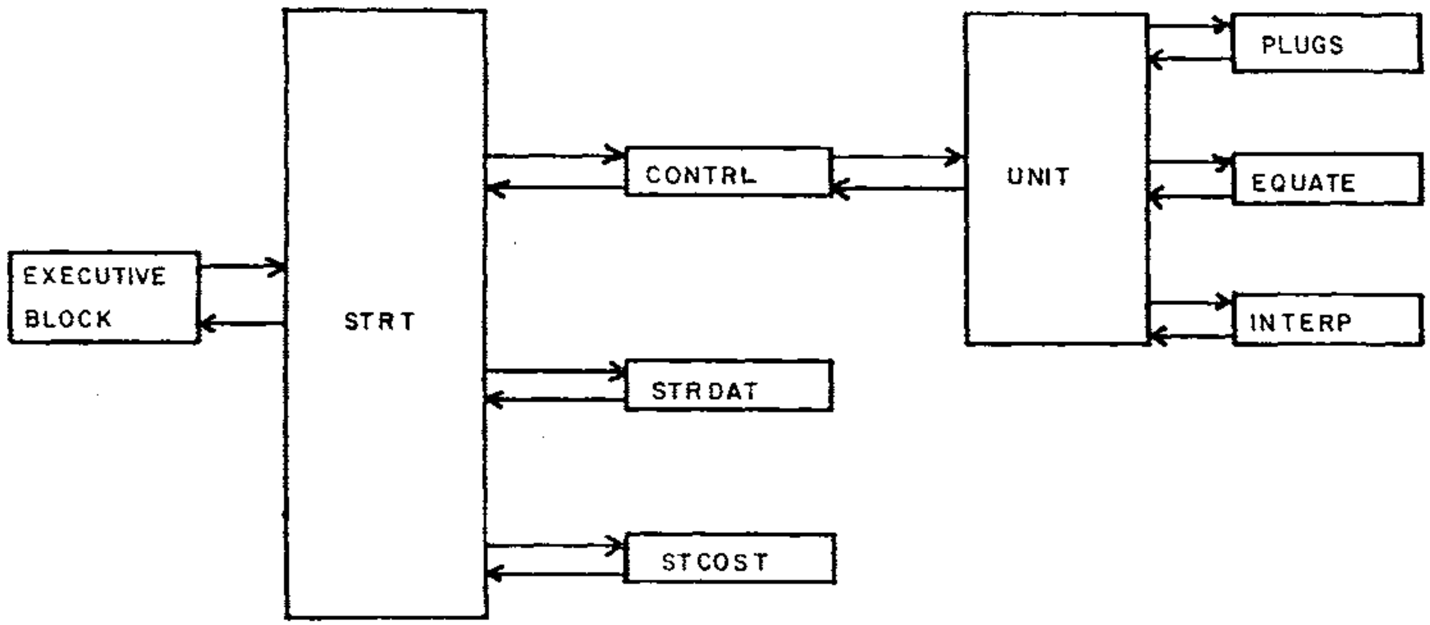

Figure 7-1. Storage/Treatment Block.

from the S/T Block transferred to other blocks is also handled by STRT (through the Executive Block). The information transferred to other blocks is discussed in the next paragraph. Subroutine STRDAT is called in STRT at the start of a run and is responsible for reading the input data describing the units, their configuration, the pollutant removal mechanisms, the method of characterizing pollutants and the remainder of the data provided by the user (excluding flow and pollutant inputs). STRDAT also prints the input data for verification. Subroutine CONTRL is called each time-step from the main driving loop in subroutine STRT. CONTRL directs flow and pollutants between units and any subsequent block. CONTRL also coordinates the accounting and printout of detailed and summarized performance information. Flow and pollutant inputs from cards are also read in this subroutine. Subroutine UNIT is called from subroutine CONTRL for each unit and is the heart of the S/T Block. UNIT has the flexibility and capability to model detention and non-detention units with a variety of pollutant removal mechanisms, residual removal schemes and outflow structures. Subroutine EQUATE is used by UNIT to provide a variety of pollutant removal equations. Subroutine INTERP is employed by UNIT for linear interpolation in routing flows through detention units. Subroutine PLUGS is used by UNIT to model pollutant routing through a detention unit when perfect plug flow is specified. Subroutine STCOST is called from STRT to estimate the capital cost and operation and maintenance cost for each unit.

Use of Off-line Computer Storage

No scratch data sets are required to run the Storage/Treatment Block. However, disks or tapes may be used as an input source (from an external block) or to transfer output to other blocks. This interfacing file consists of descriptive titles, user-supplied pollutant names and dimensions, the simulation starting date and time, the name of the external block generating the output (input) file, the number of time steps and time step size, the total catchment or tributary area, the number of elements (inlets, outfalls, nonconduits, etc.) and pollutants found on the output (input) file, and the elements for which flow and pollutant data are placed (read from) the output (input) file. This preliminary information is followed by the flow and pollutant data for each time step (up to the total number of time steps) for each of the specified elements. The user should refer to Section 2 for a detailed description of the interfacing file.

Flow and up to three pollutants are transferred unchanged from an input file to an output file if the data are from elements or are pollutants not selected for use in the S/T Block. In other words, the flow and pollutant data from an input file (external block) are altered only if they pass through a storage/ treatment facility. However, the dimensions of the data on the input file will be made to conform to the standard SWMM dimensions before being placed on an output file (see Section 2). The methods of selecting these data from particular external element numbers and processing specific pollutants is discussed in the next subsection.

INSTRUCTIONS FOR DATA PREPARATION

The Storage/Treatment Block is a user-intensive model, i.e., the user should have a thorough knowledge of what he/she is modeling. This is an obvious, but often overlooked, axiom. This is especially true when a model provides "default" values. The user is herein required to describe each unit in some detail with data of his own choosing. Storage/treatment performance depends on local pollutant characteristics, flow rates, etc.; thus, the user is encouraged to use local operating data, whenever possible, to aid in the modeling effort.

Instructions for preparing the input data cards are presented below with suggestions and examples. All entries not described in the text are considered to be self-explanatory or covered sufficiently in Table 7-3. The user is referred to this table for input format and order. All card groups are required unless otherwise stated. Figure 7-2 shows the general structure of the data deck.

Preliminary Information

Title --

Card Group A1 -- This card group allows the user to print a descriptive heading at the start of the printed output. The heading is also transferred to the next block. Two cards are required.

General Information --

Card Group B1 -- The variable NOTAPE allows the user to specify the source of flow and pollutants used for input to the S/T Block. If NOTAPE = 0, the input is provided by an external input file (arranged by the Executive Block). When NOTAPE = 1, the input is provided by card group J1. If NOTAPE = 2, the input is the sum of the entries for each time step from the external file and card group J1. The parameter JNS selects the external element number (from an external file, NOTAPE = 0 or 2) from which flows and pollutants will be taken and passed through the S/T Block. If the input is provided solely by card group J1 (NOTAPE = 1 or 2), the user may label the output of the S/T Block with an element number. When NOTAPE = 0 or 2, the variables NDT and DS are read from the external input file. However, the value of NDT from an external block may be altered by specifying a non-zero value on card B1. There is no limit on the number of time steps. This is useful for extending the simulation beyond the limit of the external block or input file. The value of DS from an external block will supersede any value for DS entered on card B1.

The variable NU specifies the number of storage/treatment units, including residuals (sludge) handling units, to be modeled and the number of times that card groups F1 through I1 are repeated. The model, as written, is limited to five units. However, a few program modifications can increase this limit (see later discussion). The variable NP specifies the number of pollutants to be routed through the storage/treatment system. If NP = 0, then only flows are routed. A maximum of three pollutants may be selected

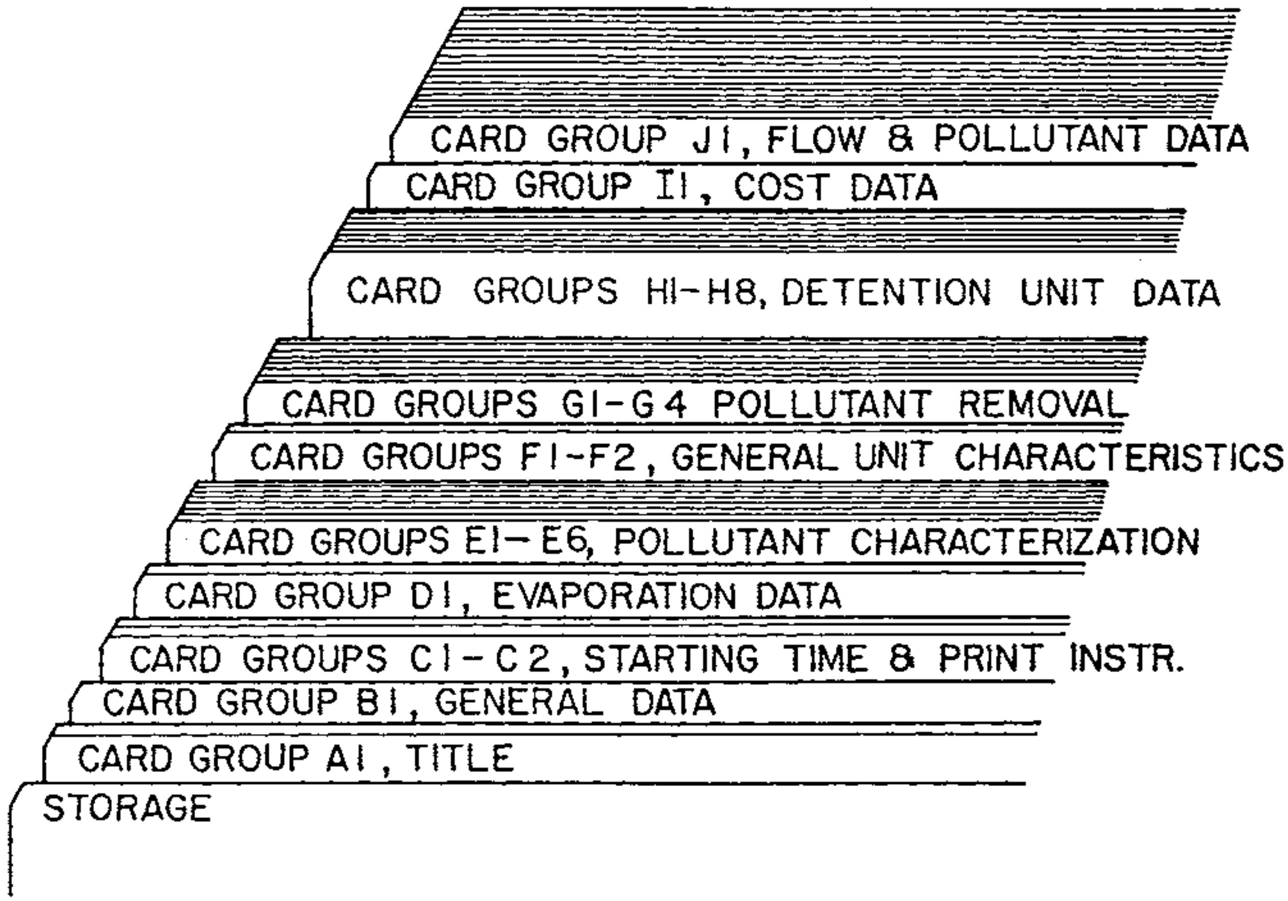

Figure 7-2. Data Deck for the Storage/Treatment Block

for routing. The specific pollutants are selected on card E1. However, NP may not be greater than the number of pollutants transferred from other blocks (NOTAPE = 0 or 2).

If ICOST = 1, the cost model is called and the capital and operation and maintenance costs are computed for each unit. Cost equation parameters are entered on card group J1. The value of METRIC determines whether U.S. customary or metric units are used for all card input and the resulting output. The value of TRIBA is the service area of the S/T plant. It does not enter into the computations but is transferred to the next block.

Starting Time and Print Instructions --

Card Group C1 -- The values of IDATE and ITIME are used to start the date/time algorithm of the S/T Block. The date (year, month, and day) and time (hour, minutes, and seconds) are updated for each time step. If NOTAPE = 0 or 2 (card B1) the values of IDATE and ITIME read from the external file supersede the values entered on card C1.

The user is cautioned against printing large quantities of unwanted information. The first runs should have as little printout as possible (ISUM = 0 and IDET = 0) to check for obvious errors in the input data. As simulation efforts proceed, more detailed printouts may be desired.

Card Group C2 -- These cards (up to two) are used to enter the first and last dates of the detailed print periods specified by NPR (card C1).

Evaporation Data --

Card Group D1 -- Monthly evaporation rates are required to correct for evaporation from detention units. However, two cards must be included even if there are no detention units. If needed, values of E(1) through E(12) are entered for the months during which the simulation occurs; others may be left blank.

Pollutant Characterizations --

Card groups E1 through E6 are omitted if NP = 0 (card B1).

Card Group E1 -- These cards (up to two) allow the user to select the NP (card B1) pollutants to be routed through the S/T Block. The variables IPOLL(1), IPOLL(2), and IPOLL(3) are used to select pollutants from an external input file (NOTAPE = 0 or 2, card B1). For example, if IPOLL(1) = 5, then the first pollutant routed through the S/T Block is the fifth pollutant found on the input file. If data from card group J1 are to be added to the external input file data (NOTAPE = 2, card B1), the pollutants entered on that card group must be in the same order as specified by IPOLL(1), IPOLL(2), and IPOLL(3).

Pollutants may be characterized by their magnitude alone (concentration) or by their magnitude and a particle size/specific gravity or settling velocity distribution by specifying IPART(IP) = 0 or 1, respectively. If

IPART(IP) = 1, the user is required to enter these distributions on card groups E2 through E6. Using these distributions, however, limits the type of unit that may be modeled (discussed in later card groups).

The variables NDIM1(1), NDIM1(2), and NDIM1(3) are used to describe the dimensions of the pollutant data on card group J1 when NOTAPE = 1. When NOTAPE = 0 or 2 (card B1) this information is provided by the external input file. For example, if NDIM1(1) = 0, then the first pollutant has dimensions of mg/l. If NDIM1(1) = 1, then the first pollutant has dimensions of liter^{-1}. This is used when pollutants such as coliforms are routed. When NDIM1(1) = 2, pollutant 1 has other concentration dimensions such as JTU, μmho, °C, pH, etc.

The entry of pollutant names PNAME1(IN,1), PNAME1(IN,2), and PNAME1(IN,3) and dimension names PUNIT1(IN,1), PUNIT1(IN,2), and PUNIT1(IN,3) is required only when the source of flow and pollutant data is solely card group J1 (NOTAPE = 1, card B1). If flow and pollutant data are read from an external input file (NOTAPE = 0 or 2, card B1) this information is already provided.

Naturally, if NP = 2 (card B1), for example, then the values for IPOLL (3), IPART(3), NDIM1(3), PNAME1(IN,3), and PUNIT1(IN,3) are not required under any circumstances. The order in which this pollutant information is entered determines the numbering of the pollutants.

Card groups E2 through E6 are required only if IPART(IP) = 1 for <u>any</u> pollutant. The user is referred to Appendix IV for a more detailed discussion of this form of pollutant characterization.

<u>Card Group E2</u> -- The variable NVS specifies the manner in which the particles in the waste stream are classified. If NVS = 0, the particles are classified by size and specific gravity. The variable NNR specifies the number of size/specific gravity ranges used to delineate the distribution (up to a maximum of 10 ranges). The size/specific gravity classification remains constant throughout the simulation for each pollutant characterized in this manner. The size and specific gravity ranges are established in card groups E3 and E4. These cards and card E5 (which enters waste stream temperature data) provide the information with which an average settling velocity is computed for each range (see Appendix IV for details). If NVS = 1, the particles are classified by NNR settling velocity ranges specified on card group E3. The average settling velocity for each size range is the average of the range endpoints. Cards E4 and E5 are not required. As with the size/specific gravity ranges, this classification remains constant throughout the simulation for each pollutant characterized by settling velocity. Obviously, a particle size or settling velocity distribution may change as it passes through the storage/treatment plant. This is accomplished by altering the pollutant fractions associated with the various size/specific gravity or settling velocity ranges as they pass through the units. The initial pollutant distributions are entered on the E6 cards. These distributions remain constant, however, at the input to the S/T plant.

The results of a literature review to characterize the pollutants in sanitary sewage, combined sewer overflows, and urban runoff by particle size and specific gravity are shown in Table 7-1. The data presented in Table 7-1 are not default values and are presented only as a guide in setting up card groups E2 through E6. Local data, through sieve and/or settling column analyses, are always preferred.

Card Group E3 -- These cards (up to two) are used to enter particle size (if NVS = 0, card E2) or settling velocity (if NVS= 1, card E2) ranges. A maximum of ten ranges (as indicated by NNR, card E2) may be entered. The variables RAN(1,1) and RAN(1,2) through RAN(NNR,1) and RAN (NNR,2) represent the lower and upper bounds of the diameters or settling velocities of particles found in ranges 1 through NNR. The ranges entered on this card remain constant through a simulation. When NVS = 0 (card E2), corresponding constant values of specific gravity are read on card E4.

Card Group E4 -- These cards (up to two) are required only if NVS = 0(card E2). The variables SPG(1) through SPG(NNR) represent the specific gravity of the particles found in size ranges 1 through NNR(card E2). Literature values are shown in Table 7-1.

Card Group E5 -- These cards (two) are required only if NVS = 0(card E2). The variables TEMP(1) through TEMP(12) represent the average wastewater temperatures for each month of the year. Water temperature has a direct effect on the settling velocity of a particle. This is reflected through the viscosity of the wastewater which is a function of temperature. The user is referred to Appendix IV for details.

Card Group E6 -- A set (consisting of up to two cards) of E6 cards is required for each pollutant characterized by a particle size/specific gravity or settling velocity distribution (IPART(IP) = 1, card E1). For example, if IPART(1) = 1(card E1) the variables PSD(1,1) through PSD(1, NNR) represent the fraction of pollutant 1 found in the particle size/ specific gravity or settling velocity ranges 1 through NNR entering unit 1 (all flows and pollutants must enter the S/T plant at unit 1). Naturally, these fractions should sum to 1.0. Table 7-1 contains some literature values for several pollutants (particle size/specific gravity distributions only).

The distribution entering the S/T plant remains constant throughout the simulation; however, it may change as the pollutants move through the various units. This is an approximation of the more probable situation in which the plant influent distributions change with time. This limitation was necessary due to the fact that no other SWMM blocks generate such distributions for input to the S/T Block. However, the S/T Block can be easily modified to accept time-varying distributions should such a capability be developed in the future.

Storage/Treatment Unit Information

Card groups F1 through I1 are repeated for each storage/treatment unit (up to NU, card B1). The unit number, I, is determined by the order in which each set of card groups F1 through I1 appears. This numbering scheme is important to the permissible configurations of units. There are two rules for numbering units; 1) flows and pollutant exiting from one unit must

Table 7-1. Particle Size Distributions.

SANITARY SEWAGE[a]

Particle Size, Microns	Percent Weighted in Each Size Range													
	Total Solids					Volatile Solids					Organic Nitrogen			Total P
	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)	(6)	(3)	(7)	(4)
< 0.001	69	68	64	64	64	50	42	41	31	46	53	22	37	68
0.001-1	6	6	7	7	7	9	9	10	14	11		11	20	9
1-100	11	11	11	12	29	18	18	19	24	43	47	34	20	15
> 100	14	15	18	17		23	25	30	31			33	23	8

Specific gravity: Suspended solids, 0.80-1.60(6); Settleable Solids, excluding grit, 1.05-1.20(11); Grit, 2.65(11)

COMBINED SEWAGE[a]

Particle Size, Microns	Percent Weight in Each Size Range: Suspended Solids (8)
< 74	48
74-295	22
295-991	16
991-3327	9
> 3327	5

Specific gravity: Suspended solids, 0.80-2.60(10); Settleable solids, excluding grit, 1.05-1.20(11); Grit, 2.65(11)

STORMWATER RUNOFF (STREET CONTAMINANTS)[a]

Particle Size, Microns	Percent Weight in Each Size Range: Suspended Solids (9)
< 43	14
43-104	11
104-246	18
246-840	22
840-2000	14
> 2000	21

Specific gravity: Same as reported by reference 11 for combined sewage.

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[a]Numbers in parentheses refer to the literature cited below:

(1) Rickert and Hunter, 1967
(2) Rickert and Hunter, 1971
(3) Hunter and Heulekekian, 1965
(4) Heulekekian and Balmat, 1959
(5) Metcalf and Eddy, Inc., 1972
(6) Helfgott et al., 1970
(7) Painter and Viney, 1959
(8) Envirogenics Co., 1970
(9) Sartor and Boyd, 1972
(10) Dalrymple et al., 1975
(11) Sullivan et al., 1974

be directed to a unit with a number greater than its own; and 2) all flows and pollutants entering the S/T system must enter unit 1. The flows entering and exiting a unit are shown in Figure 7-3. Several examples of storage/treatment plant configurations are shown in Figure 7-4.

General Unit Information --

Card Group F1 -- This card is used to enter the name of unit I.

Card Group F2 -- The variable IDENT(I) describes the unit I as a nondetention (IDENT(I) = 0) or detention process (IDENT(I) = 1). If IDENT(I) = 1, all or portions of card group H must be included.

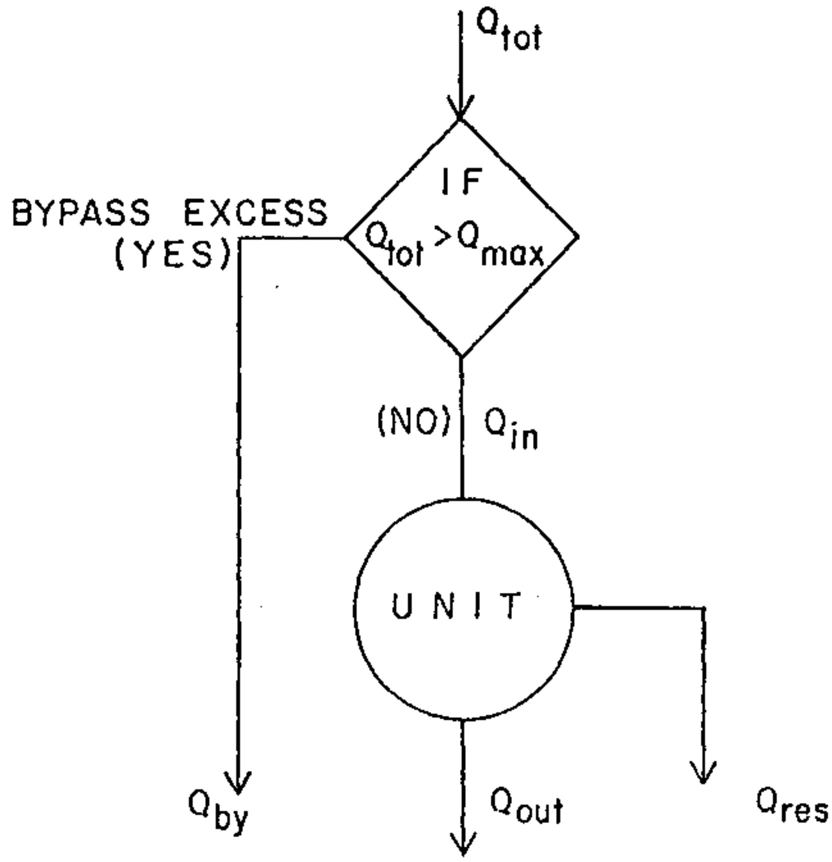
Each unit is assigned a maximum inflow, QMAX(I), beyond which all flows and pollutants are bypassed. However, this variable may be set to an abnormally high value for design purposes (i.e., responses at all possible inputs) or set at a realistic value for modeling existing or proposed facilities. The variable QRF(I) is used to specify the residual flow, as a fraction of the inflow, for non-detention units only (IDENT(I) = 0).

The variables IDIREC(I,1), IDIREC(I,2) and IDIREC(I,3) are used to direct bypassed flow and pollutants, treated outflow, and residuals from unit I to other units. The values entered for these variables represent the unit numbers to which these flows and pollutants are to be directed. Additionally, these flows may be sent directly to the next block (e.g., Receiving Block) or to ultimate disposal (which simply removes them from the simulation) by specifying IDIREC(I,ID) = 100 or 200, respectively. The flows and pollutants directed to the next block are summed for all the units and transferred as a single stream. Any unit to which flows are directed must have a unit number greater than the source unit (see Figure 7-4 for examples).

Pollutant Removal --

Pollutants are removed by settling or obstruction when characterized by particle size/specific gravity or settling velocity distributions. When they are characterized by magnitude (concentration) alone, removal is simulated through removal equations. Card groups G1 through G3 are used to establish these removal equations. When a particle size/specific gravity or settling velocity distribution is used and the unit is classified as a non-detention process, then a critical size or settling velocity is selected. The model removes all particles with a size or settling velocity greater than or equal to the critical size. Card G4 is used to enter this parameter.

Card groups G1 through G4 are repeated for each pollutant unless a detention unit is specified (IDENT(1) = 1, card F2) and a particle size/specific gravity or settling velocity distribution is specified for pollutant IP (IPART(IP) = 1, card E1). Naturally, these card groups are omitted if no pollutants are routed (NP = 0, card B1). Again, card groups G1 through G3 are used only if the pollutant is characterized solely by magnitude. Card G4 is used only if a pollutant is characterized by magnitude and a particle size/specific gravity or settling velocity distribution (IPART(IP) = 1, card E1) and a non-detention unit is specified (IDENT(I) = 0, card F2).



LEGEND

Q_{tot} = TOTAL INFLOW, ft^3/sec

Q_{max} = MAXIMUM ALLOWABLE INFLOW, ft^3/sec

Q_{by} = BYPASSED FLOW, ft^3/sec

Q_{in} = DIRECT INFLOW TO UNIT, ft^3/sec

Q_{out} = TREATED OUTFLOW, ft^3/sec

Q_{res} = RESIDUAL STREAM, ft^3/sec

Figure 7-3. Flows Into, Through, and Out of a Storage/Treatment Unit.

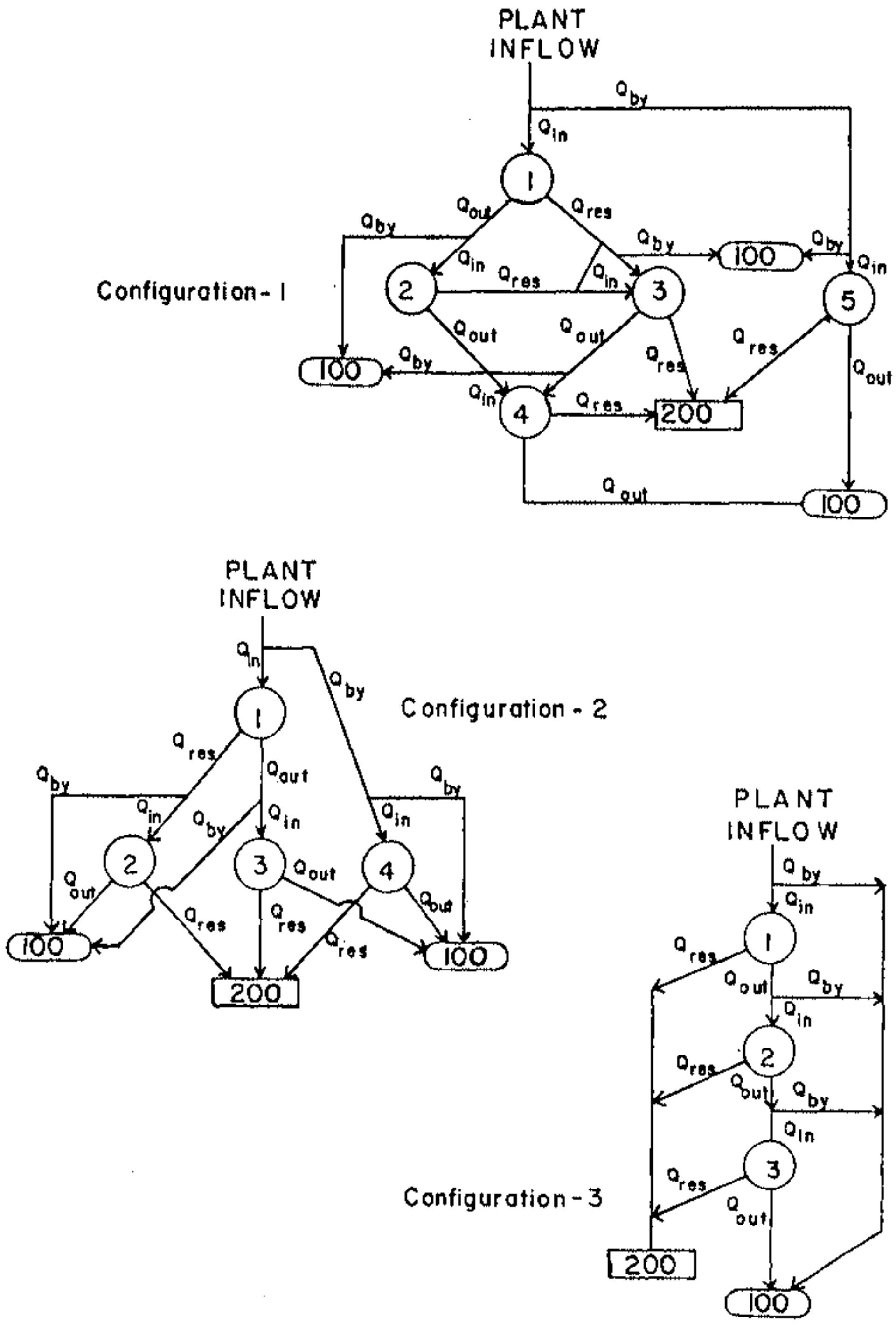


Figure 7-4. Storage/Treatment Plant Configurations.

Table 7-2. Program Variables Available for Pollutant Removal Equations

Value of INPUT(I,IP,K)[a] (G2 cards)	Non-Detention Units, IDENT(I) = 0 (card F2)	Detention Units, IDENT(I) = 1 (card F2)	
		Perfect plug flow is used, to route pollutants, IROUTE(I)=0 (card I2)	Complete mixing is used to route pollutants, IROUTE(I) = 1 (card I2)
0	Not used.	Not used.	Not used.
1	Not used.	Detention time of each plug in detention unit I, seconds.	Time step size, seconds.
2	Concentration of pollutant 1 passing through unit I.[b]	Initial concentration of pollutant 1 in each plug in detention unit I.[b]	Not used.
3	Concentration of pollutant 2 passing through unit I.[b]	Initial concentration of pollutant 2 in each plug in detention unit I.[b]	Not used.
4	Concentration of pollutant 3 passing through unit I.[b]	Initial concentration of pollutant 3 in each plug in detention unit I.[b]	Not used.
5	Removal fraction of pollutant 1 in unit I (used only for pollutants 2 and 3).	Removal fraction of pollutant 1 for each plug in detention unit I (used only for pollutants 2 and 3).	Removal fraction of pollutant 1 in detention unit I (used only for pollutants 2 and 3).
6	Removal fraction of pollutant 2 in unit I (used only for pollutant 3).	Removal fraction of pollutant 2 for each plug in detention unit I (used only for pollutant 3).	Removal fraction of pollutant 1 in detention unit I (used only for pollutant 3).
7	Inflow rate, ft^3/sec [m^3/sec].	Not used.	Not used.

[a]I = unit number.
IP = pollutant number.
K = Subscript of x in equations 7-1.

[b]Dimensions determined by NDIM(IP) on card E1.

Card Group G1 -- A single flexible functional form is avaliable for use as a pollutant removal equation (See Appendix IV):

$$R = \left(a_{12} e^{a_1 x_1} x_2^{a_2} + a_{13} e^{a_3 x_3} x_4^{a_4} + a_{14} e^{a_5 x_5} x_6^{a_6} + a_{15} e^{(a_7 x_7 + a_8 x_8)} x_9^{a_9} x_{10}^{a_{10}} x_{11}^{a_{11}} \right)^{a_{16}} \tag{7-1}$$

where x_i = removal equation variables,

a_j = coefficients, and

R = removal fraction, $0 \leq R \leq 1.0$.

Each removal equation variable, x_i, may represent, one of several parameters available in the program at each time step and these options are discussed below (card group G2). With these variables and the coefficients, a_i, the user can develop the desired removal equation. The coefficients are entered on card group G3.

A maximum removal fraction is specified by RMX(I,IP). This is particcularly useful for equations which mathematically generate values of the removal fraction, R, that may exceed a reasonable value or 1.0. RMX(I,IP) provides an upper bound on such equations.

Card Group G2 -- These cards (two) allow the user to assign various program variables to the variables in equation 7-1. For example, if pollutant 1 (IP = 1) is to be removed in unit I by a removal equation, the values given INPUT(I,1,1) through INPUT(I,1,11) assign program variables to the corresponding variables x_1 through x_{11} in equation 7-1. The program variables available for inclusion are shown in Table 7-2. An example removal equation is discussed below.

Card Group G3 -- The variables A(I,IP,1) through A(I,IP,16) represent the variables a_1 through a_{16} in equation 7-1 as applied to pollutant IP in unit I. Two cards are required.

An example of applying equation 7-1 is provided by a suspended solids removal equation used in an earlier version of the Storage/Treatment Block for sedimentation (detention) units:

$$R_{SS} = R_{max} \left(1 - e^{-kt_d}\right) \tag{7-2}$$

where R_{SS} = suspended solids removal fraction, $0 \leq R_{SS} \leq R_{max}$,

R_{max} = maximum removal fraction,

t_d = detention time, seconds, and

k = first order decay coefficient, 1/sec.

This equation can be constructed from equation 7-1 by setting a_{12} (or A(I, IP,12)) = R_{max}, a_{13} (or A(I,IP,13)) = $-R_{max}$, a_3 (or A(I,IP,3)) = -k, a_{16} (or A(I,IP,16)) = 1.0, and letting x_3 = detention time, t_d, by setting INPUT(I,IP,3) = 1 (card group G2). All other coefficients, a_j (or A(I,IP,J)), would equal zero. RMX(I,IP) (card G1) would not be necessary, as R_{max} limits the value of R. Appendix IV contains other examples.

Card Group G4 -- The variable PSC(I) specifies a critical particle size (if NVS = 0, card E2) or settling velocity (if NVS = 1, card E2) that denotes the point above which all particles are removed from the influent. This parameter is included primarily to model such non-detention units as micro-screens, fine screens, and coarse screens. An approximation of the removal effectiveness of screens may be obtained by letting PSC(I) equal the aperture size of the screen (see Appendix IV). Card G4 is required only if IPART(IP) = 1 (card E1) and IDENT(I) = 0 (card F2).

Detention Unit Data --

Card groups H1 through H8 are used to describe the special characteristics of detention units. Sedimentation, dissolved air floatation, chlorination, and sludge thickening are some of the processes that may be modeled by a detention unit.

These cards primarily describe the hydraulic characteristics of a detention unit and, thus, are required only if IDENT(I) = 1 (card F2).

Card Group H1 -- The variable IROUTE(I) specifies the manner in which pollutants are routed in detention unit I. When IROUTE(I) = 0 the unit routes pollutants under the assumption of perfect plug flow. Perfect plug flow is recommended for long, rectangular tanks where settling is the most important removal mechanism and is required when any pollutant is characterized by a particle size/specific gravity or settling velocity distribution (IPART(IP) = 1, card E1). Removed pollutants are accumulated in plug-flow units, without decay, until removed by the residual flow. When IROUTE(I) = 1 the unit routes pollutants under the assumption of perfect miximg. Complete mixing is most applicable to small tanks where the primary purpose is to thoroughly mix the contents (e.g., rapid-mix chlorination, flocculators, and mixing tanks). Removed pollutant quantities are not allowed to accumulate in completely-mixed units (i.e., no settling). The user is referred to Appendix IV for further explanation.

The variable IOUT(I) is used to describe the depth-treated outflow relationship that characterizes the discharge of treated outflow (e.g., weir flow) from unit I. The user is given three options. The first (IOUT(I) = 0) is to provide the model with as many as sixteen data pairs describing the depth-outflow relationship (entered on card group I3). The second option (IOUT(I) = 1) is to approximate the relationship by a power equation (entered on card H4). The third option (IOUT(I)=2) specifies a constant pumping rate between certain depths (entered on card H5).

In addition to treated outflow, a residual stream may be drawn from the unit during periods of no inflow or treated outflow. When a residual stream occurs from a plug-flow unit the entire unit contents (including the removed pollutant quantities) are mixed (i.e., the remaining plugs lose their identity) and drawn off until the unit is empty or inflow occurs. If inflow begins before the unit is empty the remaining contents are placed in a single plug for further routing. In a completely-mixed unit, the pollutant concentrations in the residual flow are identical to the concentrations in the treated outflow. Again, the flow is suspended when inflow occurs. The variable IDRAW(I) simply specifies the conditions under which a residual stream begins. If IDRAW(I) = 0, a residual stream is never drawn and the accumulated pollutants (if IROUTE(I) = 0) remain in the unit. If IDRAW(I) ≦ -1, the residuals are drawn off starting at every -IDRAW(I) time steps (but the flow is delayed if inflow and/or treated outflow is in progress). This option corresponds with the situation in which the unit is drained on a regular (e.g., scheduled) basis. If IDRAW(I) ≧ 1, the residuals are drawn after IDRAW(I) time steps of no inflow or treated outflow. The conditions specified by IDRAW(I) ≧ 1 apply directly to the case in which the unit contents are drained after each runoff event.

The variable IRES(I) is used to describe the depth-residual flow relationship that characterizes the draw off of the residual stream from unit I. If IRES(I) = 0, the user provides the model with as many as sixteen data pairs describing the depth-residual flow relationship (entered on the H3 cards). If IRES(I) = 1, the relationship is approximated by a power equation (entered on card H6).

Card Group H2 -- The parameters on this card are required only when a particle size/specific gravity or settling velocity distribution is used to characterize any pollutant (IPART(IP) = 1, card E1) and unit I is a plug-flow detention unit (IROUTE(I) = 0, card H1).

The variable ALEN(I) represents the travel length for plugs in unit I. The variable AMAN(I) is the Manning's roughness coefficient for the surfaces of unit I and is commonly available for many materials. These values are required for the pollutant removal algorithms used when a particle size/specific gravity or settling velocity distribution characterizes a pollutant (see Appendix IV).

Card Group H3 -- These cards are used to enter up to sixteen sets of data describing the geometry and hydraulics of detention unit I. Each card enters a value for depth, SDEPTH(I,MM), along with the corresponding values of surface area, SAREA(I,MM), volume, SSTORE(I,MM), treated outflow, SQQOU(I,MM), and residual flow, SQQRS(I,MM). The series is terminated by a blank card.

The only required parameters are DEPTH(I,MM) and SAREA(I,MM); the need for the other parameters depends on other factors. If SSTORE(I,MM) is left blank on every H3 card, the program will estimate the volume at each depth by averaging the surface area at each depth and the lower adjacent depth, multiplying by the difference in depth, and adding the result to the estimated volume at the lower adjacent depth. A value for treated outflow, SQQOU(I,MM), is required for each depth only if IOUT(I) = 0 (card H1). If IOUT = 1 or 2 (card H1), this relationship is provided by card H4 or card H5, respectively. Likewise, a value for residual flow, SQQRS(I,MM), is required for each depth only if IRES(I) = 0 (card H1). If IRES(I) = 1 (card H1), this relationship is described by card H6. The values entered for SQQRS(I,MM) are used during periods in which a residual stream is drawn from the unit (IDRAW(I), card I1).

The values specified on these cards (or computed as a result of cards H4, H5, and H6) are used to establish relationships between depth, surface area, volume, treated outflow, and residual flow. The program also generates a relationship between depth and the evaporation rate (see card group D1). These relationships are used to route flows through a detention unit using the Puls method (Viessman et al., 1977). This method is described in detail in Appendix IV.

Card Group H4 -- This card is required only if a power equation is to describe the depth-treated outflow relationship (IOUT(I) = 1, card H1). The equation is

$$Q_{out} = C_1(D - D_0)^{C_2} \tag{7-3}$$

where Q_{out} = treated outflow, ft^3/sec [m^3/sec],

C_1, C_2 = coefficients,

D = water depth in detention unit, ft [m], and

D_0 = depth below which there is no treated outflow, ft [m].

The user supplies the values of D_0, C_1, and C_2 (program variables D0, C1, and C2, respectively).

Two common outlet structures that may be modeled with equation 7-3 are the orifice and the broad-crested weir. For example, a weir could be modeled by letting $C_1 = 3.33 \cdot L$ where L = length of the weir in feet, $C_2 = 1.5$, and D_0 = depth at the bottom of the weir in feet. These substitutions yield the familiar weir equation.

Card Group H5 -- This card is required only if pumping is specified for the treated outflow from a detention unit (IOUT(I) = 2, card H1). The variables DSTART(I,1) and DSTART(I,2) represent the depths at which the pumping rates QPUMP(I,1) and QPUMP(I,2) begin. The variable DSTOP(I) specifies the depth at which all pumping stops. In other words, the rate QPUMP(I,1) occurs when the depth is equal to or exceeds DSTART(I,1) and the rate QPUMP(I,2) occurs when the depth is greater than or equal to DSTART(I,2). The pumping rate reverts to the rate QPUMP(I,1) when the depth falls below DSTART(I,2) and continues at that rate until the depth falls to DSTOP(I). The value of DSTART(I,1) must be less than or equal to DSTART(I,2) and DSTOP(I) must be less than or equal to DSTART (I,1).

Card Group H6 -- This card is required only if a power equation is used to describe the depth-residual flow relationship (IRES(I) = 1, card H1). The equation is

$$Q_{res} = C_3(D - D_1)^{C_4} \tag{7-4}$$

where Q_{res} = residual flow, ft^3/sec [m^3/sec],

C_3, C_4 = coefficients,

D = water depth in detention unit, ft [m], and

D_1 = depth below which there is no residual flow, ft [m].

The user supplies the values of D_1, C_3, and C_4 (program variables D1, C3, and C4, respectively). Recall that a residual flow occurs only when dictated by IDRAW(I) (card H1).

Card Group H7 -- This card is used to indicate the build up of sludge in a plug-flow detention unit (IROUTE(I) = 0, card H1). The user specifies the pollutant used to calculate the sludge volume, NPSL(I); the concentration of pollutant NPSL(I) in sludge; and the depth at which a warning is given to indicate that sludge has accumulated to an unacceptable level. The sludge volume is increased by dividing the amount of pollutant NPSL(I) removed each time step by SLDEN(I). The model assumes that the sludge volume has no effect on the available storage volume and that no compression occurs. The information on this card is only used to warn the user of a possible maintenance/performance problem.

Card Group H8 -- This card specifies the total volume, WARN(I), and pollutant concentrations, PCO(I,IP), present in the unit at the start of the simulation. Obviously, the values of PCO(I,IP) are not required if NP = 0 (card B1) or WARN(I) = 0.0.

Cost Data --

Card Group I1 -- This card is required only if ICOST = 1 (card B1).

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

$$C_{cap} = a\ Q_{max}^{b} \tag{7-5}$$

or

$$C_{cap} = a(Q_{in})_{max}^{b} \tag{7-6}$$

or

$$C_{cap} = a\ V_{max}^{b} \tag{7-7}$$

or

$$C_{cap} = a(V_{obs})_{max}^{b} \tag{7-8}$$

where C_{cap} = initial capital cost, dollars,

Q_{max} = maximum allowable inflow, ft^3/sec [m^3/sec],

$(Q_{in})_{max}$ = maximum inflow encountered during the simulation, ft^3/sec [m^3/sec],

V_{max} = maximum allowable storage (detention units only), ft^3 [m^3],

$(V_{obs})_{max}$ = maximum storage encountered during the simulation (detention units only), ft^3 [m^3], and

a, b = coefficients (specified by the user).

Equations 7-5 through 7-8 differ only in the variable used to compute the initial capital cost of unit I. The variable KPC(I,1) specifies which variable is used (as shown in Table 7-3) and CC(I,1) and CC(I,2) represent the coefficients a and b.

The operation and maintenance costs are calculated as a function of the variables listed above and the total operating time (calculated as the number of time steps with flow to or from the unit).

$$C_{om} = d\ Q_{max}^{f} + hD_{op} \tag{7-9}$$

or

$$C_{om} = d(Q_{in})_{max}^{f} + hD_{op} \tag{7-10}$$

or

$$C_{om} = d\, V_{max}^{f} + hD_{op} \tag{7-11}$$

or

$$C_{om} = d(V_{obs})_{max}^{f} + hD_{op} \tag{7-12}$$

where C_{om} = operation and maintenance cost, dollars,

D_{op} = total operating time during the simulation period, hours, and

d,f,h = coefficients (supplied by the user).

Equations 7-9 through 7-12 differ only in the variable used to compute the operation and maintenance costs for unit I. The variable KPC(I,2) specifies which variable is used (as shown in Table 7-3) and CC(I,3), CC(I,4), and CC(I,5) represent the coefficients d, f, and h.

The user is cautioned not to misinterpret the cost calculated by the model. For example, in a single-event simulation the calculated capital cost can only be considered an estimator of the true capital cost when the simulated event is a design event. Likewise, when operating time is a factor in computing operation and maintenance costs, the calculated costs can be a valid estimator of the true costs only when a long-term simulation is performed. Recent EPA publications provide useful information for the proper selection of the coefficients required in equations 7-5 through 7-12 (EPA, 1976; Benjes, 1976).

Input Waste Stream

Flow and Pollutant Data --

Card group J1 is required only if NOTAPE = 1 or 2 (card B1).

Card Group J1 -- This card is repeated for each time step including those with no inflow. The pollutant concentrations, PCAR(IP), must be entered in the same order as on card E1 and have the same dimensions specified by NDIM(IP) and PUNIT(IN,IP)(card E1). If NOTAPE = 2 (card B1), the flow and concentrations are added to the values from the external tape or disk. All values are instantaneous flows or concentrations (at the end of the time step).

ALTERING THE PROGRAM SIZE

The Storage/Treatment Block, as presently written, is capable of modeling a maximum of five S/T units. To alter this restriction requires that the number 5, which appears in several lines of seven subrountines, be changed to the desired maximum. The specific subroutines and lines (numbered in columns 72 through 80) are as follows:

Subroutine STRT: 14 through 27.
Subroutine STRDAT: 4 through 18.
Subroutine CONTRL: 4 through 19 and 21 through 24.
Subroutine UNIT: 4 through 23 and 25.
Subroutine PLUGS: 3
Subroutine EQUATE: 3 through 16.
Subroutine STCOST: 4 through 17.

When a detention unit is modeled as a plug-flow reactor(IDENT(I) = 1, card F2, and IROUTE(I) = 0, card H1) the maximum number of plugs allowed to be in the unit at any one time is 50. The program will terminate if this limit is exceeded. However, the user can increase this capacity by changing the number 50 to the desired value in the following lines (numbered in columns 72-80):

Subroutine UNIT: 18 through 21, 23, 25 and 29.

Table 7-3. Storage/Treatment Block Card Data

Card Group	Format	Card Column	Description	Variable Name	Default Value
			CARD GROUP A1; TITLE		
			Title cards: two cards with heading to be printed on output.		
A1	2X	1-2	Card identifier = A1.	--	Blank
	2X	3-4	Skip	--	Blank
	19A4	5-80	Title.	TITLE2	None
			CARD GROUP B1; GENERAL DATA		
B1	2X	1-2	Card identifier = B1.	--	Blank
	I3	3-5	Input data source. = 0, Input is from an external input file. = 1, Input is supplied on card group J1. = 2, Input is from an external input file and card group J1.	NOTAPE	0
	I5	6-10	External element number from the outside block (e.g., NOE in Transport Block) which routes flow to the S/T Block. If NOTAPE = 1, the value of JNS is placed on the output file.	JNS	None
	I10	11-20	Total number of simulation time steps.	NDT	0
	F10.0	21-30	Size of time step, seconds. Required only if NOTAPE = 1.	DS	None
	4I5	31-35	Number of storage/treatment units. (maximum = 5).	NU	1
		36-40	Number of pollutants routed (maximum = 3).	NP	0
		41-45	Cost calculations performance? = 0, No. = 1, Yes.	ICOST	0

Table 7-3 (continued). Storage/Treatment Block Card Data

Card Group	Format	Card Column	Description	Variable Name	Default Value
		46-50	Metric input-output. = 0, Use U.S. customary units. = 1, Use metric units. Metric input indicated in brackets[ ].	METRIC	0
	F10.0	51-60	Service area, acres [ha]. Not required.	SAREA	0
			CARD GROUPS C1 AND C2; STARTING TIME AND PRINT INSTRUCTIONS		
			Starting date/time and print instructions card.		
C1	2X	1-2	Card identifier = C1.	--	Blank
	I8	3-10	Date at beginning of simulation (6 digit number; year, month, day -- e.g., March 10, 1979 = 790310).	IDATE	0
	F10.0	11-20	Time at beginning of simulation (24-hour clock, e.g., 5:30 pm = 17.5.	TIME	0
	3I10	21-30	Summary print control parameter. = 0, Print a summary at the end of the simulation only. = 1, Print an annual summary and a summary at the end of the simulation. = 2, Print monthly and annual summaries and a summary at the end of the simulation.	ISUM	0
		31-40	Detailed print control parameter. = 0, No detailed print of simulation results. > 0, Detailed print of results is provided at every time step that is a multiple of IDET (e.g., IDET = 2 gives a detailed report at every other time step) during specified periods (see below and card group C2).	IDET	0
		41-50	Number of detailed print periods. Up to 8 periods may be specified (see C2 cards). Required only if IDET > 0.	NPR	0

Table 7-3 (continued). Storage/Treatment Block Card Data

Card Group	Format	Card Column	Description	Variable Name	Default Value
			Detailed print period cards. NPR (card C1) periods must be specified. Only date to date periods may be used (e.g., 790720 to 790806). Required only if IDET > 0 (card C1).		
C2	2X	1-2	Card group identifier = C2.	--	Blank
	I8	3-10	First detailed print period starting date (e.g., July 20, 1979 = 790720).	ISTART(1)	None
	7I10	11-20	First detailed print period ending date (e.g., August 6, 1979 = 790806).	IEND(1)	None
		21-30	Repeat for second period, etc., up to NPR (card C1) periods (may require two cards).	ISTART(2)	None
		31-40		IEND(2)	None
		.	.	.	.
		.	.	.	.
		.	.	.	.
			CARD GROUP D1; EVAPORATION DATA		
			Evaporation data cards. May leave blank if there are no detention units (IDENT(I) = 0 for all units, see card F2). However, two cards must be included.		
D1	2X	1-2	Card group identifier = D1.	--	Blank
	F8.0	3-10	Evaporation rate, January, in/day [mm/day].	E(1)	0.0
	7F10.0	11-20	Evaporation rate, February, in/day [mm/day].	E(2)	0.0
		.	.	.	.
		.	.	.	.
		.	.	.	.
		.	Repeat for each month.	.	.
			CARD GROUPS E1-E6; POLLUTANT CHARACTERIZATION.		
			REQUIRED ONLY IF NP > 0 (CARD B1).		

