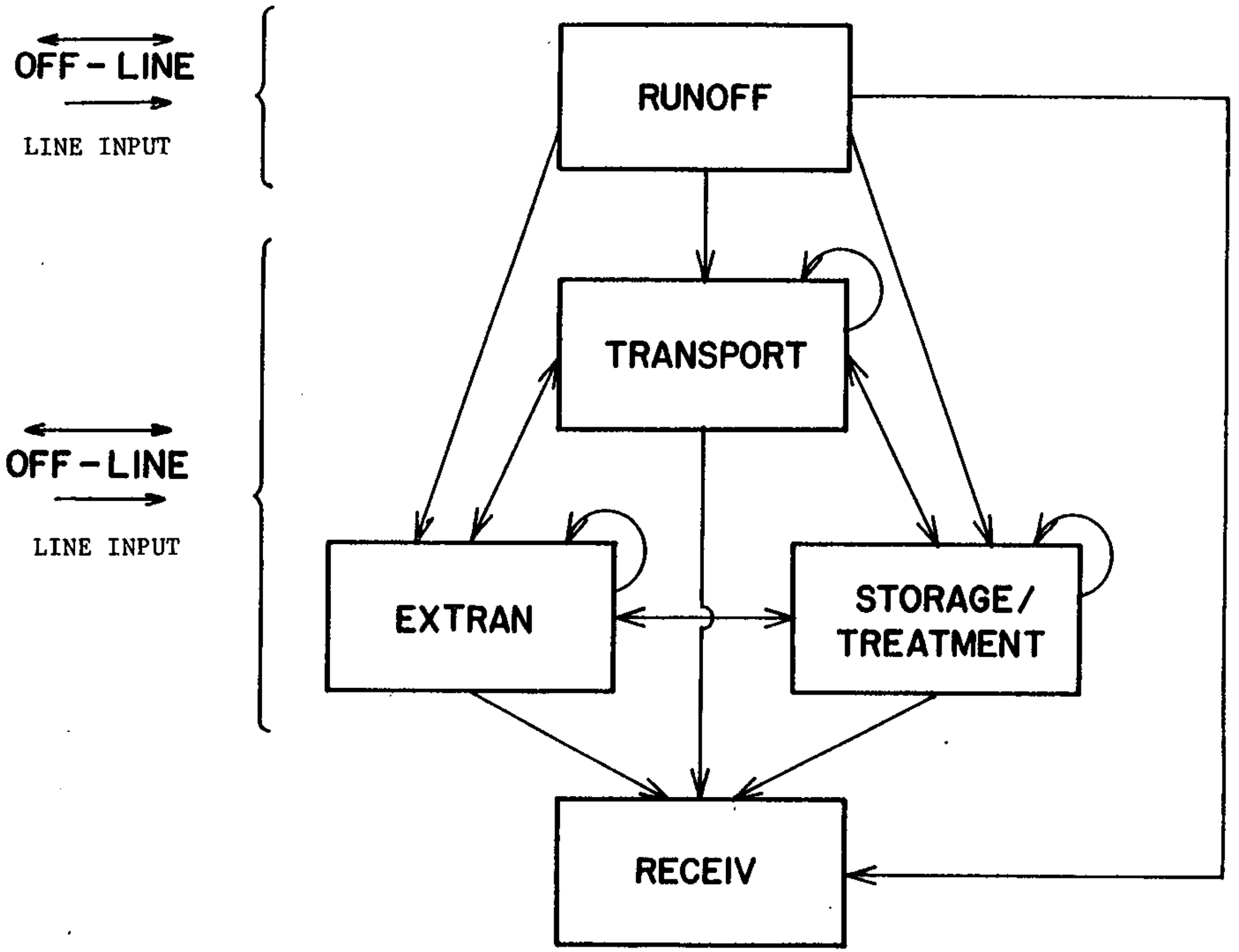


Figure 1-1. Overview of SWMM Model Structure, Indicating Linkages Among the Computational Blocks. Receiving water Simulation is by external programs, not Receive Block. "Line input" refers to data input from terminal, etc.

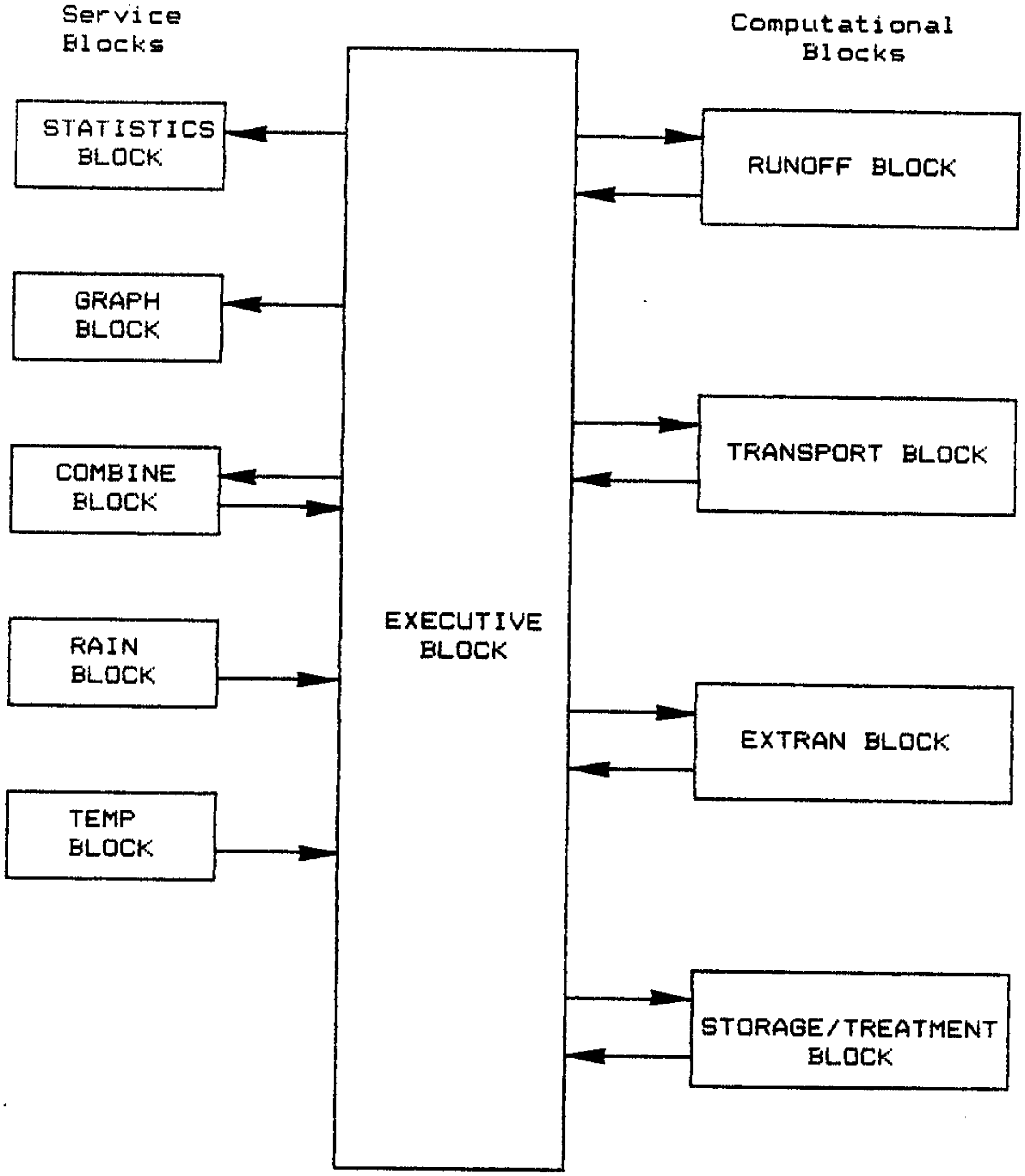


Figure 2-1. Relationship Among SWMM Blocks. Executive Block manipulates interface file and other off-line files. All blocks may receive off-line input (e.g., tapes, disks) and user line input (e.g., terminal, cards, etc.)

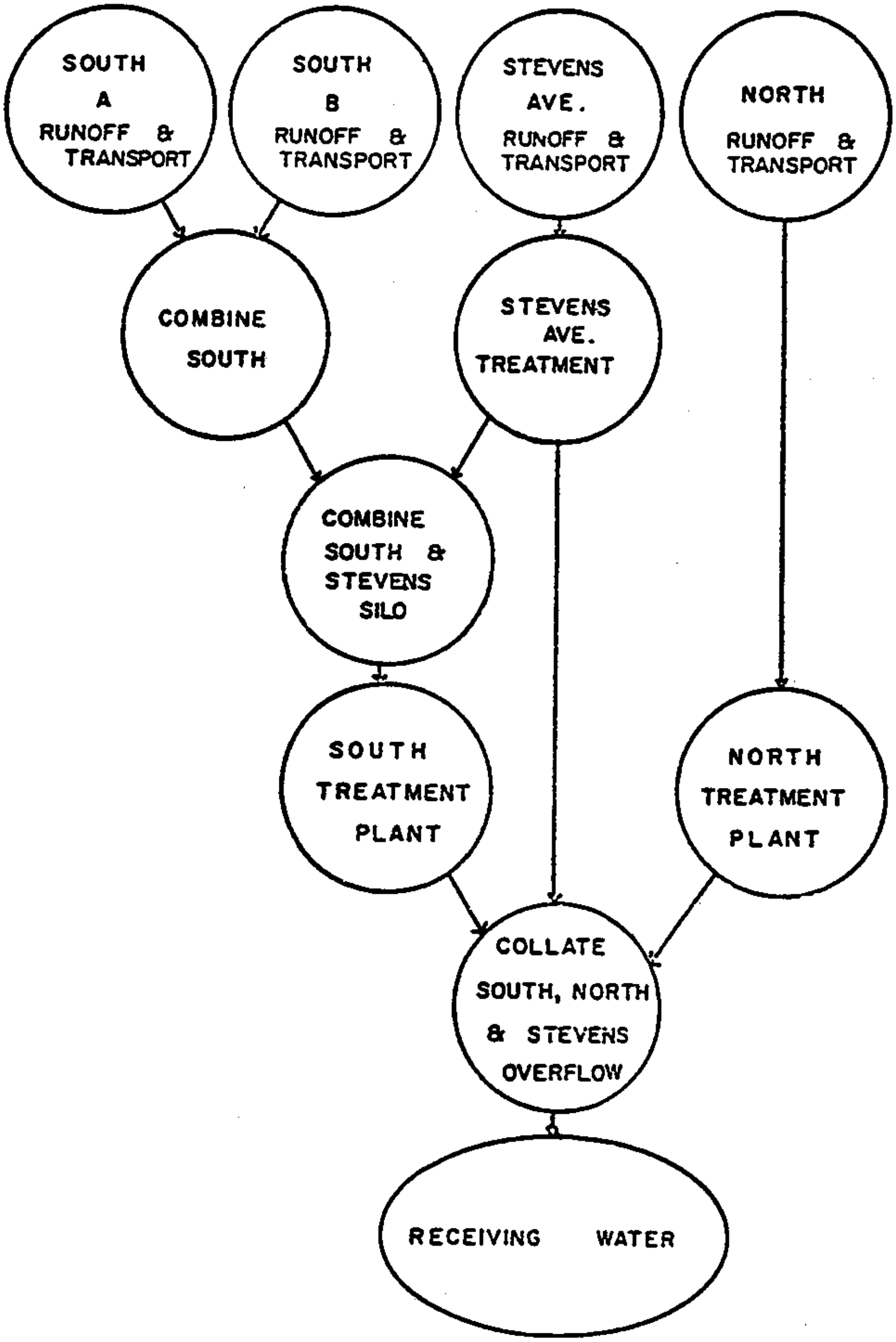


Figure 3-1. Combination of SWMM Runs for Overall Lancaster Simulation.

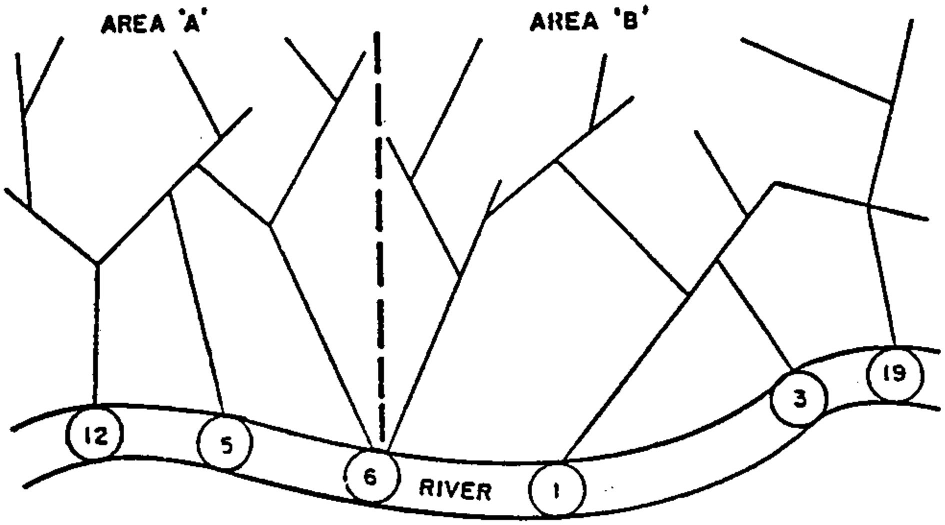


Figure 3-2. Hypothetical Drainage Network to Be Collated.

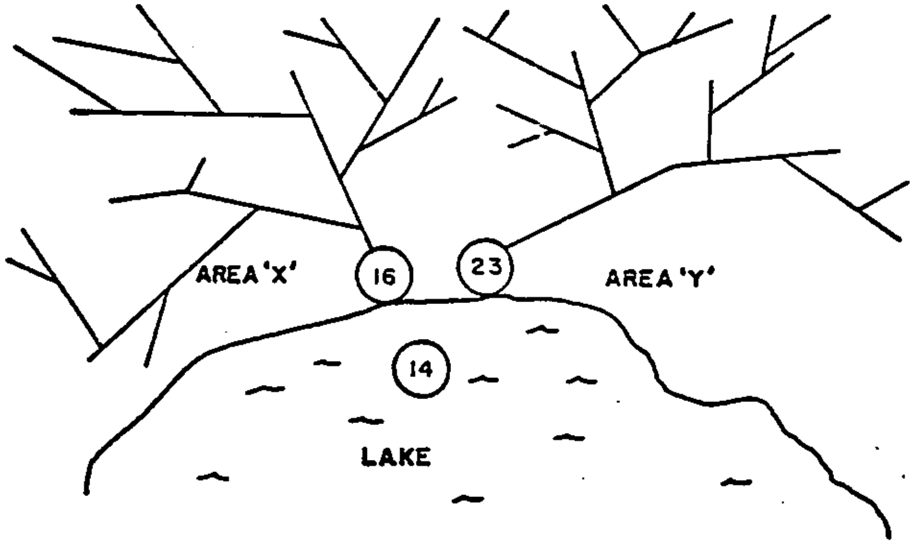


Figure 3-3. Hypothetical Drainage Network to Be Combined.

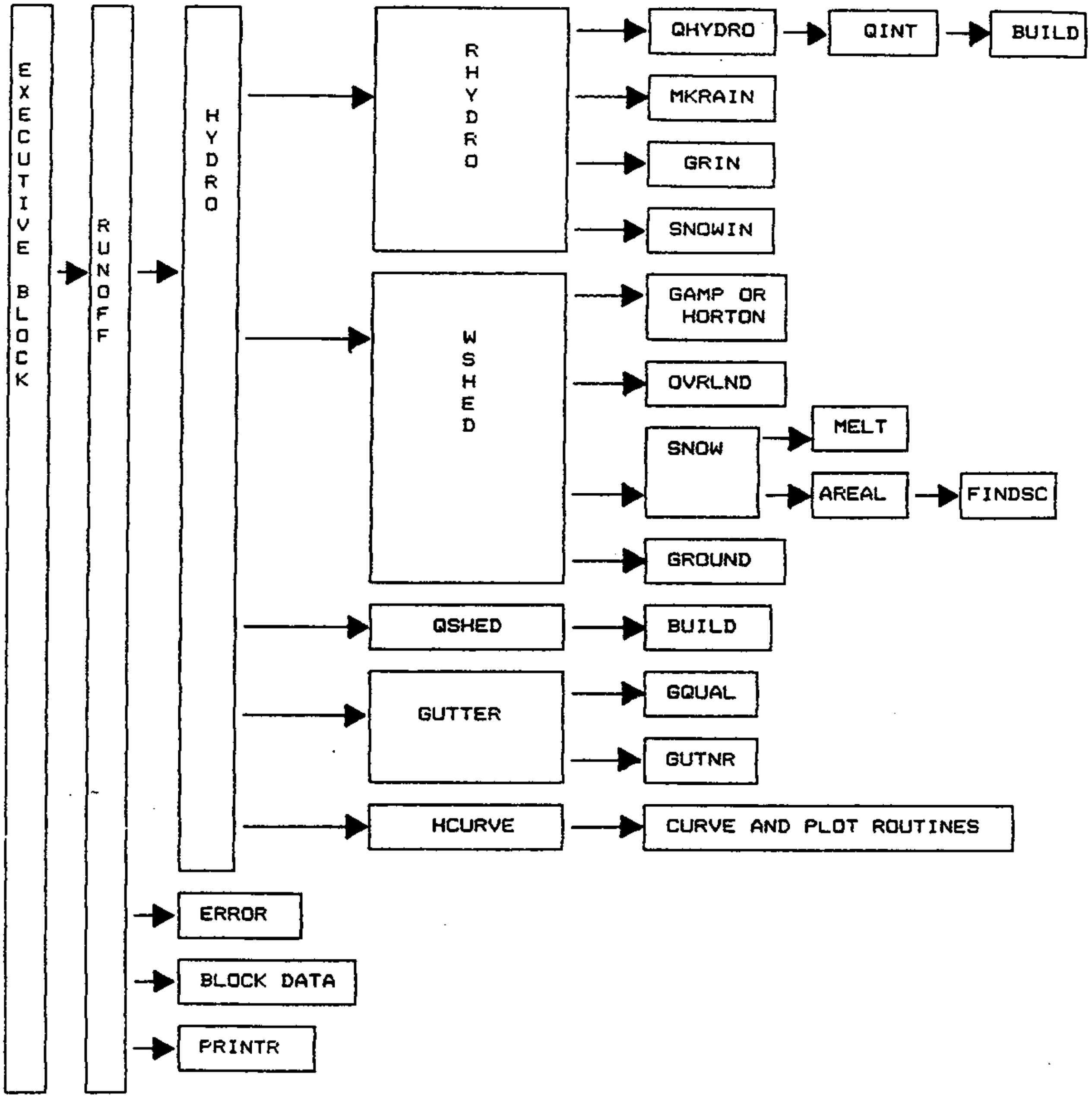


Figure 4-1. Structure of Runoff Block Subroutines.

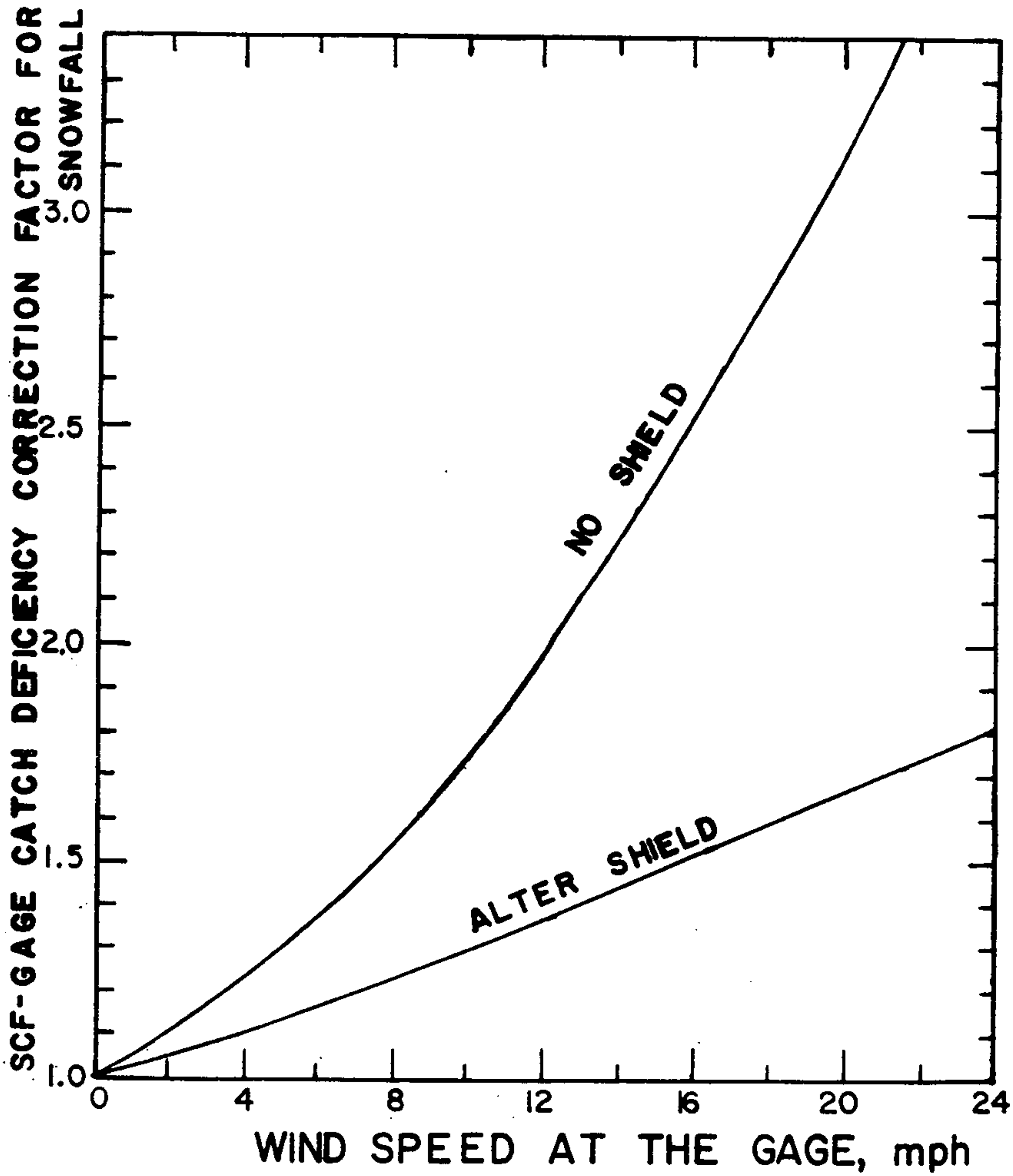


Figure 4-2. Gage Catch Deficiency Factor (SCF) Versus Wind Speed. (After Anderson, 1973 p. 5-20).

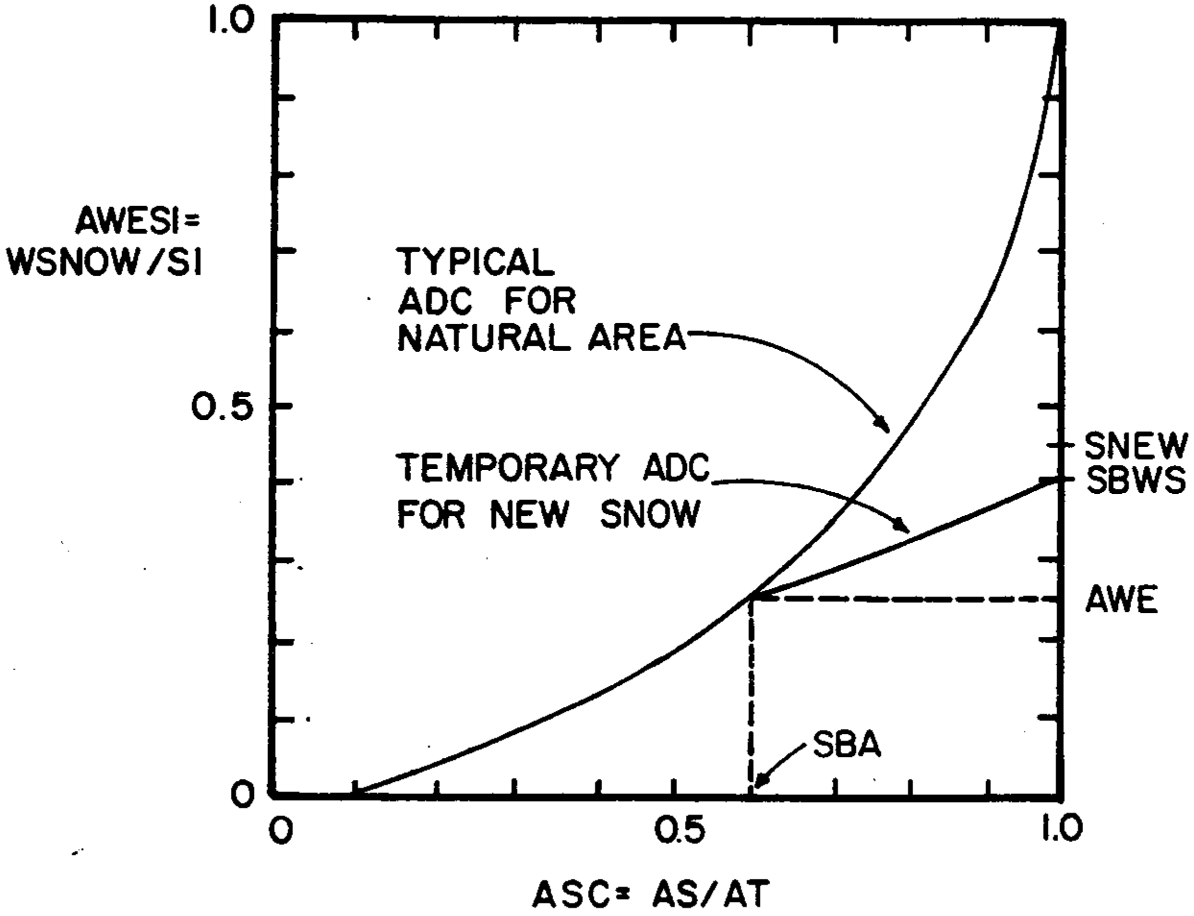


Figure 4-3. Actual Areal Depletion Curve for Natural Area. (After Anderson, 1973, p. 3-15).

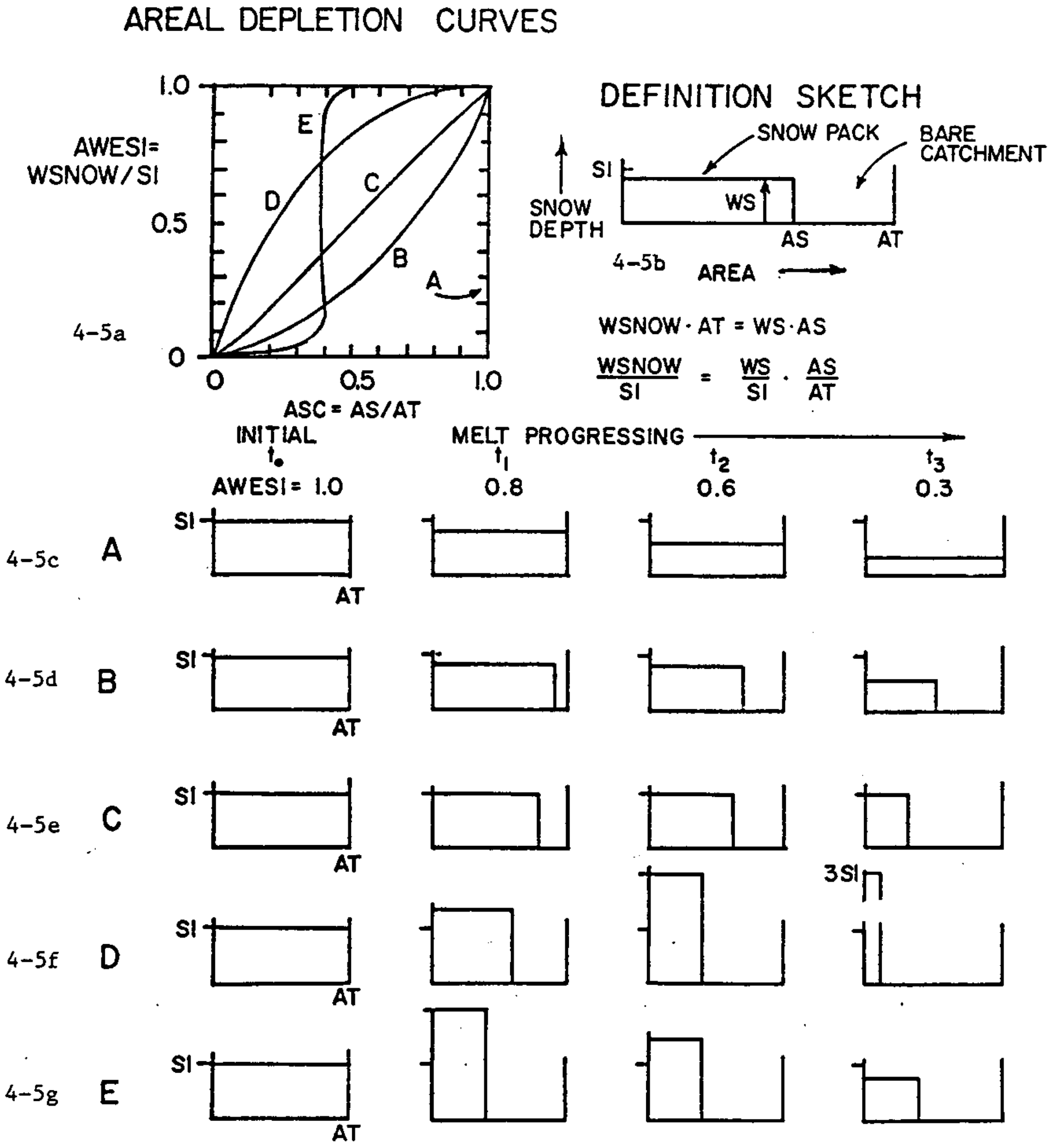


Figure 4-4. Effect on Snow Cover on Areal Depletion Curves.

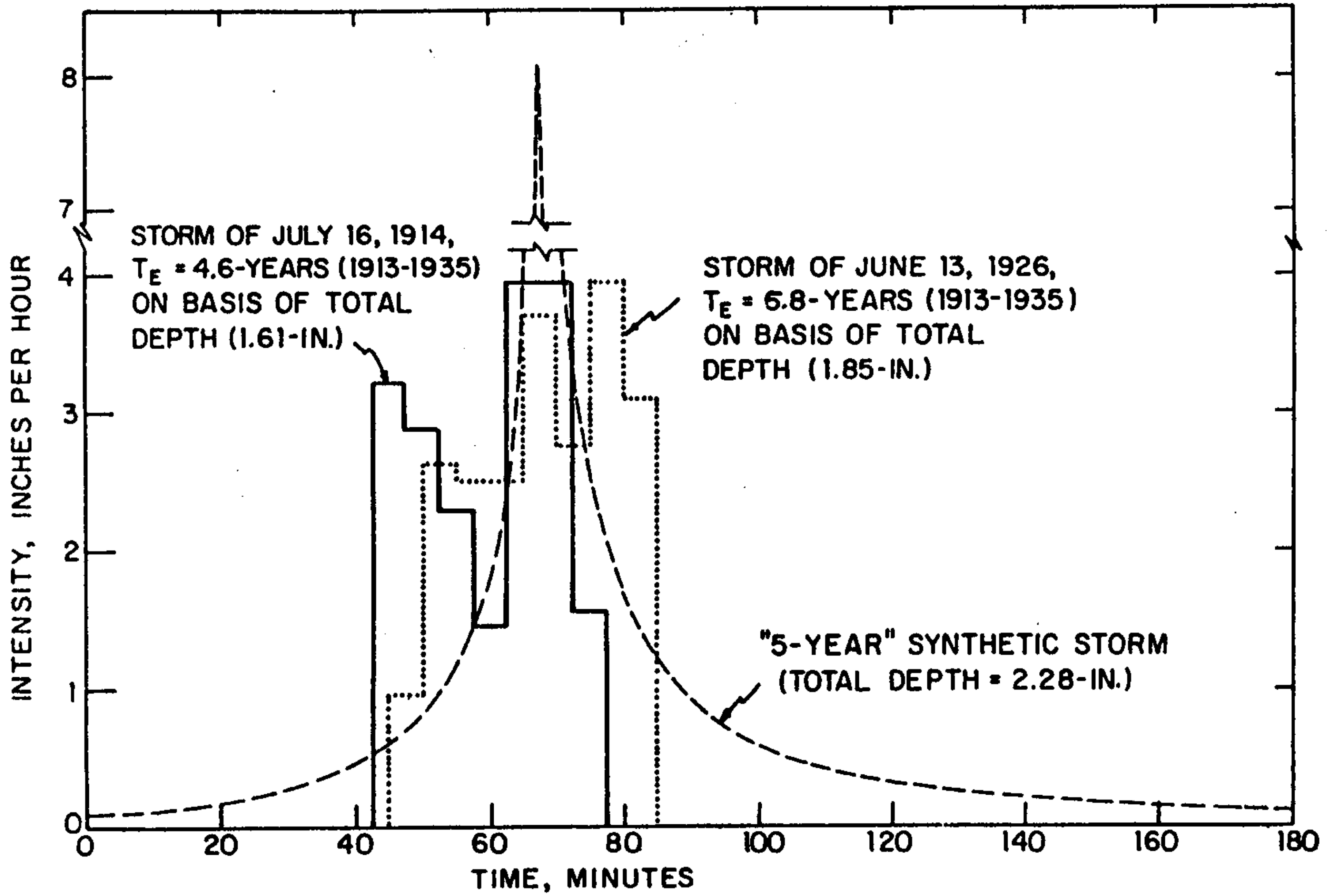


Figure 4-5. Comparison of Synthetic Versus Actual Storm Patterns, Chicago. (After McPherson, 1978, p. 111.)

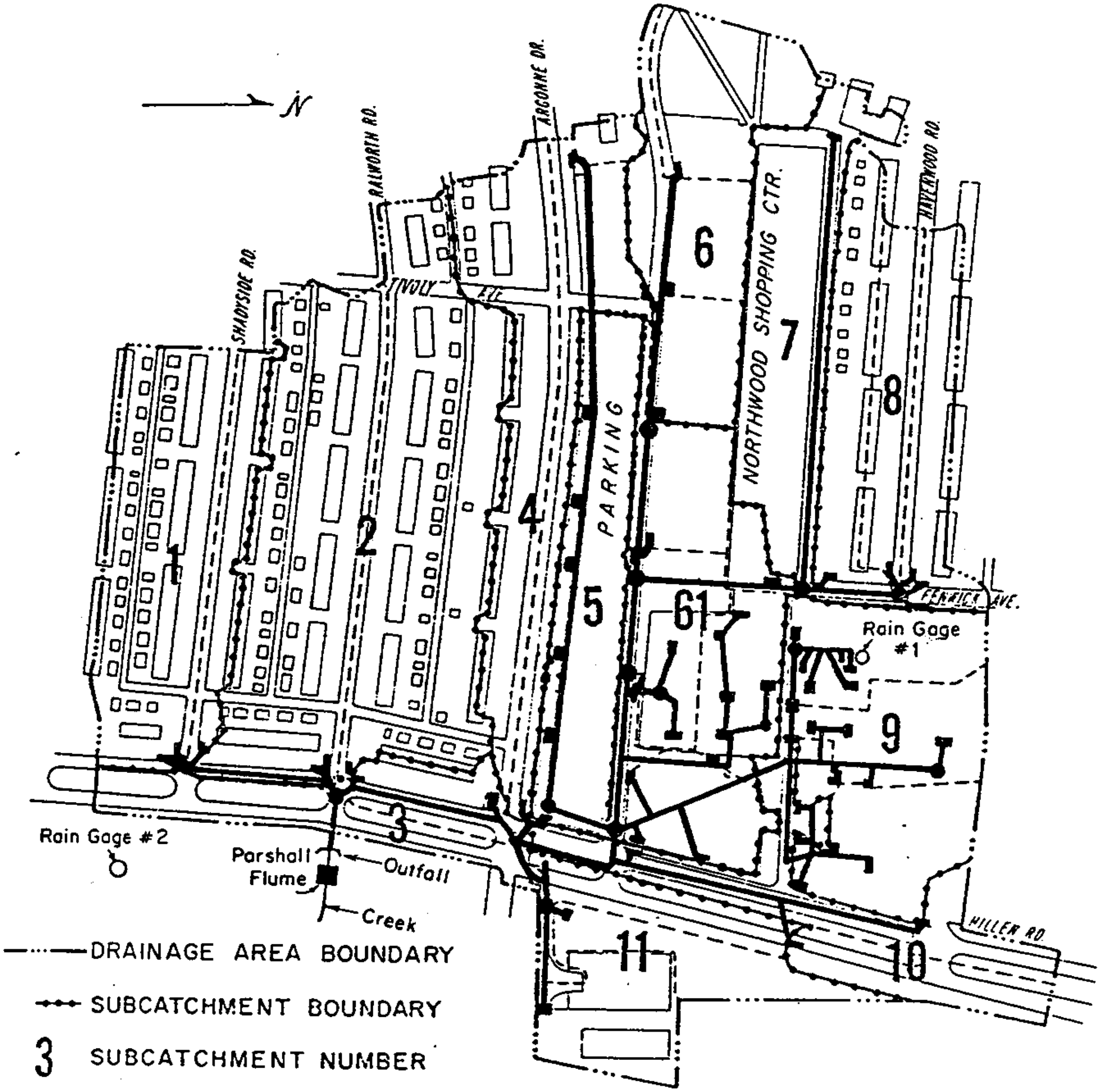


Figure 4-6. Northwood (Baltimore) Drainage Basin "Fine" Plan. (After Metcalf and Eddy et al., 1971a, p. 50)

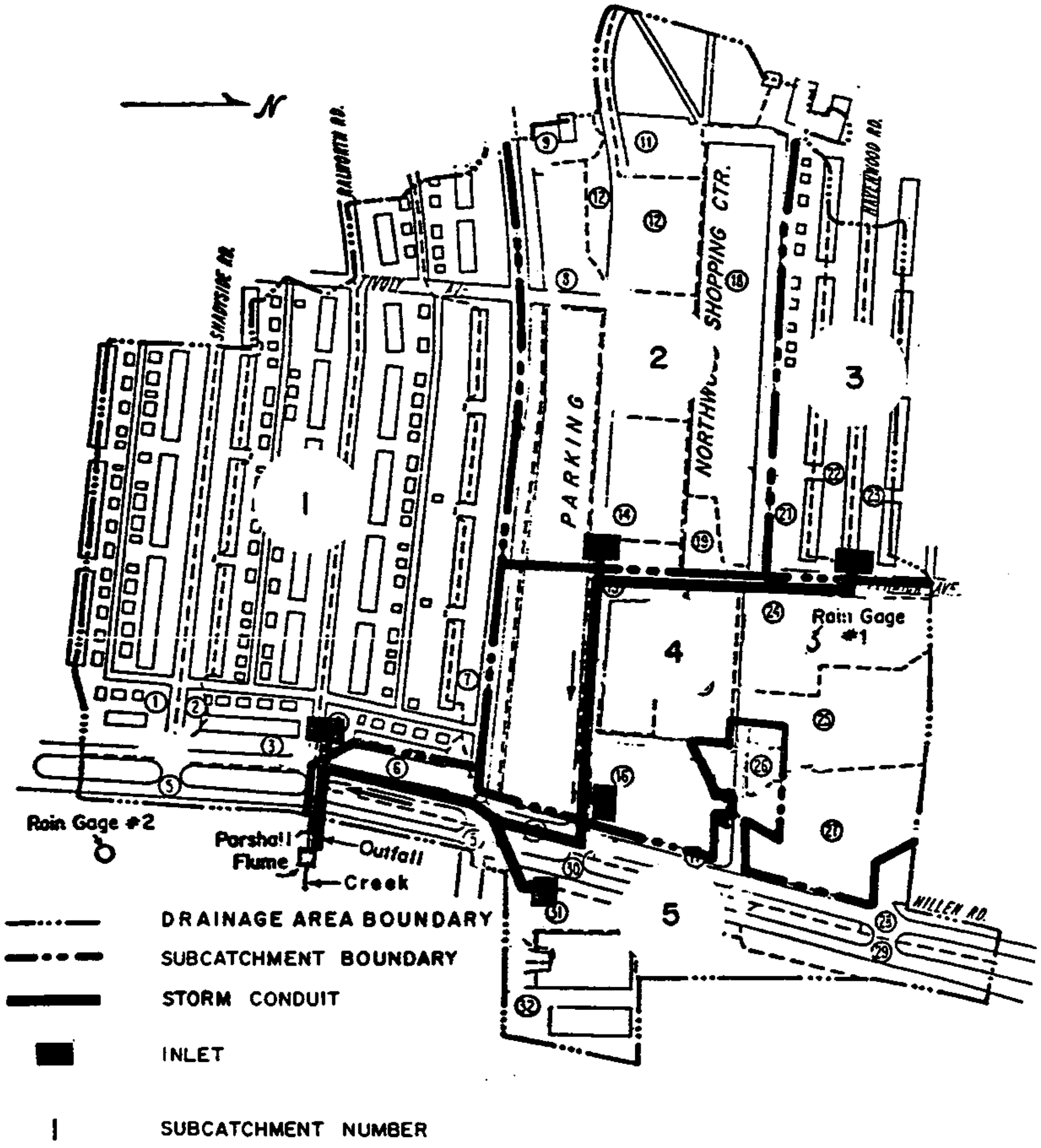


Figure 4-7. Northwood (Baltimore) Drainage Basin "Coarse" Plan. (After Metcalf and Eddy et al., 1971a, p. 51)

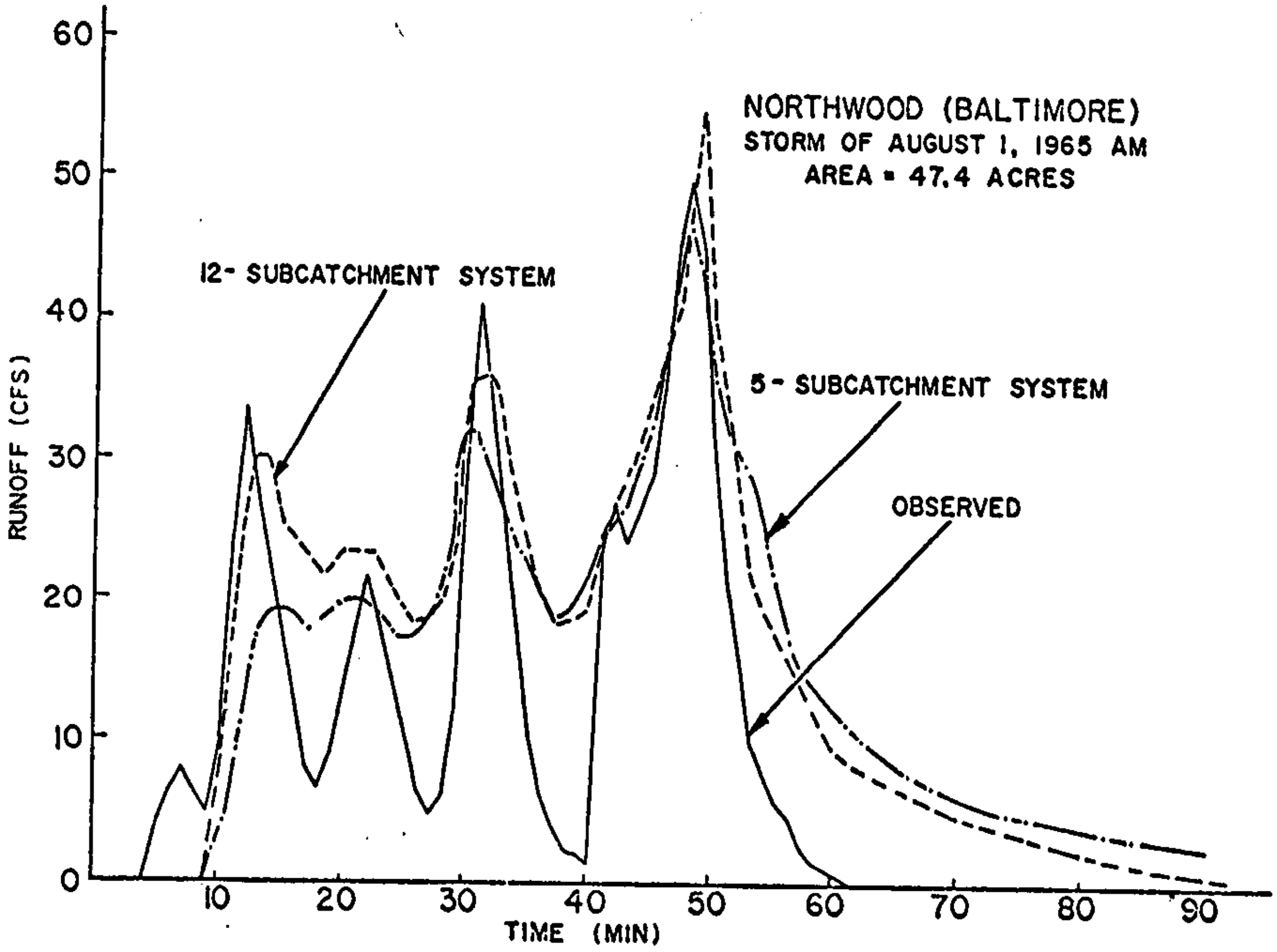
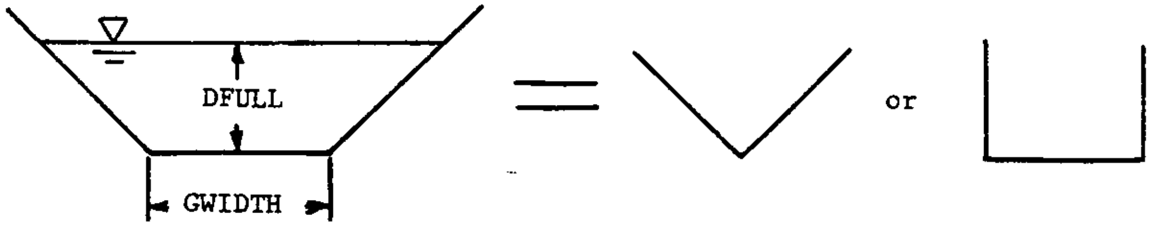


Figure 4-8. Effect of Coarse Subcatchment System, Northwood (Baltimore). (After Metcalf and Eddy et al., 1971a, p. 74)



a. Trapezoidal Channel

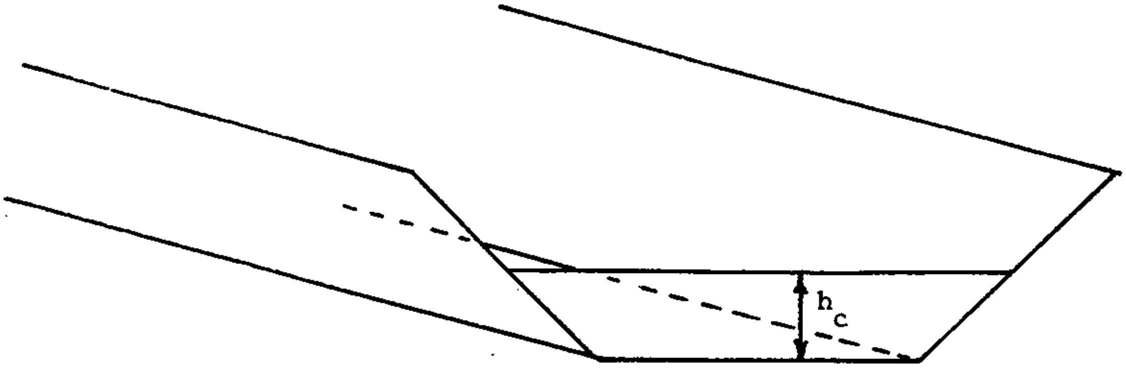
b. Triangular Channel

c. Rectangular Channel

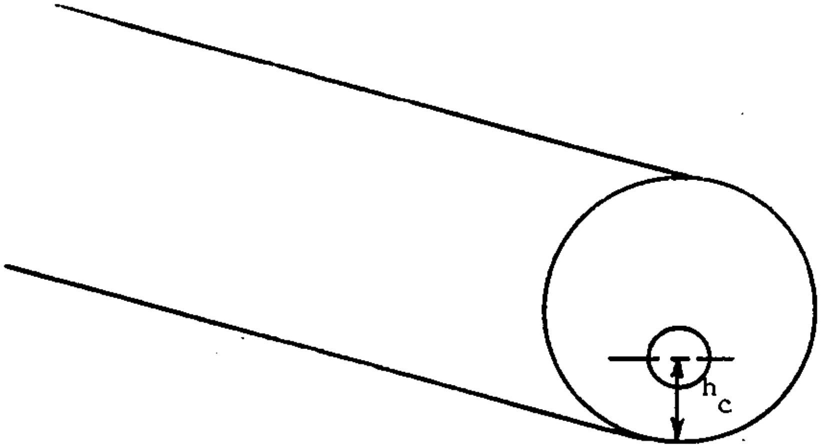
d. Circular Pipe

e. Parabolic Channel

Figure 4-9. Channels and Pipe of the Runoff Block



a. Trapezoidal channel with weir



b. Circular pipe with orifice

Figure 4-10. Example Weir and Orifice Configurations.

