

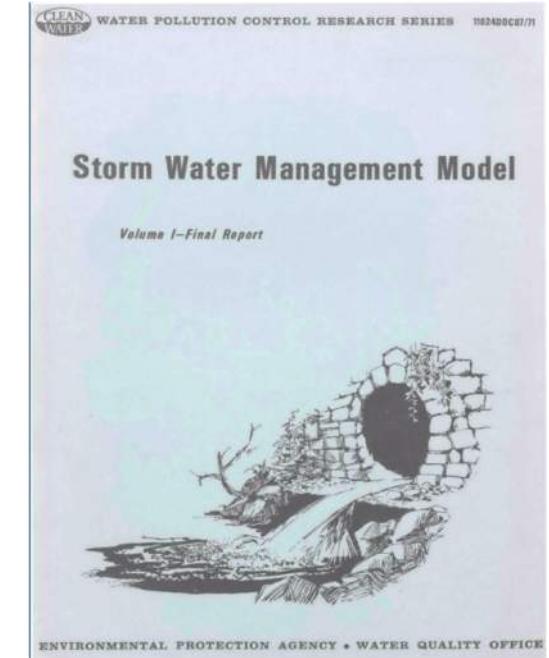
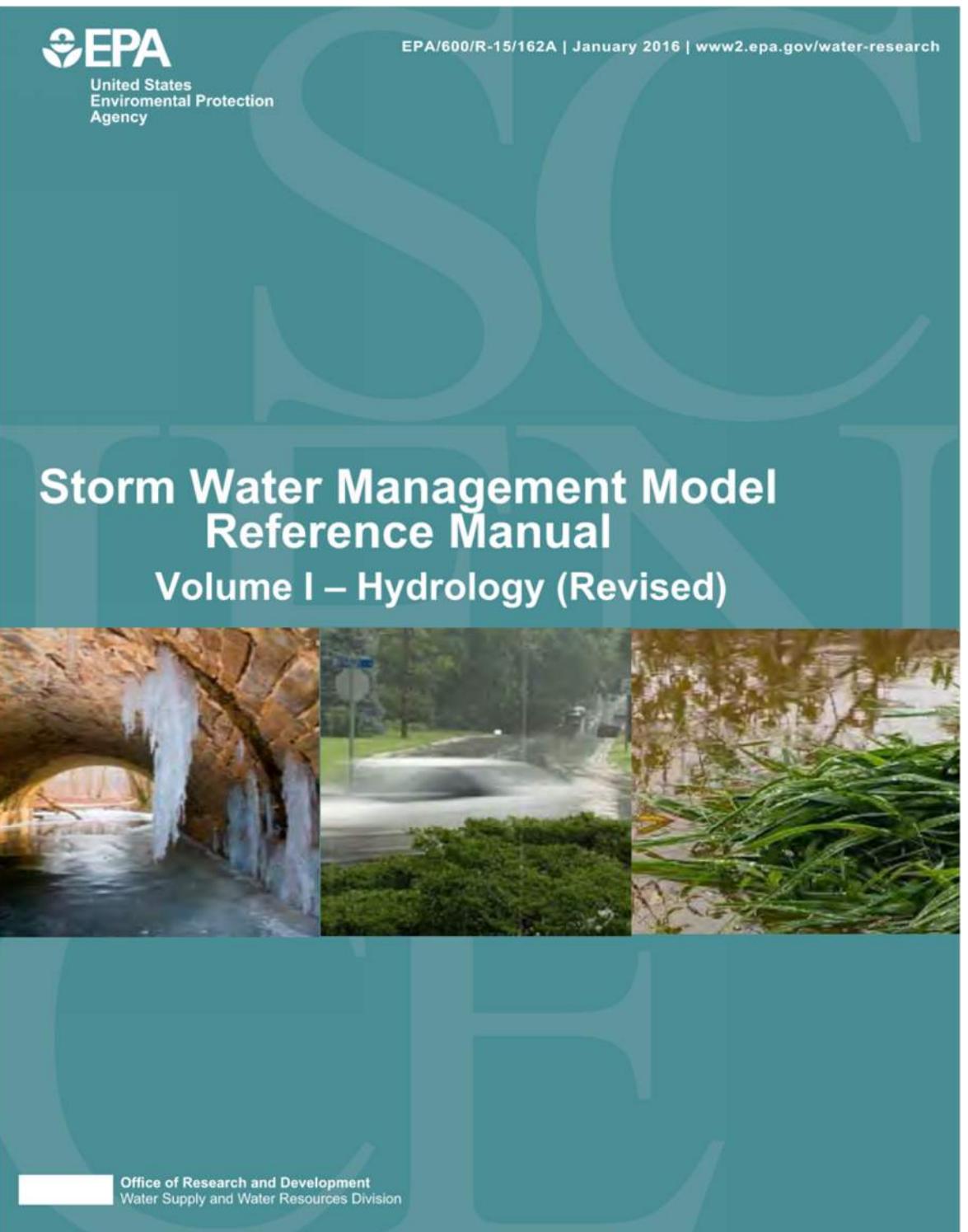
Hydrology