Table 7-3 (continued). Storage/Treatment Block Card Data

Card Group	Format	Card Column	Description	Variable Name	Default Value
			General pollutant characteristics card.		
E1	2X	1-2	Card group identifier = E1.	--	Blank
	3I1	3	Pollutant 1 selector. Required only if NOTAPE = 0 or 2 (card B1). The value selected depends on the order in which the pollutants were placed on the external input file. For example, if suspended solids was the third pollutant listed on the file and it was desired for use in the S/T Block, then IPOLL(1) = 3.	IPOLL(1)	None
		4	Dimensions for pollutant 1. Required only if NOTAPE = 1 (card B1). = 0, Dimensions are mg/l. = 1, Dimensions are $liter^{-1}$. = 2, Other concentration dimensions are used (e.g., JTU, µmho, °C, pH)	NDIM1(1)	0
		5	Particle size/specific gravity or settling velocity distribution parameter. = 0, Distribution not used to characterize pollutant 1. = 1, Distribution used to characterize pollutant 1.	IPART(1)	0
	2(2X,2A4)	8-15	Pollutant 1 name. Required only if NOTAPE = 1 (card B1).	PNAME1(IN,1)	None
		18-25	Pollutant 1 dimension label. Required only if NOTAPE = 1 (card B1).	PUNIT1(IN,1)	None
	2X,3I1	28	Pollutant 2 selector. Required only if NP ≧ 2 and NOTAPE = 0 or 2 (card B1). See above.	IPOLL(2)	None
		29	Dimensions for pollutant 2. Required only if NP ≧ 2 and NOTAPE = 1 (card B1). See above.	NDIM1(2)	0
		30	Particle size/specific gravity or settling velocity distribution parameter. Required only if NP ≧ 2 (card B1). See above.	IPART(2)	0
	2(2X,2A4)	33-40	Pollutant 2 name. Required only if NP ≧ 2 and NOTAPE = 1 (card B1).	PNAME1(IN,2)	None

Table 7-3 (continued). Storage/Treatment Block Card Data

Card Group	Format	Card Column	Description	Variable Name	Default Value
		43-50	Pollutant 2 dimension label. Required only if NP ≥ 2 and NOTAPE = 1 (card B1).	PUNIT1(IN,2)	None
	2X,3I1	53	Pollutant 3 selector. Required only if NP = 3 and NOTAPE = 0 or 2 (card B1). See above.	IPOLL(3)	None
		54	Dimensions for pollutant 3. Required only if NP = 3 and NOTAPE = 1 (card B1). See above.	NDIM1(3)	0
		55	Particle size/specific gravity or settling velocity distribution parameter. Required only if NP = 3 (card B1). See above.	IPART(3)	0
	2(2X,2A4)	58-65	Pollutant 3 name. Required only if NP = 3 and NOTAPE = 1 (card B1).	PNAME1(IN,3)	None
		68-75	Pollutant 3 dimension label. Required only if NP = 3 and NOTAPE = 1 (card B1).	PUNIT1(IN,3)	None
			CARD GROUPS E2-E6 ARE REQUIRED ONLY IF IPART(IP) = 1 (CARD E1) FOR ANY POLLUTANTS.		
E2	2X	1-2	Card identifier = E2.	--	Blank
	I8	3-10	Classification parameter. = 0, Particle size/specific gravity distribution is used to classify particles in waste stream. = 1, Settling velocity distribution is used.	NVS	0
	I10	11-20	Number of particle size ranges or settling velocities used to classify particles in waste stream.	NNR	None
			Particle size (if NVS =0, card E2) or settling velocity (if NVS = 1, card E2) range cards. May require up to three cards.		
E3	2X	1-2	Card group identifier = E3.	--	Blank
	I8	3-10	Lower bound of size or velocity range 1, microns or ft/sec [cm/sec].	RAN(1,1)	None
	7I10	11-20	Upper bound of size or velocity range 1, microns or ft/sec [cm/sec].	RAN(1,2)	None

Table 7-3 (continued). Storage/Treatment Block Card Data

Card Group	Format	Card Column	Description	Variable Name	Default Value
		21-30	Lower bound of size or velocity range 2, microns or ft/sec [cm/sec].	RAN(2,1)	None
		31-40	Upper bound of size or velocity range 2, microns or ft/sec [cm/sec].	RAN(2,2)	None
		. . . .	. . . Repeat for each size or velocity range, up to NNR (card E2) ranges.	. . . .	. . . .
			Specific gravity cards. Required <u>only</u> if NVS = 0 (card E2). May require up to two cards.		
E4	2X	1-2	Card group identifier = E4.	--	Blank
	F8.0	3-10	Specific gravity for particles in size range 1.	SPG(1)	None
	7F10.0	11-20	Specific gravity for particles in size range 2.	SPG(2)	None
		. . . .	. . . Repeat for each size range, up to NNR (card E2) ranges.	. . . .	. . . .
			Waste stream temperature cards. Required <u>only</u> if NVS = 0 (card E2). Requires two cards.		
E5	2X	1-2	Card group identifier = E5.	--	Blank
	F8.0	3-10	Waste stream temperature, January, °F [°C].	TEMP(1)	None
	7F10.0	11-20	Waste stream temperature, February, °F [°C].	TEMP(2)	None
			[illegible]		

Table 7-3 (continued). Storage/Treatment Block Card Data

Card Group	Format	Card Column	Description	Variable Name	Default Value
			Fraction of pollutant associated with each particle size/specific gravity or settling velocity range (card group E3). Repeat these cards for each pollutant for which IPART(IP) = 1(card E1). Each pollutant may require up to two cards.		
E6	2X	1-2	Card group identifier = E6.	--	Blank
	F8.0	3-10	Fraction of pollutant IP in range 1.	PSD(IP,1)	None
	7F10.0	11-20	Fraction of pollutant IP in range 2.	PSD(IP,2)	None
		. . . .	. . . Repeat for each range up to NNR (card E2) ranges.	. . . .	. . . .

REPEAT CARD GROUPS F1-I1 FOR EACH UNIT I. THERE WILL BE NU(CARD B1) SETS. THE UNIT NUMBER IS DICTATED BY THE ORDER IN WHICH THE SETS OF CARD GROUPS F1-I1 ARE READ.

CARD GROUPS F1-F2; GENERAL UNIT CHARACTERISTICS

Card Group	Format	Card Column	Description	Variable Name	Default Value
F1	2X	1-2	Card group identifier = F1.	--	Blank
	6A3	3-20	Name of unit.	UNAME(I,ID)	None
			General unit parameters and flow directions.		
F2	2X	1-2	Card group identifier = F2.	--	Blank
	I8	3-10	Detention modeling parameter. = 0, Unit is the non-detention type. = 1, Unit is the detention type.	IDENT(I)	0

Table 7-3 (continued). Storage/Treatment Block Card Data

Card Group	Format	Card Column	Description	Variable Name	Default Value
	2F10.0	11-20	Maximum inflow (above which bypass occurs), ft^3/sec [m^3/sec].	QMAX(I)	None
		21-30	Residual flow as a fraction of the inflow. Required only if IDENT(I) = 0. Residual flows for detention units (IDENT(I) = 1) are determined in card groups H1, H3, and H6.	QRF(I)	None
	3I10	31-40	Unit number to which bypass is directed (must be greater than I). = 2-5, Downstream S/T unit. = 100, Next block. = 200, Ultimate disposal.	IDIREC(I,1)	None
		41-50	Unit number to which treated outflow is directed (must be greater than I). See above.	IDIREC(I,2)	None
		51-60	Unit number to which residuals stream is directed (must be greater than I). See above. If IDRAW(I) = 0 (card H1), set equal to any number greater than I.	IDIREC(I,3)	None
			CARD GROUPS G1-G4; POLLUTANT REMOVAL REQUIRED ONLY IF NP > 0 (card B1).		
			REPEAT CARD GROUPS G1 - G3 FOR EACH POLLUTANT FOR WHICH IPART(IP) = 0.		
G1	2X	1-2	Card identifier = G1.	--	Blank
	F8.0	3-10	Maximum removal fraction(≤ 1.0).	RMX(I,IP)	None
			Removal equation variable card (equation 7-1). Requires two cards.		

Table 7-3 (continued). Storage/Treatment Block Card Data

Card Group	Format	Card Column	Description	Variable Name	Default Name
G2	2X	1-2	Card group identifier = G2.	--	Blank
	I8	3-10	Program variable for equation variable x_1. = 0, Not used. = 1 = 2 = 3 See Table 7-2 in text. = 4 = 5 = 6 = 7	INPUT(I,IP,1)	0
	7I10	11-20	Program variable for equation variable x_2. See above.	INPUT(I,IP,2)	0
		.	.	.	.
		.	.	.	.
		.	.	.	.
		.	Repeat for each program variable x_i.	.	.
			Equation coefficients cards. Requires two cards. The coefficients must be consistent with the units used (see METRIC, card B1).		
G3	2X	1-2	Card group identifier = G3.	--	Blank
	F8.0	3-10	Value of coefficient a_1.	A(I,IP,1)	0.0
	7F10.0	11-20	Value of coefficient a_2.	A(I,IP,2)	0.0
		.	.	.	.
		.	.	.	.
		.	.	.	.
		.	Repeat for each coefficient a_j.	.	.
			Critical particle size or settling velocity card. Required only if IPART(IP) = 1 (card E1) for any pollutant and unit I is a non-detention unit, IDENT(I) = 0 (card F2).		
G4	2X	1-2	Card group identifier = G4.	--	Blank

Table 7-3 (continued). Storage/Treatment Block Card Data

Card Group	Format	Card Column	Description	Variable Name	Default Value
	F8.0	3-10	Critical particle size microns (if NVS = 0, card E2), or settling velocity, ft/sec [cm/sec] (if NVS = 1, card E2).	PSC(I)	None
			CARD GROUP H1-H8; DETENTION UNIT DATA REQUIRED <u>ONLY</u> IF IDENT(I) = 1 (CARD F2).		
			General detention unit parameters card.		
H1	2X	1-2	Card group identifier = H1.	--	Blank
	I8	3-10	Pollutant routing parameter. = 0, Plug flow mode is used. = 1, Complete mixing mode is used. (Note: Particle size or settling velocity distribution are not routed through completely-mixed units.)	IROUTE(I)	0
	3I10	11-20	Treated outflow routing parameter. = 0, The depth-treated outflow relationship is described by as many as sixteen data pairs on card group H3. = 1, The depth-treated outflow relationship is described by a power equation on card H4. = 2, The depth-treated outflow relationship is controlled by the pumps described on card H5.	IOUT(I)	0
		21-30	Residuals stream draw-off scheme. ≤ -1, A residual stream is drawn off starting at every -IDRAW(I) time step (if possible). = 0, Residuals are never drawn off. ≥ 1, A residuals stream (if available) is drawn off only after IDRAW(I) time steps of no inflow or treated outflow.	IDRAW(I)	0

Table 7-3 (continued). Storage/Treatment Block Card Data

Card Group	Format	Card Column	Description	Variable Name	Default Value
		31-40	Residual stream routing parameter. Required only if IDRAW(I) ≠ 0. = 0, The depth-residual flow relationship is described by as many as sixteen data pairs on card group H3. = 1, The depth-residual flow relationship is described by a power equation on card H6.	IRES(I)	0
			Detention unit (plug flow only) parameters required when pollutants are characterized by a particle size/specific gravity or settling velocity distribution. Thus, this card is required <u>only</u> if IPART(IP) = 1 for any pollutant (card E1) and IROUTE(I) = 0 (card H1).		
H2	2X	1-2	Card group identifier = H2.	--	Blank
	F8.0	3-10	Travel length for plug flow, ft [m].	ALEN(I)	None
	F10.0	11-20	Manning's roughness coefficient for detention unit surfaces.	AMAN(I)	None
			Depth-surface area-volume-treated outflow- residual flow data cards. Each card contains a column for a unit depth and the corresponding values of area, volume, treated outflow, and residual flow. The columns for treated outflow and residual flow may be left blank depending on the values of IOUT(I) and IRES(I) on card H1. If no values for volume are entered the program estimates volume from the depth-surface area relationship. Order the cards from the bottom of the unit (SDEPTH(I,1) = 0.0) to the maximum depth (including freeboard). There may be as many as sixteen cards. End the card series with a blank card.		
H3	2X	1-2	Card group identifier = H3.	--	Blank
	F8.0	3-10	A unit depth, ft [m].	SDEPTH(I,MM)	None

Table 7-3 (continued). Storage/Treatment Block Card Data

Card Group	Format	Card Column	Description	Variable Name	Default Value
	4F10.0	11-20	Surface area corresponding to the above depth, ft^2 [m^2].	SAREA(I,MM)	None
		21-30	Volume corresponding to the above depth, ft^3 [m^3].	SSTORE(I,MM)	None
		31-40	Treated outflow at the above depth, ft^3/sec [m^3/sec].	SQQOU(I,MM)	None
		41-50	Residuals stream flow at the above depth, ft^3/sec [m^3/sec]. Occurs only when IDRAW(I) (card H1) permits.	SQQRS(I,MM)	None
			*** Follow the last card (maximum depth) with *** a blank card.		
			Depth-treated outflow power equation card (equation 7-3). Required <u>only</u> if IOUT(I) = 1 (card H1). Coefficients must be consistent with the units used (see METRIC, card B1).		
H4	2X	1-2	Card group identifier = H4.	--	Blank
	F8.0	3-10	Depth-treated outflow equation coefficient, C_1.	C1	0.0
	2F10.0	11-20	Depth below which no treated outflow occurs, D_0.	D0	0.0
		21-30	Depth-treated outflow equation coefficient, C_2.	C2	0.0
			Treated outflow pumping card. Required <u>only</u> if IOUT(I) = 2 (card H1).		
H5	2X	1-2	Card identifier = H5.	--	Blank
	F8.0	3-10	Depth at which pumping rate QPUMP(I,1) begins, ft [m].	DSTART(I,2)	None
	4F10.0	11-20	Depth at which pumping rate QPUMP(I,2) begins, ft [m]. Must be greater than or equal to DSTART(I,1).	DSTART(I,2)	None
		21-30	Pumping rate when depth is greater than or equal to DSTART(I,1), ft^3/sec [m^3/sec].	QPUMP(I,1)	None

Table 7-3 (continued). Storage/Treatment Block Card Data

Card Group	Format	Card Column	Description	Variable Name	Default Value
		31-40	Pumping rate when depth is greater than or equal to DSTART(I,2), ft^3/sec [m^3/sec].	QPUMP(I,2)	None
		41-50	Depth below which all pumping stops, ft [m]. Must be less than or equal to DSTART(I,1).	DSTOP(I)	None
			Depth-residual flow power equation card (equation 7-4). Required only if IRES(I) = 1 (card H1). Coefficients must be consistent with the units used (see METRIC, card B1).		
H6	2X		Card group identifier = H6.	--	Blank
	F8.0	3-10	Depth-residual flow equation coefficient, C_3.	C3	0.0
	2F10.0	11-20	Depth below which no residual flow occurs, D_1.	D1	0.0
		21-30	Depth-residual flow equation coefficient, C_4.	C4	0.0
			Sludge generation in detention unit I. Required only if I is a plug-flow detention unit (IROUTE(I) = 0, card H1) and NP > 0 (card B1).		
H7	2X	1-2	Card group identifier = H7.	--	Blank
	I8	3-10	Pollutant responsible for sludge generation. Required only if a sludge depth warning message is desired. = 0, Not used. = 1, 2, or 3, Pollutant used to generate sludge volume (must correspond to the position on card E1).	NPSL(I)	0
	2F10.0	11-20	Concentration of pollutant NPSL(I) in sludge. Required only if NPSL(I) ≥ 1. The dimensions used must be consistent with those indicated by NDIM(I) (card E1).	SLDEN(I)	None

Table 7-3 (continued). Storage/Treatment Block Card Data

Card Group	Format	Card Column	Description	Variable Name	Default Value
		21-30	Maximum sludge depth, ft [m]. A warning message is printed if this depth is exceeded by the accumulated sludge. Required only if NPSL(I) ≥ 1.	SLDMAX(I)	None
			Initial conditions in detention unit I.		
H8	2X	1-2	Card identifier = H8.	--	Blank
	F8.0	3-10	Total volume of water in unit at the start of the simulation, ft^3 [m^3].	WARN(I)	0.0
			The following concentrations must be given with dimensions consistent with those entered on card E1(NDIM(IP)) if NOTAPE = 1(card B1) or on the external input file if NOTAPE = 2.		
	3F10.0	11-20	Concentration of pollutant 1 in the unit at the start of the simulation. Required only if NP ≥ 1 (card B1) and WARN(I) > 0.0.	PCO(I,1)	0.0
		21-30	Concentration of pollutant 2 in the unit volume at the start of the simulation. Required only if NP ≥ 2 (card B1) and WARN(I) > 0.0.	PCO(I,2)	0.0
		31-40	Concentration of pollutant 3 in the unit volume at the start of the simulation. Required only if NP = 3 (card B1) and WARN(I) > 0.0.	PCO(I,3)	0.0
			CARD GROUP I1, COST DATA REQUIRED ONLY IF ICOST = 1 (CARD B1).		
			Cost data card. The coefficients must be consistent with the units used (see METRIC, card B1).		
I1	2X	1-2	Card group identifier = I1.		Blank

Table 7-3 (continued). Storage/Treatment Block Card Data

Card Group	Format	Card Column	Description	Variable Name	Default Value
	I8	3-10	Type of cost variable used in calculating initial capital cost. = 0, Not used. = 1, Maximum allowable inflow, QMAX(I), ft^3/sec [m^3/sec], is used. = 2, Maximum inflow observed during simulation, QMAXS(I), ft^3/sec [m^3/sec], is used. = 3, Maximum allowable storage, VMAX(I), ft^3 [m^3], is used (not applicable if IDENT(I) = 0, card F2). = 4, Maximum storage observed during simulation, VMAXS(I), ft^3 [m^3], is used (not applicable if IDENT(I) = 0, card F2).	KPC(I,1)	0
	2F10.0	11-20	Initial capital cost equation coefficient, a.	CC(I,1)	0.0
		21-30	Initial capital cost equation coefficient, b.	CC(I,2)	0.0
	I10	31-40	Type of cost variable used in calculating operation and maintenance costs. See list for initial capital cost (above).	KPC(I,2)	0
	3F10.0	41-50	Operation and maintenance costs equation coefficient, d.	CC(I,3)	0.0
		51-60	Operation and maintenance costs equation coefficient, f.	CC(I,4)	0.0
		61-70	Operation and maintenance costs equation coefficient, h.	CC(I,5)	0.0

CARD GROUP J1; FLOW AND POLLUTANT DATA.

REQUIRED <u>ONLY</u> IF NOTAPE = 1 OR 2 (CARD B1).

Card Group	Format	Card Column	Description	Variable Name	Default Value
			Flow and pollutant data cards. Requires one card for each time step. All flows and concentrations are instantaneous values at the end of the time step. The dimensions for concentration must be identical to those on card E1 (NDIM(IP)) if NOTAPE = 1 (card B1) or on the external input file if NOTAPE = 2 (card B1).		

Table 7-3 (continued). Storage/Treatment Block Card Data

Card Group	Format	Card Column	Description	Variable Name	Default Value
J1	2X	1-2	Card group identifier = J1.	--	Blank
	F8.0	3-10	Flow entering S/T plant (at unit 1), ft^3/sec [m^3/sec].	QCAR	0.0
	3F10.0	11-20	Concentration of pollutant 1 entering S/T plant (at unit 1). Required only if NP ≧ 1 (card B1) and QCAR > 0.0.	PCAR(1)	0.0
		21-30	Concentration of pollutant 2 entering S/T plant (at unit 1). Required only if NP ≧ 2 (card B1) and QCAR > 0.0.	PCAR(2)	0.0
		31-40	Concentration of pollutant 3 entering S/T plant (at unit 1). Required only if NP = 3 (card B1) and QCAR > 0.0.	PCAR(3)	0.0

END OF STORAGE/TREATMENT BLOCK DATA

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

SECTION 8

RECEIVING WATER BLOCK

The Receiving Water Model (Receive) has been a block of SWMM since the original SWMM development. Receive is a dynamic, branching one-dimensional network model that is often used as a pseudo-two dimensional model when the links and nodes are arranged in a triangular or other grid pattern. Based upon the EPA Dynamic Estuary Model (DEM), it is one of several variants of the DEM, and in turn, has had several other models developed based upon it. Due to the proliferation of link-node models that are direct descendants of DEM or Receive, the EPA Athens, Georgia Laboratory decided in 1980 to combine the best features of the several variants into one new Receive/DEM-type model. It was also decided that this would be the appropriate model for use with SWMM when completed. As of this writing (May 1981), work is still underway on the model and its User's Manual. Rather than publish outdated information on Receive, it was decided to use this documentation in the form of an addendum to this SWMM Version III User's Manual when it became available. Hence, no details on Receive are included herein.

Current (May 1981) Receive capabilities are relatively unchanged since the Version II SWMM (Huber et al., 1975), although a few minor changes were included with an interim SWMM release in 1977. Persons needing the Receive model should contact Mr. Tom Barnwell or Robert Ambrose of the EPA Athens lab for information on the best available version since it will not be included with the rest of the SWMM Version III release.

SECTION 9

STATISTICS BLOCK

BLOCK DESCRIPTION

Introduction

The Statistics Block has been developed to provide the added capability within SWMM to perform simple statistical analyses on continuous event data. Both quantity and quality parameters may be analyzed. The options available include a table depicting the sequential series of events, a table of magnitude, return period and frequency of events, a graph of magnitude vs. return period, a graph of magnitude vs. frequency, and the first three moments of the event data.

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

Separation of the data into events depends on the unique series of zero and non-zero instantaneous flow values found at each location within the system being simulated. The results of the analyses would be expected to vary from location to location. The Statistics Block handles only one location at a time.

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

Program Operation

The Statistics Block is a Fortran program of approximately 1500 statements in length and consists of six subroutines. The relationships among the Statistics Block, the rest of SWMM and the various subroutines are shown in Figure 9-1.

The subroutine STATS comprises the major portion of the block. Input data and data from the interface file are read in STATS. Descriptive information from the file header is printed, followed by a summary of the input data. STATS separates the flow/pollutant data into events and writes this

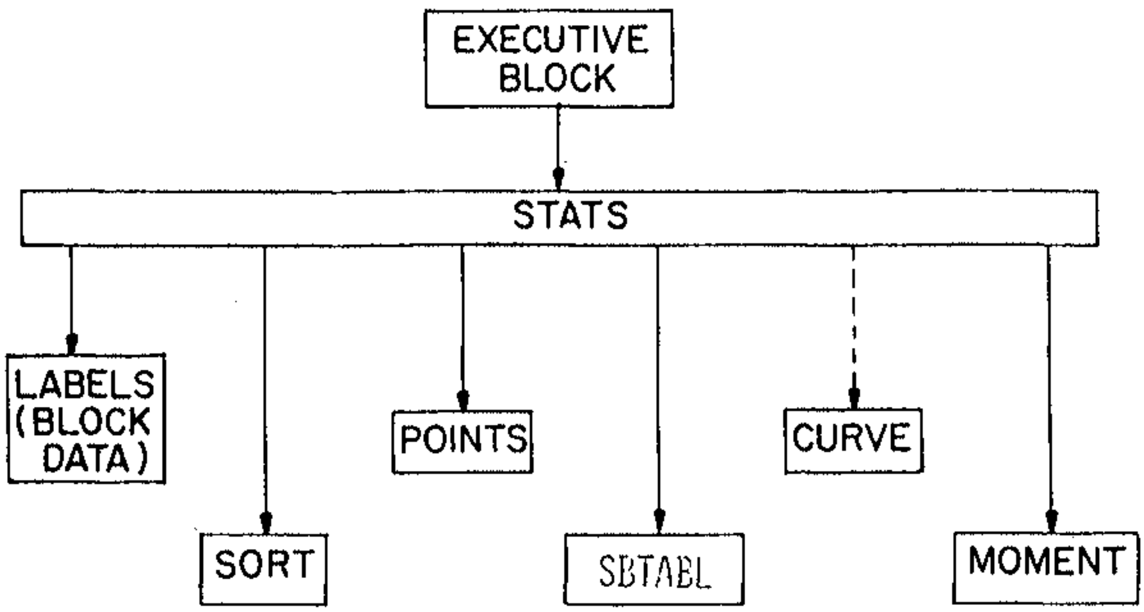


Figure 9-1. Structure of the Statistics Block Subroutines.

new data set on an off-line file. The write statement contains 561 bytes. Using disk storage with 19500 bytes per track, data for 34 events can be stored on one track. With an internal program limit of 3750 events, 111 tracks of disk storage are required for the Statistics Block. The limit of 3750 can be changed, resulting in a change in off-line storage requirements.

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

Output Options

The table of sequential series of events depicts the original time series of flow data after the time steps have been grouped into events. The table includes the date and time of day that each event began, flow volume of each event, duration of each event and interevent durations. The table of magnitude, return period and frequency is a rank order table showing the date and time that each event began, the magnitude of the event being analyzed, the return period (in months) of that magnitude and the percent of occurrences that are less than or equal to the given magnitude. The graph of magnitude vs. return period is a plot of two columns of the table, except that return period is presented as the base ten logarithm. The graph of magnitude vs. frequency is a similar plot with frequency presented as a percent. Although the graphing routines plot information centered in the table, it is not necessary to select the table option in order to select the graph options. Any of these may be printed independently of the others. The last option available is a calculation of a number of sample statistics of the event data (enumerated above).

The table of sequential series pertains only to the volume of the flow events. The remaining options can be requested for flow or pollutants. Any (or all) of these can be selected for any (or all) of the five flow parameters and for any (or all) of the five pollutant parameters. Different pollutant parameters can be analyzed for different pollutants. Events are identified on the basis of zero and nonzero flow values so that the duration of events and interevents will be identical for flow and any of the pollutants selected.

Potential for Output

Sequential Series of Events --

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

Table of Magnitude, Return Period and Frequency --

For those parameters where this option is requested, one table will be printed for each parameter chosen for each constitutent chosen. For example, if, for the constitutent 'FLOW', two parameters are chosen (e.g., total flow and event duration), and for each of two pollutants two parameters are chosen (e.g., total load and peak concentration), then six separate tables are printed, each containing magnitude, return period and frequency for the appropriate parameter. Therefore, although it is unlikely that one would have reason to do so, up to 55 tables can be printed in one run (five flow parameters, and five pollutant parameters for ten pollutants). The length of each table depends on the number of events within the period of analysis (180 events are printed per page).

Graph of Magnitude vs. Return Period or Graph of Magnitude vs. Frequency --

The following discussion refers to either type of graph. As with the tables above, one graph is printed for each parameter chosen of each constituent for which a graph is requested. Each graph comprises one page of output. Again, up to 55 graphs can be printed, although this would be an unlikely choice.

Moments --

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

PREPARATION OF INPUT DATA

Extent of Data

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

Card by card instructions for preparing the input data cards will be presented. The user is referred to Table 9-2 at the end of this section for input format and order. With regard to integer formats, it is imperative that all values be right-justified within the format field. All card groups are required. Figure 9-2 shows the general structure of the data deck.

Card Group A1

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

Card Group B1

The minimum interevent time (MIT) indicates the minimum number of dry time steps (time steps with zero flow) that will constitute an interevent. In other words, the number of consecutive dry time steps encountered in the search must be equal to or greater than MIT in order that the preceding wet period (made up of at least one nonzero flow value) be considered a separate event. Dry periods of duration less than MIT may exist within an event preceded and followed by wet time steps. The number of events in a given period of analysis is directly dependent on the value of MIT. A value of zero may be chosen for MIT; in this manner every wet time step will be viewed as a separate event. No "correct" value of MIT can be suggested, although a value of 6 to 22 hrs is often used to separate rainfall events (Heaney et al., 1977). The value utilized depends on the criteria employed by the user in defining an event.

The variable LOCRQ indicates at which location, e.g., inlet or manhole number, within the system the analyses are being performed. The interface file may contain data for up to 200 locations, each identified in the array LOCNOS(K). The variable LOCRQ should have the same value as one of the elements of the array LOCNOS(K).

The variable NPR indicates the number of pollutants requested for statistical analysis. NPR must be less than or equal to NPOLL (the number of pollutants on the interface file).

Card Group B2

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

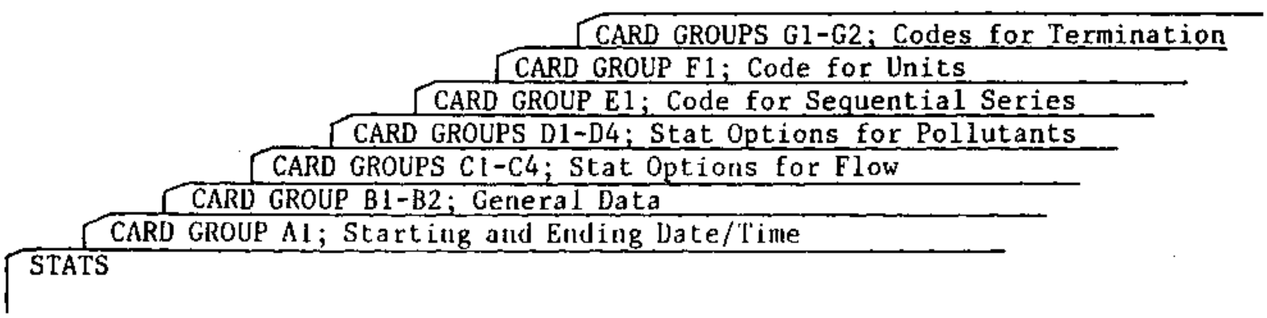


Figure 9-2. Structure of the Data Deck.

Card Groups C1-C4

The four "C" cards indicate the statistical options requested for flow. One card is used for each type of statistical option. Card C1 is for a table of event magnitude, return period and frequency. Card C2 is for a graph of magnitude vs. return period. Card C3 is for a graph of magnitude vs. frequency. Card C4 is for a table of the first three moments of the event data. There are five fields on each card, one field for each of the five flow parameters. The five parameters are (1) total flow for the event, measured as a volume and reported as inches [mm], (2) average flow for the event, measured as a rate and reported as inches/hour [mm/hr], (3) peak flow for the event, measured as an instantaneous rate and reported as inches/hour [mm/hr], (4) duration of the event, measured as the number of time steps making up the event and reported as hours, and (5) duration of the inter-event, measured as the number of dry time steps preceding the event and reported as hours. For a given card, those fields containing a 1 indicate the flow parameters for which that option has been selected. Values of zero indicate that the analyses should not be performed.

Card Groups D1-D4

The four "D" cards are identical in format to the "C" cards. The four statistical options available for flow are also available for pollutants. Again, one card is used for each type of statistical option. An entire set of "D" cards must be included for each pollutant requested, indicating which options for which parameters should be performed for each pollutant. The "D" cards should be arranged as a group (D1-D4), with groups of cards in a sequence corresponding to the order in which the pollutants were requested. Again, there are five fields on each card, one field for each of the five pollutant parameters. The five parameters are (1) total load, measured as a sum of the concentration times the flow rate and reported as pounds [kg], (2) average load, measured as a rate of pollutant loading and reported as lbs/hour [kg/hr], (3) peak load, measured as an instantaneous rate of pollutant loading and reported as lbs/hour [kg/hr], (4) flow weighted average concentration, reported as mg/l, and (5) peak concentration, reported as mg/l. As noted in Table 9-2, at least one set of D1-D4 cards must be included. If NPR = 0, all "D" cards would contain zero values (or be left blank).

Card Group E1

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

Card Group F1

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

Card Groups G1 and G2

The variable KTERM indicates whether or not to terminate analyses in the case where the number of events exceeds the allowable computer memory space. The number of events that can be sorted and analyzed has been set within the program at 3750. This value corresponds to 150 events per year for a 25 year period. As noted at the beginning of the STATS subroutine, this value may be altered by the user. If the number of events exceeds the limit set, the program will either (a) perform the analyses on the events already identified, ignoring the remainder of the record (KTERM = 0), or (b) terminate execution of the block, performing no event analysis (KTERM = 1). If the analyses are being performed, a table of the sequential series will be printed if KSEQ = 1. If the analyses are not performed, the option still exists to print the table of sequential series before termination. The variable KTSEQS indicates that the table should or should not be printed in this case.

COMPUTATIONS

Return Period and Frequency

The logic of the program is described by comment statements at the beginning of each subroutine and throughout the program listing. Computations that require further explanation will be discussed.

In subroutine STATS, the variables T1 and T2 indicate the beginning and end, respectively, of the period of analysis. The values are reported as elapsed time from the beginning of the simulation, measured in hours. The return period of an event of a given magnitude is reported as months so that a calculation of the number of months (NOMOS) within the period of analysis is required. The average number of hours per month in a year of 365.25 days is 730.5. This value is used to find a value for NOMOS, rounded to the nearest month, by the equation

$$\text{NOMOS} = \text{Integer}\left\{\frac{(\text{T2}-\text{T1})}{730.5} + 0.5\right\}. \qquad (9\text{-}1)$$

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

In subroutine TABLES, calculations are made of the return period and frequency of events. The program is set up in such a way that the equation used depends on the column of the table in which the values will be printed. These calculations are summarized in the general forms

$$\text{Return Period (months)} = \frac{\text{NOMOS} + 1}{M} \qquad (9\text{-}2)$$

where NOMOS = number of months within the period of analysis, and
M = rank of the given event (ranked in descending order), and

$$\text{Frequency} = \left\{1 - \frac{(M-1)}{N}\right\} \times 100 \qquad (9\text{-}3)$$

where Frequency = percent of occurrences less than or equal to the given magnitude,
M = rank of the event, and
N = total number of events within the period of analysis.

Moments

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

$$\bar{X} = \frac{\Sigma X}{N}, \qquad (9\text{-}4)$$

$$S^2 = \frac{\Sigma X^2 - (N)(\bar{X})^2}{N-1}, \qquad (9\text{-}5)$$

$$S = (S^2)^{\frac{1}{2}}, \qquad (9\text{-}6)$$

$$CV = \frac{S}{\bar{X}}, \text{ and} \qquad (9\text{-}7)$$

$$C_s = \frac{\frac{\Sigma X^3}{N} - 3\,\frac{\Sigma X^2}{N}\,(\bar{X}) + 2(\bar{X})^3}{\left\{\frac{\Sigma X^2}{N} - (\bar{X})^2\right\}^{1.5}} \quad \left\{\frac{N\,(N-1)}{N-2}\right\}^{\frac{1}{2}} \qquad (9\text{-}8)$$

Equation 9-8 is equivalent to the more usual form

$$C_s = \frac{\frac{\Sigma(X-\bar{X})^3}{N}}{\left\{\frac{\Sigma(X-\bar{X})^2}{N}\right\}^{1.5}} \quad \left\{\frac{N\,(N-1)}{N-2}\right\}^{\frac{1}{2}} \qquad (9\text{-}9)$$

where X = magnitude of the event parameter, and
N = total number of events within the period of analysis.

S^2 and C_s are unbiased estimates. All summations are from 1 to N.

Messages/Labels

The majority of the messages printed as part of the program execution are self-explanatory and do not require discussion in the text. A notable exception to this involves the units printed for pollutants. As a prelude to this discussion, an explanation of the units provided in the tables and graphs is called for. Table 9-1 summarizes the units printed for flow and three types of pollutants. The labels printed for the ordinate of the graphs are also presented.

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

When NDIM = 2, a special message is printed on the graph or table. Rather than printing the units described in Table 9-2, the output contains "SEE NOTE" and the note "Magnitude has units of .... See user manual for explanation." The explanation referred to is included in the following discussion.

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

Table 9-1. Labels and Units.

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

ANALYSIS OF RAINFALL DATA

A series of rainfall measurements can be viewed as analogous to a series of flow values and can be analyzed using the statistical options for flow. The following discussion assumes that the rainfall record is in hourly time steps. The user can make similar adjustments for other types of rainfall records.

An interface file of the standardized SWMM format must be generated by the user. This will contain rainfall data only, no pollutants. The file may contain data for a number of locations, but only one location may be analyzed during a run.

The event parameters will be viewed as follows: Values reported as "total flow" will be total depth of the storm, in inches; values reported as "average flow" will be average intensity during the event, in inches/hour, and calculated as the total depth divided by the duration of the event; "peak flow" will be peak intensity, in inches/hour, and will be the largest single hourly value recorded for the storm; event duration and interevent duration are identical in concept to stormwater events.

Variables that require the assignment of particular values are:

For the interface file:

- DTSEC = 3600

- TRIBA = 1.000

- QCONV = 1.00833 = $\frac{43560 \text{ ft/ac}}{12 \text{ in/ft} \times 3600 \text{ sec/hr}}$

For the input data:

- NPR = 0

- KENGSI = 0

The input data also require one set of "D" cards, all blank.

As regards labels for the output, the term "FLOW" will remain. The user must think of this in the context of the options selected (i.e., depth or intensity). The remainder of the program operation will be identical to stormwater events.

Table 9-2. Statistics Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
CARD GROUP A1; Starting and Ending Date/Time					
A1	2X	1-2	Card identifier = A1.	--	Blank
	I6	3-8	Starting date, yr/mo/day.	ISTART	000000
	4X	9-12	Skip	--	Blank
	F5.2	13-17	Starting time, decimal hours.	TSTART	00.00
	5X	18-22	Skip	--	Blank
	I6	23-28	Ending date, yr/mo/day.	IEND	000000
	4X	29-32	Skip	--	Blank
	F5.2	33-37	Ending time, decimal hours.	TEND	00.00
CARD GROUP B1; General Data					
B1	2X	1-2	Card identifier = B1.	--	Blank
	I10	3-12	Minimum interevent time, no. of time steps.	MIT	0
	I10	13-22	Location requested.	LOCRQ	none
	I10	23-32	Number of pollutants requested.	NPR	0
	F10.0	33-42	Base flow to determine end of event, in/hr [mm/hr]. Only flows $\geq$ BASE (and their associated pollutant loads) are analyzed. Others are treated as zeroes.	BASE	00.00
B2	2X	1-2	Card identifier = B2.	--	Blank
	10I5	3-7	First pollutant requested, identified by position on interface file.	IPOLRQ(1)	none

Table 9-2. (continued). Statistics Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
		8-12 " " "	Second pollutant requested, identified by position on interface file.	IPOLRQ(2) " " "	none
		48-52	Tenth pollutant requested, identified by position on interface file.	IPOLRQ(10)	none
CARD GROUPS C1-C4; Stat Options for Flow					
			Requests to print table of magnitude, return period and frequency for each of five parameters. In all cases, No = 0, Yes = 1.		
C1	2X	1-2	Card identifier = C1.	--	Blank
	5I10	3-12	Request table for total flow.	ISFLOW(1,1)	0
		13-22	Request table for average flow.	ISFLOW(1,2)	0
		23-32	Request table for peak flow.	ISFLOW(1,3)	0
		33-42	Request table for event duration.	ISFLOW(1,4)	0
		43-52	Request table for interevent duration.	ISFLOW(1,5)	0
			Requests to print graph of magnitude vs. return period for each of five parameters. In all cases, No = 0, Yes = 1.		

Table 9-2. (continued). Statistics Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
C2	2X	1-2	Card identifier = C2.	--	Blank
	5I10	3-12	Request graph for total flow.	ISFLOW(2,1)	0
		13-22	Request graph for average flow.	ISFLOW(2,2)	0
		23-32	Request graph for peak flow.	ISFLOW(2,3)	0
		33-42	Request graph for event duration.	ISFLOW(2,4)	0
		43-52	Request graph for interevent duration.	ISFLOW(2,5)	0
			Requests to print graph of magnitude vs. frequency for each of five parameters. In all cases, No = 0, Yes = 1.		
C3	2X	1-2	Card identifier = C2.	--	Blank
	5I10	3-12 etc.	Card similar to C1 and C2.		
			Requests to print moments for each of five flow parameters. In all cases, No = 0, Yes = 1.		
C4	2X	1-2	Card identifier = C4.	--	Blank
	5I10	3-12 etc.	Card similar to C1 and C2.		

Table 9-2. (continued). Statistics Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
CARD GROUPS D1-D4; Stat Options for Pollutants					
MUST INCLUDE AT LEAST ONE SET OF D1-D4 CARDS, EVEN IF NPR = 0. IF NPR = 0, USE FOUR BLANK CARDS FOR D1-D4. IF NPR>1, USE ONE SET OF D1-D4 CARDS FOR EACH POLLUTANT REQUESTED, UP TO TEN SETS OF CARDS, IN THE ORDER DEFINED BY CARD B2. THE FIRST INDEX OF ISPOLL (K, I, J) IDENTIFIES THE POLLUTANT.					
			Requests to print table of magnitude, return period and frequency for each of five parameters. In all cases, No = 0, Yes = 1.		
D1	2X	1-2	Card identifier = D1.	--	Blank
	5I10	3-12	Request table for total load.	ISPOLL(1,1,1)	0
		13-22	Request table for average load.	ISPOLL(1,1,2)	0
		23-32	Request table for peak load.	ISPOLL(1,1,3)	0
		33-42	Request table for flow weighted average concentration.	ISPOLL(1,1,4)	0
		43-52	Request table for peak concentration.	ISPOLL(1,1,5)	0
			Requests to print graph of magnitude vs. return period for each of five parameters. In all cases, No = 0, Yes = 1.		
D2	2X	1-2	Card identifier = D2.	--	Blank

Table 9-2. (continued). Statistics Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
	5I10	3-12	Request graph for total load.	ISPOLL(1,2,1)	0
		13-22	Request graph for average load.	ISPOLL(1,2,2)	0
		23-32	Request graph for peak load.	ISPOLL(1,2,3)	0
		33-42	Request graph for flow weighted average concentration.	ISPOLL(1,2,4)	0
		43-52	Request graph for peak concentration.	ISPOLL(1,2,5)	0
			Requests to print graph of magnitude vs. frequency for each of five parameters. In all cases, No = 0, Yes = 1.		
D3	2X	1-2	Card identifier = D3.	--	Blank
	5I10	3-12 etc.	Card similar to D1 and D2.		
			Requests to print moments for each of five parameters. In all cases, No = 0, Yes = 1.		
D4	2X	1-2	Card identifier = D4.	--	Blank
	5I10	3-12 etc.	Card similar to D1 and D2.		

Table 9-2. (continued). Statistics Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
			CARD GROUP E1; Code for Sequential Series		
E1	2X	1-2	Card identifier = F1.	--	Blank
	I10	3-12	Request to print sequential series of flow events. No = 0, Yes = 1.	KSEQ	0
			CARD GROUP F1; Code for Units		
F1	2X	1-2	Card identifier = F1.	--	Blank
	I10	3-12	Request type of units for output. = 0, U.S. customary. = 1, Metric.	KENGSI	0
			CARD GROUPS G1 AND G2; Codes for Termination		
			In the case where the number of events exceeds allowable memory space:		
G1	2X	1-2	Card identifier = G1.	--	Blank
	I10	3-12	Code for terminat- ing program. = 0, Do not terminate (perform analyses on those events already identified). = 1, Terminate program (no event analysis performed).	KTERM	0

Table 9-2. (continued). Statistics Block Card Data

Card Group	Format	Card Columns	Description	Variable Name	Default Value
G2	2X	1-2	Card identifier = G2.	--	Blank
	I10	3-12	Code for printing sequential series if termination occurs (where number of events exceeds limit and KTERM = 1). = 0, Do not print sequential series. = 1, Print sequential series of those events already identified.	KTSEQS	0

END OF STATISTICS BLOCK DATA. AT THIS POINT, PROGRAM EXECUTION COMMENCES WITH READING OF INTERFACE FILE HEADER.

DATA CARDS FOLLOWING THESE WILL BE READ BY THE EXECUTIVE BLOCK.

SECTION 10

REFERENCES

Alley, W.M., "An Examination of the Storm Water Management Model (SWMM) Surface-Runoff-Quality Algorithms," Proceedings Storm Water Management Model User's Group Meeting, January 1980, EPA-600/9-80-017, Environmental Protection Agency, Washington, DC, March 1980, pp. 93-110.

Alley, W.M., "Estimation of Impervious-Area Washoff Parameters," Water Resources Research, Vol. 17, No. 4, August 1981, pp. 1161-1166.

Alley, W.M., Dawdy, D.R. and Schaake, J.C., Jr., "Parametric-Deterministic Urban Watershed Model," Journal of the Hydraulics Division, ASCE, Vol. 106, No. HY5, May 1980a, pp. 679-690.

Alley, W.M. and Ellis, S.R., "Rainfall-Runoff Modeling of Flow and Total Nitrogen from Two Localities in the Denver, Colorado Metropolitan Area," Proceedings Storm Water Management Model User's Group Meeting, May 1979, EPA-600/9-79-026, Environmental Protection Agency, Washington, DC, 1979, pp. 362-403.

Alley, W.M., Ellis, F.W. and Sutherland, R.C., "Toward a More Deterministic Urban Runoff-Quality Model," International Symposium on Urban Storm Runoff, University of Kentucky, Lexington, KY, July 1980b, pp. 171-182.

American National Standards Institute, "American National Standard Programming Language FORTRAN," ANSI X3.9-1978, New York, NY, 1978.

American Public Works Association, "Water Pollution Aspects of Urban Runoff," Federal Water Pollution Control Administration Contract WP-20-15, 1969.

American Public Works Association, "Managing Snow Removal and Ice Control Programs," Special Report No. 42, American Public Works Association, Chicago, IL, 1974.

American Public Health Association, American Public Works Association, Water Pollution Control Federation, <u>Standard Methods for the Examination of Water and Wastewater</u>, 13th Edition, American Public Health Association, Washington, DC, 1971.

American Society of Civil Engineers, Water Pollution Control Federation, Design and Construction of Sanitary and Storm Sewers, Water Pollution Control Federation, Washington, DC, 1969.

American Society of Heating and Air Conditioning Engineers, "Heating, Ventilating, Air Conditioning Guide," New York, NY, Annual Publication (superseded by the American Society of Heating, Refrigerating and Ventilating Engineers Handbook).

Ammon, D.C., "Urban Stormwater Pollutant Buildup and Washoff Relationships," Master of Engineering Thesis, University of Florida, Gainesville, FL, 1979.

Amy, G., Pitt, R., Singh, R., Bradford, W.L. and LaGraff, M.B., "Water Quality Management Planning for Urban Runoff," EPA-440/9-75-004 (NTIS PB 241 689), Environmental Protection Agency, Washington, DC, December 1974.

Anderson, E.R., "Energy Budget Studies, Water Loss Investigations: Lake Hefner Studies," U.S. Geological Survey Professional Paper 269, Washington, DC, 1954.

Anderson, E.A., "National Weather Service River Forecast System - Snow Accumulation and Ablation Model," NOAA Tech. Memo NWS HYDRO-17, U.S. Department of Commerce, Washington, DC, 1973.

Anderson, E.A., "A Point Energy and Mass Balance Model of a Snow Cover," NOAA Tech. Report NWS 19, U.S. Department of Commerce, Washington, DC, February 1976.

AVCO Economic Systems Corporation, "Storm Water Pollution from Urban Land Activity," EPA 11034FKL07/70 (NTIS PB 195 281), Environmental Protection Agency, July 1970.

Bedient, P.B., Harned, D.A. and Characklis, W.G., "Stormwater Analysis and Prediction in Houston," Journal of the Environmental Engineering Division, ASCE, Vol. 104, No. EE6, December 1978, pp. 1087-1100.

Bengston, L., "Snowmelt-Generated Runoff in Urban Areas," Proc. Second International Conference on Urban Storm Drainage, Urbana, IL, June 14-19, 1981, Vol. I, pp. 444-451.

Benjes, H.H., "Cost Estimating Manual - Combined Sewer Overflow Storage and Treatment," EPA-600/2-76-286 (NTIS PB 266 359), Environmental Protection Agency, Cincinnati, OH, December 1976.

Brakensiek, D.L. and Onstad, C.A., "Parameter Estimation of the Green-Ampt Equation," Water Resources Research, Vol. 13, No. 6, December 1977, pp. 1009-1012.

Brandstetter, A.B., "Assessment of Mathematical Models for Storm and Combined Sewer Management," EPA-600/2-76-175a (NTIS PB 259 597), Environmental Protection Agency, Cincinnati, OH, August 1977.

Brezonik, P.L., "Nutrients and Other Biologically Active Substances in Atmospheric Precipitation", Proceedings Symposium on Atmospheric Contribution to the Chemistry of Lake Waters, International Association Great Lakes Research, September 1975, pp 166-186.

Brown, C.B., "Sedimentation Engineering", Chapter XII in Engineering Hydraulics, Rouse, H., ed., John Wiley and Sons, New York, NY, 1950.

Butler, S.S., Engineering Hydrology, Prentice Hall, New York, NY, 1957.

Camp, T.L., "Sedimentation and the Design of Settling Tanks," Transactions ASCE, Vol. 111, 1946, pp. 895-936.

Chan, S. and Bras, R.L., "Urban Storm Water Management: Distribution of Flood Volumes," Water Resources Research, Vol. 15, No. 2, April 1979, pp. 371-382.

Chemical Rubber Company, Handbook of Chemistry and Physics, Weast, R.C., ed., 57th Editions, Chemical Rubber Company, Cleveland, OH, 1976.

Chen, C., "Flow Resistance in Broad Shallow Grassed Channels", Journal of the Hydraulics Division, ASCE, Vol. 102, No. HY3, March 1976, pp. 307-322.

Chen, C.N., "Design of Sediment Retention Basins," Proceedings National Symposium on Urban Hydrology and Sediment Control, University of Kentucky, Lexington, KY, July 1975.

Chow, V.T., Open-Channel Hydraulics, McGraw-Hill, New York, NY, 1959.

Chow, V.T. and Yen, B.C., "Urban Stormwater Runoff: Determination of Volumes and Flowrates," EPA-600/2-76-116 (NTIS PB 253 410), Environmental Protection Agency, Cincinnati, OH, May 1976.

Christensen, B.A., "Hydraulics of Sheet Flow in Wetlands," Symposium on Inland Waterways for Navigation, Flood Control and Water Diversions, Colorado State University, ASCE, New York, NY, August 1976, pp. 746-759.

Chu, C.S. and Bowers, C.E., "Computer Programs in Water Resources," WRRC Bulletin 97, Water Resources Research Center, University of Minnesota, Minneapolis, MN, November 1977.

Chu, S.T., "Infiltration During an Unsteady Rain," Water Resources Research, Vol. 14, No. 3, June 1978, pp. 461-466.

Clapp, R.B. and Hornberger, G.M., "Empirical Equations for Some Soil Properties," Water Resources Research, Vol. 14, No. 4, August 1978, pp. 601-604.

Colyer, P.J. and Pethick, R.W., "Storm Drainage Design Methods, A Literature Review," Report No. INT 154, Hydraulics Research Station, Wallingford, Oxon, England, March 1976.

Corps of Engineers, "Snow Hydrology," NTIS PB 151 660, North Pacific Division, Corps of Engineers, Portland, OR, June 1956.

Corps of Engineers, "Runoff Evaluation and Streamflow Simulation by Computer," Tech. Report, North Pacific Division, Corps of Engineers, Portland, OR, 1971.

Crawford, N.H. and Linsley, R.K., "Digital Simulation in Hydrology: Stanford Watershed Model IV," Tech. Report No. 39, Civil Engineering Department, Stanford University, Palo Alto, CA, July 1966.

Croley, T.E., Hydrologic and Hydraulic Computations on Small Programmable Calculators, Iowa Institute of Hydraulic Research, University of Iowa, Iowa City, 1977.

Dalrymple, R.J., Hodd, S.L. and Morin, D.C., "Physical and Settling Characteristics of Particulates in Storm and Sanitary Wastewaters," EPA-670/2-75-011 (NTIS PB 242 001), Environmental Protection Agency, Cincinnati, OH, April 1975.

Davis, C.V., Handbook of Applied Hydraulics, Second Edition, McGraw-Hill, New York, NY, 1952.

Dawdy, D.R., Schaake, J.C., Jr. and Alley, W.M., "User's Guide for Distributed Routing Rainfall-Runoff Model," Water-Resources Investigations 78-90, U.S. Geological Survey, NSTL Station, MS, September 1978.

Digiano, F.A., Adrian, D.D. and Mangarella, P.A., eds., "Short Course Proceedings-Applications of Stormwater Management Models, 1976," EPA-600/2-77-065 (NTIS PB 265 321), Environmental Protection Agency, Cincinnati, OH, March, 1977.

Diniz, E.V., "Modifications to the Storm Water Management Model and Application to Natural Drainage Systems," Proceedings International Conference at the University of Southampton, April 1978, Helliwell, P.R., ed., Urban Storm Drainage, Pentech Press, London, 1978, pp. 256-274.

Dobbins, W.E., "Effect of Turbulence on Sedimentation," Transactions ASCE, Vol. 109, 1944, pp. 629-678.

Donigian, A.S., Jr., Beyerlein, D.C., Davis, H.H., Jr. and Crawford, N.H., "Agricultural Runoff Management Model Version II: Refinement and Testing," EPA-600/3-77-098, Environmental Protection Agency, Athens, GA, August 1977.

Donigian, A.S., Jr. and Crawford, N.H., "Modeling Non-point Pollution from the Land Surface," EPA-600/3-76-083, Environmental Protection Agency, July 1976.

Eagleson, P.S., Dynamic Hydrology, McGraw-Hill, New York, NY, 1970.

Ellis, F.W. and Sutherland, R.C., "An Approach to Urban Pollutant Washoff Modeling," Proceedings International Symposium on Urban Storm Runoff, University of Kentucky, Lexington, KY, July 1979, pp. 325-340.

Ellis, S.R., "Hydrologic Data for Urban Storm Runoff from Three Localities in the Denver Metropolitan Area, Colorado," Open-File Report 78-410, U.S. Geological Survey in cooperation with the Denver Board of Water Commissioners, the Denver Regional Council of Governments and the Urban Drainage and Flood Control District, Lakewood, Colorado, May 1978.

Emmett, W.W., "Overland Flow," Kirkby, M.J., ed., Hillslope Hydrology, John Wiley and Sons, New York, NY, 1978, pp. 145-176.

Envirogenics Company, "In-Sewer Fixed Screening of Combined Sewer Overflows," EPA-11024FKJ10/70 (NTIS PB 213 118), Environmental Protection Agency, Cincinnati, OH, November 1970.

Environmental Protection Agency, "Handbook for Sewer System Evaluation and Rehabilitation," EPA-430/9-75-021, Environmental Protection Agency, Washington, DC, December 1975.

Environmental Protection Agency, "Areawide Assessment Procedures Manual," Three Volumes, EPA-600/9-76-014, Environmental Protection Agency, Cincinnati, OH, July 1976 et seq.