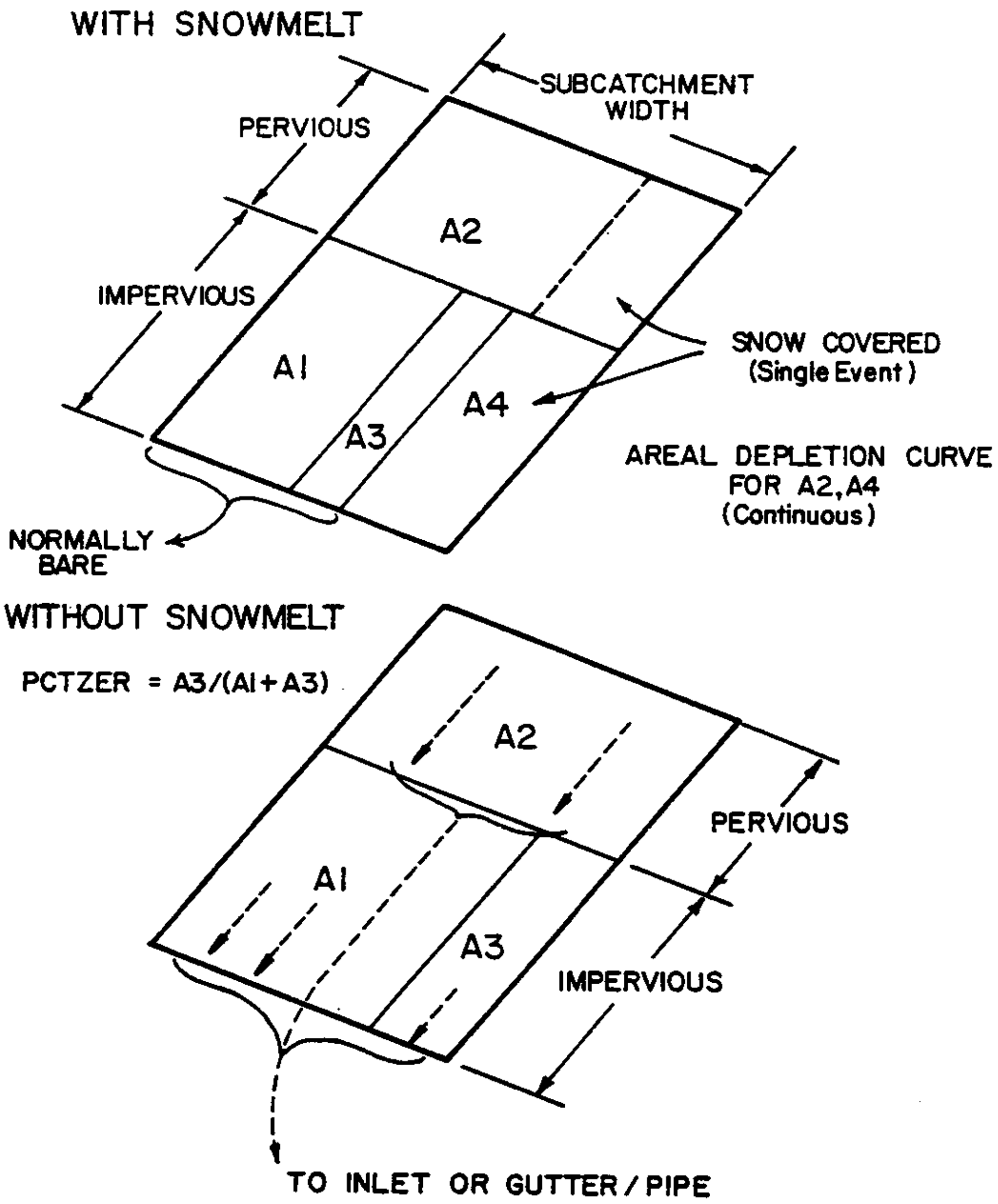


Figure 4-11. Subcatchment Schematization. Flows from pervious and total impervious subareas go <u>directly</u> to gutter/pipe or inlet. (E.g., flow from the pervious subarea does <u>not</u> travel over impervious area.)

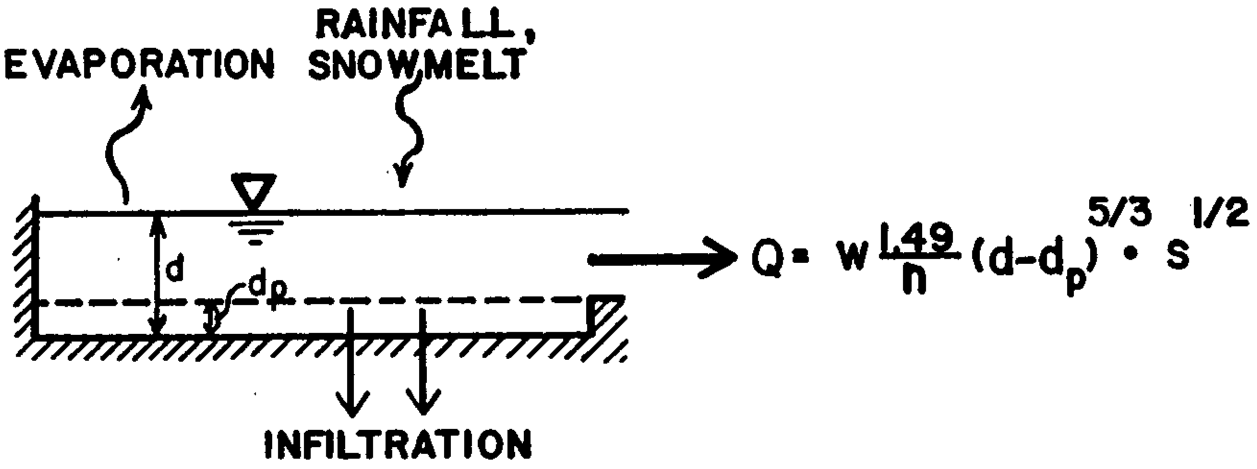


Figure 4-12. Non-linear Reservoir Representation of Subcatchment.

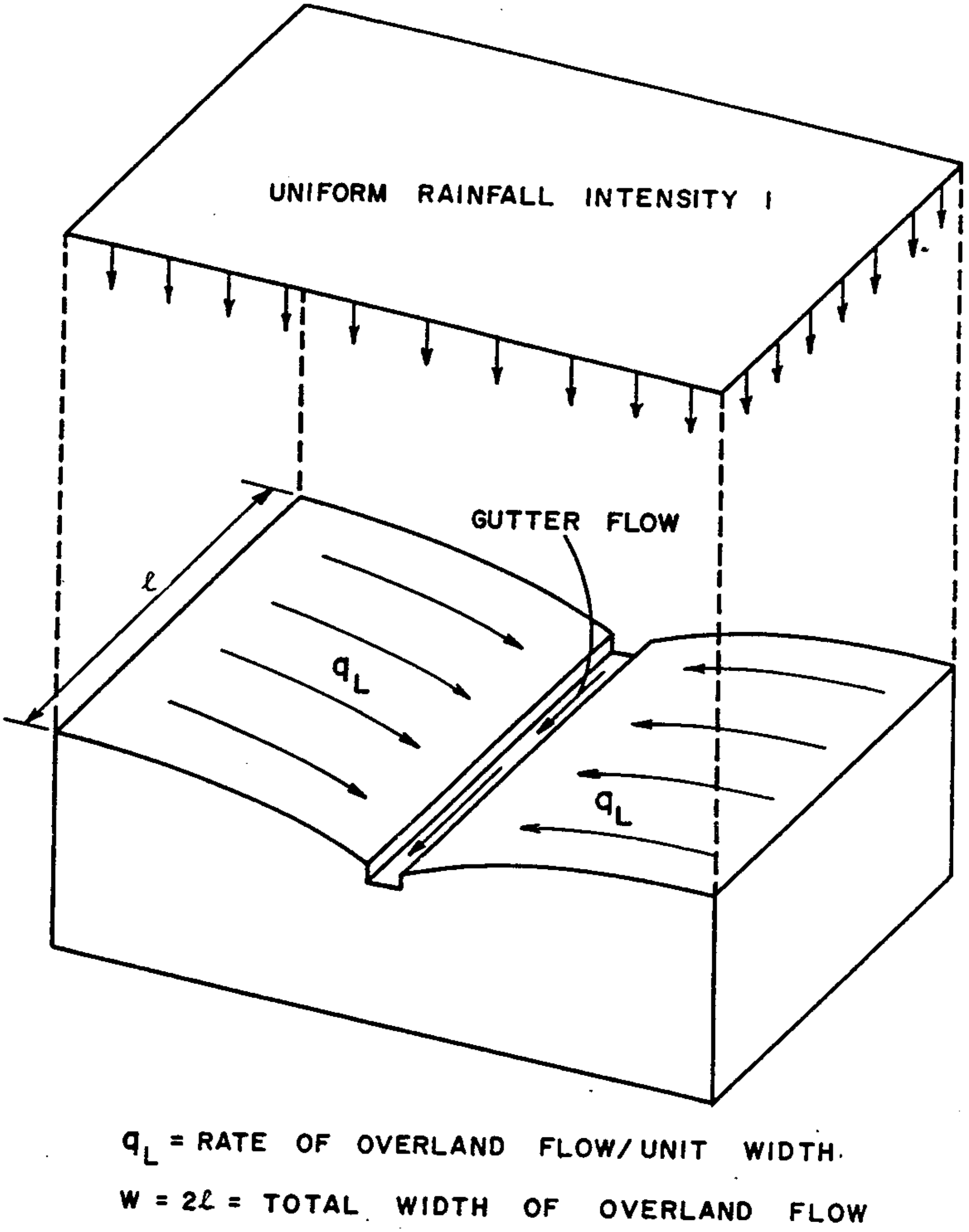
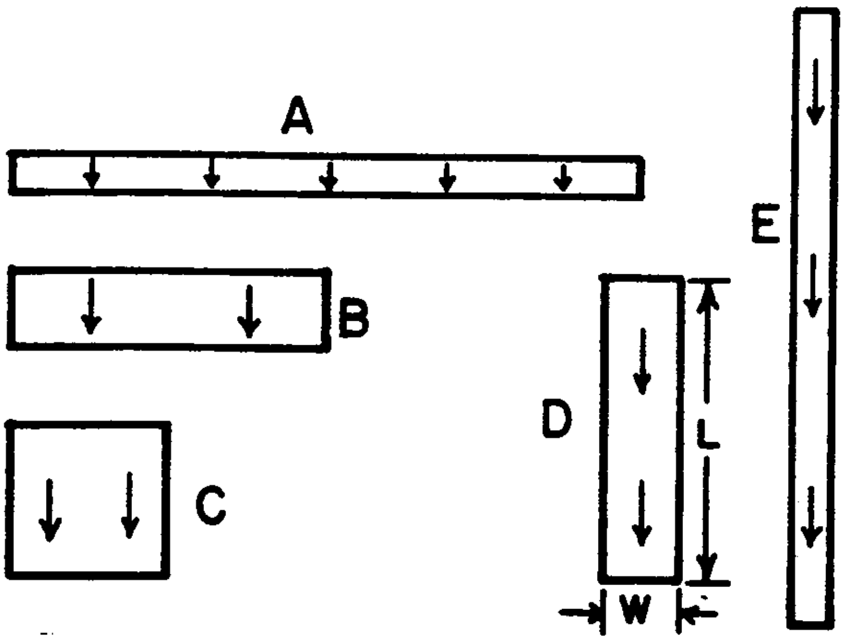


Figure 4-13. Idealized Subcatchment-Gutter Arrangement Illustrating the Subcatchment Width.



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

DELT = 5 min = 300 sec

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

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

[a] Equation 4-7

[b] Equation 4-6

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

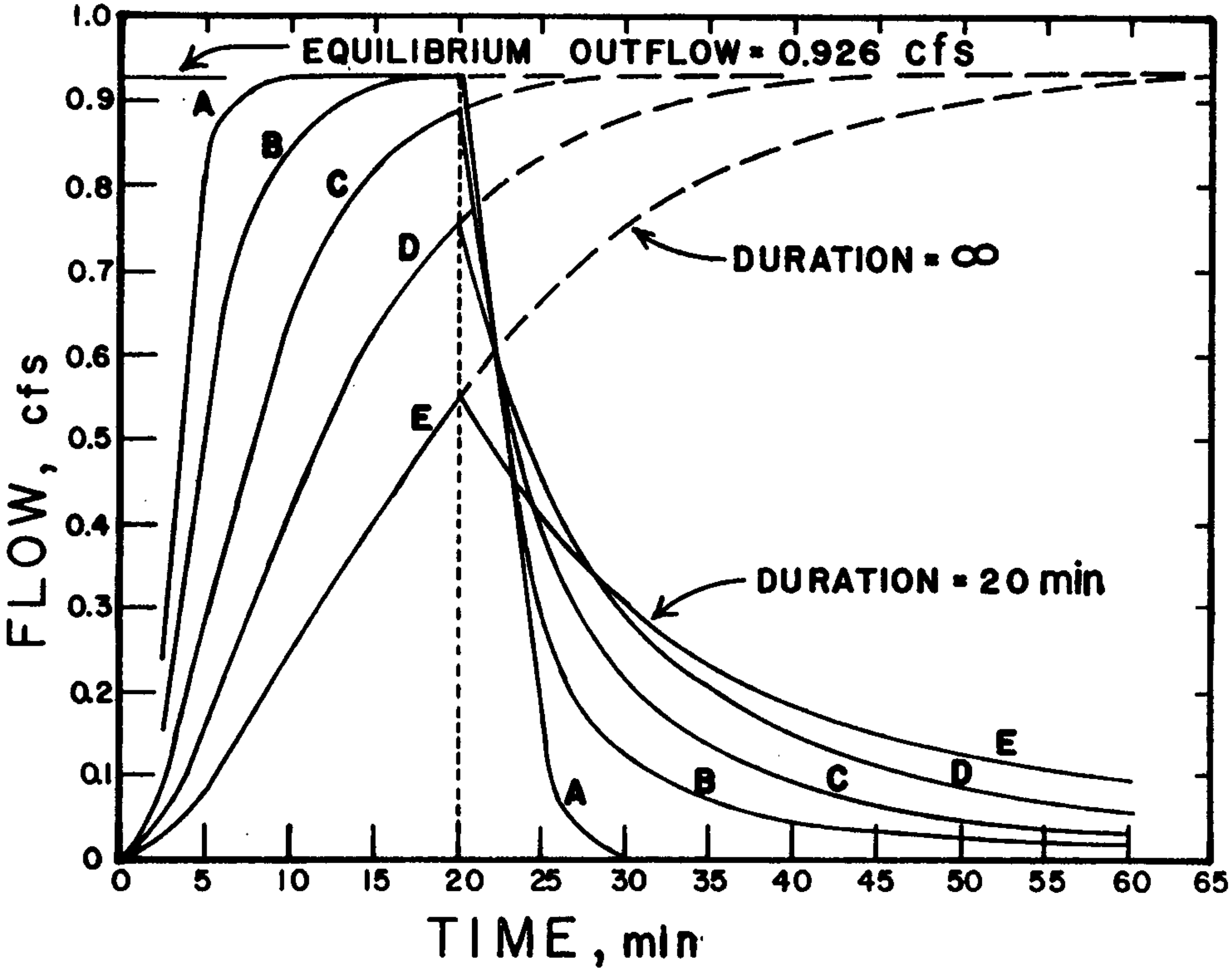


Figure 4-15. Subcatchment Hydrographs for Different Shapes of Figure 4-14.

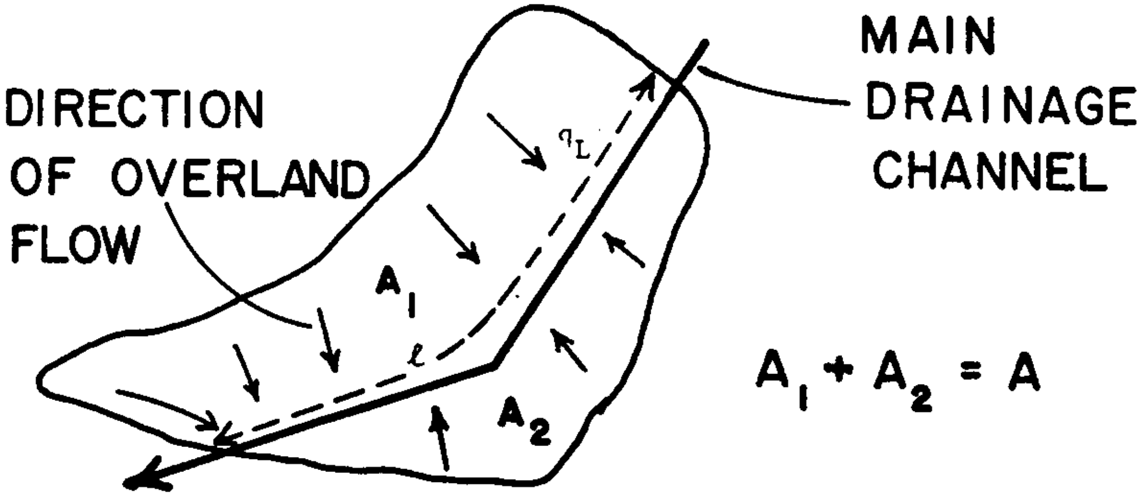


Figure 4-16. Irregular Subcatchment Shape for Width Calculation. (After DiGiano et al., 1977, p. 165.)

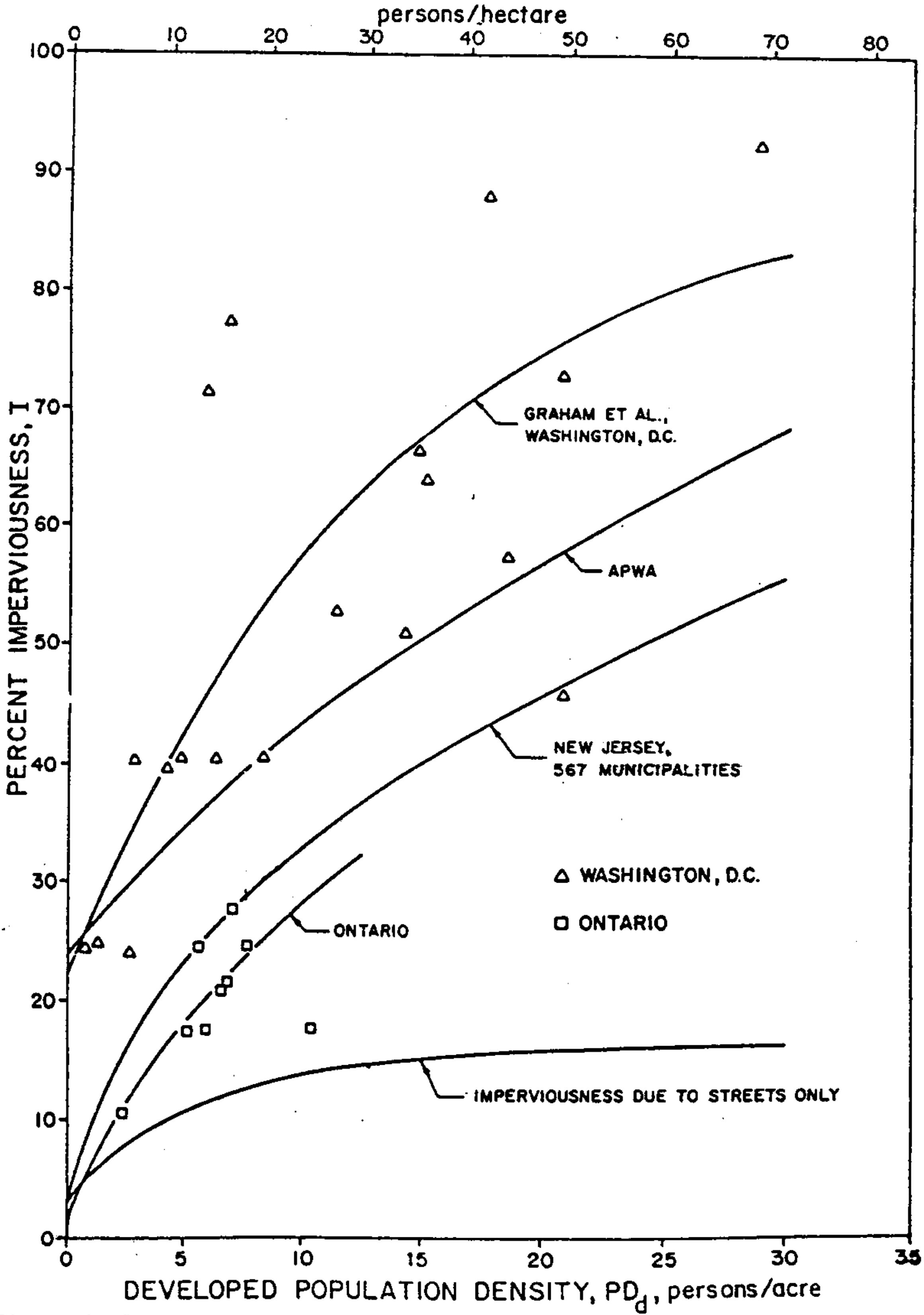


Figure 4-17. Percent Imperviousness Versus Developed Population Density for Large Urban Areas. (After Heaney, et al., 1977, p. 105)

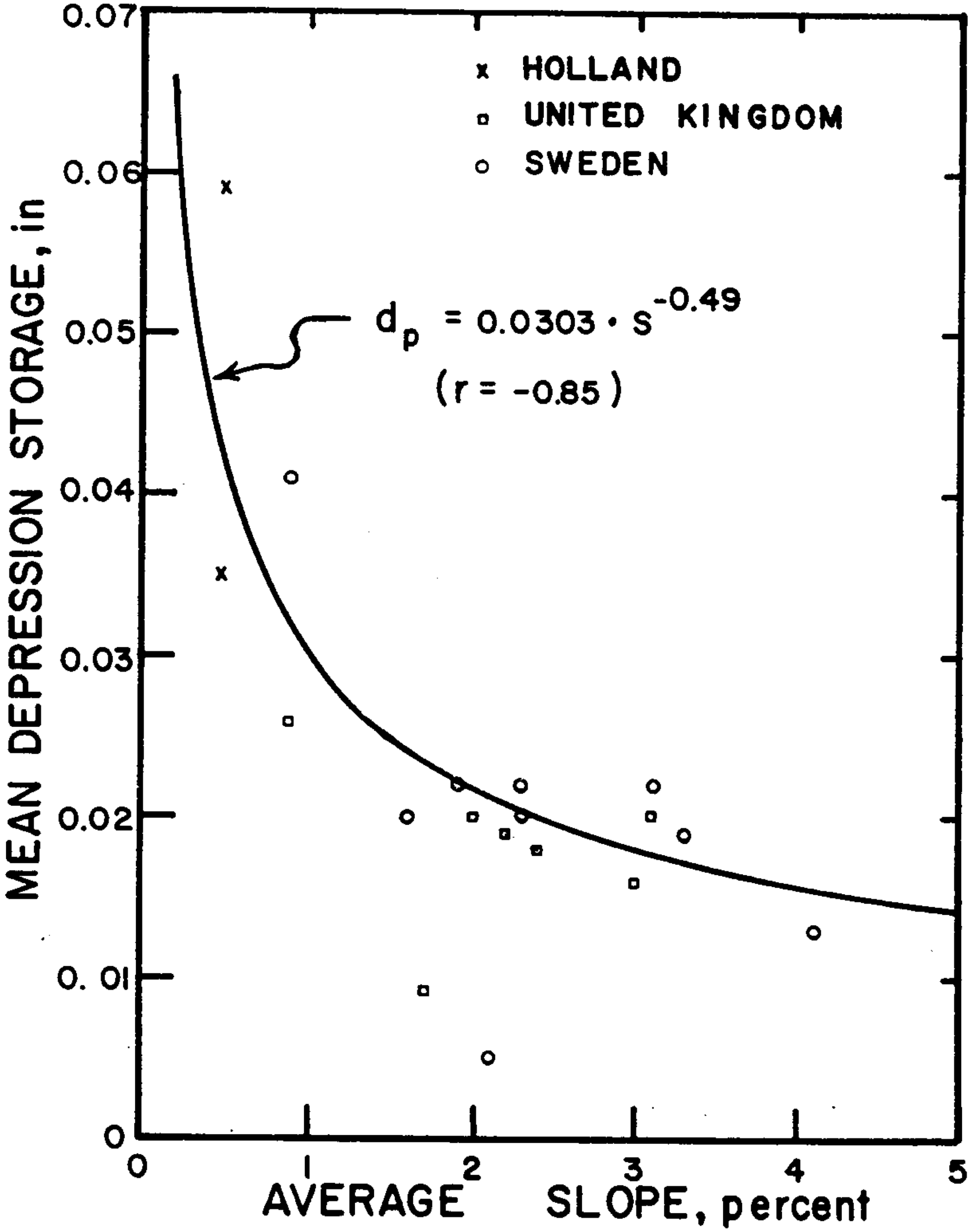
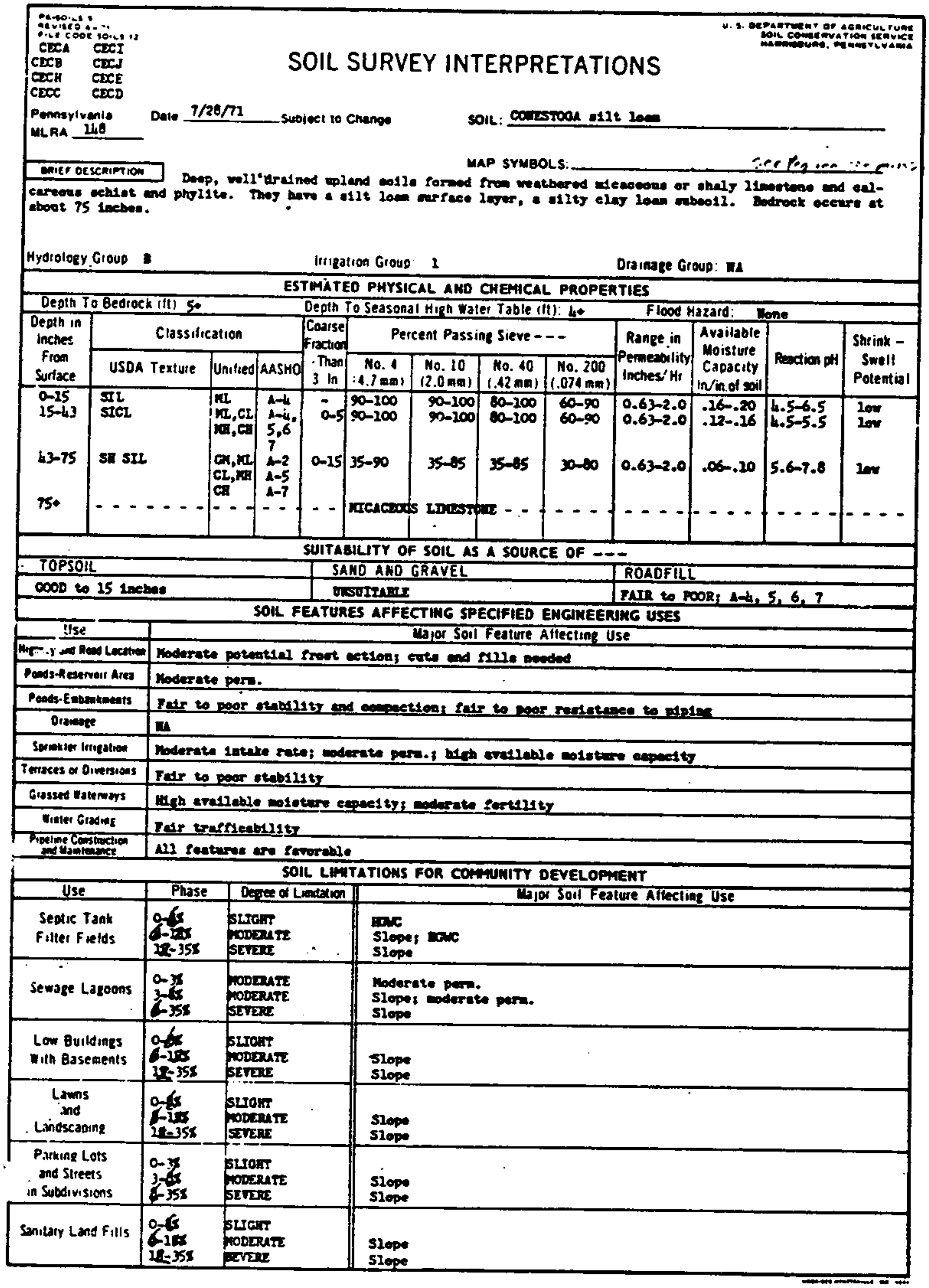


Figure 4-18. Depression Storage vs. Catchment Slope (after Kidd, 1978b). See Table 4-6 for catchment data.



PA-SOILS-5
REVISED 4-71
FILE CODE SOILS-12
CECA CECI
CECB CECJ
CECH CECE
CECC CECD

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

SOIL SURVEY INTERPRETATIONS

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

MAP SYMBOLS: [illegible]

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

Hydrology Group B Irrigation Group 1 Drainage Group: WA

ESTIMATED PHYSICAL AND CHEMICAL PROPERTIES

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

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

SUITABILITY OF SOIL AS A SOURCE OF ---

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

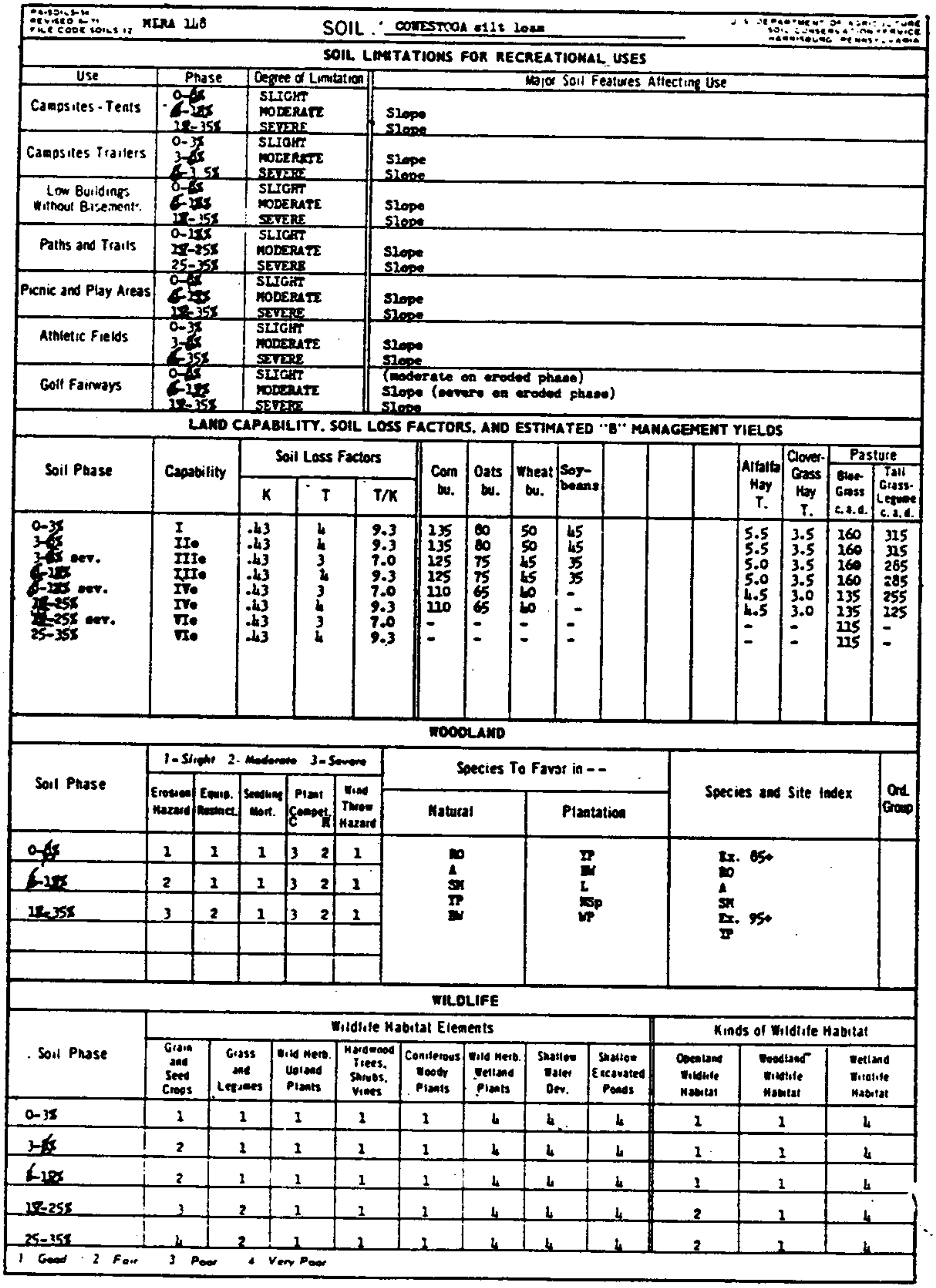
SOIL FEATURES AFFECTING SPECIFIED ENGINEERING USES

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

SOIL LIMITATIONS FOR COMMUNITY DEVELOPMENT

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

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



FILE CODE SOILS 12   MLRA 148

SOIL . COWESTOGA silt loam

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

SOIL LIMITATIONS FOR RECREATIONAL USES

Use	Phase	Degree of Limitation	Major Soil Features Affecting Use
Campsites - Tents	0-6% 6-12% 12-35%	SLIGHT MODERATE SEVERE	 Slope Slope
Campsites Trailers	0-3% 3-6% 6-35%	SLIGHT MODERATE SEVERE	 Slope Slope
Low Buildings Without Basements	0-6% 6-12% 12-35%	SLIGHT MODERATE SEVERE	 Slope Slope
Paths and Trails	0-12% 12-25% 25-35%	SLIGHT MODERATE SEVERE	 Slope Slope
Picnic and Play Areas	0-6% 6-12% 12-35%	SLIGHT MODERATE SEVERE	 Slope Slope
Athletic Fields	0-3% 3-6% 6-35%	SLIGHT MODERATE SEVERE	 Slope Slope
Golf Fairways	0-6% 6-12% 12-35%	SLIGHT MODERATE SEVERE	(moderate on eroded phase) Slope (severe on eroded phase) Slope

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

Soil Phase	Capability	Soil Loss Factors			Corn bu.	Oats bu.	Wheat bu.	Soy-beans				Alfalfa Hay T.	Clover-Grass Hay T.	Pasture	
		K	T	T/K										Blue-Grass c.a.d.	Tall Grass-Legume c.a.d.
0-3%	I	.43	4	9.3	135	80	50	45				5.5	3.5	160	315
3-6%	IIe	.43	4	9.3	135	80	50	45				5.5	3.5	160	315
3-6% sev.	IIIe	.43	3	7.0	125	75	45	35				5.0	3.5	160	285
6-12%	IIIe	.43	4	9.3	125	75	45	35				5.0	3.5	160	285
6-12% sev.	IVe	.43	3	7.0	110	65	40	-				4.5	3.0	135	255
12-25%	IVe	.43	4	9.3	110	65	40	-				4.5	3.0	135	125
12-25% sev.	VIe	.43	3	7.0	-	-	-	-				-	-	115	-
25-35%	VIe	.43	4	9.3	-	-	-	-				-	-	115	-

WOODLAND

Soil Phase	1 = Slight 2 - Moderate 3 = Severe						Species To Favor in - -		Species and Site Index	Ord. Group
	Erosion Hazard	Equip. Restrict.	Seedling Mort.	Plant Compet. C	Plant Compet. H	Wind Throw Hazard	Natural	Plantation		
0-6%	1	1	1	3	2	1	RO A SM YP BW	YP BW L NSp WP	Ex. 85+ RO A SM Ex. 95+ YP	
6-12%	2	1	1	3	2	1				
12-35%	3	2	1	3	2	1				

WILDLIFE

Soil Phase	Wildlife Habitat Elements								Kinds of Wildlife Habitat		
	Grain and Seed Crops	Grass and Legumes	Wild Herb. Upland Plants	Hardwood Trees, Shrubs, Vines	Coniferous Woody Plants	Wild Herb. Wetland Plants	Shallow Water Dev.	Shallow Excavated Ponds	Openland Wildlife Habitat	Woodland Wildlife Habitat	Wetland Wildlife Habitat
0-3%	1	1	1	1	1	4	4	4	1	1	4
3-6%	2	1	1	1	1	4	4	4	1	1	4
6-12%	2	1	1	1	1	4	4	4	1	1	4
12-25%	3	2	1	1	1	4	4	4	2	1	4
25-35%	4	2	1	1	1	4	4	4	2	1	4

1 Good 2 Fair 3 Poor 4 Very Poor

Figure 4-19b

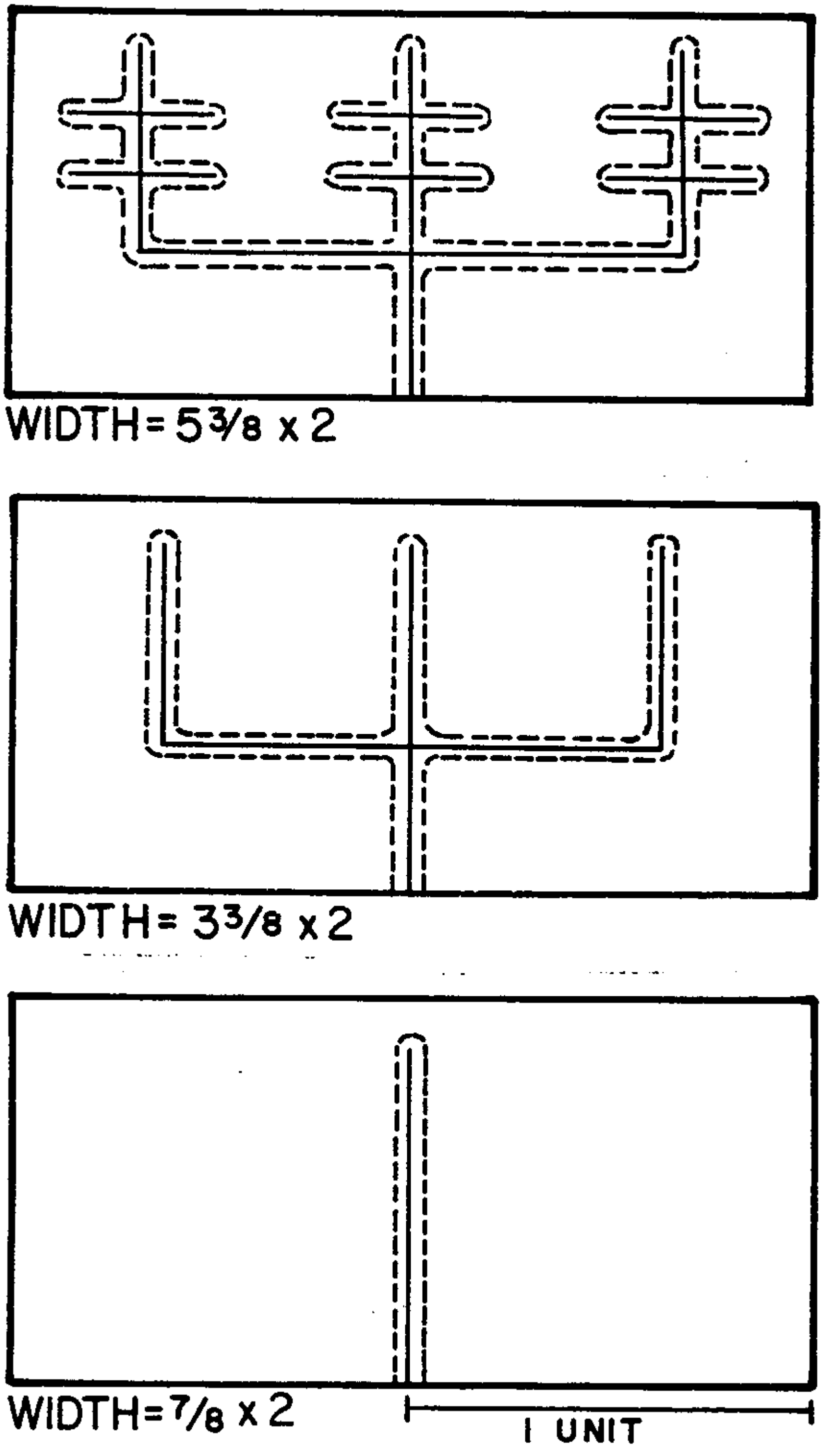


Figure 4-20. Effect of Changing the Level of Discretization on the Width of Overland Flow. (After Smith, 1975, p. 57.)

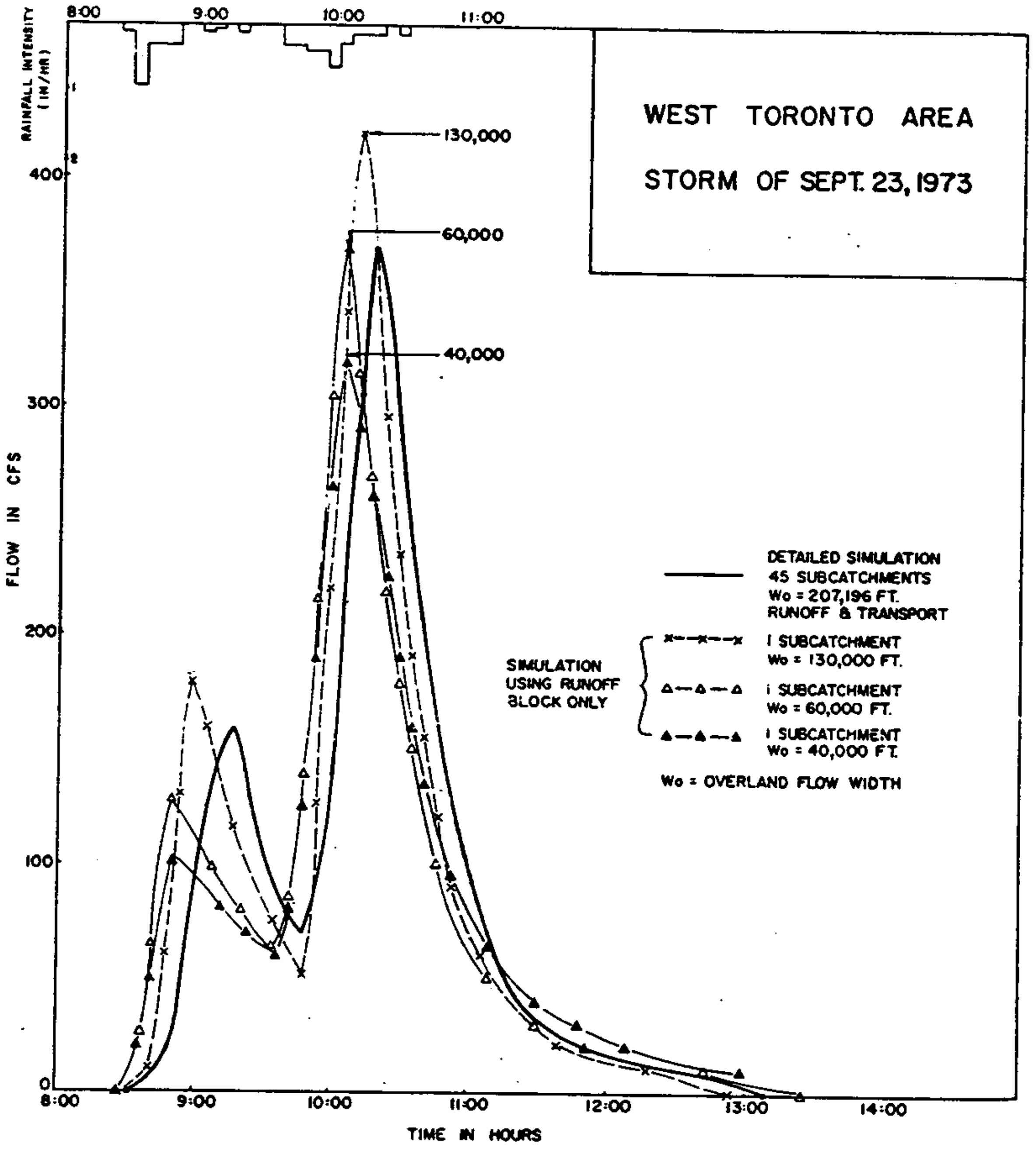


Figure 4-21. Effect on Hydrographs of Changing Subcatchment Width for West Toronto Area. (After Proctor and Redfern and J.F. MacLaren, 1976a, p. 216.)

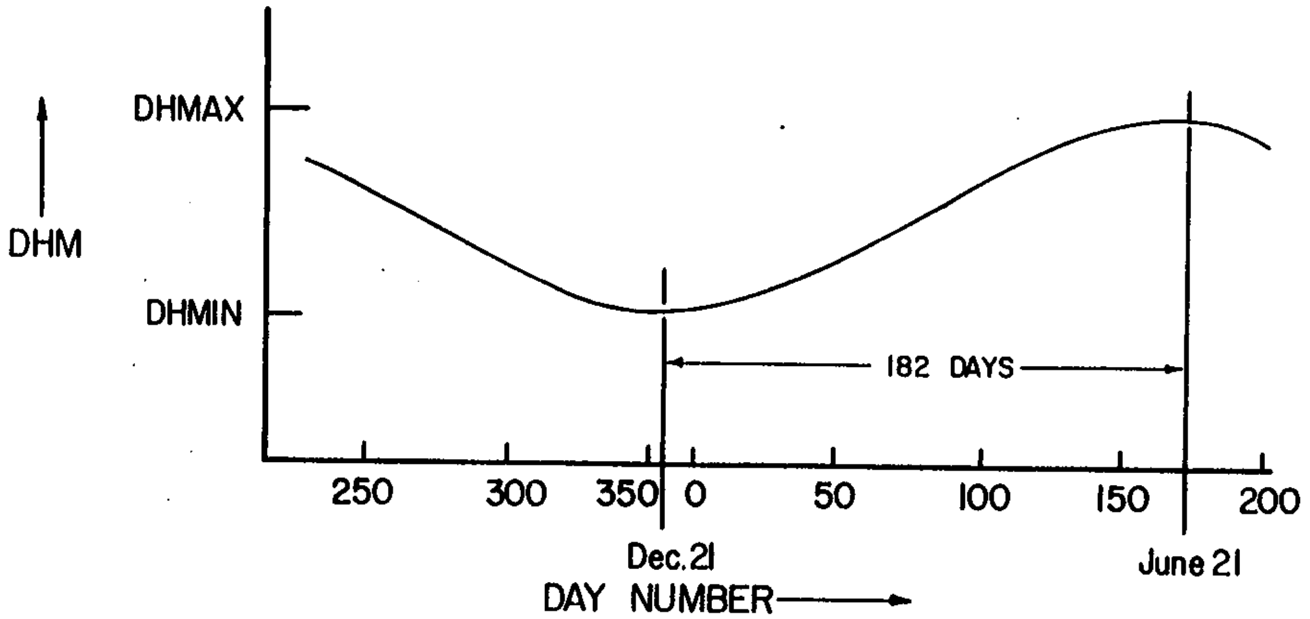
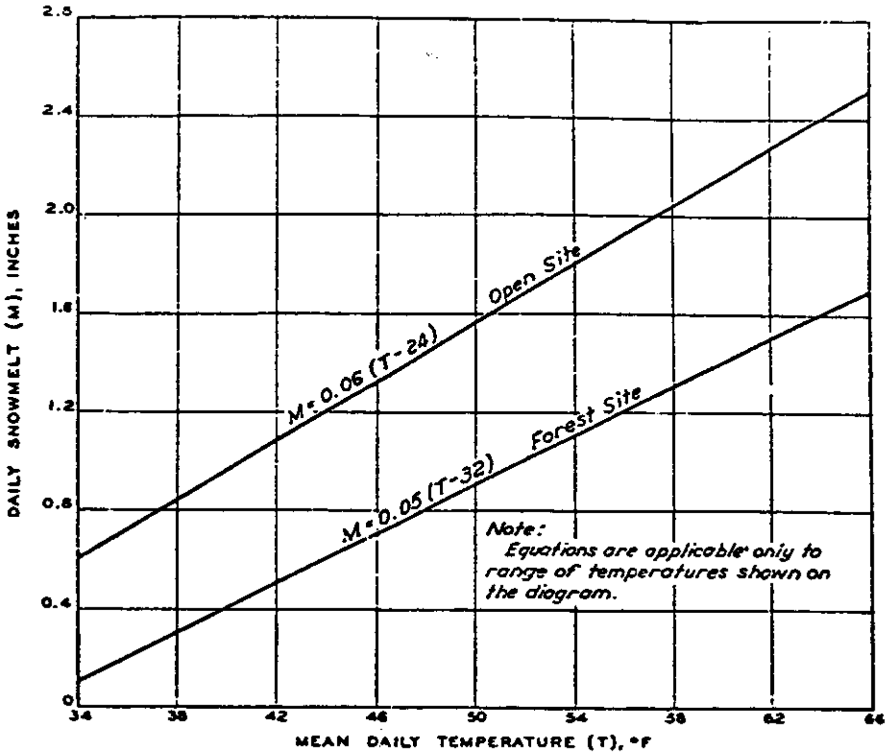


Figure 4-22. Seasonal Variation of Melt Coefficients for Continuous Simulation.



(a) MEAN TEMPERATURE INDEX

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

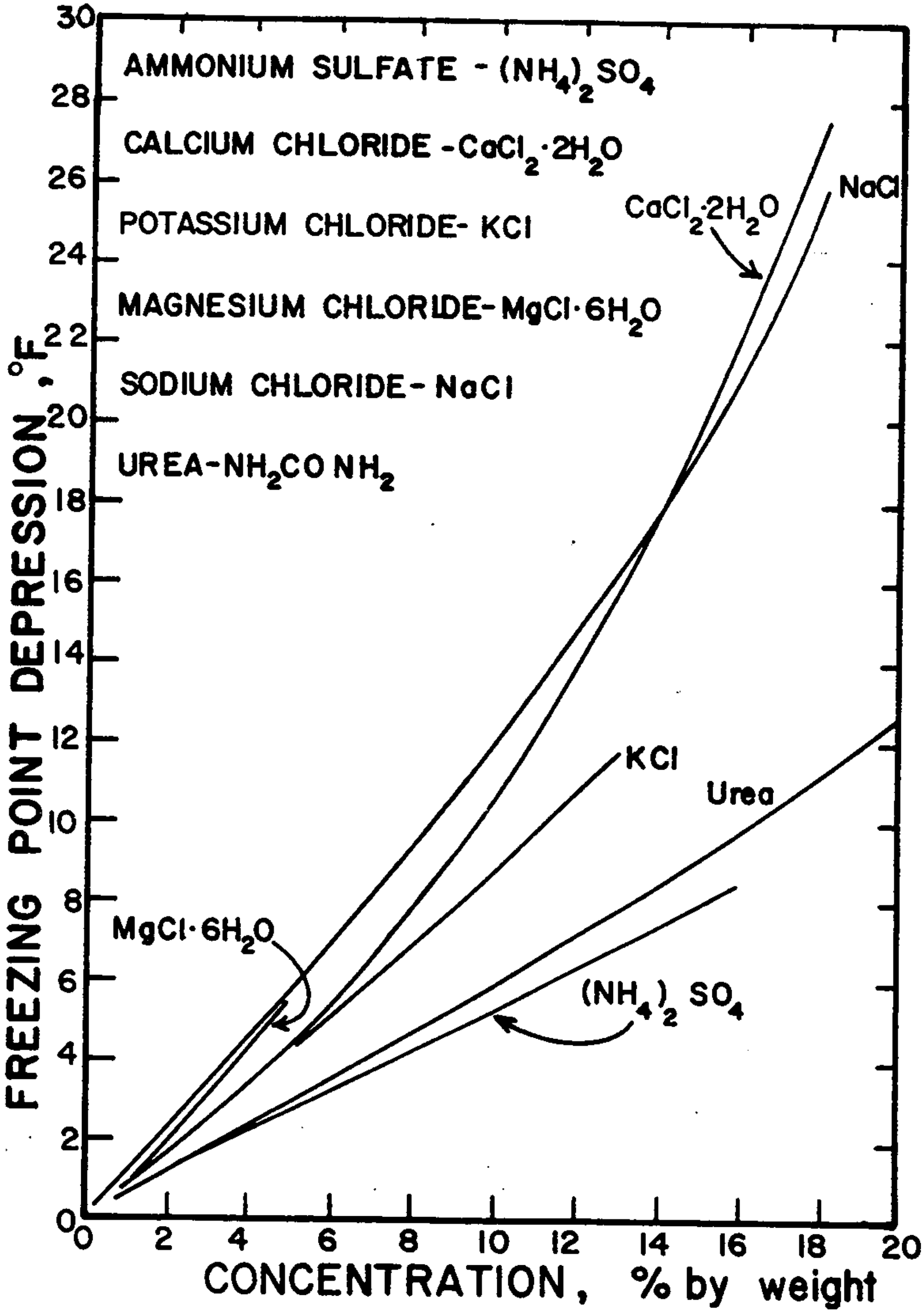


Figure 4-24. Freezing Point Depression Versus Roadway Salting Chemical Concentration. Compiled from data from CRC (1976).

AI = IMPERVIOUS AREA WITH DEPRESSION STORAGE
A2 = PERVIOUS AREA
A3 = IMPERVIOUS AREA WITH ZERO DEPRESSION STORAGE
A4 = SNOW COVERED IMPERVIOUS AREA

AI + A3 = NORMALLY BARE

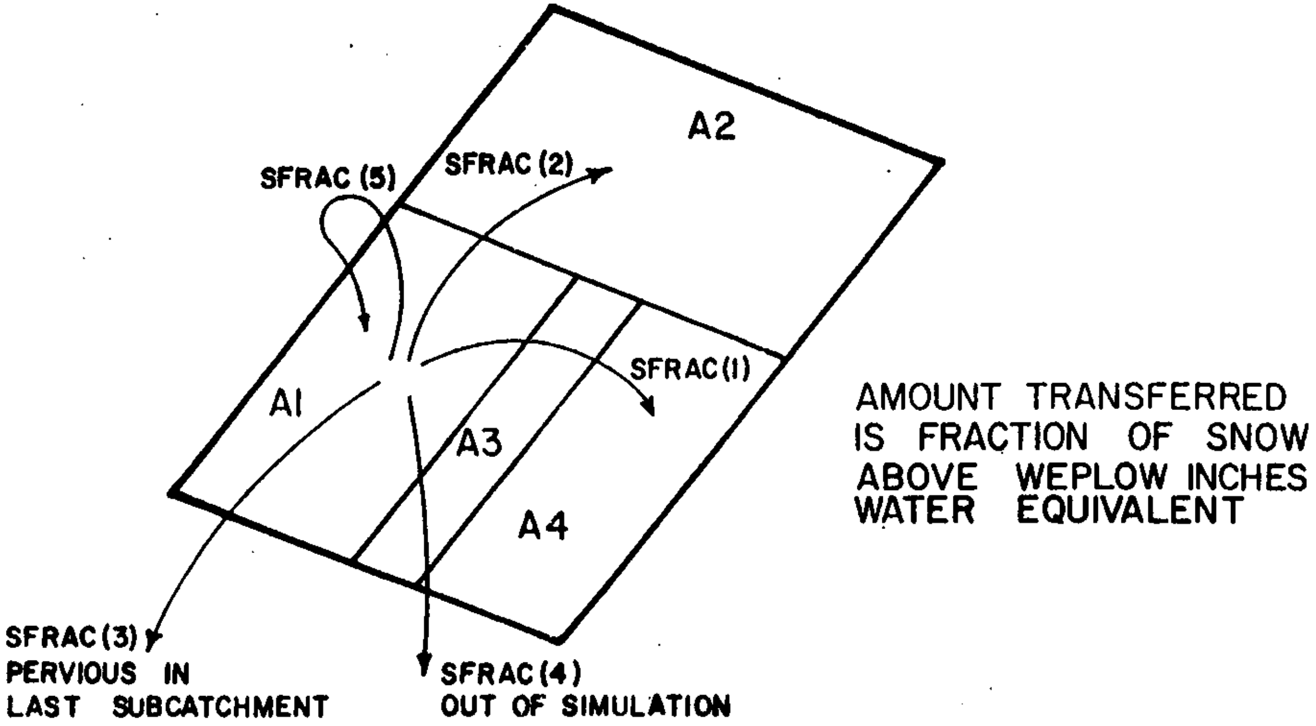


Figure 4-25. Illustration of Snow Redistribution Fractions.

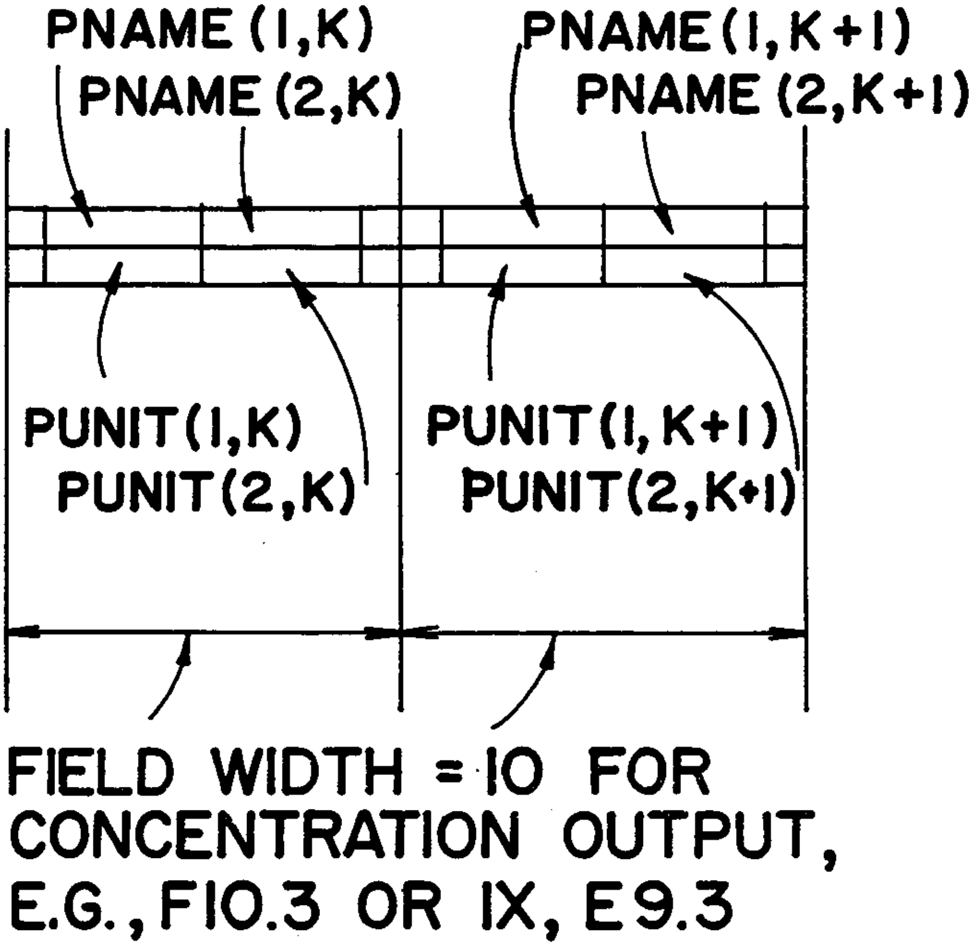


Figure 4-26. Layout of Quality Constituent Headings. Parameters PNAME and PUNIT are entered in card group J3, Table 4-31.

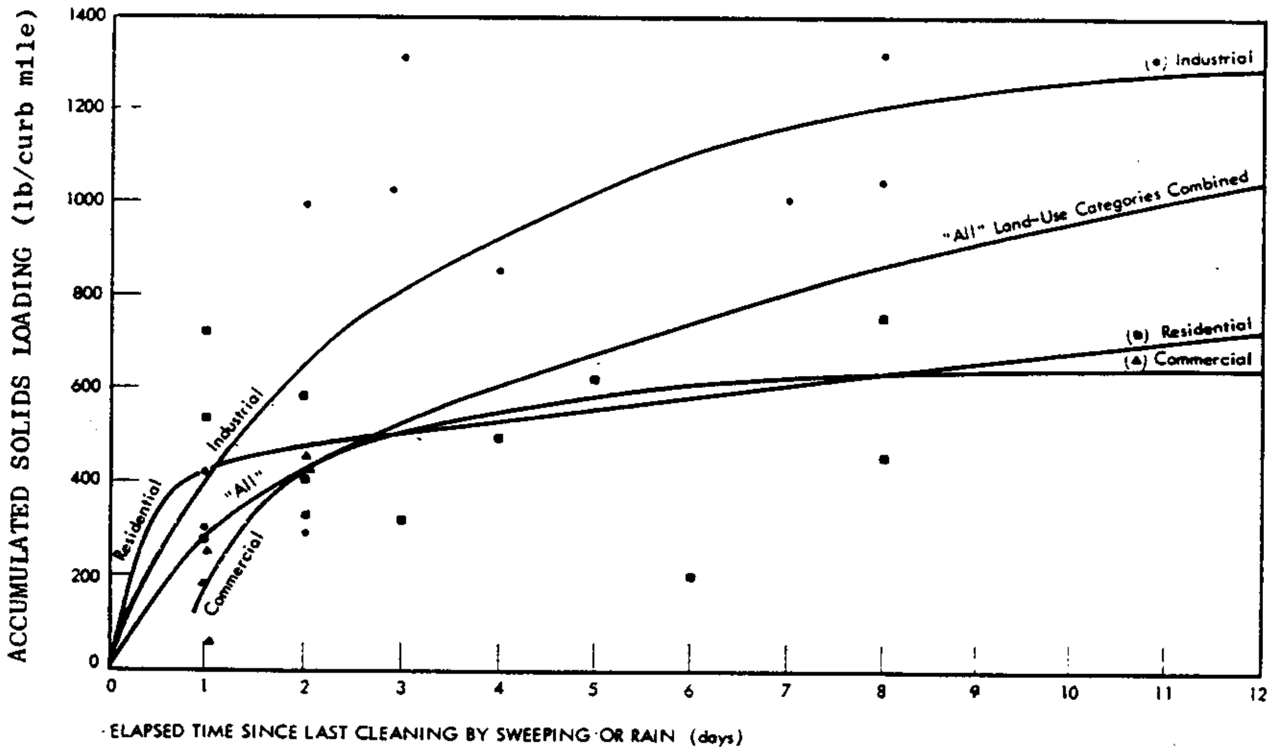


Figure 4-27. Non-linear Buildup of Street Solids. (After Sartor and Boyd, 1972, p. 206.)

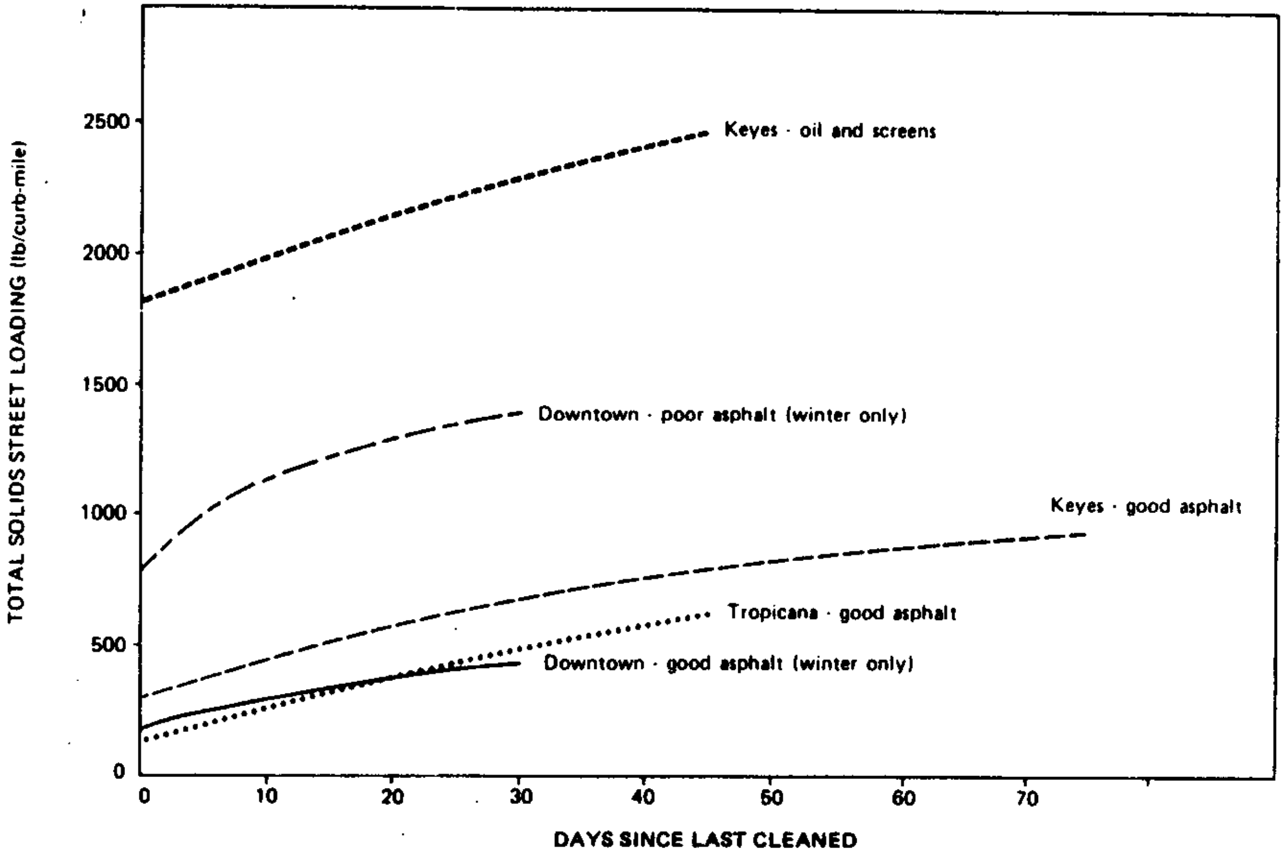


Figure 4-28. Buildup of Street Solids in San Jose. (After Pitt, 1979, p. 29.)

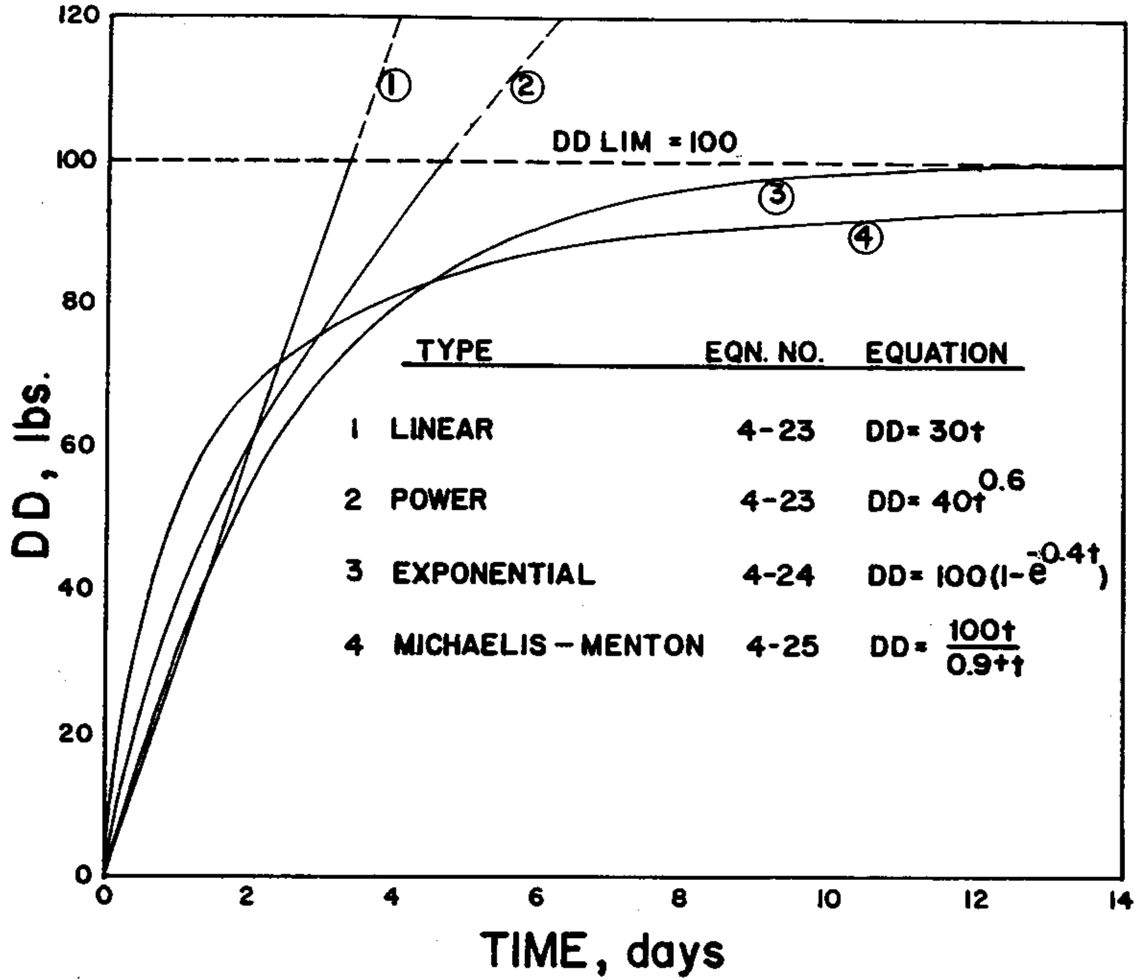


Figure 4-29. Comparison of Linear and Three Non-linear Buildup Equations. "Dust and dirt," DD, is used as an example. Numerical values have been chosen arbitrarily.

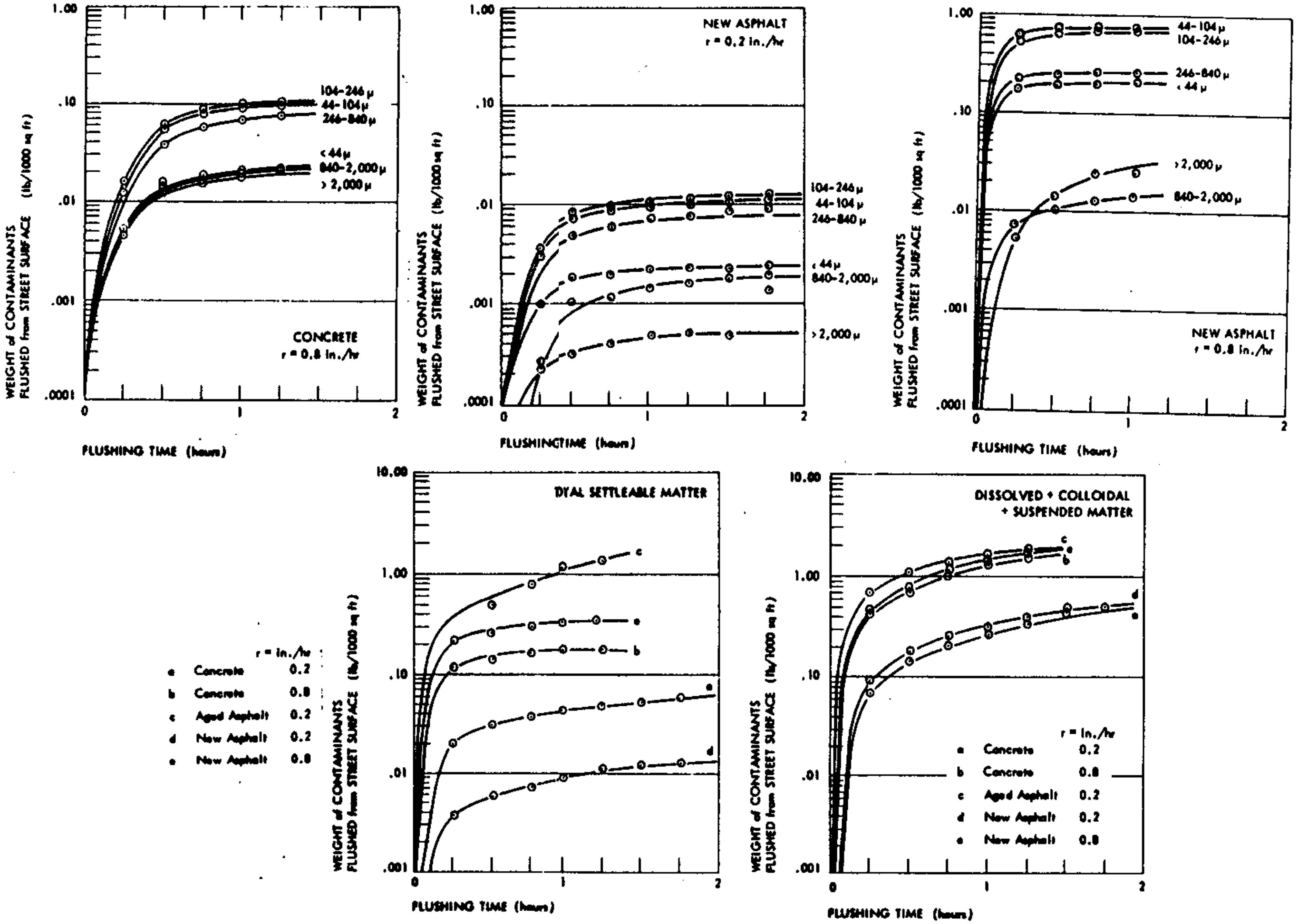


Figure 4-30. Washoff of Street Solids by Flushing with a Sprinkler System. (After Sartor and Boyd, 1972, pp. 86-87.)

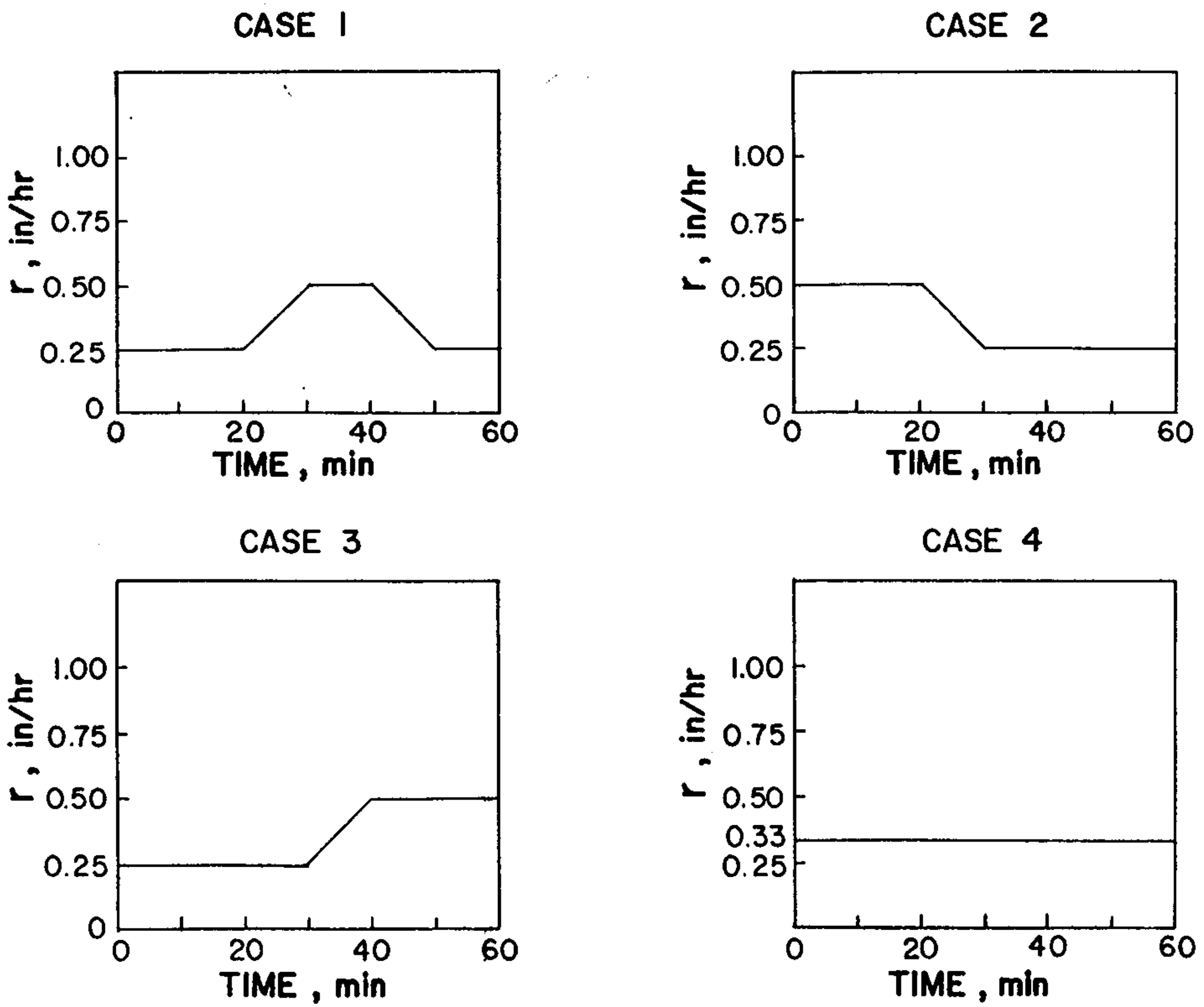


Figure 4-31. Time Variation of Runoff Rate Used in Example of Table 4-21 and Figures 4-32 to 4-35

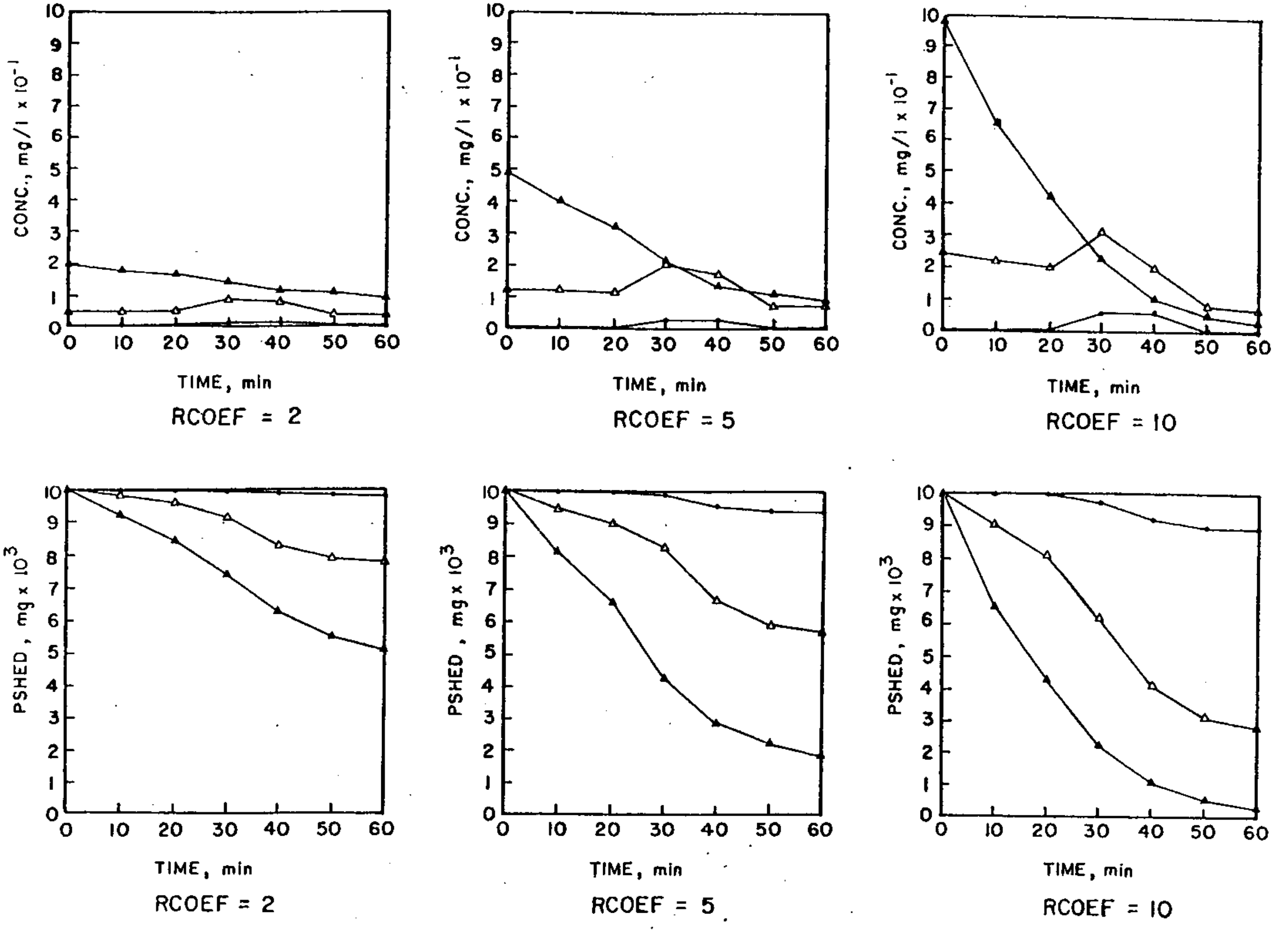


Figure 4-32. Time History of Concentration and Subcatchment Load (PSHED) for Case 1 Runoff (Figure 4-31).

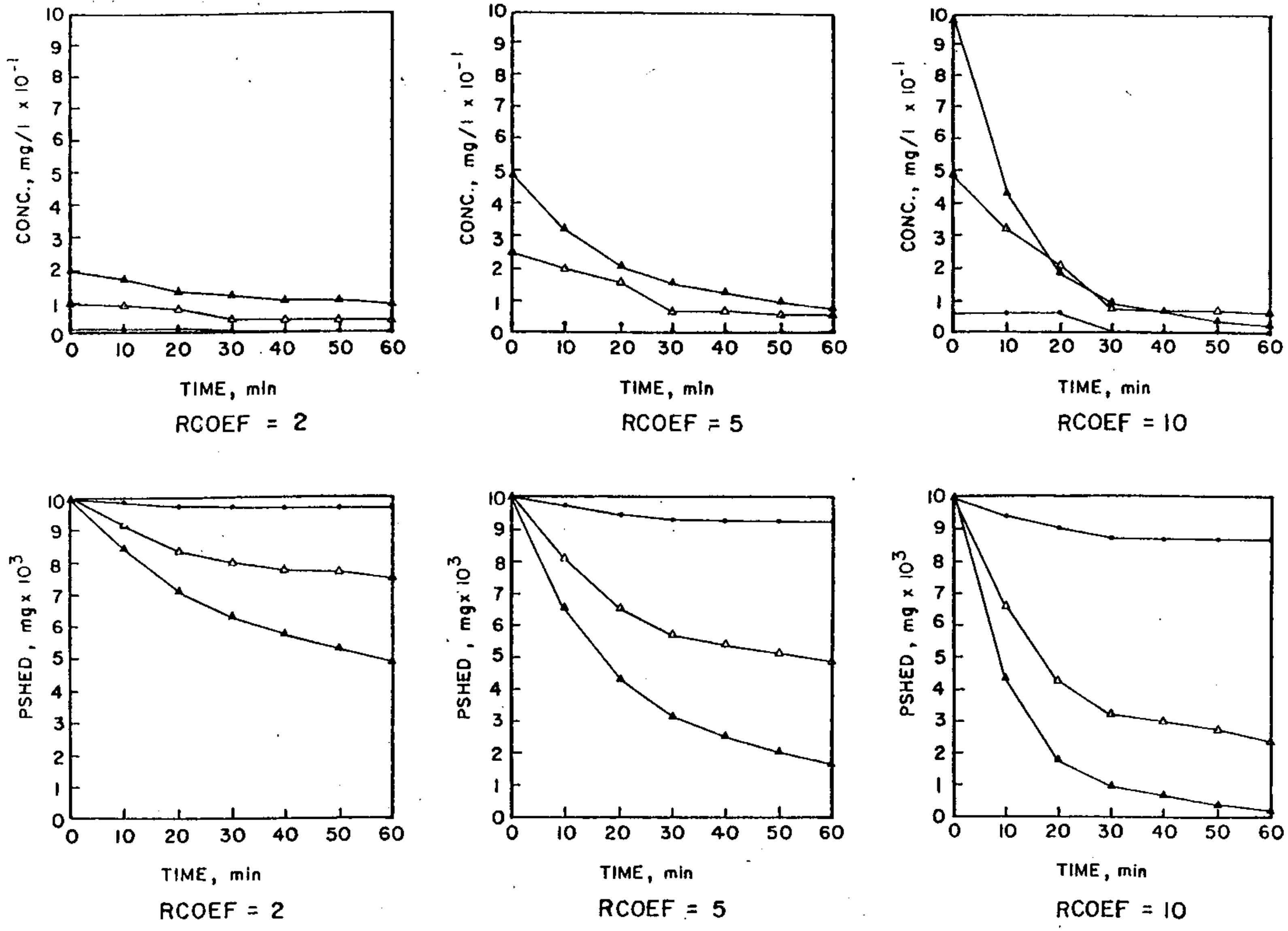


Figure 4-33. Time History of Concentration and Subcatchment Load (PSHED) for Case 2 Runoff (Figure 4-31).

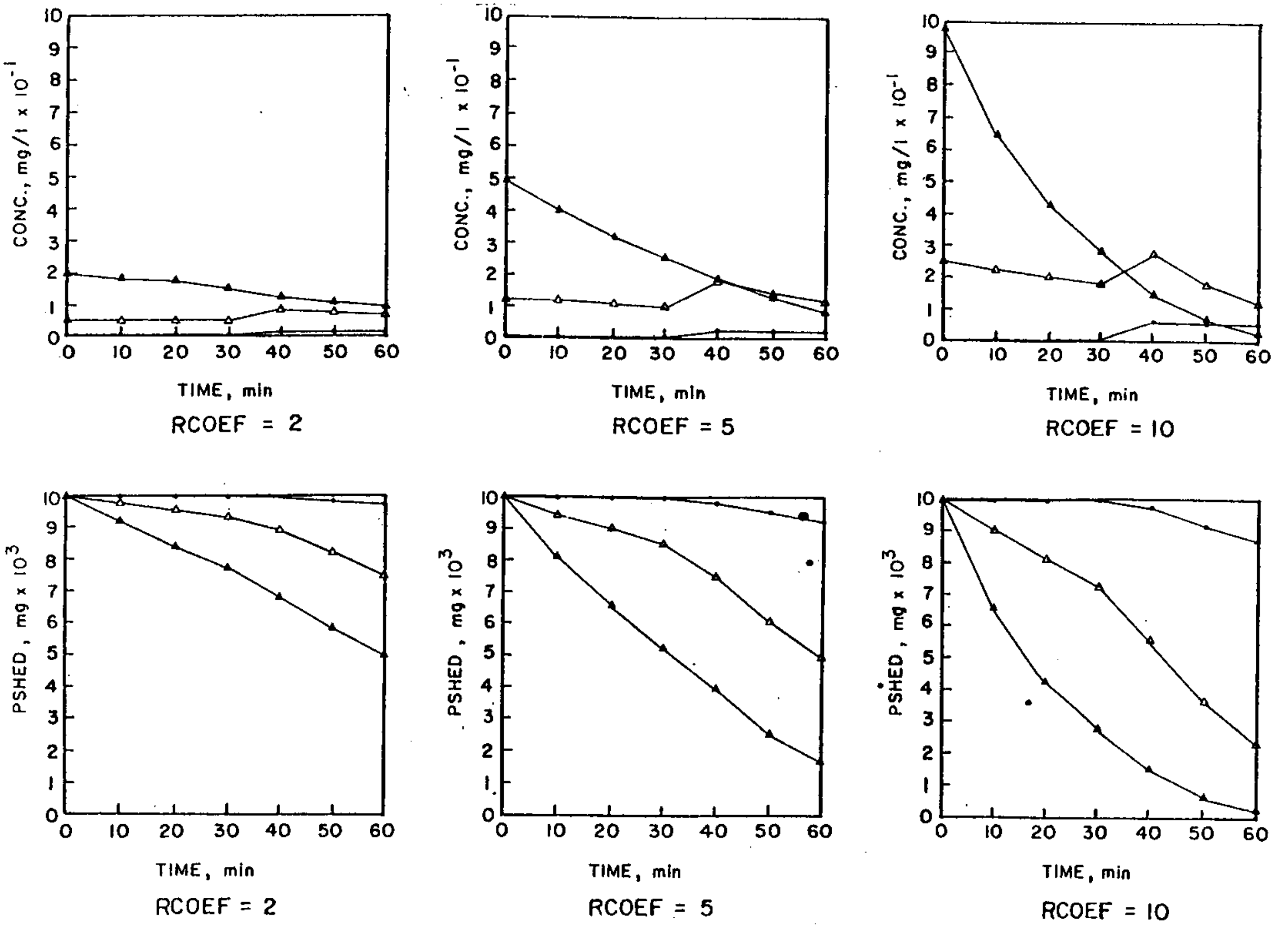


Figure 4-34. Time History of Concentration and Subcatchment Load (PSHED) for Case 3 Runoff (Figure 4-31).

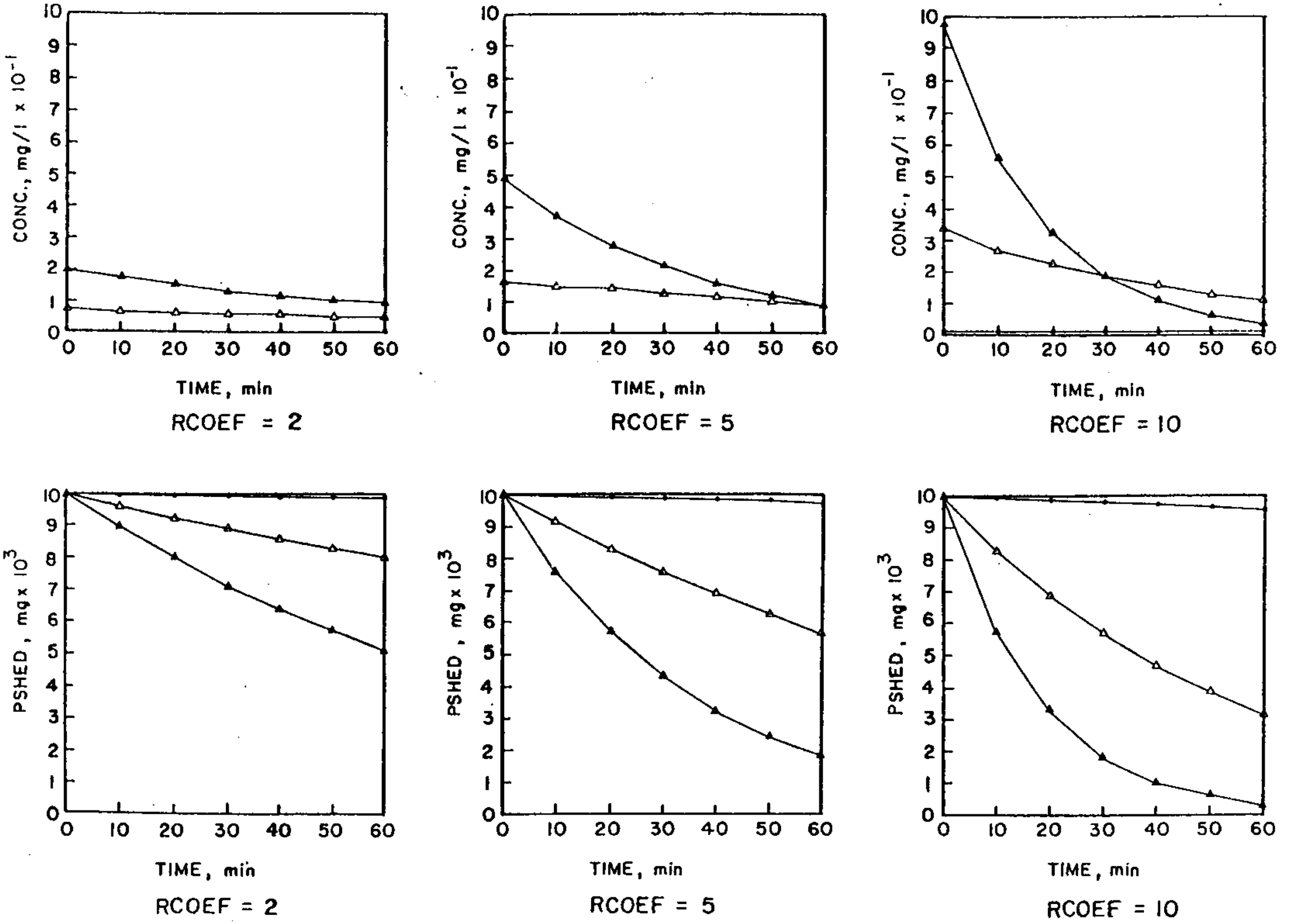


Figure 4-35. Time History of Concentration and Subcatchment Load (PSHED) for Case 4 Runoff (Figure 4-31).

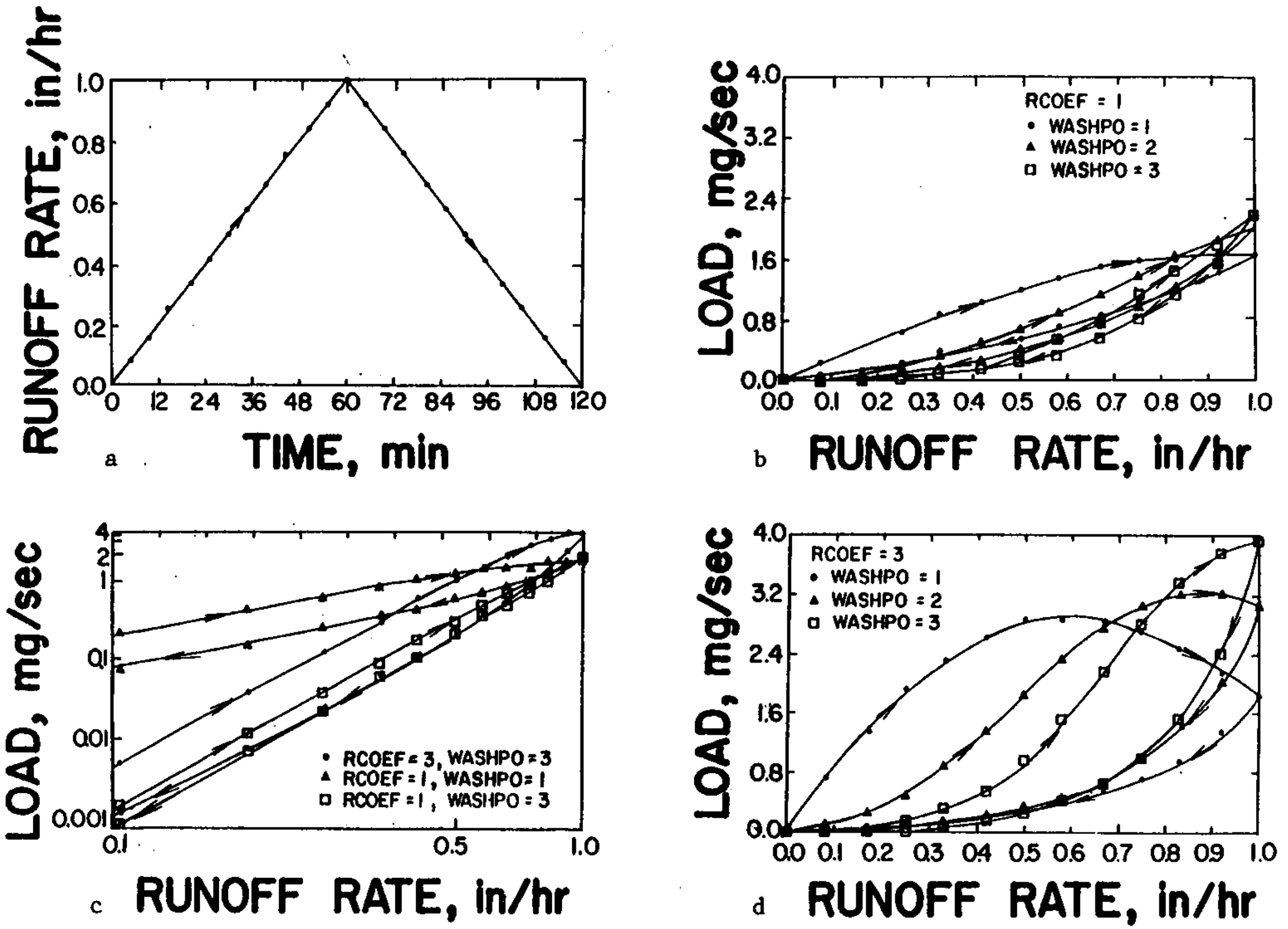


Figure 4-36. Simulated Load Variations within a Storm as a Function of Runoff Rate. The initial surface load is 1000 mg on a 1 ac catchment, and the time step is 5 min. The loop effect is exagerated as RCOEF is increased (Figures b vs. d). The loops are flattened when using a log-log scale (Figure c).