Fair, M.F., Geyer, J.C. and Okun, D.A., Water and Wastewater Engineering, John Wiley and Sons, Inc., New York, NY, 1968.

Falk, J. and Niemczynomicz, J., "Characteristics of the Above-Ground Runoff in Sewered Catchments," Proceedings International Conference at the University of Southampton, April 1978, Helliwell, P.R., ed., Urban Storm Drainage, Pentech Press, London, 1978, pp. 159-171.

Field, R., Struzeski, E.J., Jr., Masters, H.E. and Tafuri, A.N., "Water Pollution and Associated Effects from Street Salting," EPA-R2-73-257 (NTIS PB 222 795), Environmental Protection Agency, Cincinnati, OH, May 1973.

Fleming, G., Computer Simulation Techniques in Hydrology, American Elsevier Publishing Co., New York, NY 1975.

Franz, D.D., "Prediction of Dew Point Temperature, Solar Radiation and Wind Movement Data for Simulation and Operations Research Models," Report for Office of Water Resources Research, Hydrocomp, Inc., Palo Alto, CA, April 1974

Geiger, W.F. and Dorsch, H.R., "Quantity-Quality Simulation (QQS): A Detailed Continuous Planning Model for Urban Runoff Control, Volume I, Model Description, Testing and Applications," EPA-600/2-80-011 (NTIS PB80 190507), Environmental Protection Agency, Cincinnati, OH, March 1980.

Geiger, W.F., LaBella, S.A. and McDonald, G.C., "Overflow Abatement Alternatives Selected by Combining Continuous and Single Event Simulations," Proceedings National Symposium on Urban Hydrology, Hydraulics and Sediment Control, University of Kentucky, Lexington, KY, July 1976.

Geyer, J.C. and Lentz, J.J., "An Evaluation of the Problems of Sanitary Sewer System Design," Department of Sanitary Engineering and Water Resources, Johns Hopkins University, Baltimore, MD, 1963.

Golding, B.L., "Flood Routing Program," Civil Engineering, Vol 51, No. 6, June 1981, pp. 74-75.

Graf, W.H., Hydraulics of Sediment Transport, McGraw-Hill, New York, NY, 1971.

Graf, W.H. and Chhun, V.H., "Mannings Roughness for Artificial Grasses," Journal of the Irrigation and Drainage Division, ASCE, Vol. 102, No. IR4, December 1976, pp. 413-423.

Graham, P.H., Costello, L.S. and Mallon, H.J., "Estimation of Imperviousness and Specific Curb Length for Forecasting Stormwater Quality and Quantity," Journal Water Pollution Control Federation, Vol. 46, No. 4, April 1974, pp. 717-725.

Gray, D.M., ed., Handbook on the Principles of Hydrology, Water Information Center, Fort Washington, NY, 1970.

Green, W.H. and Ampt, G.A., "Studies on Soil Physics, 1. The Flow of Air and Water Through Soils," Journal of Agricultural Sciences, Vol. 4, 1911, pp. 11-24.

Gupta, M.K., Bollinger, E., Vanderah, S., Hansen, C. and Clark, M., "Handling and Disposal of Sludges from Combined Sewer Overflow Treatment: Phase I - Characterization," EPA-600/2-77-053a (NTIS PB 270 212), Environmental Protection Agency, Cincinnati, OH, May 1977.

Han, J. and Delleur, J.W., "Development of an Extension of Illudas Model for Continuous Simulation of Urban Runoff Quantity and Discrete Simulation of Runoff Quality," Water Resources Research Center Technical Report No. 109, Purdue University, West Lafayette, IN, July 1979.

Hazen, A., "On Sedimentation," Transactions ASCE, Vol. 53, 1904, pp. 45-71.

Heaney, J.P., Huber, W.C., Medina, M.A., Jr., Murphy, M.P., Nix, S.J. and Hasan, S.M., "Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges - Vol. II: Cost Assessment and Impacts," EPA-600/2-77-064b (NTIS PB 266 005), Environmental Protection Agency, Cincinnati, OH, March 1977.

Heaney, J.P., Huber, W.C. and Nix, S.J., "Storm Water Management Model - Level I: Preliminary Screening Procedures," EPA-600/2-76-275 (NTIS PB 259 916), Environmental Protection Agency, Cincinnati, OH, October 1976.

Heaney, J.P., Huber, W.C., Sheikh, H., Medina, M.A., Doyle, J.R., Peltz, W.A. and Darling, J.E., "Urban Stormwater Management Modeling and Decision Making," EPA-670/2-75-022 (NTIS PB 242 290), Environmental Protection Agency, Cincinnati, OH, May 1975.

Heaney, J.P. and Nix, S.J., "Storm Water Management Model: Level I - Comparative Evaluation of Storage-Treatment and Other Management Practices," EPA-600/2-77-083 (NTIS PB 265 671), Environmental Protection Agency, Cincinnati, OH, April 1977.

Helfgott, T., Hunter, J.V. and Rickert, D., "Analytic and Process Classification of Effluents," Journal of the Sanitary Engineering Division, ASCE, Vol. 96, No. SA3, June 1970, pp. 779-803.

Heukelekian, H. and Balmat, J.L., "Chemical Composition of Particulate Fractions of Domestic Sewage," Sewage and Industrial Wastes, Vol. 31, No. 4, April, 1959, pp. 413-423.

Hicks, W.I., "A Method of Computing Urban Runoff," Transactions ASCE, Vol. 109, 1944, pp. 1217-1253.

Horton, R.E., "The Role of Infiltration in the Hydrologic Cycle," Transactions American Geophysical Union, Vol. 14, 1933, pp. 446-460.

Horton, R.E., "An Approach Toward a Physical Interpretation of Infiltration Capacity," Proceedings Soil Science of America, Vol. 5, 1940, pp. 399-417.

Howard, C.D.D., "Theory of Storage and Treatment-Plant Overflows," Journal of the Environmental Engineering Division, ASCE, Vol. 102, No. EE4, August 1976, pp. 709-722.

Howard, Charles and Associates, Ltd., "Analysis and Use of Urban Rainfall Data in Canada," Economical and Technical Review Report No. EPS 3-WP-79-4, Environmental Protection Service, Environment Canada, Ottawa, Ontario, Canada, July 1979.

Huber, W.C., "Urban Wasteload Generation by Multiple Regression Analysis of Nationwide Urban Runoff Data," in Workshop on Verification of Water Quality Models, R.V. Thomann and T.O. Barnwell, eds., EPA-600/9-80-016 (NTIS PB80 186539), Environmental Protection Agency, Athens, GA, April 1980, pp. 167-174.

Huber, W.C. and Heaney, J.P., "Urban Rainfall-Runoff-Quality Data Base," EPA-600/8-77-009 (NTIS PB 270 065), Environmental Protection Agency, Cincinnati, OH, July 1977.

Huber, W.C. and Heaney, J.P., "Analyzing Residuals Generation and Discharges from Urban and Nonurban Land Surfaces," Basta, D.J. and Bower, B.T., eds., Analyzing Natural Systems, Analysis for Residuals - Environmental Quality Management, Resources for the Future, Washington, DC, December 1979, (EPA-600/3-83-046, NTIS PB83-223321).

Huber, W.C. and Heaney, J.P., "Operational Models for Stormwater Quality Management," Overcash, M.R. and Davidson, J.M., eds., Environmental Impact of Nonpoint Source Pollution, Ann Arbor Science, Ann Arbor, MI, 1980, pp. 397-444.

Huber, W.C., Heaney, J.P., Aggidis, D.A., Dickinson, R.E., Smolenyak, K.J. and Wallace, R.C., "Urban Rainfall-Runoff-Quality Data Base", EPA-600/2-81-238 (NTIS PB82-221094), Environmental Protection Agency, Cincinnati, OH, September 1980.

Huber, W.C., Heaney, J.P., Medina, M.A., Peltz, W.A., Sheikh, H. and Smith, G.F., "Storm Water Management Model User's Manual - Version II," EPA-670/2-75-017 (NTIS PB257809), Environmental Protection Agency, Cincinnati, OH, March 1975.

Huber, W.C., Heaney, J.P., Smolenyak, K.J. and Aggidis, D.A., "Urban Rainfall-Runoff-Quality Data Base, Update With Statistical Analysis,: EPA-600/8-79-004, Environmental Protection Agency, Cincinnati, OH, August 1979.

Huggins, L.F. and Monke, E.J., "Mathematical Simulation of Hydrologic Events of Ungaged Watersheds," Purdue University Water Resources Research Center Technical Report No. 14, West Lafayette, IN, March 1970.

Huibregtse, K.R., "Handling and Disposal of Sludges From Combined Sewer Overflow Treatment: Phase II - Impact Assessment," EPA-600/2-77-053b (NTIS PB 280 309), Environmental Protection Agency, Cincinnati, OH, 1977.

Hunter, J.V. and Heukelekian, H., "The Composition of Domestic Sewage Fractions," Journal Water Pollution Control Federation, Vol. 37, No. 8, August 1965, pp. 1142-1163.

Hydrologic Engineering Center, "Storage, Treatment, Overflow, Runoff Model, STORM," User's Manual, Generalized Computer Program 723-S8-L7520, HEC, Corps of Engineers, Davis, CA, August 1977a.

Hydrologic Engineering Center, "Guidelines for Calibration and Application of STORM," Training Document No. 8, HEC, Corps of Engineers, Davis, CA, December 1977b.

Hydroscience, Inc., "Areawide Assessment Procedures Manual," Vols. I, II and III, EPA-600/9-76-014, Environmental Protection Agency, Cincinnati, OH, July 1976, et seq.

Hydroscience, Inc., "A Statistical Method for the Assessment of Urban Stormwater," EPA-440/3-79-023, Environmental Protection Agency, Washington, D.C., May 1979.

James, W. and Drake, J.J., "Kinematic Design Storms Incorporating Spatial and Time Averaging," Proceedings Storm Water Management Model User's Group Meeting, June 1980, EPA-600/9-80-064, Environmental Protection Agency, Athens, GA, December 1980, pp. 133-149.

Jennings, M.E. and Doyle, W.H., Jr., "Deterministic Modeling of Urban Storm Water Processes, Broward County, Florida," Proceedings International Symposium on Urban Storm Water Management, University of Kentucky, Lexington, KY, July 1978, pp. 275-281.

Jens, S.W. and McPherson, M.B., "Hydrology of Urban Areas," Chow, V.T., ed., Handbook of Applied Hydrology, McGraw-Hill, New York, NY, 1964.

Jewell, T.K. and Adrian, D.D., "SWMM Stormwater Pollutant Washoff Functions," Journal of the Environmental Engineering Division, ASCE, Vol. 104, No. EE5, October 1978, pp. 1036-1040.

Jewell, T.K. and Adrian, D.D., "Development of Improved Stormwater Quality Models," Journal of the Environmental Engineering Division, ASCE, Vol. 107, No. EE5, October 1981, pp. 957-974.

Jewell, T.K., Adrian, D.D. and DiGiano, F.A., "Urban Stormwater Pollutant Loadings," Water Resources Research Center Publication No. 113, University of Massachusetts, Amherst, MA, May 1980.

Jewell, T.K., Nunno, T.J. and Adrian, D.D., "Methodology for Calibrating Stormwater Models," Journal of the Environmental Engineering Division, ASCE, Vol. 104, No. EE5, June 1978, pp. 485-501.

Johanson, R.C., Imhoff, J.C. and Davis, H.H., "User's Manual for Hydrological Simulation Program - Fortran (HSPF)," EPA-600/9-80-015, Environmental Protection Agency, Athens, GA, April 1980.

Keifer, C.J. and Chu, H.H., "Synthetic Storm Pattern for Drainage Design," Proceedings ASCE, Vol. 83, No. HY4, Paper No. 1332, August 1957.

Kidd, C.H.R., "A Calibrated Model for the Simulation of the Inlet Hydrograph for Fully Sewered Catchments," Proceedings International Conference at the University of Southampton, April 1978, Helliwell, P.R., ed., Urban Storm Drainage, Pentech Press, London, 1978a, pp. 171-186.

Kidd, C.H.R., "Rainfall-Runoff Processes Over Urban Surfaces," Proceedings International Workshop held at the Institute of Hydrology, Wallingford, Oxon, England, April 1978b.

Kluesener, J.W. and Lee, G.F., "Nutrient Loading from a Separate Storm Sewer in Madison, Wisconsin," Journal Water Pollution Control Federation, Vol. 46, No. 5, May 1974, pp. 920-936.

Lager, J.A., Didriksson, T. and Otte, G.B., "Development and Application of a Simplified Stormwater Management Model," EPA-600/2-76-218 (NTIS PB 258 074), Environmental Protection Agency, Cincinnati, OH, August 1976.

Lager, J.A., Smith, W.G., Lynard, W.G., Finn, R.F. and Finnemore, E.J., "Urban Stormwater Management and Technology: Update and User's Guide," EPA-600/8-77-014 (NTIS PB 275 264), Environmental Protection Agency, Cincinnati, OH, September 1977a.

Lager, J.A., Smith W.G. and Tchobanoglous, G., "Catchbasin Technology Overview and Assessment," EPA-600/1-77-051 (NTIS PB 270 092), Environmental Protection Agency, Cincinnati, OH, May 1977b.

Lentz, J.J., "Estimation of Design Maximum Domestic Sewage Flow Rates," Department of Sanitary Engineering and Water Resources, Johns Hopkins University, Baltimore, MD, May 1963.

Linsley, R.K. and Crawford, N.H., "Continuous Simulation Models in Urban Hydrology," Geophysical Research Letters, Vol. 1, No. 1, May 1974, pp. 59-62.

Linsley, R.K., Jr., Kohler, M.A. and Paulhus, J.L.H., Hydrology for Engineers, McGraw-Hill, New York, NY, 1975.

Linsley, R.K., Kohler, M.A. and Paulhus, J.L.H., Applied Hydrology, McGraw-Hill, New York, NY, 1949.

List, R.J., ed., Smithsonian Meteorological Tables, Smithsonian Institution, Washington, DC, 1966.

Maher, M.B., "Microstraining and Disinfection of Combined Sewer Overflows - Phase III," EPA-670/2-74-049 (NTIS PB 235 771), Environmental Protection Agency, Cincinnati, OH, August 1974.

Manning, M.J., Sullivan, R.H. and Kipp, T.M., "Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges - Vol. III: Characterization of Discharges," EPA-600/2-77-064c (NTIS PB 272 107), Environmental Protection Agency, Cincinnati, OH, August 1977.

Marsalek, J., "Synthesized and Historical Storms for Urban Drainage Design," Proceedings International Conference at the University of Southampton, April 1978, Helliwell, P.R., ed., Urban Storm Drainage, Pentech Press, London, 1978a, pp. 87-99.

Marsalek, J., "Research on the Design Storm Concept," ASCE Urban Water Resources Research Program Tech. Memo No. 33 (NTIS PB 291936), ASCE, New York, NY, September 1978b.

Maryland Water Resources Administration, "Technical Guide to Erosion and Sediment Control Design," Maryland Department of Natural Resources, September 1973.

Mattraw, H.C., Jr., and Sherwood, C.B., "Quality of Storm Water Runoff From a Residential Area, Broward County, Florida," Journal Research U.S. Geological Survey, Vol. 5, No. 6, November-December 1977, pp. 823-834.

McElroy, A.D., Chiu, S.Y., Nebgen, J.W., Aleti, A. and Bennett, F.W., "Loading Functions for Assessment of Water Pollution for Non-point Sources" EPA-600/2-76-151 (NTIS PB 253 325), Environmental Protection Agency, Washington, D.C., May 1976.

McPherson, M.B., "Some Notes on the Rational Method of Storm Drain Design," ASCE Urban Water Resources Research Program Tech. Memo No. 6, ASCE, New York, NY, January 1969.

McPherson, M.B., "Urban Runoff Control Planning," EPA-600/9-78-035, Environmental Protection Agency, Washington, DC, October 1978.

Medina, M.A., Jr., "Interaction of Urban Stormwater Runoff, Control Measures and Receiving Water Response," Ph.D. Dissertation, University of Florida, Gainesville, FL, 1976.

Medina, M.A., Jr., "Level III: Receiving Water Quality Modeling for Urban Stormwater Management," EPA-600/2-79-100 (NTIS PB 80 134406), Environmental Protection Agency, Cincinnati, OH August 1979.

Medina, M.A., Huber, W.C. and Heaney, J.P., "Modeling Stormwater Storage/Treatment Transients: Theory," Journal of the Environmental Engineering Division, ASCE, Vol. 107, No. EE4, August 1981, pp. 787-797.

Mein, R.G. and Larson, C.L., "Modeling Infiltration During a Steady Rain," Water Resources Research, Vol. 9, No. 2, April 1973, pp. 384-394.

Metcalf, L. and Eddy, H.P., American Sewerage Practice, Design of Sewers, Volume 1, First Edition, McGraw-Hill, New York, NY, 1914.

Metcalf and Eddy, Inc., Wastewater Engineering, McGraw-Hill, New York, NY, 1972.

Metcalf and Eddy, Inc., University of Florida, and Water Resources Engineers, Inc., "Storm Water Management Model, Volume I - Final Report," EPA Report 11024 DOC 07/71 (NTIS PB 203 289), Environmental Protection Agency, Washington, DC, July 1971a.

Metcalf and Eddy, Inc., University of Florida, and Water Resources Engineers, Inc., "Storm Water Management Model, Volume II - Verification and Testing," EPA Report 11024 DOC 08/71 (NTIS PB 203 290), Environmental Protection Agency, Washington, DC, August 1971b.

Metcalf and Eddy, Inc., University of Florida, and Water Resources Engineers, "Storm Water Management Model, Volume III - User's Manual," EPA-11024 DOC 09/71 (NTIS PB 203 291), Environmental Protection Agency, Washington, DC, September 1971c.

Metcalf and Eddy, Inc., University of Florida, and Water Resources Engineers, Inc., "Storm Water Management Model, Volume IV - Program Listing," EPA Report 11024 DOC 10/71 (NTIS PB 203 292), Environmental Protection Agency, Washington, DC, October 1971d.

Meyer, L.D. and Kramer, L.A., "Erosion Equations Predict Land Slope Developments," Agricultural Engineer, Vol. 50, No. 9, September 1969, pp. 522-523.

Miller, C.R. and Viessman, W., Jr., "Runoff Volumes from Small Urban Watersheds," Water Resources Research, Vol. 8, No. 2, April 1972, pp. 429-434.

Miller, R.A., Mattraw, H.C., Jr. and Jennings, M.E., "Statistical Modeling of Urban Storm Water Processes, Broward County, Florida," Proceedings International Symposium on Urban Storm Water Management, University of Kentucky, Lexington, KY, July 1978, pp. 269-273.

Musgrave, G.W., "How Much Water Enters the Soils," U.S.D.A. Yearbook, U.S. Department of Agriculture, 1955, pp. 151-159.

National Oceanic and Atmospheric Administration, Climates of the States, Volumes I and II, Water Information Center, Inc., Port Washington, NY, 1974.

Ogrosky, H.O. and Mockus, V., "Hydrology of Agricultural Lands," Chow, V.T., ed., Handbook of Applied Hydrology, McGraw-Hill, New York, NY, 1964.

Ontario Ministry of the Environment, "A Review of Literature on the Environmental Impact of Deicing Compounds and Snow Disposal from Streets and Highways," Unpublished Report to the Technical Task Force on Snow Disposal, Water Resources Branch, Ontario Ministry of the Environment, Toronto, Ontario, Canada, May 1974.

Osantowski, R., Geinopolos, A., Wullschleger, R.E. and Clark, M.J., "Handling and Disposal of Sludges from Combined Sewer Overflow Treatment: Phase III - Treatability Studies," EPA-600/2-77-053c (NTIS PB 281 006) Environmental Protection Agency, Cincinnati, OH, December 1977.

Overton, D.E. and Meadows, M.E., Stormwater Modeling, Academic Press, New York, NY, 1976.

Painter, J. and Viney, M., "Composition of Domestic Sewage," Journal of Biochemical and Microbiological Technology and Engineering, Vol. 1, No. 2, 1959, pp. 143-162.

Patry, G. and McPherson, M.B., eds., "The Design Storm Concept," Ecole Polytechnique de Montreal, Civil Engineering Dept., EP80-R-8, GREMU-79/02, Montreal, Quebec, Canada, December 1979.

Petryk, S. and Bosmajian, G, "Analysis of Flow Through Vegetation," Journal of the Hydraulics Division, ASCE, Vol. 101, No. HY7, July 1975, pp. 871-884.

Pisano, W.C., Aronson, G.L., Queiroz, C.S., Blanc, F.C. and O'Shaughnessy, J.C., "Dry-Weather Deposition and Flushing for Combined Sewer Overflow Pollution Control," EPA-600/2-79-133 (NTIS PB 80 118524), Environmental Protection Agency, Cincinnati, OH, August 1979.

Pitt, R. and Amy, G., "Toxic Materials Analysis of Street Surface Contaminants," EPA-R2-73-283 (NTIS PB 224 677), Environmental Protection Agency, Washington, DC, August 1973.

Pitt, R., "Demonstration of Non-point Pollution Abatement Through Improved Street Cleaning Practices," EPA-600/2-79-161 (NTIS PB 80 108988), Environmental Protection Agency, Cincinnati, OH, August 1979.

Portland Cement Association, "Design and Construction of Concrete Sewers," Chicago, IL, 1968, p. 13.

Ports, M.A., "Use of the Universal Soil Loss Equation as a Design Standard," ASCE Water Resources Engineering Meeting, Washington, DC, 1973.

Proctor and Redfern, Ltd. and James F. MacLaren, Ltd., "Stormwater Management Model Study - Vol. I, Final Report," Research Report No. 47, Canada-Ontario Research Program, Environmental Protection Service, Environment Canada, Ottawa, Ontario, September 1976a.

Proctor and Redfern, Ltd. and James F. MacLaren, Ltd., "Storm Water Management Model Study - Volume II, Technical Background," Research Report No. 48, Canada-Ontario Research Program, Environmental Protection Service, Environment Canada, Ottawa, Ontario, September 1976b.

Proctor and Redfern, Ltd., and James F. MacLaren, Ltd., "Storm Water Management Model Study - Volume III, User's Manual," Research Report No. 62, Canada-Ontario Research Program, Environmental Protection Service, Environment Canada, Ottawa, Ontario, 1977.

Rich, L.G., Environmental Systems Engineering, McGraw-Hill, New York, NY, 1973.

Richardson, D.L., Terry, R.C., Metzger, J.B., Carroll, R.J. and Little, A.D., "Manual for Deicing Chemicals: Application Practices," EPA-670/2-74-045 (NTIS PB 236 152), Environmental Protection Agency, Cincinnati, OH, December 1974.

Rickert, D. and Hunter, J.V., "Rapid Fractionation and Materials Balance of Solids Fractions in Wastewater and Wastewater Effluent," Journal Water Pollution Control Federation, Vol. 39, No. 9, September 1967, pp. 1475-1486.

Rickert, D. and Hunter, J.V., "General Nature of Soluble and Particulate Organics in Sewage and Secondary Effluent," Water Research, Vol. 5, 1971, pp. 421-436.

Roesner, L.A., Nichandros, H.M., Shubinski, R.P., Feldman, A.D., Abbott, J.W. and Friedland, A.O., "A Model for Evaluating Runoff-Quality in Metropolitan Master Planning," ASCE Urban Water Resources Research Program Tech. Memo No. 23 (NTIS PB 234 312), ASCE, New York, NY, April 1974.

Roesner, L.A., Shubinski, R.P. and Aldrich, J.A., "Storm Water Management Model User's Manual Version III: Addendum I, EXTRAN," EPA Report, Cincinnati, OH, 1981.

Sartor, J.D. and Boyd, G.B., "Water Pollution Aspects of Street Surface Contaminants," EPA-R2-72-081 (NTIS PB 214 408), Environmental Protection Agency, Washington, DC, November 1972.

Scholl, J.E., "Water Quality Response to Sewage Effluent and Urban Runoff in the Halifax River, Florida," Master of Engineering Thesis, University of Florida, Gainesville, FL, 1978.

Shaheen, D.G., "Contributions of Urban Roadway Usage to Water Pollution," EPA-600/2-75-004 (NTIS PB 245 854), Environmental Protection Agency, Washington, DC, April 1975.

Shubinski, R.P. and Fitch, W.N., "Urbanization and Flooding, an Example," in Environmental Modeling and Simulation, EPA-600/9-76-016 (NTIS PB 257 142), Environmental Protection Agency, Washington, DC, July 1976, pp. 69-73.

Shubinski, R.P. and Roesner, L.A., "Linked Process Routing Models," Presented at Spring Meeting, American Geophysical Union, Washington, DC, April 1973.

Simons, D.B. and Senturk, F., Sediment Transport Technology, Water Resources Publications, Ft. Collins, CO, 1977.

Smith, G.F., "Adaptation of the EPA Storm Water Management Model for Use in Preliminary Planning for Control of Urban Storm Runoff," Master of Engineering Thesis, University of Florida, Gainesville, FL, 1975.

Smolenyak, K.J., "Urban Wet-Weather Pollutant Loadings," Master of Engineering Thesis, University of Florida, Gainesville, FL, 1979.

Soil Conservation Service, SCS National Engineering Handbook, U.S. Department of Agriculture, 1972.

Sonnen, M.B., "Subroutine for Settling Velocities of Spheres," Journal of the Hydraulics Division, ASCE, Vol. 103, No. HY9, September 1977a, pp. 1097-1101.

Sonnen, M.B., "Abatement of Deposition and Scour in Sewers," EPA-600/2-77-212 (NTIS PB 276 585), Environmental Protection Agency, Cincinnati, OH, November 1977b.

Sonnen, M.B., "Urban Runoff Quality: Information Needs," Journal of the Technical Councils, ASCE, Vol. 106, No. TC1, August 1980, pp. 29-40.

Stankowski, S.J., "Magnitude and Frequency of Floods in New Jersey with Effects of Urbanization," Special Report 38, U.S. Goelogical Survey, Water Resources Division, Trenton, NJ, 1974.

Stoneham, S.M. and Kidd, C.H.R., "Prediction of Runoff Volume From Fully Sewered Urban Catchments," Report No. 41, Institute of Hydrology, Wallingford, Oxon, England, September 1977.

Sullivan, R.H., Cohn, M.M., Ure, J.E. and Parkinson, F., "The Swirl Concentrator as a Grit Separator Device," EPA-670/2-74-026 (NTIS PB 223 964), Environmental Protection Agency, Cincinnati, OH, June 1974.

Sullivan, R.H., Hurst, W.D., Kipps, T.M., Heaney, J.P., Huber, W.C. and Nix, S.J., "Evaluation of the Magnitude and Significance of Pollution from Urban Storm Water Runoff in Ontario," Research Report No. 81, Ontario Ministry of Environment, Toronto, Ontario, 1978.

Surkan, A.J., "Simulation of Storm Velocity Effects on Flow From Distributed Channel Networks," Water Resources Research, Vol. 10, No. 6, December 1974, pp. 1149-1160.

Tennessee Valley Authority, "Heat and Mass Transfer Between a Water Surface and the Atmosphere," Water Resources Research Lab, Report No. 14, Engineering Laboratory, Norris, TN, April 1972.

Terstriep, M.L., Bender, G.M. and Benoit, J., "Buildup, Strength and Washoff of Urban Pollutants," Preprint No. 3439, ASCE Convention and Exposition, Chicago, IL, October 1978.

Terstriep, M.L. and Stall, J.B., "The Illinois Urban Drainage Area Simulator, ILLUDAS," Bulletin 58, Illinois State Water Survey, Urbana, IL, 1974.

Tholin, A.L. and Keifer, C.J., "Hydrology of Urban Runoff," Transactions ASCE, Paper No. 3061, Vol. 125, 1960, pp. 1308-1355.

Torno, H.C., "Model Application in EPA Planning Programs," Preprint No. 3526, ASCE Convention and Exposition, Boston, MA, April 1979.

Tucker, L.S., "Sewage Flow Variations in Individual Homes," ASCE Combined Sewer Separation Project Tech. Memo No. 2, ASCE, New York, NY, 1967, p. 8.

Tucker, L.S., "Northwood Gaging Installation, Baltimore - Instrumentation and Data," Tech. Memo No. 2, ASCE Urban Water Resources Research Program, ASCE, New York, NY, August 1968.

Turner, A.K., Langford, K.J., Win, M. and Clift, T.R., "Discharge-Depth Equation for Shallow Flow," Journal of the Irrigation and Drainage Division, ASCE, Vol. 104, No. IR1, March 1978, pp. 95-110.

Uttormark, P.D., Chapin, J.D. and Green, K.M., "Estimating Nutrient Loadings of Lake from Non-point Sources," EPA-660/3-74-020, Environmental Protection Agency, Washington, DC, August 1974.

Van den Berg, J.A., "Quick and Slow Response to Rainfall by an Urban Area," Proceedings International Conference at the University of Southampton, April 1978, Helliwell, P.R., ed., Urban Storm Drainage, Pentech Press, London, 1978, pp. 705-712.

Vanoni, V.A., ed., Sedimentation Engineering, ASCE, New York, NY, 1975.

Viessman, J.W., Knapp, J.W., Lewis, G.L., and Harbaugh, T.E., Introduction to Hydrology, IEP, New York, NY, 1977.

Walesh, S.G. and Snyder, D.F., "Reducing the Cost of Continuous Hydrologic-Hydraulic Simulation," Water Resources Bulletin, AWRA, Vol. 15, No. 3, June 1979, pp. 644-659.

Wallace, R.C., "Statistical Modeling of Water Quality Parameters in Urban Runoff," Master of Engineering Technical Report (unpublished), Department of Environmental Engineering Sciences, University of Florida, Gainesville, FL, 1980.

Waller, D.H., "Pollution Attributable to Surface Runoff and Overflows from Combined Sewerage Systems," Atlantic Industrial Research Institute, Halifax, Nova Scotia, April 1971.

Wanielista, M.P., Stormwater Management-Quantity and Quality, Ann Arbor Science Publishers, Ann Arbor, MI, 1978, pp. 57-59.

Weibel, S.R., Anderson, R.J. and Woodward, R.L., "Urban Land Runoff as a Factor in Stream Pollution," Journal Water Pollution Control Federation, Vol. 36, No. 7, July 1964, pp. 914-924.

Weibel, S.R., Weidner, R.B., Cohen, J.M. and Christianson, A.G., "Pesticides and Other Contaminants in Rainfall and Runoff," Journal American Water Works Association, Vol.58, No. 8, August 1966, pp. 1075-1084.

Wenzel, H.G., Jr., and Voorhees, M.L., "Evaluation of the Design Storm Concept," paper presented at the 1978 Fall Meeting of American Geophysical Union, San Francisco, CA, December 1978.

Westerstrom, G., "Snowmelt Runoff from Urban Plot," Proc. Second International Conference on Urban Storm Drainage, Urbana, IL, June 14-19, 1981, Vol. I, pp. 452-459.

Wetzel, E.D. and Johnson, R.L., "Alteration of EPA's SWMM for Use on a CDC 6400," Fritz Engineering Laboratory Report 416.1, Lehigh University, Bethlehem, PA, December 1976.

Wischmeier, W.H., Johnson, C.B. and Cross, B.U., "A Soil Erodibility Nomograph for Farmland and Construction Sites," Journal of Soil and Water Conservation, Vol. 26, No. 5, September-October 1971, pp. 189-193.

Wischmeier, W.H. and Smith, D.D., "Rainfall Energy and Its Relationship to Soil Loss," Transactions American Geophysical Union, Vol. 39, No. 2, April 1958, pp. 285-291.

Wischmeier, W.H. and Smith, D.D., "Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains," Agricultural Handbook 282, U.S. Department of Agriculture, Washington, DC, 1965.

Whipple, W., Jr., Hunter, J.V. and Yu, S.L., "Effects of Storm Frequency on Pollution from Urban Runoff," Journal Water Pollution Control Federation, Vol. 49, No. 11, November 1977, pp. 2243-2248.

Yen, B.C. and Chow, V.T., "A Study of Surface Runoff Due to Moving Rainstorms," Hydraulic Engineering Series Report No. 17, Dept. of Civil Engineering, University of Illinois, Urbana, IL, June 1968.

Zison, S.W., "Sediment-Pollutant Relationships in Runoff From Selected Agricultrual, Suburban and Urban Watersheds," EPA-600/3-80-022, Environmental Protection Agency, Athens, GA, January 1980.

APPENDIX I

CONTINUOUS SIMULATION

CONTINUOUS AND SINGLE EVENT SIMULATION

The original Storm Water Management Model, designed for single event simulation, produced detailed (i.e., short time increment) hydrographs and pollutographs for individual storm events. Although this capability remains, the model has now been altered so that it may be run for an unlimited number of time steps, for multiple events. In this mode it may be used in a planning context, that is, for an overall assessment of urban runoff problems and estimates of the effectiveness and costs of abatement procedures. Tradeoffs among various control options, such as storage, treatment and street sweeping, may be evaluated. Complex interactions between the meteorology, e.g., precipitation patterns, and the hydrology of an area may be simulated without resorting to average values or very simplified methods. In this manner, critical events from the long period of simulation may be selected for detailed analysis. In addition, return periods for intensity, duration and volume (mass) of runoff (pollutant loads) may be assigned on the basis of the simulated record instead of incorrectly equating them to the same statistics of the rainfall record. In this manner, the critical events chosen for study may be substituted for hypothetical "design storms", the latter often being synthesized from intensity-duration-frequency curves on the basis of questionable statistical assumptions. Linsley and Crawford (1974) present a useful discussion of continuous simulation in urban hydrology.

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

CONTINUOUS SWMM OVERVIEW

SWMM is run continuously using only the Runoff and Storage/Treatment (S/T) blocks. Routing in Transport, WRE Transport (EXTRAN) or Receiving is avoided and is unnecessary for the planning purposes to which the model is applied. (However, there is no limitation on the number of time steps for either Extran, Transport or Receive). A "Level III" receiving water model that will couple with either continuous SWMM or STORM has been developed based upon earlier work (Heaney et al., 1977) and is documented (Medina, 1979). The algorithms used in Runoff and S/T are almost identical when run continuously or as a single event model, the only differences occuring in a minor way in the snowmelt routines. A one-hour time step is required when the model receives input from National Weather Service (NWS) precipitation and temperature tapes, which will be true for most applications. Although other time steps may be used, the output is generally formated for an assumed 24 time steps per day. In fact, inclusion of daily, monthly and annual totals along with a few other I/O features forms about the only distinction between the continuous and single event mode.

It is anticipated that continuous, long-term simulation will only be used with a very coarse, "lumped" or aggregated catchment schematization in order to minimize computer costs. For example, only one subcatchment and no gutter/pipes will often suffice.

SNOWMELT

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

Urban snow removal practices may be simulated through "redistribution fractions" input for each subcatchment (see Figure II-6 in Appendix II), through alteration of the melt coefficients and base temperatures for the regions of each subcatchment, and through the areal depletion curves used for continuous simulation. Anderson's temperature-index and heat balance melt equations are used for melt computations during dry and rainy periods, respectively. For continous simulation, the "cold content" of the pack is maintained in order to "ripen" the snow before melting. Routing of melt water through the snow pack is performed as a simple reservoir routing procedure, as in the Canadian study.

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

INPUT DATA

Continuous SWMM requires all data entries previously required except that a coarse schematization greatly reduces the amount of entries required for subcatchments and gutter/pipes (see below). The key data need is a long-term precipitation record for the area. SWMM is keyed to the use of magnetic tapes available from the National Weather Records Center of the NWS at Asheville, North Carolina. These tapes contain card images of "NWS Card Deck 488, USWB Hourly Precipitation" and cost approximately $200 per station for a 25 year record of hourly precipitation totals. (Similar tapes are supplied in Canada by the Atmospheric Environment Service.) When snowmelt is simulated, a record of daily temperature data is also required; see the snowmelt documentation in Appendix II. These data are processed in subroutine CTRAIN in Runoff for later use by the other routines in the block. Optionally, the processed data, including a tabulation of the 50 highest values, may be examined prior to proceeding with the remainder of the simulation. When snowmelt is simulated, rainfall or snowfall is determined from hourly air temperatures synthesized from the daily max-min values for the station. Snowfall values are keyed as negative precipitation for internal use in the program.

Other input data unique to continuous simulation consist mainly of dates for starting and stopping, printing, etc. In addition, NWS Station ID numbers must be known for the precipitation and temperature tapes.

CATCHMENT SCHEMATIZATION

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

OUTPUT

Runoff Block

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

In addition, the 50 highest hourly totals are listed, by both runoff volume and BOD load. These may be compared to the 50 highest hourly rainfall depths and used in selecting critical time periods for more detailed study.

For example, a two-year simulation of a 312 ac (126 ha) catchment tributary to Lake Calhoun in Minneapolis was made, and the ten highest rainfall, runoff and BOD loads (from the output of the 50 highest) are shown in Table I-1. The comparisons indicate that the rankings differ according to antecedent conditions, etc. affecting each parameter. For example, the highest rainfall depth corresponds to the third highest runoff depth and second highest BOD load. The table adds further justification to the contention that it is necessary to treat rainfall, runoff and pollutant loads separately in terms of statistical analyses.

The most useful review of continuous SWMM output is probably accomplished using the Statistics Block. Therein a frequency analysis of many storm quantity and quality parameters (e.g., depth, duration, interevent time, load, peak concentration, etc.) may be performed. Output is available in both tabular and graphical forms. Analysis by the Statistics Block may follow any other block (except Receive).

Storage/Treatment Block

There is no distinction made between output for a single event or continuous simulation in the Storage/Treatment Block. Regardless of the number of time steps specified, the user has the option of printing a detailed report for each time step during eight different intervals (or less), a monthly summary, an annual summary, and/or a final summary. Of course, the monthly and annual summaries have little value in a single event simulation and should only be used for long-term runs.

DRY-PERIOD REGENERATION

Quantity

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

Quality

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

Street sweeping occurs at intervals specified for each land use. The intervals are computed on the basis of intervening dry time steps. A dry time step is one in which the subcatchment receives no precipitation and has no water remaining in impervious area depression storage or as snow. When snowmelt is simulated, street sweeping may be bypassed for a specified interval of the year (e.g., the winter months).

Table I-1. Hourly Event Ranking by Rain Flow and BOD for Two Year Simulation of Lake Calhoun Catchment, Minneapolis.

Ten highest values are taken from the tabulated output of 50 highest given by SWMM.

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

Runoff simulates any ten quality parameters with arbitrary units, plus, optionally, erosion using the Universal Soil Loss Equation. As a user option, regeneration of selected constituents (e.g, chlorides) during dry periods will occur only when snow is present.

CONTINUOUS SWMM COMPARED TO STORM

Preliminary comparisons of SWMM and STORM, without S/T simulation, indicate that the two outputs are comparable and STORM is approximately 50 percent cheaper (see Appendix II). Why, then, might SWMM be used over STORM or other existing continuous models? When just the Runoff Block is required, STORM could be the choice because of its simplicity, good documentation, useful output and inclusion of the SCS method for rural runoff generation. SWMM might be preferred if flow routing in gutter/pipes were desired or particular features of runoff or quality generation were needed. In addition, SWMM now couples both the single event and continuous simulation capability into one model.

The principal advantage of continuous SWMM lies in its Storage/Treatment block described in Appendix IV. Several pathways among and through the various storage and/or treatment devices may be utilized instead of one fixed configuration. Most importantly, the treatment that occurs in storage as well as sludge generation by all control options, may be simulated by SWMM. Finally, SWMM S/T will compute operation and maintenance costs on the basis of actual hours of operation of wet-weather treatment devices, providing more realistic cost data.

APPENDIX II

SWMM SNOWMELT ROUTINES

INTRODUCTION

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

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

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

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

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

OVERVIEW

Snow Depths

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

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

Single Event Simulation

For single event simulation, it is unnecessary to generate a long record of precipitation and temperature data. Snow quantities are input as initial depths (water equivalent) on subcatchments and as negative rainfall intensities on rainfall input cards. Snowfall is generally keyed as negative precipitation on input files. Temperature data are read for each time step from card input. (Other parameters are explained subsequently.)

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

Continuous Simulation

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

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

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

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

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

Pollutant Simulation

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

SNOW AND TEMPERATURE GENERATION FROM NWS TAPES

National Weather Service (NWS) Data

As explained in the description, continuous SWMM and other continuous simulation models utilize long-term precipitation and temperature data obtained from the National Weather Records Center (NWRC) at Asheville, North Carolina for the nearest NWS or airport weather station of record. If snowmelt is not simulated only the precipitation tape is needed; hourly precipitation totals are included on it for every day with measureable precipitation, plus for the first day of each month whether or not there is precipitation. For continuous SWMM without snowmelt, all such hourly values are treated as rainfall.

Maximum and minimum temperatures as well as several other meteorological parameters are given for every day of the year on the NWRC's "WBAN Summary of Day, Deck 345". A card is illustrated in Figure II-1. Only the ID number, date and max-min temperatures are used although other data may be useful for other purposes. Note that the five-digit ID number is not necessarily the same as for the hourly precipitation data. The program, in subroutine CTRAIN, accesses a magnetic tape containing card images of data shown in Figure II-1. The unit number of the tape is input in the executive Block as NSCRAT(3). As explained in the description of continuous SWMM, a

CARD DECK 345 WBAN SUMMARY OF DAY

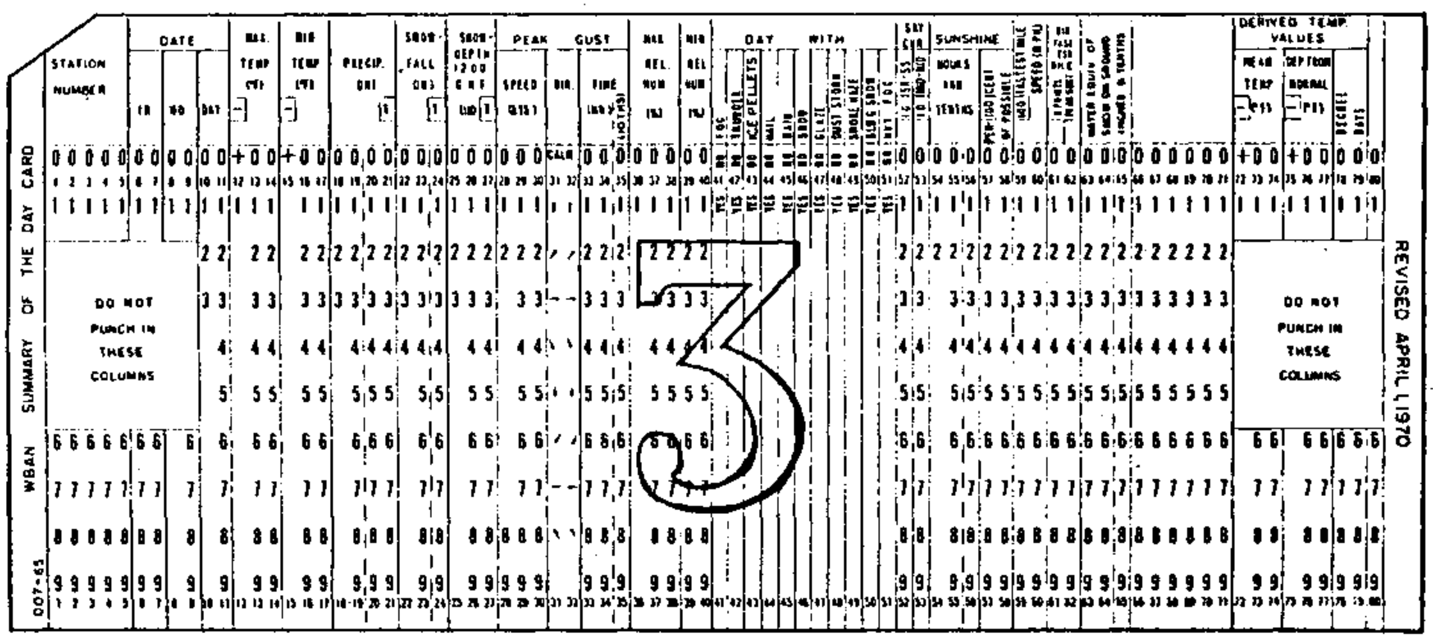


Figure II-1. Card Image of NWS Card Deck 345, "WBAN Summary of Day." The only parameters used by SWMM are Station number, date, maximum temperature and minimum temperature. One card is read for each day of the simulation.

magnetic tape containing card images of hourly precipitation values is accessed similarly using unit number JIN(1).

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

Creation of Hourly Temperatures

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

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

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

$$\cos h = -\tan \delta \cdot \tan \phi \tag{II-1}$$

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

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

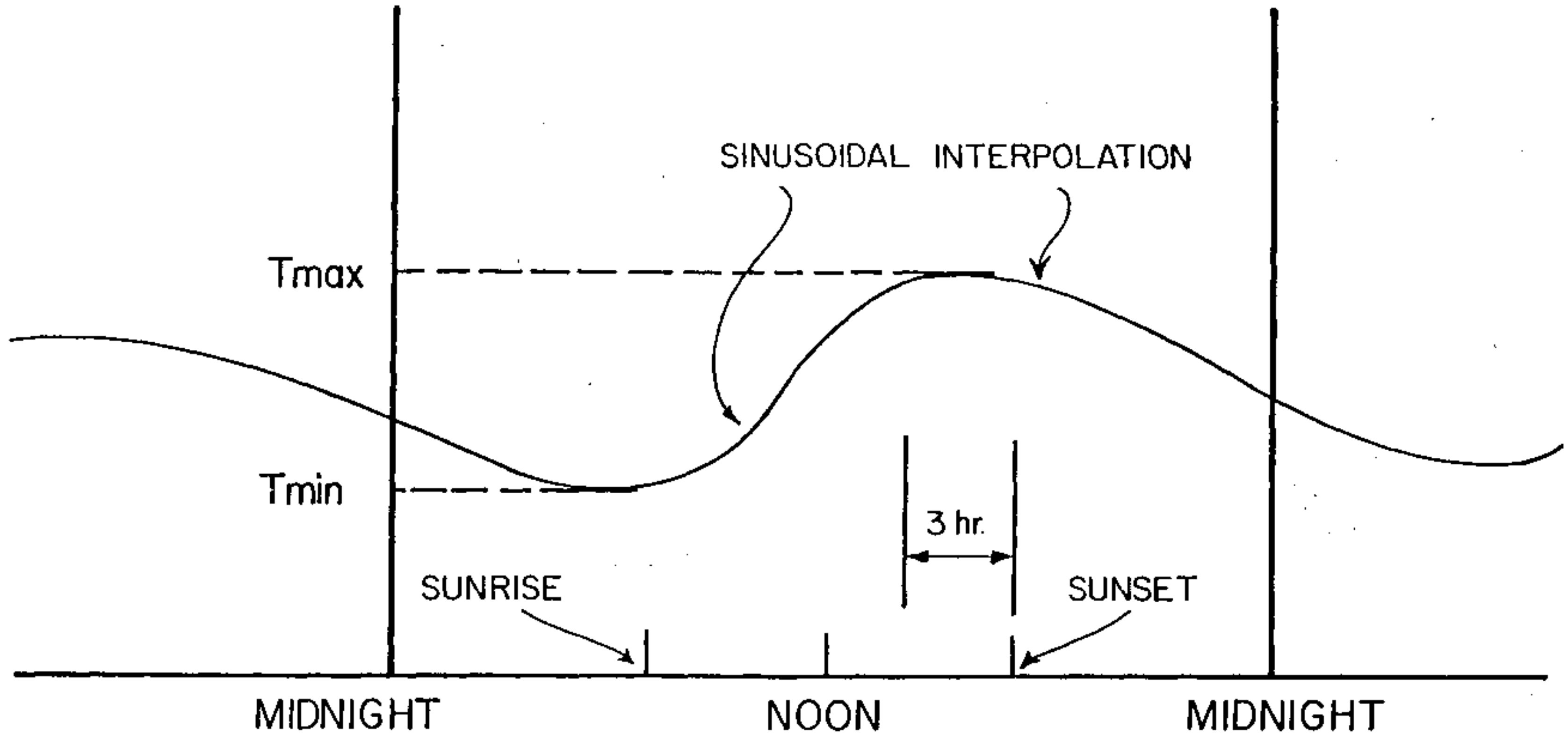


Figure II-2. Sinusoidal Interpolation of Hourly Temperatures.

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

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

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

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

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

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

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

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

The time of day of sunrise is then

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

and the time of day of sunset is

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

These times are rounded to the nearest hour for use in continuous SWMM since hourly time steps are used. If shorter time steps are allowed in the future, such rounding could be removed. As stated earlier, the maximum temperature is assumed to occur at hour HSS - 3.

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

Table II-1. Time Zones and Standard Meridians

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

[a]The time zone of the island of Newfoundland is offset one half hour from other zones.

[b]All of the Yukon Territory is on Pacific Standard Time.

Generation of Snowfall Intensities

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

$$\begin{array}{l} T > SNOTMP, \text{ precipitation = rain;} \\ T \leq SNOTMP, \text{ precipitation = snow.} \end{array} \qquad \text{(II-7)}$$

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

Gage Catch Deficiency Correction

Precipitation gages tend to produce inaccurate snowfall measurements because of the complicated aerodynamics of snow flakes falling into the gage. Snowfall totals are generally underestimated as a result, by a factor that varies considerably depending upon gage exposure, wind velocity and whether or not the gage has a wind shield. The program includes a parameter, SCF, which multiplies snow depths only, as computed using equation II-7. Although it will vary considerably from storm to storm, it acts as a mean correction factor over a season in the model. Anderson (1973) provides typical values of SCF as a function of wind speed, as shown in Figure II-3, which may be helpful in establishing an initial estimate. The value of SCF can also be used to account for other factors, such as losses of snow due to interception and sublimation not accounted for in the model. Anderson (1973) states that both losses are usually small compared to the gage catch deficiency.

Structure of Precipitation - Temperature Data Set

Output from subroutine CTRAIN is placed as a file on off-line storage unit number NSCRAT(2) as diagrammed in Figure II-4. If snowmelt is not simulated, only hourly rainfall intensities (in feet/second) are placed on the unit, in blocks of eight 24 hour days, for 192 values. No other parameters (e.g., dates) are included.

When snowmelt is run, the subroutine first makes all the temperature calculations, and stores these temporarily on unit NSCRAT(1). (This voluminous file may optionally be printed for error checking.) These values are then retrieved for utilization with the precipitation tape. The final file is stored on unit NSCRAT(2) in the form day number/hour, temperature, precipitation, day number/hour, temperature, precipitation, etc., to 192 groups of three, as diagrammed in Figure II-4. The day number/hour parameter is IDTHR where the first three digits are the day of the year and the last two are the hour of the day, (e.g., for noon on February 3, IDTHR = 03412). The year is not included and must be calculated knowing the date of the initial entry on the file. This file may also be printed for debugging purposes but will produce voluminous output.