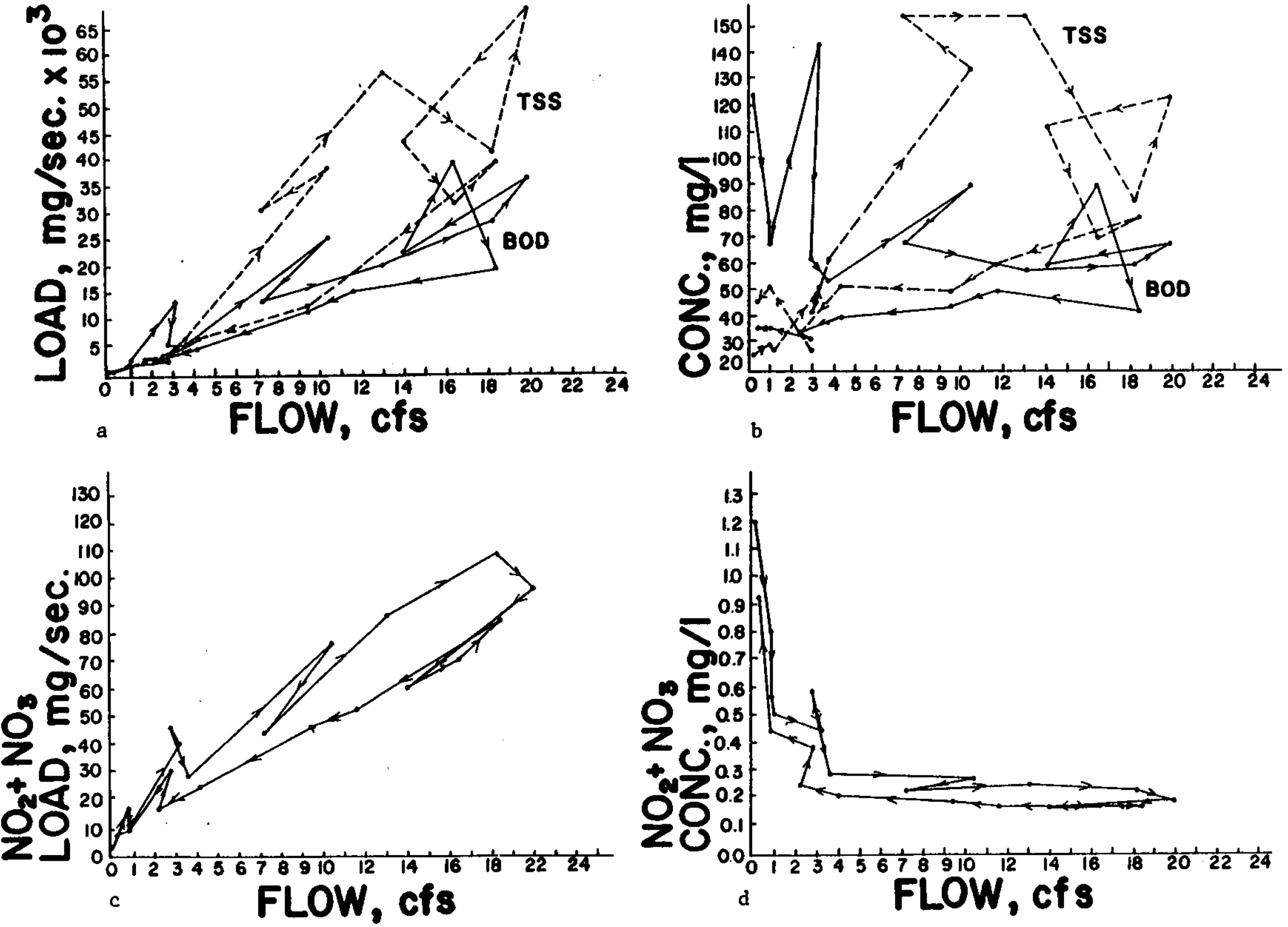
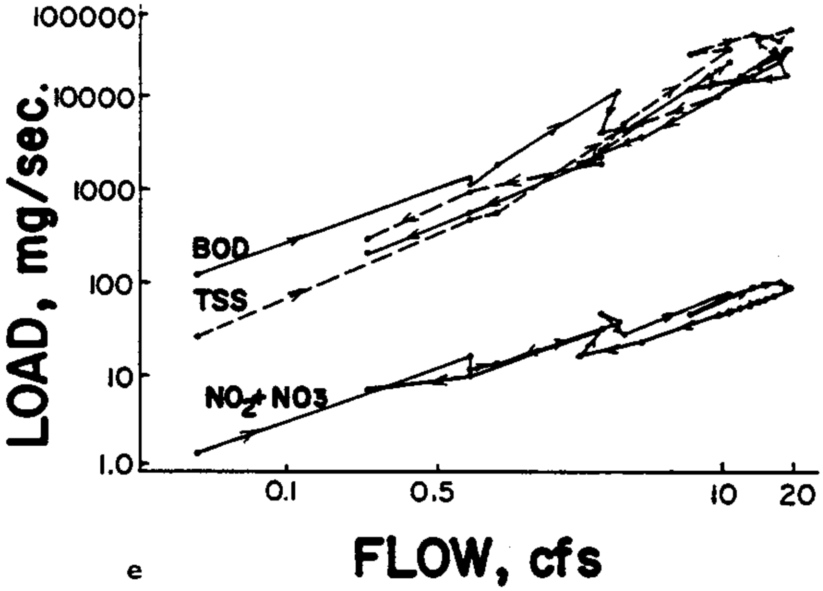
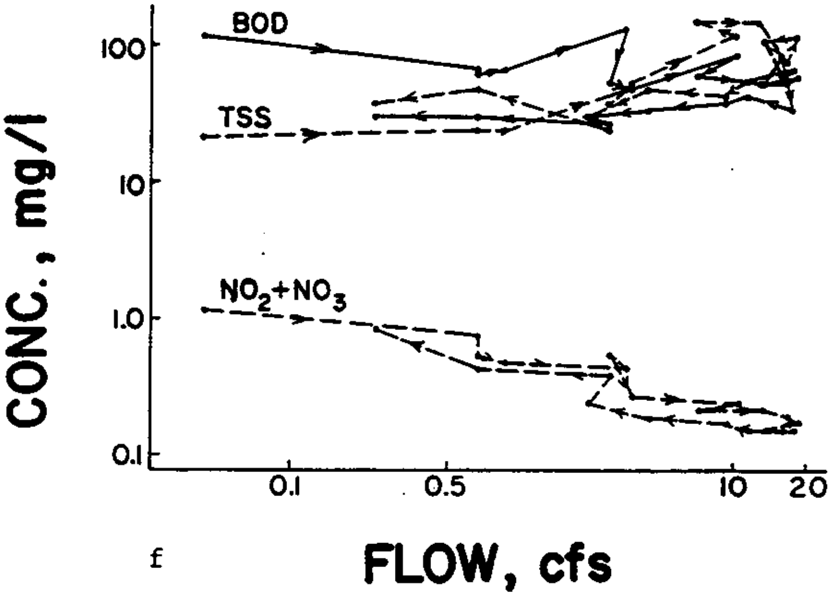


Figure 4-37. Variation of BOD_5, TSS and NO_2+NO_3-N Load and Concentration for Storm of 11/17/74 for View Ridge 1 Catchment, Seattle (from Huber et al., 1979). Connected points trace time history. (Figure continued, next page.)



e



f

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

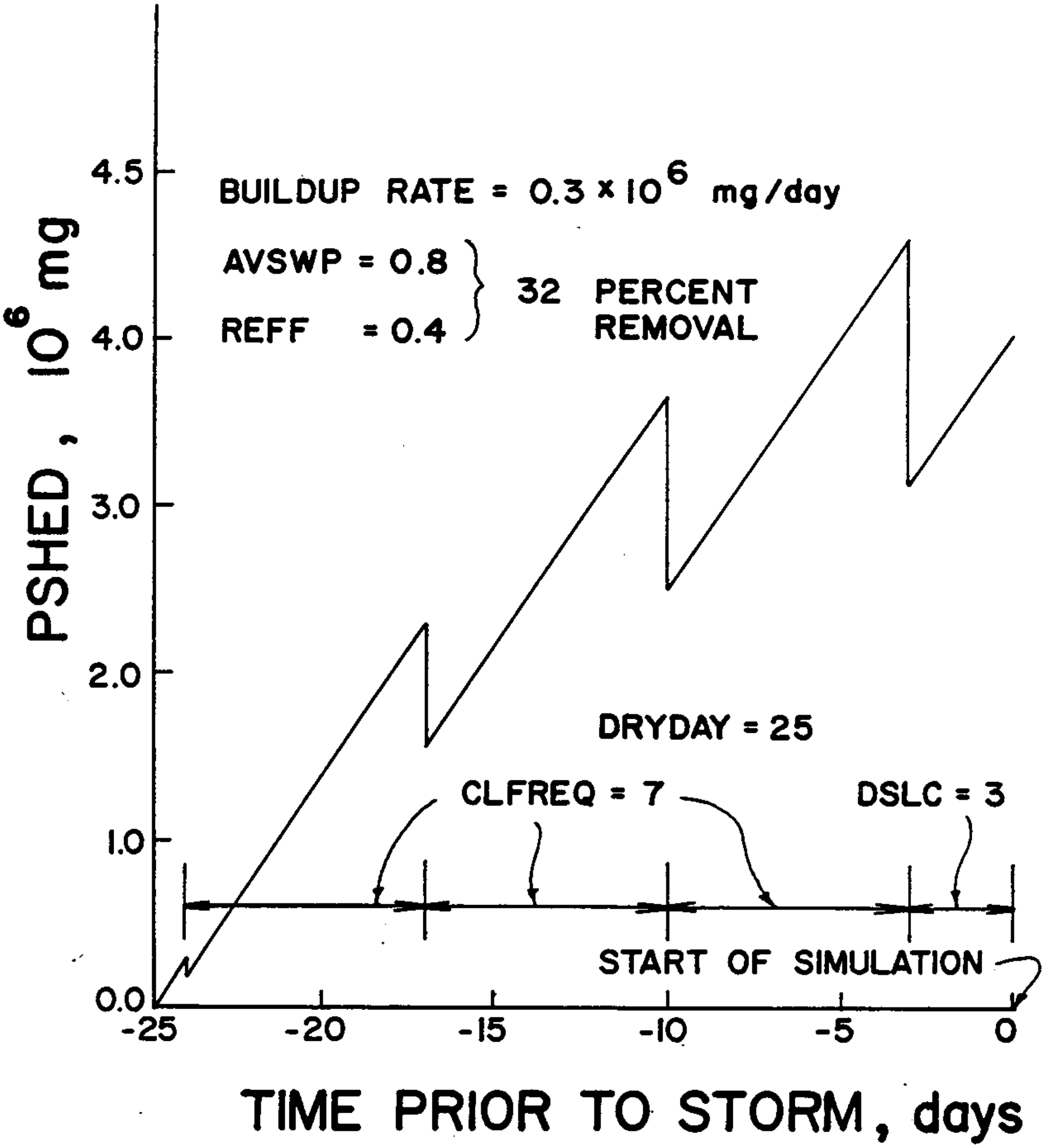
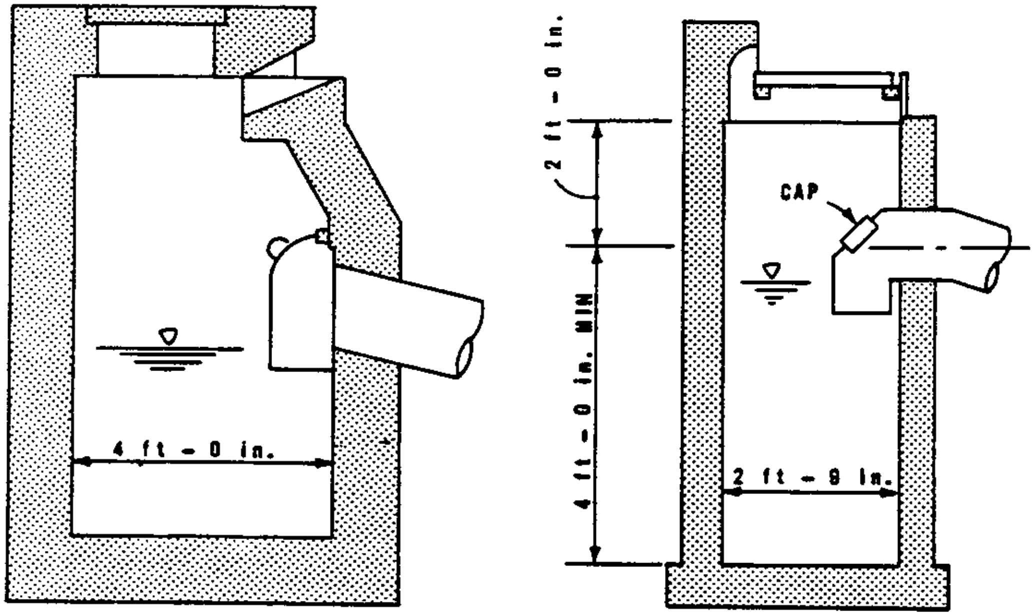
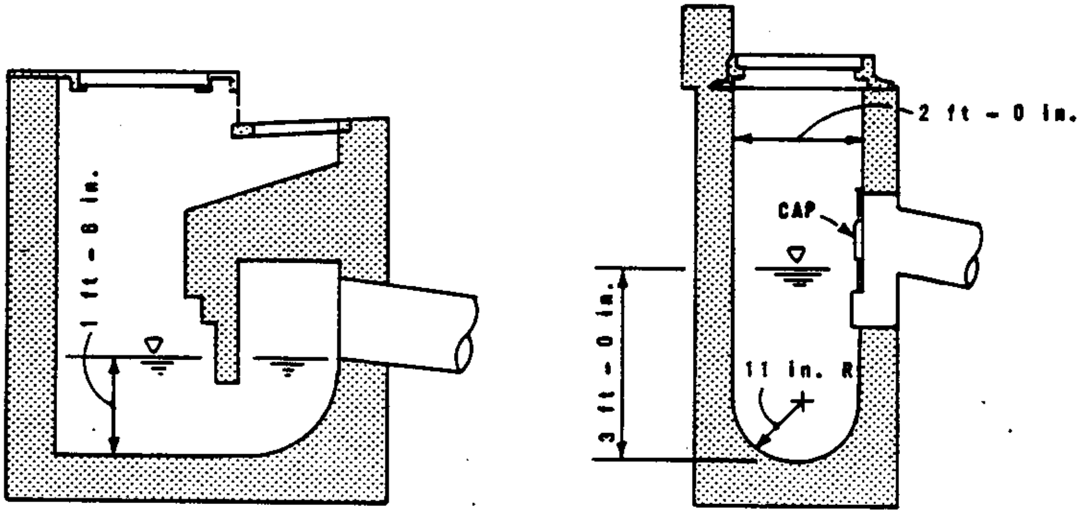


Figure 4-38. Hypothetical Time Sequence of Linear Buildup and Street Sweeping.



NEW YORK

SAN FRANCISCO



ATLANTA

TORONTO

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

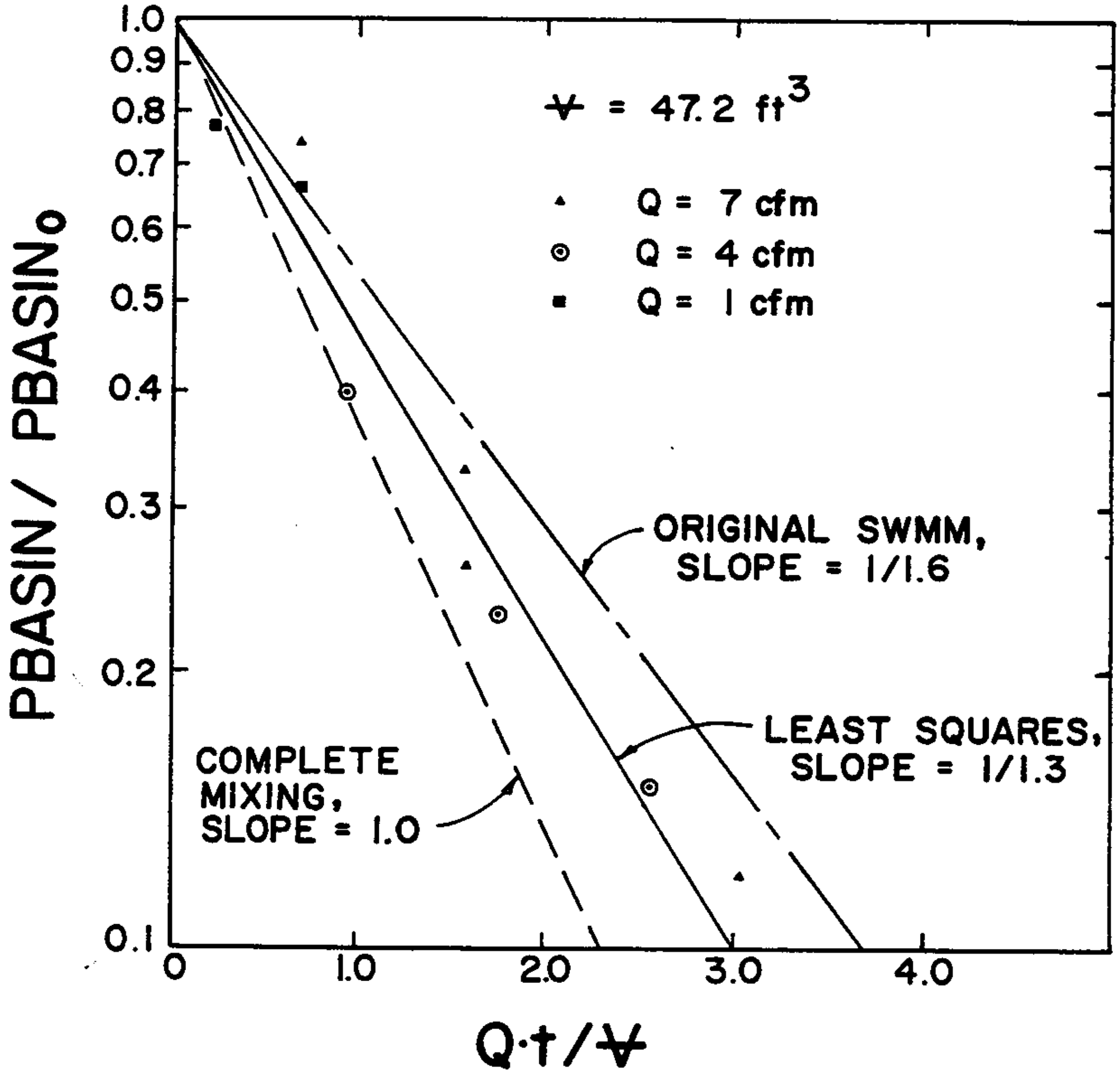


Figure 4-40. Catchbasin Flushing Characteristics. Data are from APWA (1969).

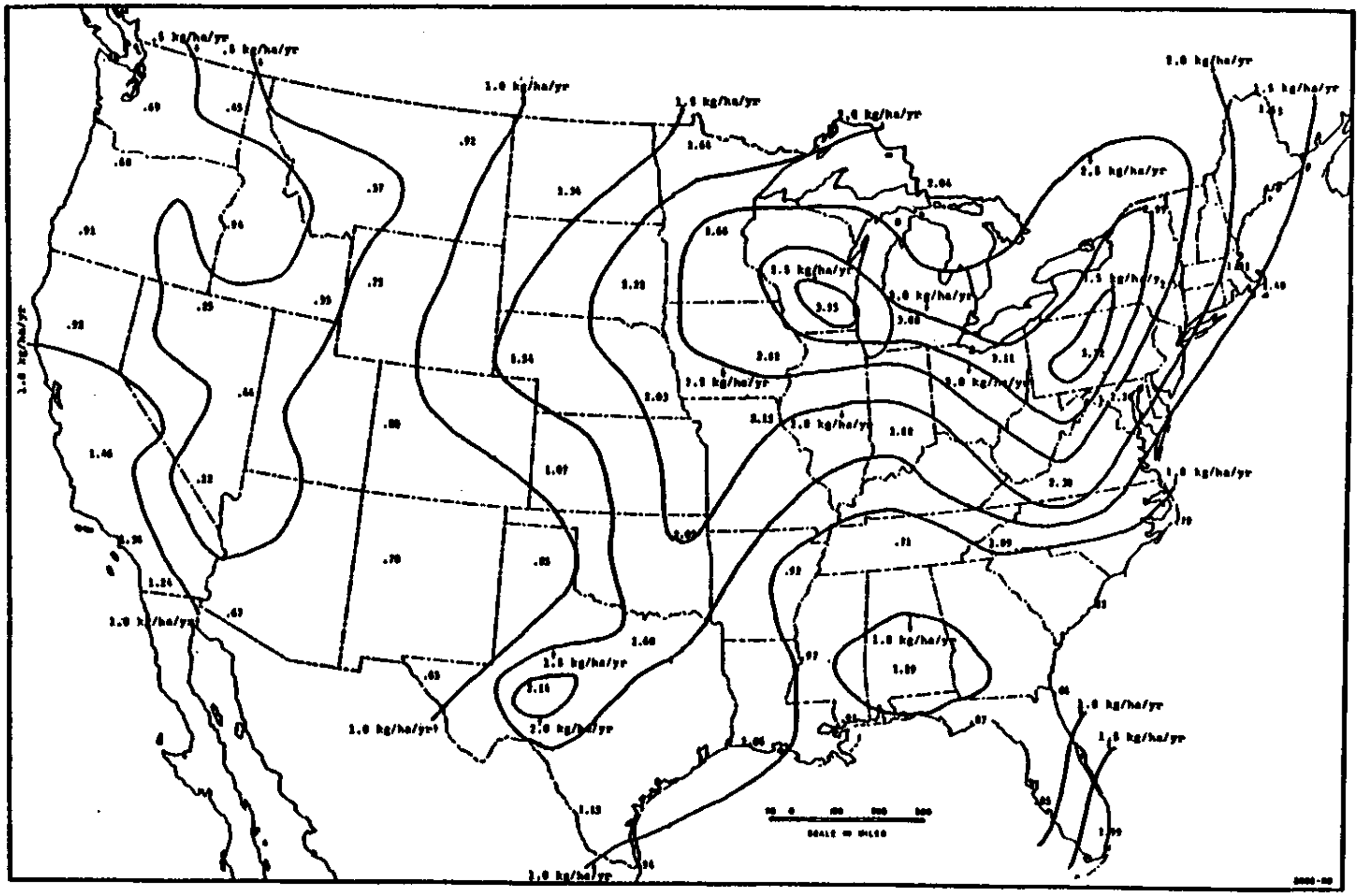
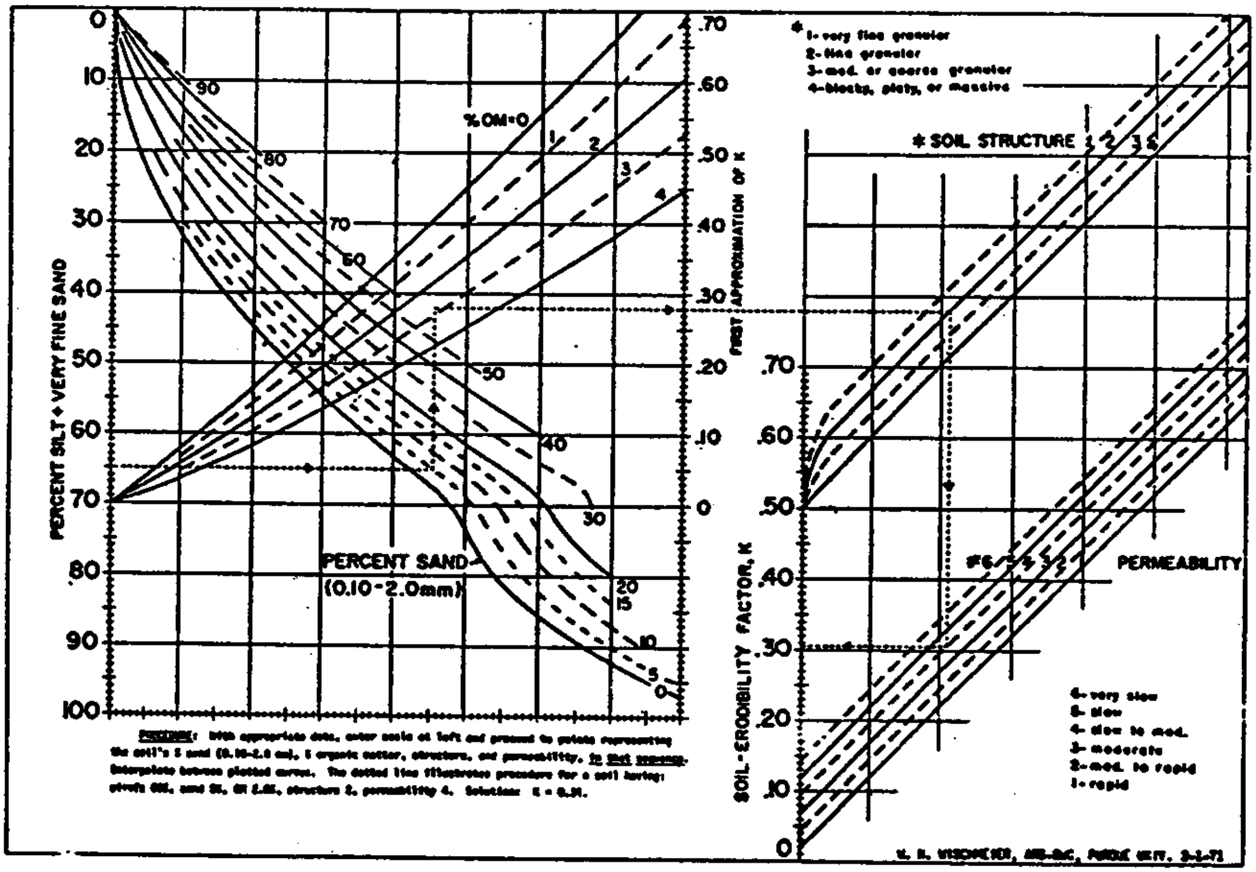


Figure 4-41. Nationwide Annual Loadings of NH_4^+-N + NO_3-N in Precipitation (after Uttormark et al., 1974, p. 87). Dry fallout is not included.



PROCEDURE: With appropriate data, enter scale at left and proceed to points representing the soil's % sand (0.10-2.0 mm), % organic matter, structure, and permeability, in that sequence. Interpolate between plotted curves. The dotted line illustrates procedure for a soil having: si+vfs 65%, sand 5%, OM 2.8%, structure 2, permeability 4. Solution: K = 0.31.

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

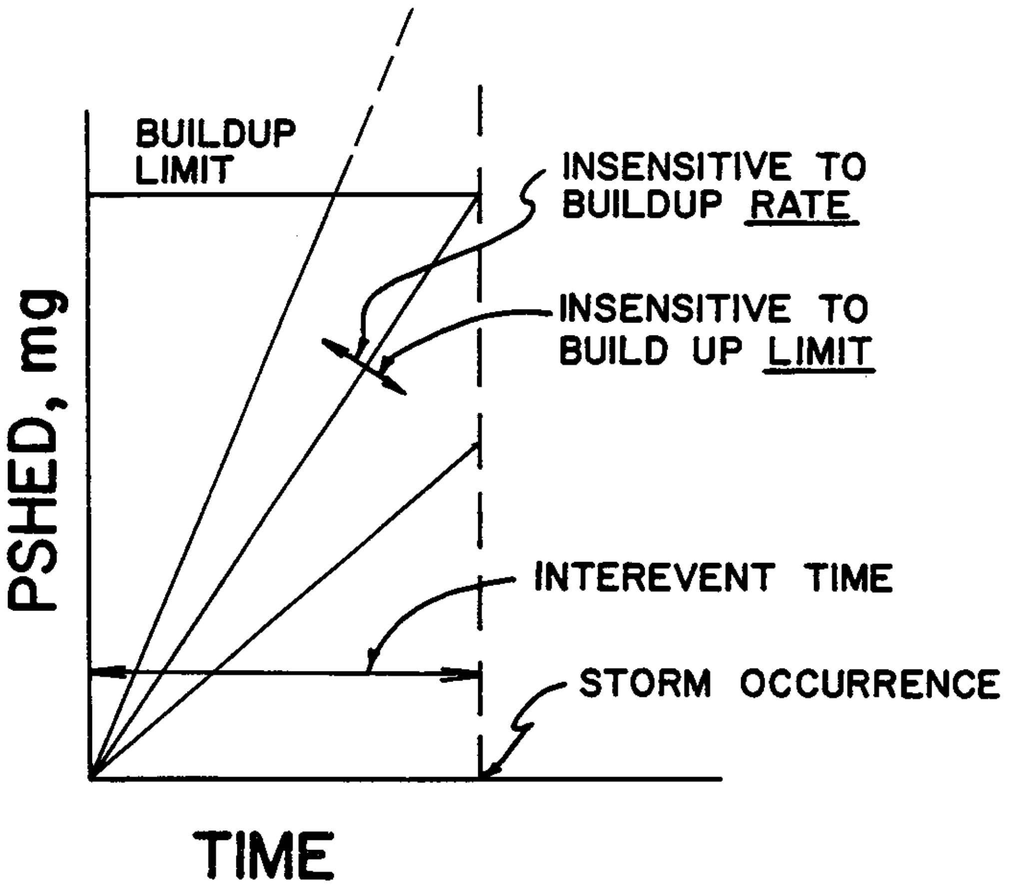


Figure 4-43. Interaction of Buildup Parameters and Storm Interevent Time.

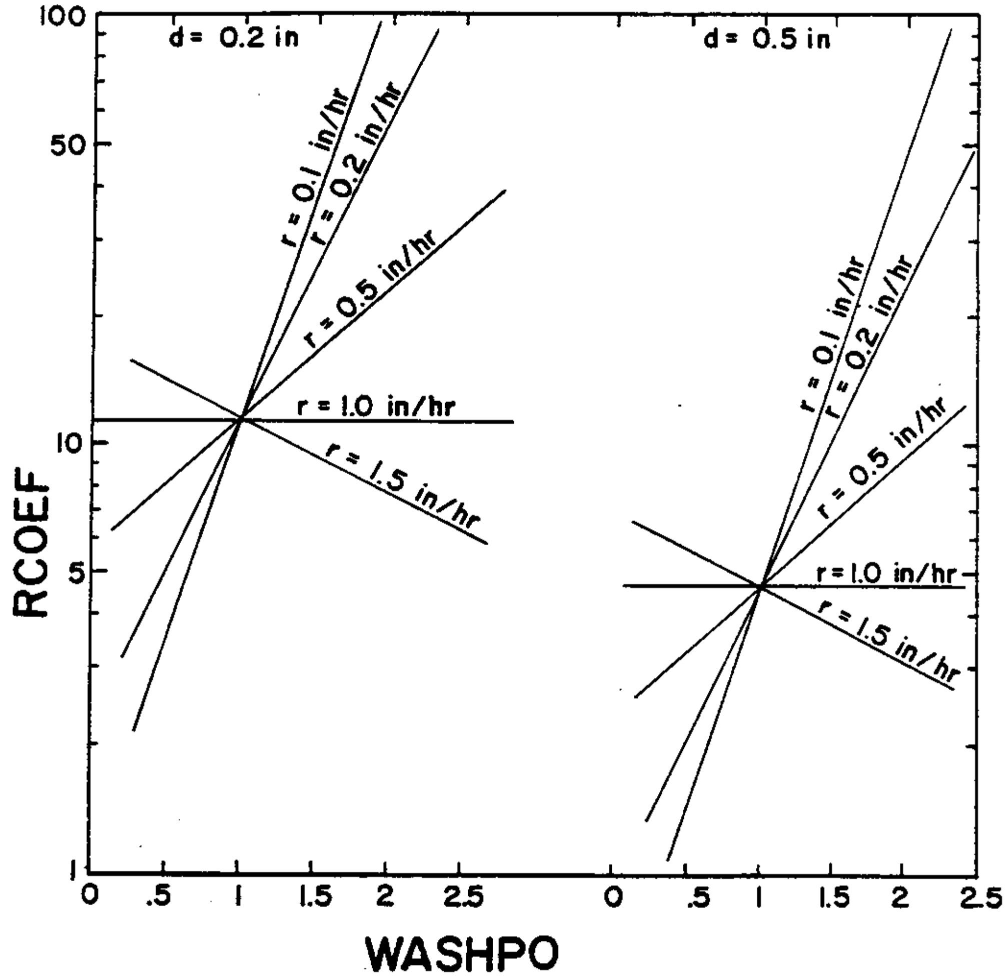


Figure 4-44. Relationship Between RCOEF and WASHPO for 90 Percent Washoff During a Storm Event of Runoff Depth d. The runoff rate is r.

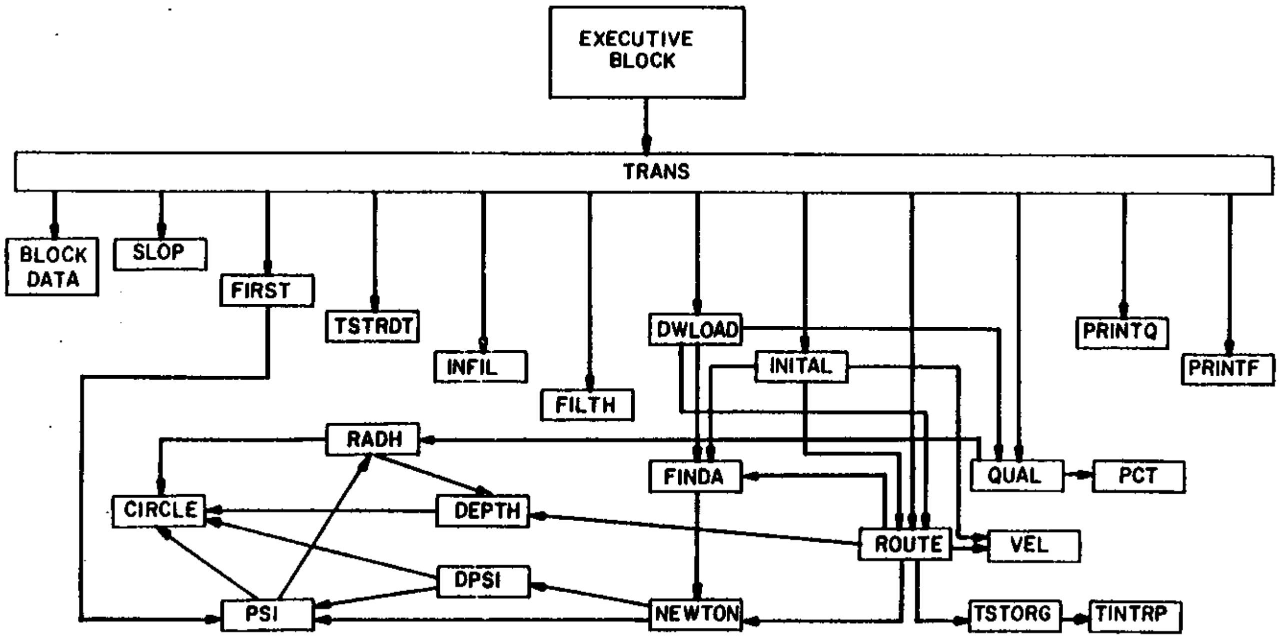


Figure 6-1. Structure of Transport Block Subroutines

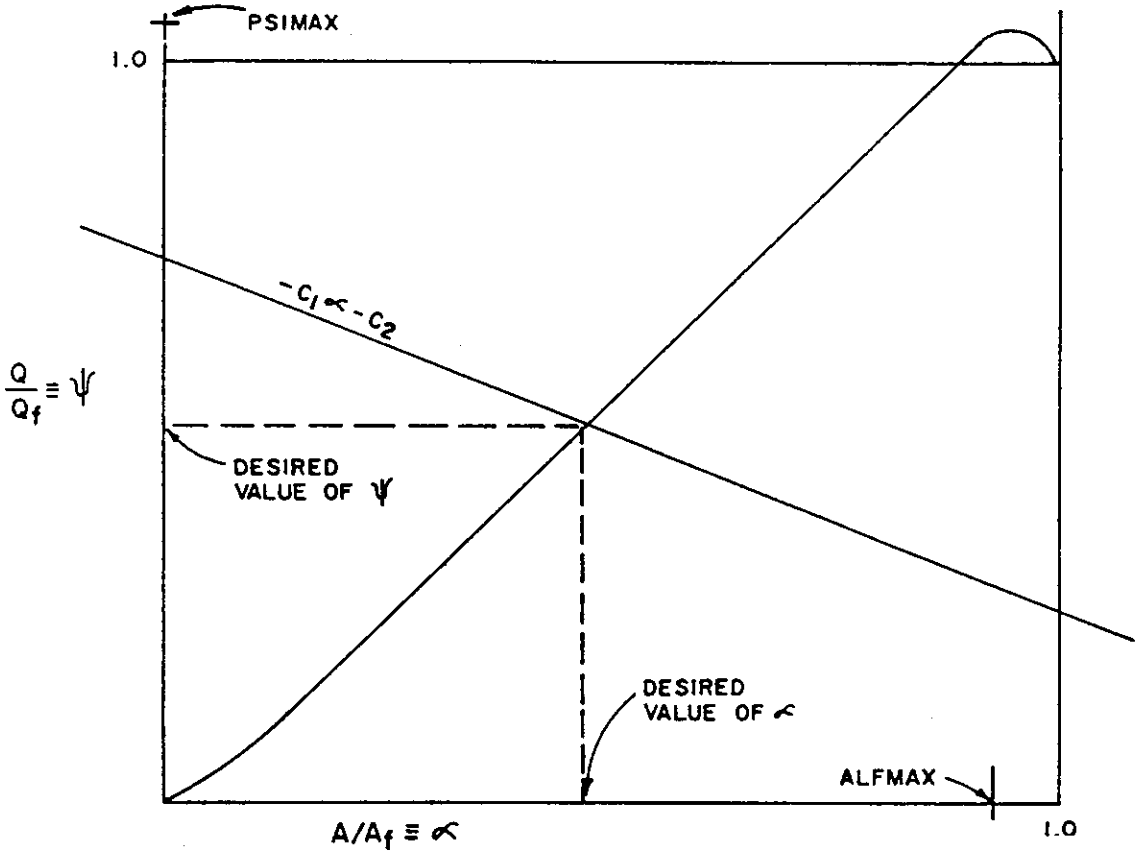
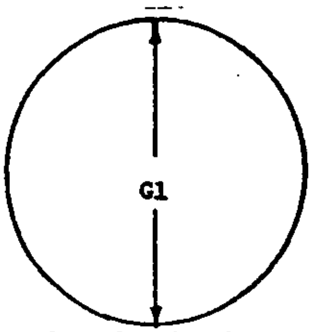
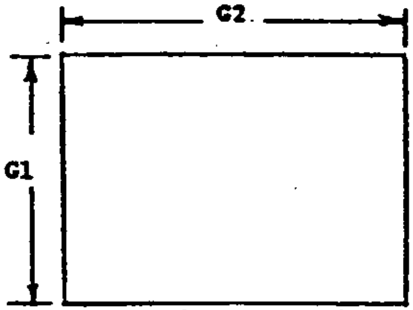


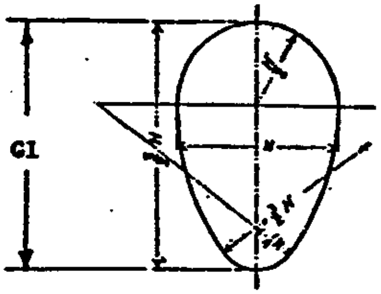
Figure 6-2. The Intersection of the Straight Line and the Normalized Flow-Area Curve as Determined in Route. The ψ–α Curve is Formed by Straight Line Segments Delineated by the Variables ANORM and QNORM, for Conduits with a Tabular Q-A Relationship. Q Denotes Flow, A Denotes Area, and the Subscript f Denotes Values at Full-Flow. The Line $-C_1 \alpha -C_2$ is Formed by the Program from the Continuity Equation.



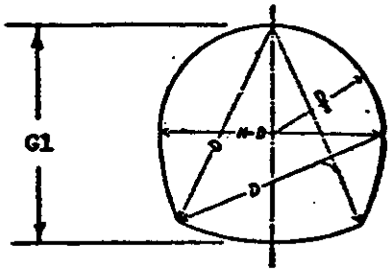
Type 1: Circular



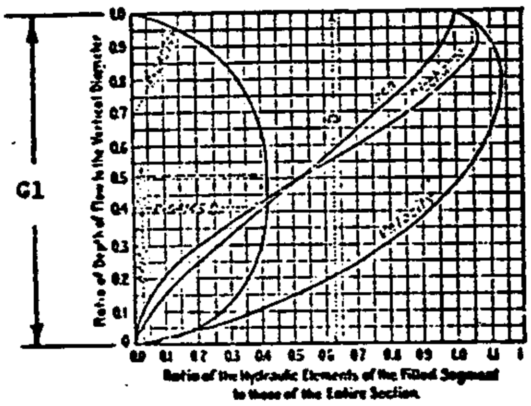
Type 2: Rectangular



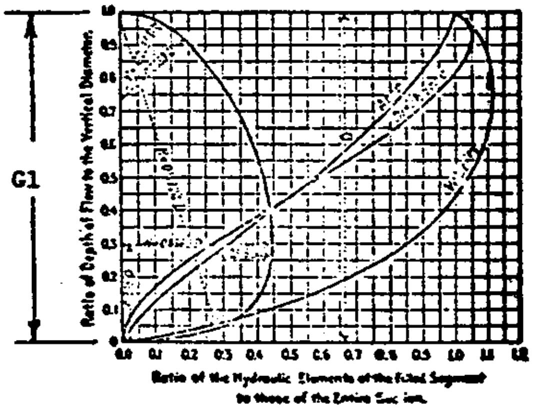
Type 3: Phillips Standard Egg Shape



Type 4: Boston Horseshoe

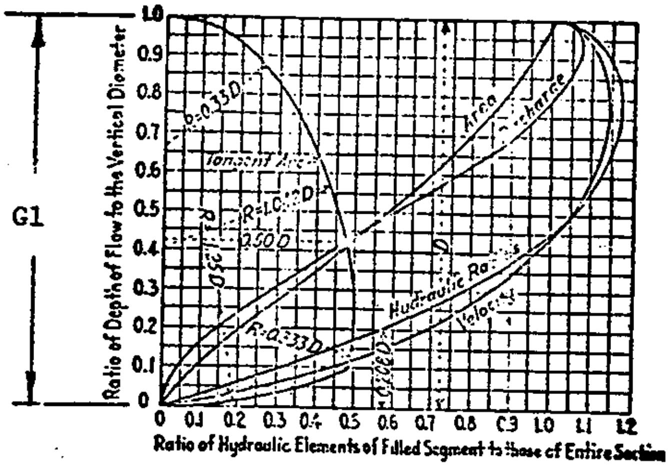


Type 5: Gothic

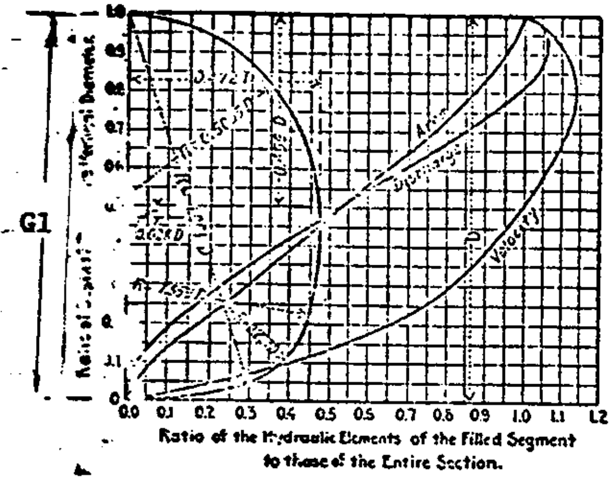


Type 6: Catenary

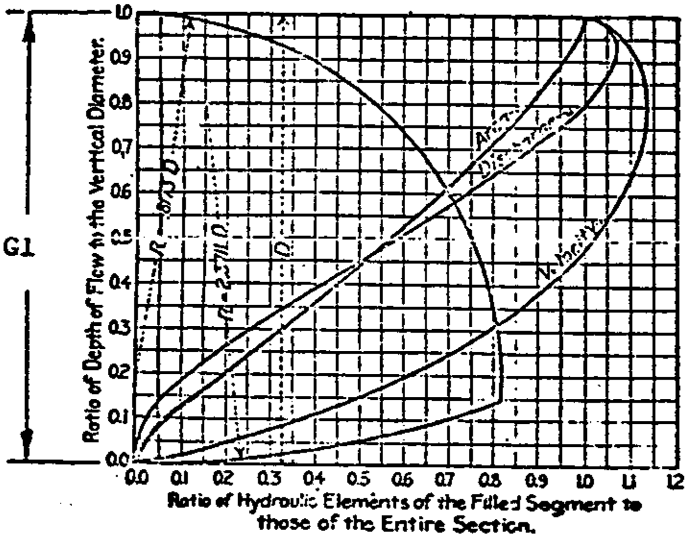
Figure 6-3. Sewer Cross-Sections



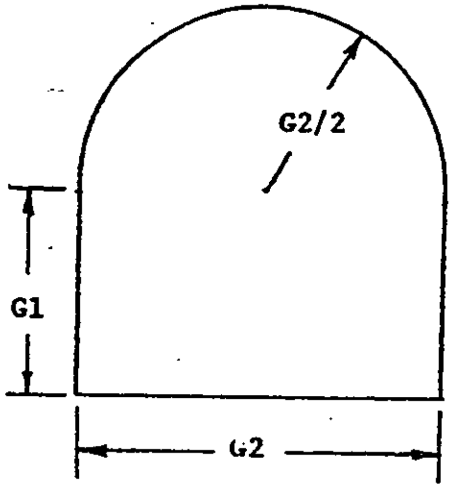
Type 7: Louisville Semielliptic



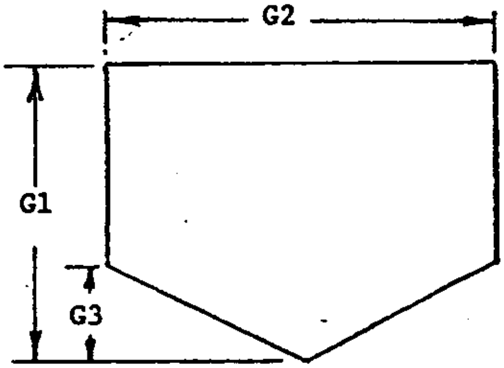
Type 8: Basket-handle



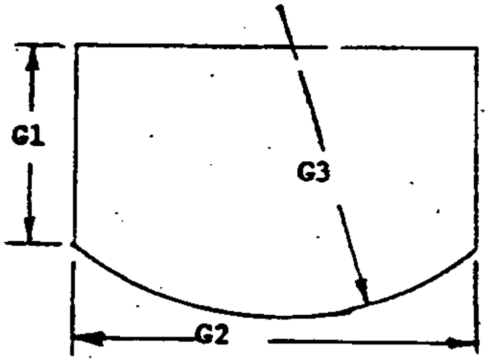
Type 9: Semi-circular



Type 10: Modified Basket-handle

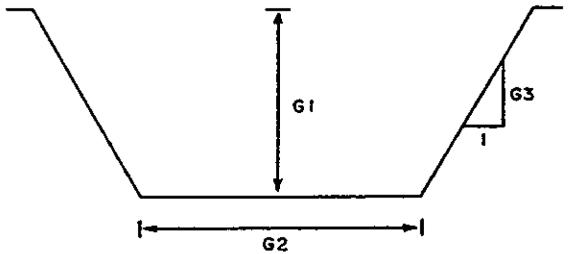


Type 11: Rectangular, Triangular Bottom

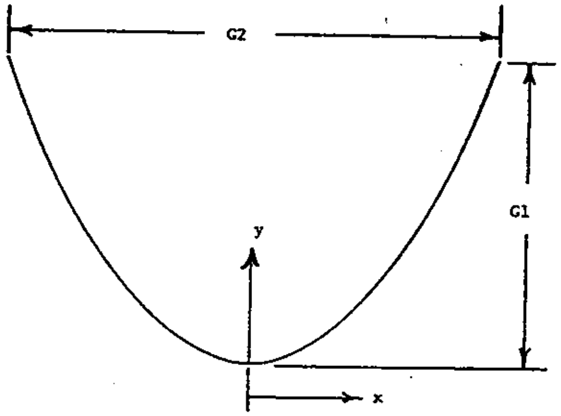


Type 12: Rectangular, Round Bottom

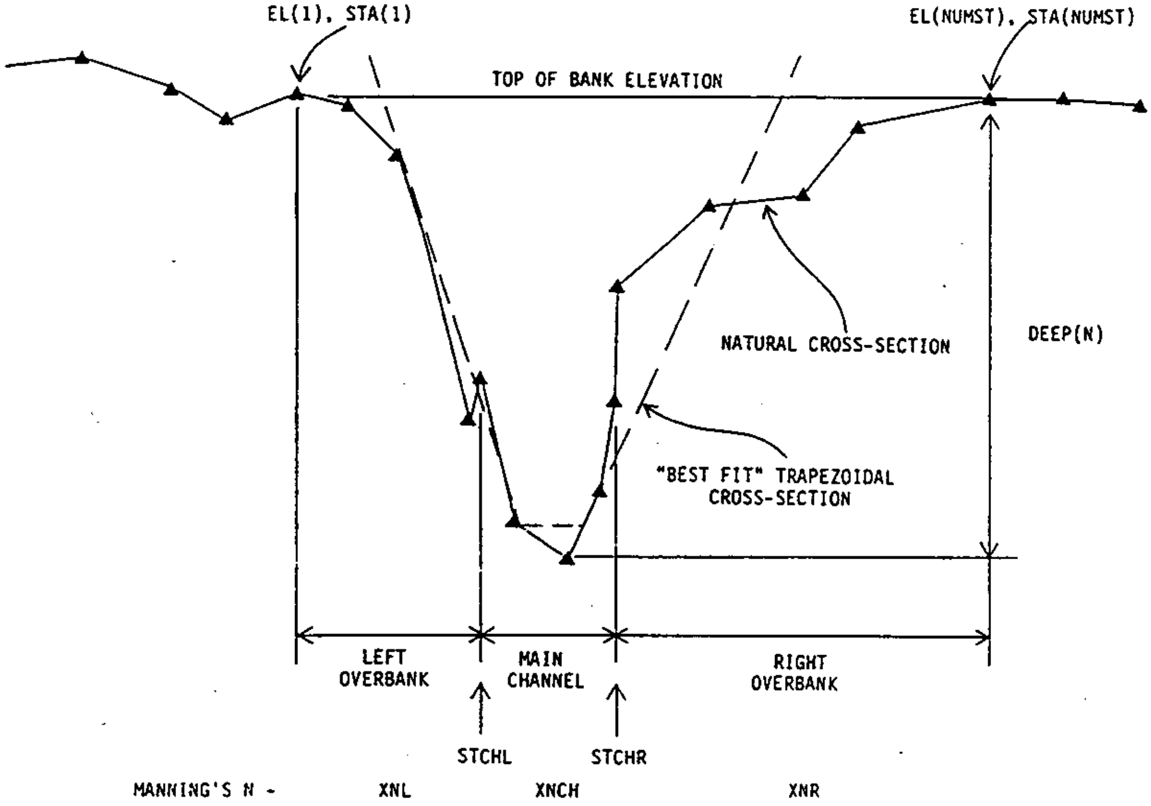
Figure 6-3 (continued). Sewer Cross-Sections



TYPE 13: TRAPEZOID



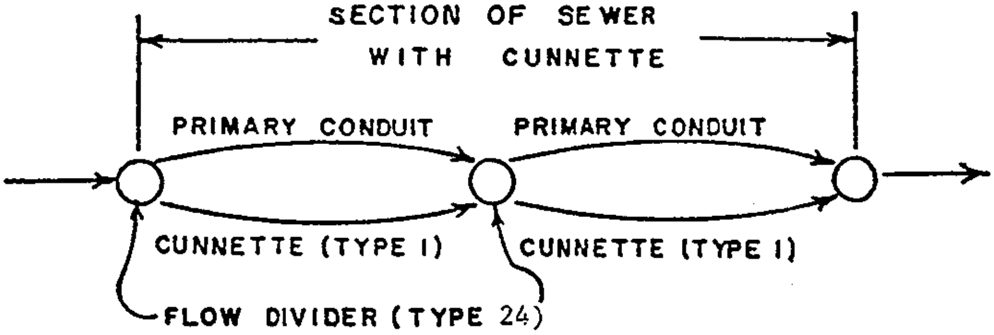
Type 14: Parabolic, and
Type 15: Power Function



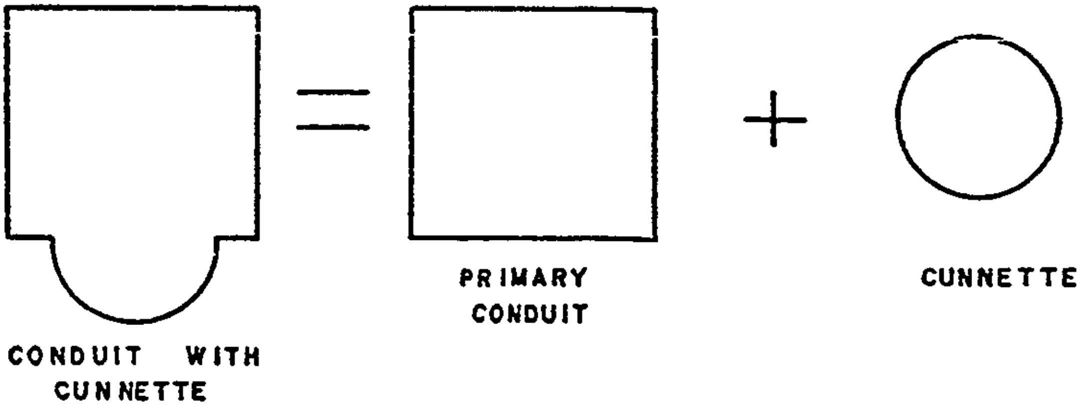
Type 16

Definition Sketch of an Irregular Cross-Section.