For most purposes, it will be best to use appropriate job control language (JCL) to save permanently the file on NSCRAT(2) for future repeated use. This avoids reprocessing the NWS tapes; reuse is available as a program option by setting ICRAIN = 2. The JCL required to do this is highly

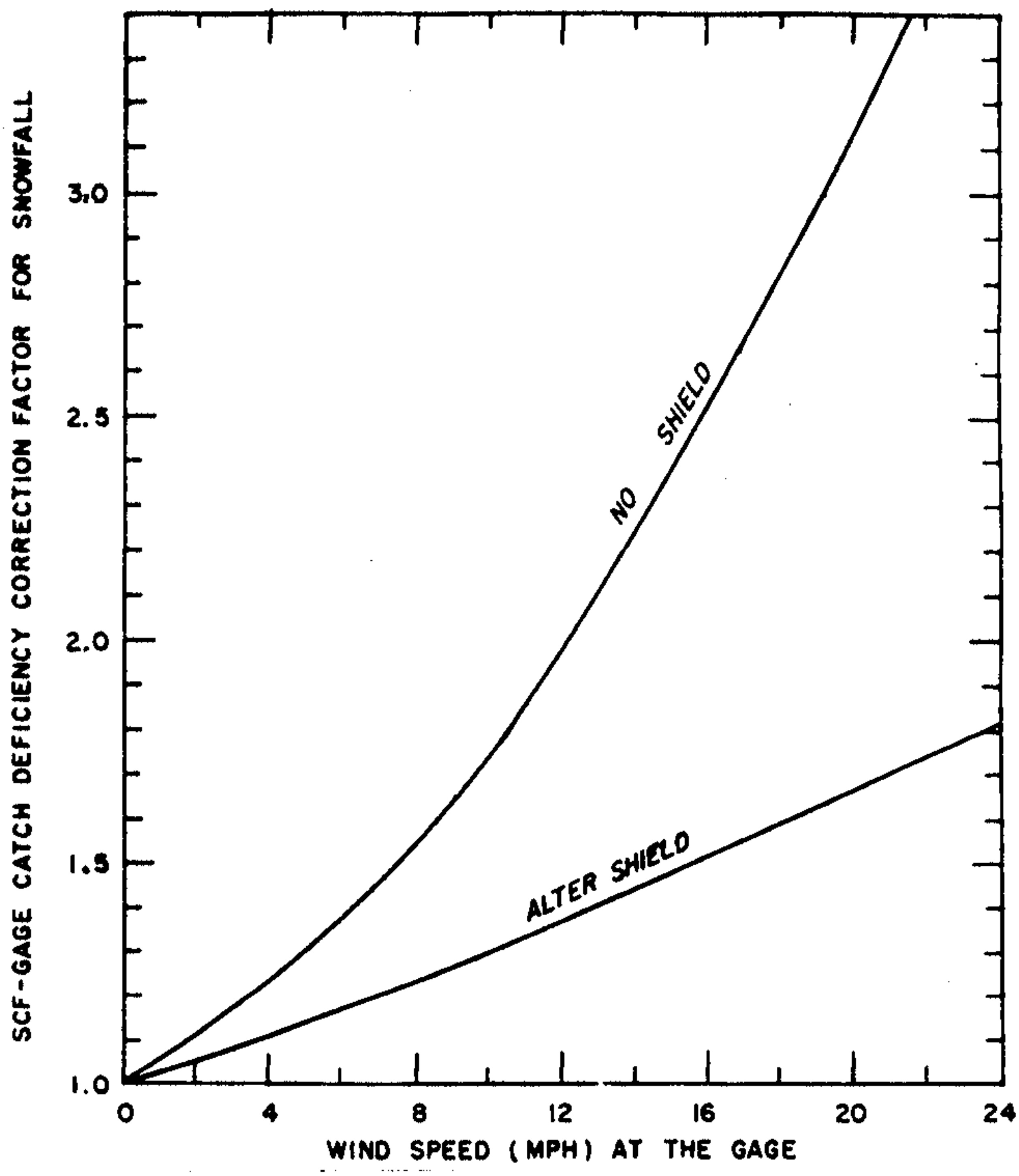


Figure II-3. Typical Gage Catch Deficiency Correction (Anderson, 1973, p. 5-20).

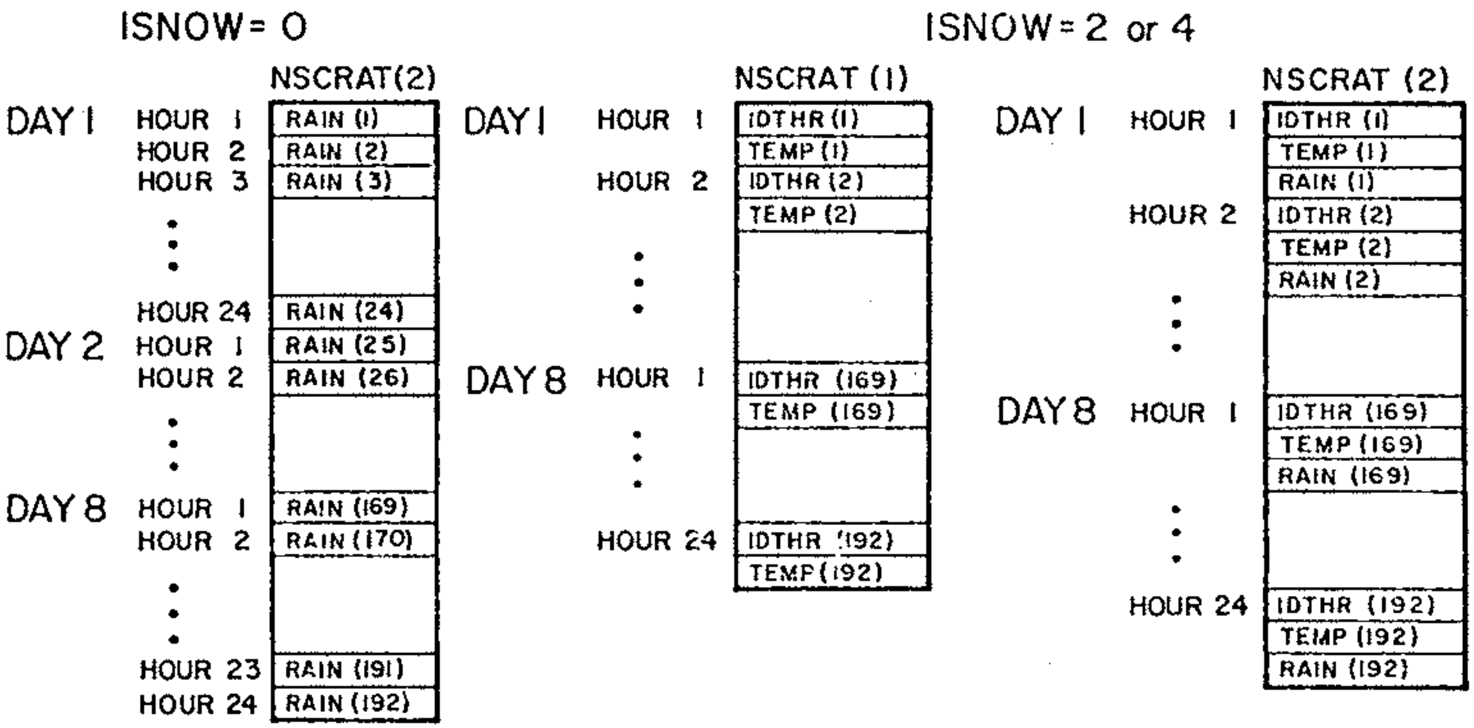


Figure II-4. Structure of Precipitation-Temperature Data Set Used Internally in Runoff for Continuous Simulation.

dependent upon the type of machine and upon the invididual computer installation. If it is not done, however, the file will be "lost" after the program has executed.

Output Options

Depending upon the value of IRPRNT, all non-zero, hourly precipitation values may be printed along with either all generated hourly temperatures for all days, or only the max-min temperatures for all days. In addition, the 50 highest hourly precipitation intensities are printed to aid in choosing critical events for detailed simulation. At the option of the user, the program will stop at this point, by setting parameter ICRAIN = 4, so that this output may be reviewed prior to the actual continuous SWMM simulation. Of course, in this case file NSCRAT(2) should be saved so that it can be retrieved and used later for a continuous SWMM simulation when ICRAIN is set equal to 2.

Single Event SWMM

NWS tapes are not used, nor is subroutine CTRAIN called for single event simulation. Precipitation is entered on cards as in the past. However, snowfall can be included, if desired, as a negative precipitation value at any time step.

SUBCATCHMENT SCHEMATIZATION

Land Surface - Snow Cover Combinations

In order to have flexibility in treating different combinations of snow cover and ground surface types, four such combinations are provided, as described in Table II-2 and illustrated in Figure II-5. When snowmelt is not simulated, only the first three are used, as in the past. (Type 3, impervious area with no depression storage, is specified in Runoff by the parameter PCTZER, percent of impervious area with immediate runoff.) Snow cover is treated identically on types 1 and 3 since these surfaces are likely to be of a similar nature, e.g., streets, sidewalks, parking lots, etc. For continuous simulation, these surfaces are considered "normally bare" because of probable plowing, salting or other rapid snow removal, but are subject to snow cover also, as described subsequently. For single event simulation, these surfaces are always bare; all snow on impervious areas is handled in type 4.

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

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

Apportionment of impervious area is different when simulating with and without snowmelt. For the latter situation, the area with zero depression storage (type 3) is taken as a percentage, PCTZER, of the total impervious area. For the former situation (with snowmelt), it is taken as a percentage, the same PCTZER, of the bare impervious area (single event simulation) or of the "normally bare" impervious area (continuous simulation). Thus, the type 3 area will vary according to whether snowmelt is simulated or not, as shown in Figure II-5. The effect on outflow is very minor. The fraction of impervious area with 100 percent snow cover (single event) or subject to an areal depletion curve (continuous) is an input parameter, SNN1, for each subcatchment.

Table II-2. Subcatchment Surface Classification

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

Redistribution and Simulation of Snow Removal

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

It is assumed that all snow subject to "redistribution", (e.g. plowing) resides on the "normally bare" category, type 1 plus 3 above, (see Figure II-5), which might consist of streets, sidewalks, parking lots, etc. (The desired degree of definition may be obtained by using several subcatchments, although a coarse schematization, e.g., one or two subcatchments, is likely to be all that is required for continuous simulation.) For each subcatch-

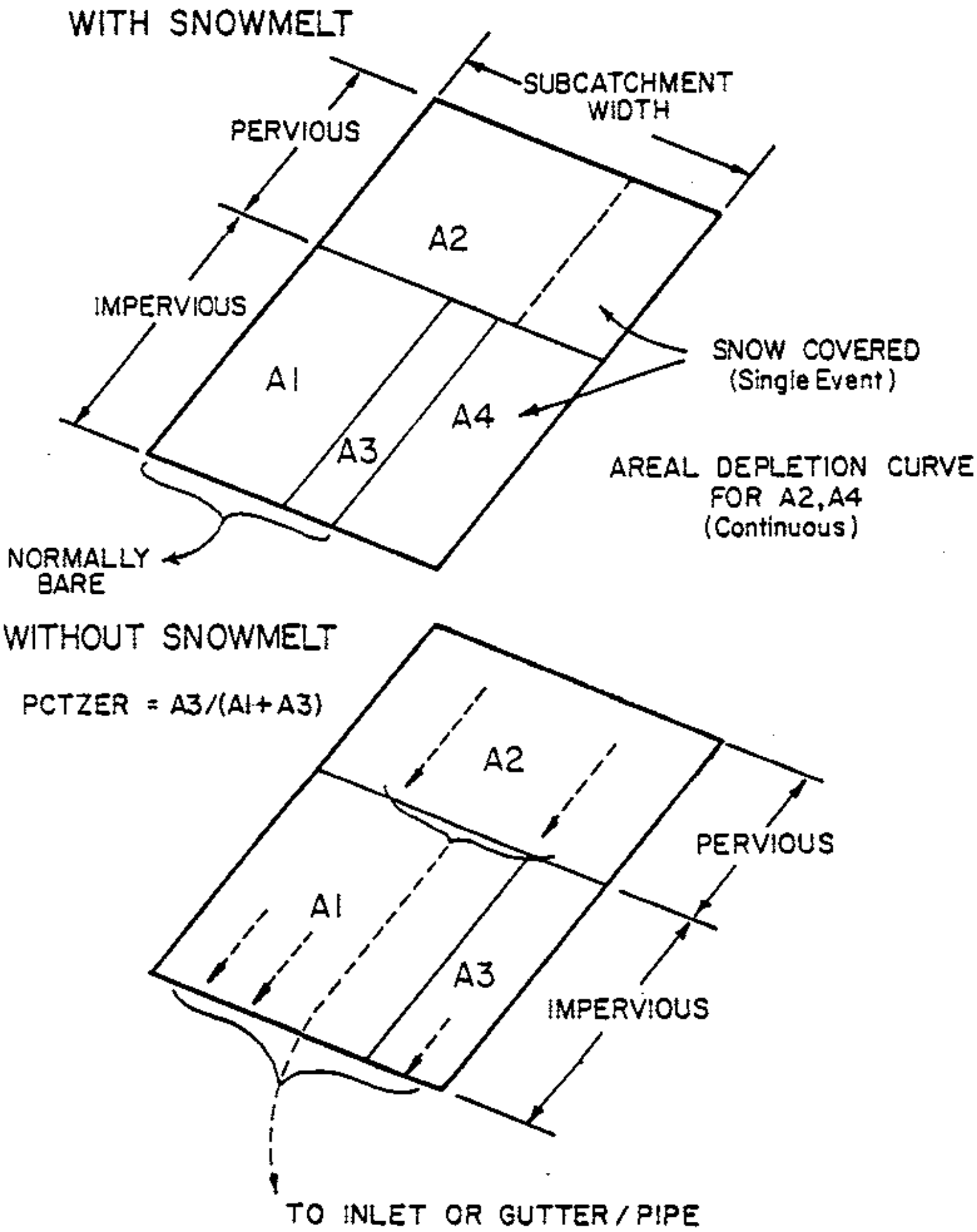


Figure II-5. Subcatchment Schematization With and Without Snowmelt Simulation. See also Table II-2.

ment, a depth of snow, WEPLOW, is input for this area, above which redistribution occurs as indicated in Figure II-6. All snow in excess of this depth, say 0.1 - 0.2 in. water equivalent (2.5 - 5.1 mm), is redistributed to other areas according to five fractions, SFRAC, input for each subcatchment. These are described on Figure II-6. For instance, if snow is usually windrowed onto adjacent impervious or pervious areas, SFRAC(1) or SFRAC(2) may be used. If it is trucked to another subcatchment, (the last one input is used for this purpose), a fraction SFRAC(3) will so indicate, or SFRAC(4) if the snow is removed entirely from the simulated watershed. In the latter case, such removals are tabulated and included in the final continuity check. Finally, excess snow may be immediately "melted", (i.e., treated as rainfall), using SFRAC(5). The transfers are area weighted, of course, and the five fractions should sum to 1.0. A depth of snow WEPLOW remains on the normally bare area and is subject to melting as on the other areas. See Table II-3 for guidelines as to typical levels of service for snow and ice control (Richardson et al., 1974).

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

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

Array Restrictions

In an attempt to maintain a manageable size of the Runoff Block, continuous SWMM is limited to 30 subcatchments and 30 inlets because several additional parameters are needed. However, this should be more than adequate for continuous simulation, with and without snowmelt, since only a coarse catchment discretization should be sufficient. Limitations for single event SWMM remain at 200 subcatchments and 200 gutter/pipes plus inlets.

MELT CALCULATIONS

Theory of Snowmelt

Introduction --

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

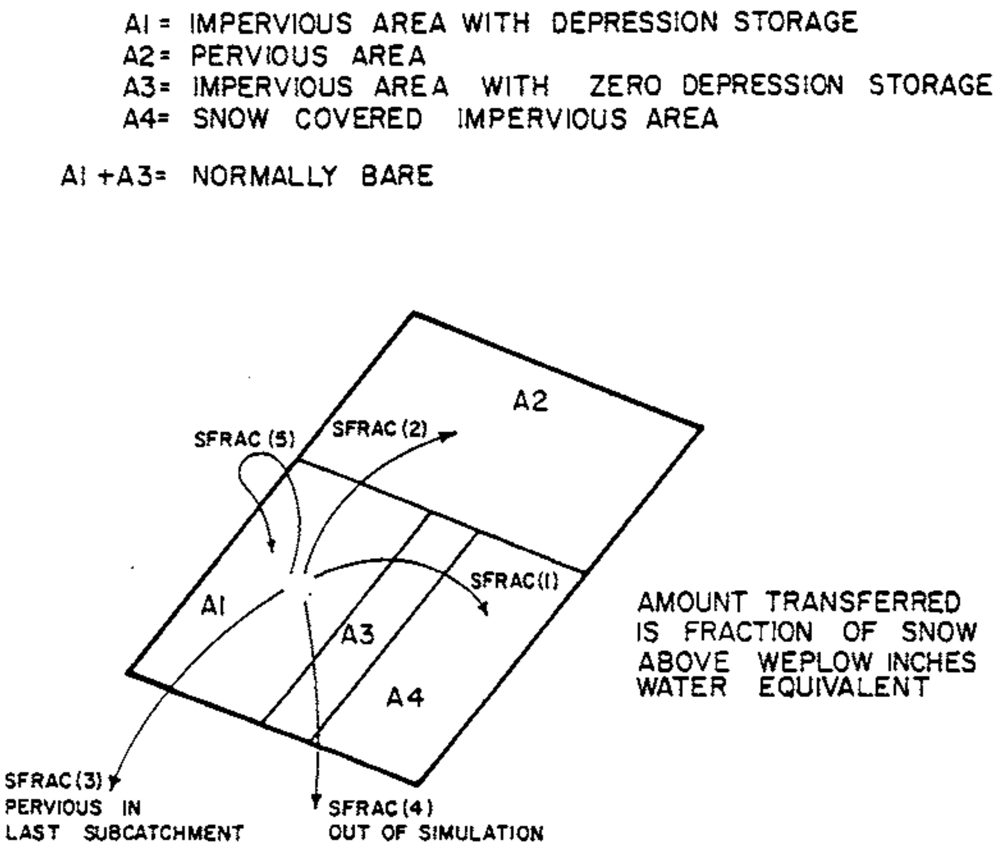


Figure II-6. Redistribution of Snow During Continuous Simulation.

Table II-3. Guidelines for Levels of Service in Snow and Ice Control (Richardson et al., 1974).

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

[a] ADT - average daily traffic

Snowpack Heat Budget --

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

1. Absorbed solar radiation (addition).

2. Net longwave radiation exchange with the surrounding environment (addition or removal).

3. Convective transfer of sensible heat from air (addition or removal).

4. Release of latent heat of vaporization by condensate (addition) or, the opposite, its removal by sublimation (removing the latent heat of vaporization plus the latent heat of fusion).

5. Advection of heat by rain (addition) plus addition of the heat of fusion if the rain freezes.

6. Conduction of heat from underlying ground (removal or addition).

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

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

Melt Prediction Techniques --

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

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

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

Choice of Predictive Method --

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

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

For these and other reasons, simple snowmelt prediction techniques have been incorporated into SWMM. In their literature review preparatory to similar earlier work, Proctor and Redfern and James F. MacLaren (1976a, 1976b) felt that Anderson's NWS (1973) temperature-index method was most appropriate for SWMM. It is also well documented and tested, and has been incorporated into the SWMM version described herein. As described subsequently, the snowmelt modeling follows Anderson's work in several areas, not just in the melt equations. The energy budget technique is illustrated in this report, however, in Appendix III, in order to show how it reduces to a temperature-index equation under certain assumptions. It may be noted that the STORM model (Hydrologic Engineering Center, 1977, Roesner et al., 1974) also uses the temperature-index method for snowmelt prediction, in a considerably less complex manner than is now programmed in SWMM.

SWMM Melt Equations

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

$$\begin{aligned} \text{SMELT} = {} & (\text{TA} - 32) \cdot (0.001167 + \text{SGAMMA} \cdot \text{UADJ} + \\ & 0.007 \cdot \text{PREC}) + 8.5 \cdot \text{UADJ} \cdot (\text{EA} - 0.18) \end{aligned} \tag{II-8}$$

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

The psychometric constant, γ, is calculated as

$$\gamma = 0.000359 \cdot \text{PA} \tag{II-9}$$

where PA = atmospheric pressure, in. Hg.

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

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

where z = average catchment elevation, ft.

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

$$\text{UADJ} = 0.006 \cdot \bar{u} \tag{II-11}$$

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

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

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

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

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

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

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

where SMELT = snowmelt, in./hr or ft/sec,
TA = air temperature, °F,
TBASE = base melt temperature, °F, and
DHM = melt factor, in./hr-°F or ft/sec-°F.

Different values of TBASE and DHM may be input for three area classifications for each subcatchment (see Table II-2 and Figure II-5). For instance, these parameters may be used to account for street salting which lowers the base melt temperature. If desired, rooftops could be simulated as a separate subcatchment using a lower value of TBASE to reflect heat transfer vertically through the roof. Values of TBASE will probably range between 25 and 32 °F (-4 and 0°C). Unfortunately, few urban area data exist to define adequately appropriate modified values for TBASE and DHM, and they may be considered calibration parameters.

In rural areas, the melt coefficient ranges from 0.03 - 0.15 in./day-°F (1.4 - 6.9 mm/day-°C) or from 0.001 - 0.006 in./hr-°F (0.057 - 0.29 mm/hr-°C); the latter are units used for SWMM input. In urban areas, values may tend toward the higher part of the range due to compression of the pack by vehicles, pedestrians, windrows, etc. Again, there appear to be few data available to produce accurate estimates. However, Bengston (1981) and Westerstrom (1981) do describe preliminary results of urban snowmelt studies in Sweden, including degree-day coefficients which range from 3 to 8 mm/°C-day (0.007 - 0.17 in./°F-day).

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

For single event SWMM, parameters DHM and TBASE are constant throughout the simulation. For continuous SWMM, TBASE remains constant, but DHM is allowed a seasonal variation, as illustrated in Figure II-7. Following Anderson (1973), the minimum melt coefficient is assumed to occur on December 21 and the maximum on June 21. Parameters DHMIN and DHMAX are input for the three areas of each subcatchment, and sinusoidal interpolation is used to produce a value of DHM, constant over each day,

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

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

No special allowance is made for leap year in any seasonal computations of the type of equation II-14. However, the correct date (and day number, D) is maintained.

Heat Exchange During Non-Melt Periods

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

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

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

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

The weighting factor, TIPM, is an indication of the thickness of the "surface" layer of snow. Values of TIPM less than 0.1 give significant weight to temperatures over the past week or more and would thus indicate a deeper layer than TIPM values greater than, say, 0.5 which would essentially only give weight to temperatures during the past day. In other words, the pack will both warm and cool more slowly with low values of TIPM. Anderson states that TIPM = 0.5 has given reasonable results in natural watersheds,

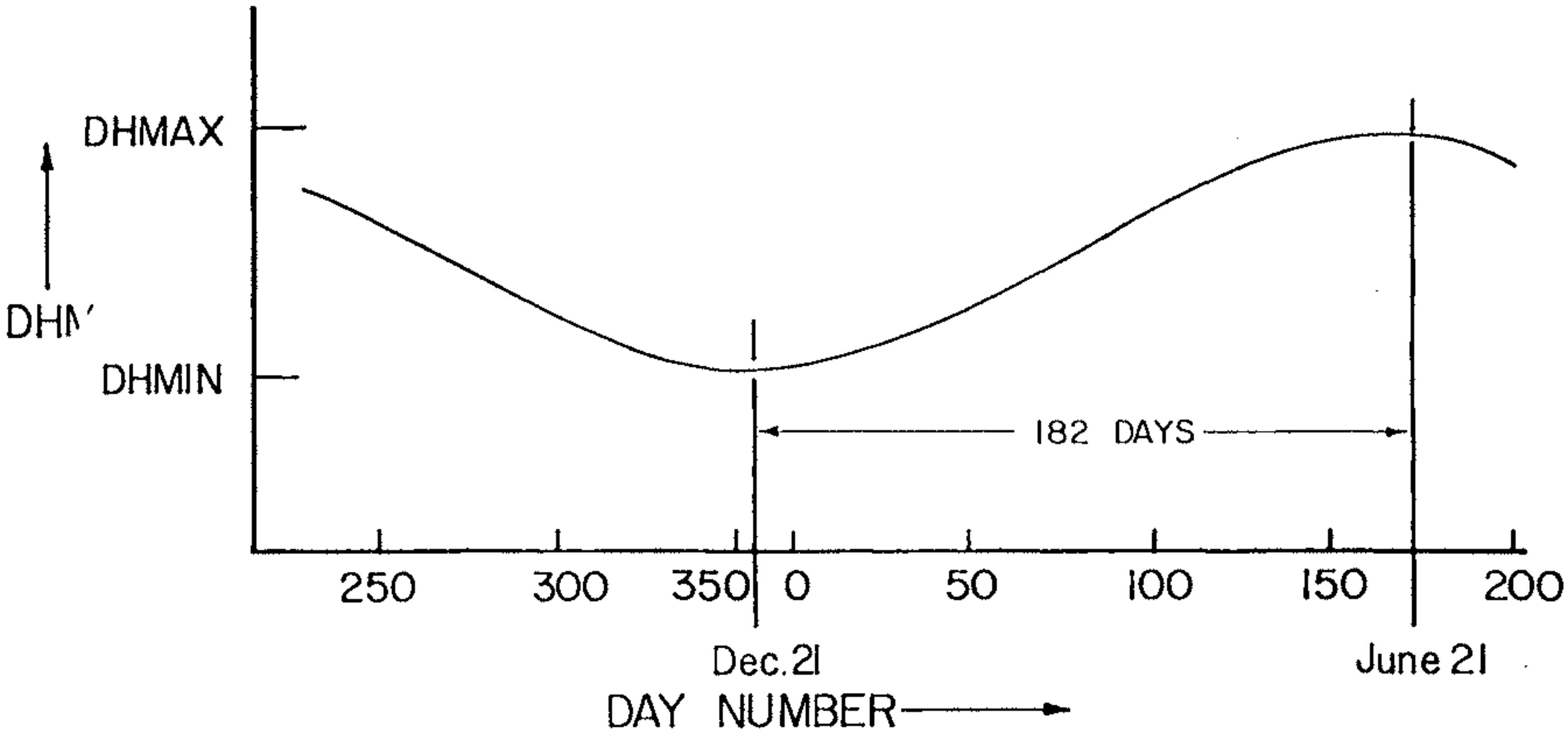


Figure II-7. Seasonal Variation of Melt Coefficients.

although there is some evidence that a lower value may be more appropriate. No calibration has been attempted on urban watersheds.

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

$$\Delta COLDC = RNM \cdot DHM \cdot (ATI - TA) \cdot \Delta t \qquad \text{(II-16)}$$

where $\Delta COLDC$ = change in cold content, ft water equiv.,
RNM = ratio of negative melt coefficient to melt coefficient,
DHM = melt coefficient, ft/sec-°F,
TA = air temperature, °F,
ATI = antecedent temperature index, °F, and
Δt = time step, sec.

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

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

Areal Extent of Snow Cover

Introduction --

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

Areal Depletion Curves --

The functional dependence of the areal depletion curve, ADC, has just been described. As used in most snowmelt models, it is assumed that there is a depth, SI, above which there will always be 100 percent cover. In some models, the value of SI is adjusted during the simulation; in SWMM it remains constant. The amount of snow present at any time is indicated by the parameter WSNOW, which is the depth (water equivalent) over each of the three possible snow covered areas of each subcatchment, (see Figure II-5). This depth is nondimensionalized by SI for use in calculating ASC. Thus, an areal depletion curve is a plot of WSNOW/SI versus ASC; a typical ADC for a natural catchment is shown in Figure II-8. For values of the ratio AWESI = WSNOW/SI greater than 1.0, ASC = 1.0, that is, the area is 100 percent snow covered.

Some of the implications of different functional forms of the ADC may be seen in Figure II-9. Since the program maintains snow quantities, WSNOW, as the depth over the total area, AT, the actual snow depth, WS, and actual area covered, AS, are related by continuity,

$$WSNOW \cdot AT = WS \cdot AS \tag{II-17}$$

where WSNOW = depth of snow over total area AT, ft water equivalent,

AT = total area, ft^2,

WS = actual snow depth, ft water equivalent, and

AS = snow covered area, ft^2.

In terms of parameters shown on the ADC, equation II-17 may be rearranged to read

$$AWESI = \frac{WSNOW}{SI} = \frac{WS}{SI} \cdot \frac{AS}{AT} = \frac{WS}{SI} \cdot ASC \tag{II-18}$$

Equation II-18 can be used to compute the actual snow depth, WS, from known ADC parameters, if desired. It is unnecessary to do this in the program, but it is helpful in understanding the curves of Figure II-9. Thus,

$$WS = \frac{AWESI}{ASC} \cdot SI \tag{II-19}$$

Consider the three ADC curves, B, C and D. For curve B, AWESI is always less than ASC; hence, WS is always less than SI as shown in Figure II-9d. For curve C, AWESI = ASC, hence WS = SI, as shown in Figure II-9e. Finally, for curve D, AWESI is always greater than ASC; hence, WS is always greater than SI, as shown in Figure II-9f. Constant values of ASC at 100 percent cover and 40 percent cover are illustrated in Figures II-9c, curve A, and Figure II-9g, curve E, respectively. At a given time (e.g., t_1 in Figure II-9), the area of each snow depth versus area curve is the same and equal to AWESI · SI, (e.g., 0.8 SI for time t_1).

Curve B on Figure II-9a is the most common type of ADC occurring in nature, as shown in Figure II-8. The convex curve D requires some mechanism for raising snow levels above their original depth, SI. In nature,

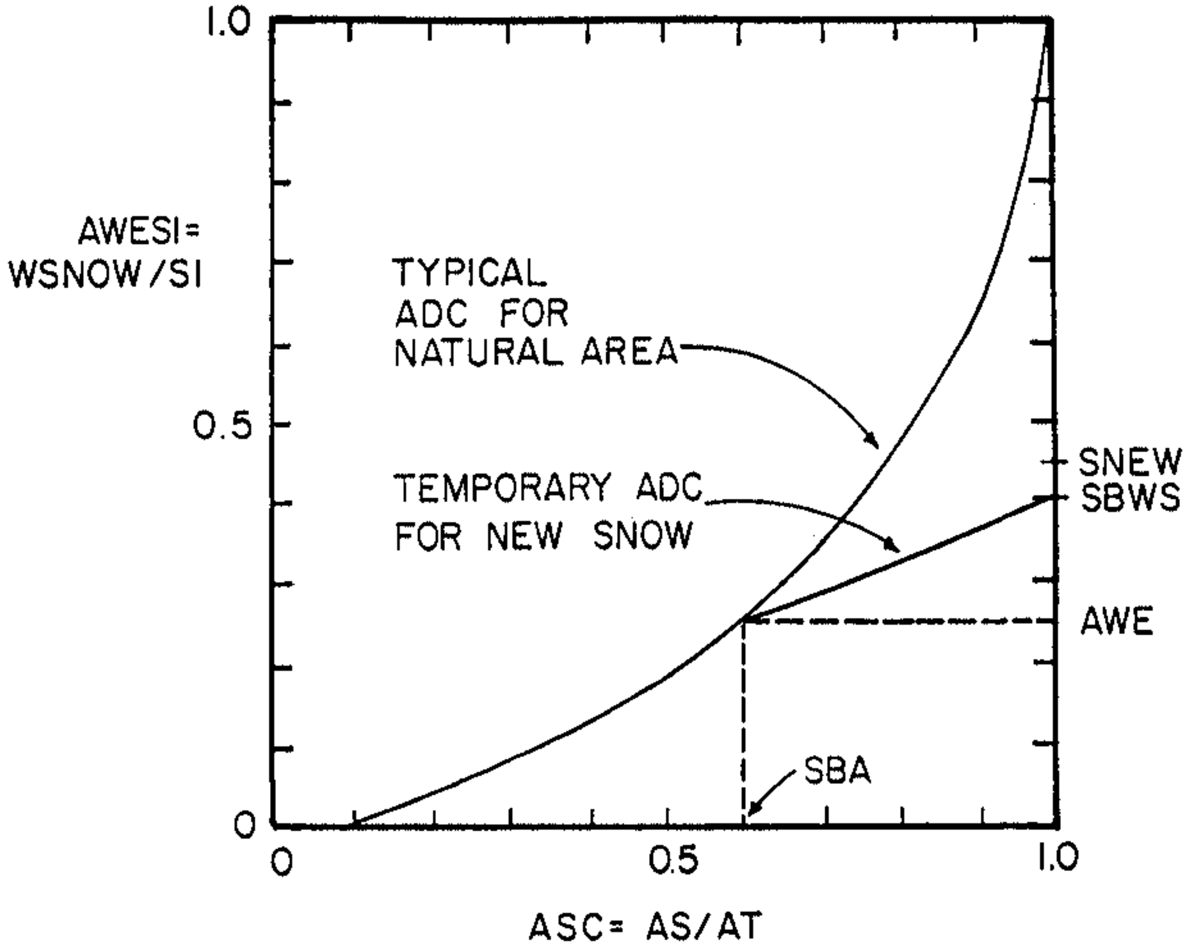


Figure II-8. Typical Areal Depletion Curve for Natural Area (Anderson, 1973, P. 3-15) and Temporary Curve for New Snow.

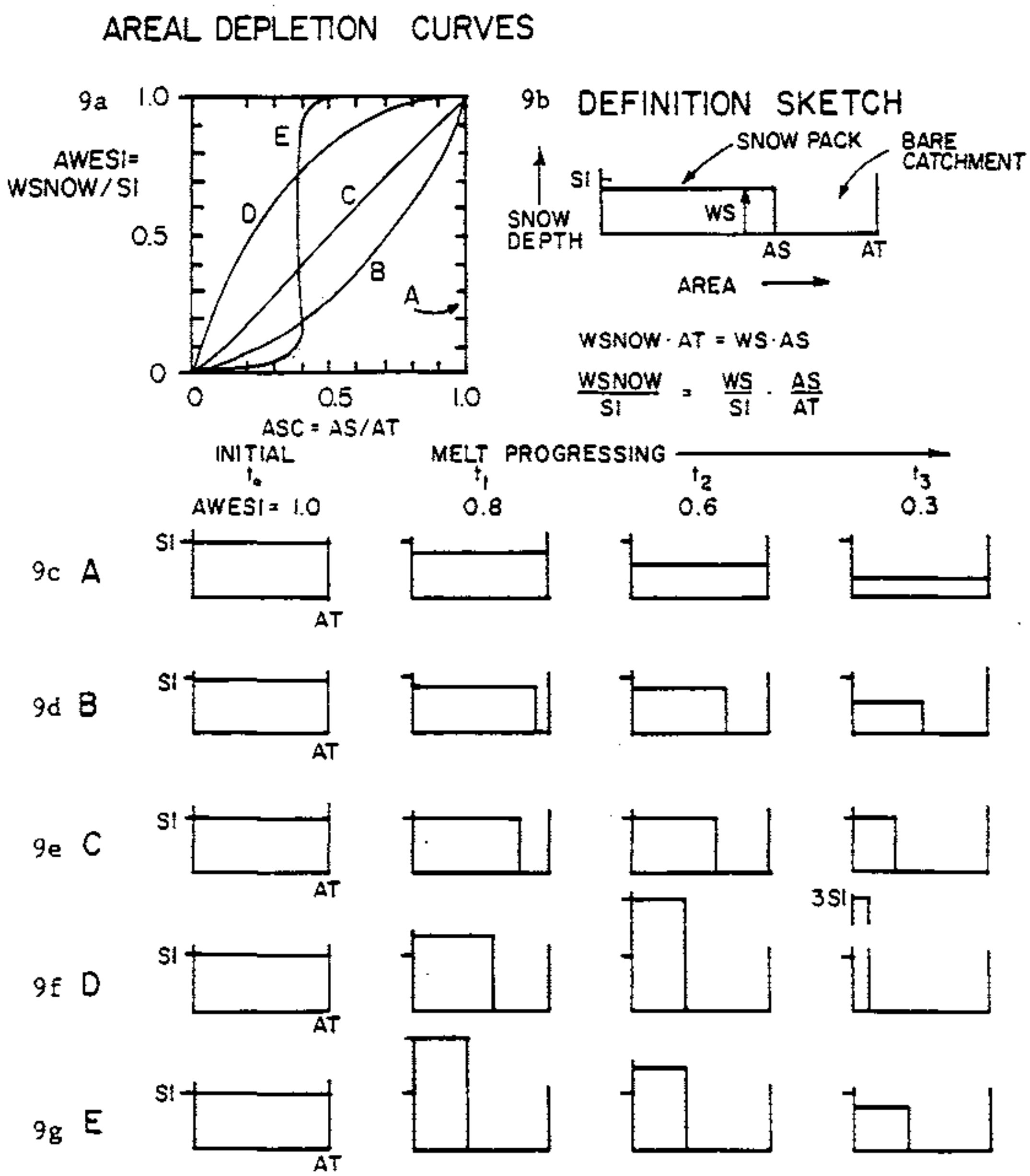


Figure II-9. Effect on Snow Cover of Areal Depletion Curves.

drifting might provide such a mechanism; in urban areas, plowing and windrowing could cause a similar effect. A complex curve could be generated to represent specific snow removal practices in a city. However, the program utilizes only one ADC curve for all impervious areas (e.g., area A4 of Figure II-5 for all subcatchments) and only one ADC curve for all pervious areas (e.g., area A2 of Figure II-5 for all subcatchments). This limitation should not hinder an adequate simulation since the effects of variations in individual locations are averaged out in the city-wide scope of most continuous simulations.

The two ADC curves for pervious and impervious areas are input by the user, as are values of SI for each subcatchment. The program does not require the ADC curves to pass through the origin, AWESI=ASC=0; they may intersect the abscissa at a value of ASC > 0 in order to maintain some snow covered area up until the instant that all snow disappears (see Figure II-8). However, the curves may not intersect the ordinate, AWESI > 0 when ASC = 0.

The preceding paragraphs have centered on the situation where a depth of snow greater than or equal to SI has fallen and is melting. (The ADC curves are not employed until WSNOW becomes less than SI.) The situation when there is new snow needs to be discussed, starting from both zero or non-zero initial cover. The SWMM procedure again follows Anderson's NWS method (1973).

When there is new snow and WSNOW is already greater than or equal to SI, then ASC remains unchanged at 1.0. However, when there is new snow on bare or partially bare ground, it is assumed that the total area is 100 percent covered for a period of time, and a "temporary" ADC is established as shown in Figure II-8. This temporary curve returns to the same point on the ADC as the snow melts. Let the depth of new snow be SNO, measured in equivalent feet of water. Then the value of AWESI will be changed from an initial value of AWE to a new value of SNEW by

$$\text{SNEW} = \text{AWE} + \text{SNO/SI} \tag{II-20}$$

It is assumed that the areal snow cover remains at 100 percent until 25 percent of the new snow melts. This defines the value of SBWS of Figure II-8 as

$$\text{SBWS} = \text{AWE} + 0.75 \cdot \text{ANO/SI} \tag{II-21}$$

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

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

Use of Value of ASC --

The fraction of area that is snow covered, ASC, is used to adjust 1) the volume of melt that occurs, and 2) the "volume" of cold content change, since it is assumed that heat transfer occurs only over the snow covered area. The melt rate is computed from either equation II-8 or equation II-13. The snow depth is then reduced from its value at time step 1 to time step 2 as

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

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

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

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

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

Liquid Water Routing in Snow Pack

Production of melt does not necessarily mean that there will be liquid runoff at a given time step since a snow pack, acting as a porous medium with a "porosity", has a certain "free water holding capacity" at a given instant in time. Following PR-JFM (1976a, 1976b), this capacity is taken as a constant fraction, FWFRAC, of the variable snow depth, WSNOW, at each time step. This volume (depth) must be filled before runoff from the snow pack occurs. The program maintains the depth of free water, FW, ft of water, for use in these computations. When FW = FWFRAC · WSNOW, the snow pack is fully ripe. The procedure is sketched in Figure II-10.

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

Net Runoff

Melt from snow covered areas and rainfall on bare surfaces are area weighted and combined to produce net runoff onto the surface as follows,

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

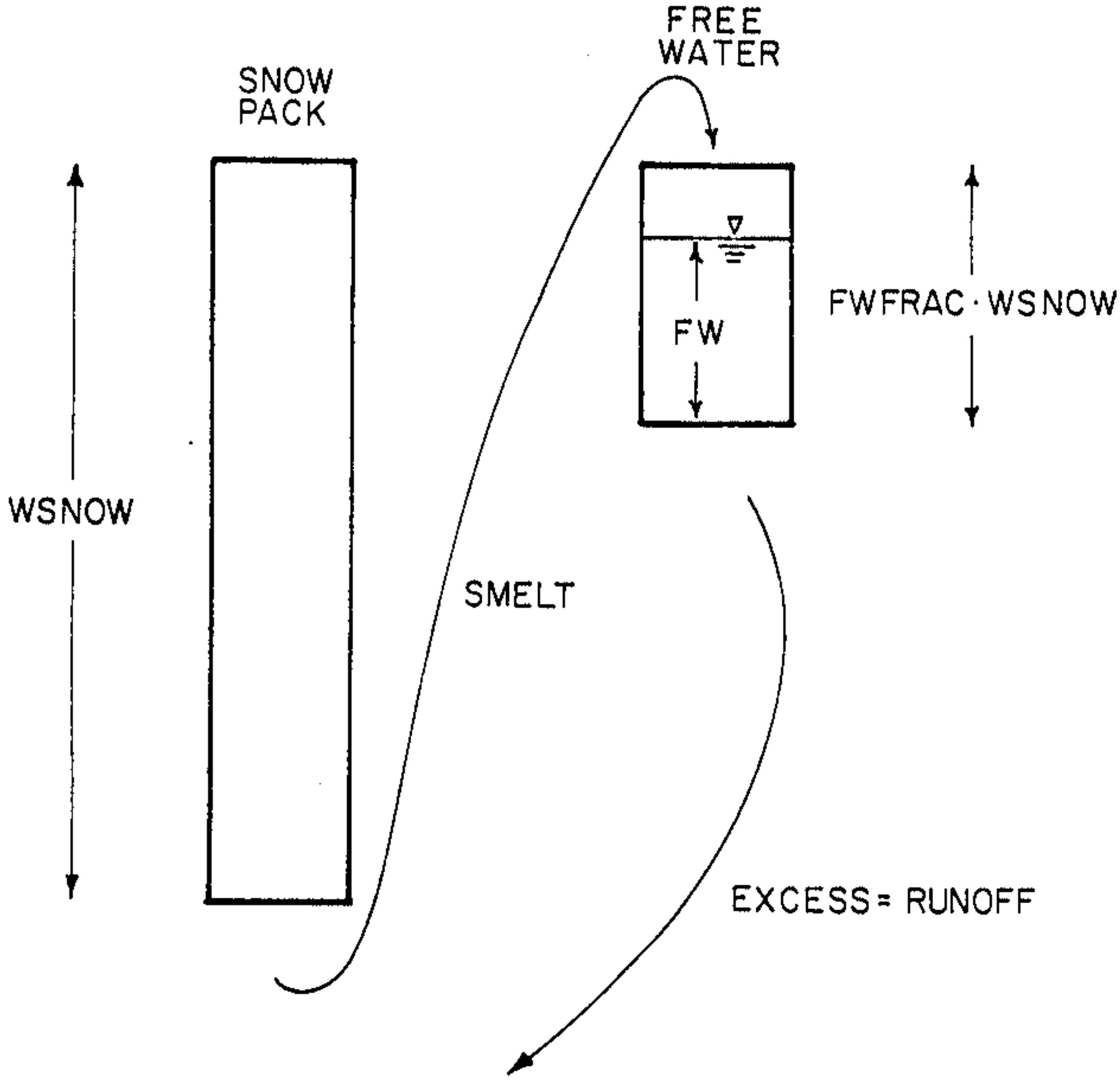


Figure II-10. Schematic of Liquid Water Routing Through Snow Pack.

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

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

If immediate melt is produced through the use of the snow redistribution fraction SFRAC(5), discussed earlier (see Figure II-6), it is added to equation II-24. Furthermore, all melt calculations are ended when the depth of snow water equivalent becomes less than 0.001 in. (0.025 mm), and remaining snow and free water are converted to immediate melt and added to equation II-24.

Effect of Snow on Infiltration and Surface Parameters

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

QUALITY INTERACTIONS

Pollutant Accumulation

Snowmelt Quality --

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

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

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

Pollutant Loadings --

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

Adjustments for Presence of Snow --

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

Possible Loading Rates --

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

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

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

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

Street Sweeping

Simulation of street sweeping in SWMM is performed as in the past, except for slight modifications as described in Section 4. The effect of snow is included in two minor ways. First, beginning and ending dates, parameters KLNBGN and KLNEND respectively, may be input for continuous SWMM to indicate the interval during the year subject to street sweeping. If sweeping normally is not done between, say, December 1 and March 1, because of high snow volumes, this may be so indicated.

Second, the presence of snow can alter the street sweeping interval. These intervals are specified for each of the five land uses. Each subcatchment is swept when the number of dry time steps for that subcatchment exceeds the interval for the given land use. A dry time step, in subroutine QSHED, is one in which there is no precipitation and no water or snow on areas A1 and A3 (Figure II-5). Thus, subcatchments will not be swept until there is no snow or water on "normally bare" impervious areas.

Other Considerations

The snow itself is assumed to be "pure" and contain no pollutants. Thus, the redistribution or transfers of snow described earlier (Figure II-6) will not remove accumulated pollutants. This is partially justified on the basis of the assumption that such transfers would occur soon after fresh snow has fallen. They occur during the same time step in the model.

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

DATA REQUIREMENTS

New Parameters

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

Sensitivity

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

OUTPUT

Temperature and Snowfall Generation

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

Runoff Simulation Output

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

PROGRAMMING NOTES

Subroutines

Hourly temperatures are synthesized in subroutine CTRAIN, called from subroutine RHYDRO. Hourly precipitation intensities (rain and snow) are also computed therein. All input data other than NWS tapes are read in subroutine RHYDRO, as in the past.

The bulk of the melt computations are performed in subroutine WSHED, used to generate overland flow from rainfall, and now, from snowmelt as well. Subroutine WSHED calls subroutine MELT to compute the melt rate and to perform computations related to the areal depletion curves. Subroutine AREAL calls subroutine FINDSC for linear interpolation along the curves.

Minor changes related to snowmelt have also been made in subroutines HYDRO and QSHED. Changes in the former relate primarily to initialization and the continuity check output. Changes in the latter account for the minor interactions of snow and quality predictions.

Variable Names

Variable names for input snowmelt parameters are included in the Runoff Block input data format table. Other key parameters have been mentioned in the preceding text and used in the equations.

Computer Time

Although not tested extensively, an approximate idea of computer costs for various conditions may be seen in Table II-6. STORM results are shown

Table II-6. Comparative Computer Runs of Continuous SWMM with Snowmelt (Runoff Block only).

Run	Simulation Time, months	CPU[a] Time, sec	Cost[b], $
1. Generation of temperature and precipitation file ICRAIN = 4, ISNOW =2)	13	11.01	5.49
	25	12.89	6.27
	63	19.68	8.91
	121	33.65	13.88
2. Use of generated file (above) for continuous simulation with snowmelt. One subcatchment, no gutter/pipes. (ICRAIN = 2, ISNOW = 2)	13	12.80	4.15
	25	22.80	6.29
	63	49.39	12.31
	121	96.46	22.64
3. Generation of precipitation file only. (ICRAIN = 4, ISNOW = 0).	25	8.00	3.96
4. Use of generated precipitation for continuous simulation without snowmelt. One sub-catchment, no gutter/pipes. (ICRAIN = 2, ISNOW = 0)	25	19.43	5.74
5. STORM run comparable to combined runs 1 plus 2 above.	25	9.86	5.12

[a]University of Florida Amdahl 470. Appears to user similar to IBM 370/165 but is approximately four times as fast.

[b]Includes costs for CPU (link edit and execute), cards read, lines and pages printed, off-line I/O, etc. Rate is approximately half the commercial rate.

for comparison. The latter runs prove to be faster and cheaper, reflecting the considerably simpler formulations used in STORM. Thus, the choice of STORM or continuous SWMM for runoff generation will depend upon costs, model formulations, I/O, availability, etc.

Computer Size Requirements

Every effort was made during the snowmelt programming to minimize the use of new arrays, although several were necessary. However, during the course of the programming it was possible to eliminate several unneeded arrays and overlay others. As a result, the present size of the Runoff Block plus the Executive Block is a bit less than 360K bytes or 90K words.

APPENDIX III

REDUCTION OF ENERGY BALANCE EQUATION TO DEGREE-DAY EQUATION

PURPOSE

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

ENERGY BUDGET

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

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

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

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

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

It will be assumed that the snow pack is ripe, and all heat added will product liquid melt. Since inches of melt are desired, and it requires about 80 cal to melt one gram of water (the latent heat of fusion) or 80 ly per cm, it requires 2.54 cm/in. x 80 ly/cm = 203.2 ly per inch of melt. Thus, equation III-1 will eventually be linearized and put in the form of equation II-13 in Appendix II,

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

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

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

SHORT WAVE RADIATION, H_{rs}

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

HEAT CONDUCTION THROUGH GROUND, H_g

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

NET LONG WAVE RADIATION, H_{rl}

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

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

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

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

The key unknown is the atmospheric emissivity, for which several empirical formulas are available and in which the effect of clouds may also be included (TVA, 1972). For example, a simple formula due to Anderson (1954) for clear skies is

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

where e = ground level atmospheric vapor pressure, mb.

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

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

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

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

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

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

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

Which is linear in T_a, in °K. Later, temperatures must be converted to °F for consistency.

CONVECTIVE HEAT TRANSFER, H_c

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

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

where p_s = surface atmospheric pressure (consistent units with p_o),
p_o = sea level atmospheric pressure (consistent units with p_s),
z_a = height above surface of air temperature (and humidity) measurement, ft,

z_b = height above surface of wind speed measurement, ft,
$\bar{u}_b$ = wind speed at height z_b, mph,
T_a = air temperature, °F,
T_s = snow surface temperature, °F, and
H_c = heat transfer in ly/day.

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

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

CONDENSATION HEAT TRANSFER, H_e

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

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

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

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

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

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

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

HEAT ADVECTION BY RAIN, H_p

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

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

where H_p = heat advected in ly/day, and

d = daily rainfall depth, in./day, and

the temperatures are in °F.

COMBINED EQUATIONS

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

$$
\begin{aligned}
\text{SMELT} = \frac{\Delta H}{203.2} = \; & \frac{0.97\ \varepsilon_a\ \sigma\ 4\ T_o^3}{203.2}\ (265.2 + 5/9\ T_a) \quad ① \\
& + (z_a \cdot z_b)^{-1/6}\ \bar{u}_b \cdot k_c \cdot p_s/p_o \cdot T_a \quad ② \\
& + \frac{H_{rs} + H_g}{203.2} \; ③ \; - \left.\frac{0.97\ \sigma\ T_s^4}{203.2}\right|_{°K} \; ④ \qquad \text{(III-13)} \\
& + (z_a \cdot z_b)^{-1/6}\ \bar{u}_b [8.5 \cdot k_e\ (e_a - e_s) - k_c\ p_s/p_o\ T_s] \quad ⑤ \\
& - \frac{0.97\ \varepsilon_a\ \sigma\ 3\ T_o^4}{203.2} \; ⑥ \; + \frac{1.41 \cdot d \cdot (T_a - T_s)}{203.2} \quad ⑦
\end{aligned}
$$

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

T_o = reference temperature, °K,

T_s = snow surface temperature, °F, (except °K in term 4), and

T_a = air temperature, °F.

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

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

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

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

NUMERICAL EXAMPLE

The following meteorological parameters are assumed,

H_{rs} = 288 ly/day,

T_o = 35°F = 274.7°K

T_s = 32°F = 273°K

z_a = 6 ft

z_b = 20 ft

$\bar{u}_b$ = 9 mph

$e_s = e_s(32°F)$ = 6.11 mb

r = 0.6

$e_a = 0.6 \cdot e_s(35°F) = 0.6 \cdot 6.87 = 4.12$ mb

ε_a = 0.90

p_o = 1013.2 mb

p_s = 950 mb (about 2000 ft elevation),

rainfall = zero

H_g = zero

Each of the terms in equation III-13 is now evaluated, with units of inches/day.

Term	Constant	Temperature Term
1	+11.24	+ 0.0235 T_a
2	+ 1.24	+ 0.0239 T_a
3	+ 1.417	
4	- 3.154	
5	- 1.200	
6	- 8.729	
	- 0.426	+ 0.0474 T_a

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

$$SMELT = DHM \cdot (T_a - T_b) \tag{III-15}$$

$$= 0.0474\ T_a - 0.426 \quad \text{in./day}$$

$$= 0.0474\ (T_a - 8.99) \quad \text{in./day}$$

$$= 0.00198\ (T_a - 8.99) \quad \text{in./hr}$$

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

APPENDIX IV

STORAGE/TREATMENT SIMULATION

OBJECTIVES

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

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

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

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

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

PROGRAM DEVELOPMENT AND OVERVIEW

Development

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

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

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

Overview

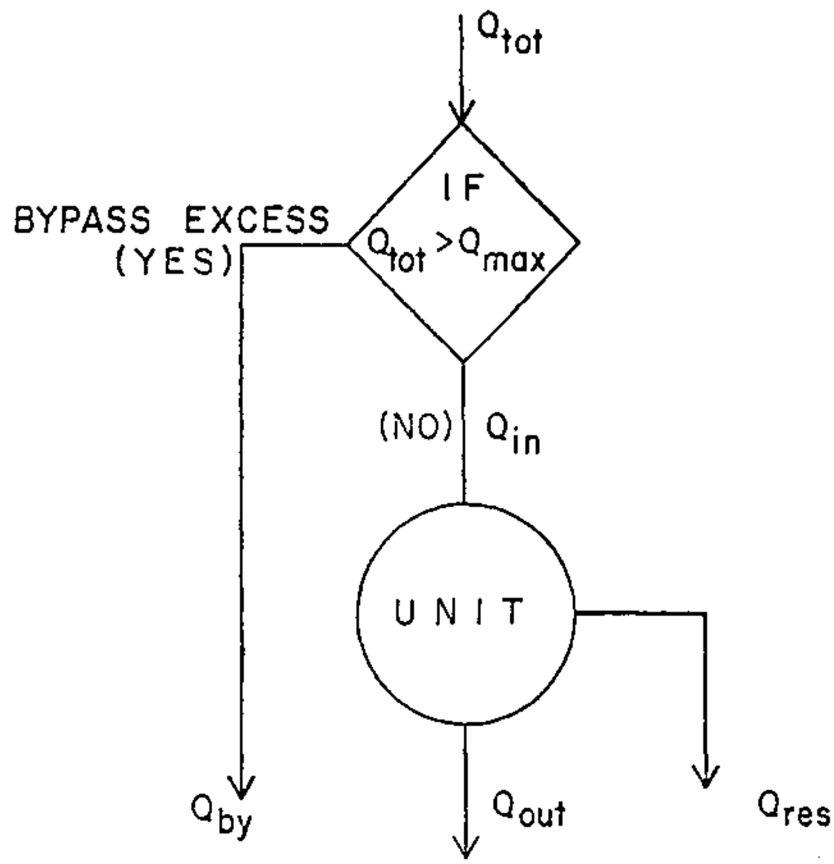
The present Storage/Treatment Block is approximately 2000 Fortran statements in length and consists of eight subroutines. The routing of flow and pollutants through the entire block is controlled by subroutine STRT which is called from the Executive Block. STRT also provides the main driving loop for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

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

SIMULATION TECHNIQUES

Introduction

Flow and pollutants are routed through one or more storage/treatment units by several techniques. The flows into, through and out of a unit are shown in Figure IV-1. The units may be arranged in any fashion, restricted only by the requirements that inflow to the plant enters at only one unit



LEGEND

Q_{tot} = TOTAL INFLOW, ft^3/sec
Q_{max} = MAXIMUM ALLOWABLE INFLOW, ft^3/sec
Q_{by} = BYPASSED FLOW, ft^3/sec
Q_{in} = DIRECT INFLOW TO UNIT, ft^3/sec
Q_{out} = TREATED OUTFLOW, ft^3/sec
Q_{res} = RESIDUAL STREAM, ft^3/sec

Figure IV-1. Flows Into, Through, and Out of a Storage/Treatment Unit.

and that the products (treated outflow, residuals, and bypass flow) from each unit not be directed to more than three units. Treatment and sludge handling units are modeled by the same subroutine (UNIT). Additionally, both wet- and dry-weather facilities may be simulated by the proper selection of unit arrangement and characteristics. Units may be modeled as having a detention capability or instantaneous throughflow. Pollutants or sludges may be represented as mass only or further characterized by a particle size or settling velocity distribution. A unit may remove pollutants (or concentrate sludges) as a function of particle size and specific gravity, detention time, incoming concentration, the removal rate of another pollutant, or a constant percentage. The S/T Block can receive the flow and any three pollutants from any one outlet in any other block of SWMM. Also, flows and pollutants may be provided by the user and fed directly to the S/T Block. If both sources are present they are combined and treated as one input. For example, the user may enter directly dry-weather flows and enter wet-weather flows from the Runoff Block. All flows and pollutant concentrations reported by the S/T Block are average values over each time step. This is necessary for some of the algorithms in the S/T Block (in particular, the plug flow routines); it does not significantly affect the results.

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

Flow Routing

Detention vs. Instantaneous Throughflow --

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

Detention Units --

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

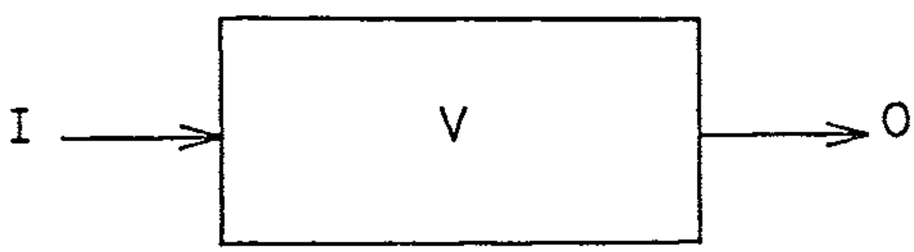


Figure IV-2. Time Varying Inflow and Outflow Rates for a Reservoir.

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

$$\Delta V/\Delta t = \bar{I} - \bar{O} \tag{IV-1}$$

where $\bar{I}$ = average inflow rate during Δt, ft^3/sec,

$\bar{O}$ = average outflow rate during Δt, ft^3/sec,

V = reservoir volume, ft^3, and

Δt = time step, sec.

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

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

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

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

Also, the change in reservoir volume is

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

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

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

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

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

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

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

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

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

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

the model to calculate the depth-volume relationship. This is accomplished by averaging the surface area between adjacent values of depth, multiplying by the difference in depth, and adding the incremental volume to the accumulated total. The depth-area data pairs are also used to estimate the volume lost from the reservoir due to evaporation.

Recalling equation IV-6, the objective is to find

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

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

The computational procedure is summarized as follows:

1. Known values of I_1, I_2, O_1, Δt, and V_1 are substituted into the right hand side of equation IV-6. The result is the first value of $0.5O_2\Delta t + V_2$.
2. Knowing $(0.5O_2\Delta t + V_2)$ the value of $0.5O_2\Delta t$ is obtained by interpolating between adjacent values of O2DT2 and SATERM.
3. The values of V_2 and O_2 are determined and become the values of V_1 and O_1, respectively, in the next time step.
4. Add $0.5(I_1 + I_2)\ \Delta t$ to the new value of $V_1 - 0.5O_1\Delta t$ to get the new value of $0.5O_2\Delta t + V_2$.
5. Continue this process until all inflows have been routed.

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

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

Residual Flow --

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

Evaporation --

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

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

where e_v = evaporation loss rate, ft^3/sec,

A = surface area at the water level in the unit, ft^2,

e_d = evaporation rate, in./day, and

k = 1036800.0, conversion factor, in./day per ft/sec.

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

Instantaneous Throughflow --

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

Pollutant Routing

Complete Mixing --

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

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

where V = reservoir volume, ft^3

C^I = influent pollutant concentration, mg/l,

C = effluent and reservoir pollutant concentration, mg/l,

I = inflow rate, ft^3/sec,

O = outflow rate, ft^3/sec,

t = time, sec, and

K = decay coefficient, sec^{-1}.

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

Change in mass in basin during Δt	=	Mass entering during Δt	-	Mass leaving during Δt	-	Decay during Δt

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

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

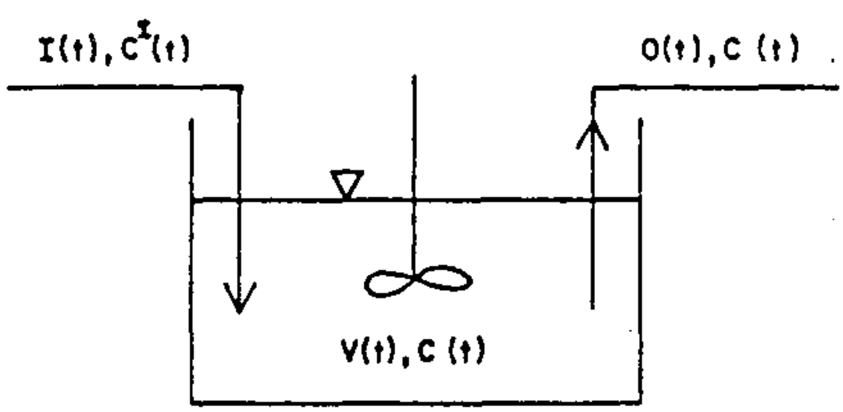


Figure IV-3. Well-Mixed, Variable-Volume Reservoir (Rich, 1973).

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

$$C_2 = \frac{C_1 V_1 + \frac{(C_1^I\, I_1 + C_2^I\, I_2)}{2}\,\Delta t - \frac{C_1 O_1}{2}\,\Delta t - \frac{K\, C_1 V_1}{2}\,\Delta t}{V_2 (1 + \frac{K\,\Delta t}{2}) + \frac{O_2}{2}\,\Delta t} \qquad \text{(IV-11)}$$

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

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

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

Plug Flow --

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

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

where V_o = volume leaving unit during the present time step, ft^3,

V_j = volume entering unit during j^{th} time step (plug j), ft^3,

f_j = fraction of plug j that must be removed to satisfy continuity with V_o, $0 \leq f_j \leq 1$,

JP = time step number of the oldest plug in the unit, and

LP = time step number of the youngest plug required to satisfy continuity with V_o.

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

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

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

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

Instantaneous Throughflow --

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

Pollutant Characterization

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

Pollutant Removal

Characterized by Magnitude --

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

$$R = \left(a_{12} e^{a_1 x_1} x_2^{a_2} + a_{13} e^{a_3 x_3} x_4^{a_4} + a_{14} e^{a_5 x_5} x_6^{a_6} + a_{15} e^{(a_7 x_7 + a_8 x_8)} x_9^{a_9} x_{10}^{a_{10}} x_{11}^{a_{11}} \right)^{a_{16}} \qquad \text{(IV-14)}$$

where x_i = removal equation variables,

a_j = coefficients, and

R = removal fraction, $0 \leq R \leq 1.0$

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

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

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

where R_{SS} = suspended solids removal fraction, $0 \leq R_{SS} \leq R_{max}$,

R_{max} = maximum removal fraction,

t_d = detention time, sec, and

K = first order decay coefficient, sec^{-1}.

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

All other coefficients, a_j, would equal zero.

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

$$R_{SS} = 0.0963\ SS^{0.286} \quad \text{(IV-16)}$$

where R_{SS} = suspended solids removal fraction, and $0 \leq R_{SS} \leq 1.0$, and,

SS = influent suspended solids concentration, mg/l.

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

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

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

where R_{VS} = volatile solids reduction, $0 \leq R_{VS} \leq 1.0$

t_d = detention time, sec,

P_{VS} = percent volatile solids in raw sludge,

$$P_{VS} = 100\ \frac{VS}{SS} \quad \text{(IV-18)}$$

where VS = influent volatile solids concentration, mg/l, and

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

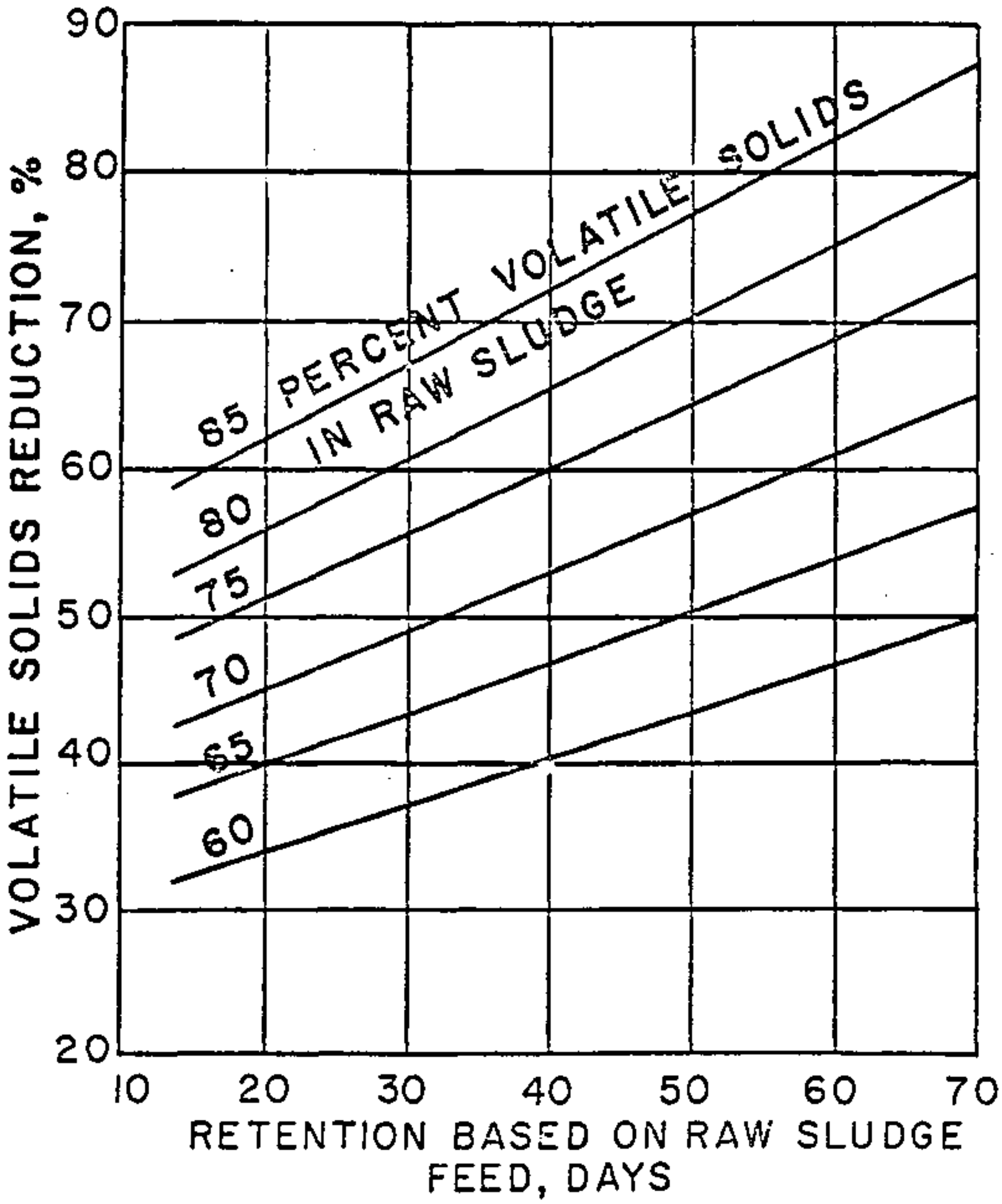


Figure IV-4. Reduction in Volatile Solids in Raw Sludge (Rich, 1973).

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

Characterized by Particle Size Specific Gravity or Settling Velocity Distribution --

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

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

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

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

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

$$v_s = \sqrt{\frac{4}{3}\frac{gd}{C_D}(S_p - 1)} \tag{IV-19}$$

where v_s = terminal velocity of particle, ft/sec,

g = gravitational constant, 32 ft/sec^2,

C_D = drag coefficient,

S_p = specific gravity of particle, and

d = diameter of particle, ft.

Additionally,

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

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

$$C_D \cong 0.4, \text{ if } N_R \geqq 10^4. \tag{IV-22}$$

where N_R = Reynolds number, dimensionless,

$$N_R = v_s\, d/\nu \tag{IV-23}$$

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

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

where T = water temperature, °F.

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

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

For quiescent conditions,

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

where E_Q = particle removal efficiency as a fraction, $0 \leq E_Q \leq 1$,

v_s = terminal velocity of particle, ft/sec, and

v_u = overflow velocity, ft/sec.

Additionally,

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

where Q = flow rate, ft^3/sec,

A = surface area of detention unit, ft^2,

y = depth of water in unit, ft, and

t_d = detention time, sec.

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

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

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

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

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

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

where τ_o = boundary shear stress, lb/ft^2 and

ρ = density of water $\cong$ 1.94 slug/ft^3 (1.00 g/cm^3).

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

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

where n = Manning's roughness coefficient.

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

$$v_t = \ell/t_d \qquad \text{(IV-30)}$$

where ℓ = travel length of detention unit, ft, and

t_d = detention time, sec.

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

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

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

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

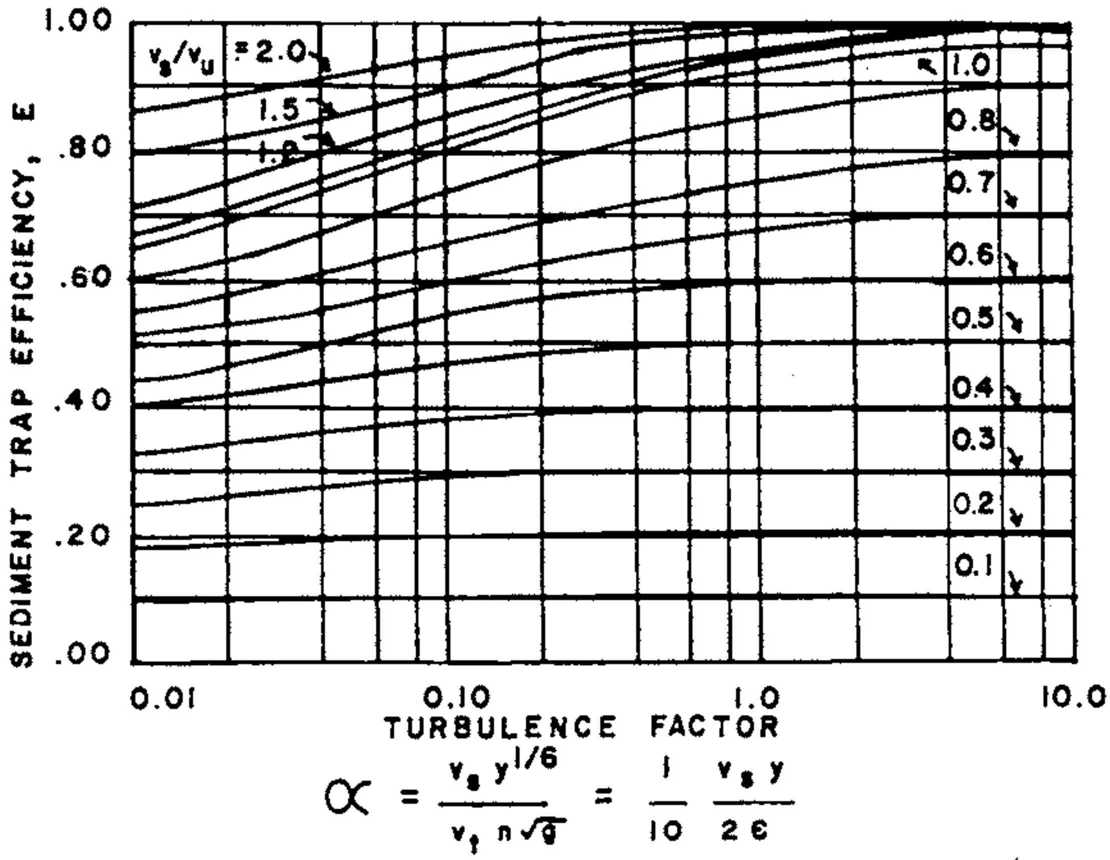


Figure IV-5. Camp's Sediment Trap Efficiency Curves (Camp, 1946, Dobbins, 1944, Brown, 1950, Chen, 1975).

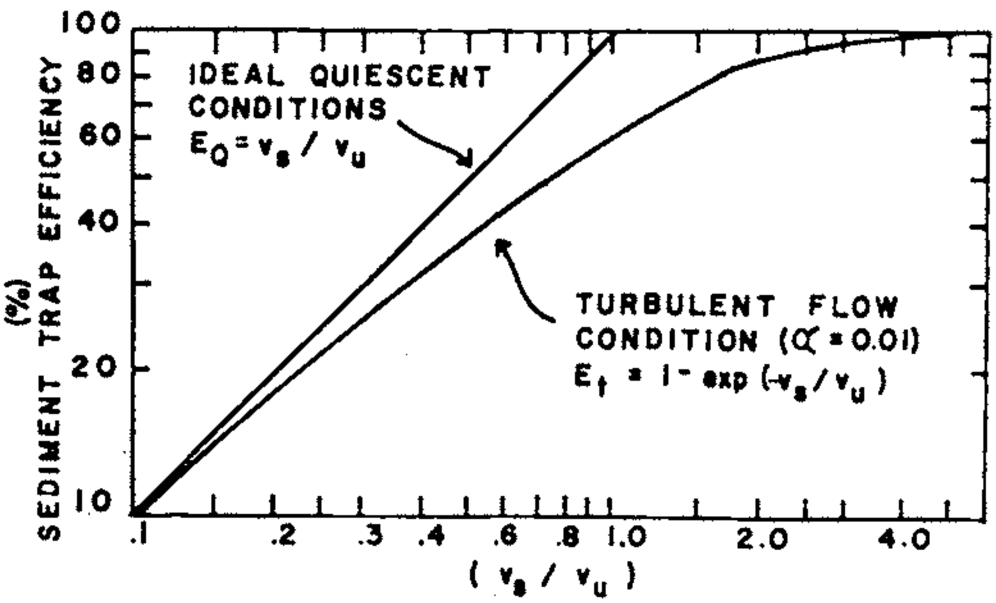


Figure IV-6. Limiting Cases in Sediment Trap Efficiency (Chen, 1975).

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

$$E_T = (1 - e^{-v_s/v_u}) \tag{IV-32}$$

or

$$E_T = (1 - e^{-v_s\, t_d/y}) \tag{IV-33}$$

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

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

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

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

To summarize, the particle settling computations proceed as follows.

1. For each size and specific gravity range a settling velocity is computed using equations IV-19 to IV-24 or a distribution of settling velocities is provided by the user. If a settling velocity distribution is used the end points of each range are averaged to estimate the representative velocity. Then for each velocity (in each plug leaving the unit) all steps below are performed.

2. The turbulence factor, α, is computed from equation IV-31.

3. E_Q is computed using equation IV-25.

4. E_T is computed using equation IV-32 or IV-33.

5. Finally, the removal efficiency for the particular particle settling velocity is computed from equation IV-34.

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

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

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

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

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

Cost Calculations

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

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

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

or

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

or

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

or

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

where C_{cap} = initial capital cost, dollars,

Q_{max} = maximum allowable inflow, ft^3/sec,

$(Q_{in})_{max}$ = maximum inflow encountered during the simulation, ft^3/sec,

V_{max} = maximum allowable storage (detention units only), ft^3,

$(V_{obs})_{max}$ = maximum storage encountered during the simulation (detention units only), ft^3, and

a, b = coefficients (specified by the user).

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

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

$$C_{om} = d\ Q_{max}^{f} + hD_{op} \qquad \text{(IV-39)}$$

or

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

or

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

or

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

where C_{om} = operation and maintenance costs, dollars,

D_{op} = total operating time during the simulation period, hours, and

d,f,h = coefficients (supplied by the user).

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

SUMMARY

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

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

APPENDIX V

OTHER RUNOFF BLOCK REVISIONS

INFILTRATION

Introduction

For pervious areas SWMM users now have the option of specifying one of two alternative infiltration models: The Horton model or the modified Green-Ampt model (Horton, 1940, Green and Ampt, 1911). Horton's model is empirical and is perhaps the best known of the infiltration equations. Many hydrologists have a "feel" for the best values of its three parameters despite the fact that little published information is available. In its usual form it is applicable only to events for which the rainfall intensity always exceeds the infiltration capacity, although the modified form used in SWMM is intended to overcome this deficiency.

On the other hand the Green-Ampt equation is a physically based model which can give a good description of the infiltration process. The Mein-Larson (1973) formulation of it is applicable also for the case of rainfall intensity being less than the infiltration capacity at the beginning of the storm. Work is currently underway to help users evaluate the parameter values from available soil data. With results from these studies now being published, use of the Green-Ampt model for estimating infiltration should increase.

Evaporation

Evaporation is input for each month as parameter VAP in subroutine RHYDRO and used in equations in subroutine WSHED as parameter EVAP. It is considered as a loss "off the top". That is, evaporation is subtracted from rainfall depths and/or ponded water prior to calculating infiltration. Thus, subsequent use of the symbol i for "rainfall intensity" is really rainfall intensity less evaporation rate. Although evaporation and infiltration are summed to form one total loss (RLOSS in subroutine WSHED) for the subcatchment runoff calculations, separate totals are maintained for the overall continuity check.

Integrated Horton's Equation

Cumulative Infiltration --

SWMM and many other hydrologic analysis techniques have used Horton's equation (Horton, 1940) for prediction of infiltration capacity into the soil as a function of time,

$$f_p = f_\infty + (f_o - f_\infty)\, e^{-\alpha t} \qquad \text{(V-1)}$$

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

f_∞ = minimum or ultimate value of f_p (at $t = \infty$), ft/sec,

f_o = maximum or initial value of f_p (at $t = 0$), ft/sec,

t = time from beginning of storm, sec, and

α = decay coefficient, sec^{-1}.

See Figure V-1 for a sketch of equation V-1. Actual infiltration is

$$f(t) = \min\, [f_p(t),\ i(t)] \qquad \text{(V-2)}$$

where f = actual infiltration into the soil, ft/sec, and

i = rainfall intensity, ft/sec.

Equation V-2 simply states that actual infiltration will be the lesser of actual rainfall and infiltration capacity.

Typical values for parameters f_o and f_∞ are often greater than typical rainfall intensities. Thus, when equation V-1 is used such that f_p is a function of time only, f_p will decrease even if rainfall intensities are very light, as sketched in Figure V-1. This results in a reduction in infiltration capacity regardless of the actual amount of entry of water into the soil.

To correct this problem, the integrated form of Horton's equation V-1 may be used,

$$F(t_p) = \int_0^{t_p} f_p\, dt = f_\infty\, t_p + \frac{(f_o - f_\infty)}{\alpha}\,(1 - e^{-\alpha t_p}) \qquad \text{(V-3)}$$

where F = cumulative infiltration at time t_p, ft.

This is shown schematically in Figure V-2 and assumes that actual infiltration has been equal to f_p. In fact, this is seldom the case, as sketched in Figure V-1. Thus, the true cumulative infiltration will be

$$F(t) = \int_0^t f(\tau)\, d\tau \qquad \text{(V-4)}$$

where f is given by equation V-2.

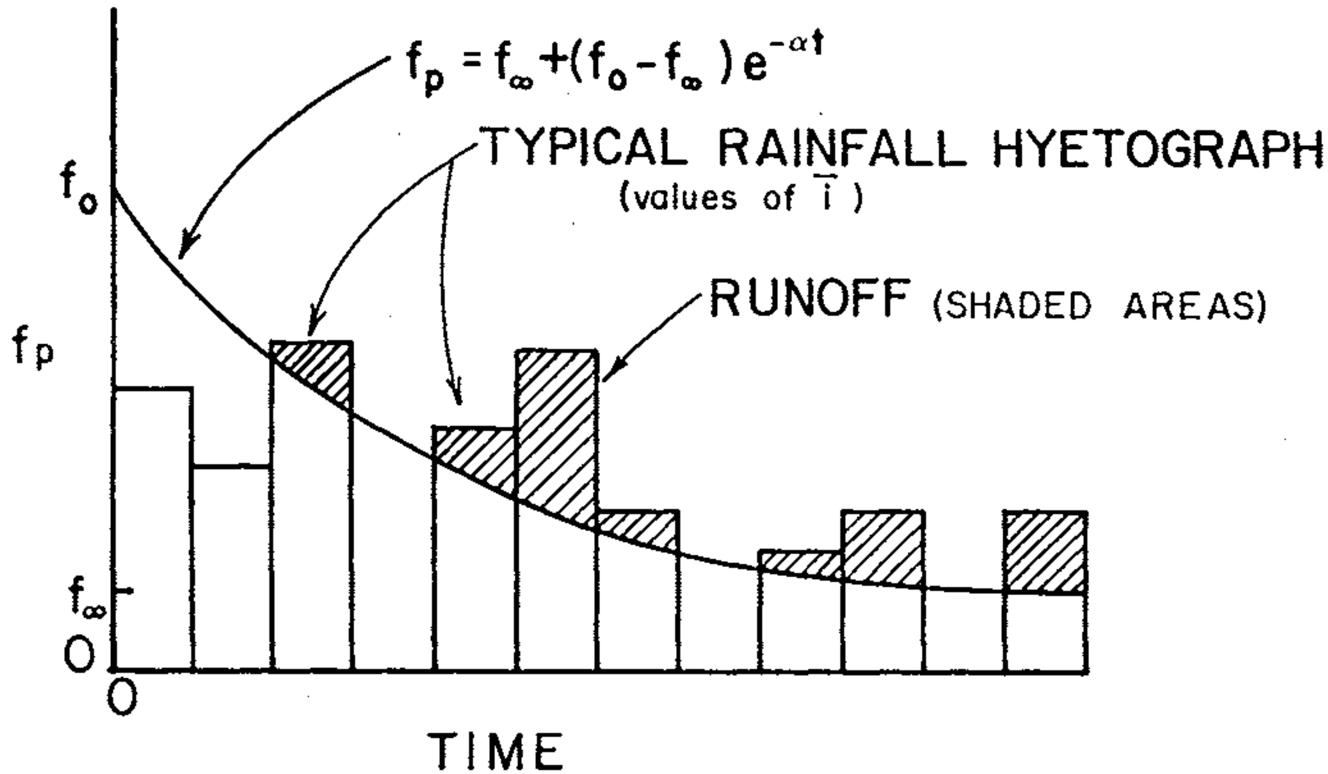


Figure V-1. Horton Infiltration Curve and Typical Hyetograph. For the case illustrated, runoff would be intermittent.

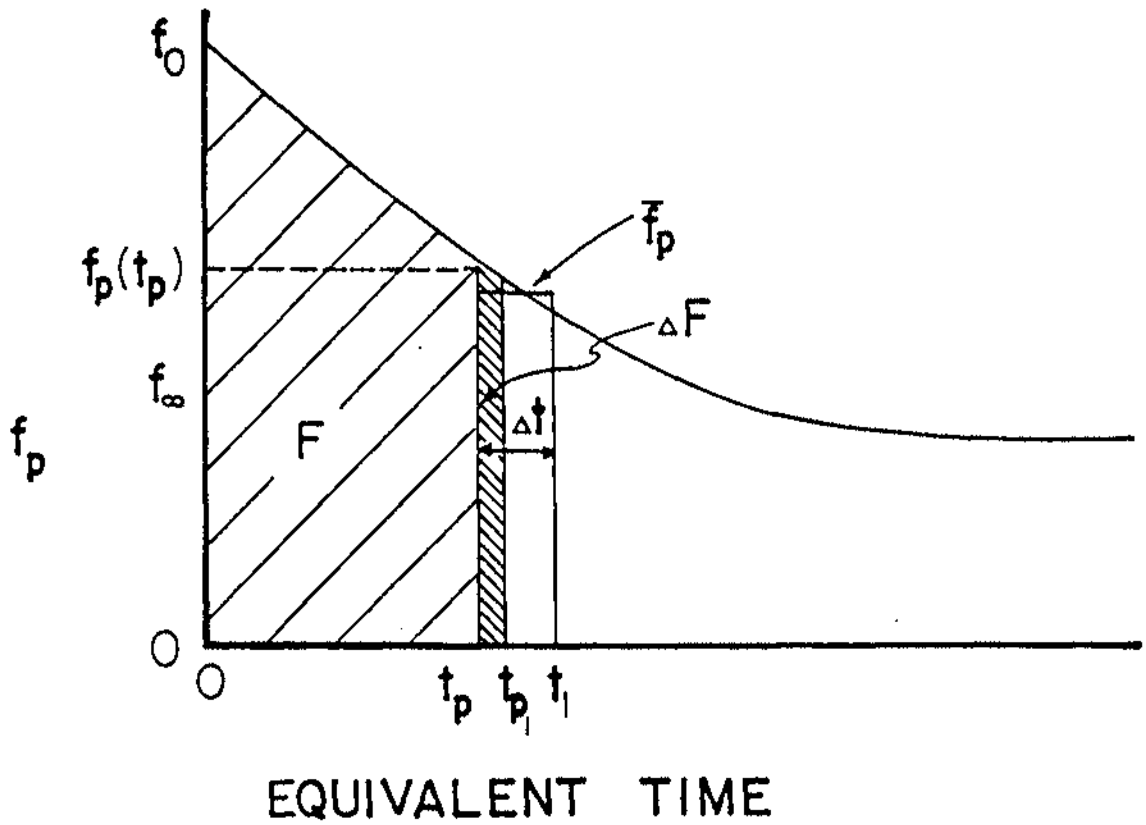


Figure V-2. Cumulative Infiltration, F, is the Integral of f, i.e., the Area Under the Curve.

Equations V-3 and V-4 may be used to define the time t_p. That is, actual cumulative infiltration given by equation V-4 is equated to the area under the Horton curve, given by equation V-3, and the resulting equation is solved for t_p and serves as its definition. Unfortunately, the equation

$$F = f_\infty t_p + \frac{(f_o - f_\infty)}{\alpha} \left(1 - e^{-\alpha t_p}\right) \tag{V-5}$$

cannot be solved explicity for t_p, and it must be done iteratively. Note that

$$t_p \leq t \tag{V-6}$$

which states that the time t_p on the cumulative Horton curve will be less than or equal to actual elapsed time. This also implies that available infiltration capacity, $f_p(t_p)$ in Figure V-2, will be greater than or equal to that given by equation V-1. Thus, f_p will be a function of actual water infiltrated and not just a function of time that ignores other effects.

Summary of Procedure --

Use of the cumulative Horton function in SWMM may be summarized as follows. Note that average values over time intervals are used.

1. At each time step, the value of f_p depends upon F, the actual infiltration up to that time. This is known by maintaining the value of t_p. Then the average infiltration capacity, $\bar{f}_p$, available over the next time step is

$$\bar{f}_p = \frac{1}{\Delta t} \int_{t_p}^{t_1 = t_p + \Delta t} f_p \, dt = \frac{F(t_1) - F(t_p)}{\Delta t} \tag{V-7}$$

2. Equation V-2 is then used.

$$\bar{f} = \begin{array}{ll} \bar{f}_p & \text{if } \bar{i} \geq \bar{f}_p \\ \bar{i} & \text{if } \bar{i} < \bar{f}_p \end{array} \tag{V-8}$$

where $\bar{f}$ = average actual infiltration over the time step, ft/sec, and

$\bar{i}$ = average rainfall intensity over the time step, ft/sec.

3. Cumulative infiltration is then incremented.

$$F(t + \Delta t) = F(t) + \Delta F = F(t) + \bar{f} \, \Delta t \tag{V-9}$$

where $\Delta F = \bar{f} \, \Delta t$ = additional cumulative infiltration, ft, (see Figure V-2).

4. A new value of t_p is then found, t_{p_1}, from equation V-5. If $\Delta F = \bar{f}_p \Delta t$, t_{p_1} is found simply by $t_{p_1} = t_p + \Delta t$. However, it is necessary to solve equation V-5 iteratively when the new t_{p_1} will be less than $t_p + \Delta t$, as sketched in Figure V-2. This is done using the Newton-Raphson procedure:

$$FF = 0 = f_\infty t_p + \frac{(f_o - f_\infty)}{\alpha} (1 - e^{-\alpha t_p}) - F \tag{V-10}$$

$$FF' = f_p(t_p) = f_\infty + (f_o - f_\infty) e^{-\alpha t_p} \tag{V-11}$$

An initial guess is made for t_{p_1}, say $t_{p_1}(n) = t_p + \Delta t/2$ (V-12)

where n refers to the number of the iteration. Then a correction is made to $t_{p_1}(n)$ using FF and FF',

$$t_{p_1}(n+1) = t_{p_1}(n) - FF/FF' \tag{V-13}$$

The convergence criterion is

$$FF/FF' < 0.001\ \Delta t \tag{V-14}$$

and is achieved quite rapidly.

5. If $t_p \geq 16/\alpha$, the Horton curve is essentially flat and $f_p = f_\infty$. Beyond this point there is no need to iterate since f_p will be constant at f_∞ and independent of F.

Regeneration of Infiltration Capacity --

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

$$f_p = f_o - (f_o - f_\infty) e^{-\alpha_d (t - t_w)} \tag{V-15}$$

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

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

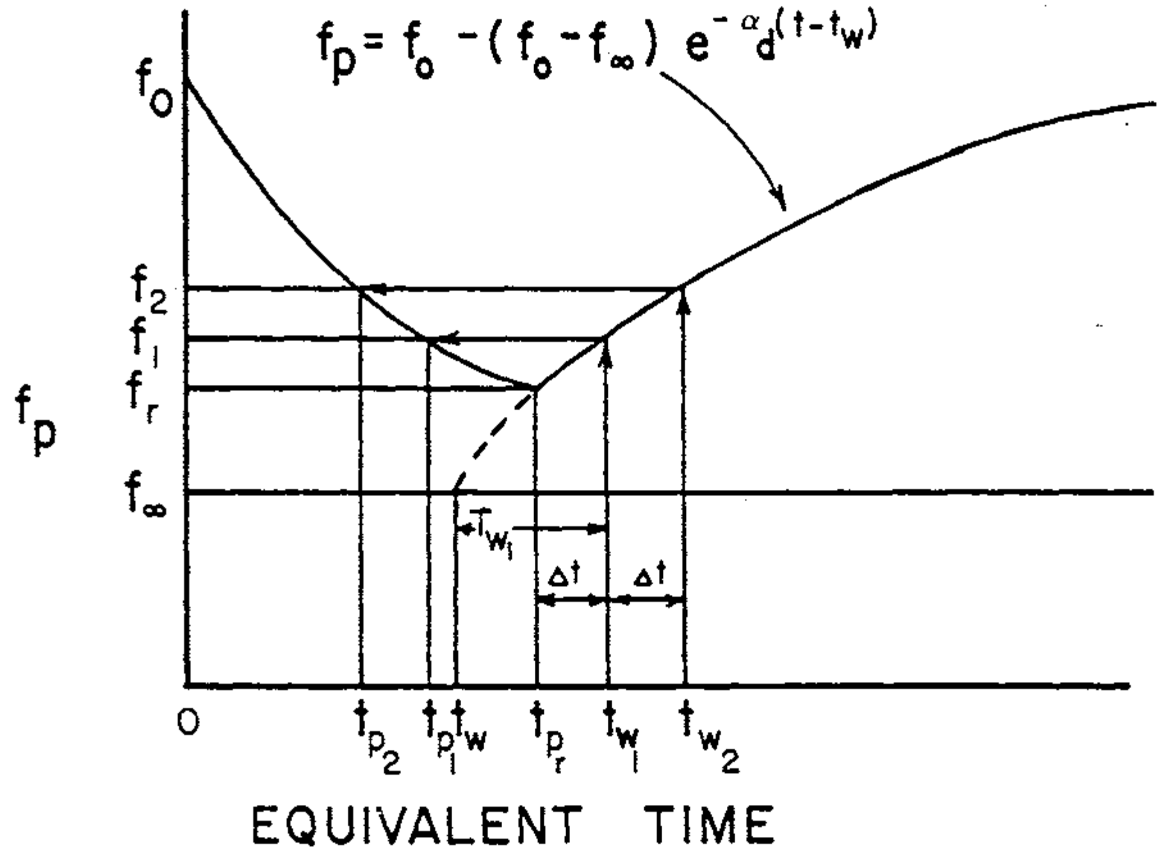


Figure V-3. Regeneration (Recovery) of Infiltration Capacity During Dry Time Steps.

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

$$\alpha_d = R\,\alpha \tag{V-16}$$

where R = constant ratio, probably << 1.0, (implying a "longer" drying curve than wetting curve).

New values of t_p are then generated as indicated in Figure V-3. Let

t_{p_r} = value of t_p at beginning of recovery, sec,

f_r = corresponding value of f_p, ft/sec, and

$T_{w_1} = t_{w_1} - t_w$, $T_{w_2} = t_{w_2} - t_w$, etc.

Thus, along the recovery curve, for example,

$$f_1 = f_p(t_{w_1}) = f_o - (f_o - f_\infty)\, e^{-\alpha_d T_{w_1}} \tag{V-17}$$

Solving equation V-17 for the initial time difference, T_{w_r},

$$T_{w_r} = t_{p_r} - t_w = \frac{1}{\alpha_d} \ln \frac{f_o - f_\infty}{f_o - f_r} \tag{V-18}$$

Then

$$T_{w_1} = T_{w_r} + \Delta t \tag{V-19}$$

and f_1 in Figure V-3 is found from equation V-17. Finally t_{p_1} is found from equation V-1,

$$t_{p_1} = \frac{1}{\alpha} \ln \frac{f_o - f_\infty}{f_1 - f_\infty} \tag{V-20}$$

The procedure may be summarized as follows:

1. Knowing t_{p_r}, find f_r from equation V-1.
2. Solve for T_{w_r} from equation V-18.
3. Increment T_{w_r} according to equation V-19.
4. Solve for f_1 from equation V-17.
5. Solve for t_{p_1} from equation V-20.

All steps are combined in

$$t_{p_1} = -\frac{1}{\alpha} \ln \left[1 - e^{-\alpha_d \Delta t} (1 - e^{-\alpha t_{p_r}}) \right] \tag{V-21}$$

On succeeding time steps, t_{p_1} may be substituted for t_{p_r} and t_{p_2} may be substituted for t_{p_1}, etc. Note that f_p has reached it maximum value of f_o when $t_p = 0$.

Program Variables --

The infiltration computations are performed in subroutine WSHED in the Runoff Block of SWMM. Correspondence of program variables to those of this subsection is as follows:

Δt = DELT	t_{p_1} = TP1
f_o = WLMAX	FF = FF
f_∞ = WLMIN	FF' = DFF
α = DECAY	$\bar{f}$ = RLOSS (RLOSS is also the sum of infiltration plus evaporation)
R = REGEN	$\bar{i}$ = RI
t_p = TP	$\bar{f}_p$ = RLOSS1
F = CUMINF = CUMI	

Green-Ampt Equation

Infiltration During Rainfall Events --

The Green-Ampt equation (Green and Ampt, 1911) has received considerable attention in recent years. The original equation, was for infiltration with excess water at the surface at all times. Mein and Larson (1973) showed how it could be adapted to a steady rainfall input and proposed a way in which the capillary suction parameter could be determined. More recently Chu (1978) has shown the applicability of the equation to the unsteady rainfall situation, using data for a field catchment.

The Mein-Larson formulation is a two-stage model. The first step predicts the volume of water which will infiltrate before the surface becomes saturated. From this point onward, infiltration capacity is predicted by the Green-Ampt equation. Thus, For $F < F_s$:

$$F_s = \frac{S \cdot IMD}{i/K_s - 1} \quad \text{for } i > K_s$$

$$f = i \qquad \text{and} \qquad \text{(V-22)}$$

No calculation of F_s for $i \leq K_s$

For $F \geq F_s$:

$$f = f_p \qquad \text{and} \qquad f_p = K_s\left(1 + \frac{S \cdot IMD}{F}\right) \qquad \text{(V-23)}$$

where f = infiltration rate, ft/sec,

f_p = infiltration capacity, ft/sec,

i = rainfall intensity, ft/sec,

F = cumulative infiltration volume, this event, ft,

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

S = average capillary suction at the wetting front, ft. water,

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

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

Equation V-22 shows that the volume of rainfall required to saturate the surface depends on the current value of the rainfall intensity. Hence, at each time step for which $i > K_s$, the value of F_s is calculated and compared with the volume of rainfall already infiltrated for this event. Only if $F \geq F_s$ does the surface saturate, and further calculations for this condition use equation V-23.

When rainfall occurs at an intensity less than or equal to K_s, all rainfall infiltrates and is used only to update the initial moisture deficit, IMD. (The mechanism for this is discussed in the next subsection with reference to equation V-31.) The cumulative infiltration is not altered for this case of low rainfall intensity (relative to the saturated hydraulic conductivity, K_s).

Equation V-23 shows that the infiltration capacity after surface saturation depends on the infiltrated volume, which in turn depends on the infiltration rates in previous time steps. To avoid numerical errors over long time steps, the integrated form of the Green-Ampt equation is more suitable. That is, f_p is replaced by dF/dt and integrated to obtain

$$K_s(t_2 - t_1) = F_2 - C \cdot \ln(F_2 + C) - F_1 + C \cdot \ln(F_1 + C) \qquad \text{(V-24)}$$

where $C = IMD \cdot S$, ft of water,

t = time, sec, and

1,2 = subscripts for start and end of time interval respectively.

Equation V-24 must be solved iteratively for F_2, the cumulative infiltration at the end of the time step. A Newton-Raphson routine is used.

The infiltration volume during time step $(t_2 - t_1)$ is thus $(t_2 - t_1) \cdot i$ if the surface does not saturate, and $(F_2 - F_1)$ if saturation has previously occurred and a sufficient water supply is at the surface. If saturation occurs during the time interval, the infiltration volumes over each stage of the process within the time steps are calculated and summed. When rainfall ends (or falls below infiltration capacity) any water ponded on the surface is allowed to infiltrate and added to the cumulative infiltration volume.

Recovery of Infiltration Capacity (Redistribution) --

Evaporation, subsurface drainage, and moisture redistribution between rainfall events decrease the soil moisture content in the upper soil zone and increase the infiltration capacity of the soil. The processes involved are complex and depend on many factors. In SWMM a simple empirical routine is used as outline below; commonly used units are given in the equations to make the description easier to understand.

Infiltration is usually dominated by conditions in the uppermost layer of the soil. The thickness of this layer depends on the soil type; for a sandy soil it could be several inches, for a heavy clay it would be less. The equation used to determine the thickness of the layer is

$$L = 4 \cdot \sqrt{K_s} \tag{V-25}$$

where L = thickness of layer, in, and

K_s = saturated hydraulic conductivity, in/hr.

Thus for a high K_s of 0.5 in/hr (12.7 mm/hr) the thickness computed by equation V-25 is 2.83 inches (71.8 mm). For a soil with a low hydraulic conductivity, say K_s = 0.1 in/hr (2.5 mm), the computed thickness is 1.26 inches (32.1 mm).

A depletion factor is applied to the soil moisture during all time steps for which there is no infiltration from rainfall or depression storage. This factor is indirectly related again to the saturated hydraulic conductivity of the soil and is calculated by

$$DF = L/300 \tag{V-26}$$

where DF = depletion factor, hr^{-1}, and

L = depth of upper zone, in.

Hence, for $K_s = 0.5$ in/hr (12.7 mm/hr), DF = 0.9 percent per hour; for K_s = 0.1 in/hr (2.5 mm/hr), DF = 0.4 percent per hour. The depletion volume (DV) per time step is then

$$DV = DF \cdot FU_{max} \cdot \Delta t \qquad (V\text{-}27)$$

where $FU_{max} = L \cdot IMD_{max}$ = saturated moisture content of the upper zone, in,

IMD_{max} = maximum initial moisture deficit, in/in, and

Δt = time step, hr.

The computations used are

$$FU = FU - DV \qquad \text{for} \qquad FU \geq 0 \qquad (V\text{-}28)$$

$$F = F - DV \qquad \text{for} \qquad F \geq 0 \qquad (V\text{-}29)$$

where FU = current moisture content of upper zone, in, and

F = cumulative infiltration volume for this event, in.

To use the Green-Ampt infiltration model in continuous SWMM, it is necessary to choose a time interval after which further rainfall will be considered as an independent event. This time is computed as

$$T = 6/(100 \cdot DF) \qquad (V\text{-}30)$$

where T = time interval for independent event, hr.

For example, when K_s = 0.5 in/hr (12.7 mm/hr) the time between independent events as given by equation V-30 is 6.4 hr; when K_s = 0.1 in/hr (2.5 mm/hr) the time is 14.3 hr. After time T has elapsed the variable F is set to zero, ready for the next event. The moisture remaining in the upper zone of the soil is then redistributed (diminished) at each time step by equation V-28 in order to update the current moisture deficit (IMD). The deficit is allowed to increase up to its maximum value (IMD_{max}, an input parameter) over prolonged dry periods. The equation used is

$$IMD = \frac{FU_{max} - FU}{L} \qquad \text{for } IMD \leq IMD_{max} \qquad (V\text{-}31)$$

When light rainfall ($i \leq K_s$) occurs during the redistribution period, the upper zone moisture storage, FU, is increased by the infiltrated rainfall volume and IMD is again updated using equation V-31.

Guidelines for estimating parameter values for the Green-Ampt model are given in Section 4. As is also the case for the Horton equation, different soil types can be modeled for different subcatchments.

Program Variables --

The infiltration computations are performed in subroutines WSHED and GAMP in the Runoff Block. Correspondence of program variables to those of this subsection is as follows:

S = SUCT(J)	L = UL(J)
IMD_{max} = SMDMAX (J)	DF = DF(J)
K_s = HYDCON(J)	i = RI
FU_{max} = FUMAX(J)	t = TIME
FU = FU(J)	Δt = DELT
IMD = SMD(J)	DV = DEP
F = F(J)	F_s = FS

SUBCATCHMENT RUNOFF CALCULATIONS

Overland Flow

The Runoff Block forms the origin of flow generation within SWMM, and much of the emphasis in data preparation and user effort is aimed at successful execution of this block. In order to understand better the conversion of rainfall excess (rainfall and/or snowmelt less infiltration and/or evaporation) into runoff (overland flow), this subsection briefly describes the equations used for this purpose. It is intended to supplement the material presented in the original SWMM documentation (Metcalf and Eddy et al., 1971a).

As discussed in Section 4, subcatchments are subdivided into three subareas that simulate impervious area, with and without depression (detention) storage, and pervious area (with depression storage). These are areas A1, A3 and A2 respectively on Figure V-4 and are denoted in subroutine WSHED by the subscript J, (J = 1, 2, 3, 4). When snowmelt is included, a fourth subarea is added to account for the presence or absence of snow cover, (see Figure II-5 in Appendix II) but that case will not be considered further here. The depth of depression storage is an input parameter (WSTORE) for the impervious and pervious areas of each catchment. The impervious area without depression storage is specified for all subcatchments by parameter PCTZER (as a percent),

$$A3 = \frac{PCTZER}{100} \cdot (A1 + A3) \qquad (V\text{-}32)$$

Of course, any subcatchment may be assigned zero depression storage over its entirety through the use of parameter WSTORE.

Overland flow is generated from each of the three subareas by approximating them as non-linear reservoirs, as sketched in Figure V-5. This is a

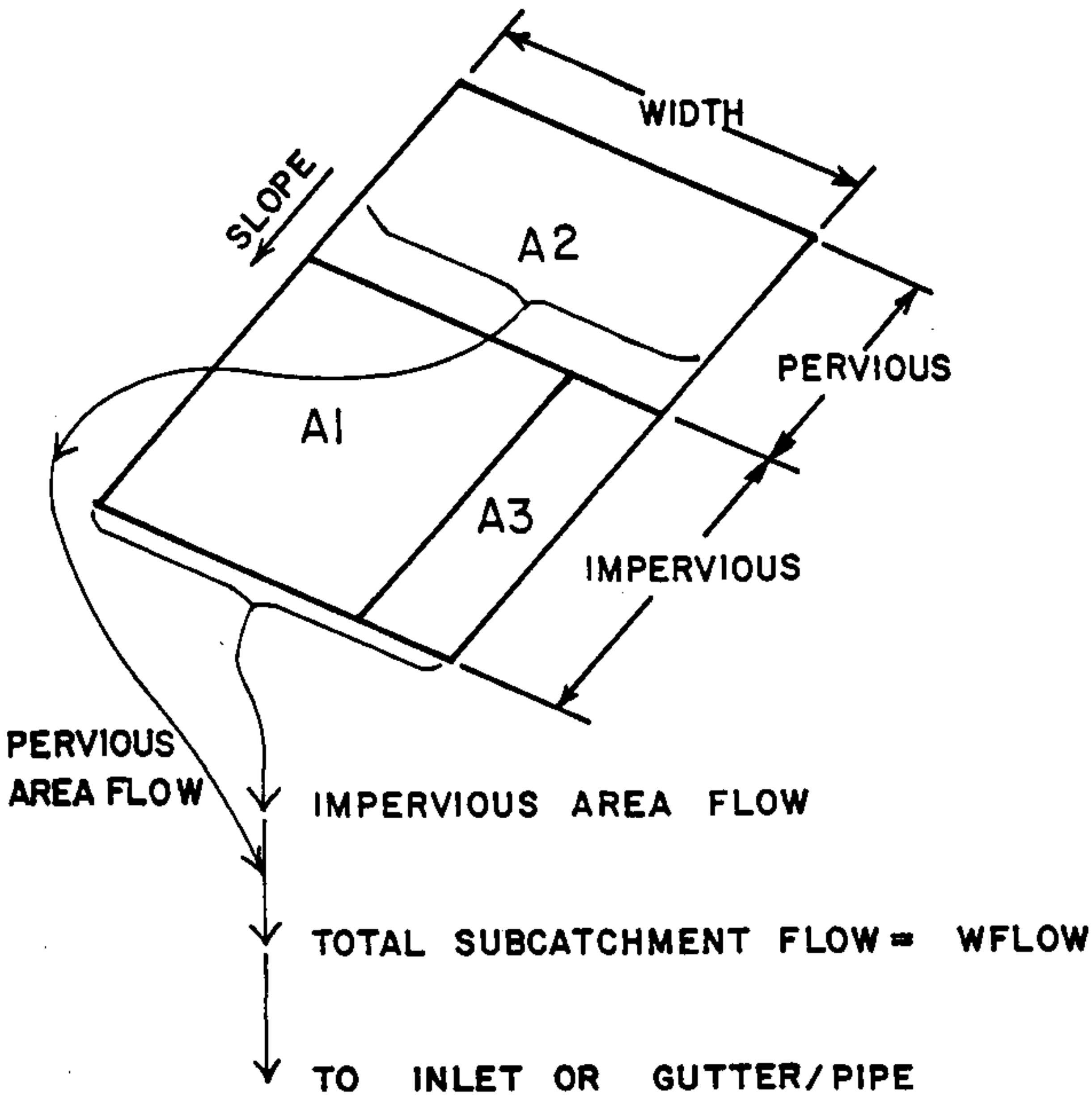


Figure V-4. Subcatchment Schematization for Overland Flow Calculations. Flow from each subarea is directly to an inlet or gutter/pipe. Flow from one subarea is not routed over another subarea.