Figure 6-3 (continued). Sewer Cross-Sections

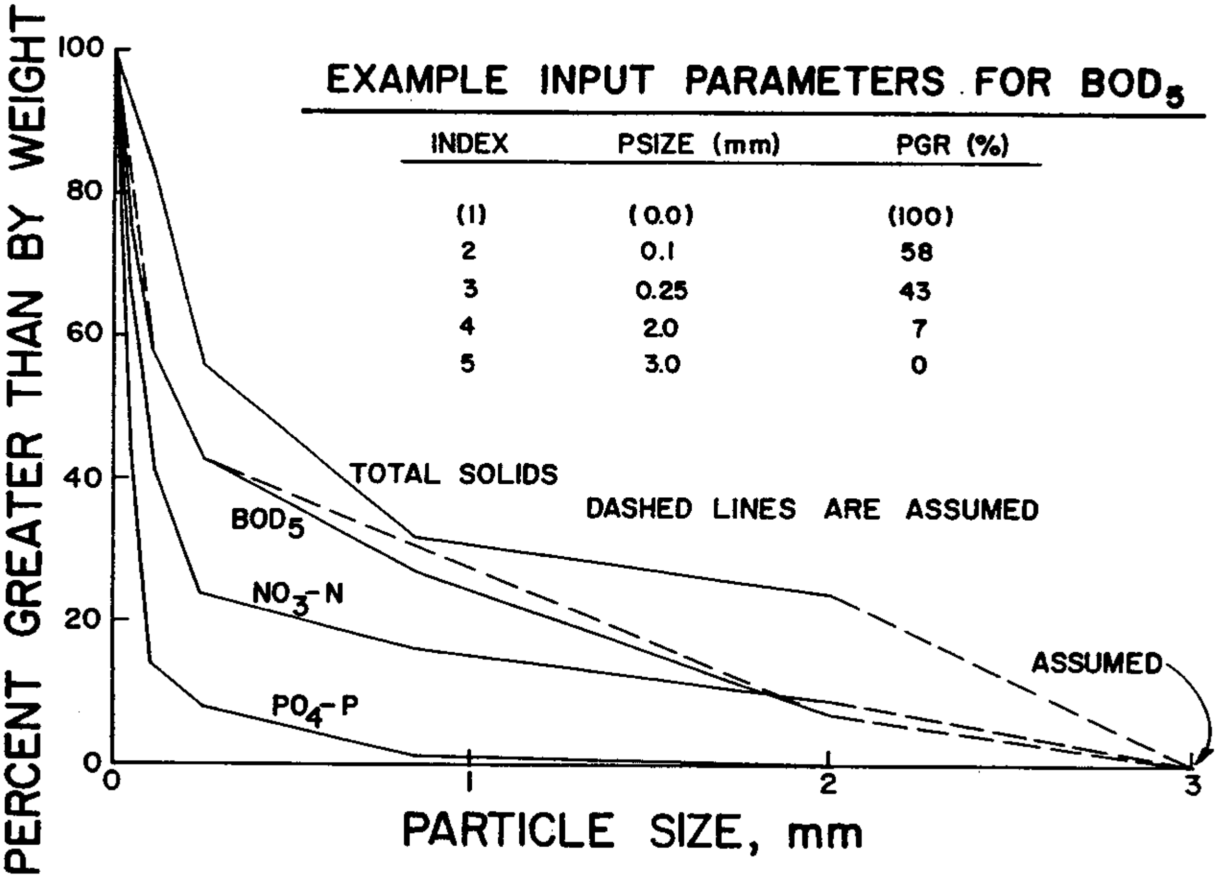


a. SCHEMATIC OF HYPOTHETICAL FLOW DIVISION



b. SPLIT OF CONDUIT INTO PRIMARY CONDUIT AND CUNNETTE

Figure 6-4. Cunnette Section



EXAMPLE INPUT PARAMETERS FOR BOD$_5$

INDEX	PSIZE (mm)	PGR (%)
(1)	(0.0)	(100)
2	0.1	58
3	0.25	43
4	2.0	7
5	3.0	0

Figure 6-5. Example Particle Size Distributions for Pollutants found on Street Surfaces. (After Sartor and Boyd, 1972, p. 146.)

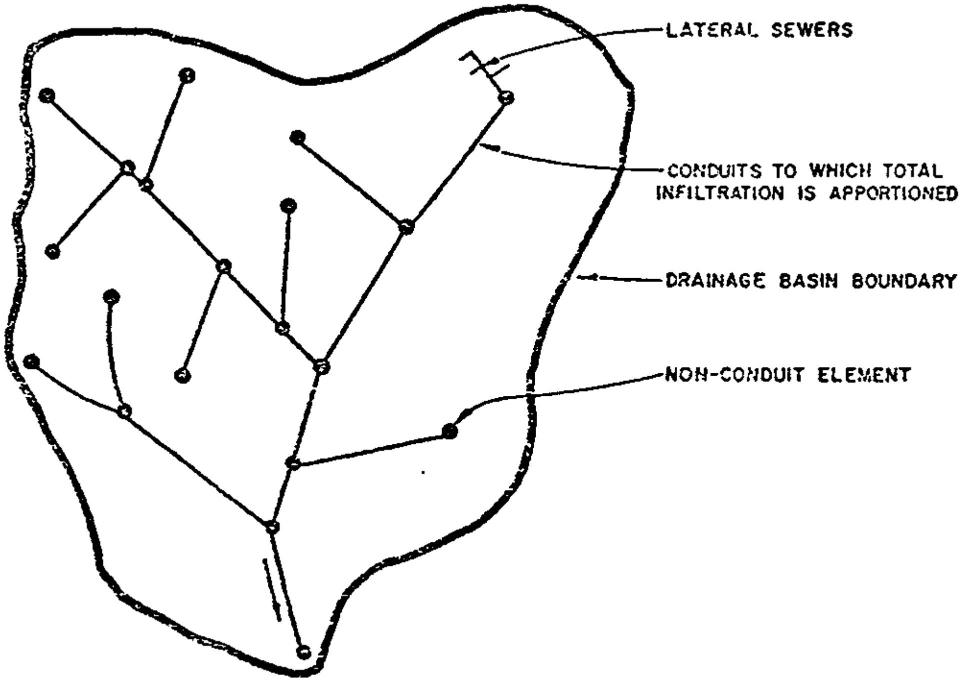
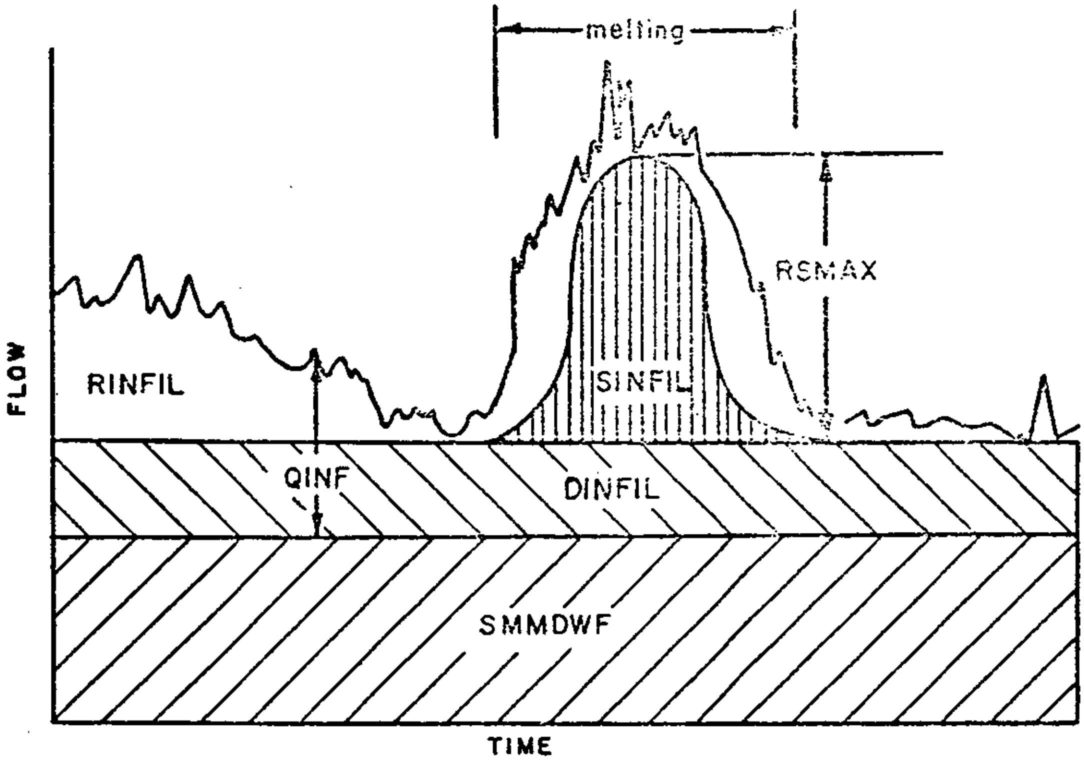
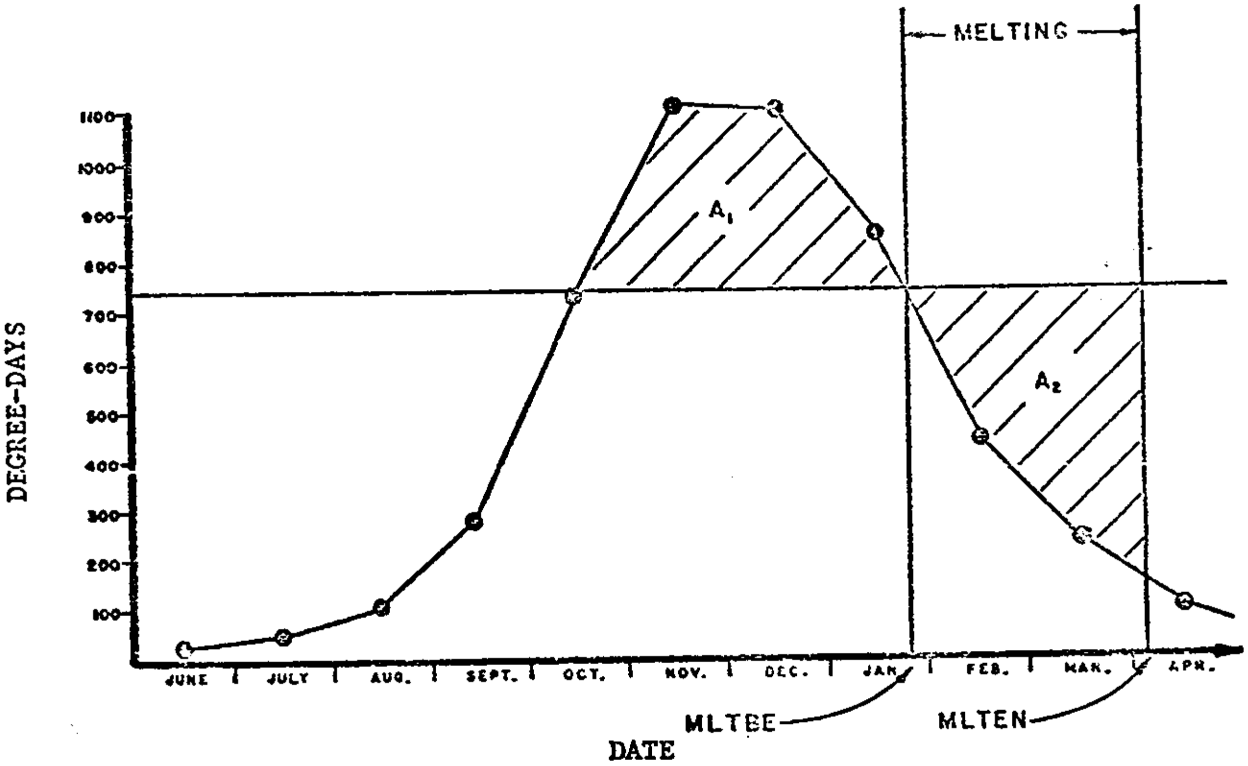


Figure 6-6. Typical Drainage Basin in which Infiltration is to be Estimated



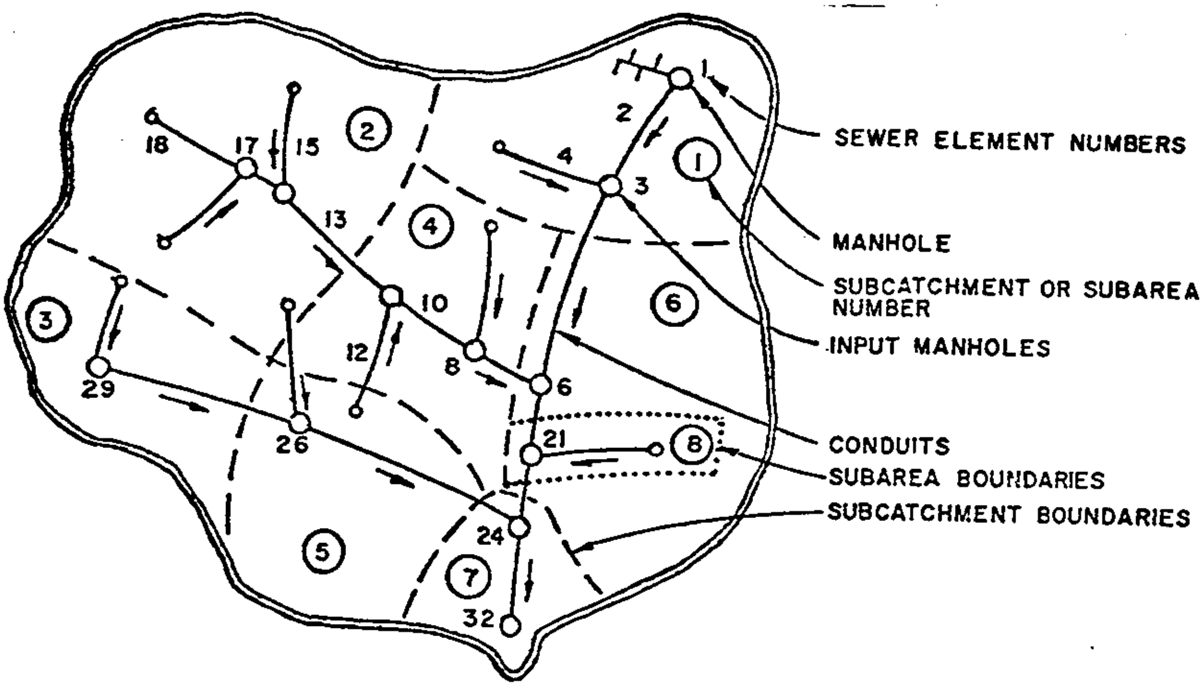
QINF = Total infiltration
DINFIL = Dry weather infiltration
RINFIL = Wet weather infiltration
SINFIL = Melting residual ice and snow infiltration
RSMAX = Residual moisture peak contribution
SMMDWF = Accounted for sewage flow

Figure 6-7. Components of Infiltration



MLTBE = Day on which melting period begins
MLTEN = Day on which melting period ends

Figure 6-8. Prescribed Melting Period



Sewer and Subcatchment Data

1. Manhole 32 is the most downstream point.
2. Subcatchments 1,2,3, and 4 are single-family residential areas, each 100 acres in size and each with water metering.
3. Subcatchments 5 and 7 are 220-acre industrial areas.
4. Subarea 6 is a 250-acre park.
5. Subarea 8 is a 50-acre commercial area.

Subareas 6 and 8 constitute a subcatchment draining to input manhole number 21.

Resulting Data

8 sewage estimates
KTNUM, total subcatchments and subareas in drainage basin = 8.
TOTA, total acres in drainage basin = 1,140.

KNUM, subcatchment or subarea	INPUT, input manhole number	KLAND, land use category	ASUB, acres in subcatchment or subarea
1	3	1	100
2	17	1	100
3	29	1	100
4	8	1	100
5	26	4	220
6	21	5	250
7	24	4	220
8	21	3	50

Figure 6-9. Determination of Subcatchment and Identification to Estimate Sewage at 8 Points

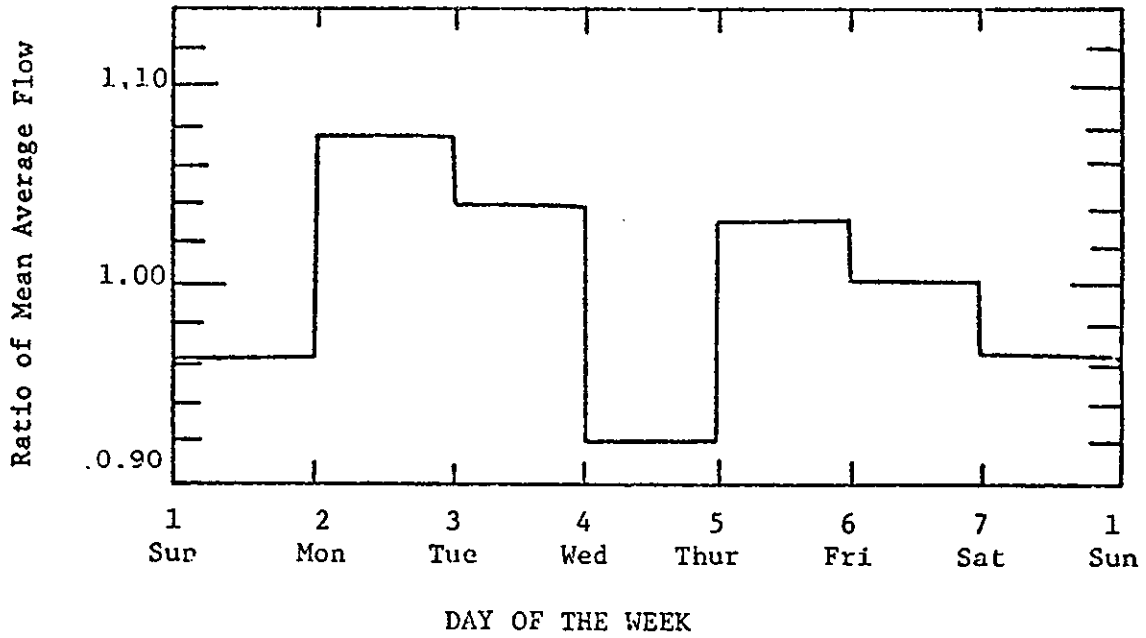


Figure 6-10. Representative Daily Flow Variation

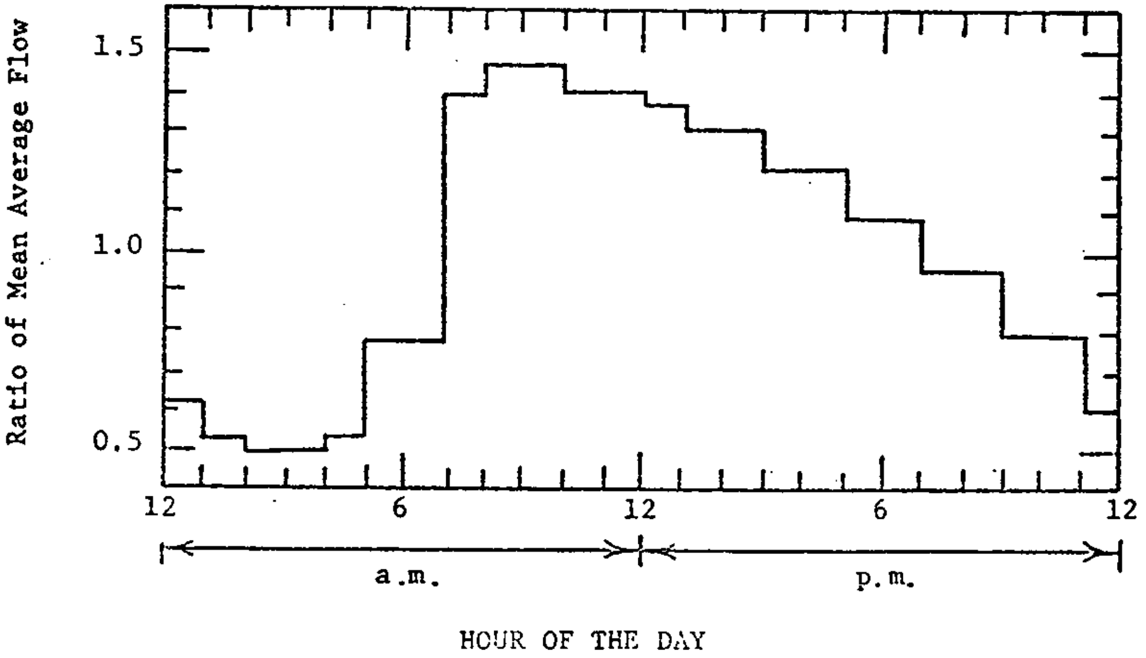


Figure 6-11. Representative Hourly Flow Variation

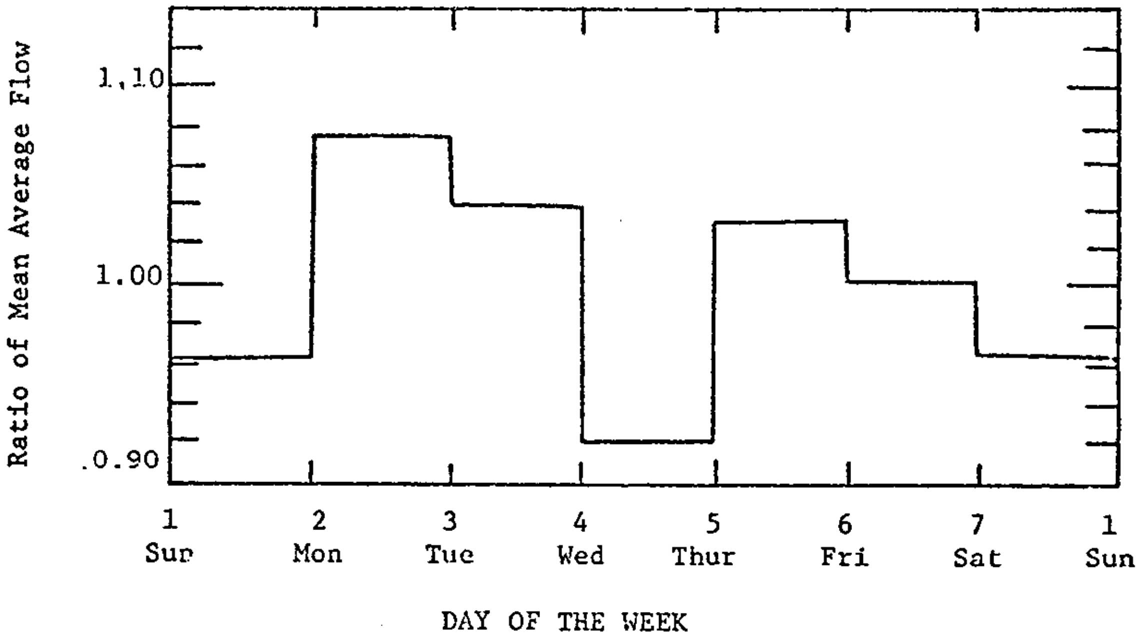


Figure 6-10. Representative Daily Flow Variation

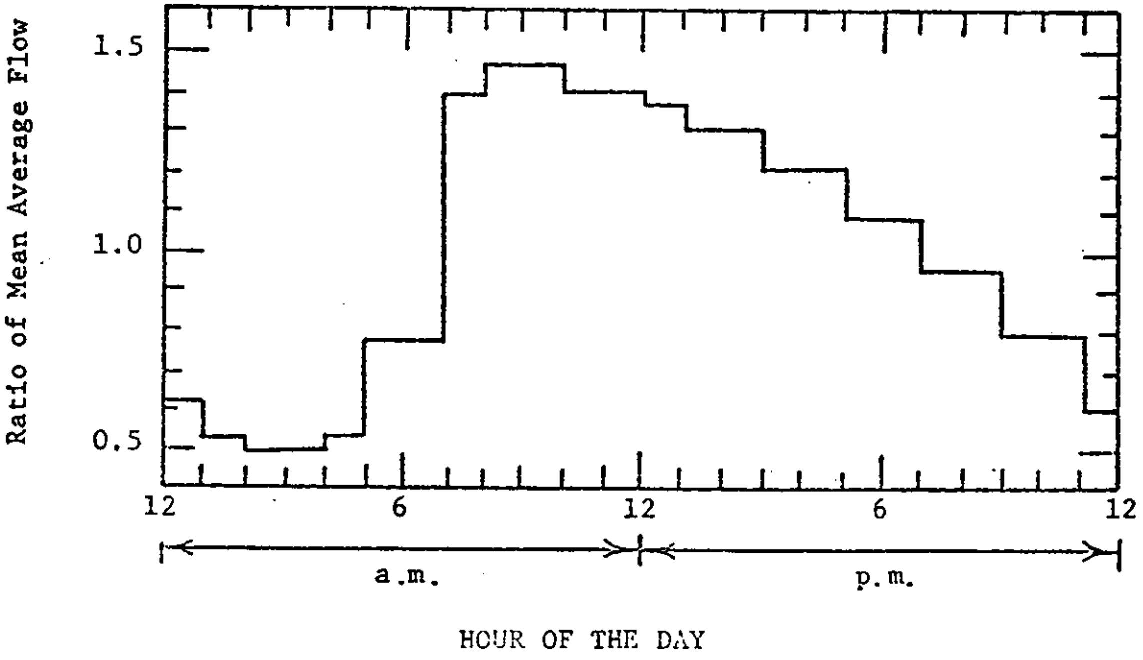


Figure 6-11. Representative Hourly Flow Variation

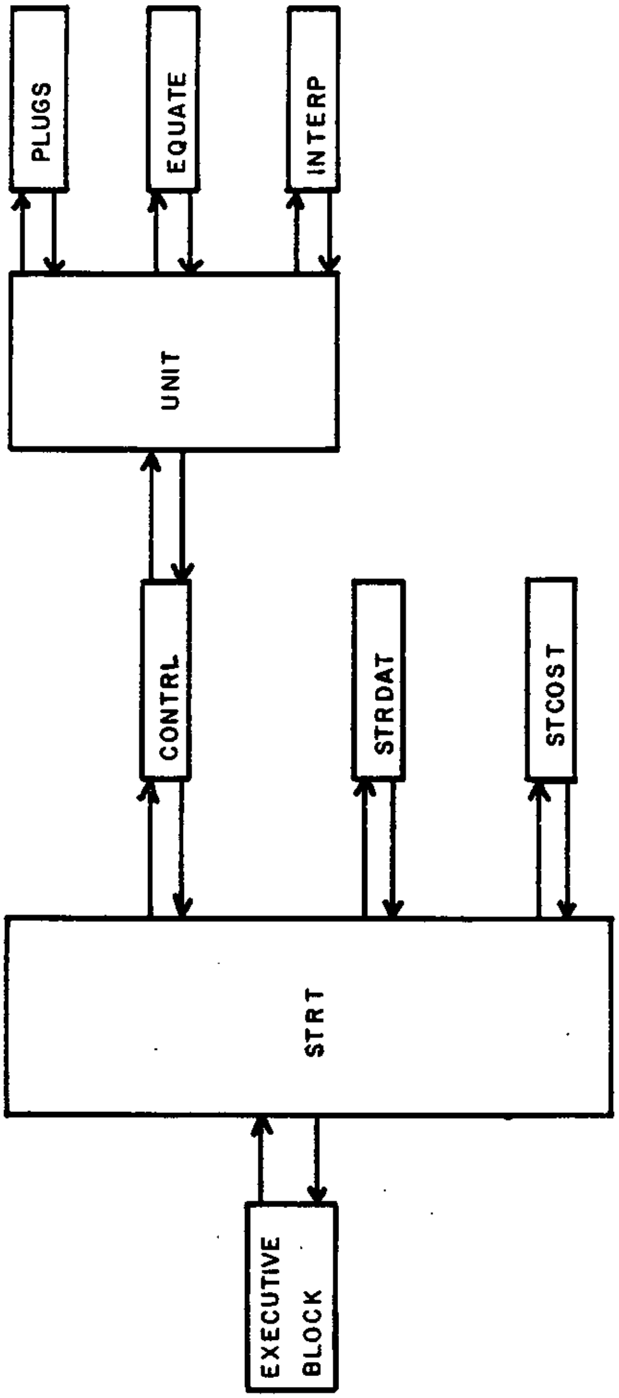
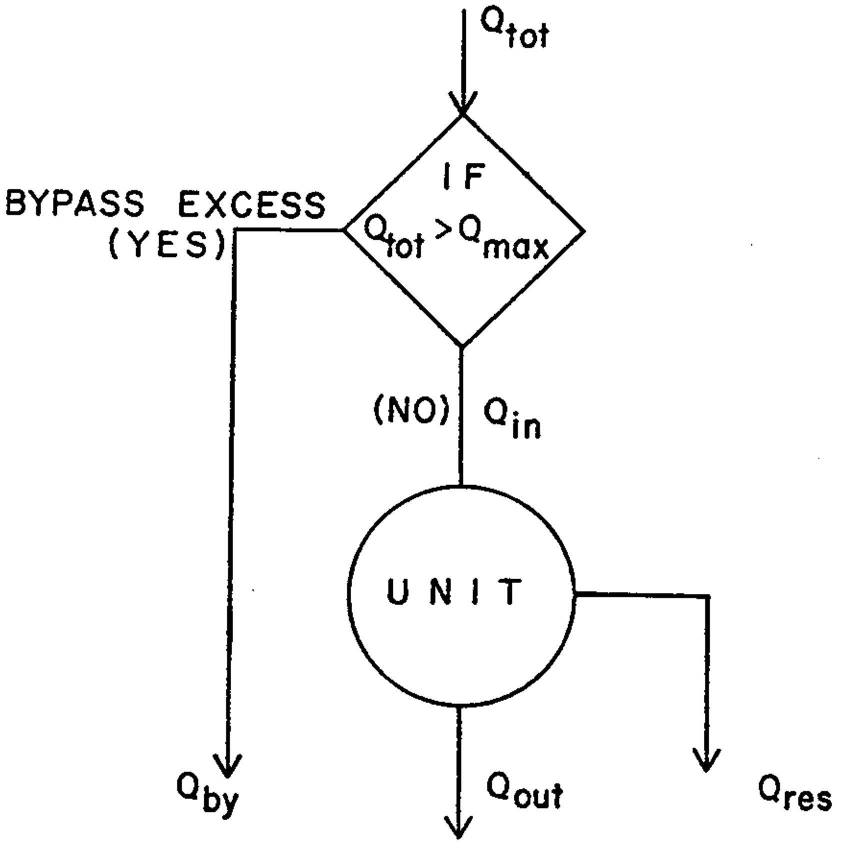


Figure 7-1. Storage/Treatment Block.



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 7-2. Flows Into, Through, and Out of a Storage/Treatment Unit.

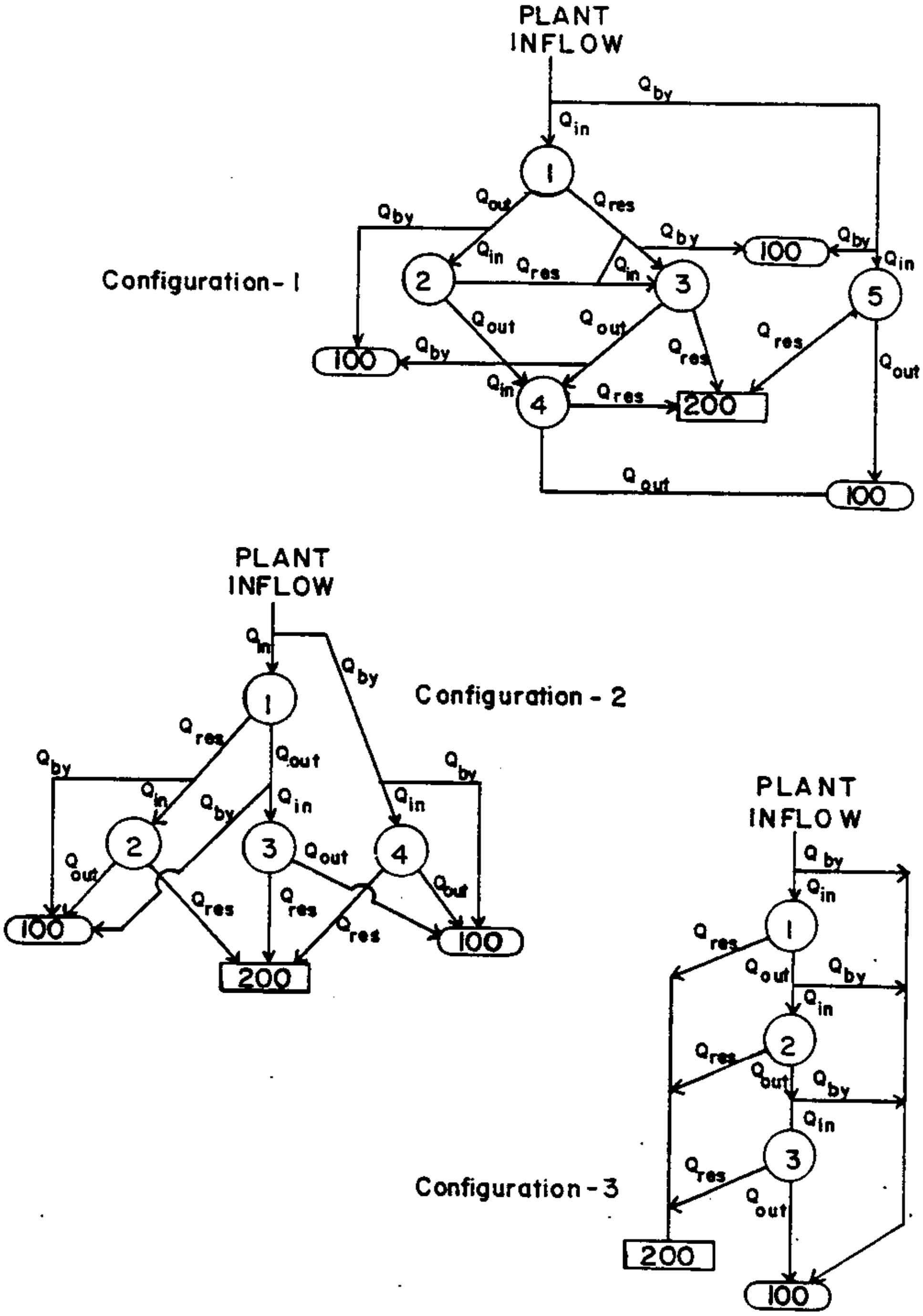


Figure 7-3. Storage/Treatment Plant Configurations.

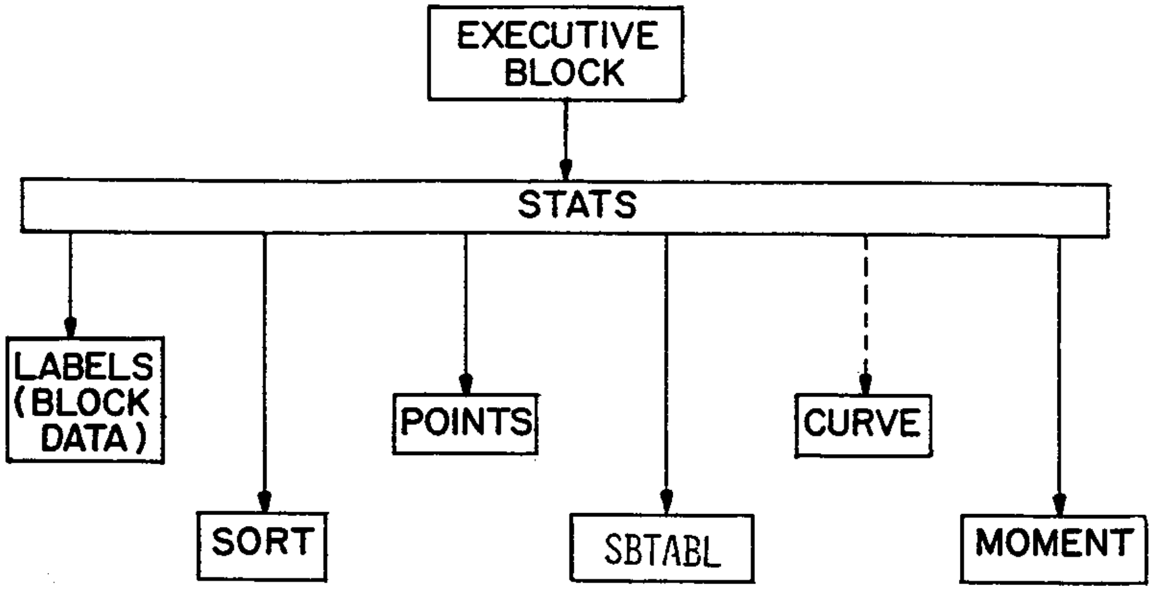


Figure 9-1. Structure of the Statistics Block Subroutines.

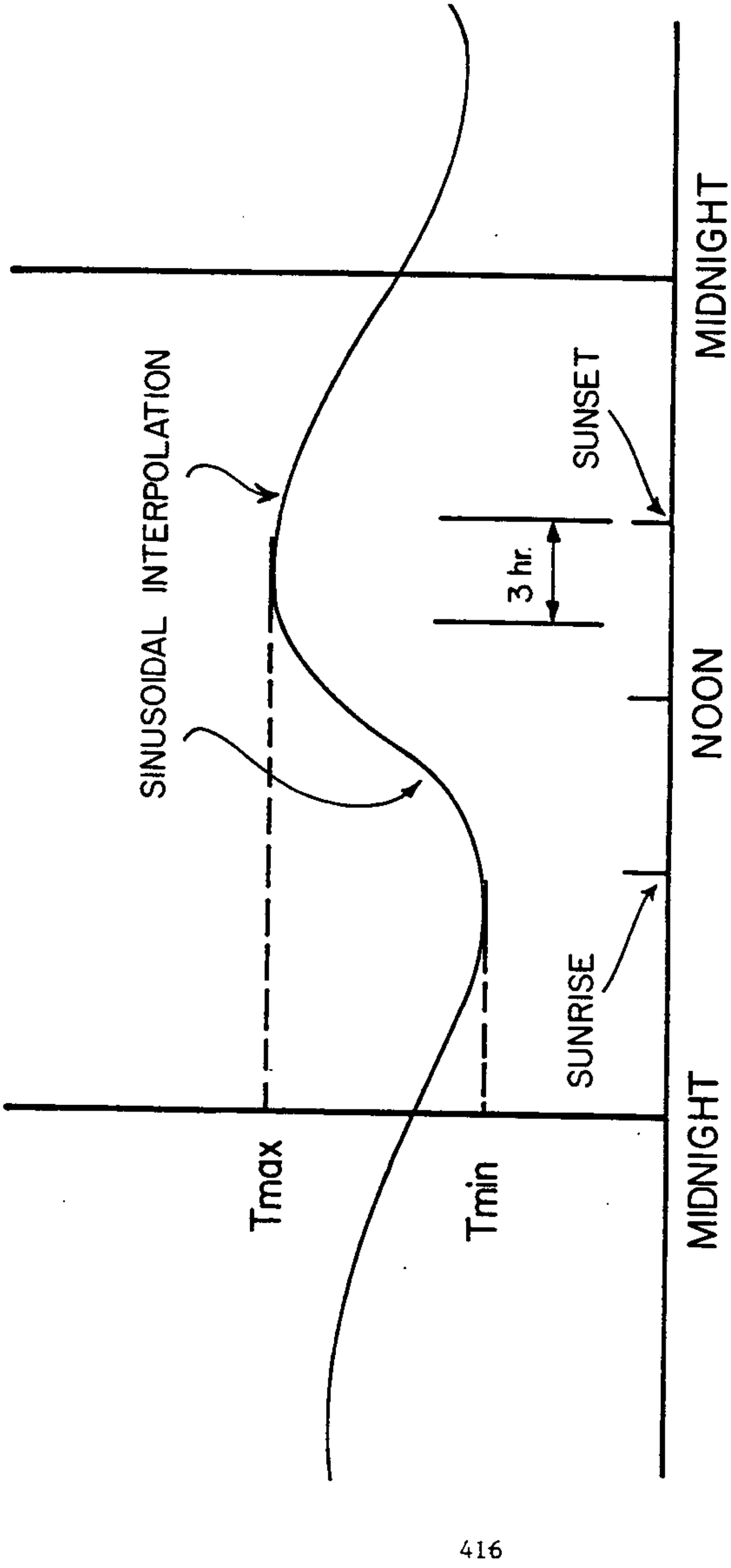


Figure II-1. Sinusoidal Interpolation of Hourly Temperatures.

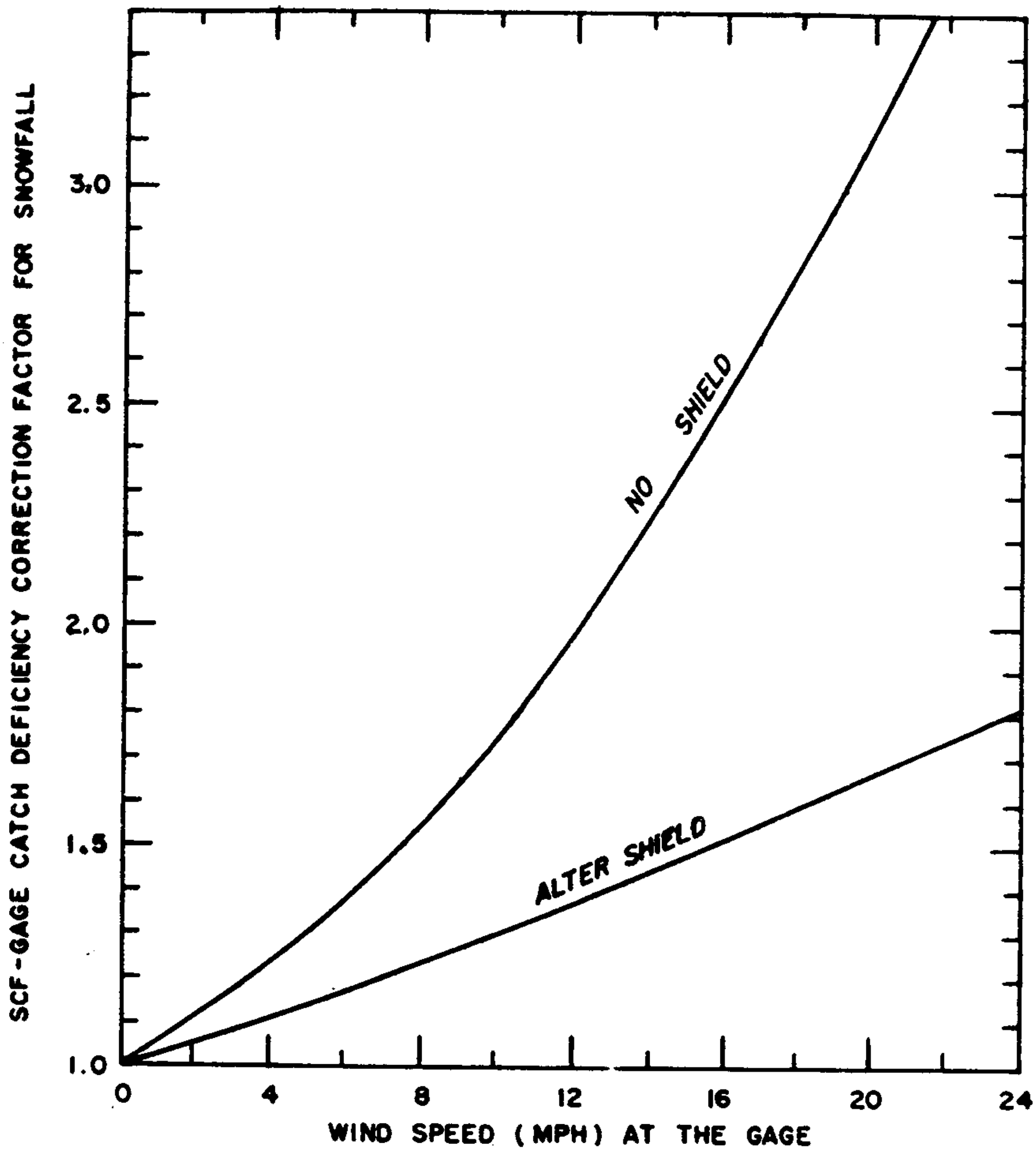


Figure II-2. Typical Gage Catch Deficiency Correction (Anderson, 1973, p. 5-20).

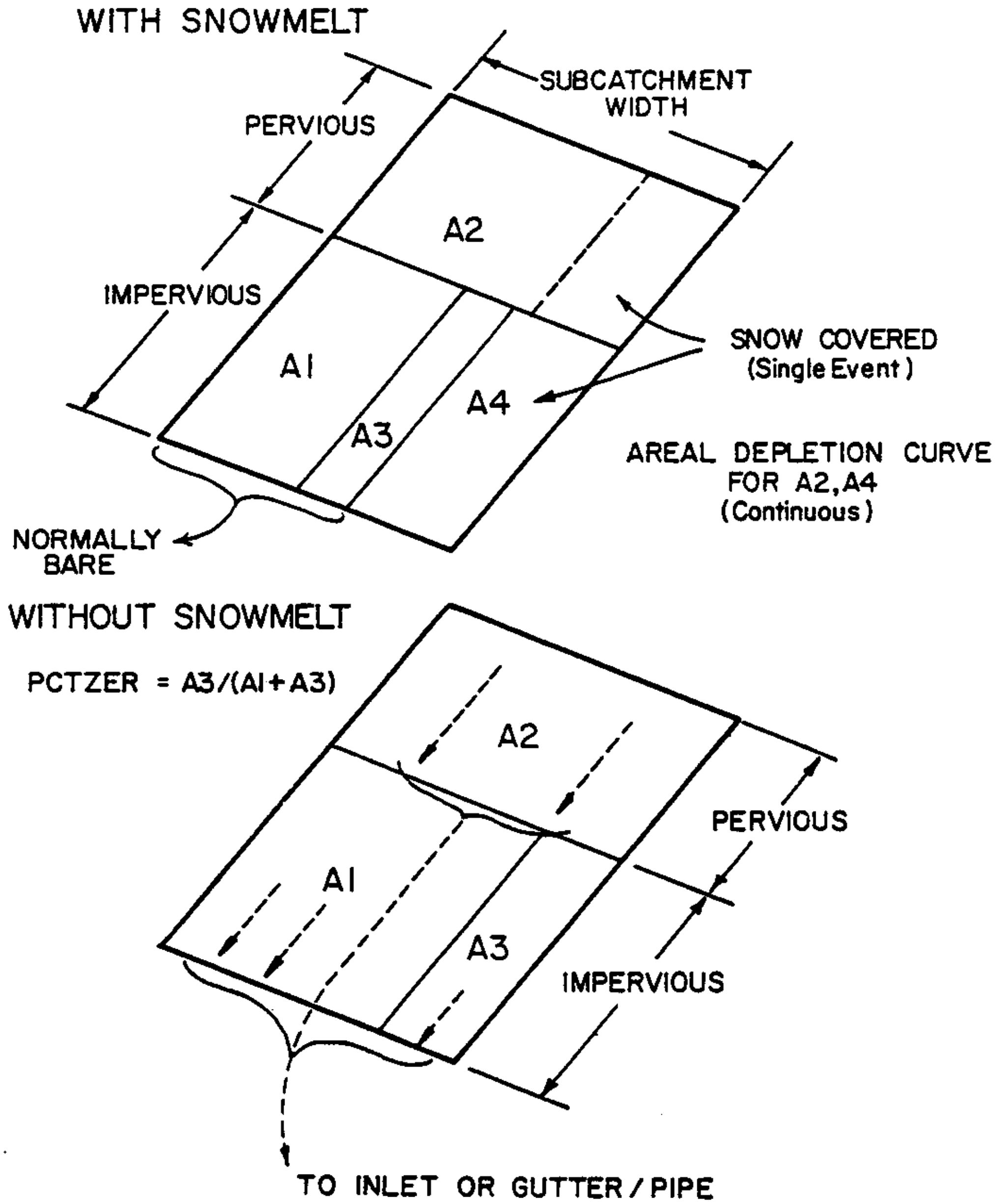


Figure II-3. Subcatchment Schematization With and Without Snowmelt Simulation. See also Table II-2.

A1 = IMPERVIOUS AREA WITH DEPRESSION STORAGE
A2 = PERVIOUS AREA
A3 = IMPERVIOUS AREA WITH ZERO DEPRESSION STORAGE
A4 = SNOW COVERED IMPERVIOUS AREA

A1 + A3 = NORMALLY BARE

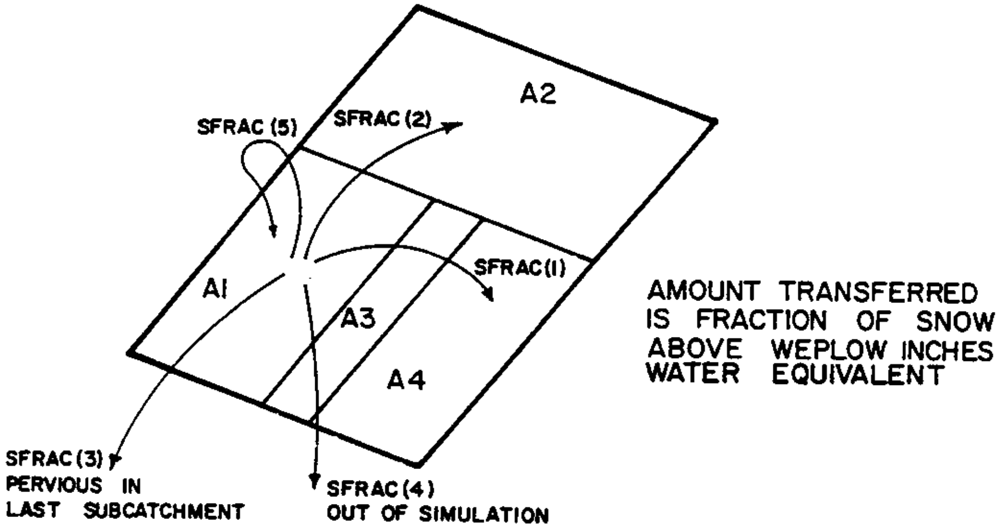


Figure II-4. Redistribution of Snow During Continuous Simulation.