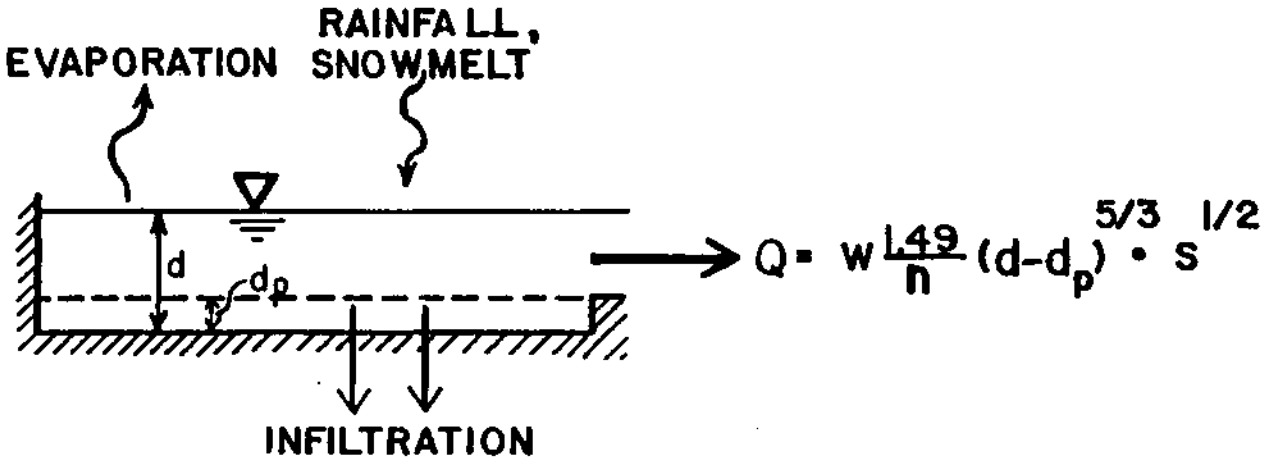


Figure V-5. Non-linear Reservoir Model of Subcatchment.

spatially "lumped" configuration and really assumes no special shape. However, if the subcatchment width, W, is assumed to represent a true prototype width of overland flow, then the reservoir will behave as a rectangular catchment, as sketched in Figure V-4. Otherwise, the width (and the slope and roughness) may be considered calibration parameters and used to adjust predicted to measured hydrographs.

The non-linear reservoir is established by coupling the continuity equation with Manning's equation. Continuity may be written for a subarea as

$$\frac{dV}{dt} = A\,\frac{dd}{dt} = A \cdot i^* - Q \tag{V-33}$$

where $V = A \cdot d$ = volume of water on the subarea, ft^3,

d = water depth, ft,

t = time, sec,

A = surface area of subarea, ft^2,

i^* = rainfall excess = rainfall/snowmelt intensity minus evaporation/infiltration rate, ft/sec, and

Q = outflow rate, cfs.

The outflow is generated using Manning's equation

$$Q = W \cdot \frac{1.49}{n}\,(d - d_p)^{5/3}\;S^{1/2} \tag{V-34}$$

where W = subcatchment width, ft.

n = Manning's roughness coefficient,

d_p = depth of depression storage, ft, and

S = subcatchment slope, ft/ft.

Equations V-33 and V-34 may be combined into one non-linear differential equation that may be solved for one unknown, the depth, d. This produces the non-linear reservoir equation,

$$\frac{dd}{dt} = i^* - \frac{1.49 \cdot W}{A \cdot n}\,(d - d_p)^{5/3}\;S^{1/2} \tag{V-35}$$

$$= i^* + WCON \cdot (d - d_p)^{5/3}$$

where $$WCON = -\,\frac{1.49 \cdot W \cdot S^{1/2}}{A \cdot n} \tag{V-36}$$

Note the grouping of width, slope and roughness into only one parameter.

Equation V-35 is solved at each time step by means of a simple finite difference scheme. For this purpose, the net inflow and outflow on the right hand side (RHS) of the equation must be averages over the time step. The rainfall excess, i*, is given in the program as a time step average. The average outflow is approximated by computing it using the average between the old and new depths. That is, letting subscripts 1 and 2 denote the beginning and the end of a time step, respectively, equation V-35 is approximated by

$$\frac{d_2 - d_1}{\Delta t} = i^* + \text{WCON} \cdot [d_1 + \tfrac{1}{2}(d_2 - d_1) - d_p]^{5/3} \qquad \text{(V-37)}$$

where Δt = time step, sec.

Equation V-37 is then solved for d_2 using a Newton-Raphson iteration; the Fortran coding is located near the end of subroutine WSHED.

Given d_2, the instantaneous outflow at the end of a time step, WFLOW, is computed using equation V-34. Parameter WFLOW is used in runoff quality calculations and is the flow value that is input to inlets and gutter/pipes. The instantaneous outflow at a given time is also the flow value transfered to subsequent SWMM blocks.

Although the solution of equation V-37 is straightforward and simple (and in fact may be performed on programmable hand calculators), some peculiarities exist in the way the parameters for individual subareas (A1, A2, A3 in Figure V-4) are specified. In particular, only two values of WCON are computed (equation V-36), one for the pervious and one for the total impervious subareas. Thus, WCON is the same for calculating depths on subareas A1 and A3 and is computed from equation V-36 using the total impervious area, A1 plus A3, in the denominator. However, the instantaneous flow is computed using the individual area of each subarea (e.g., A1 or A3). The net effect for subareas A1 and A3 is approximately to reduce the subcatchment width by the ratio A1/(A1 + A3) or A3/(A1 + A3) as implied in Figure V-4. Numerical tests of this scheme versus one that uses the individual areas (and proportional widths) in parameter WCON indicate only about a half percent difference between the two methods. Hence, it should be satisfactory.

Prior to performing these calculations, a check is made to see if losses are greater than the rainfall depth plus ponded water. If so, the losses (evaporation plus infiltration) absorb all water and outflow is zero. Similarly, if losses alone would be sufficient to lower the depth below the depression storage, the new depth is computed on this basis only and the outflow is zero.

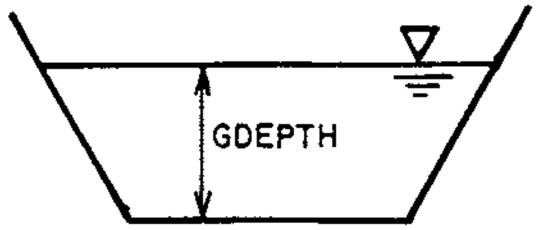
The computational scheme (equations V-37 and V-38) has proven quite stable. The only instance for which non-convergence problems arise (or an attempt to compute a negative depth) is when the subarea values are very small (e.g., a few square feet) coupled with a large time step (e.g., ten minutes). Should a non-convergence message be printed, the problem may usually be cured by increasing the appropriate area or decreasing the time step.

Gutter/Pipes

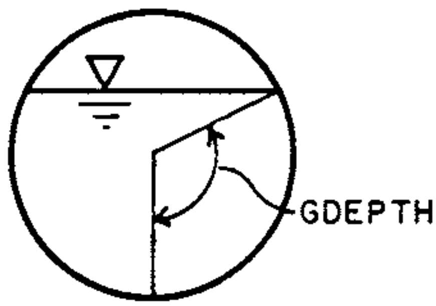
Flow routing in gutter/pipes is also performed by coupling the continuity equation with Manning's equation to produce a non-linear reservoir. The solution technique is performed in subroutine GUTTER and is entirely analogous to that just described for overland flow; no details will be given here. However, a few comments are in order. Two cross sectional shapes are available for gutter/pipes: circular and trapezoidal, as shown in Figure V-6. Parameters representing depth (e.g., GDEPTH, D1, DO) are actual depths, in feet, for trapezoidal gutters but not for circular pipes. Rather, for pipes the "depth" parameters are half of the angle subtended by the wetted perimeter, in radians, as shown in Figure V-6. Knowledge of this fact aids in understanding the Fortran coding in subroutine GUTTER.

Since a gutter/pipe acts as a reservoir with a water surface parallel to the invert, inflows are automatically "distributed" along its length. Hence, concentration of subcatchment inflows only at the upstream end of a gutter/pipe may be reasonable. On the other hand, this leads to considerable dispersion or flattening of a hydrograph peak when it is routed through a cascade of gutter/pipes. Of course, for this flow routing scheme, downstream changes are not "felt" upstream, and no backwater effects can be simulated.

Non-convergence messages are encountered more frequently during gutter/pipe routing than for subcatchment flow routing, due to the tendency to include short gutter/pipes of small dimensions in the simulation. Again, this can usually be cured by increasing the dimensions (e.g., length and width/diameter) or decreasing the time step.



TRAPEZOIDAL
GUTTER



CIRCULAR
PIPE

Figure V-6. Depth Parameters for Trapezoidal Gutter and Circular Pipe.

APPENDIX VI

TRANSPORT BLOCK SCOUR AND DEPOSITION

INTRODUCTION

Deposition of solid material during dry-weather flow (DWF) in combined sewers and subsequent scour during wet-weather flow has long been assumed to form a significant contribution of solids to combined sewer overflows. The deposition-scour phenomenon is also evident in the "first flush" — high solids concentrations at the beginning of a storm event — found in many sewer systems. Even storm sewer systems may show a first flush if there is a base flow due to infiltration or illegal connections.

Deposition and scour processes were included in the original SWMM Transport Block as described in the documentation (Metcalf and Eddy et al., 1971a). It simulated solids buildup during DWDAYS dry days prior to the storm and scour during the storm, as velocities increased. A constant horizontal approximation to the dimensionless shear stress on Shields' curve (described subsequently) was used to determine incipient motion, and one fixed particle size distribution (for suspended solids only) and specific gravity of 2.7 were used to characterize the solids.

Several problems existed in the routine, perhaps unknown to most SWMM users. The deposition-scour was dependent on the time step. Buildup of solids would occur using a 1-hr time step for the dry days prior to simulation, but scour would occur using, say, a 10-min simulation time step with the same flow conditions. The particle size distribution was unaffected by the amount scoured from the bottom or deposited from the flow. Thus, there was no simulation of large particles being deposited in upstream conduits (and thereby unavailable for deposition further downstream). It was not possible to calibrate the routine or even "turn it off" since all constants were incorporated into the program and were not input parameters. Finally, there were situations in which conservation of solids mass was violated. Although the revised routine still represents a gross approximation to the real sediment transport processes at work in sewer systems, it is at least consistent within itself, it conserves mass, and is both calibratable and avoidable.

There have been other recent investigations of solids deposition in sewers, most notably the work of Sonnen (1977) and Pisano et al. (1979). Sonnen's work is highly relevant to the modeling aspect since he developed a deposition-scour routine to accompany the Extran Block of SWMM. This model simulated both bed load and suspended load sediment transport and characterized the sediment by up to ten particle size-specific gravity ranges. Although his routines worked satisfactorily, they are not compatible with the "old" Transport Block, and the "new" Extran Block no longer routes quality parameters. In addition, they are perhaps overly sophisticated for the present needs. Thus, the current programming utilizes an approximate method that is not as sound as Sonnen's but does have the attributes described earlier.

The best characterization of solids in real sewer systems is given by Pisano et al. (1979) in their description of extensive field and analytical work done in the Boston area. The many problems inherent in dealing with real systems are amply demonstrated.

METHODOLOGY AND ASSUMPTIONS

Overview

Since the criterion for deposition and scour depends upon the sediment characteristics (notably size and specific gravity), one option for simulation of the range of characteristics found in real sewer sediment is to carry along a group of different sizes and specific gravities and route each range individually. This is done in the Storage/Treatment Block of SWMM and was done by Sonnen (1977). This has the disadvantage of requiring large array sizes since each range must be simulated for each conduit and preferably for each pollutant.

As an alternative, the present methodology utilizes a fixed particle size distribution and specific gravity (input by the user) for each desired pollutant and maintains a time history for each conduit of the maximum particle diameter (DS) in suspension (really, in motion -- via bed or suspended load) and the minimum particle diameter (DB) in the bed. Thus, the particle size distribution of particles in motion is the input distribution truncated on the right at DS, and the particle size distribution of deposited solids is the input distribution truncated on the left at DB. Mass-weighted values of DS are routed downstream for entry to subsequent conduits.

Assumptions

Several assumptions are inherent in the following development, including the following:

1. Solids in sewer systems are assumed to behave like ideal non-cohesive sediment described in various texts (e.g., Graf, 1971, Vanoni, 1975). Unfortunately, the work of Pisano et al. (1979) shows little evidence of this, and in fact, it may be an impossible task to provide an accurate theoretical description of transport of the highly heterogeneous material constituting "solids" in real sewer systems. The only hope is that the theory will appear to behave in a "reasonable" manner.

2. No distinction is made between particle size distributions resulting from different pollutant sources, e.g., dry-weather flow and storms water. Only one distribution (and one average specific gravity) is used for each pollutant.

3. Shields' criterion is used to determine the dividing particle size between motion and no motion.

4. Once in motion, no distinction is made between bed and suspended load. Particles in motion ("suspension") are routed downstream in each conduit by complete mixing, the same as other quality parameters.

5. When a critical diameter (CRITD) is determined for scour, all particles with diameter less than or equal to CRITD are eroded. There is no effect simulated of armoring or of erosion of layers of the bed.

6. Scour-deposition is considered only in conduits. It is not simulated in non-conduits, including storage elements.

7. The effect of deposited sediment on the bed geometry is not considered. When the hydraulic radius (an important parameter) is calculated to determine the critical diameter for motion, the bed is assumed to have the geometry of the conduit. This leads to some underestimation of deposited material, mainly at low flows.

SHIELDS' CRITERION

Shields' diagram for the definition of incipient motion is shown in Figure VI-1. It is widely accepted as a good definition of the beginning of particle motion and describes the balance between the hydrodynamic forces of drag and lift on a particle (tending to induce motion) and the submerged weight of a particle (tending to resist motion). When hydrodynamic forces acting on a sediment particle reach a value such that if increased even slightly will put the particle into motion, critical or threshold conditions are said to have been reached. Dimensional analysis of this condition leads to

$$\frac{\tau_c}{(\gamma_s-\gamma)d} = f\left(\frac{u_* d}{\nu}\right) \qquad \text{(VI-1)}$$

where τ_c = critical shear stress required to induce particle motion, lb/ft^2,

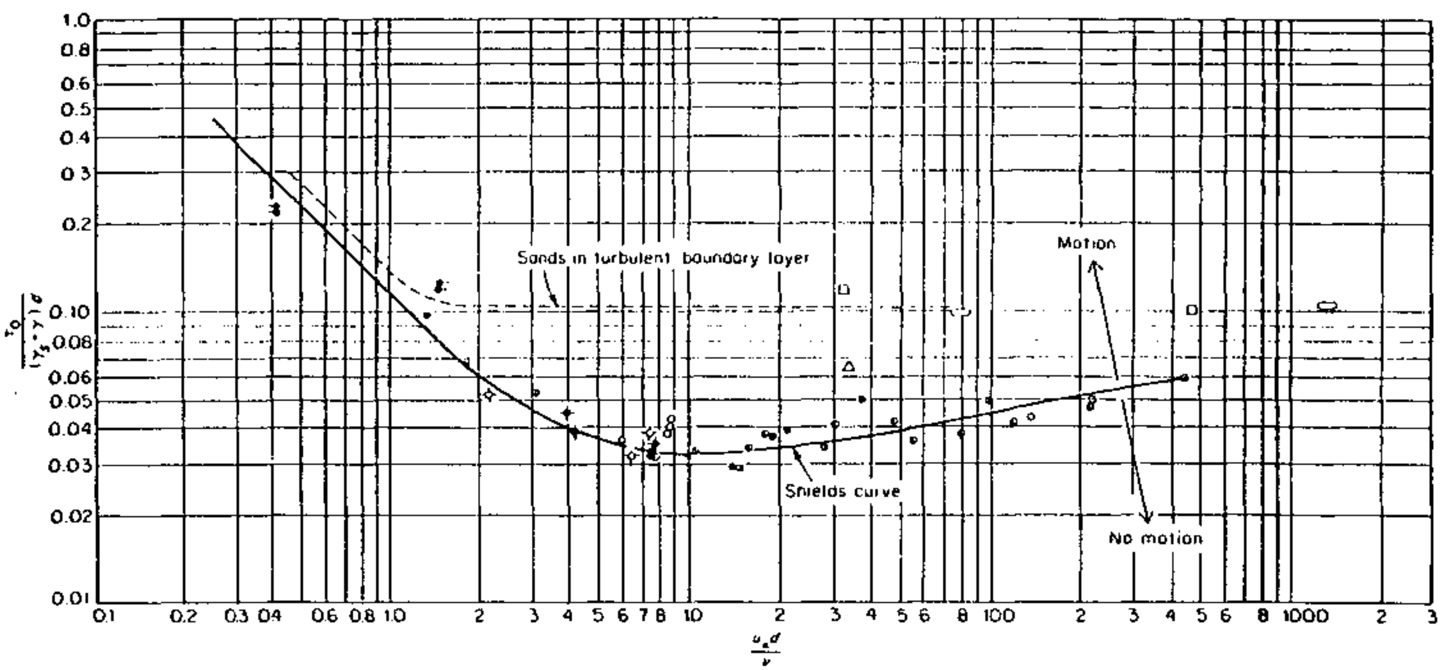
γ_s = specific weight of the sediment, lb/ft^3,

γ = specific weight of water = 62.4 lb/ft^3,

d = sediment diameter, ft (a conversion is made from mm),

u_* = shear or friction velocity, ft/sec, and

ν = kinematic viscosity of water, ft^2/sec.



	Sym	Description	γ_s, g/cm^3
Fully developed turbulent velocity profile	o	Amber (Shields)	1.06
	•	Lignite (Shields)	1.27
	⊙	Granite (Shields)	2.7
	◐	Barite (Shields)	4.25
	◒	Sand (Casey)	2.65
	✧	Sand (Kramer)	2.65
	✦	Sand (U.S.W.E.S.)	2.65
	◉	Sand (Gilbert)	2.65

	Sym	Description	γ_s, g/cm^3
Turbulent boundary layer	•-	Sand (Vanoni)	2.65
	-•	Glass beads (Vanoni)	2.49
	◻	Sand (White)	2.61
	⬭	Sand in air (White)	2.10
	△	Steel shot (White)	7.9

Figure VI-1. Shields' Diagram for Definition of Incipient Motion. (After Graf, 1971, p. 96)

The equation may be stated in words that the dimensionless critical shear stress is a function of the shear Reynolds number. The critical shear stress and shear velocity are related to each other and to flow properties by

$$u_* = \sqrt{\tau_c/\rho} = \sqrt{g\ R\ S} \qquad \text{(VI-2)}$$

where ρ = water density = 1.98 slug/ft^3,

g = gravity = 32.2 ft/sec^2,

R = hydraulic radius, ft, and

S = slope of energy grade line (assumed equal to invert slope).

In addition, the specific weight difference may be related to the specific gravity difference between sediment and water,

$$\gamma_s - \gamma = \gamma(SPG - 1) \qquad \text{(VI-3)}$$

where SPG = specific gravity of the sediment,

and the specific gravity of water is taken as 1.0.

Experiments on critical shear stress (e.g., see Graf, 1971 and Vanoni, 1975) reveal the motion of sediment grains to be highly unsteady and non-uniformly distributed. Near critical conditions, observations of a large area of the sediment bed will show that the incidence of sediment motion occurs as gusts and is random in both time and space. Shields and others observed the process of initiation of motion to be stochastic in nature, so that there is no true "critical condition" at which motion suddenly begins. In fact, data on critical shear stress are based upon arbitrary definitions of critical conditions by several investigators. Shields himself determined τ_c as the value for zero sediment discharge obtained by extrapolation on a graph of observed sediment discharge versus shear stress.

Although experiments have been performed incorporating various materials, (e.g., sand, glass beads, steel shot, minerals), size ranges and specific gravities, the Shields criterion is generally not used for cohesive sediment that may be more characteristic of sewer systems. Nonetheless, it appears to be the only well documented criterion for initiation of motion and is utilized in spite of its limitations.

In SWMM, the Shields diagram is used to determine the dividing sediment diameter between motion and no motion. Thus, it is necessary to solve the functional relationship for the critical diameter, d = CRITD. For programming purposes, the diagram is approximated as shown in Figure VI-2, where two straight line segments bound a central polynomial approximation, all on a log-log plot. Letting the dimensionless shear stress ≡ Y, and the shear Reynolds number ≡ R_*, then the functional forms and their best-fit parameters are as follows:

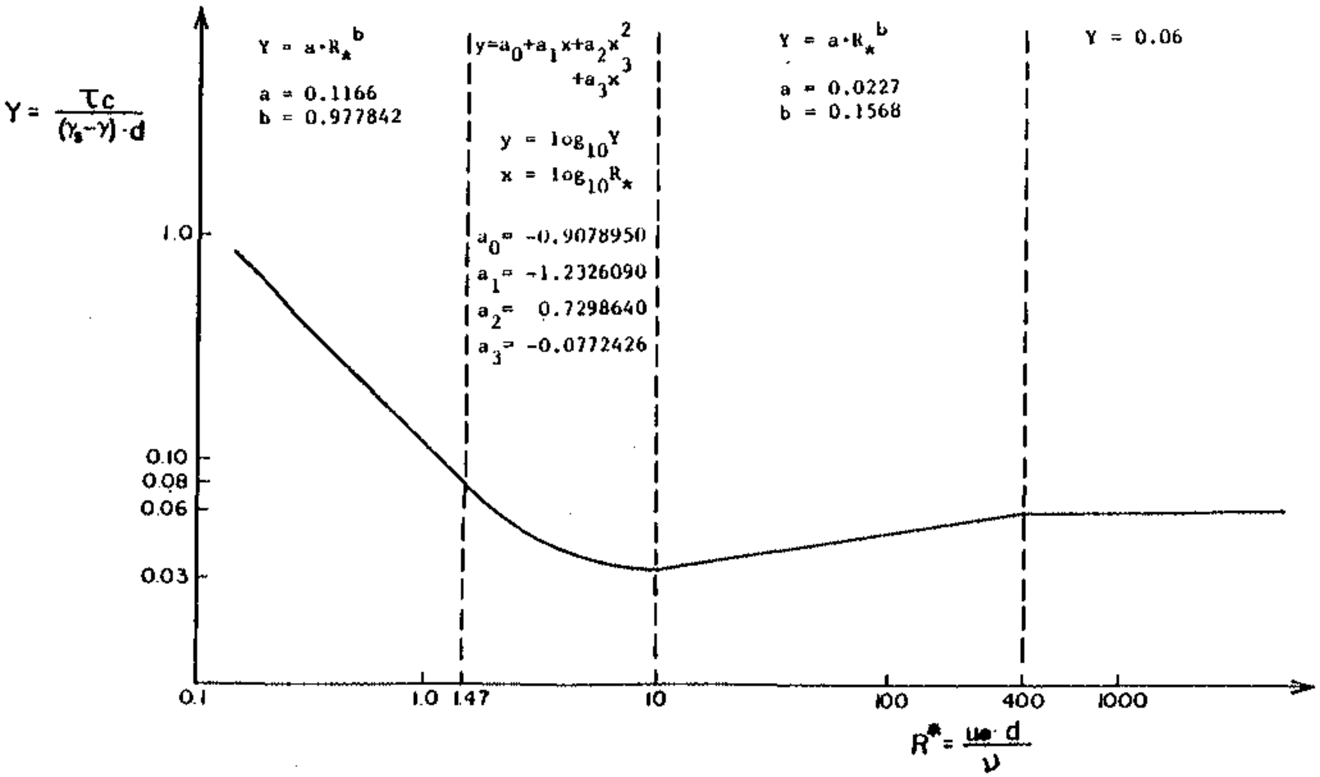


Figure VI-2. Linear and Parabolic Approximation of Shields' Diagram

$\underline{R_* \leq 1.47}$

$$Y = a \cdot R_*^{\,b} \qquad \text{(VI-4)}$$

with $a = 0.1166$, and

$b = -0.977842 \simeq -1$

$\underline{1.47 \leq R_* \leq 10}$

$$y = a_0 + a_1 \cdot x + a_2 \cdot x^2 + a_3 \cdot x^3 \qquad \text{(VI-5)}$$

where $y = \log_{10} \frac{\tau_c}{(\gamma_s - \gamma) d}$

$x = \log_{10} R_*$

and with $a_0 = -0.9078950$

$a_1 = -1.2326090$

$a_2 = 0.7298640$

$a_3 = -0.0772426$

$\underline{10 \leq R_* \leq 400}$

$$Y = a \cdot R_*^{\,b} \qquad \text{(VI-6)}$$

with $a = 0.0227$, and

$b = 0.1568$

$\underline{R_* \geq 400}$

$Y = 0.06$ or

$$d = \frac{R \cdot S}{(SPG-1) \cdot 0.06} \qquad \text{(VI-7)}$$

The straight line segments may be solved directly for the critical diameter from

$$\frac{\tau_c}{(\gamma_s - \gamma) d} = a \left(\frac{u_* d}{\nu} \right)^b \qquad \text{(VI-8)}$$

and using the relationships of equations VI-2 and VI-3, resulting in

$$\text{CRITD} = \left[\frac{(R \cdot S)^{1-b/2} \; \nu^b}{(SPG-1) \cdot a \cdot g^{b/2}} \right]^{\frac{1}{1+b}} \qquad \text{(VI-9)}$$

Equation VI-9 works well for the coefficients a and b of equation VI-6. But for equation VI-4, b ≈ -1 and the exponent approaches infinity. For the region $R_* \leq 1.47$, all sediment particles are within the laminar sublayer of the flow, and motion is independent of the diameter (Graf, 1971). For practical purposes, there is no apparent motion, and the critical diameter is assumed to be the value at $R_* = 1.47$ in the model,

that is $d = \frac{1.47 \cdot \nu}{\sqrt{RSg}}$.

The polynomial for the transition region, $1.47 \leq R_* \leq 10$, is rapidly solved using a Newton-Raphson iteration. In the program, equation VI-9 is first solved using the a and b values for equation VI-6 ($10 \leq R_* \leq 400$). If the resulting value of R_* is greater than 400, the critical diameter is evaluated from equation VI-7. If R_* is less 10, the polynomial approximation is then solved. If the resulting value of R_* from polynomial is greater than 10, the critical diameter is assumed to be the value at $R_* = 10$, and if R_* is less than 1.47, the value at $R_* = 1.47$ is used as a default.

Regarding the parameters of equation VI-9, the slope, S is taken as the invert slope (SLOPE) for each conduit, used by the Transport Block. The hydraulic radius is calculated at each time step, and the kinematic viscosity, ν, (GNU) is input for each run. (It incorporates any temperature effects.). The specific gravity (SPG) of sewer particles ranges from 1.1 for organic material to 2.7 for sand and grit. An average value, based upon the rough composition of the sediment, must be used. When quality parameters are input in card group F1 of the Transport Block, if SPG $\leq$ 1.0, the deposition-scour routine will not be used. It may be seen that if SPG is greater than 1.0 but very close to it, the value of CRITD in equation VI-9 becomes highly sensitive to it.

PARTICLE SIZE DISTRIBUTION

The particle size distribution for each pollutant for which it is desired to simulate deposition and scour is input by up to four straight line segments, as shown in Figure VI-3 (see also Figure 6-6). The distribution may be based upon characteristics of surface sediment for simulation of storm sewers, but should utilize sewer conduit samples for combined sewers.

An example will best illustrate the use of the particle size distribution. Consider first an example of scour. The distribution of Figure VI-3 is sketched again in Figure VI-4a. At the beginning of the time step, all particles in the bed are assumed to have diameters $\geq$ DB = 0.6 mm in the example. If a new critical diameter, CRITD, is calculated that is greater than DB, (CRITD = 1.5 mm in the example), the new bed distribution will become as shown in Figure VI-4b. The percent of the bed mass that is scoured is

$$\frac{72-35}{72} \times 100 = 51\%$$

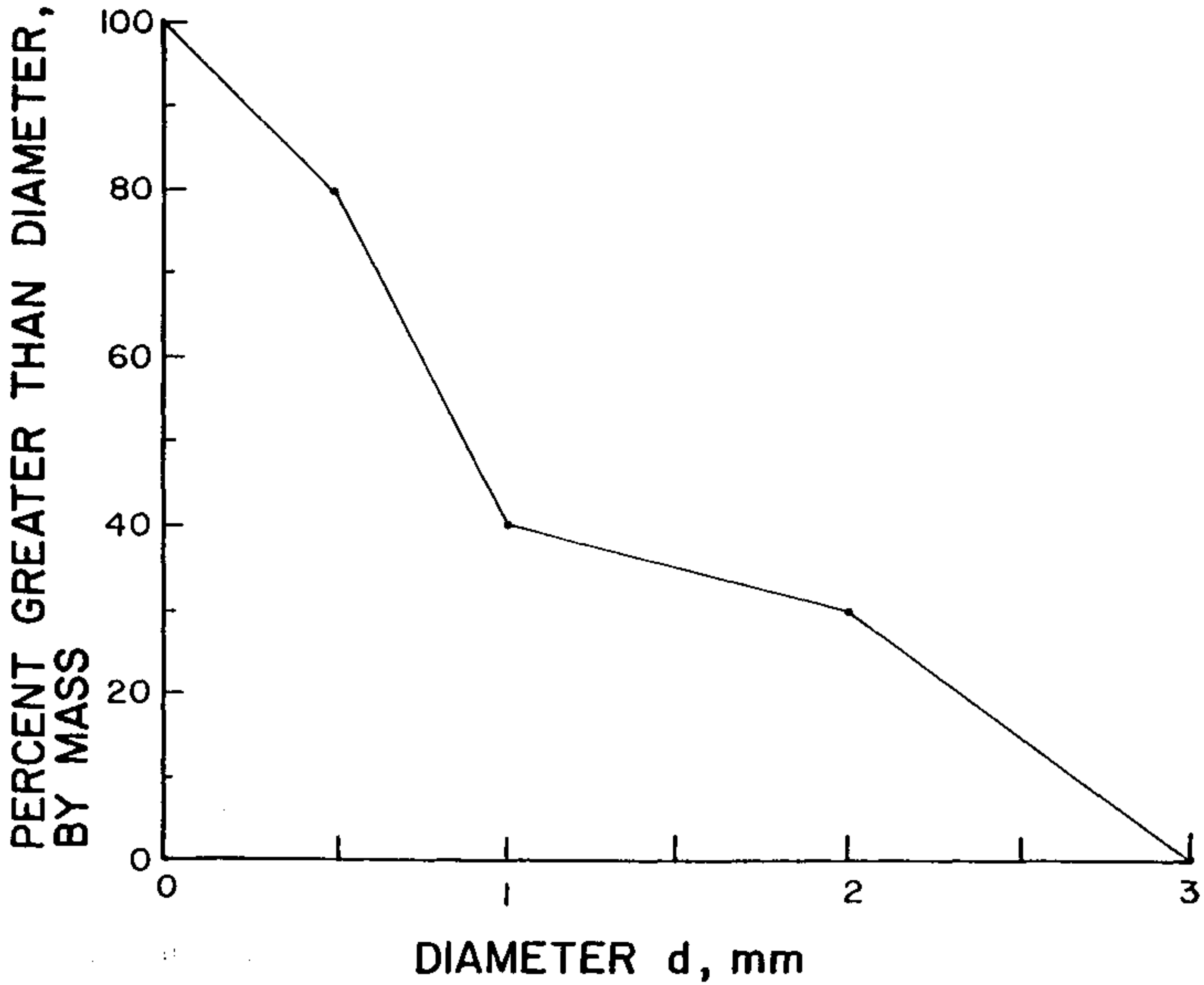


Figure VI-3. Particle Size Distribution for a Pollutant.

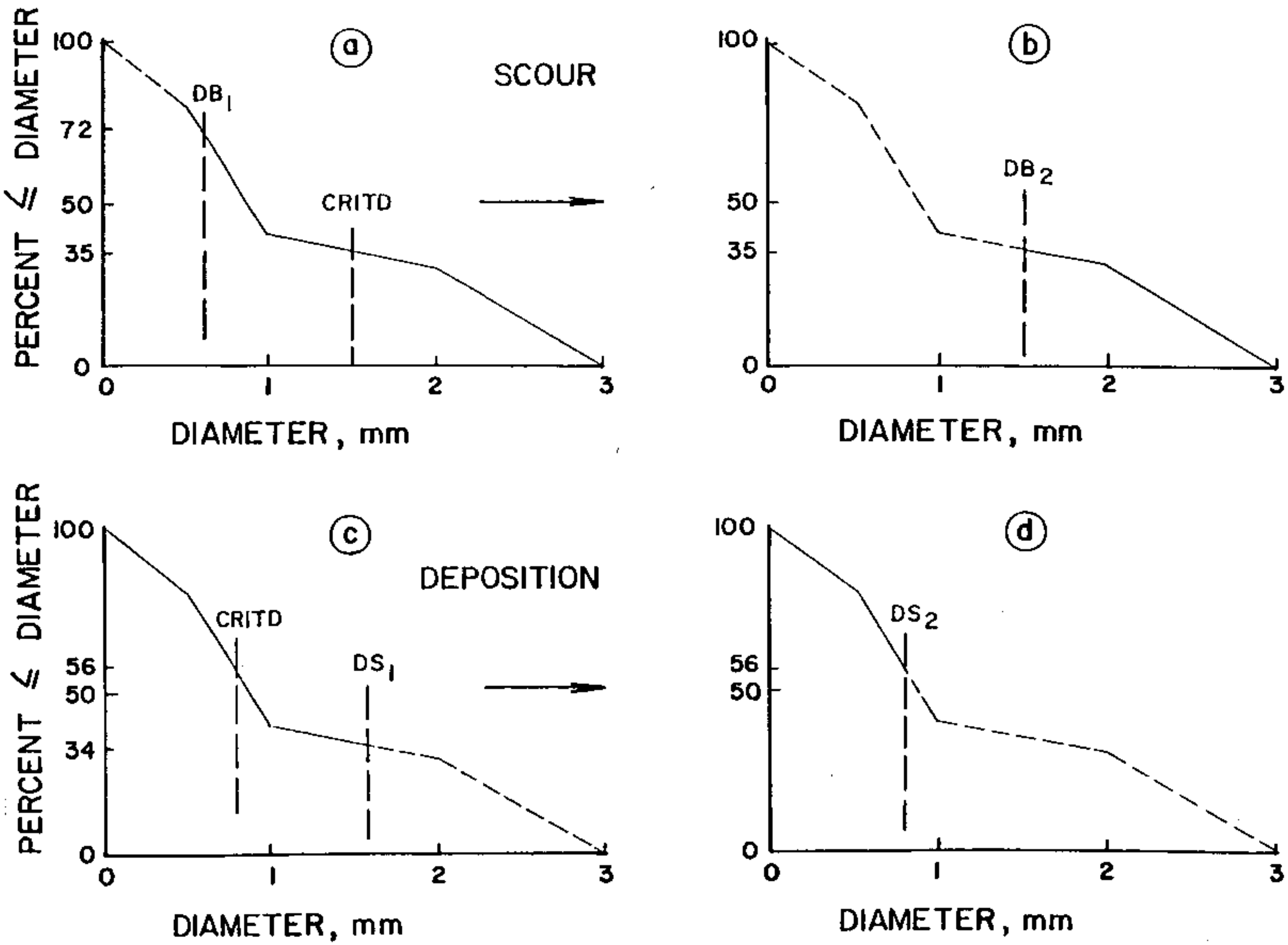


Figure VI-4. Truncation of Particle Size Distribution During Scour and Deposition.

(Under the original methodology in the Transport Block, it would have been assumed that 100-35 or 65 percent of the mass of the bed would be scoured.)

A similar calculation applies to deposition. If the suspended material (particles in motion) have the distribution shown in Figure VI-4c, it becomes that of Figure VI-4d. The percent of the suspended load that is deposited is

$$\frac{56-34}{100-34} \times 100 = 33\%$$

(Under the original methodology in the Transport Block, it would have been assumed that 56 percent of the suspended load would be deposited.) When scoured material is added to suspended material, a new value of DS is computed by mass-weighting:

$$DS_2 = \frac{DS_1 \cdot M_s + CRITD \cdot M_e}{M_s + M_e} \qquad \text{(VI-10)}$$

where DS_2 = new value of DS, mm,

DS_1 = old value of DS, mm,

M_s = original mass in suspension, mg, and

M_e = mass eroded from bed, mg.

Similarly, if suspended material is deposited,

$$DB_2 = \frac{DB_1 \cdot M_b + CRITD \cdot M_d}{M_b + M_d} \qquad \text{(VI-11)}$$

where DB_2 = new value of DB, mm,

DB_1 = old value of DB, mm,

M_b = original mass of bed material, mg, and

M_d = mass deposited from flow, mg.

Due to this weighting, ordinarily it will not be true that DB=DS even though the same critical diameter, CRITD, applies to both.

Another reason why DB will not necessarily equal DS results from the condition in which CRITD < DB_1 for scour (or CRITD > DS_1 for deposition). In these cases, DB_2 = DB_1 (or DS_2 = DS_1), prior to addition of mass from the flow (or bed), since no mass would be lost from the bed (or from the suspended material).

INFLOWS AND JUNCTIONS

To allow some difference between surface inflows to the sewer system and dry-weather flow inflows (e.g., domestic sewage) a maximum particle size, PSDWF, may be specified (in card group F1) for the pollutant found in DWF. This also applies to pollutants entering as a base flow in manholes. Pollutants entering via infiltration are assumed to be completely dissolved and have "zero particle sizes."

At junctions (manholes or other non-conduits), a new value of DS is computed by mass weighting the merging values. For instance,

$$DS_m = \frac{\sum_{i=1}^{3} DS_{u_i} \cdot Q_{u_i} \cdot C_{u_i} + PSDWF \cdot Q_{DWF} \cdot C_{DWF}}{\sum_{i=1}^{3} Q_{u_i} \cdot C_{u_i} + Q_{DWF} \cdot C_{DWF} + Q_{inf}} \qquad \text{(VI-12)}$$

where DS_m = value of DS of mixture, mm,

DS_{u_i} = DS value in upstream conduit i, mm,

Q_{u_i} = outflow from upstream conduit i, cfs,

C_{u_i} = concentration in upstream conduit i, mg/l, and

subscripts DWF and inf refer to dry-weather flow and infiltration respectively.

APPENDIX VII

EXAMPLE ANALYSIS OF URBAN RUNOFF QUALITY DATA FOR MODELING APPLICATIONS

Options for simulation of surface runoff quality in SWMM have been described in Section 4 of this report. They are basically two: use of a buildup-washoff equation or use of a rating curve. The former (equation 4-35) results in a characteristic loop effect when intra-storm loads are plotted versus runoff rate (Figure 4-36) while the latter must result in a single valued function. In this appendix, data from three separate sewered catchments in Seattle and one combined sewered catchment in Lancaster, PA are examined in order to see if SWMM has the ability to mimic their load and concentration versus flow characteristics. The data were taken from the EPA Urban Rainfall-Runoff-Quality Data Base (Huber et al., 1979) and analyzed using library statistical packages.

Three parameters were chosen for analysis:

1) Five day biochemical oxygen demand, BOD_5,

2) Total suspended solids, TSS, and

3) NO_2+NO_3-N for Seattle and NO_3-N for Lancaster.

The first parameter, BOD, is likely to be associated with solids, the second parameter is a solid, and the nitrogen parameters are likely to be dissolved. Hence, they may exhibit different characteristic relationships.

Results are presented in the following figures. (See also Figure 4-37.) Loops are evident in the Lancaster data (Figures VII-17 to VII-19) although eratic, since the runoff hydrographs are eratic. Loops are also present for the Seattle data although harder to detect since sucessive points are not connected (Figures VII-4 to VII-6). As expected, nitrate concentrations decrease with increasing flow rate (Figures VII-16 and VII-20). Log-log plots tend to reduce the magnitude of the loops and could form the basis of a rating curve approximation. When loads for the three Seattle catchments are normalized by dividing by their respective catchment areas the data are grouped with less scatter (Figure VII-12) than when not normalized (Figure VII-11). The runoff rate in inches/hr is already a normalized flow rate for these catchments.

SEATTLE VIEW RIDGE I (MAIN) CATCHMENT AREA = 630 ACRES
EVENT #1 2/14/73

STORET CODE	61		310	530	630			
HOUR	FLOW (CFS)	RUNOFF (IN/HR)	BOD (MG/L)	TSS (MG/L)	NO2+NO3 (MG/L)	BOD LOAD (MG/SEC)	TSS LOAD (MG/SEC)	NO2+NO3 LOAD (MG/SEC)
1300	0.100	0.159E-03	1.3	6.	2.30	3.68	17.0	6.51
1330	0.100	0.159E-03	1.3	6.	2.30	3.68	17.0	6.51
1345	0.100	0.159E-03	1.0	4.	2.20	2.83	11.3	6.23
1415	0.150	0.238E-03	1.0	4.	2.20	4.25	17.0	9.37
1447	0.481	0.763E-03	8.0	12.	2.40	109.	163.	32.7
1507	0.686	0.109E-02	94.0	216.	1.20	0.180E 04	0.420E 04	23.3
1526	0.620	0.984E-03	33.0	416.	0.90	911.	0.730E 04	15.8
1546	0.522	0.829E-03	20.0	170.	0.80	274.	0.231E 04	11.8
1604	0.564	0.895E-03	25.0	74.	1.30	399.	0.118E 04	20.8
1631	0.600	0.952E-03	17.1	70.	0.80	291.	0.119E 04	13.6
1717	0.461	0.732E-03	17.1	58.	0.80	222.	757.	10.6
1734	0.386	0.613E-03	13.2	36.	1.10	131.	390.	12.0
1833	0.270	0.429E-03	13.2	54.	1.10	93.3	413.	9.41
1853	0.237	0.376E-03	13.0	40.	0.90	87.3	268.	6.04
2000	0.120	0.190E-03	13.0	40.	0.90	44.2	136.	3.06

SEATTLE VIEW RIDGE I
EVENT #6 10/20/74

STORET CODE	61		310	530	630			
HOUR	FLOW (CFS)	RUNOFF (IN/HR)	BOD (MG/L)	TSS (MG/L)	NO2+NO3 (MG/L)	BOD LOAD (MG/SEC)	TSS LOAD (MG/SEC)	NO2+NO3 LOAD (MG/SEC)
320	0.040	0.[illegible]E-04	97.0	4380.	2.00	110.	0.496E 04	2.27
335	1.600	0.254E-02	150.0	260.	1.70	0.680E 04	0.118E 05	77.0
350	2.180	0.346E-02	110.0	134.	1.60	0.679E 04	0.766E 04	98.8
405	2.710	0.430E-02	95.0	124.	1.40	0.729E 04	0.952E 04	107.
420	63.690	0.101	34.0	446.	0.74	0.613E 05	0.804E 06	0.133E 04
440	21.710	0.346E-01	23.0	196.	0.80	0.143E 05	0.122E 06	494.
455	19.980	0.317E-01	16.0	66.	0.74	0.903E 04	0.373E 05	419.
510	16.360	0.260E-01	14.0	40.	0.67	0.649E 04	0.185E 05	310.
525	14.680	0.233E-01	12.0	24.	0.62	0.499E 04	0.998E 04	258.
530	6.890	0.109E-01	12.0	18.	0.61	0.234E 04	0.351E 04	119.
545	3.940	0.625E-02	11.0	18.	0.68	0.123E 04	0.201E 04	75.9
600	4.430	0.706E-02	13.0	22.	0.67	0.164E 04	0.277E 04	84.4
615	6.430	0.102E-01	12.0	20.	0.67	0.219E 04	0.363E 04	122.
630	9.630	0.153E-01	9.3	36.	0.54	0.231E 04	0.984E 04	148.
645	4.430	0.706E-02	8.3	48.	0.45	0.105E 04	0.605E 04	56.7
700	2.180	0.346E-02	7.6	52.	0.55	469.	0.321E 04	34.0
715	1.010	0.160E-02	8.3	30.	2.80	237.	858.	80.1
730	0.700	0.111E-02	9.0	68.	2.20	178.	0.133E 04	43.6
745	0.500	0.794E-03	8.0	16.	3.30	113.	227.	46.7
800	0.330	0.524E-03	3.9	24.	4.30	36.4	224.	40.2

SEATTLE VIEW RIDGE I
EVENT #7 11/17/74

STORET CODE	61		310	530	630			
HOUR	FLOW (CFS)	RUNOFF (IN/HR)	BOD (MG/L)	TSS (MG/L)	NO2+NO3 (MG/L)	BOD LOAD (MG/SEC)	TSS LOAD (MG/SEC)	NO2+NO3 LOAD (MG/SEC)
730	0.040	0.635E-04	120.0	22.	1.20	136.	24.9	1.36
745	0.700	0.111E-02	72.0	26.	0.79	0.143E 04	515.	15.7
800	0.700	0.111E-02	64.0	26.	0.55	0.127E 04	515.	10.9
815	0.930	0.148E-02	70.0	24.	0.49	0.184E 04	632.	12.9
830	3.290	0.522E-02	140.0	48.	0.43	0.130E 05	0.447E 04	40.1
845	2.850	0.452E-02	57.0	38.	0.58	0.460E 04	0.307E 04	46.8
900	3.610	0.573E-02	49.0	38.	0.28	0.501E 04	0.393E 04	28.6
915	10.440	0.166E-01	85.0	130.	0.26	0.251E 05	0.384E 05	76.9
930	7.120	0.113E-01	64.0	150.	0.22	0.129E 05	0.302E 05	44.4
945	13.090	0.208E-01	54.0	150.	0.23	0.200E 05	0.556E 05	85.3
1000	18.130	0.288E-01	55.0	80.	0.21	0.282E 05	0.411E 05	108.
1015	19.980	0.317E-01	63.0	120.	0.17	0.356E 05	0.679E 05	96.2
1030	14.030	0.223E-01	56.0	108.	0.15	0.223E 05	0.429E 05	59.6
1045	16.360	0.260E-01	85.0	66.	0.15	0.394E 05	0.306E 05	69.3
1100	18.490	0.293E-01	37.0	74.	0.16	0.194E 05	0.387E 05	83.8
1115	11.380	0.180E-01	43.0	56.	0.16	0.148E 05	0.184E 05	52.5
1130	9.350	0.148E-01	40.0	46.	0.17	0.106E 05	0.122E 05	45.0
1145	4.100	0.651E-02	35.0	48.	0.20	0.406E 04	0.557E 04	23.2
1200	2.300	0.365E-02	30.0	30.	0.24	0.195E 04	0.195E 04	15.6
1300	2.850	0.452E-02	28.0	24.	0.38	0.224E 04	0.194E 04	30.7
1400	0.700	0.111E-02	31.0	48.	0.44	613.	952.	8.72
1500	0.240	0.381E-03	31.0	42.	0.92	211.	285.	6.25

Figure VII-1. Flow and Quality Data for Seattle, Washington View Ridge I Catchment (Single Family Residential, Separate Sewers), Event 1, Event 6, Event 7.

SEATTLE SOUTH SEATTLE (WA13) CATCHMENT AREA = 27.9 ACRES
EVENT 03 6/6/73

STORET CODE	61		310	530	630			
HOUR	FLOW (CFS)	RUNOFF (IN/HR)	BOD (MG/L)	TSS (MG/L)	NO2+NO3 (MG/L)	BOD LOAD (MG/SEC)	TSS LOAD (MG/SEC)	NO2+NO3 LOAD (MG/SEC)
1110	0.010	0.[illegible]-03	32.0	24.	0.10	9.22	6.90	0.280E-01
1215	0.010	0.[illegible]-03	33.0	24.	0.10	9.22	6.90	0.280E-01
1230	0.040	0.211E-02	42.0	170.	1.43	71.4	289.	3.46
1245	0.180	0.635E-02	88.0	300.	1.50	449.	0.133E 04	7.16
1300	0.140	0.504E-02	40.0	400.	1.30	127.	761.	5.13
1315	0.170	0.614E-02	35.0	47.	1.00	134.	497.	6.81
1330	0.120	0.860E-02	38.0	100.	1.00	190.	482.	6.23
1345	0.220	0.800E-02	31.0	43.	0.70	173.	592.	4.38
1400	0.171	0.622E-02	20.0	123.	0.70	46.9	605.	3.38
1415	0.130	0.363E-02	13.0	43.	0.70	33.3	106.	2.97
1430	0.220	0.900E-02	20.0	60.	0.70	125.	374.	4.36
1445	0.220	0.900E-02	20.0	70.	0.70	125.	123.	4.36
1530	0.250	0.709E-02	10.0	30.	0.70	142.	143.	4.96
1545	0.310	0.183E-01	46.0	80.	0.70	604.	0.114E 04	10.1
1630	0.140	0.309E-02	46.0	80.	0.70	182.	317.	2.78
1645	0.220	0.800E-02	43.0	45.	0.90	264.	592.	5.61
1800	0.037	0.135E-02	42.0	45.	0.90	64.0	90.3	0.943

SEATTLE SOUTH SEATTLE
EVENT 04 8/16/73

STORET CODE	61		310	530	630			
HOUR	FLOW (CFS)	RUNOFF (IN/HR)	BOD (MG/L)	TSS (MG/L)	NO2+NO3 (MG/L)	BOD LOAD (MG/SEC)	TSS LOAD (MG/SEC)	NO2+NO3 LOAD (MG/SEC)
1100	0.003	0.139E-03	8.4	38.	0.10	0.714	4.42	0.950E-04
1215	0.023	0.909E-03	1.0	12.	0.20	0.708	8.50	0.142
1230	0.032	0.116E-02	18.0	88.	1.40	16.3	79.7	1.37
1245	0.025	0.909E-03	22.0	76.	1.80	17.7	33.8	1.27
1300	0.014	0.691E-03	28.0	32.	0.60	13.1	28.0	0.320
1315	0.013	0.473E-03	30.0	98.	1.70	11.0	22.4	0.626
1330	0.014	0.309E-03	61.0	140.	1.60	52.1	93.9	0.634
1405	0.034	0.124E-02	40.0	140.	2.90	38.3	133.	1.53
1420	0.038	0.138E-02	38.0	93.	1.60	42.4	98.0	1.72
1505	0.022	0.800E-03	30.0	93.	1.50	36.1	37.3	0.947
1520	0.042	0.153E-02	40.0	170.	1.60	47.6	202.	1.90
1535	0.030	0.180E-02	37.0	270.	1.60	53.4	702.	1.38
1550	0.032	0.116E-02	22.0	44.	1.60	19.9	38.0	1.45
1615	0.011	0.400E-03	22.0	64.	1.60	6.93	19.9	0.498
1630	0.008	0.291E-03	18.0	36.	1.60	4.08	12.7	0.343
1735	0.005	0.182E-03	18.0	36.	1.60	2.33	7.93	0.227

SEATTLE SOUTH SEATTLE
EVENT 05 9/19/73

STORET CODE	61		310	530	630			
HOUR	FLOW (CFS)	RUNOFF (IN/HR)	BOD (MG/L)	TSS (MG/L)	NO2+NO3 (MG/L)	BOD LOAD (MG/SEC)	TSS LOAD (MG/SEC)	NO2+NO3 LOAD (MG/SEC)
1000	1.490	0.542E-01	26.0	240.	0.73	0.110E 04	0.101E 05	31.8
1015	1.670	0.607E-01	21.0	210.	0.80	993.	0.993E 04	37.8
1030	1.380	0.373E-01	23.0	170.	0.73	0.112E 04	0.741E 04	32.6
1045	1.020	0.442E-01	24.0	80.	0.80	0.124E 04	0.412E 04	41.3
1100	1.490	0.342E-01	20.0	28.	0.73	844.	0.116E 04	31.6
1115	1.380	0.373E-01	13.0	46.	0.83	671.	0.204E 04	32.0
1130	1.380	0.373E-01	13.0	46.	0.83	671.	0.204E 04	32.0
1145	1.660	0.474E-01	18.0	36.	0.83	948.	0.190E 04	44.8
1200	1.440	0.324E-01	12.0	2.	1.20	330.	81.6	48.9
1715	1.190	0.433E-01	13.0	7.	1.20	438.	67.4	40.4
1730	1.030	0.373E-01	8.9	4.	1.40	260.	58.3	40.8
1745	2.230	0.811E-01	14.0	68.	0.90	884.	0.427E 04	56.8
1800	1.660	0.476E-01	14.0	200.	1.00	737.	0.105E 05	33.7
1815	1.380	0.373E-01	7.0	40.	1.40	213.	0.179E 04	62.9
1830	1.480	0.538E-01	0.1	40.	1.40	4.19	0.160E 04	58.7

Figure VII-2. Flow and Quality Data for Seattle, Washington South Seattle Catchment (Industrial, Separate Sewers), Event 3, Event 4, Event 5.