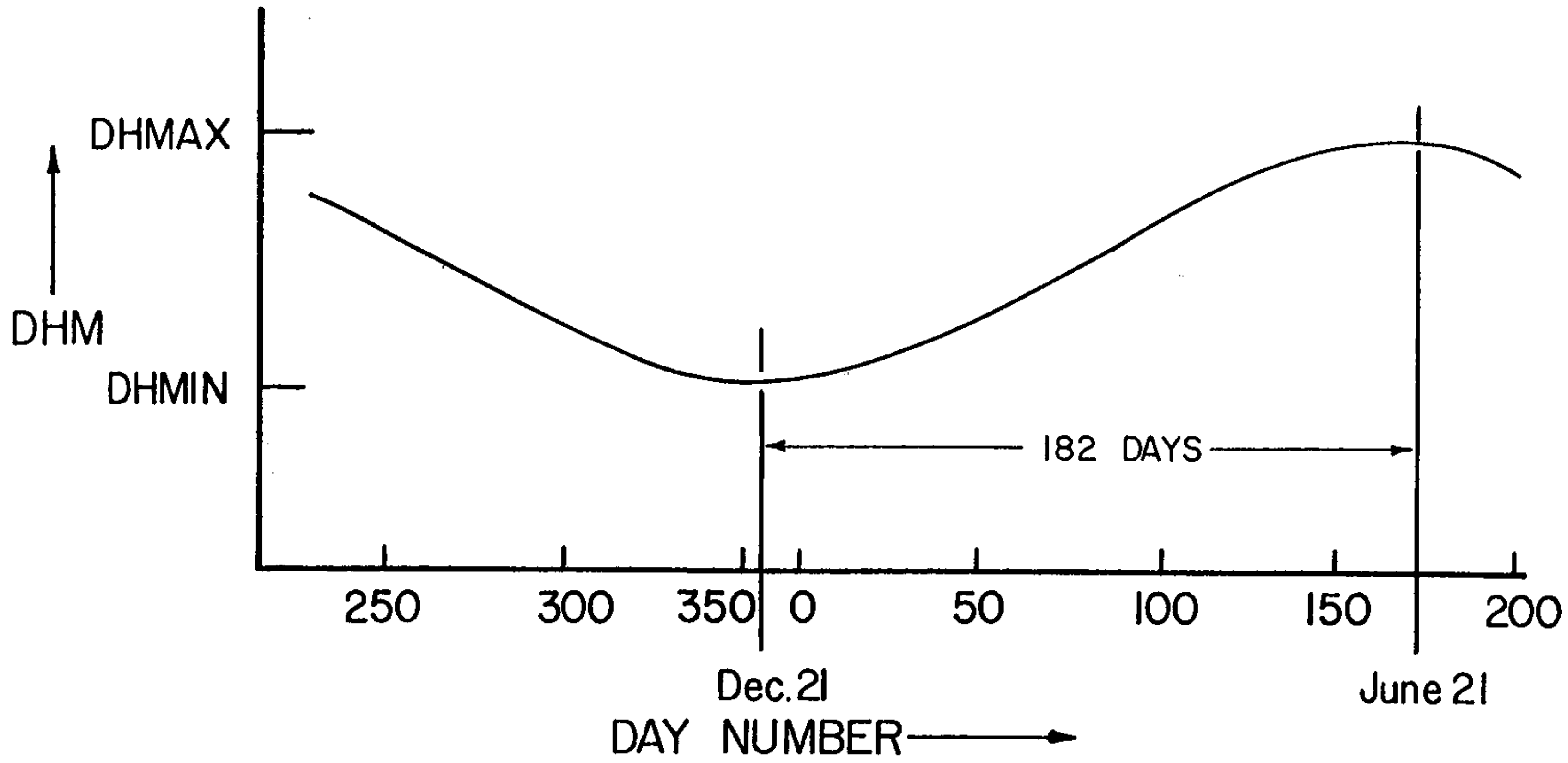


Figure II-5. Seasonal Variation of Melt Coefficients.

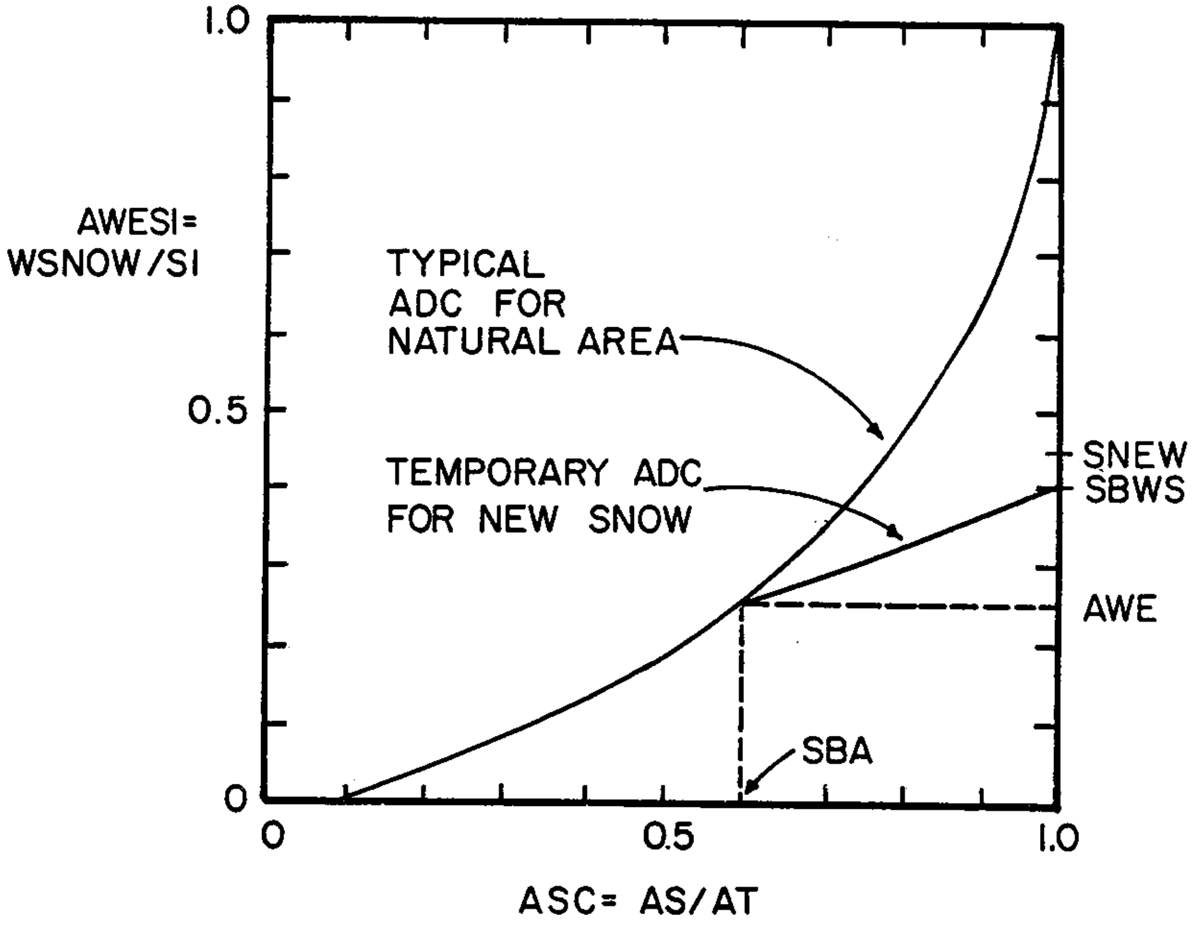


Figure II-6. Typical Areal Depletion Curve for Natural Area (Anderson, 1973, P. 3-15) and Temporary Curve for New Snow.

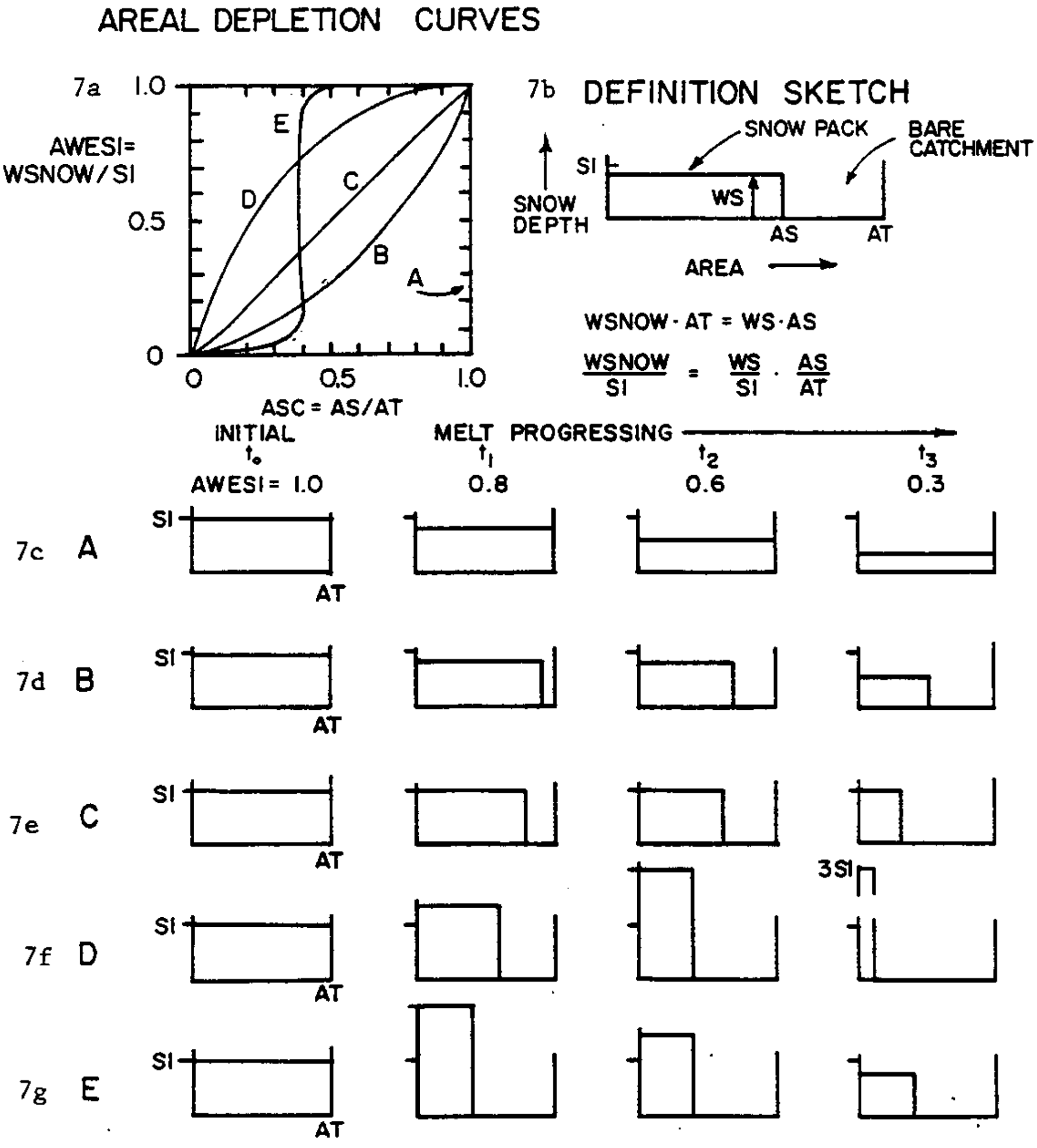


Figure II-7. Effect on Snow Cover on Areal Depletion Curves.

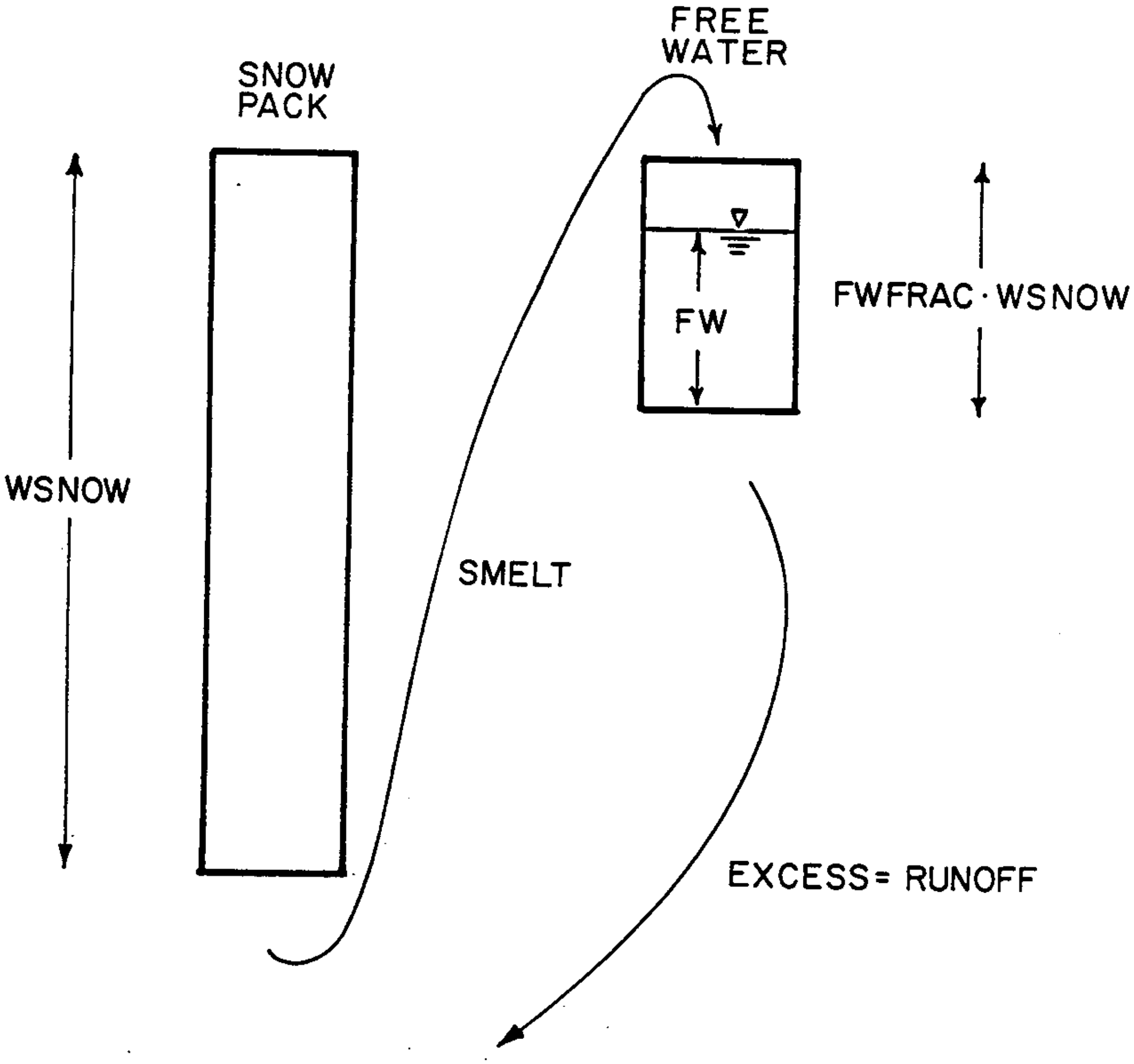


Figure II-8 . Schematic of Liquid Water Routing Through Snow Pack.

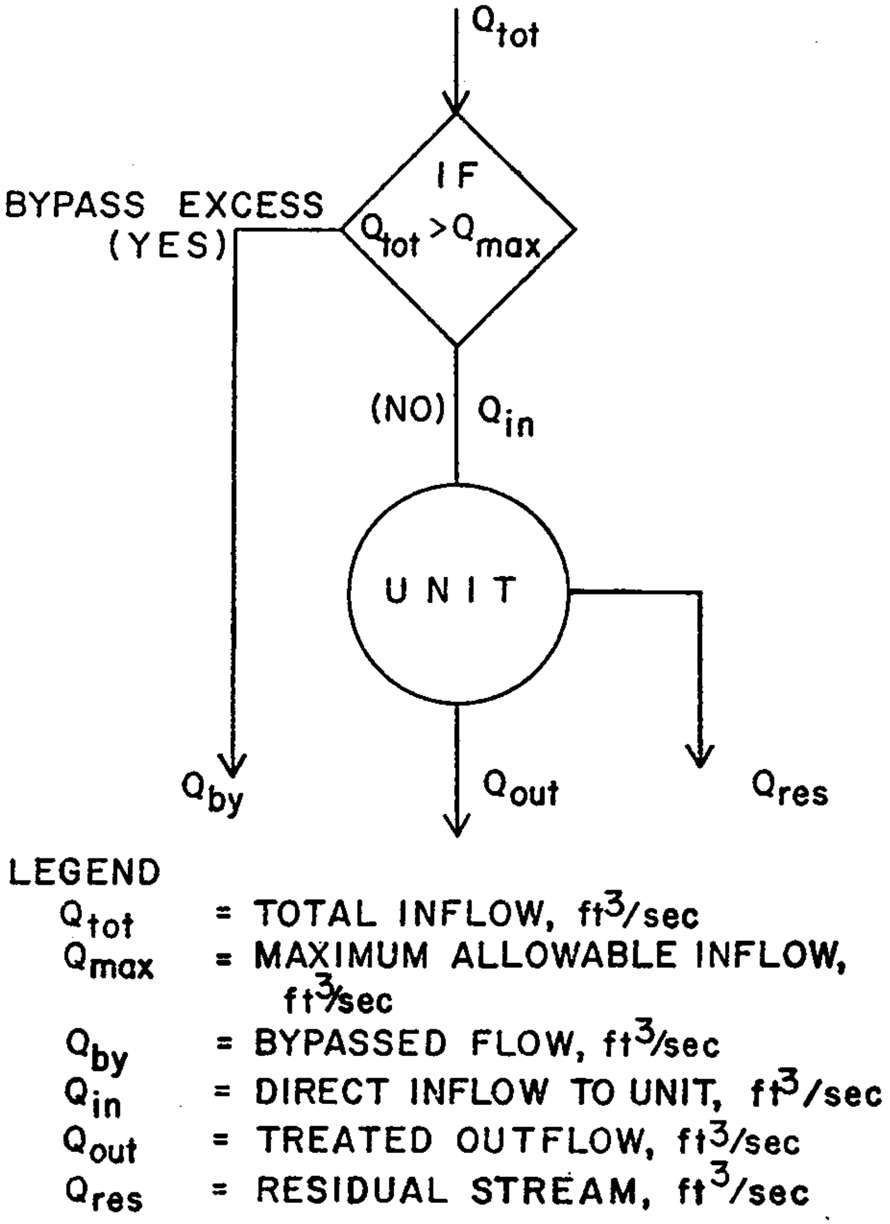


Figure IV-1. Flows Into, Through, and Out of a Storage/Treatment Unit.

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.

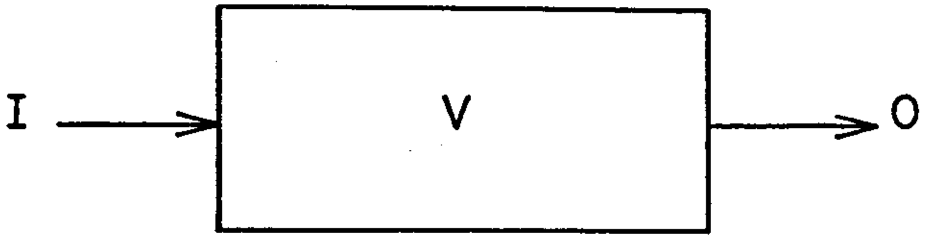


Figure IV-2. Time Varying Inflow and Outflow Rates for a Reservoir.

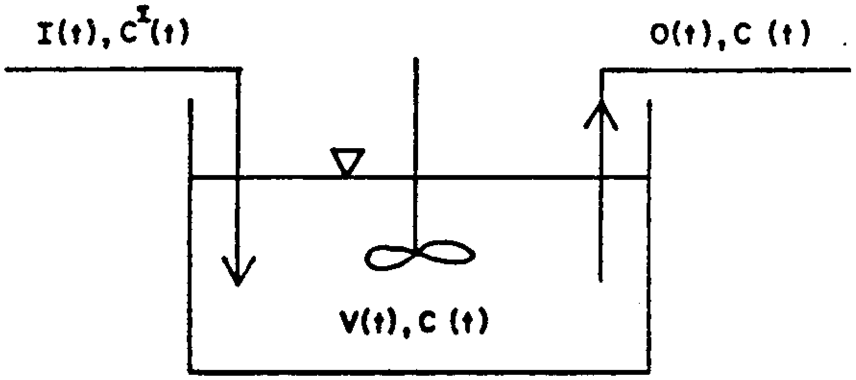


Figure IV-3. Well-Mixed, Variable-Volume Reservoir (Rich, 1973).

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

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

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.

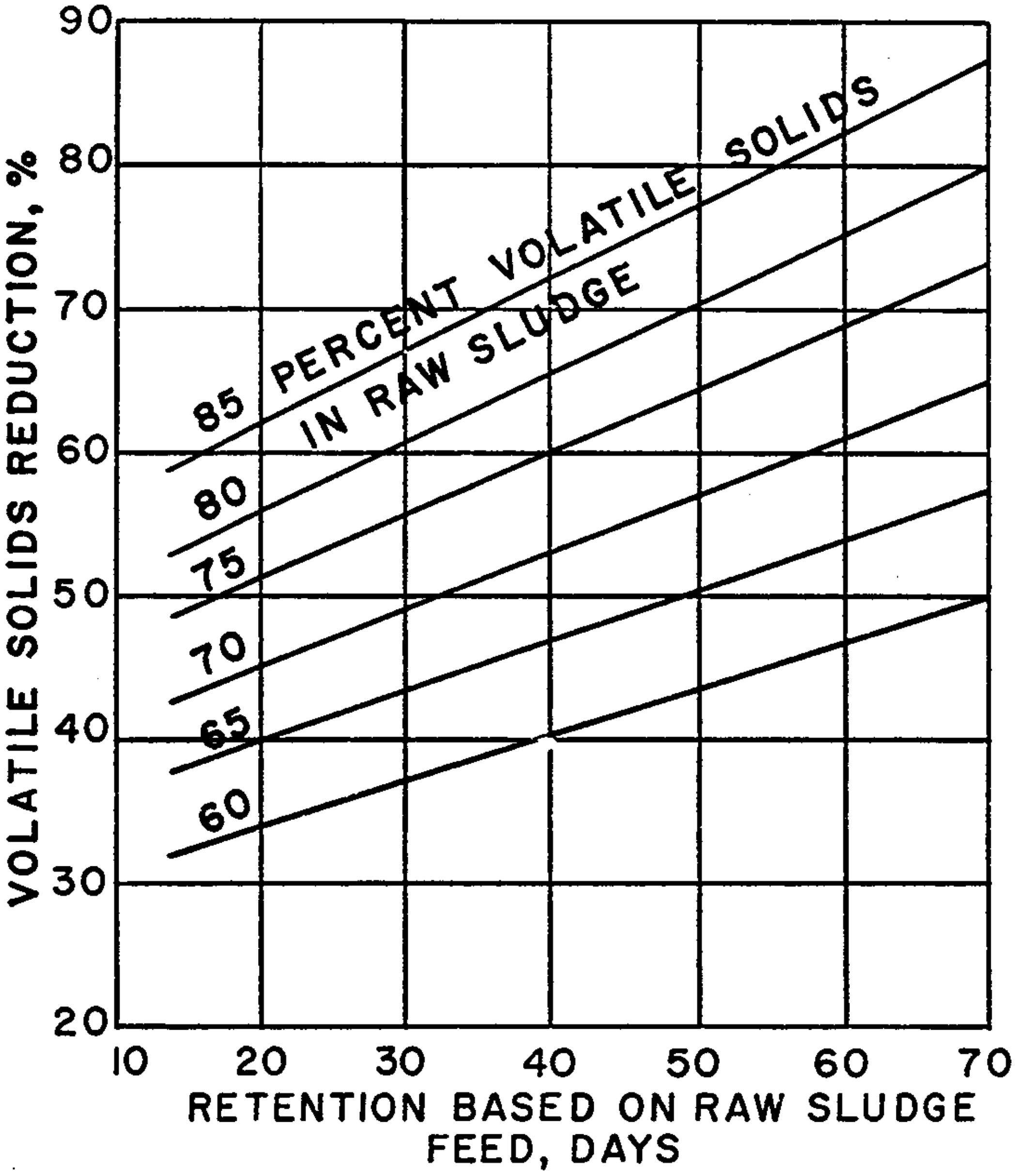


Figure IV-4. Reduction in Volatile Solids in Raw Sludge (Rich, 1973).

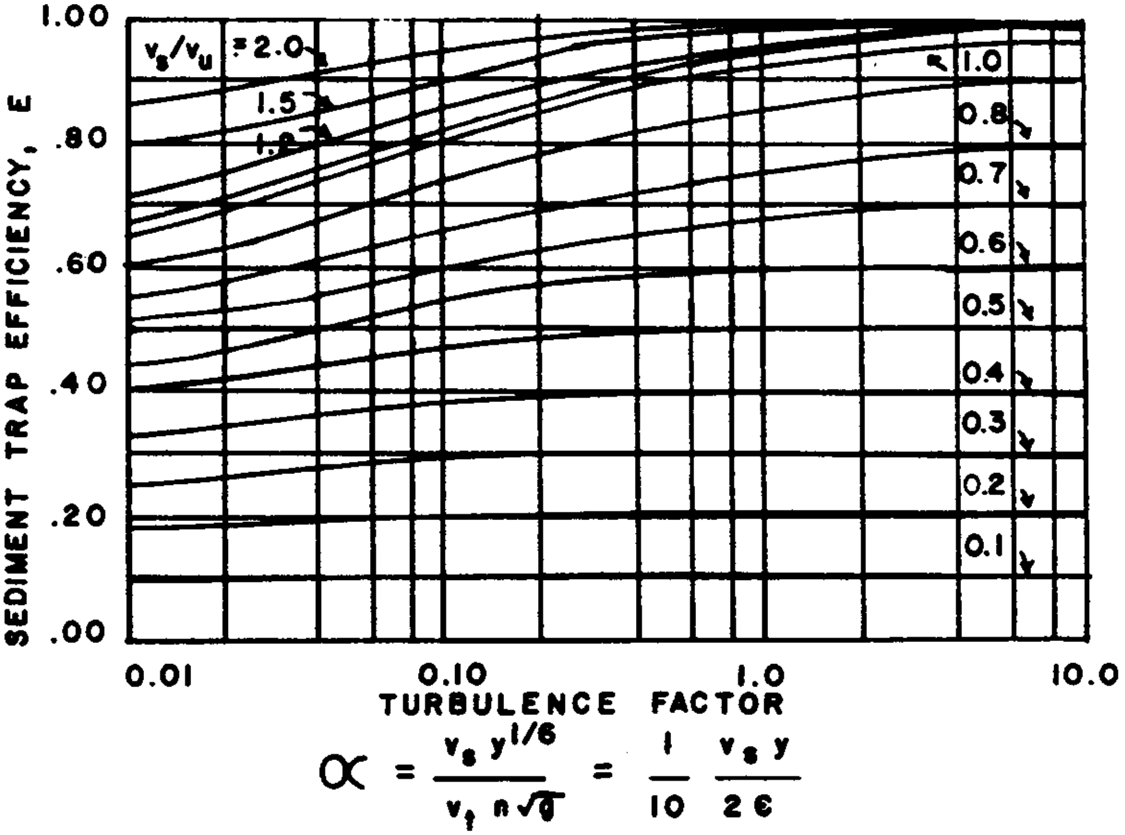


Figure IV-5. Camp's Sediment Trap Efficiency Curves (Camp, 1946, Dobbins, 1944, Brown, 1950, Chen, 1975).

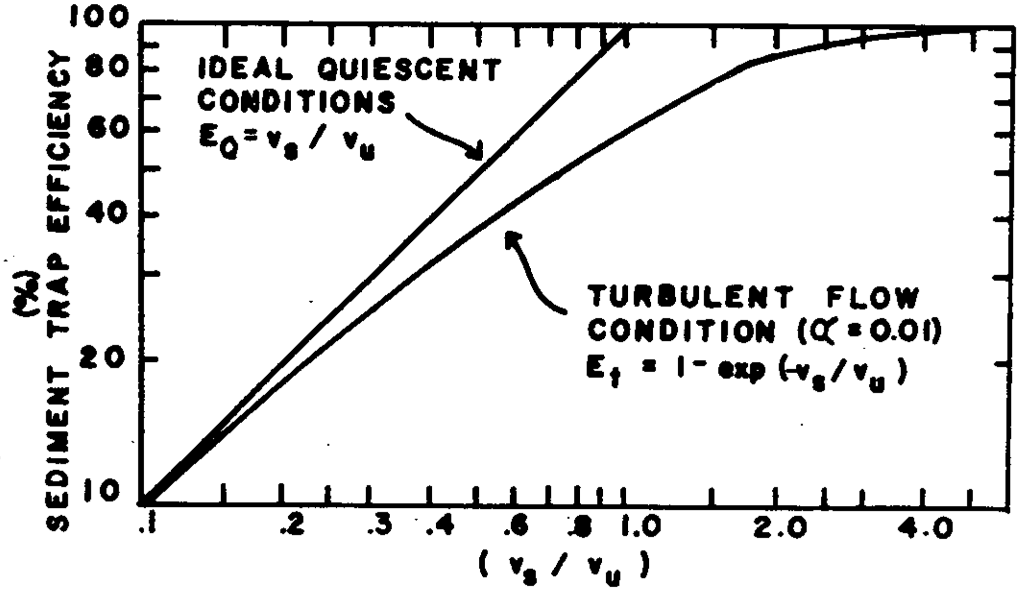


Figure IV-6. Limiting Cases in Sediment Trap Efficiency (Chen, 1975).

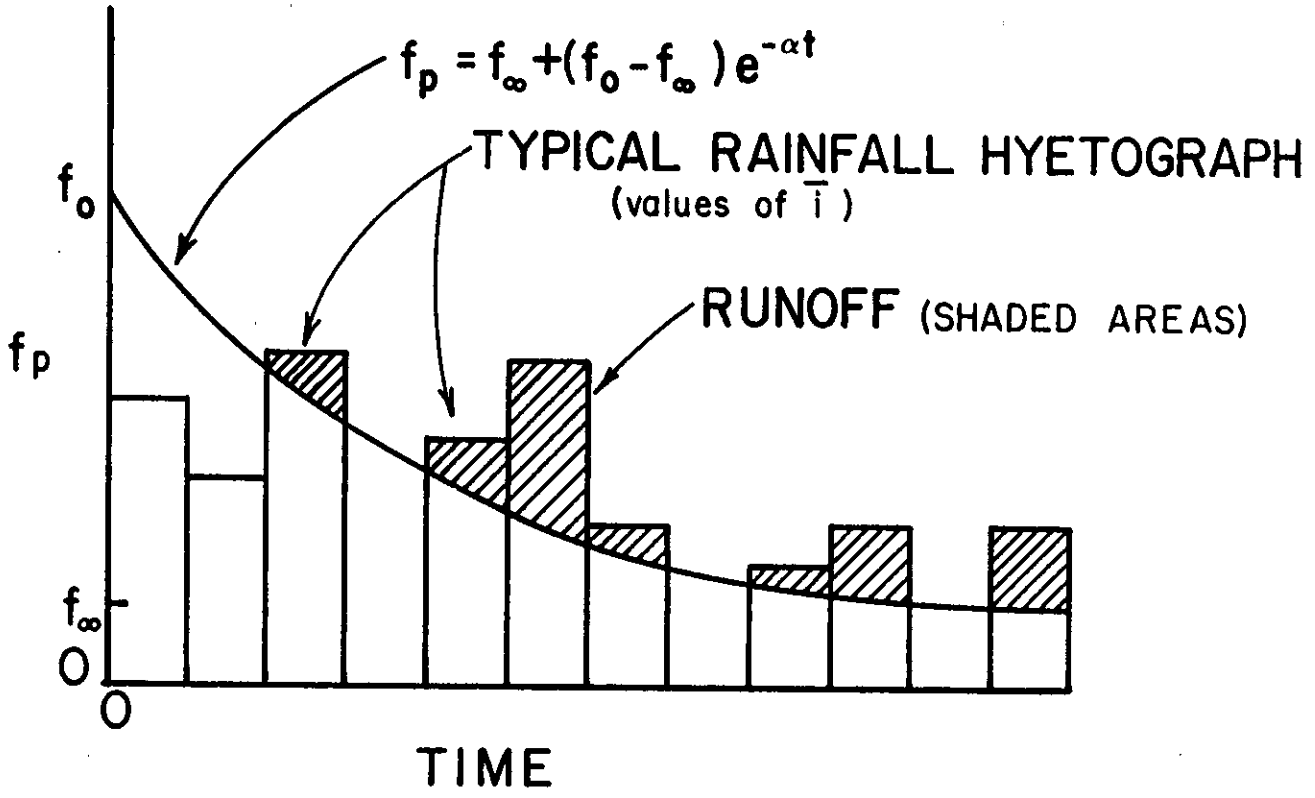


Figure V-1. Horton Infiltration Curve and Typical Hyetograph. For the case illustrated, runoff would be intermittent.

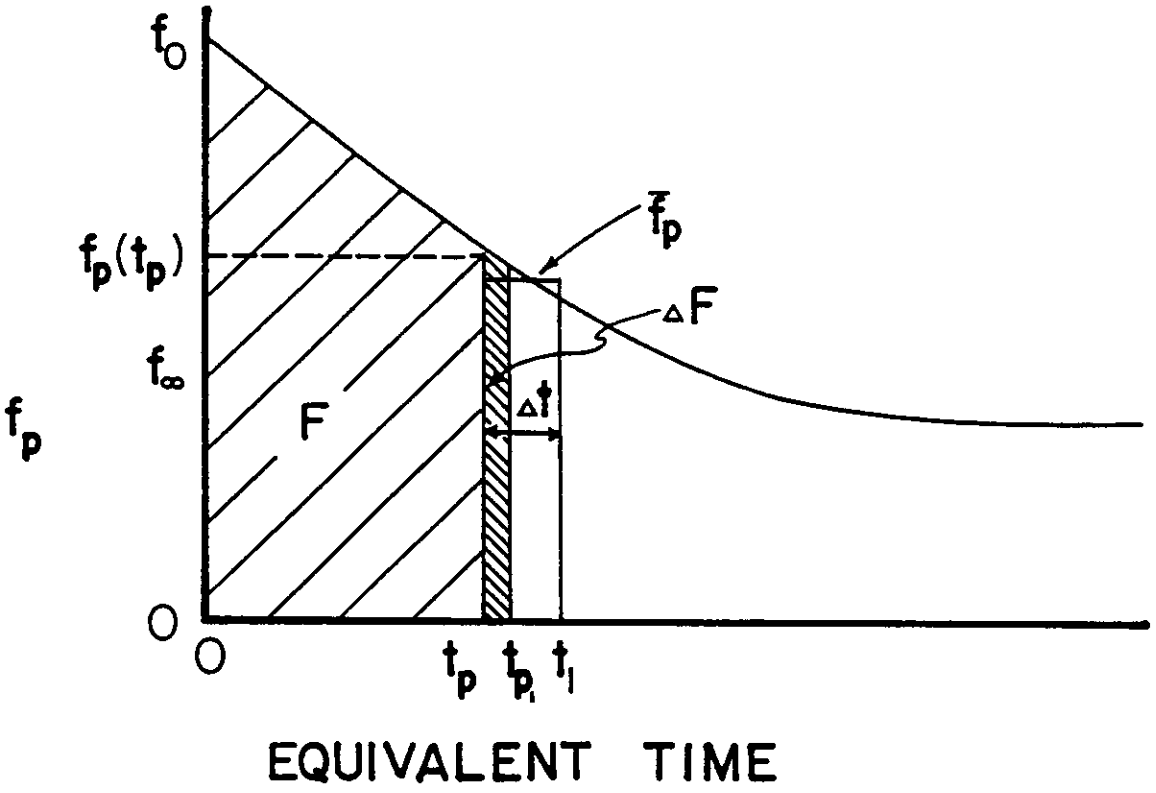


Figure V-2. Cumulative Infiltration, F, is the Integral of f, i.e., the Area Under the Curve.

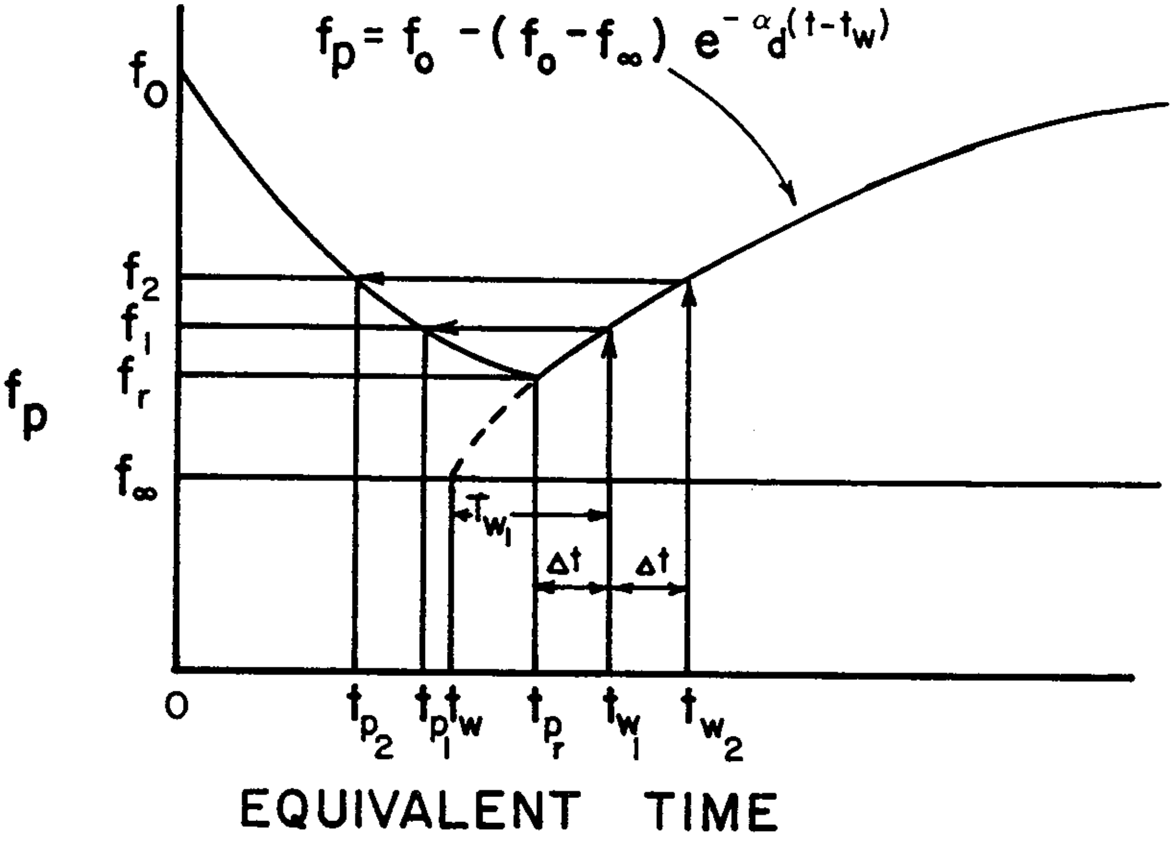


Figure V-3. Regeneration (Recovery) of Infiltration Capacity During Dry Time Steps.

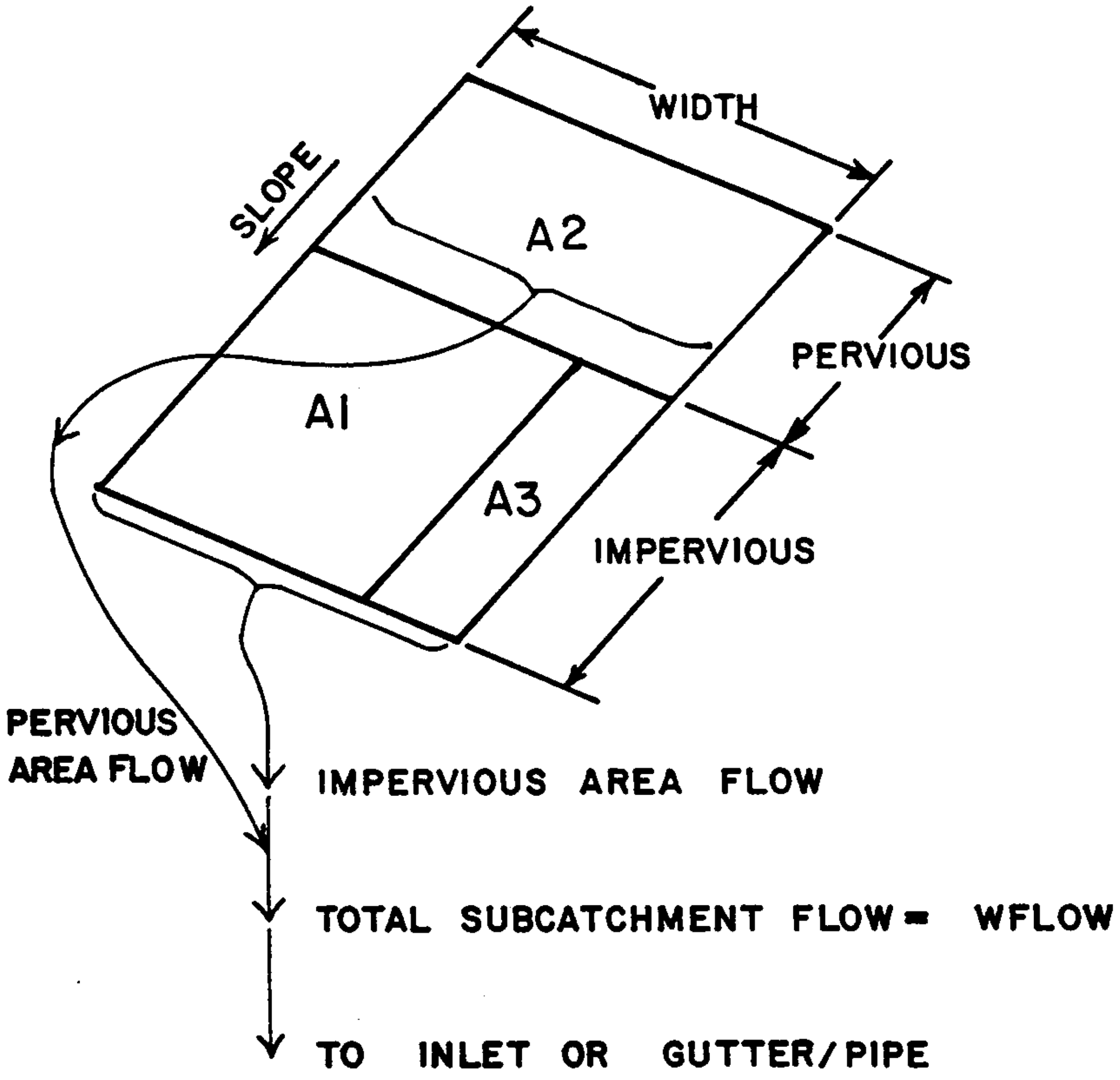


Figure V-4. Subcatchment Schematization for Overland Flow Calculations. Flow from each subarea is directly to an inlet or gutter/pipe. Flow from one subarea is not routed over another subarea.

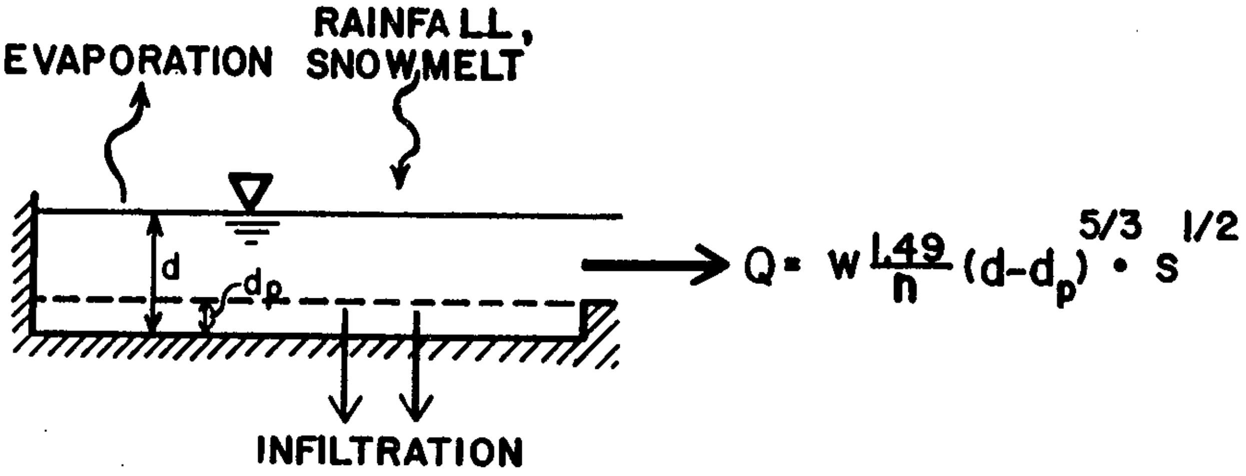
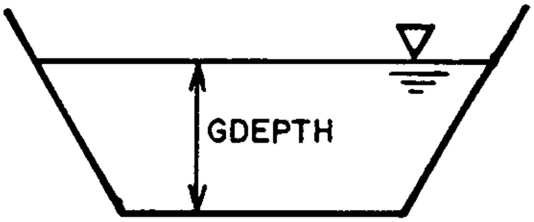
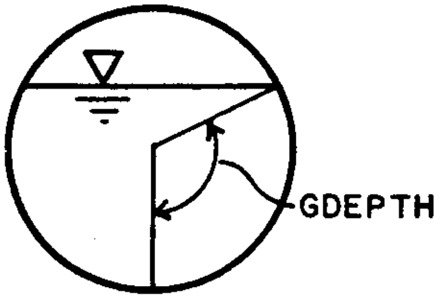


Figure V-5. Non-linear Reservoir Model of Subcatchment.



TRAPEZOIDAL
GUTTER



CIRCULAR
PIPE

Figure V-6. Depth Parameters for Trapezoidal Channel and Circular Pipe

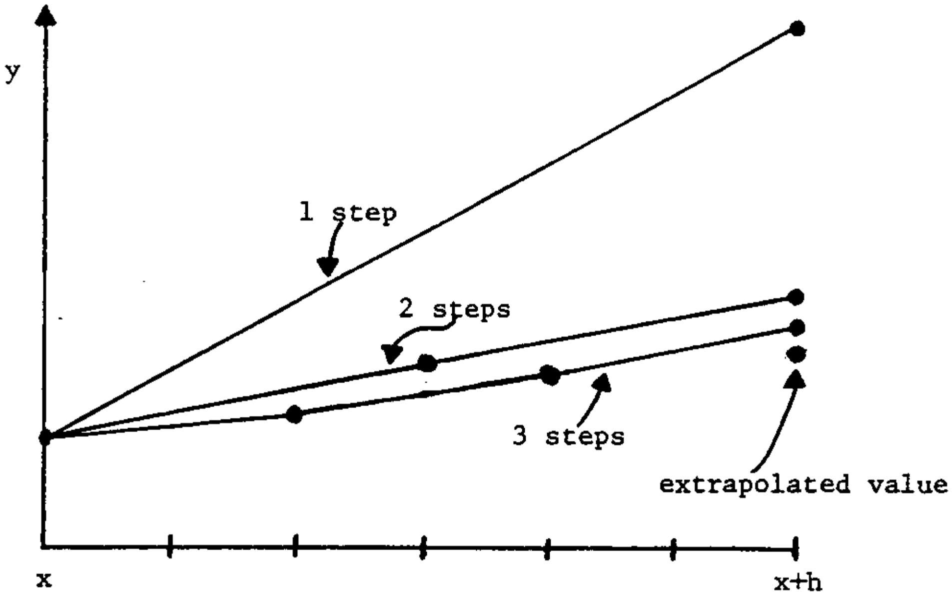


Figure V-7. Richardson Extrapolation as used in the Runoff Block. A large interval is spanned by different sequences of finer and finer substeps. Their results are extrapolated to an answer that corresponds to an infinitely small time step. Runoff uses a Newton-Raphson iteration solution for the y values at each time step, and a rational function extrapolation to calculate the extrapolated y value. (This graph is adapted from Press et al., 1986).