SEATTLE SOUTHCENTER (WA14) CATCHMENT AREA = 24 ACRES
EVENT #2 3/10/73

STORET CODE	61		310	530	630			
HOUR	FLOW (CFS)	RUNOFF (IN/HR)	BOD (MG/L)	TSS (MG/L)	NO2+NO3 (MG/L)	BOD LOAD (MG/SEC)	TSS LOAD (MG/SEC)	NO2+NO3 LOAD (MG/SEC)
30	1.140	0.475E-01	11.0	35.	0.73	355.	0.113E 04	26.2
45	0.123	0.513E-02	8.0	32.	0.65	27.9	111.	2.26
100	2.469	0.103	12.0	140.	0.30	959.	0.977E 04	21.0
115	3.000	0.125	8.0	344.	0.13	680.	0.292E 05	14.7
130	1.840	0.767E-01	4.8	128.	0.10	254.	0.667E 04	5.21
145	1.380	0.575E-01	1.9	44.	0.40	75.3	0.172E 04	15.6
200	1.359	0.630E-01	2.9	36.	0.33	128.	0.139E 04	13.5
215	1.300	0.542E-01	1.4	36.	0.33	51.3	0.132E 04	13.9
300	1.359	0.650E-01	1.4	36.	0.33	41.8	0.139E 04	13.5
315	1.218	0.508E-01	2.2	8.	0.30	75.9	276.	10.3
400	1.650	0.687E-01	2.2	8.	0.30	103.	374.	14.0
415	1.359	0.650E-01	1.0	4.	0.30	44.2	177.	13.3
500	0.663	0.276E-01	1.0	4.	0.30	18.8	75.1	5.63
515	0.243	0.102E-01	1.0	1.	0.30	6.94	6.96	2.06
600	0.210	0.875E-02	1.0	1.	0.30	5.95	5.95	1.78
615	0.210	0.875E-02	1.0	4.	0.30	5.95	23.8	1.78
630	0.210	0.875E-02	1.0	4.	0.30	5.95	23.8	1.78

SEATTLE SOUTHCENTER
EVENT #3 6/6/73

STORET CODE	61		310	530	630			
HOUR	FLOW (CFS)	RUNOFF (IN/HR)	BOD (MG/L)	TSS (MG/L)	NO2+NO3 (MG/L)	BOD LOAD (MG/SEC)	TSS LOAD (MG/SEC)	NO2+NO3 LOAD (MG/SEC)
1145	0.012	0.500E-03	1.6	37.	0.23	0.544	12.6	0.930E-01
1200	0.012	0.500E-03	1.6	37.	0.33	0.544	12.6	0.930E-01
1230	0.014	0.583E-03	76.0	84.	0.33	30.1	33.3	0.973E-01
1245	1.790	0.746E-01	20.0	910.	1.60	0.101E 04	0.461E 05	81.1
1300	1.400	0.583E-01	16.0	140.	1.10	634.	0.555E 04	43.6
1315	1.120	0.467E-01	8.0	82.	0.70	254.	0.260E 04	22.2
1330	1.390	0.462E-01	9.0	90.	0.30	405.	0.403E 04	[illegible]
1345	1.120	0.467E-01	6.3	70.	0.40	200.	0.222E 04	12.7
1400	1.060	0.442E-01	5.7	54.	0.33	171.	0.162E 04	10.3
1415	0.930	0.388E-01	6.5	56.	0.30	169.	0.144E 04	7.85
1430	1.120	0.467E-01	7.1	38.	0.30	225.	0.178E 04	9.52
1445	0.830	0.346E-01	9.3	30.	0.30	219.	705.	7.05
1530	0.780	0.325E-01	9.3	30.	0.30	205.	442.	6.63
1545	1.030	0.429E-01	6.4	26.	0.30	187.	758.	8.75
1630	0.450	0.187E-01	6.4	26.	0.30	81.6	331.	3.82
1645	0.290	0.104E-01	3.4	30.	0.33	24.1	142.	2.46
1730	0.093	0.396E-02	3.4	30.	0.33	9.15	53.8	0.942

SEATTLE SOUTHCENTER
EVENT #7 11/17/74

STORET CODE	61		310	530	630			
HOUR	FLOW (CFS)	RUNOFF (IN/HR)	BOD (MG/L)	TSS (MG/L)	NO2+NO3 (MG/L)	BOD LOAD (MG/SEC)	TSS LOAD (MG/SEC)	NO2+NO3 LOAD (MG/SEC)
715	0.050	0.208E-02	8.5	460.	0.42	11.9	586.	0.505
730	0.310	0.125E-01	15.0	44.	0.36	132.	382.	4.92
745	0.360	0.233E-01	105.0	42.	0.85	0.107E 04	482.	13.3
800	0.590	0.244E-01	70.0	46.	0.78	0.117E 04	769.	13.0
815	0.660	0.273E-01	10.0	30.	0.59	187.	561.	11.0
830	0.710	0.313E-01	8.6	40.	0.32	183.	850.	11.0
845	0.800	0.333E-01	32.0	32.	0.24	725.	725.	8.14
900	0.900	0.208E-01	4.4	30.	0.27	90.6	425.	3.85
915	1.390	0.579E-01	7.3	62.	0.20	287.	0.244E 04	7.87
930	1.190	0.496E-01	5.3	46.	0.17	179.	0.202E 04	5.73
945	1.750	0.729E-01	4.1	38.	0.14	203.	0.188E 04	6.94
1000	1.330	[illegible]	23.0	76.	0.12	879.	0.271E 04	4.97
1015	1.330	[illegible]	3.9	82.	0.10	138.	0.337E 04	3.82
1030	1.370	[illegible]	3.7	72.	0.08	137.	0.279E 04	[illegible]
1045	1.350	[illegible]	3.8	44.	0.07	107.	0.168E 04	[illegible]
1100	1.230	0.512E-01	3.0	34.	0.08	69.7	0.115E 04	2.79
1115	1.190	0.496E-01	3.0	20.	0.08	101.	674.	2.70
1130	0.880	0.275E-01	1.3	20.	0.08	24.3	274.	1.30
1145	0.310	0.129E-01	3.1	10.	0.10	18.4	87.8	0.878
1245	0.370	0.154E-01	2.8	24.	0.16	29.3	281.	1.06
1545	0.100	0.417E-02	4.1	18.	0.23	11.6	31.0	0.631
1715	0.100	0.417E-02	7.7	16.	0.30	21.8	45.3	0.850

Figure VII-3. Flow and Quality Data for Seattle, Washington Southcenter Catchment (Shopping Center, Separate Sewers), Event 2, Event 3, Event 7.

Figure VII-4. BOD Load vs. Flow. Top: View Ridge 1 catchment - (*) Event 1, (0) Event 6, (X) Event 7. Middle: South Seattle catchment - (*) Event 3, (0) Event 4, (X) Event 5. Bottom: Southcenter catchment - (*) Event 2, (0) Event 3, (X) Event 7.

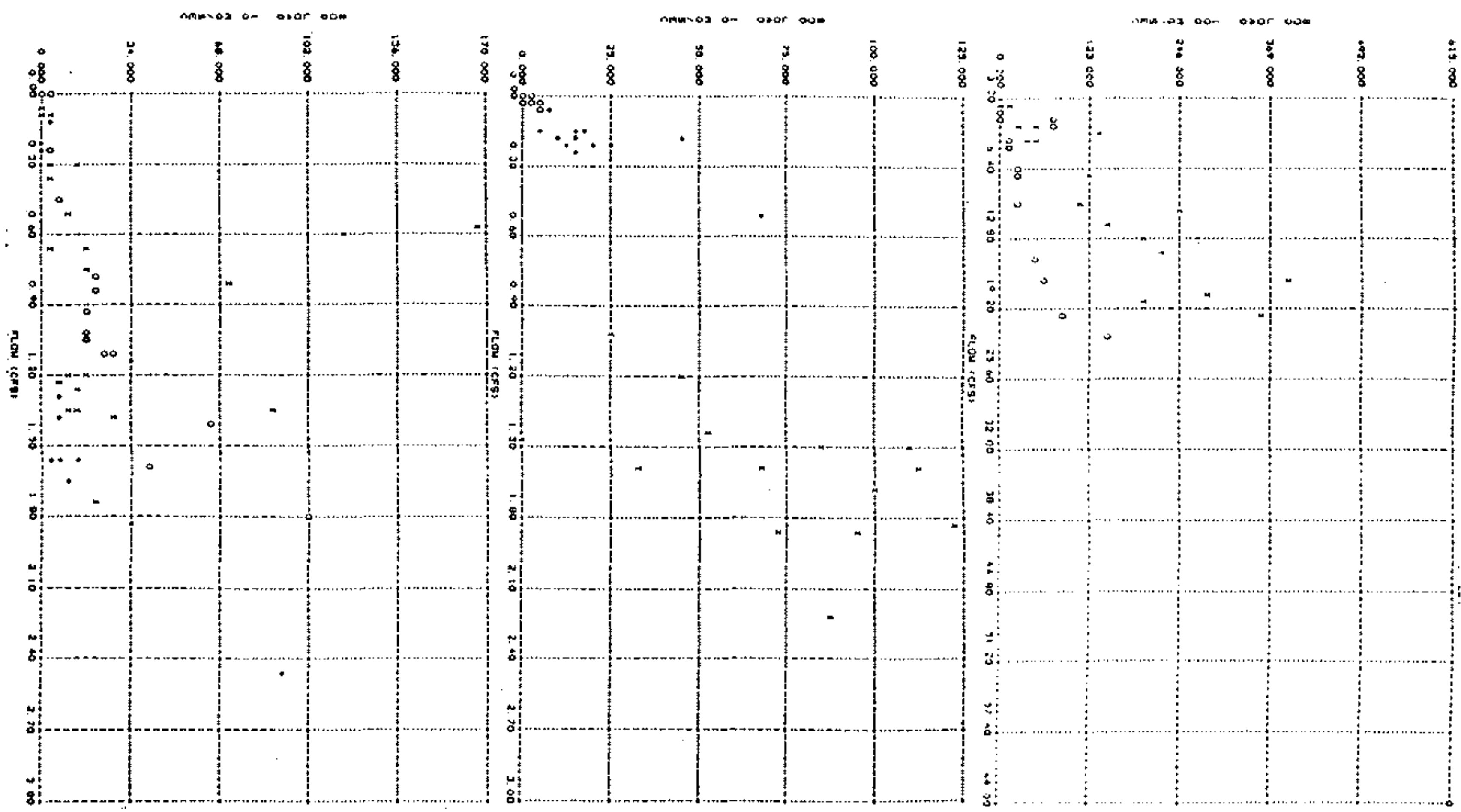


Figure VII-5. TSS Load Vs. Flow. Same symbols as Figure VII-4.

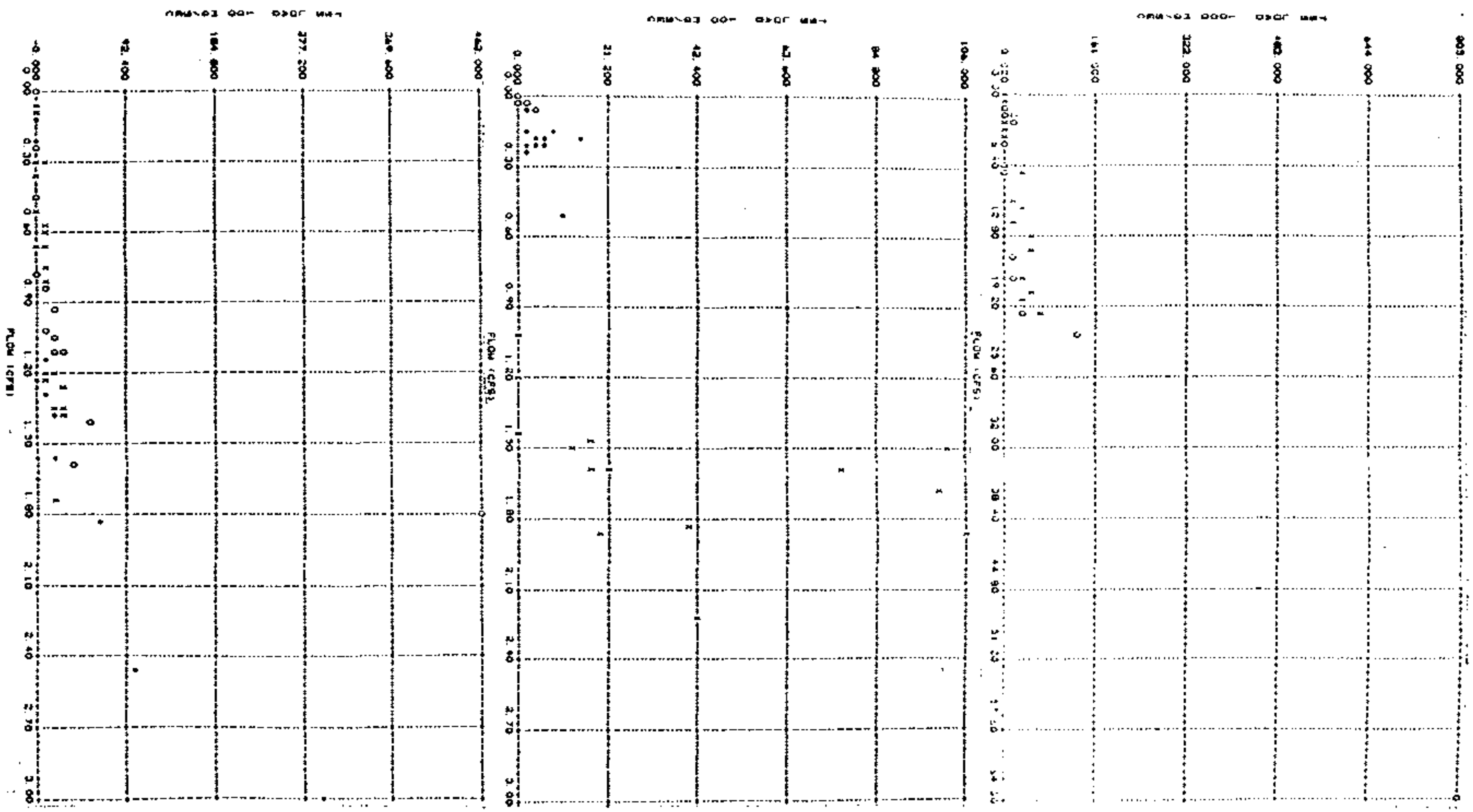


Figure VII-6. NO_2-N + NO_3-N Load Vs. Flow. Same symbols as Figure VII-4.

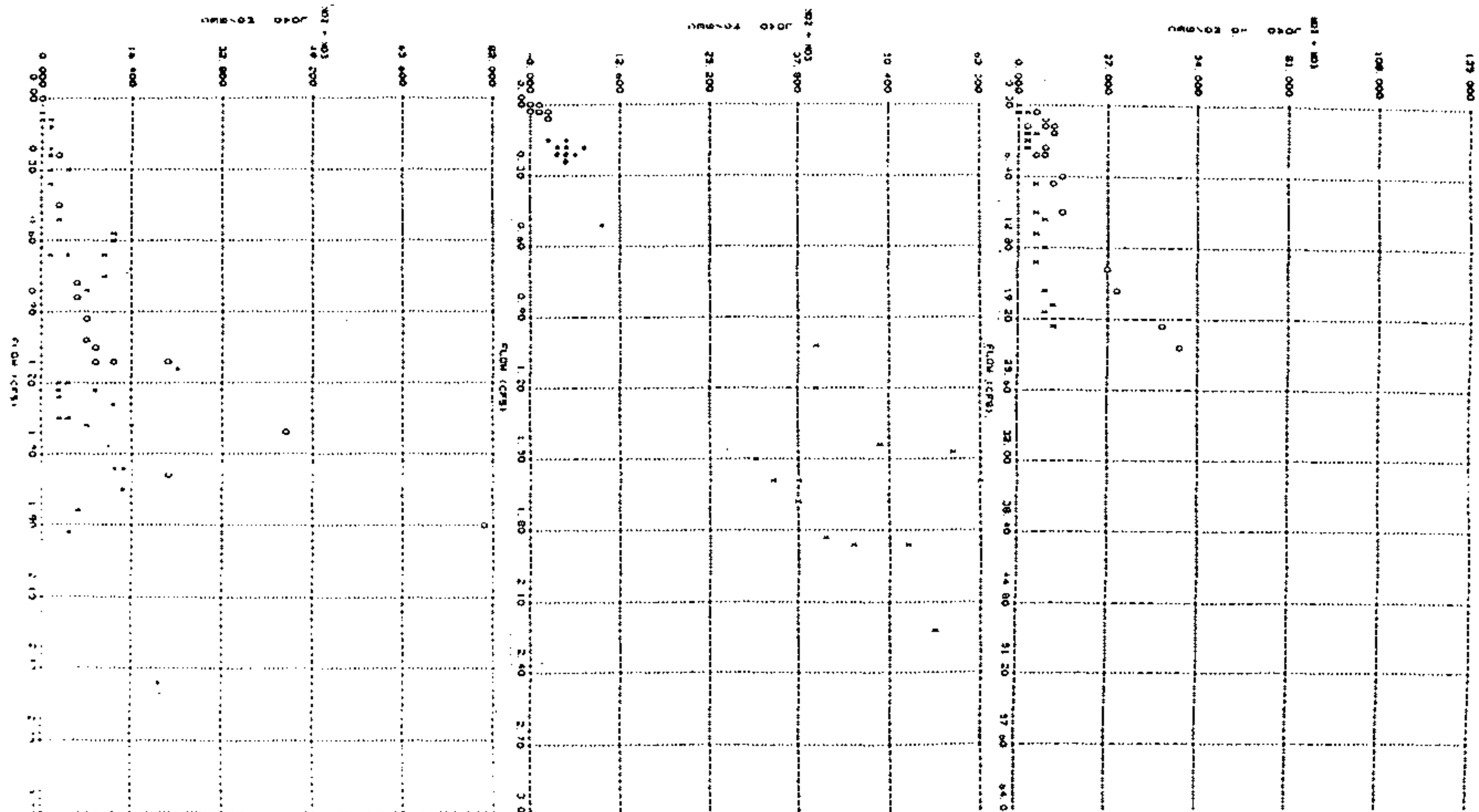


Figure VII-7. Log_{10} BOD Load Vs. Log_{10} Flow. Same symbols as Figure VII-4.

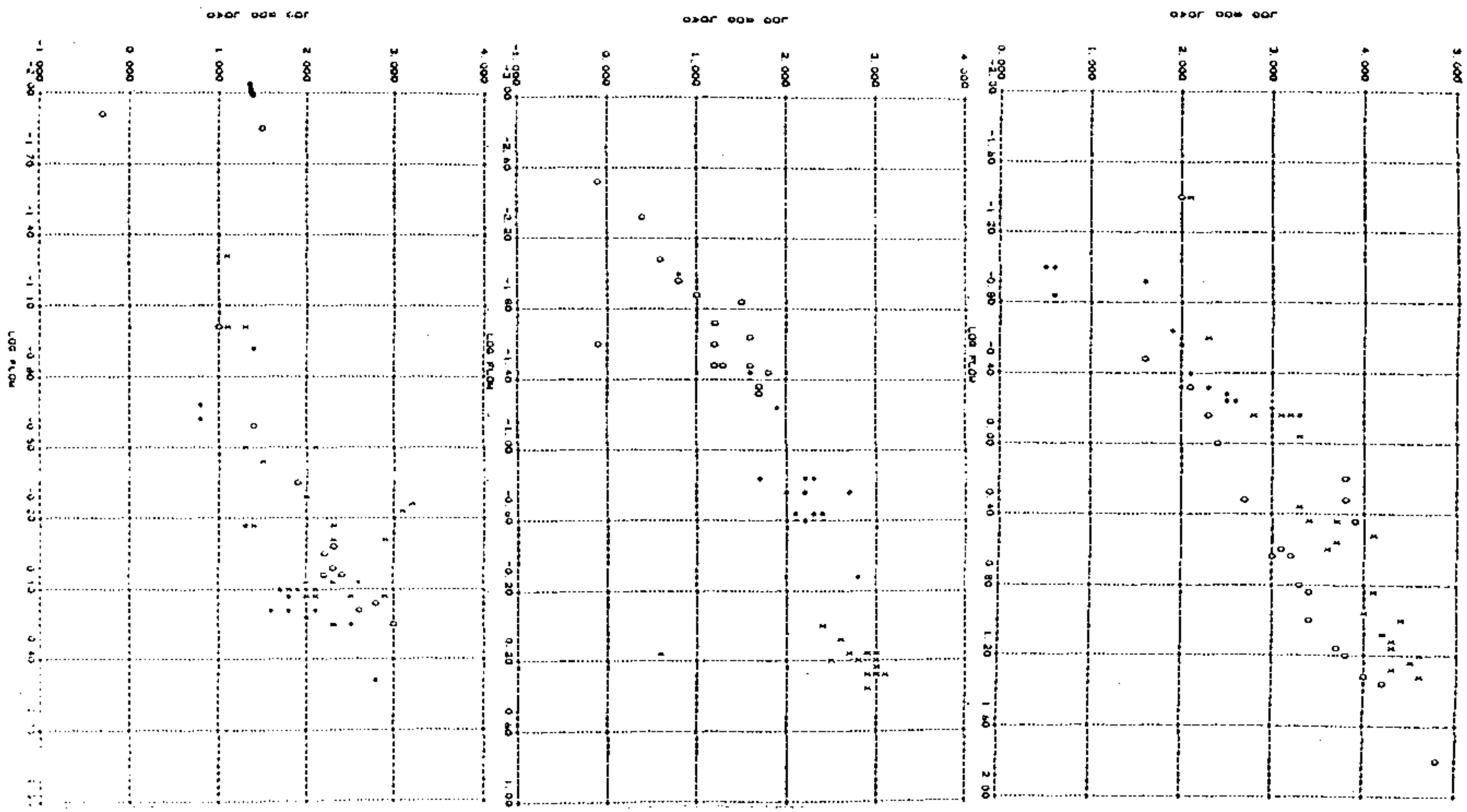


Figure VII-8. Log_{10} TSS Load Vs. Log_{10} Flow. Same symbols as Figure VII-4.

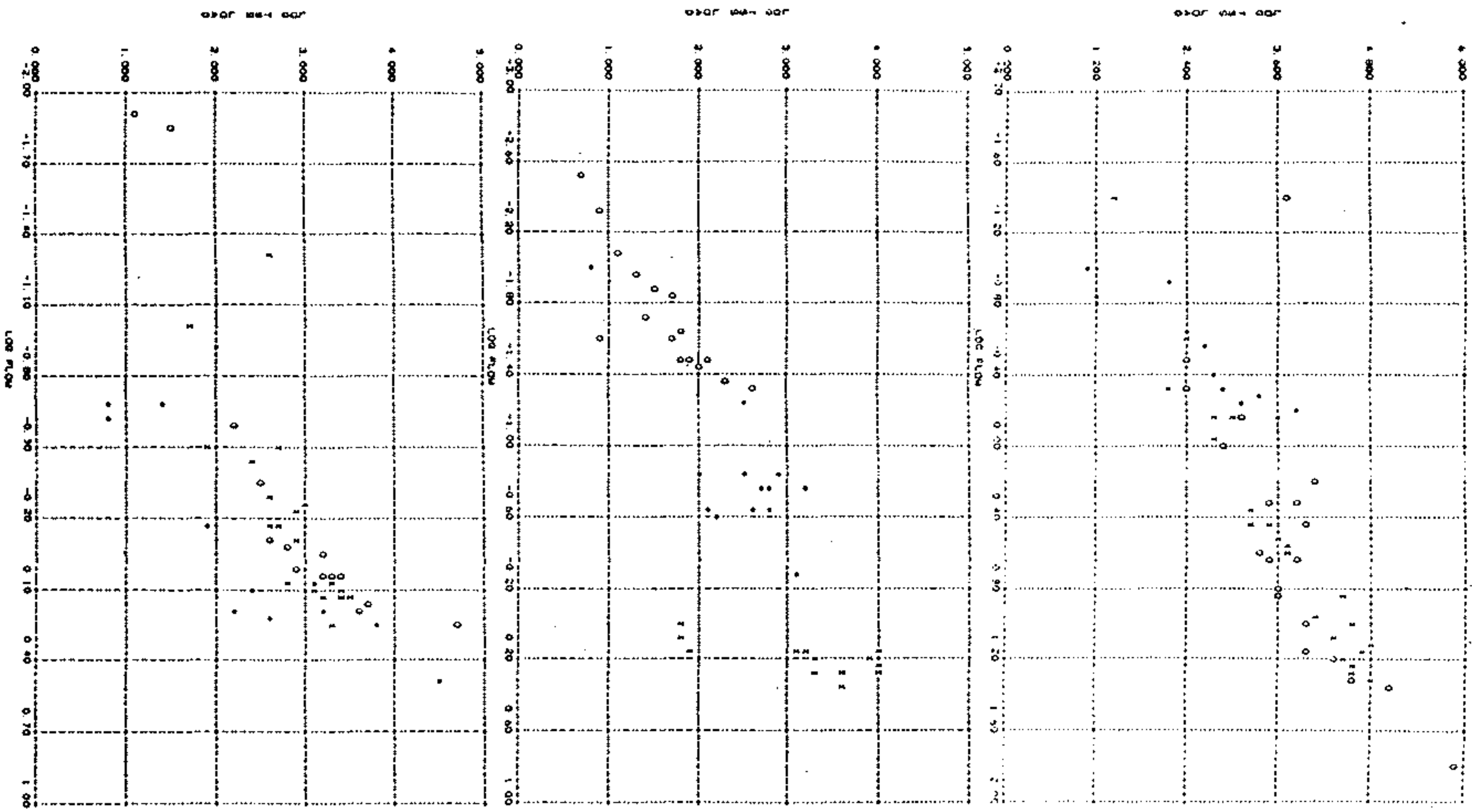


Figure VII-9. Log_{10} NO_2-N + NO_3-N Load Vs. Log_{10} Flow. Same symbols as Figure VII-4.

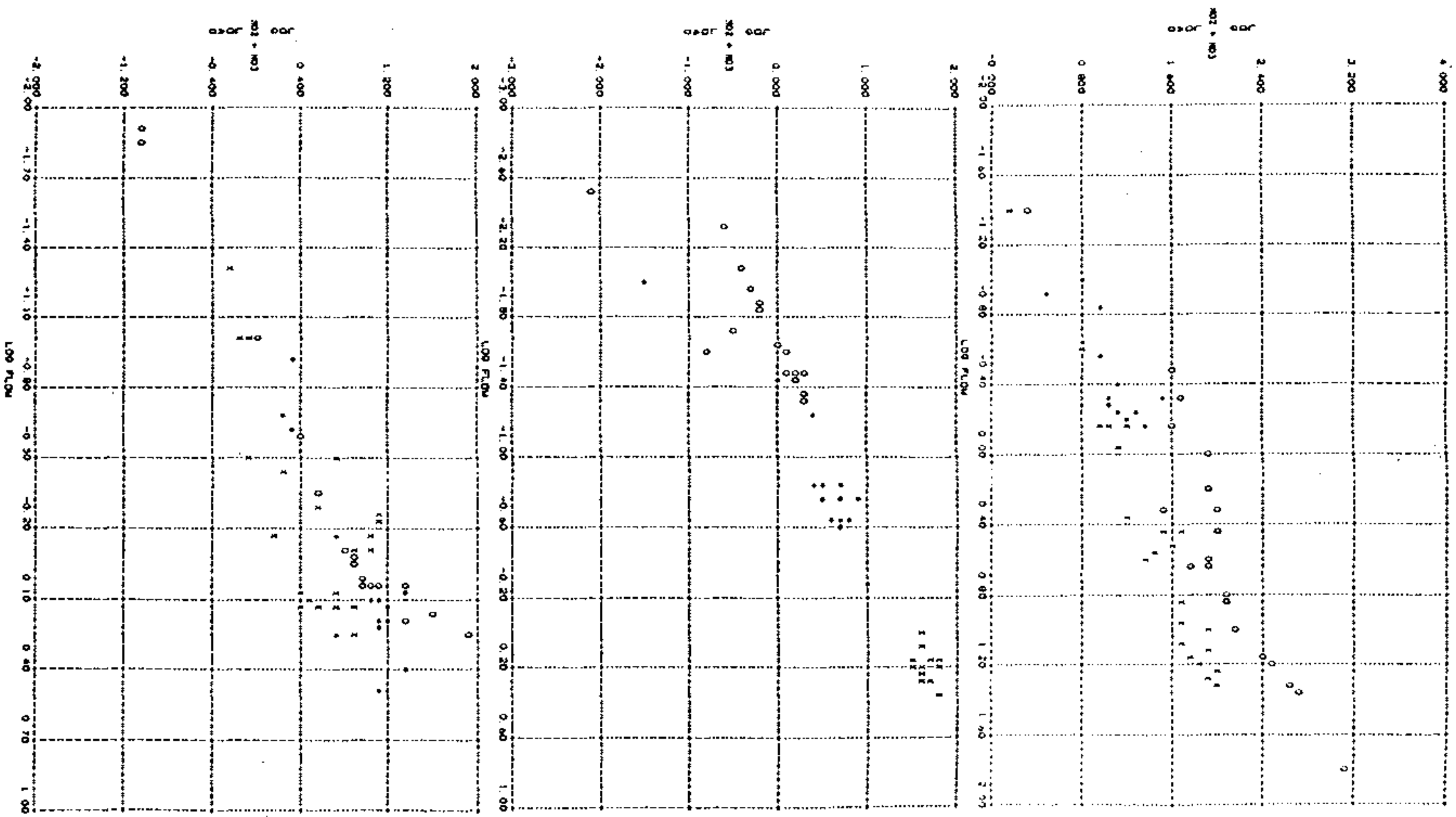


Figure VII-10. Log_{10} Load Vs. Log_{10} Flow for all Events. (1) View Ridge 1 - Event 1, (2) View Ridge 1 - Event 6, (3) View Ridge - Event 7, (4) South Seattle - Event 3, (5) South Seattle - Event 4, (6) South Seattle - Event 5, (7) Southcenter - Event 2, (8) Southcenter - Event 3, (9) Southcenter - Event 7.

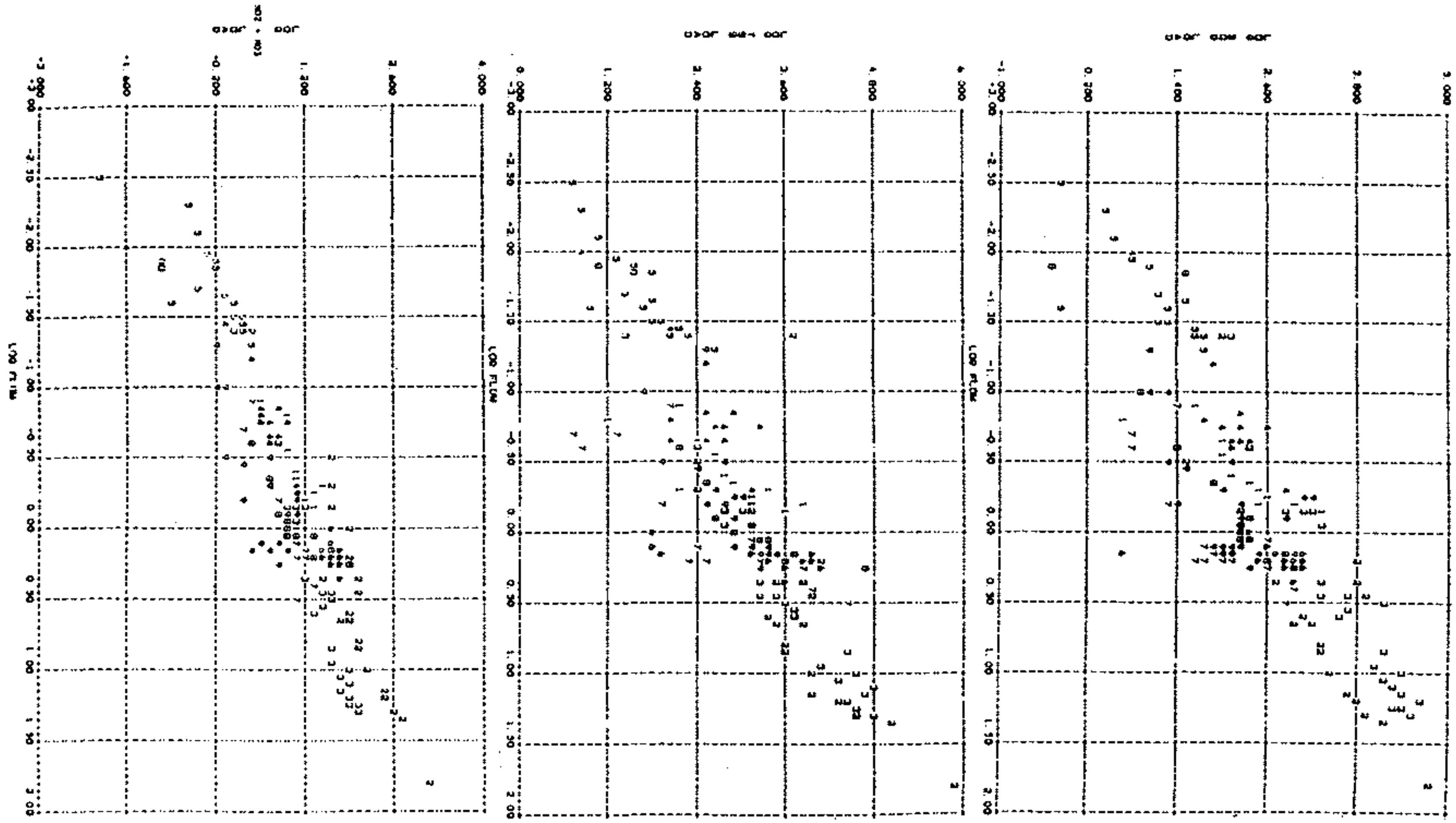


Figure VII-11. Log$_{10}$ Load Vs. Log$_{10}$ Runoff for All Events BOD, TSS and NO_2-N + NO_3-N. Same notation as Figure VII-10.

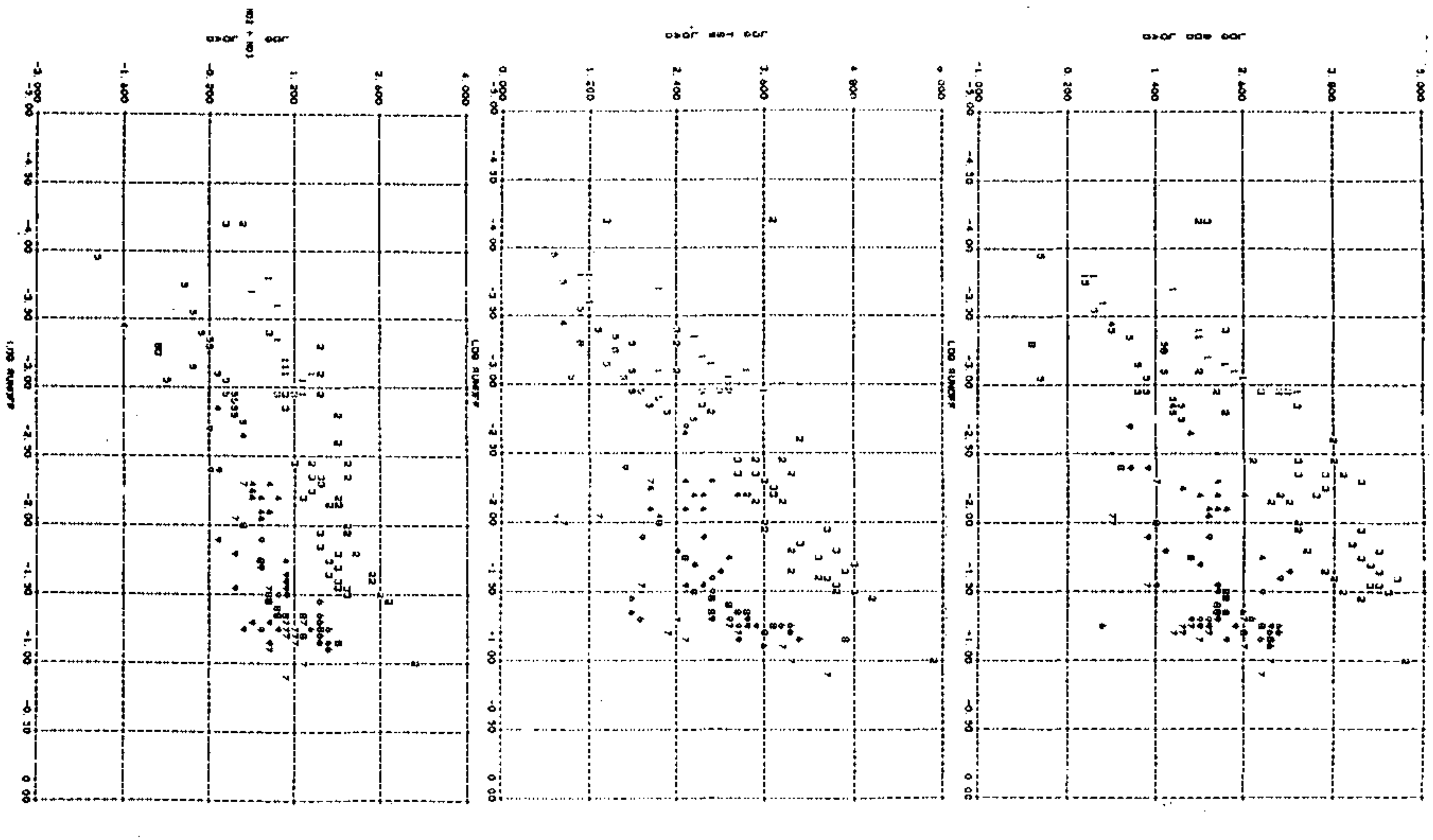
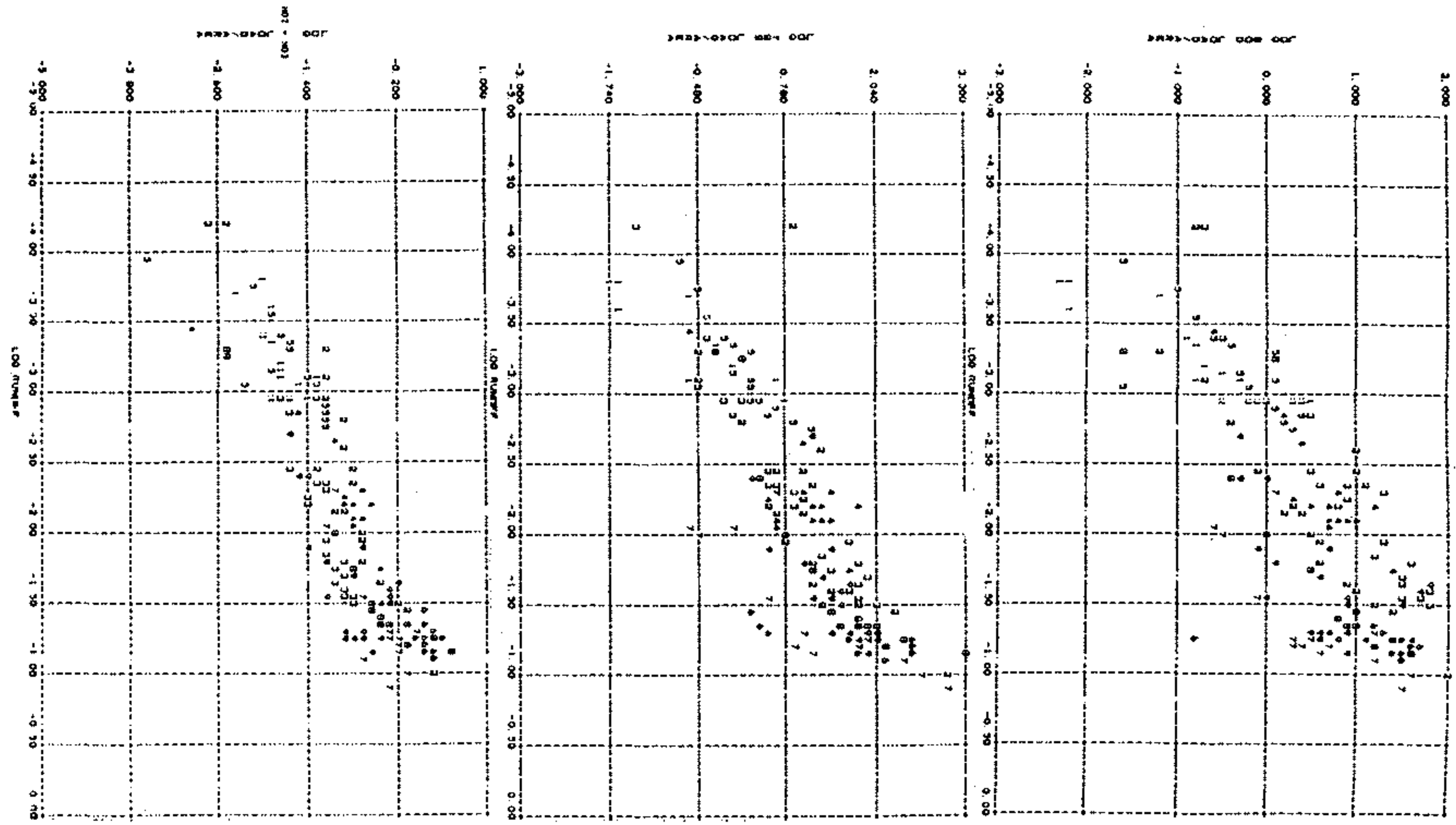


Figure VII-12. $\log_{10}$ Load/Area Vs. $\log_{10}$ Runoff for All Events BOD, TSS, & NO_2-N + NO_3-N. Same notation as Figure VII-10.



LANCASTER, PA. EVENT#1 9/14/73

OBS	TIME1	FLOW1	BOD1	TSS1	NO31	LOADBOD1	LOADTSS1	LOADNO31
1	733	2.180	43	31	9.0	2654.7	3149	333.84
2	743	1.893	45	119	13.0	2412.4	6163	696.97
3	753	1.139	50	34	13.0	1591.0	1083	414.18
4	803	0.710	130	38	14.0	2613.9	764	281.90
5	813	1.984	170	32	13.0	10675.3	2922	730.43
6	823	1.134	103	34	14.0	3941.3	1734	449.61
7	833	2.043	76	81	13.0	3934.3	4686	732.13
8	843	2.333	47	126	10.0	3131.9	8396	646.37
9	853	1.706	43	123	9.0	2077.5	5943	434.83
10	903	1.920	41	130	9.0	2229.4	7069	489.37
11	913	2.456	26	47	8.0	1808.4	3269	556.43
12	923	0.930	36	38	9.0	931.3	1004	237.80
13	933	[illegible]	37	144	8.0	2402.7	9331	389.83
14	943	9.718	43	169	8.0	8180.0	32133	951.87
15	953	7.300	46	144	8.0	9909.9	30444	1033.88
16	1003	27.436	33	153	8.0	19263.3	101547	3310.84
17	1013	9.130	18	[illegible]	5.0	4649.0	34020	1391.37
18	1023	3.219	30	[illegible]	6.0	1833.3	3470	349.97
19	1033	4.304	17	[illegible]	5.0	2189.4	8419	637.77
20	1043	3.760	23	[illegible]	3.0	1747.8	4490	340.93
21	1053	3.980	23	[illegible]	3.0	2480.9	7443	343.93
22	1113	3.740	31	56	7.0	2405.5	4265	363.18
23	1143	0.864	63	64	0.7	1550.4	1575	17.23
24	1213	6.924	25	79	0.6	4902.3	14707	117.93
25	1243	2.042	44	1	0.5	2544.3	58	28.91
26	1313	2.384	23	1	0.6	1552.8	68	40.31

LANCASTER, PA. EVENT#2 10/29/73

OBS	TIME2	FLOW2	BOD2	TSS2	NO32	LOADBOD2	LOADTSS2	LOADNO32
1	811	23.047	74	120	12	49976	81042	8104.2
2	821	11.144	72	141	10	22720	44499	3156.9
3	831	16.403	96	219	9	44601	101743	4181.3
4	841	42.347	58	156	7	69886	187969	8434.3
5	851	47.066	124	343	9	165281	456854	11996.3
6	901	9.774	49	117	9	13008	31060	2389.3
7	911	47.244	48	125	9	64224	167251	12042.1
8	921	47.473	68	117	7	91420	157296	9410.0
9	931	26.759	24	107	5	18188	81086	3789.1
10	941	37.486	12	81	8	12739	85990	8492.8
11	951	69.329	18	57	4	35443	112234	7874.3
12	1001	103.216	37	44	4	108154	128615	11692.3
13	1011	33.306	76	66	6	39399	69703	6061.3
14	1041	13.313	17	43	5	7469	18891	2196.6

LANCASTER, PA. EVENT#3 11/24/73

OBS	TIME3	FLOW3	BOD3	TSS3	NO33	LOADBOD3	LOADTSS3	LOADNO33
1	1320	10.63	60	392	15	18062.5	118008	4515.62
2	1330	8.11	52	350	13	11943.1	80384	2794.10
3	1340	6.38	112	303	12	20234.3	54478	2168.19
4	1350	6.31	189	210	13	33774.1	37527	2323.09
5	1400	3.02	131	136	14	11204.0	11575	1038.78
6	1410	3.96	157	100	13	17741.3	11138	1490.35
7	1420	2.92	146	58	17	12073.4	4799	1403.80
8	1430	2.53	155	63	14	11105.7	3947	1003.09
9	1440	3.26	142	1	13	13120.6	106	1384.28
10	1450	2.18	151	60	13	9322.4	3704	803.39

LANCASTER, PA. EVENT#4 11/28/73

OBS	TIME4	FLOW4	BOD4	TSS4	NO34	LOADBOD4	LOADTSS4	LOADNO34
1	1528	27.360	587	1172	7.2	454828	908107	5578.81
2	1538	16.661	310	798	6.0	146444	376490	2834.44
3	1548	29.737	147	466	6.2	123796	392443	5221.36
4	1558	10.738	147	456	7.0	44703	138670	2128.70
5	1608	5.333	126	792	8.4	19084	119369	1266.04
6	1618	9.198	110	298	13.3	28634	77623	3316.38
7	1628	5.023	83	252	11.7	11803	35840	1664.01
8	1638	5.633	97	118	13.6	15480	18831	2138.41
9	1648	4.333	85	114	15.0	10440	14641	1920.47

LANCASTER, PA. EVENT#5 12/11/74

OBS	TIME5	FLOW5	BOD5	TSS5	NO35	LOADBOD5	LOADTSS5	LOADNO35
1	6	27.827	170	818	9	133970	644634	7093.3
2	16	10.236	70	564	10	20292	163494	2898.8
3	26	10.016	45	256	11	12764	72615	3120.2
4	36	13.644	53	186	10	20479	71870	3864.0
5	46	22.934	35	250	6	22732	162373	3895.4
6	56	[illegible]	107	878	4	202081	1658194	7554.6
7	106	35.793	100	848	5	101371	879904	5068.6
8	116	41.593	40	570	4	47113	671399	4711.3
9	126	127.633	36	488	3	130124	1763908	10843.7
10	136	126.358	35	534	3	125244	1910897	10735.6
11	146	76.176	14	190	4	30203	[illegible]	[illegible]
12	156	32.649	15	320	4	14776	295516	3693.9
13	206	21.491	14	286	4	8521	174067	2434.3
14	216	54.162	12	246	4	18404	377331	6135.3
15	246	32.913	12	228	4	9607	132429	2261.8
16	306	38.706	30	150	9	32883	164423	9865.6
17	346	11.168	60	78	10	18977	24670	3162.8

Figure VII-13. Flow and Quality Data for Stevens Avenue Catchment (Single and Multi-Family Residential, Combined Sewers), Lancaster, Pennsylvania. Parameters are: Flow (cfs); BOD, TSS, NO_3-N concentration (mg/l); BOD, TSS and NO_3-N loads (mg/sec).

Figure VII-14. BOD Concentration Vs. Flow, Event 1, Event 2, Event 6. Sequence of letters follows time history.

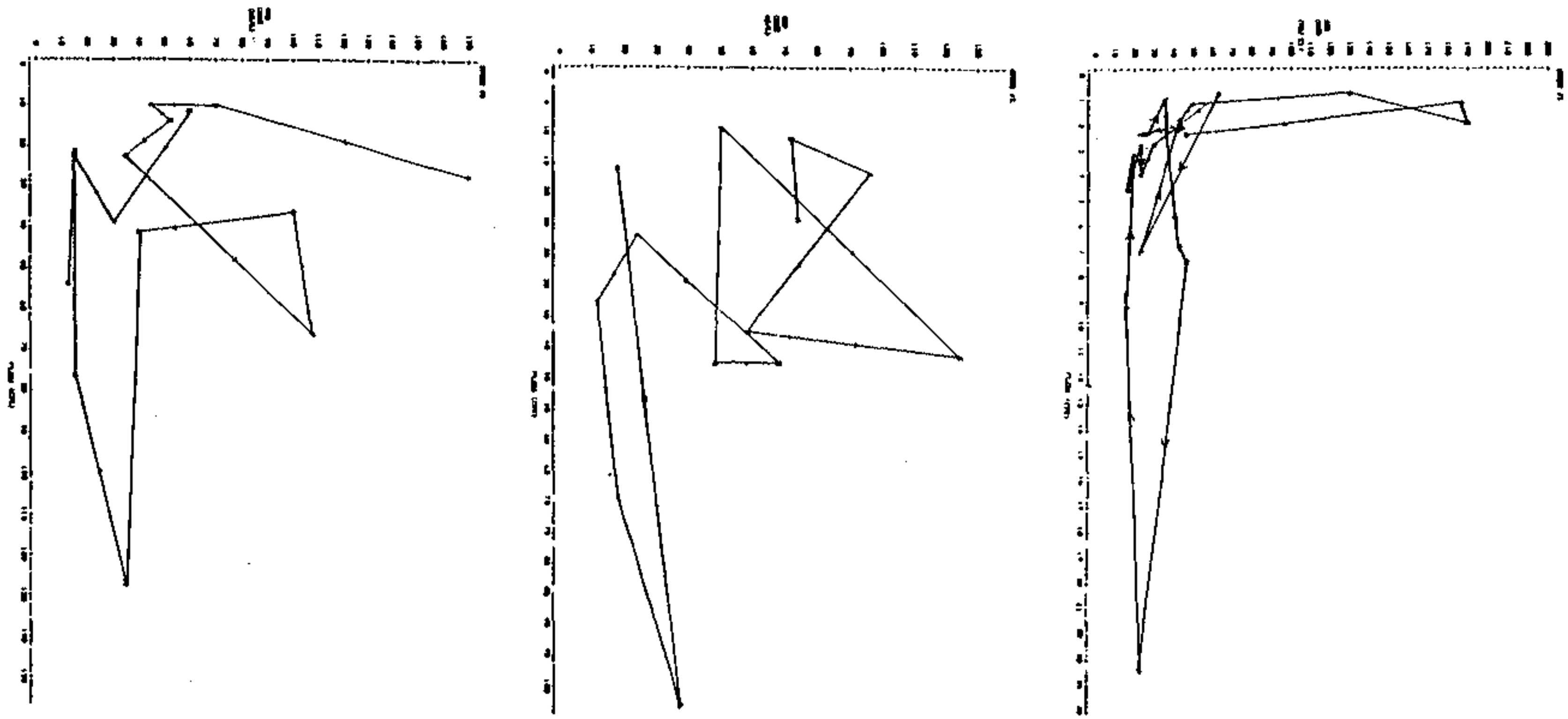


Figure VII-15. TSS Concentration Vs. Flow, Event 1, Event 2, Event 6. Sequence of letters follows time history.