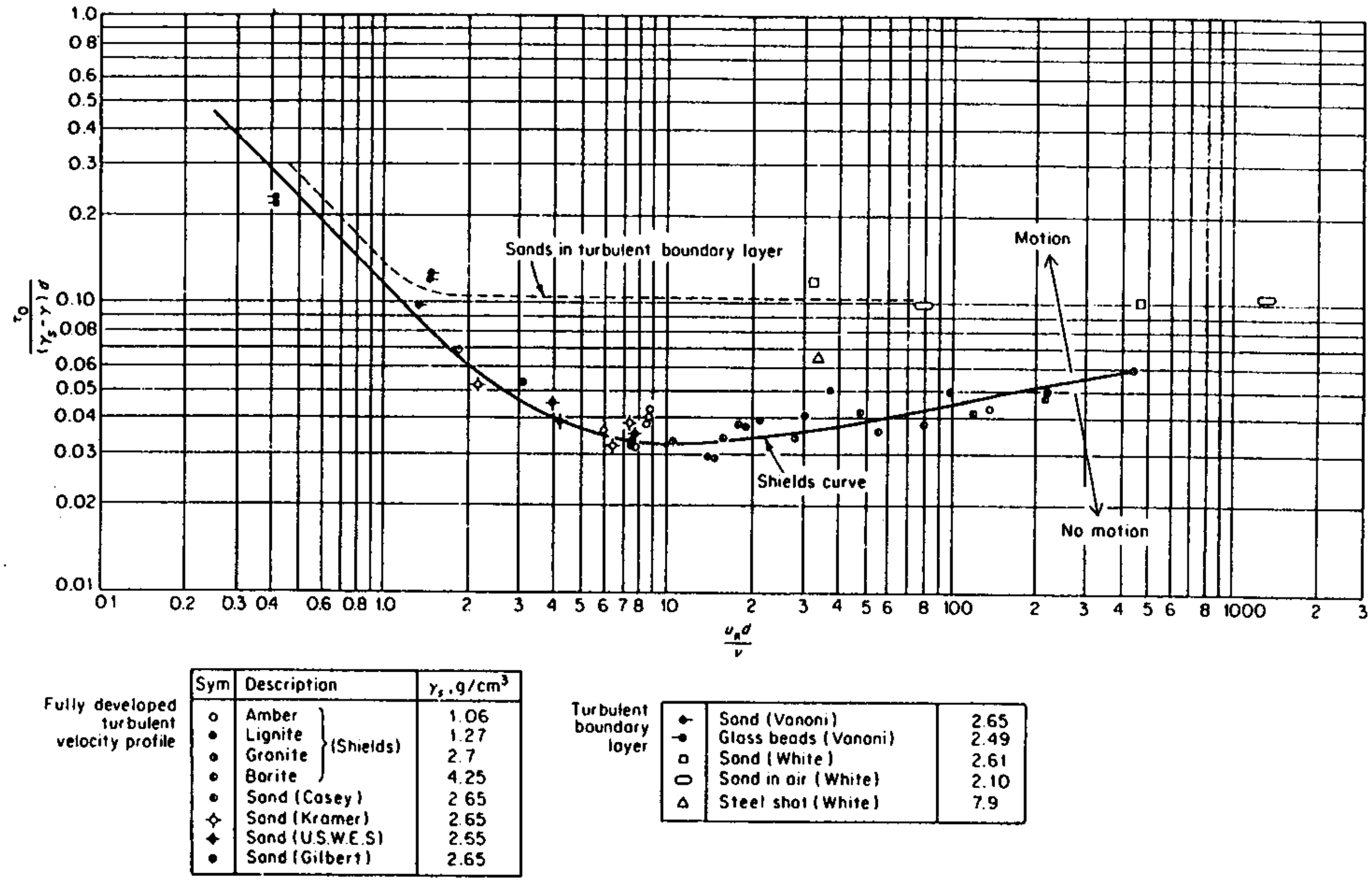


Figure VI-1. Shields' Diagram for Definition of Incipient Motion. (After Graf, 1971, p. 96)

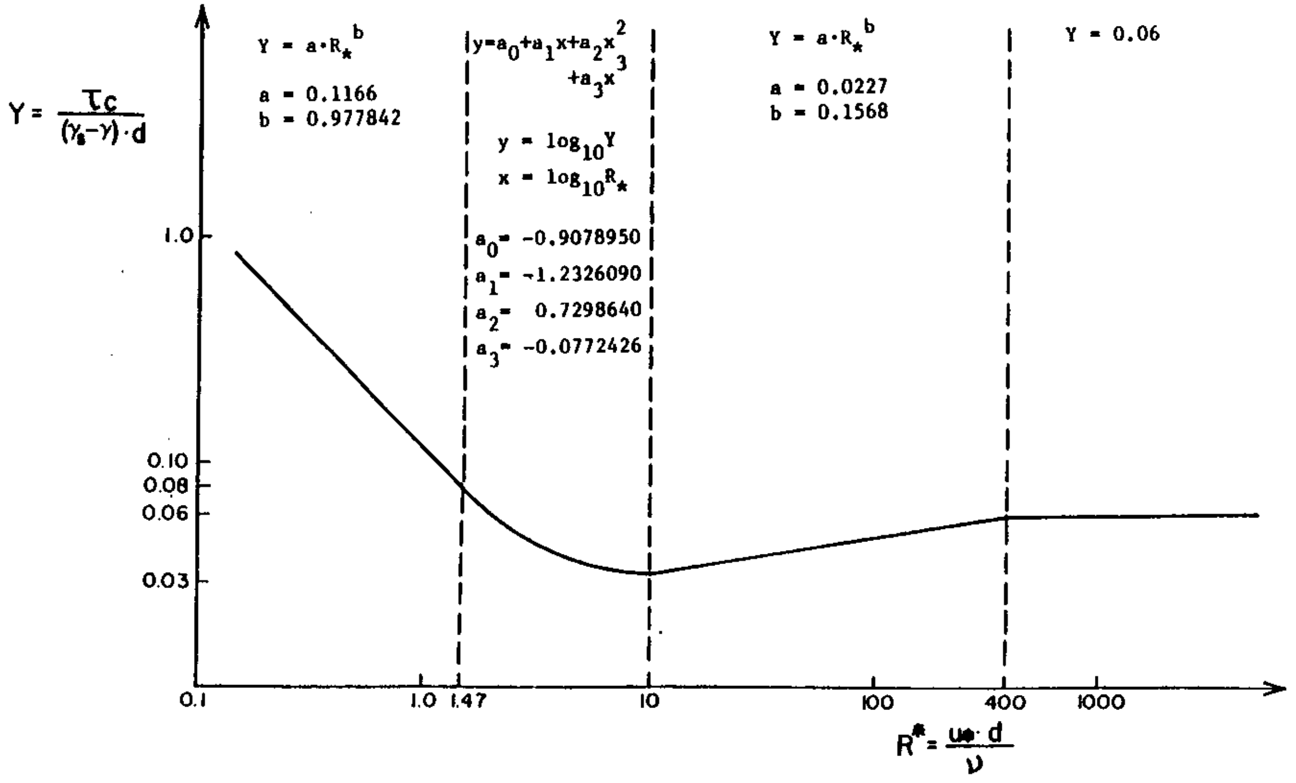


Figure VI-2. Linear and Parabolic Approximation of Shields' Diagram

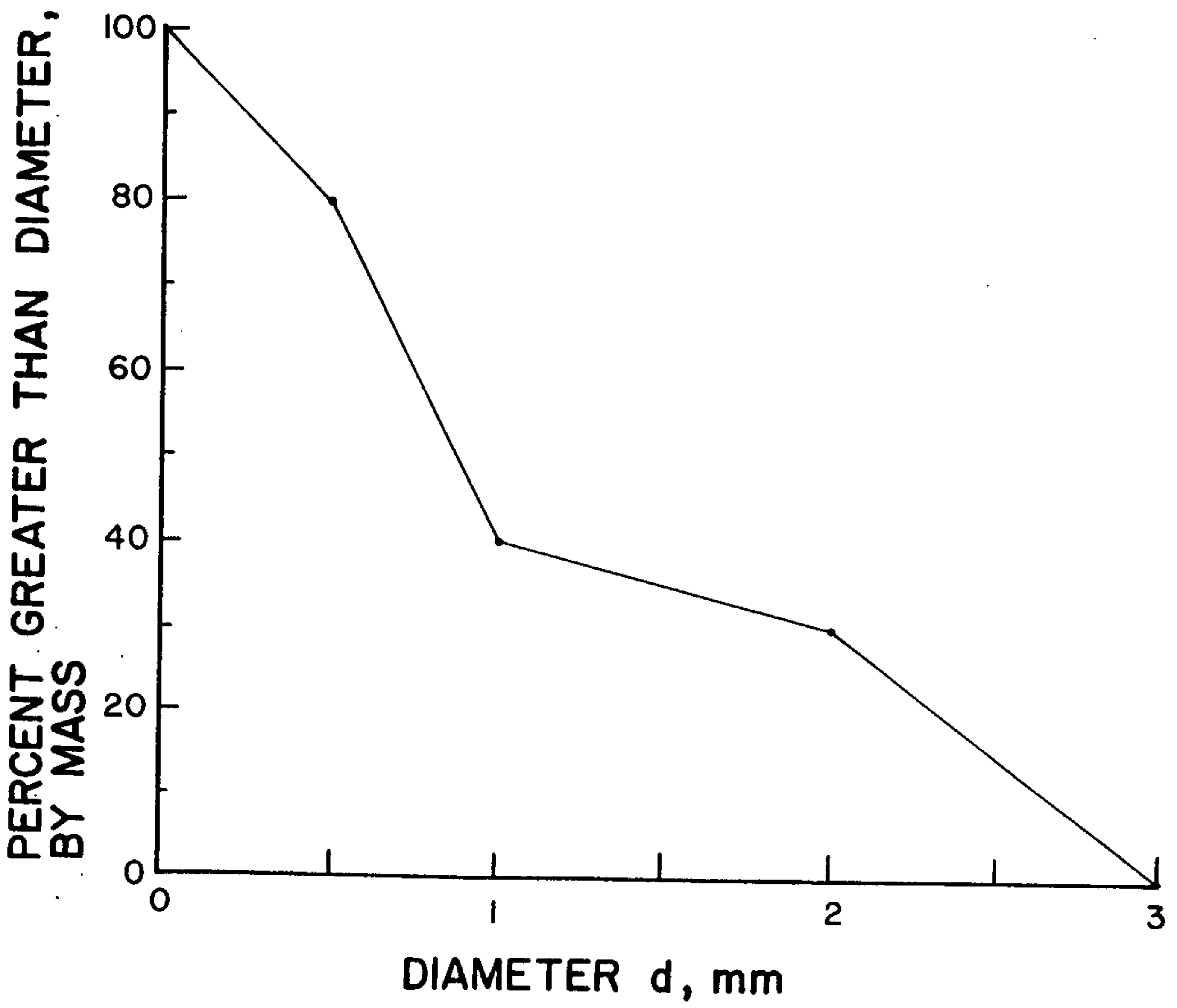


Figure VI-3. Particle Size Distribution for a Pollutant.

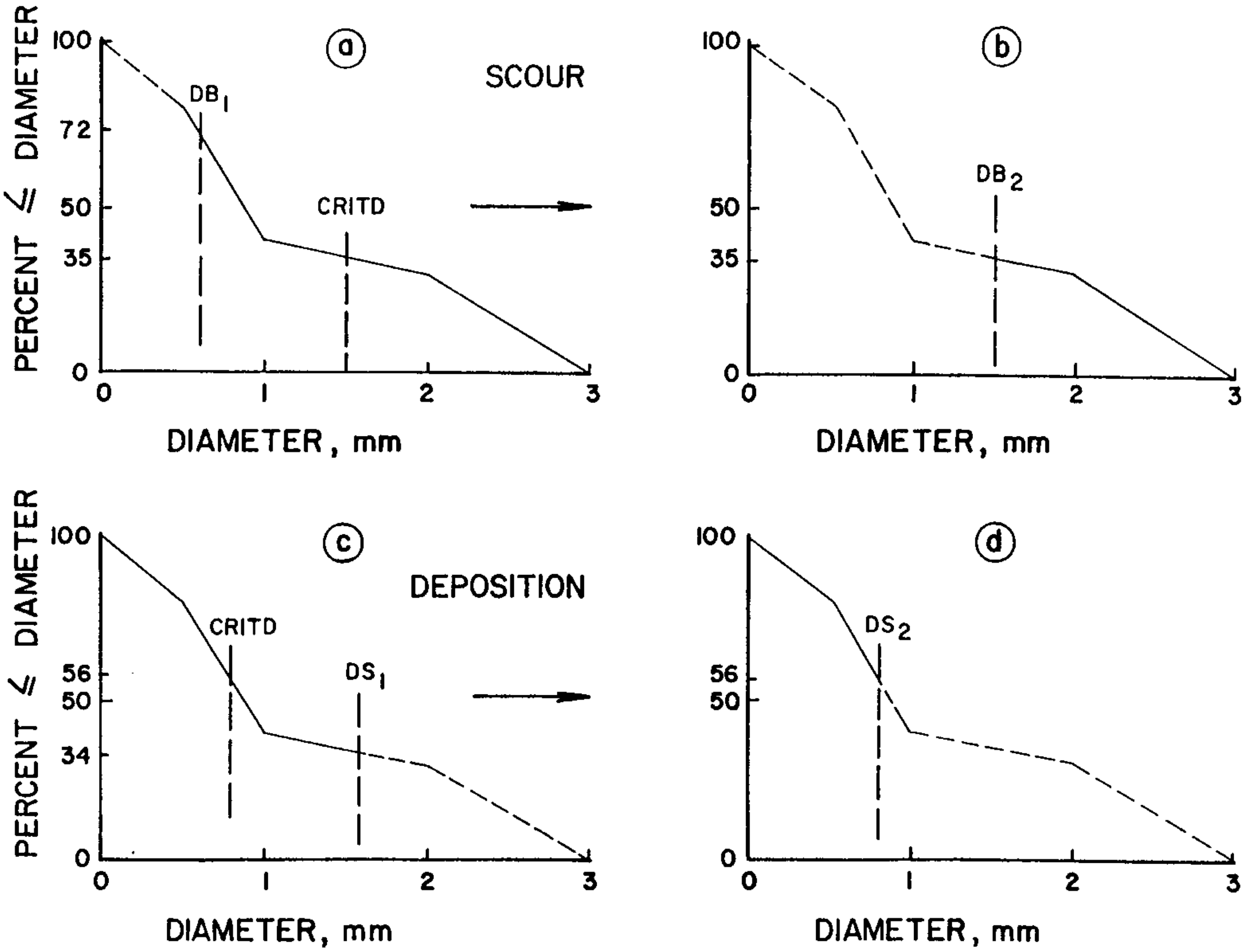


Figure VI-4. Truncation of Particle Size Distribution During Scour and Deposition.

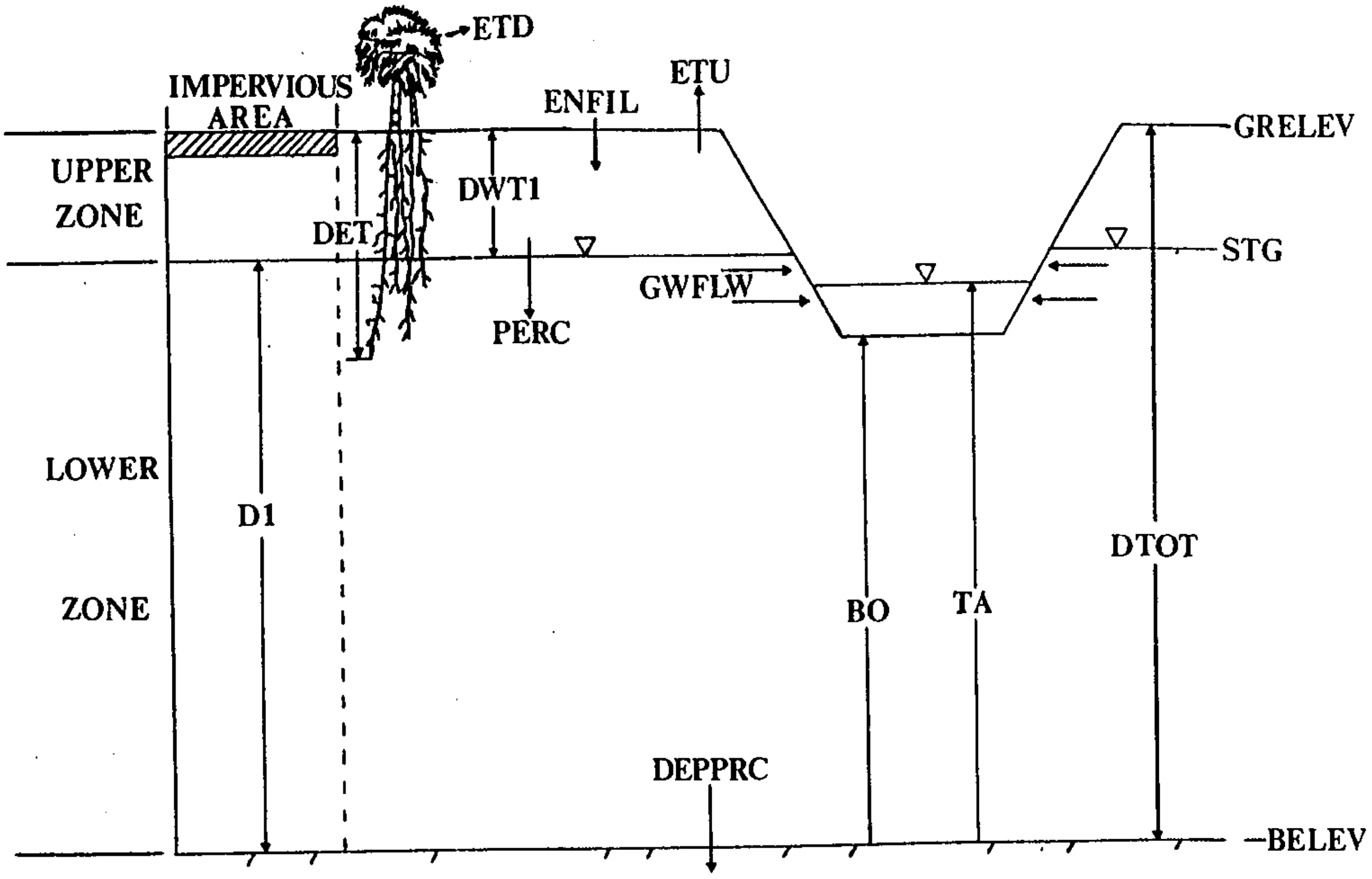


Figure X-1. GROUND Parameters and Conceptualization.

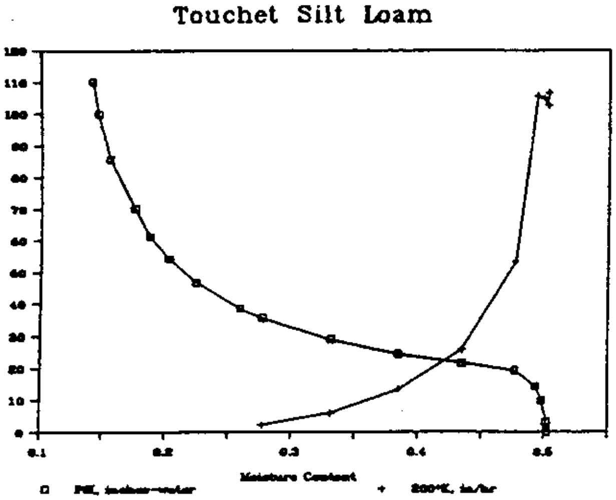


Figure X-2.

Tension, PSI (squares, in. of water) and hydraulic conductivity, K (crosses, in/hr, K multiplied by 200) versus moisture content. Derived from data of Laliberte et al (1966), Tables B-5 and C-3. Porosity = 0.503, temp. = 26.5 °C, saturated hyd. conductivity = 0.53 in/hr.

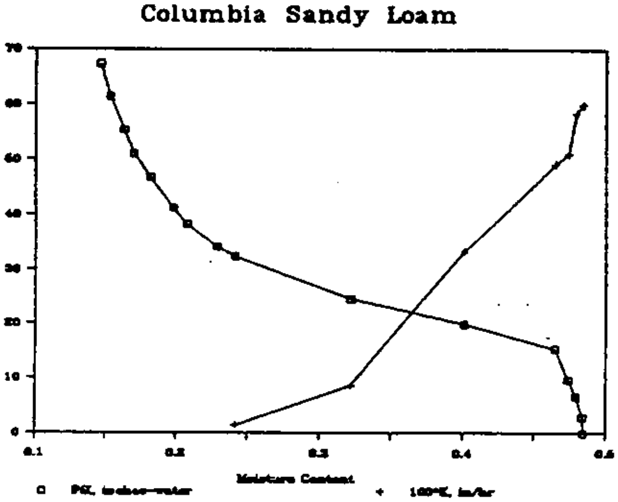


Figure X-3.

Tension, PSI (squares, in. of water) and hydraulic conductivity, K (crosses, in/hr, K multiplied by 100) versus moisture content. Derived from data of Laliberte et al. (1966), Tables B-8 and C-5. Porosity = 0.485, temp. = 25.1 °C, saturated hyd. conductivity = 0.60 in/hr.

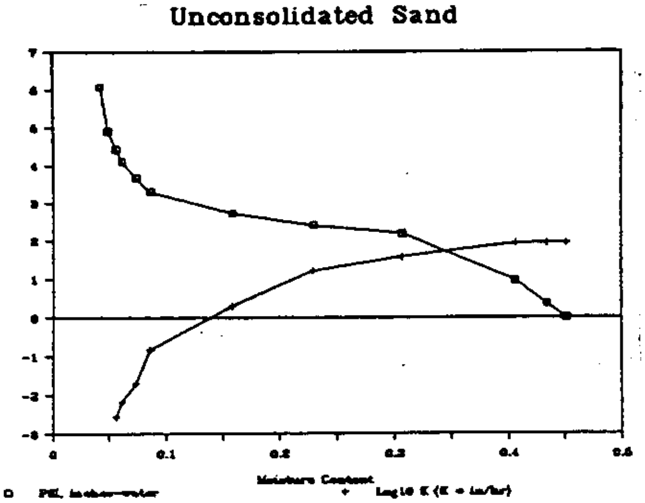


Figure X-4.

Tension, PSI (squares, in. of water) and log-10 of hydraulic conductivity, K (crosses, K in in/hr) versus moisture content. Derived from data of Laliberte et al. (1966), Tables B-14 and C-11. Porosity = 0.452, temp. = 25.1 °C, saturated hyd. conductivity = 91.5 in/hr.

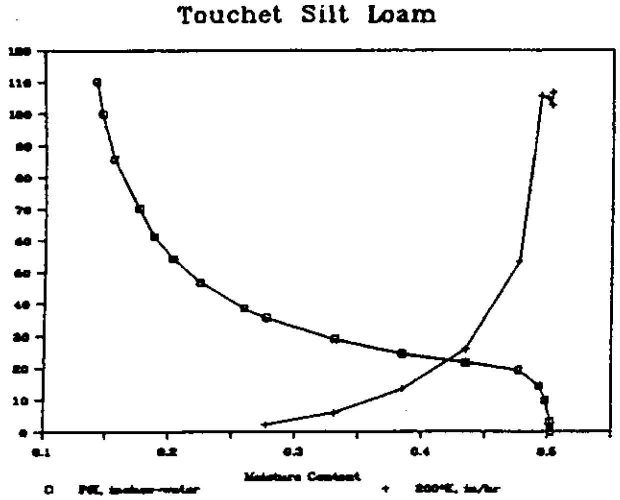


Figure X-2.

Tension, PSI (squares, in. of water) and hydraulic conductivity, K (crosses, in/hr, K multiplied by 200) versus moisture content. Derived from data of Laliberte et al (1966), Tables B-5 and C-3. Porosity = 0.503, temp. = 26.5 °C, saturated hyd. conductivity = 0.53 in/hr.

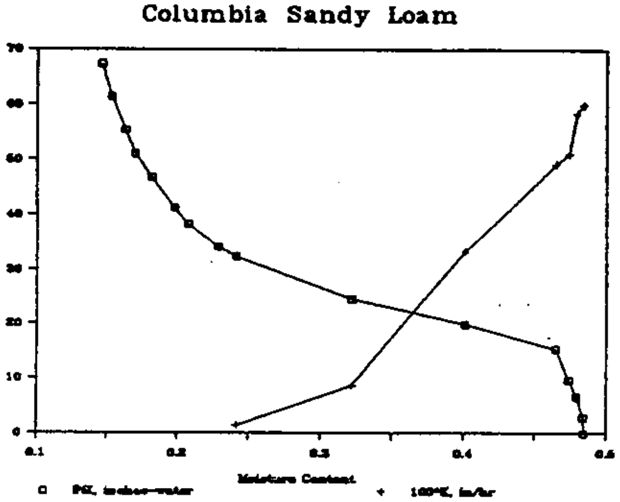


Figure X-3.

Tension, PSI (squares, in. of water) and hydraulic conductivity, K (crosses, in/hr, K multiplied by 100) versus moisture content. Derived from data of Laliberte et al. (1966), Tables B-8 and C-5. Porosity = 0.485, temp. = 25.1 °C, saturated hyd. conductivity = 0.60 in/hr.

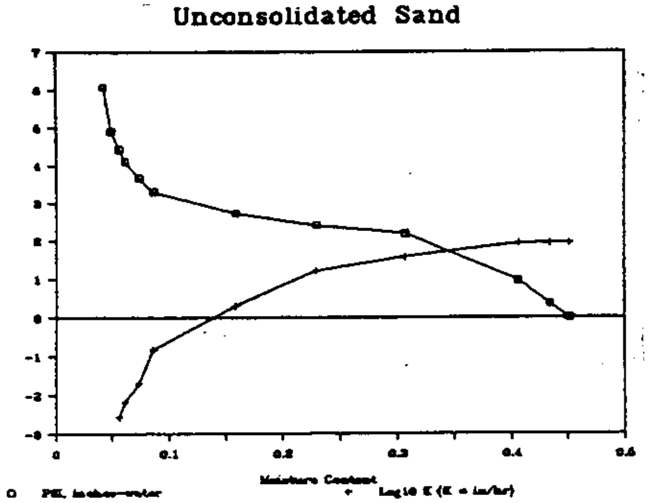


Figure X-4.

Tension, PSI (squares, in. of water) and log-10 of hydraulic conductivity, K (crosses, K in in/hr) versus moisture content. Derived from data of Laliberte et al. (1966), Tables B-14 and C-11. Porosity = 0.452, temp. = 25.1 °C, saturated hyd. conductivity = 91.5 in/hr.

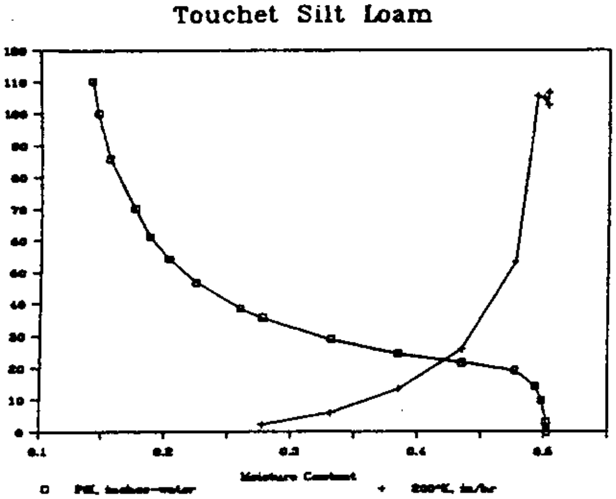

Touchet Silt Loam

Figure X-2.

Tension, PSI (squares, in. of water) and hydraulic conductivity, K (crosses, in/hr, K multiplied by 200) versus moisture content. Derived from data of Laliberte et al (1966), Tables B-5 and C-3. Porosity = 0.503, temp. = 26.5 °C, saturated hyd. conductivity = 0.53 in/hr.

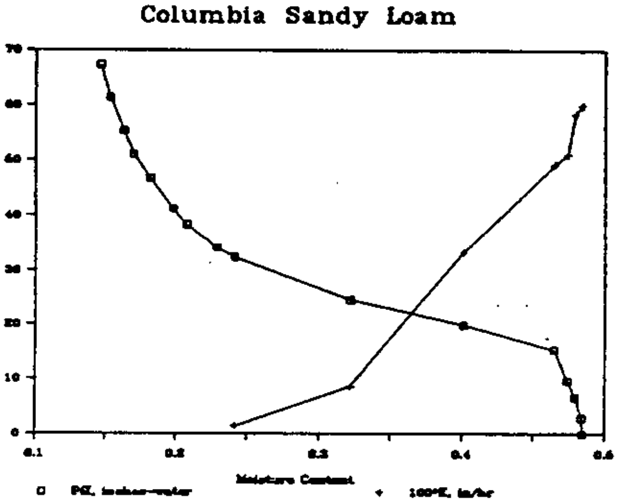

Columbia Sandy Loam

Figure X-3.

Tension, PSI (squares, in. of water) and hydraulic conductivity, K (crosses, in/hr, K multiplied by 100) versus moisture content. Derived from data of Laliberte et al. (1966), Tables B-8 and C-5. Porosity = 0.485, temp. = 25.1 °C, saturated hyd. conductivity = 0.60 in/hr.

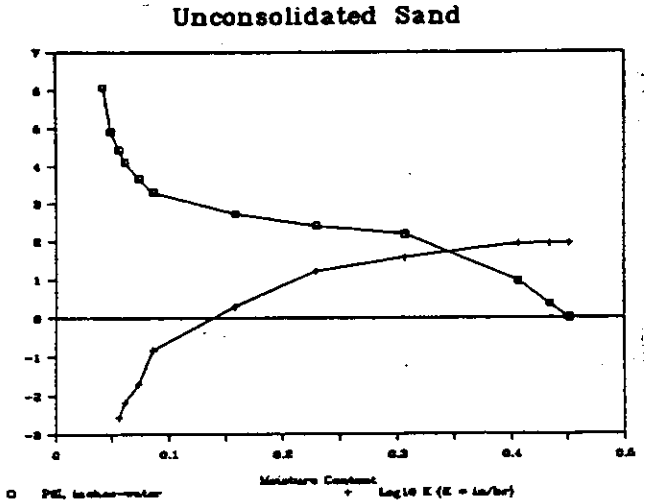

Unconsolidated Sand

Figure X-4.

Tension, PSI (squares, in. of water) and log-10 of hydraulic conductivity, K (crosses, K in in/hr) versus moisture content. Derived from data of Laliberte et al. (1966), Tables B-14 and C-11. Porosity = 0.452, temp. = 25.1 °C, saturated hyd. conductivity = 91.5 in/hr.

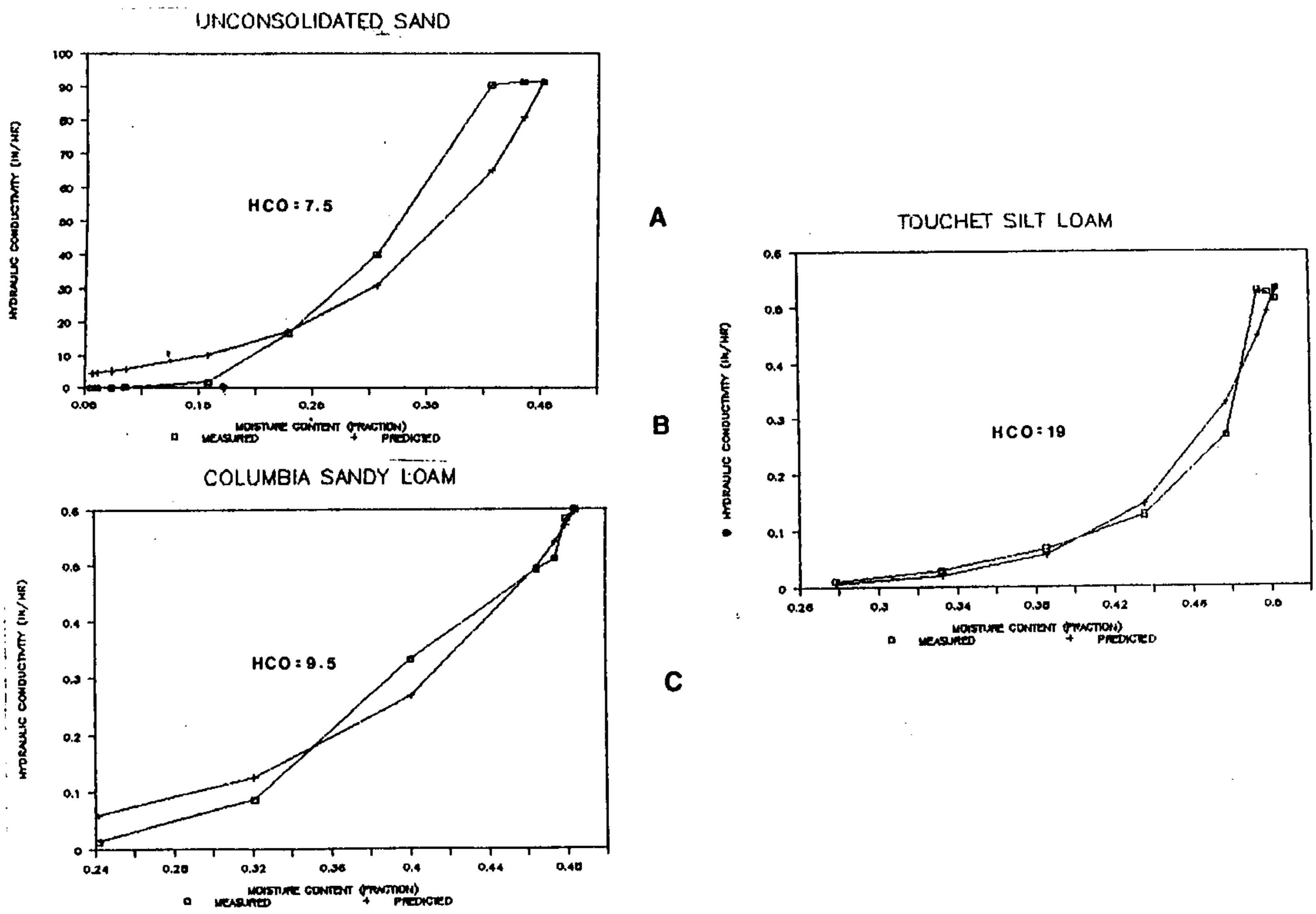


Figure X-5. Model Representation and Measured Hydraulic Conductivity Curves for Three Types of Soil.

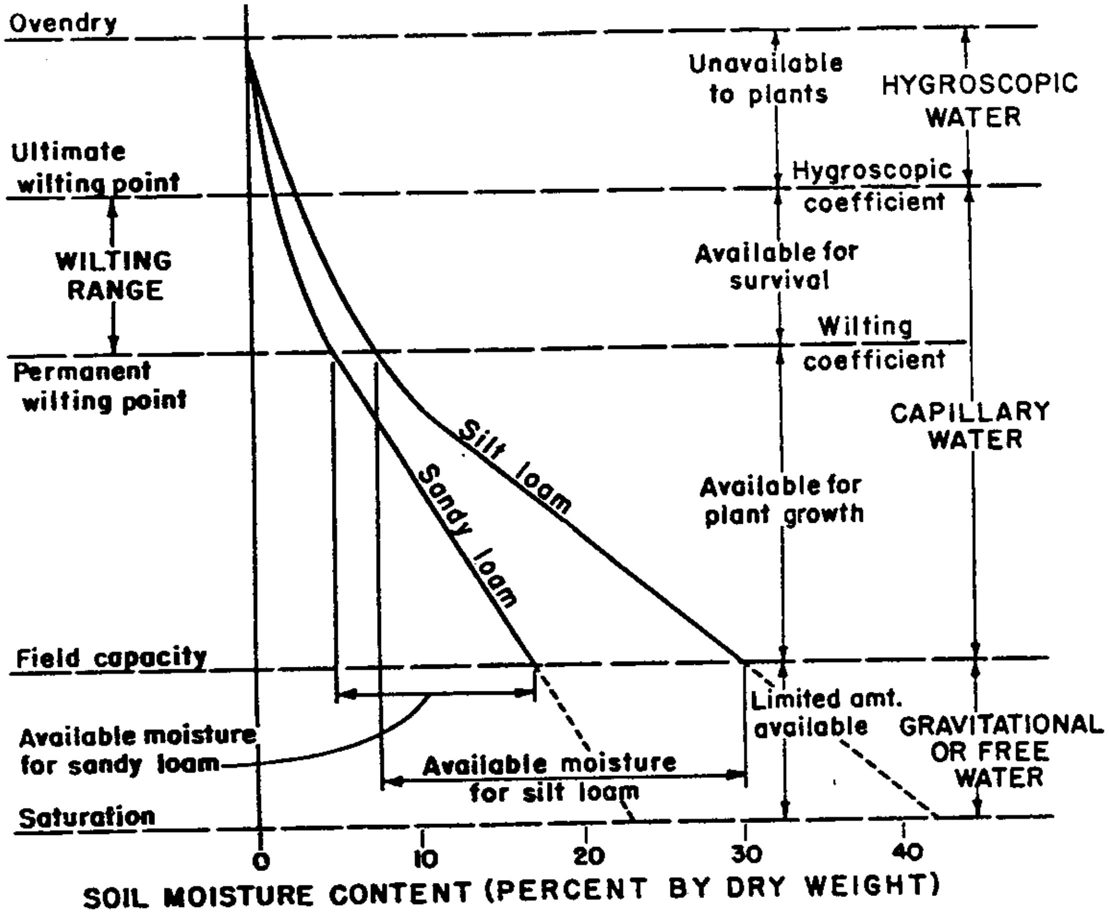


Figure X-6. Kinds of Water in Soil (SCS, 1964). Note that Silt Loam Contains more than Twice as Much Readily Available Water than Sandy Loam.

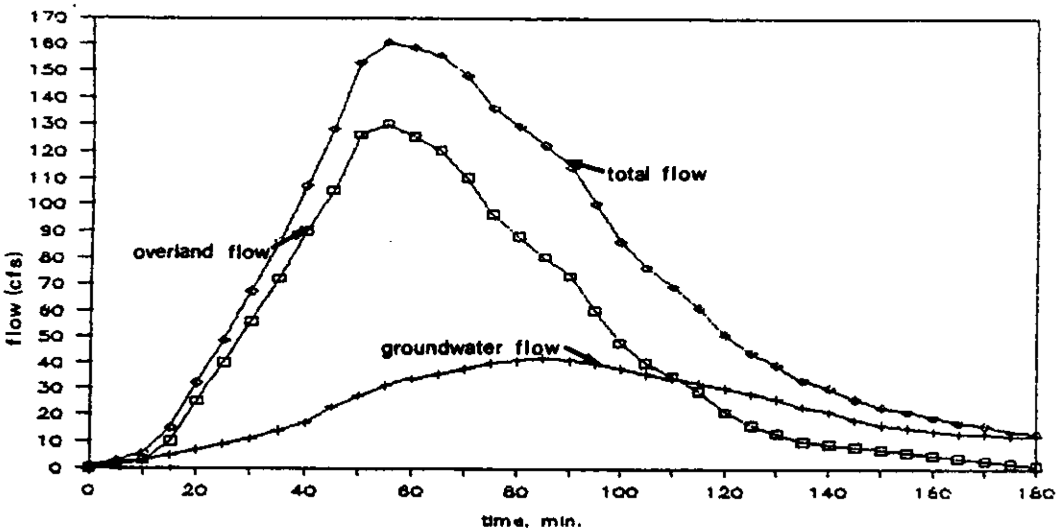


Figure X-7. Hydrograph of total flow and its two major components.

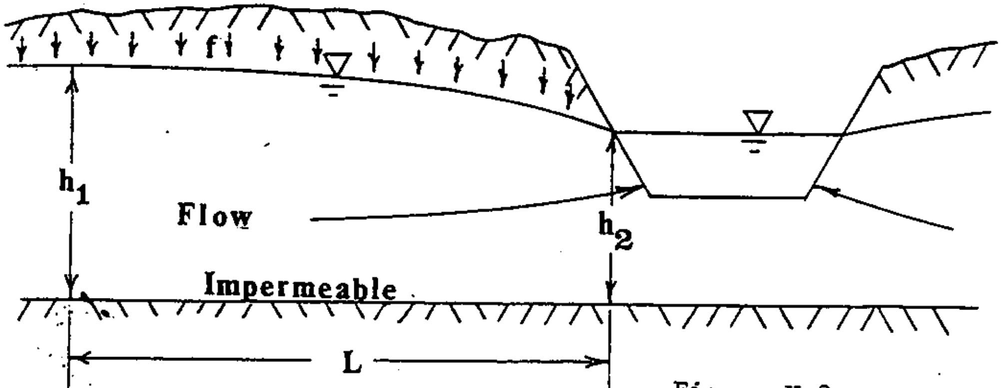


Figure X-8.
Definition sketch for Dupuit-Forcheimer approximation for drainage to adjacent channel.

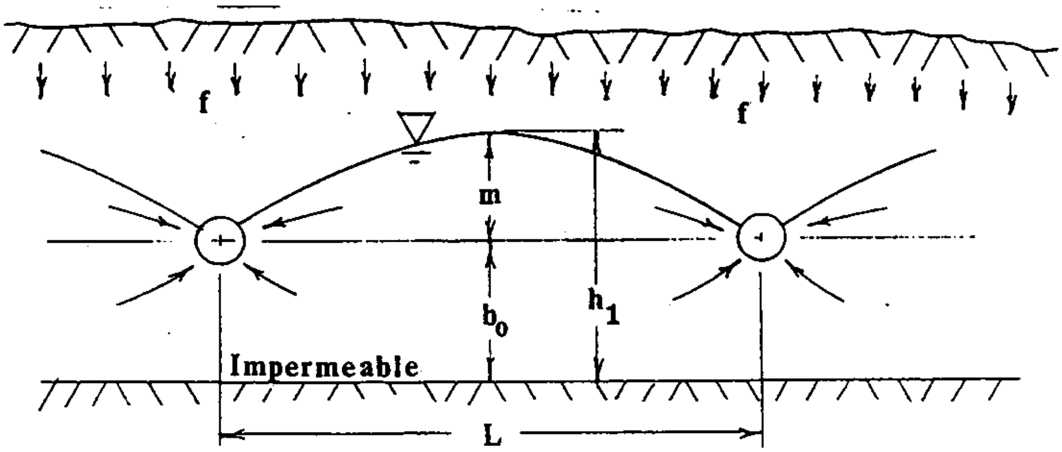


Figure X-9. Definition Sketch for Hooghoudt's Method for Flow to Circular Drains.

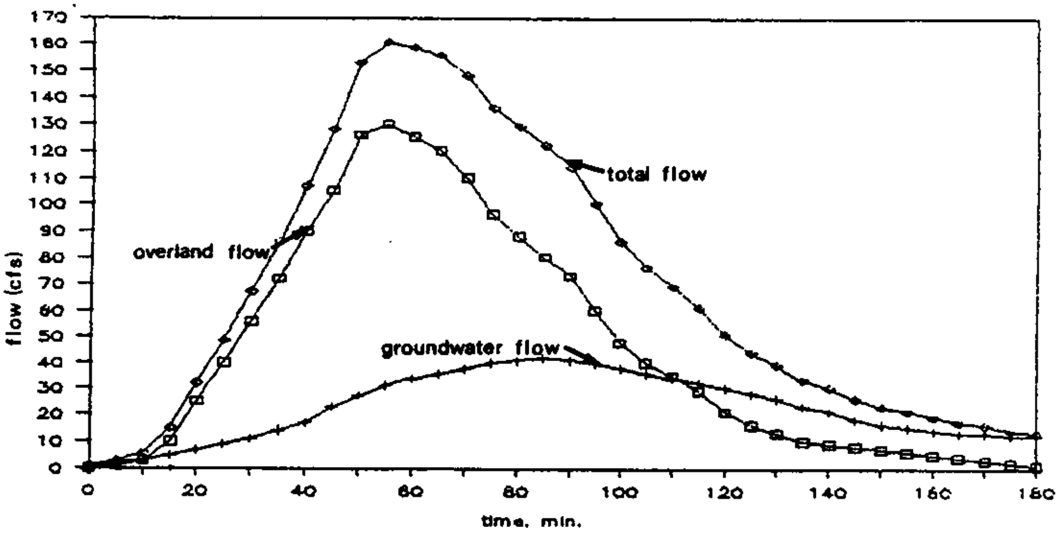


Figure X-7. Hydrograph of total flow and its two major components.

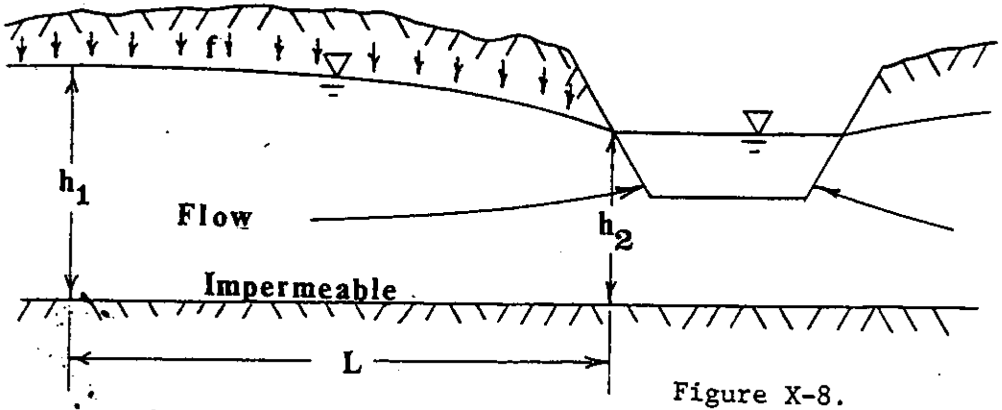


Figure X-8. Definition sketch for Dupuit-Forcheimer approximation for drainage to adjacent channel.

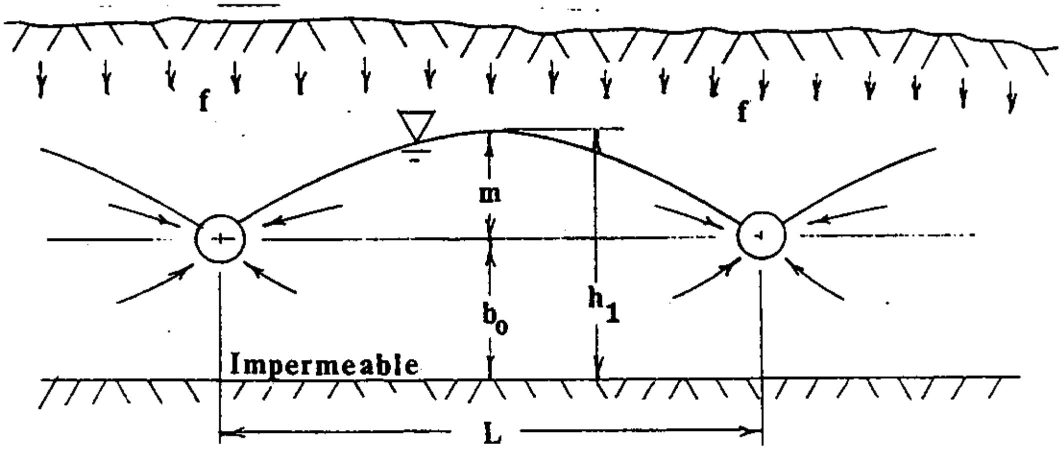


Figure X-9. Definition Sketch for Hooghoudt's Method for Flow to Circular Drains.

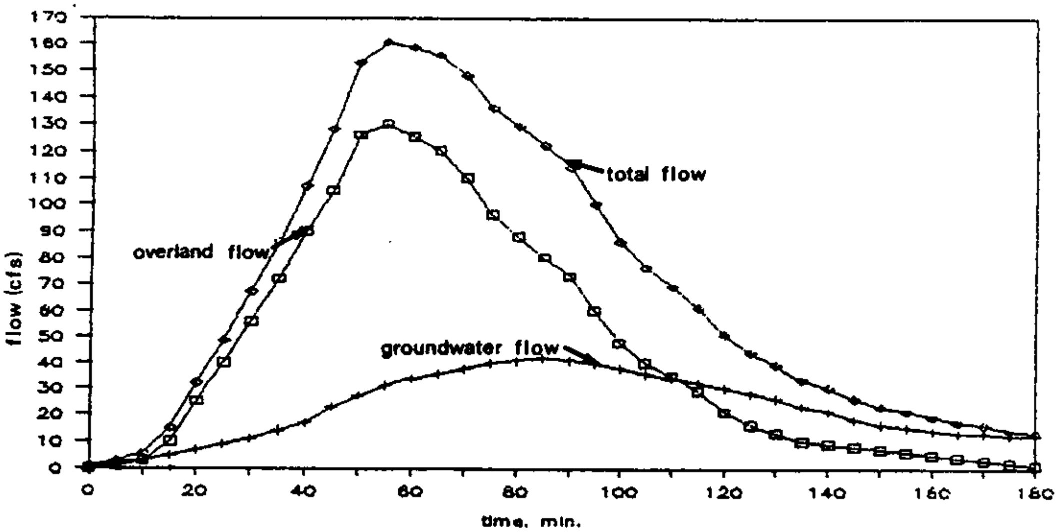


Figure X-7. Hydrograph of total flow and its two major components.

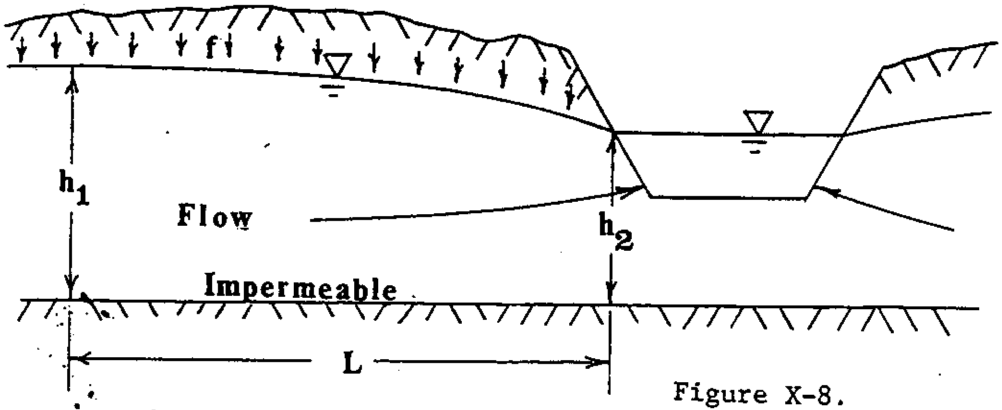


Figure X-8.
Definition sketch for Dupuit-Forcheimer approximation for drainage to adjacent channel.

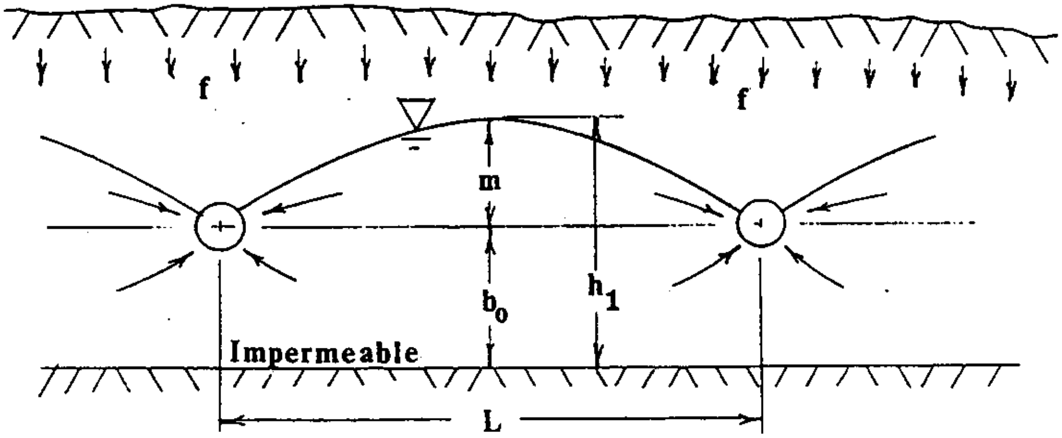


Figure X-9. Definition Sketch for Hooghoudt's Method for Flow to Circular Drains.

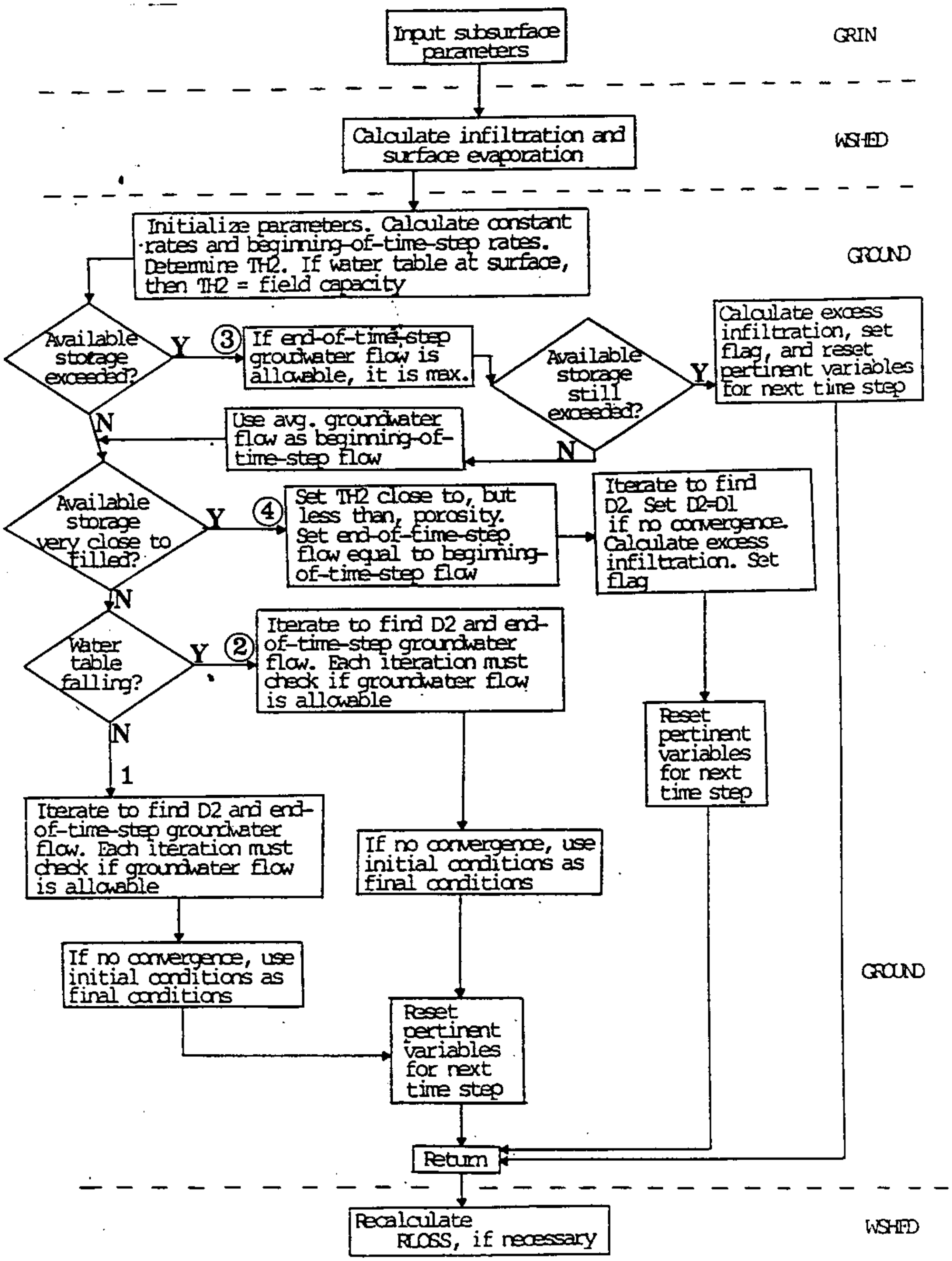


Figure X-10. Flowchart of Subsurface and Directly-connected Surface Calculations.

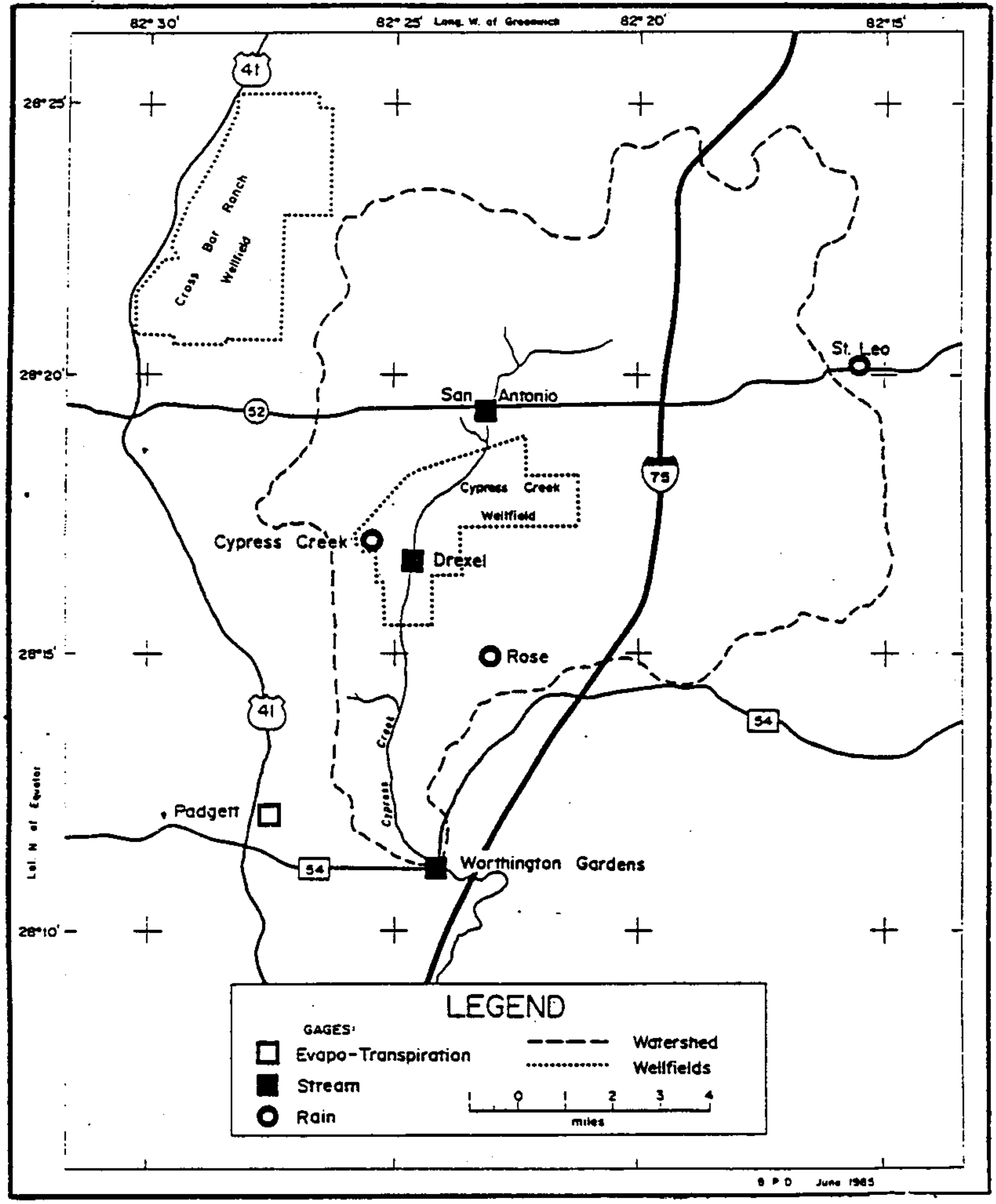


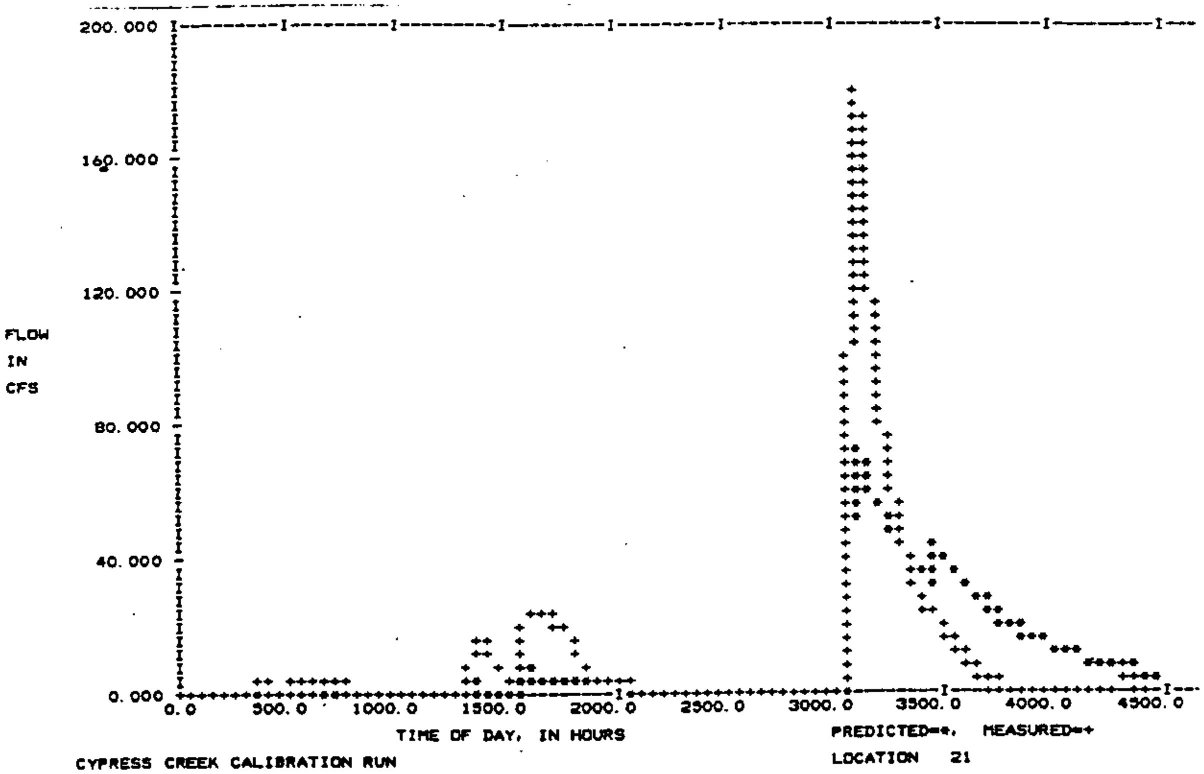
Figure X-11. Map of Cypress Creek Watershed in Pasco County, Florida. (Heaney et al., 1986)

```
* * * * * G R O U N D W A T E R   I N P U T   DATA * * * * * *
                              E L E V A T I O N S
SUBCAT.  GUTTER                      INITIAL                                F L O W   C O N S T A N T S
  NO.   OR INLET  GROUND   BOTTOM   STAGE      BC       TW           A1            B1          A2               B2
                   (FT)     (FT)     (FT)     (FT)     (FT)   (IN/HR-FT**B1)              (IN/HR-FT**B2)
   21      22     20.00     0.00     7.20     8.55     8.55     4.500E-05       2.600     0.000E+00       1.000



* * * * * G R O U N D W A T E R   I N P U T   D A T A   (CONTINUED) * * * * * *
                S O I L   P R O P E R T I E S
                         SATURATED                                                      PERCOLATION         E T   P A R A M E T E R S
SUBCAT.                  HYDRAULIC     WILTING   FIELD     INITIAL      MAX.  DEEP     PARAMETERS           DEPTH   FRACTION OF ET
  NO.      POROSITY   CONDUCTIVITY     POINT   CAPACITY  MOISTURE    PERCOLATION    HCO *    PCO **        OF ET   TO UPPER ZONE
                         (IN/HR)                                       (IN/HR)                (FT)           (FT)
  21        .4600         5.000        .1500     .3000     .3010      2.000E-03     10.00    15.00         14.00       0.350


HYD. CONDUCTIVITY = SAT. HYD. COND. * EXP((UPPER Z MOISTURE CONTENT - POROSITY) * HCO)
* PERCOLATION RATE = HYD. COND. * (1 + PCO * (UPPER ZONE MOISTURE CONTENT - FIELD CAPACITY)/(UPPER ZONE DEPTH/2))
```

Figure X-12. Subsurface Input Data for Cypress Creek Calibration.

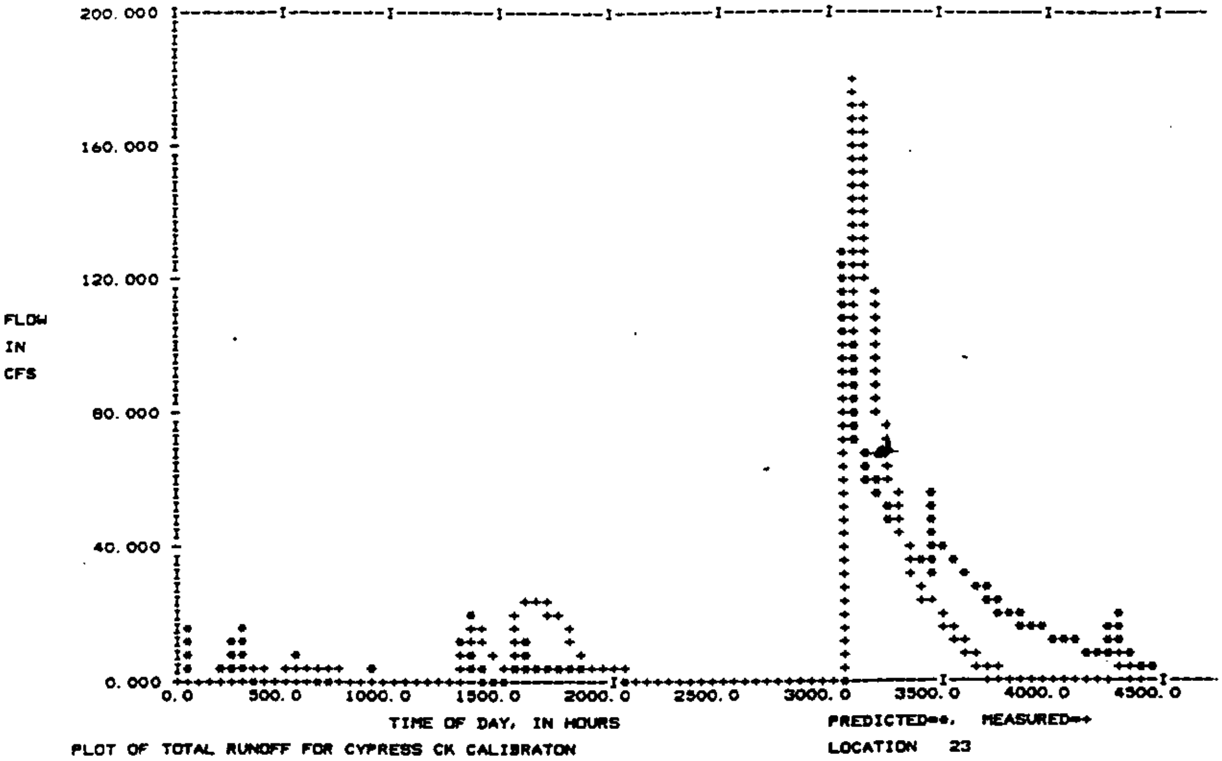
```
$ $ $ --- CONTINUITY CHECK FOR QUANTITY --- $ $ $
                                                                        INCHES OVER
                                                          CUBIC FEET    TOTAL BASIN

TOTAL PRECIPITATION (RAIN PLUS SNOW)                     3.434232E+09      30.518

TOTAL INFILTRATION                                       2.878862E+09      25.583

TOTAL EVAPORATION                                        5.298000E+08       4.708

TOTAL GUTTER/PIPE/SUBCAT FLOW AT INLETS                  2.559983E+07       0.227

TOTAL WATER REMAINING IN GUTTER/PIPES                    0.000000E+00       0.000

TOTAL WATER REMAINING IN SURFACE STORAGE                 0.000000E+00       0.000

INFILTRATION OVER THE PERVIOUS AREA...                   2.878862E+09      25.841

INFILTRATION + EVAPORATION +
SNOW REMOVAL + INLET FLOW +
WATER REMAINING IN GUTTER/PIPES +
WATER REMAINING IN SURFACE STORAGE +
WATER REMAINING IN SNOW COVER.........                   3.344122E+09      29.718

*** CONTINUITY CHECK FOR SUBSURFACE WATER ***

                                                              INCHES OVER
                                             CUBIC FEET       TOTAL BASIN

TOTAL INFILTRATION                          2.878862E+09         25.583
TOTAL UPPER ZONE ET                         1.149578E+09         10.216
TOTAL LOWER ZONE ET                         6.667578E+08          5.925
TOTAL GROUNDWATER FLOW                      9.013922E+07          0.801
TOTAL DEEP PERCOLATION                      4.816257E+08          4.280
INITIAL SUBSURFACE STORAGE                  9.675055E+09         85.978
FINAL SUBSURFACE STORAGE                    1.016489E+10         90.330

UPPER ZONE ET OVER PERVIOUS AREA            1.149578E+09         10.319
LOWER ZONE ET OVER PERVIOUS AREA            6.667578E+08          5.985

THE ERROR IN CONTINUITY IS CALCULATED AS

*****************************************
* PRECIPITATION + INITIAL SNOW COVER    *
*        - INFILTRATION -               *
*EVAPORATION - SNOW REMOVAL -           *
*INLET FLOW - WATER IN GUTTER/PIPES -   *
*WATER IN SURFACE STORAGE -             *
*WATER REMAINING IN SNOW COVER          *
*---------------------------------------*
* PRECIPITATION + INITIAL SNOW COVER    *
*****************************************

ERROR............................                                  2.624 PERCENT

********************************************
* INFILTRATION + INITIAL STORAGE - FINAL   *
* STORAGE - UPPER AND LOWER ZONE ET -      *
* GROUNDWATER FLOW - DEEP PERCOLATION      *
* ---------------------------------------- *
* INFILTRATION + INITIAL STORAGE -         *
* FINAL STORAGE                            *
********************************************

ERROR ...........................                                  0.039 PERCENT
```

Figure X-13. Continuity Check for Surface and Subsurface for Cypress Creek Calibration. The Relatively Large Surface Continuity Error does not Actually Exist; it Comes from a Double Accounting of the Groundwater Flow -- a Problem that Has Been Fixed.



```
HYDROGRAPH STATISTICS FOR LOCATION  21
                      VOLUME               PEAK FLOW                  DURATION                 NO.
               CUBIC FEET    INCHES    TIME,HR  FLOW,CFB       START,HR  END,HR  LENGTH,HR    POINTS
PREDICTED,     0.14547E+09    1.293    3105.000   73.242        0.000 4430.000 4430.000        194
TOTAL TIME
MEASURED,      0.16359E+09    1.454    3120.000  180.000        0.000 4392.000 4392.000        184
TOTAL TIME
PREDICTED,     0.14463E+09    1.285    3105.000   73.242        0.000 4393.000 4393.000        192
OVERLAPPING
TIME
MEASURED,      0.16359E+09    1.454    3120.000  180.000        0.000 4392.000 4392.000        18
OVERLAPPING
TIME
DIFFERENCES,
  ABSOLUTE     0.18964E+08    0.169      15.000  106.758
  % OF MEAS                  11.592               59.310
```

Figure X-14. Predicted Groundwater Flow Hydrograph and Total Measured Flow Hydrograph for Cypress Creek Calibration.



```
HYDROGRAPH STATISTICS FOR LOCATION  23

                    VOLUME               PEAK FLOW                  DURATION                    NO.
              CUBIC FEET   INCHES     TIME,HR   FLOW,CFS     START,HR  END,HR  LENGTH,HR      POINTS

PREDICTED.    0.17127E+09   1.522    3059.000  128.228       0.000 4430.000 4430.000         194
TOTAL TIME

MEASURED.     0.16359E+09   1.454    3120.000  180.000       0.000 4392.000 4392.000         184
TOTAL TIME

PREDICTED.    0.17042E+09   1.514    3059.000  128.228       0.000 4393.000 4393.000         192
OVERLAPPING
TIME

MEASURED.     0.16359E+09   1.454    3120.000  180.000       0.000 4392.000 4392.000         184
OVERLAPPING
TIME

DIFFERENCES.
  ABSOLUTE  -0.68276E+07   -0.061      61.000   51.772
   % OF MEAS               -4.174               28.762
```

Figure X-15. Total Predicted Flow Hydrograph and Total Measured Flow for Cypress Creek Calibration.

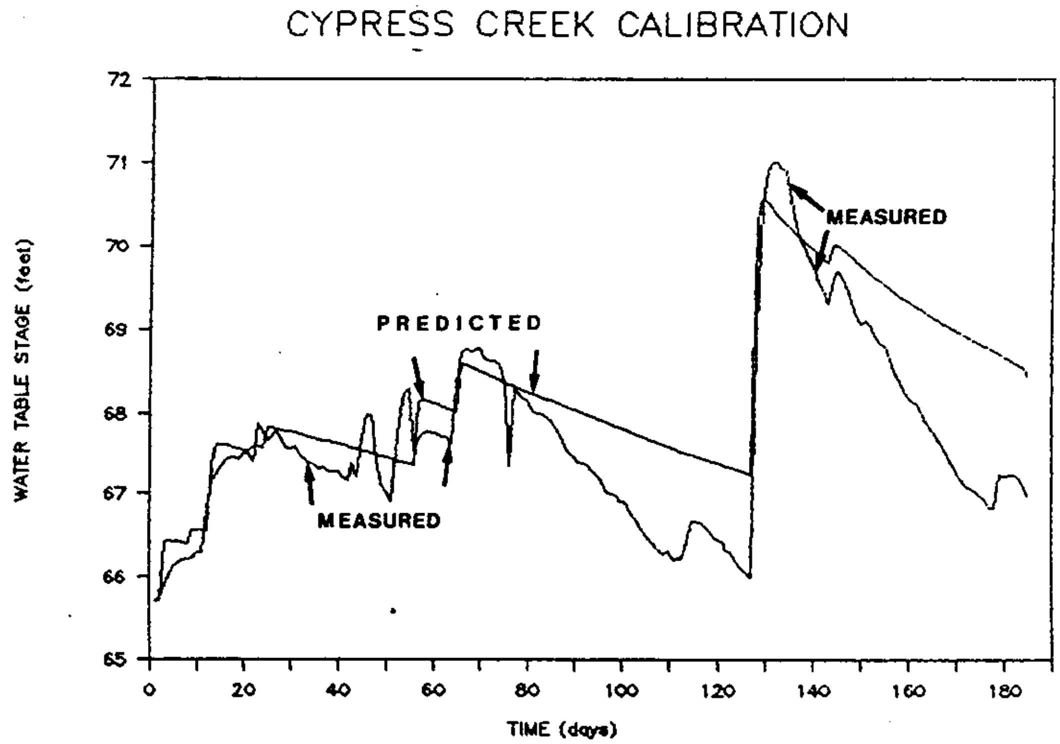


Figure X-16. Predicted and Measured Stages for Cypress Creek Calibration.

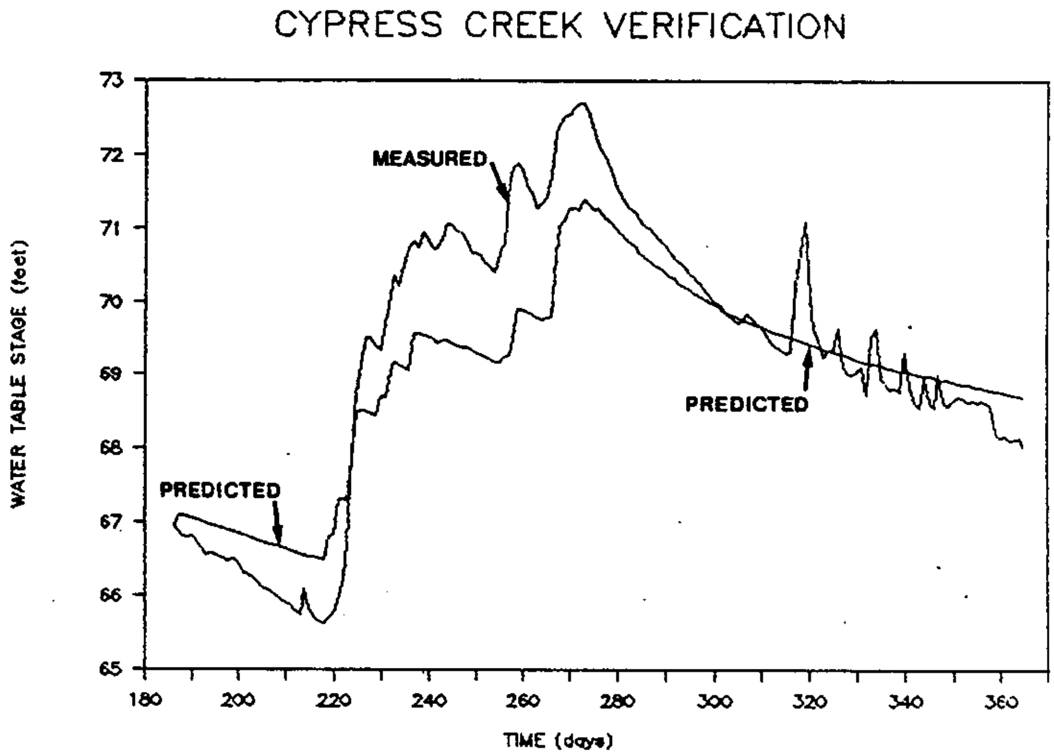


Figure X-17. Predicted and Measured Stages for Cypress Creek Verification.

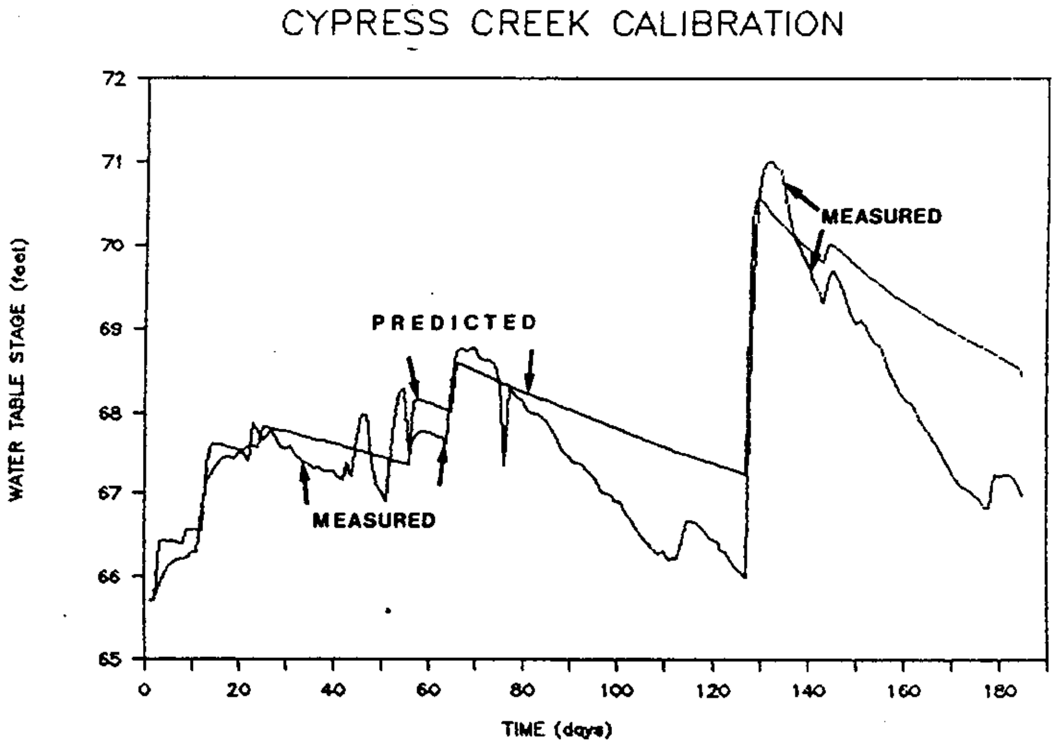


Figure X-16. Predicted and Measured Stages for Cypress Creek Calibration.

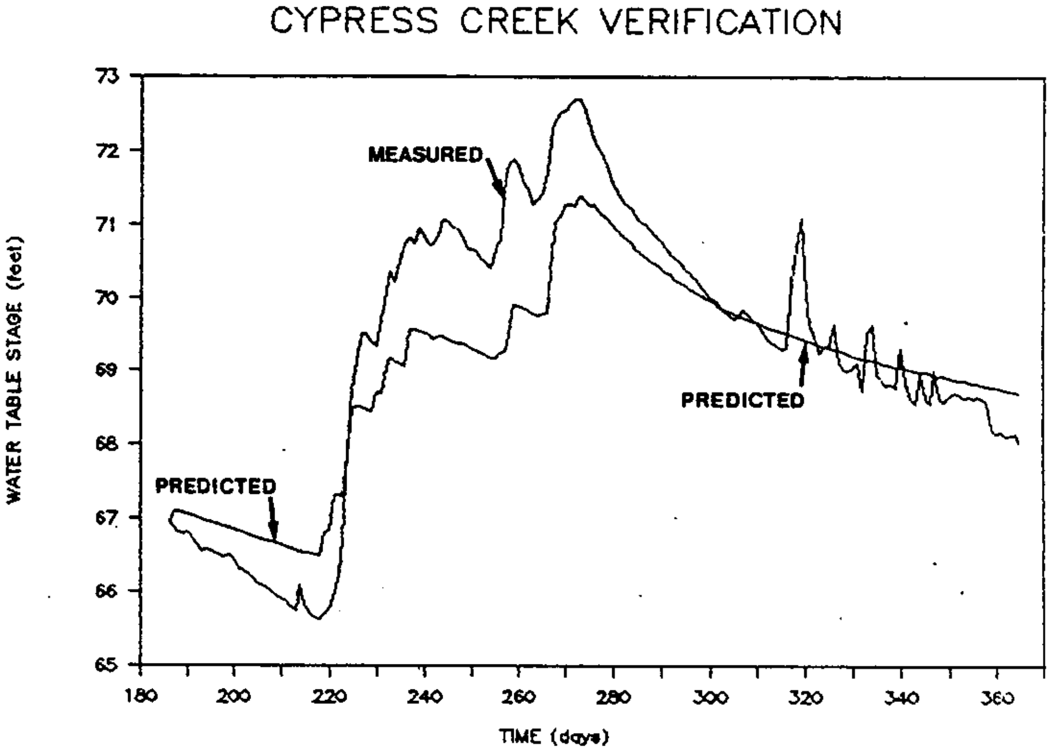
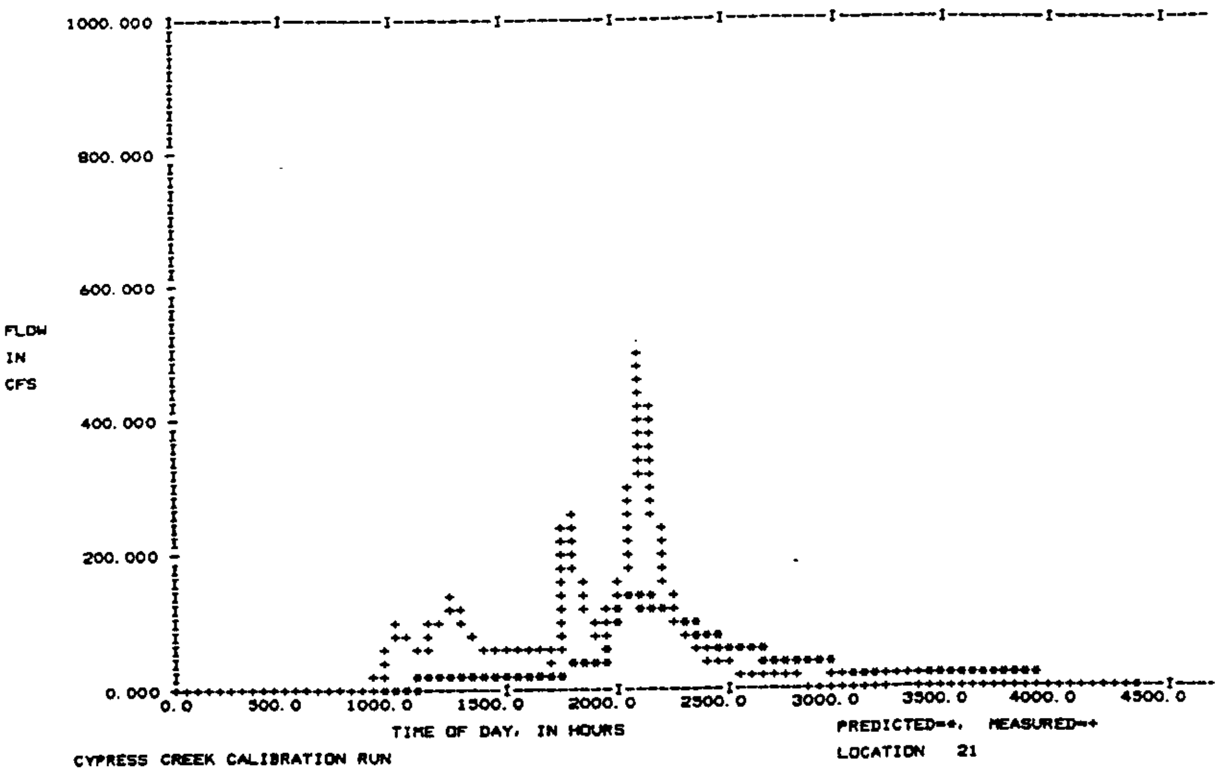
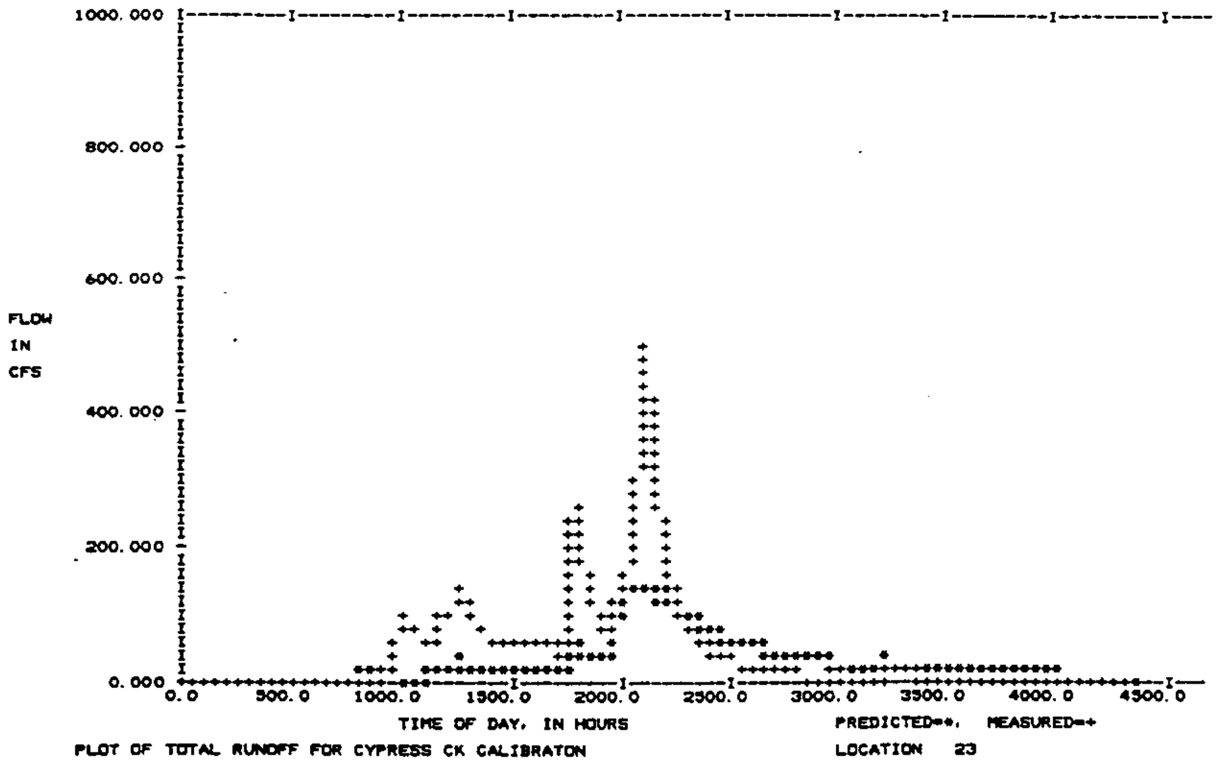


Figure X-17. Predicted and Measured Stages for Cypress Creek Verification.



```
HYDROGRAPH STATISTICS FOR LOCATION  21
                      VOLUME                  PEAK FLOW                      DURATION                  NO.
               CUBIC FEET     INCHES      TIME,HR   FLOW,CFS       START,HR   END,HR   LENGTH,HR     POINTS
PREDICTED,     0.42533E+09     3.780      2112.000  144.583          0.000  4350.000  4350.000        199
TOTAL TIME
MEASURED,      0.71232E+09     6.330   .  2112.000  500.000          0.000  4320.000  4320.000        181
TOTAL TIME
PREDICTED,     0.42426E+09     3.770      2112.000  144.583          0.000  4312.000  4312.000        197
OVERLAPPING
TIME
MEASURED,      0.71232E+09     6.330      2112.000  500.000          0.000  4320.000  4320.000        181
OVERLAPPING
TIME
DIFFERENCES,
  ABSOLUTE     0.28806E+09     2.560         0.000  355.417
  % OF MEAS                   40.440                 71.083
```

Figure X-18. Predicted Groudwater Flow Hydrograph and Total Measured Flow Hydrograph for Cypress Creek Verification.



```
HYDROGRAPH STATISTICS FOR LOCATION  23
                        VOLUME                   PEAK FLOW                        DURATION                    NO.
               CUBIC FEET    INCHES         TIME,HR   FLOW,CFS       START,HR   END,HR   LENGTH,HR         POINTS
PREDICTED,     0.44397E+09     3.945        2112.000  149.908          0.000 4350.000 4350.000               199
TOTAL TIME
MEASURED,      0.71232E+09     6.330  .     2112.000  500.000          0.000 4320.000 4320.000               181
TOTAL TIME
PREDICTED,     0.44289E+09     3.936        2112.000  149.908          0.000 4312.000 4312.000               197
OVERLAPPING
TIME
MEASURED,      0.71232E+09     6.330        2112.000  500.000          0.000 4320.000 4320.000               181
OVERLAPPING
TIME
DIFFERENCES,
  ABSOLUTE     0.26943E+09     2.394           0.000  350.092
  % OF MEAS                   37.824                   70.018
```

Figure X-19. Total Predicted Flow Hydrograph and Total Measured Flow for Cypress Creek Verification.

Hydrograph for Hypothetical Subcatchment (10-yr SCS Type II Design Storm for Tallahassee, Florida).

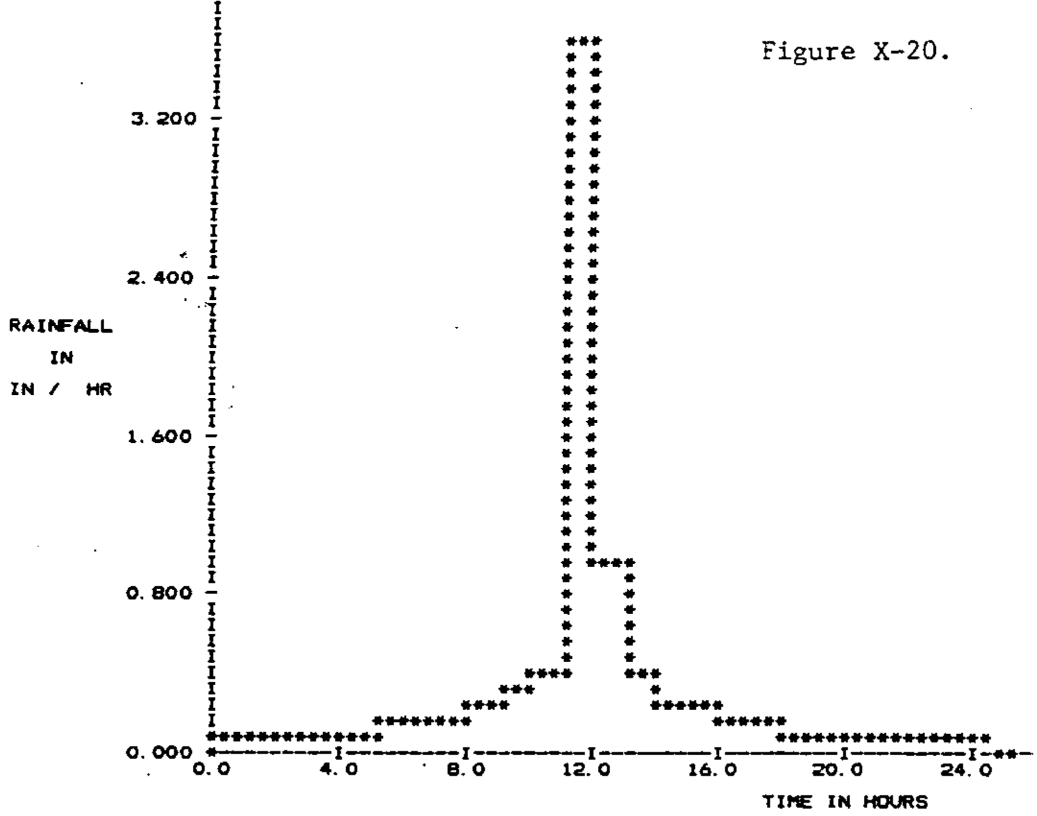


Figure X-20.

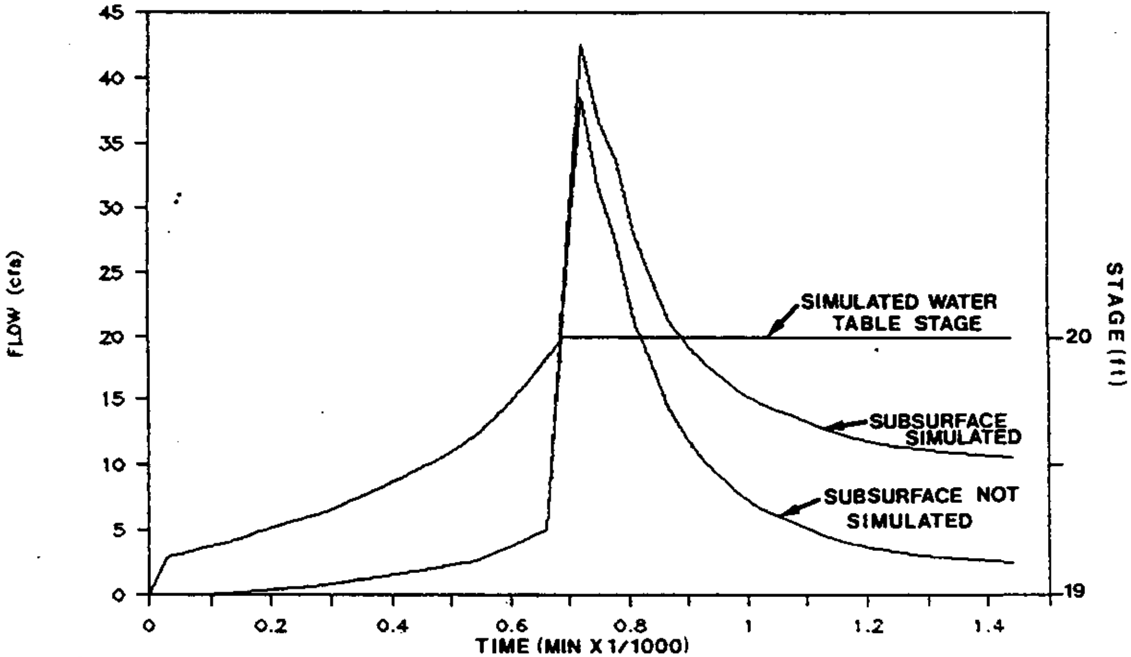


Figure X-21. Hydrographs of Surface Flow and Simulated Water Table Stage from Hypothetical Subcatchment. The Hydrographs are Identical Until the Water Table Reaches the Surface (20 ft).

Hydrograph for Hypothetical Subcatchment (10-yr SCS Type II Design Storm for Tallahassee, Florida).

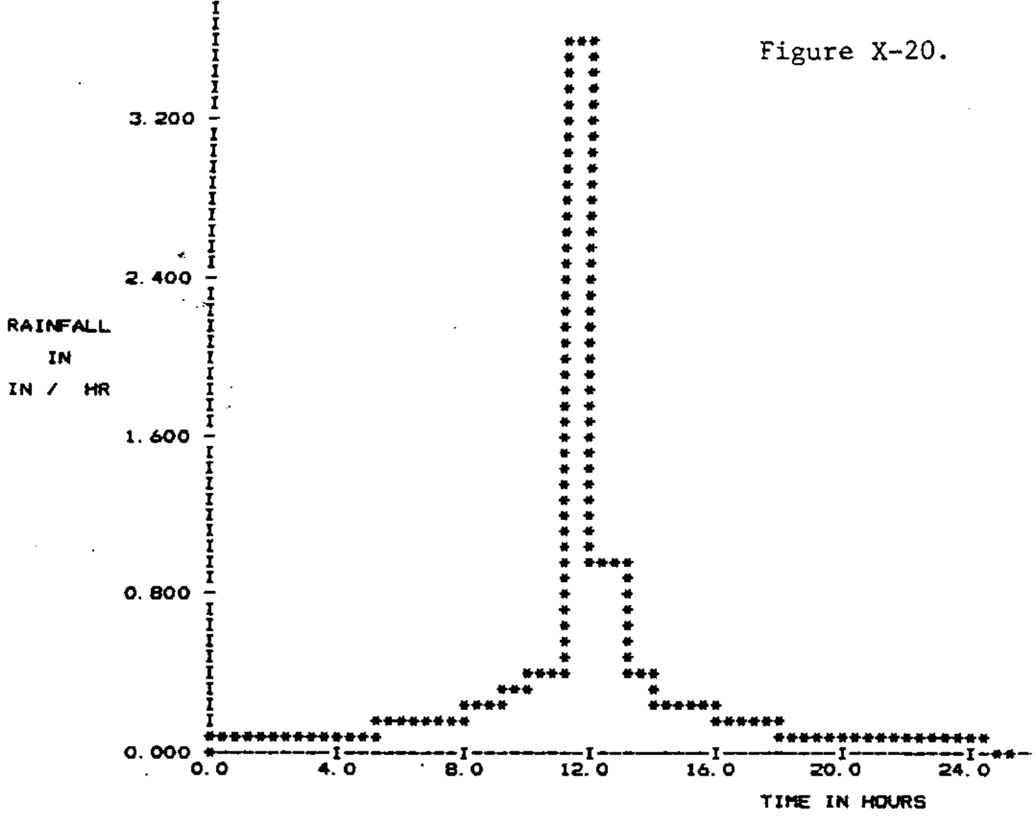


Figure X-20.

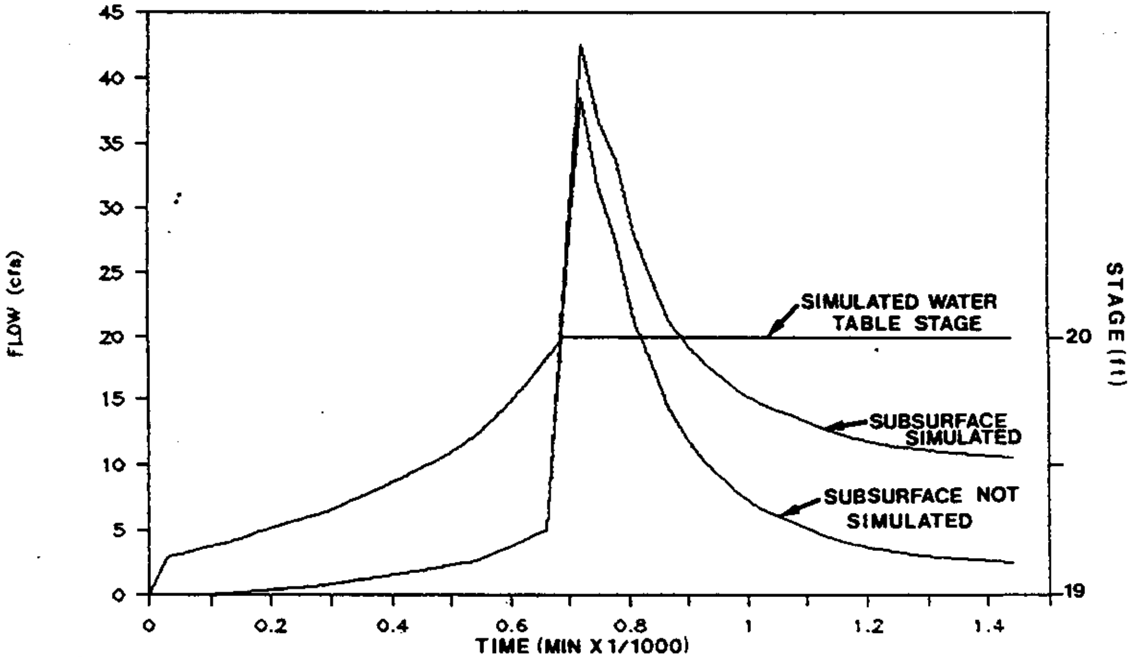


Figure X-21. Hydrographs of Surface Flow and Simulated Water Table Stage from Hypothetical Subcatchment. The Hydrographs are Identical Until the Water Table Reaches the Surface (20 ft).