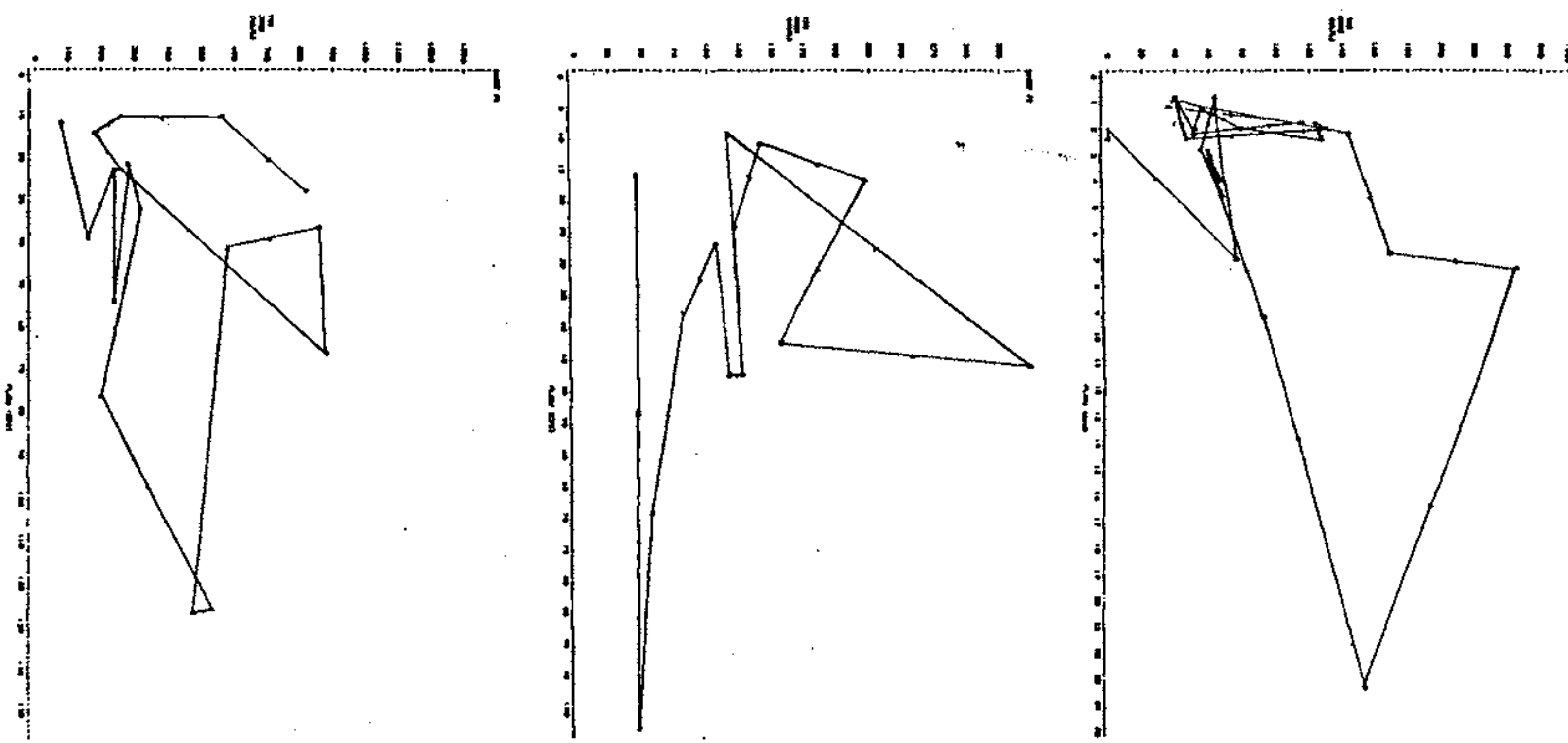


Figure VII-16. NO_3-N Concentration Vs. Flow, Event 1, Event 2, Event 6. Sequence of letters follows time history.

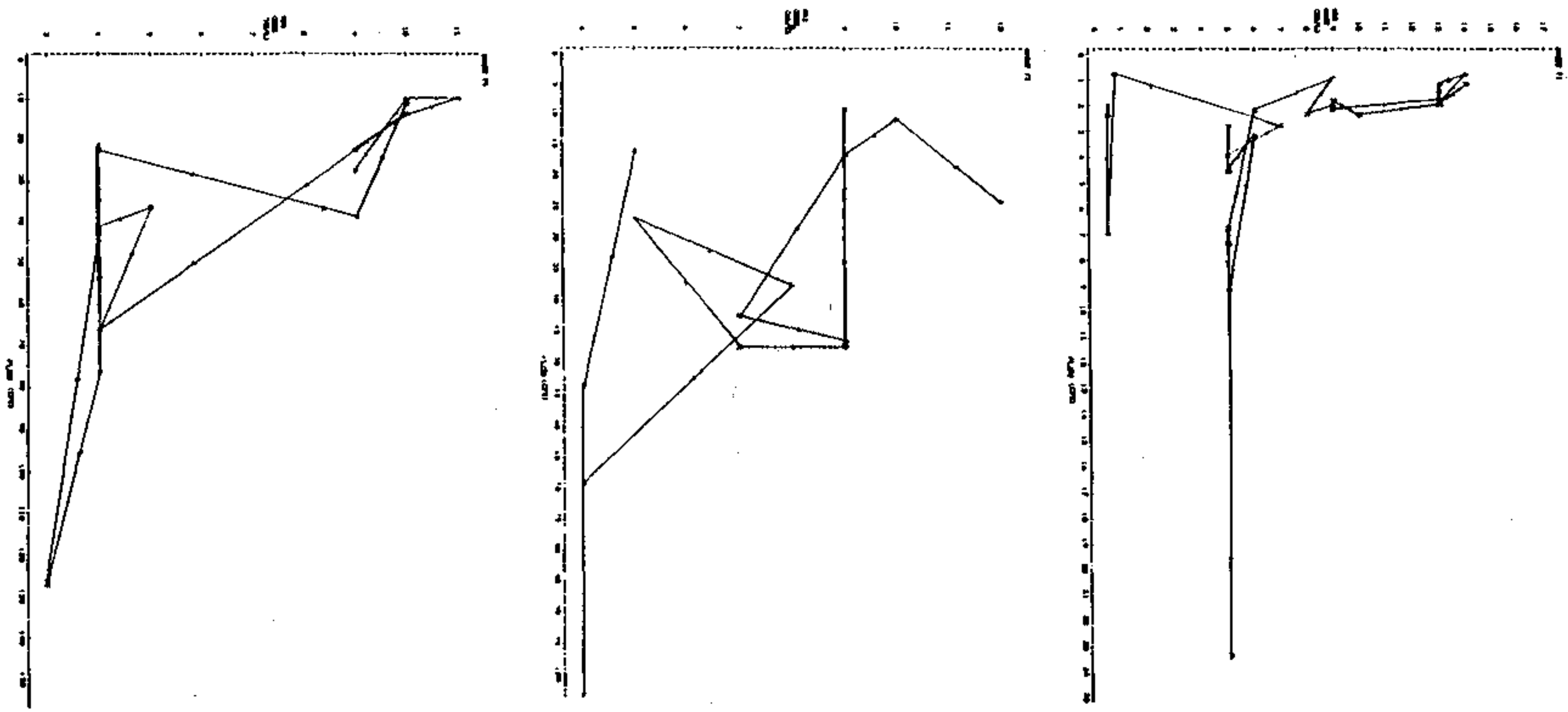


Figure VII-17. BOD Load Vs. Flow, Event 1, Event 2, Event 6. Sequence of letters follows time history.

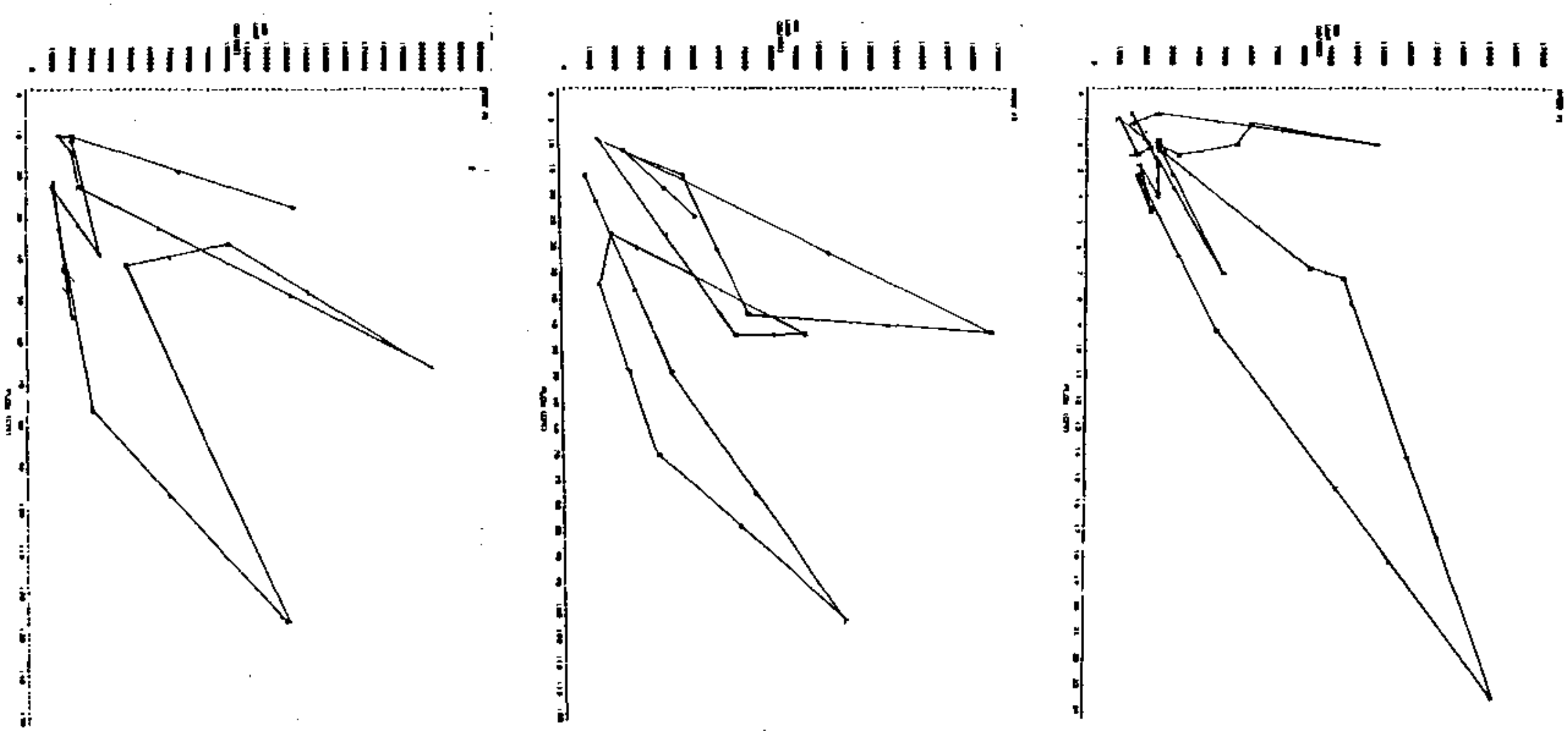


Figure VII-18. TSS Load Vs. Flow, Event 1, Event 2, Event 6. Sequence of letters follows time history.

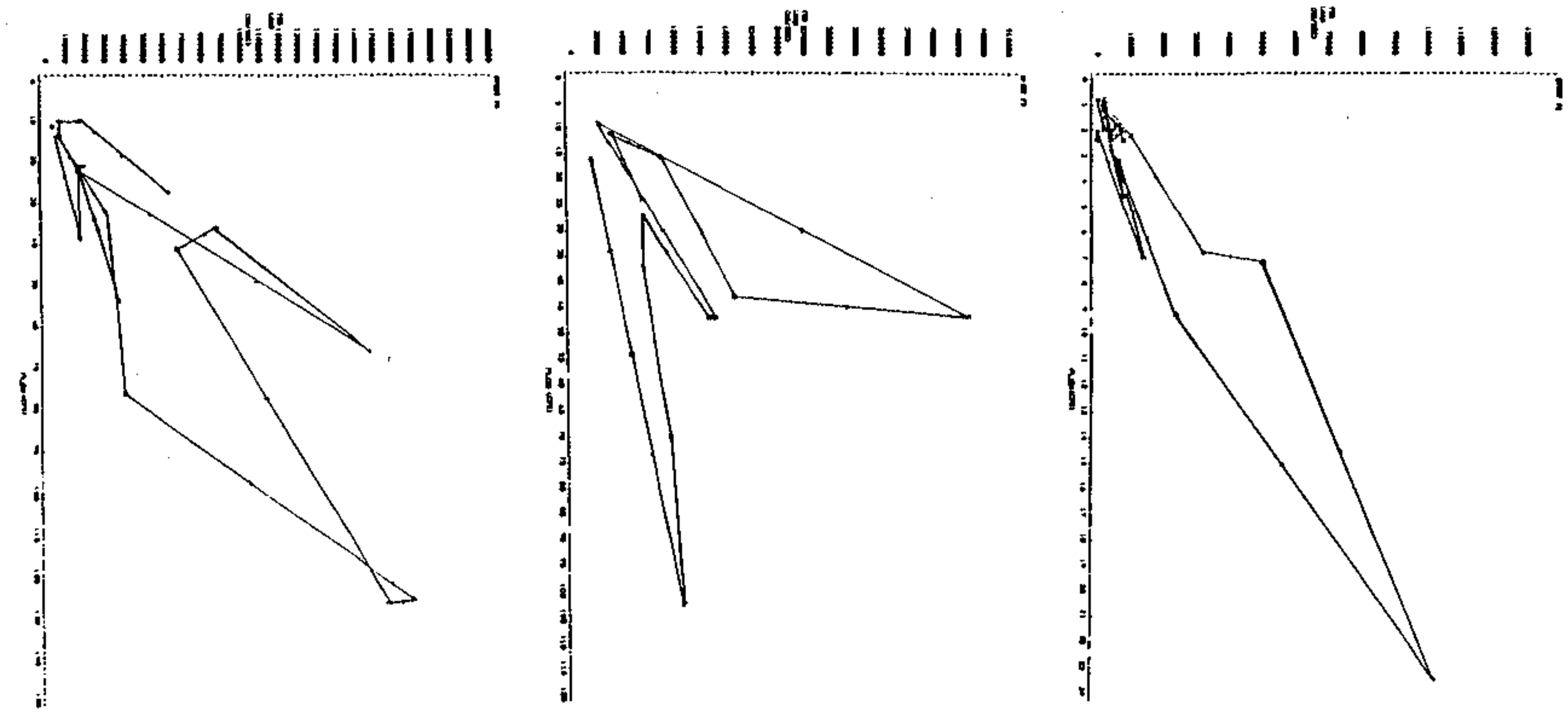


Figure VII-19. NO_3-N Load Vs. Flow, Event 1, Event 2, Event 6. Sequence of letters follows time history.

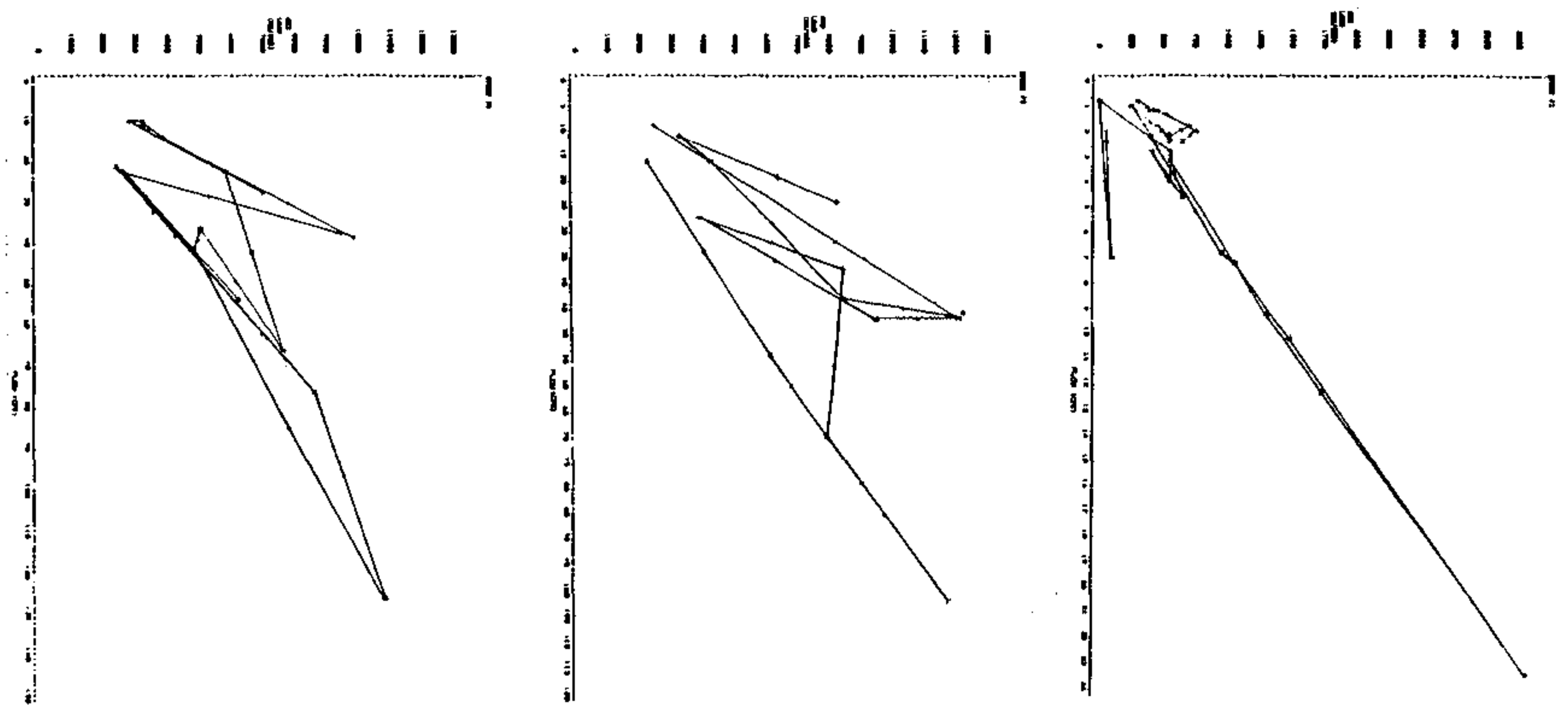


Figure VII-20. Log_{10} Concentration Vs. Log_{10} Flow for All Events, BOD, TSS, NO_3-N. (1) Event 1, (2) Event 2, (3) Event 3, (4) Event 4, (5) Event 6.

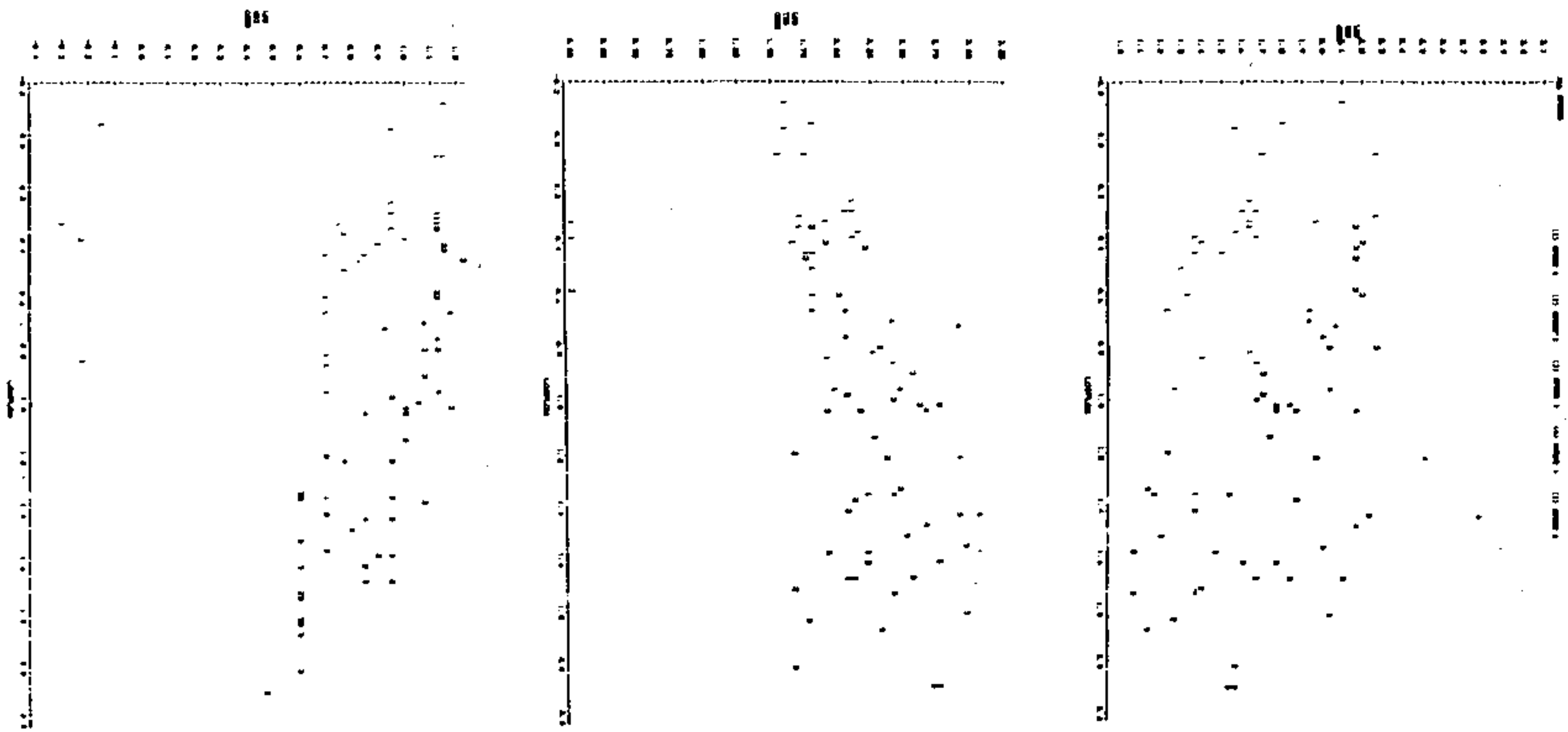
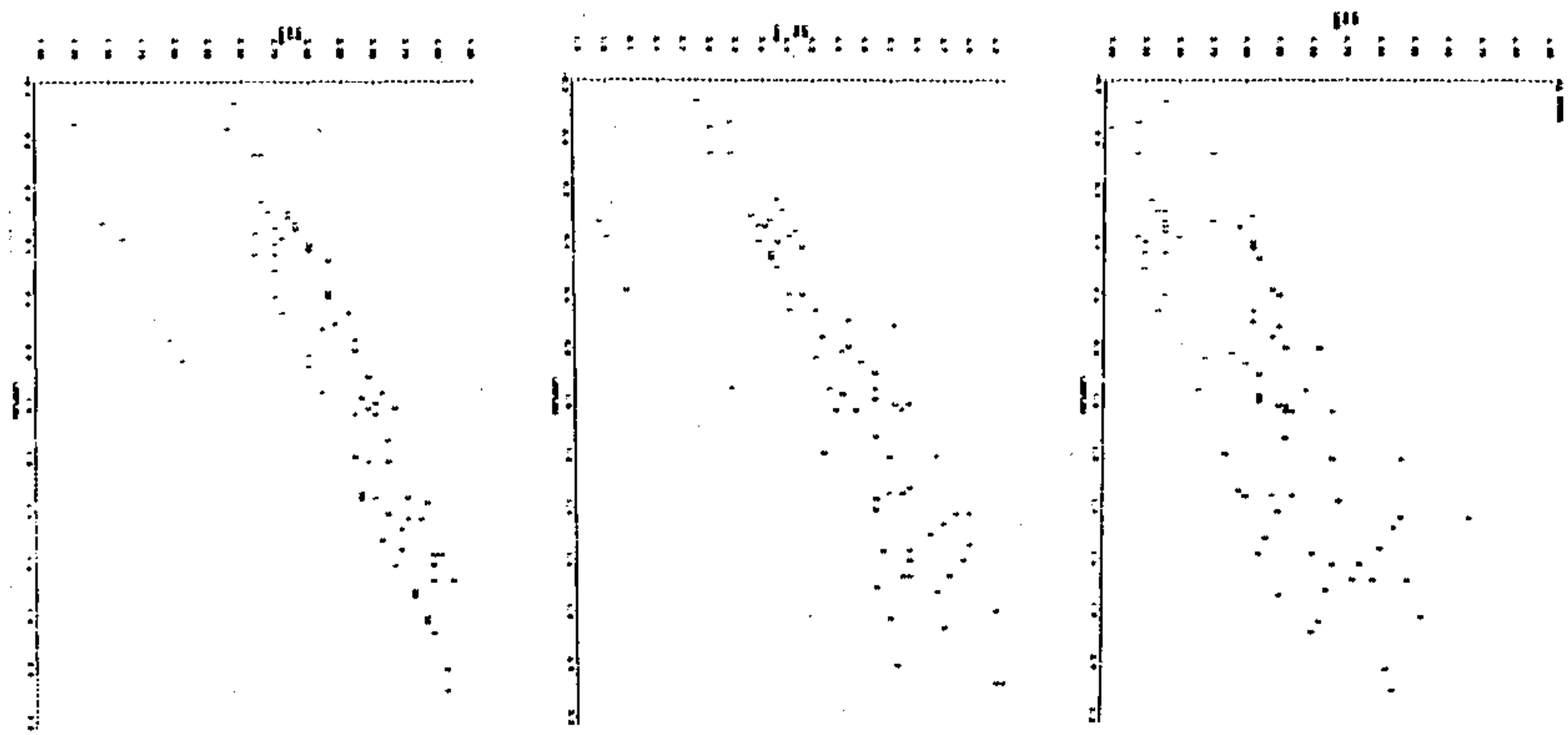


Figure VII-21. Log_{10}Load Vs. Log_{10}Flow for All Events, BOD, TSS, NO_3-N. (1) Event 1, (2) Event 2, (3) Event 3, (4) Event 4, (5) Event 6.



APPENDIX VIII

MISCELLANEOUS TRANSPORT BLOCK TABLES

The following tables provide guidelines for input into the infiltration (subroutine INFIL) and dry-weather flow (subroutine FILTH) routines of the Transport Block. Table VIII-1 gives average degree-days (cumulative deviation below 65°F, summed for the days of each month) for several U.S. cities. Current values are also tabulated in various summary forms by the National Weather Service.

Tables VIII-2 and VIII-3 provide guidelines for relative water use by various commercial establishments and industries. These may be entered as process flows in card groups P1 and Q1, for instance.

Table VIII-1. Average Monthly Degree-days for Cities in the United States (Base 65F).

State	Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June
Ala.	Anniston	0	0	17	118	438	614	614	485	381	128	25	0
	Birmingham	0	0	13	123	396	598	623	491	378	128	30	0
	Mobile	0	0	0	23	198	357	412	290	209	40	0	0
	Montgomery	0	0	0	55	267	458	483	360	265	66	0	0
Ariz.	Flagstaff	49	78	243	586	876	1135	1231	1014	949	687	465	212
	Phoenix	0	0	0	13	182	360	425	275	175	62	0	0
	Yuma	0	0	0	0	105	259	318	167	88	14	0	0
Ark.	Bentonville	1	1	38	216	516	810	879	716	519	247	86	7
	Fort Smith	0	0	9	131	435	698	775	571	418	127	24	0
	Little Rock	0	0	10	110	405	654	719	543	401	122	18	0
Calif.	Eureka	267	248	264	335	411	508	552	465	493	432	375	282
	Fresno	0	0	0	86	345	580	629	400	304	145	43	0
	Independence	0	0	28	216	512	778	799	619	477	267	120	18
	Los Angeles	0	0	17	41	140	253	328	244	212	129	68	19
	Needles	0	0	0	19	217	416	447	243	124	26	3	0
	Point Reyes	350	336	263	282	317	425	467	406	437	413	415	363
	Red Bluff	0	0	0	59	319	564	617	423	336	117	51	0
	Sacramento	0	0	17	75	321	567	614	403	317	196	85	5
	San Diego	11	7	24	52	147	255	317	247	223	151	97	43
	San Francisco	189	177	110	128	237	406	462	336	317	279	248	180
	San Jose	7	11	26	97	270	450	487	342	308	229	137	46
Colo.	Denver	0	5	103	385	711	958	1042	854	797	492	266	60
	Durango	25	37	201	535	861	1204	1271	1002	859	615	394	139
	Grand Junction	0	0	36	333	792	1132	1271	924	738	402	145	23
	Leadville	280	332	509	841	1139	1413	1470	1285	1245	990	740	434
	Pueblo	0	0	74	383	771	1051	1104	865	775	456	203	27
Conn.	Hartford	0	14	101	384	699	1082	1178	1050	871	528	201	31
	New Haven	0	18	93	363	663	1026	1113	1005	865	567	261	52
D. C.	Washington	0	0	32	231	510	831	884	770	606	314	80	0
Fla.	Apalachicola	0	0	0	17	154	304	352	263	184	33	0	0
	Jacksonville	0	0	0	11	129	276	303	226	154	14	0	0
	Key West	0	0	0	0	0	18	28	24	7	0	0	0
	Miami	0	0	0	0	5	48	57	48	15	0	0	0
	Pensacola	0	0	0	18	177	334	383	275	203	45	0	0
	Tampa	0	0	0	0	60	163	201	148	102	0	0	0
Ga.	Atlanta	0	0	8	107	387	611	632	515	392	135	24	0
	Augusta	0	0	0	59	282	494	521	412	308	62	0	0
	Macon	0	0	0	63	280	481	497	391	275	62	0	0
	Savannah	0	0	0	38	225	412	424	330	238	43	0	0
	Thomasville	0	0	2	48	208	361	359	299	178	52	5	1
Idaho	Boise	0	0	135	389	762	1054	1169	868	719	453	249	92
	Lewiston	0	0	133	406	747	961	1060	815	663	408	222	68
	Pocatello	0	0	183	487	873	1184	1333	1022	880	561	317	136
Ill.	Cairo	0	0	28	161	492	784	856	683	523	182	47	0
	Chicago	0	0	90	350	765	1147	1243	1053	868	507	229	58
	Peoria	0	11	86	339	759	1128	1240	1028	828	435	192	41
	Springfield	0	0	56	259	666	1017	1116	907	713	350	127	14
Ind.	Evansville	0	0	59	215	570	871	939	770	589	251	90	6
	Fort Wayne	0	17	107	377	759	1122	1260	1036	874	516	226	53
	Indianapolis	0	0	59	247	642	986	1051	893	725	375	140	16
	Royal Center	11	19	116	373	740	1104	1239	976	860	502	245	54
	Terre Haute	0	5	77	295	681	1023	1107	913	715	371	145	24

Table VIII-1. (continued)

State	Station	July	Aug.	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June
Iowa	Charles City	17	30	151	444	912	1352	1494	1240	1001	537	256	70
	Davenport	0	7	79	320	756	1147	1262	1044	834	432	175	35
	Des Moines	0	6	89	346	777	1178	1308	1072	849	425	183	41
	Dubuque	8	28	149	444	882	1290	1414	1187	983	543	267	76
	Keokuk	1	3	71	303	680	1077	1191	1025	761	397	136	18
	Sioux City	8	17	128	405	885	1290	1423	1170	930	474	228	54
Kan.	Concordia	0	0	55	277	687	1029	1144	899	725	341	146	20
	Dodge City	0	0	40	262	669	980	1076	840	694	347	135	15
	Iola	0	1	40	236	579	920	1026	817	599	282	98	3
	Topeka	0	0	42	242	630	977	1088	851	669	295	112	13
	Wichita	0	0	32	219	597	915	1023	778	619	280	101	7
Ky.	Louisville	0	0	41	206	549	849	911	762	605	270	86	0
	Lexington	0	0	56	259	636	933	1008	854	710	368	140	15
La.	New Orleans	0	0	0	5	141	283	341	223	163	19	0	0
	Shreveport	0	0	0	53	305	490	550	386	272	61	0	0
Me.	Eastport	141	136	261	521	798	1206	1333	1201	1063	774	524	288
	Greenville	69	113	315	642	1012	1464	1625	1443	1251	842	468	194
	Portland	15	56	199	515	825	1238	1373	1218	1039	693	394	117
Md.	Baltimore	0	0	29	207	489	812	880	776	611	326	73	0
Mass.	Boston	0	7	77	315	618	998	1113	1002	849	534	236	42
	Fitchburg	12	29	144	432	774	1139	1240	1137	940	572	254	70
	Nantucket	22	34	111	372	615	924	1020	949	880	642	394	139
Mich.	Alpena	50	85	215	530	864	1218	1358	1263	1156	762	437	135
	Detroit-Willow Run	0	10	96	393	759	1125	1231	1089	915	552	244	55
	Detroit City	0	8	96	381	747	1101	1203	1972	927	558	251	60
	Escanaba	62	95	247	555	933	1321	1473	1327	1203	804	471	166
	Grand Rapids	0	20	105	394	756	1107	1215	1086	939	546	248	58
	Houghton	70	94	268	582	965	1355	1535	1421	1251	820	474	195
	Lansing	13	33	140	455	813	1175	1277	1142	986	591	287	70
	Ludington	41	55	182	472	794	1135	1271	1183	1056	698	418	153
	Marquette	69	87	236	543	933	1299	1435	1291	1181	789	477	189
	Sault Ste. Marie	109	126	298	639	1005	1398	1587	1442	1302	846	499	224
Minn.	Duluth	66	91	277	614	1092	1550	1696	1448	1252	801	487	200
	Minneapolis	8	17	157	459	960	1414	1562	1310	1057	570	259	80
	Moorhead	20	47	240	607	1105	1609	1815	1555	1225	679	327	98
	St. Paul	12	21	154	459	951	1401	1553	1305	1051	564	256	77
Miss.	Corinth	0	1	13	142	418	669	696	570	396	149	32	1
	Meridian	0	0	0	90	338	528	561	413	309	85	9	0
	Vicksburg	0	0	0	51	268	456	507	374	273	71	0	0
Mo.	Columbia	0	6	62	262	654	989	1091	876	698	326	135	14
	Hannibal	1	3	66	288	652	1037	1139	980	710	374	128	15
	Kansas City	0	0	44	240	621	970	1085	851	666	292	111	8
	St. Louis	0	0	38	202	570	893	983	792	620	270	94	7
	Springfield	0	8	61	249	615	908	1001	790	632	295	118	16
Mont.	Billings	8	20	194	497	876	1172	1305	1089	958	564	304	119
	Harve	20	38	270	564	1023	1383	1513	1291	1076	597	313	125
	Helena	51	78	359	598	969	1215	1438	1114	992	660	427	225
	Kalispell	47	83	326	639	990	1249	1386	1120	970	639	391	215
	Miles City	6	11	187	525	966	1373	1516	1257	1048	570	285	106
	Missoula	22	57	292	623	993	1283	1414	1100	939	609	365	176
Neb.	Drexel	4	6	95	405	788	1271	1353	1096	843	493	219	38
	Lincoln	0	7	79	310	741	1113	1240	1000	794	377	172	32
	North Platte	7	11	120	425	846	1172	1271	1016	887	489	243	59
	Omaha	0	5	88	331	783	1166	1302	1058	831	389	175	32
	Valentine	11	10	145	461	891	1212	1361	1100	970	543	288	83

Table VIII-1. (continued)

State	Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June
Nev.	Reno	27	61	165	443	744	986	1048	804	756	519	318	165
	Tonopah	0	5	96	422	723	995	1082	860	763	504	272	91
	Winnemucca	0	17	180	508	822	1085	1153	854	794	546	299	111
N.H.	Concord	11	57	192	527	849	1271	1392	1226	1029	660	316	82
N.J.	Atlantic City	0	0	29	230	507	831	905	829	729	468	189	24
	Cape May	1	2	38	221	527	852	936	876	737	459	188	33
	Newark	0	0	47	301	603	961	1039	932	760	450	148	11
	Sandy Hook	1	2	40	268	579	921	1016	973	833	499	206	31
	Trenton	0	0	55	285	582	930	1004	904	735	429	133	11
N.M.	Albuquerque	0	0	10	218	630	899	970	714	589	289	70	0
	Roswell	0	0	8	156	501	750	787	566	443	185	28	0
	Santa Fe	12	15	129	451	772	1071	1094	892	786	544	297	60
N.Y.	Albany	0	6	98	388	708	1113	1234	1103	905	531	202	31
	Binghamton	0	36	141	428	735	1113	1218	1100	927	570	240	48
	Buffalo	16	30	122	433	753	1116	1225	1128	992	636	315	72
	Canton	27	61	219	550	898	1368	1516	1385	1139	695	340	107
	Ithaca	17	40	156	451	770	1129	1236	1156	978	606	292	83
	New York	0	0	31	250	552	902	1001	910	747	435	130	7
	Oswego	20	39	139	430	738	1132	1249	1134	995	654	355	90
	Rochester	9	34	133	440	759	1141	1249	1148	992	615	289	54
	Syracuse	0	29	117	396	714	1113	1225	1117	955	570	247	37
N.C.	Asheville	0	0	50	262	552	769	794	678	572	285	105	5
	Charlotte	0	0	7	147	438	682	704	577	449	172	29	0
	Hatteras	0	0	0	63	244	481	527	487	394	171	25	0
	Manteo	0	0	7	113	358	595	642	594	469	249	75	7
	Raleigh	0	0	10	118	387	651	691	577	440	172	29	0
	Wilmington	0	0	0	73	288	508	533	463	347	104	7	0
N.D.	Bismarck	29	37	227	598	1098	1535	1730	1464	1187	657	355	116
	Devils Lake	47	61	276	654	1197	1558	1866	1576	1314	750	394	137
	Grand Forks	32	60	274	663	1160	1631	1895	1608	1298	718	359	123
	Williston	29	42	261	605	1101	1528	1705	1442	1194	663	360	138
Ohio	Cincinnati	0	0	42	222	567	880	942	812	645	314	108	0
	Cleveland	0	9	60	311	636	995	1101	977	846	510	223	49
	Columbus	0	0	59	299	654	983	1051	907	741	408	153	22
	Dayton	0	5	74	324	693	1032	1094	941	781	435	179	39
	Sandusky	0	0	66	327	684	1039	1122	997	853	513	217	41
	Toledo	0	12	102	387	756	1119	1197	1056	905	555	245	60
Okla.	Broken Arrow	0	0	28	169	513	805	881	646	506	212	61	5
	Oklahoma City	0	0	12	149	459	747	843	630	472	169	38	0
Ore.	Baker	25	47	255	518	852	1138	1268	972	837	591	384	200
	Medford	0	0	77	326	624	822	862	627	552	381	207	69
	Portland	13	14	85	280	534	701	791	594	515	347	199	70
	Roseburg	14	10	98	288	531	694	744	563	508	366	223	83
Pa.	Erie	0	17	76	352	672	1020	1128	1039	911	573	273	55
	Harrisburg	0	0	69	308	630	964	1051	921	750	423	128	14
	Philadelphia	0	0	33	219	516	856	933	837	667	369	93	0
	Pittsburgh	0	0	56	298	612	924	992	879	735	402	137	13
	Reading	0	5	57	285	588	936	1017	902	725	411	123	11
	Scranton	0	18	115	389	693	1057	1141	1028	849	516	196	35
R.I.	Block Island	6	21	88	330	591	927	1026	955	865	603	335	96
	Narragansett Pier	1	26	121	366	691	1012	1113	1074	916	622	342	113
	Providence	0	7	68	330	624	986	1076	972	809	507	197	31
S.C.	Charleston	0	0	0	34	214	410	445	363	260	43	0	0
	Columbia	0	0	0	76	308	524	538	443	318	77	0	0
	Due West	0	0	9	142	393	594	651	491	411	158	39	2
	Greenville	0	0	10	131	411	648	673	552	442	161	32	0

Table VIII-1. (continued)

State	Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June
S.D.	Huron	10	16	149	472	975	1407	1597	1327	1032	558	279	80
	Pierre	4	11	136	438	887	1317	1460	1253	971	516	233	52
	Rapid City	32	24	193	500	891	1218	1361	1151	1045	615	357	148
Tenn.	Chattanooga	0	0	24	169	477	710	725	588	467	179	45	0
	Knoxville	0	0	33	179	498	744	760	630	500	196	50	0
	Memphis	0	0	13	98	392	639	716	574	423	131	20	0
	Nashville	0	0	22	154	471	725	778	636	498	186	43	0
Texas	Abilene	0	0	5	98	350	595	673	479	344	113	0	0
	Amarillo	0	0	37	240	594	859	921	711	586	298	99	0
	Austin	0	0	0	30	214	402	484	322	211	50	0	0
	Brownsville	0	0	0	0	59	159	219	106	74	0	0	0
	Corpus Christi	0	0	0	0	113	252	330	192	118	6	0	0
	Dallas	0	0	0	53	299	518	607	432	288	75	0	0
	Del Rio	0	0	0	26	188	371	419	235	147	21	0	0
	El Paso	0	0	0	70	390	626	670	445	330	110	0	0
	Fort Worth	0	0	0	58	299	533	622	446	308	90	5	0
	Galveston	0	0	0	0	131	271	356	247	176	30	0	0
	Houston	0	0	0	0	162	303	378	240	166	27	0	0
	Palestine	0	0	0	45	260	440	531	368	265	71	0	0
	Port Arthur	0	0	0	8	170	315	381	258	181	27	0	0
	San Antonio	0	0	0	25	201	374	462	293	190	34	0	0
	Taylor	0	0	2	56	234	462	494	375	214	64	8	0
Utah	Modena	6	11	156	499	832	1142	1190	944	816	567	338	97
	Salt Lake City	0	0	61	330	714	995	1119	857	701	414	208	64
Vt.	Burlington	19	47	172	521	858	1308	1460	1313	1107	681	307	72
	Northfield	62	112	283	602	947	1389	1524	1384	1176	754	405	166
Va.	Cape Henry	0	0	0	120	366	648	698	636	512	267	60	0
	Lynchburg	0	0	49	236	531	809	846	722	584	289	82	5
	Norfolk	0	0	5	118	354	636	679	602	464	220	41	0
	Richmond	0	0	31	181	456	750	787	695	529	254	57	0
	Wytheville	7	13	82	352	662	916	945	836	677	410	168	35
Wash.	North Head L.H. Reservation	239	205	234	341	486	636	704	585	598	492	406	285
	Seattle	49	45	134	329	540	679	753	602	558	396	246	107
	Spokane	17	28	205	508	879	1113	1243	988	834	561	330	146
	Tacoma	66	62	177	375	579	719	797	636	595	435	282	143
	Tatoosh Island	295	288	315	406	528	648	713	610	629	525	437	330
	Walla Walla	0	0	93	308	675	890	1023	748	564	338	171	38
	Yakima	0	7	150	446	807	1066	1181	862	660	408	205	53
W.Va.	Elkins	9	31	122	412	726	995	1017	910	797	477	224	53
	Parkersburg	0	0	56	272	600	896	949	826	672	347	119	13
Wis.	Green Bay	32	58	183	515	945	1392	1516	1336	1132	696	347	107
	La Crosse	11	20	152	447	921	1380	1528	1280	1035	552	250	74
	Madison	10	30	137	419	864	1287	1417	1207	1011	573	266	79
	Milwaukee	11	24	112	397	795	1184	1302	1117	961	606	335	100
	Wausau	26	58	216	568	982	1427	1594	1381	1147	680	315	100
Wyo.	Cheyenne	33	39	241	577	897	1125	1225	1044	1029	717	315	100
	Lander	7	23	244	632	1050	1383	1494	1179	1045	687	396	163
	Yellowstone Park	125	173	424	759	1079	1386	1464	1252	1165	841	603	334

Source: American Society of Heating and Air Conditioning Engineers, "Heating, Ventilating, Air Conditioning Guide," Annual Publication.

Table VIII-2. Guide for Establishing Water Usage in Commercial Subareas.

Commercial category	Parameter	Coefficients, mean annual water use, gpd/unit of parameter
Barber Shops	Barber Chair	97.5
Beauty Shops	Station	532.0
Bus-Rail Depots	Sq ft	5.0
Car Washes	Inside Sq ft	4.78
Churches	Member	0.14
Golf-Swim Clubs	Member	33.3-100.0
Bowling Alleys	Alley	200.0
Colleges Resid.	Student	179.0
Hospitals	Bed	150.0-559.0
Hotels	Sq ft	0.256
Laundromats	Sq ft	6.39
Laundries	Sq ft	0.64
Medical Offices	Sq ft	0.62
Motels	Sq ft unit	0.33
Drive-In Movies	Car Stall	8.0
Nursing Homes	Bed	75.0-209.0
New Office Bldgs.	Sq ft	0.16
Old Office Bldgs.	Sq ft	0.27
Jails and Prisons	Occupant Person	10.0-15.0 200.0
Restaurants	Seat	10.0-90.0
Drive-In Restaurants	Car Stalls	109.0

Table VIII-2. (continued)

Commercial category	Parameter	Coefficients, mean annual water use, gpd/unit of parameter
Night Clubs	Person Served	2.0
Retail Space	Sale Sq ft	0.16
Schools, Elementary	Student	6.0-15.0
Schools, High	Student	10.0-19.9
YMCA-YWCA	Person	50.0
Service Stations	Inside Sq ft	0.49
Theaters	Employee	30.0
	Seat	5.0
Apartments	Dwelling Unit	50.0-195.0
Shopping Centers	Sq ft	0.20

Sources: Hittman Associates, Inc., "A System for Calculating and Evaluating Municipal Water Requirements"; and F. P. Linaweaver and J. C. Geyer, "Commercial Water Use Project," Johns Hopkins University, Baltimore, Maryland.

Table VIII-3. Guide for Establishing Water Usage in Industrial Subareas.

Industrial category	Standard Industrial Classification Number	Mean Annual Usage Coefficients gpd/employee
Meat Products	201	903.890
Dairies	202	791.350
Can, Frozen Food	203	784.739
Grain Mills	204	488.249
Bakery Products	205	220.608
Sugar	206	1433.611
Candy	207	244.306
Beverages	208	1144.868
Miscellaneous Foods	209	1077.360
Cigarettes	211	193.613
Weaving, Cotton	221	171.434
Weaving, Synthetics	222	344.259
Weaving, Wool	223	464.439
Knitting Mills	225	273.429
Textile Finish	226	810.741
Floor Covering	227	297.392
Yarn-Thread Mill	228	63.558
Miscellaneous Textile	229	346.976
Whl. Apparel Industry	230	20.000
Saw-Planning Mill	242	223.822
Millwork	243	316.420
Wood Containers	244	238.000
Miscellaneous Wood	249	144.745
Home Furniture	251	122.178
Furniture Fixture	259	122.178
Pulp Mills	261	13494.110
Paper Mills	262	2433.856
Paperboard Mills	263	2464.478
Paper Products	264	435.790
Paperboard Boxes	265	154.804
Building Paper Mills	266	583.355
Whl. Print Industry	270	15.000
Basic Chemicals	281	2744.401
Fibers, Plastic	282	864.892
Drugs	283	457.356
Soap-Toilet Goods	284	672.043
Paint Allied Products	285	845.725
Gum-Wood Chemicals	286	332.895
Agricultural Chem.	287	449.836
Miscellaneous Chemicals	289	984.415

Table VIII-3. (continued)

Industrial category	Standard Industrial Classification Number	Mean Annual Usage Coefficients gpd/employee
Petroleum Refining	291	3141.100
Paving-Roofing	295	829.592
Tires, Tubes	301	375.211
Rubber Footware	302	82.592
Reclaimed Rubber	303	1031.523
Rubber Products	306	371.956
Plastic Products	307	527.784
Leather Tanning	311	899.500
Flat Glass	321	590.140
Pressed, Blown Glassware	322	340.753
Products of Purchased Glass	323	872.246
Cement, Hydraulic	324	279.469
Structural Clay	325	698.197
Pottery Products	326	326.975
Cement, Plaster	327	353.787
Cut Stone Products	328	534.789
Non-Metallic Mineral	329	439.561
Steel-Rolling	331	494.356
Iron, Steel Foundries	332	411.052
Prime Non-Ferrous	333	716.626
Secondary Non-Ferrous	334	1016.596
Non-Ferrous Rolling	335	675.475
Non-Ferrous Foundries	336	969.586
Prime Metal Industries	339	498.331
Metal Cans	341	162.547
Cutlery, Hardware	342	459.300
Plumbing, Heating	343	411.576
Structure, Metal	344	319.875
Screw Machine	345	433.193
Metal Stamping	346	463.209
Metal Service	347	1806.611
Fabricated Wire	348	343.367
Fabricated Metal	349	271.186
Engines, Turbines	351	197.418
Farm Machinery	352	320.704
Construction Equipment	353	218.365

Table VIII-3. (continued)

Industrial category	Standard Industrial Classification Number	Mean Annual Usage Coefficients gpd/employee
Metalwork, Machinery	354	196.255
Special Industry Machinery	355	290.494
General Industrial Machinery	356	246.689
Office Machines	357	138.025
Service Industrial Machine	358	334.203
Miscellaneous Machines	359	238.839
Electric Distribution Products	361	272.001
Electric Industrial Apparatus	362	336.016
Home Appliances	363	411.914
Light-Wiring Fixtures	364	369.592
Radio TV Receiving	365	235.763
Communication Equipment	366	86.270
Electronic Comp.	367	203.289
Electric Product	369	393.272
Motor Vehicles	371	318.233
Aircraft and Parts	372	154.769
Ship and Boat Building	373	166.074
Railroad Equipment	374	238.798
Motorcycle, Bike	375	414.858
Scientific Instruments	381	181.007
Mechanical Measure	383	237.021
Medical Instrument	384	506.325
Photo Equipment	386	120.253
Watches, Clocks	387	164.815
Jewelry, Silver	391	306.491
Toys, Sport Goods	394	213.907
Costume Jewelry	396	423.124
Miscellaneous Manufacturing	398	258.270
Miscellaneous Manufacturing	399	258.270

Source: Hittman Associates, Inc., "A System for Calculating and Evaluating Municipal Water Requirements".

APPENDIX IX

INTEGRATED FORM OF COMPLETE MIXING QUALITY ROUTING

Quality routing in the Transport and Runoff Blocks through conduit segments has long been accomplished by assuming complete mixing within the conduit in the manner of a continuously stirred tank reactor or "CSTR." The procedure is described in the original SWMM documentation (Metcalf and Eddy et al., 1971a, Appendix B) and was very similar to the complete mixing formulation of the Storage/Treatment Block. See, for example, the discussion of equations IV-9, IV-10 and IV-11 in Appendix IV. For the finite difference scheme of equation IV-11, however, it may easily be shown that negative concentrations may be predicted if

$$\Delta t > \frac{2V}{Q} \qquad \text{(IX-1)}$$

where
- Δt = time step, sec,
- V = average volume in the conduit or storage unit, ft^3, and
- Q = average flow through the conduit or storage unit, cfs.

This rarely causes a problem for storage unit simulation due to their large volumes. But when long time steps (e.g., 1 hr) are used in Runoff or Transport, instabilities in the predicted concentrations may arise.

These may readily be avoided with minimal loss of accuracy by using the integrated form of the solution to the differential equation. The procedure is described by Medina et al. (1981) and is outlined below as applied to the Runoff and Transport Blocks.

The governing differential equation for a completely mixed volume is

$$\frac{dVC}{dt} = V\frac{dC}{dt} + C\frac{dV}{dt} = Q_iC_i - QC - KCV + L \qquad \text{(IX-2)}$$

where
- C = concentration in effluent and in the mixed volume, e.g., mg/l,
- V = volume, ft^3,
- Q_i = inflow rate, cfs,
- C_i = concentration of influent, e.g., mg/l,
- Q = outflow rate, cfs,
- K = first order decay coefficient, 1/sec, and
- L = source (or sink) of pollutant to the mixed volume, mass/time, e.g., cfs·mg/l.

An analytical solution of this equation is seldom possible when Q, Q_i, C_i, V and L vary arbitrarily with time, as in the usual routing through conduits. However, a simple solution is available to the ordinary, first order differential equation with <u>constant</u> coefficients if parameters Q, Q_i, C_i, V, L and dV/dt are assumed to be <u>constant</u> over the solution time interval, t to $t + \Delta t$. In practice, average values over the time interval are used at each time step. Equation IX-2 is then readily integrated over the time interval t to $t + \Delta t$ with

$$C(0) = C(t) \tag{IX-3}$$

to yield

$$C(t+\Delta t) = \left(\frac{\frac{Q_i C_i + L}{V}}{\text{DENOM}}\right)\left(1 - e^{-\text{DENOM}\cdot\Delta t}\right) + C(t)\ e^{-\text{DENOM}\cdot\Delta t} \tag{IX-4}$$

where $$\text{DENOM} = Q/V + K + \frac{1}{V}\, dV/dt \tag{IX-5}$$

Thus, the concentration at the end of the time step is predicted as the sum of a weighted inflow concentration and a decaying concentration from the previous time step.

Equation IX-4 is used in both the Runoff and Transport Block and is completely stable with respect to changes in Δt. It does not reflect rapid changes in volume and flow as well as the finite difference solution (e.g., equation IV-11) but it is updated at each time step. Given the many other uncertainties of quality routing within the sewer system, it should be adequate.

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(Please read Instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES

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16. ABSTRACT

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

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

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Combined sewers, *Storm sewers, *Mathematical models, *Water quality, Sewers, Rainfall-runoff, Water storage, Waste treatment, Cost analysis, Hydraulics, Drainage, Hydrology	*Urban runoff modeling, *Combined sewer overflows, *Computer models, Water pollution control, *Urban hydrology, *Hydrologic models, Continuous simulation, Flow routing, Snowmelt	13B

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