EWRI World Environmental & Water Resources Congress 2025
Workshop for the EPA Stormwater Management Model
May 18, 2025
Mitch Heineman, PE. BC.WRE, BCEE

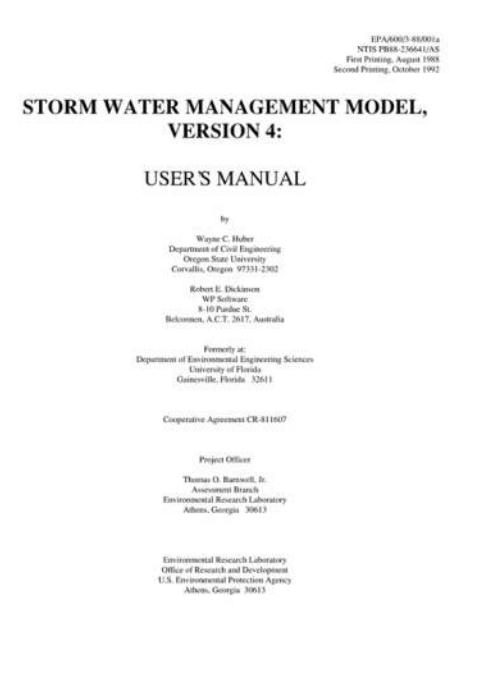
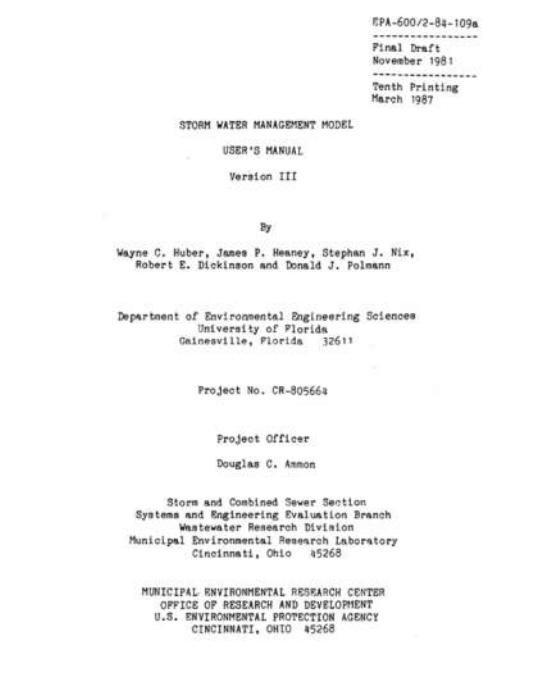
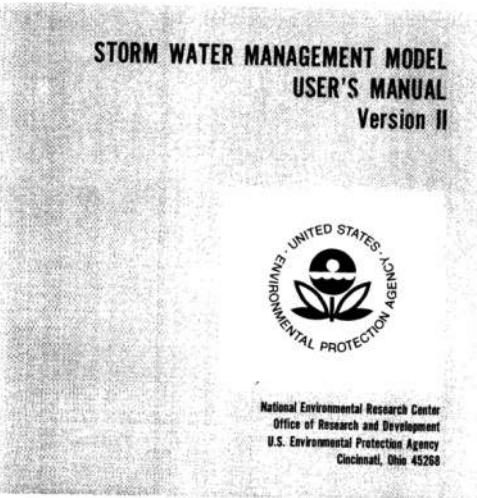


Topics

- Process models
- Nonlinear reservoir runoff
- Sanitary flow
- Infiltration methods
 - Patterns and timeseries
 - Unit hydrographs
 - Groundwater modeling

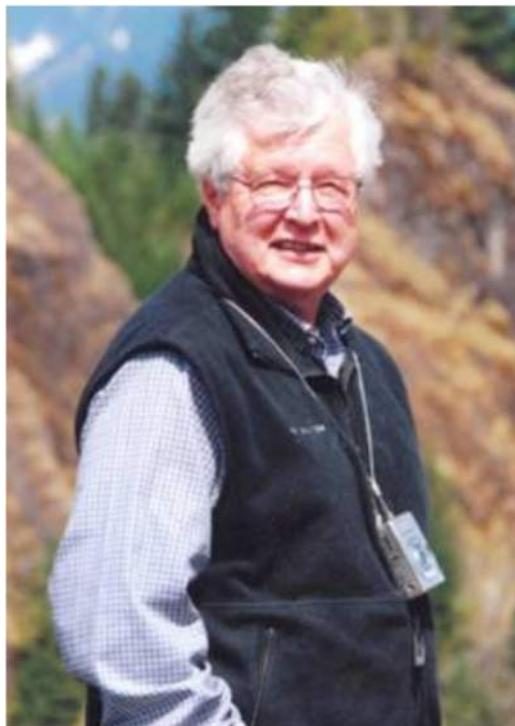


EPA-600/R-15/162A | January 2016 | www2.epa.gov/water-research
EPA-670/2-75-017-3
March 1975
Environmental Protection Technology Series

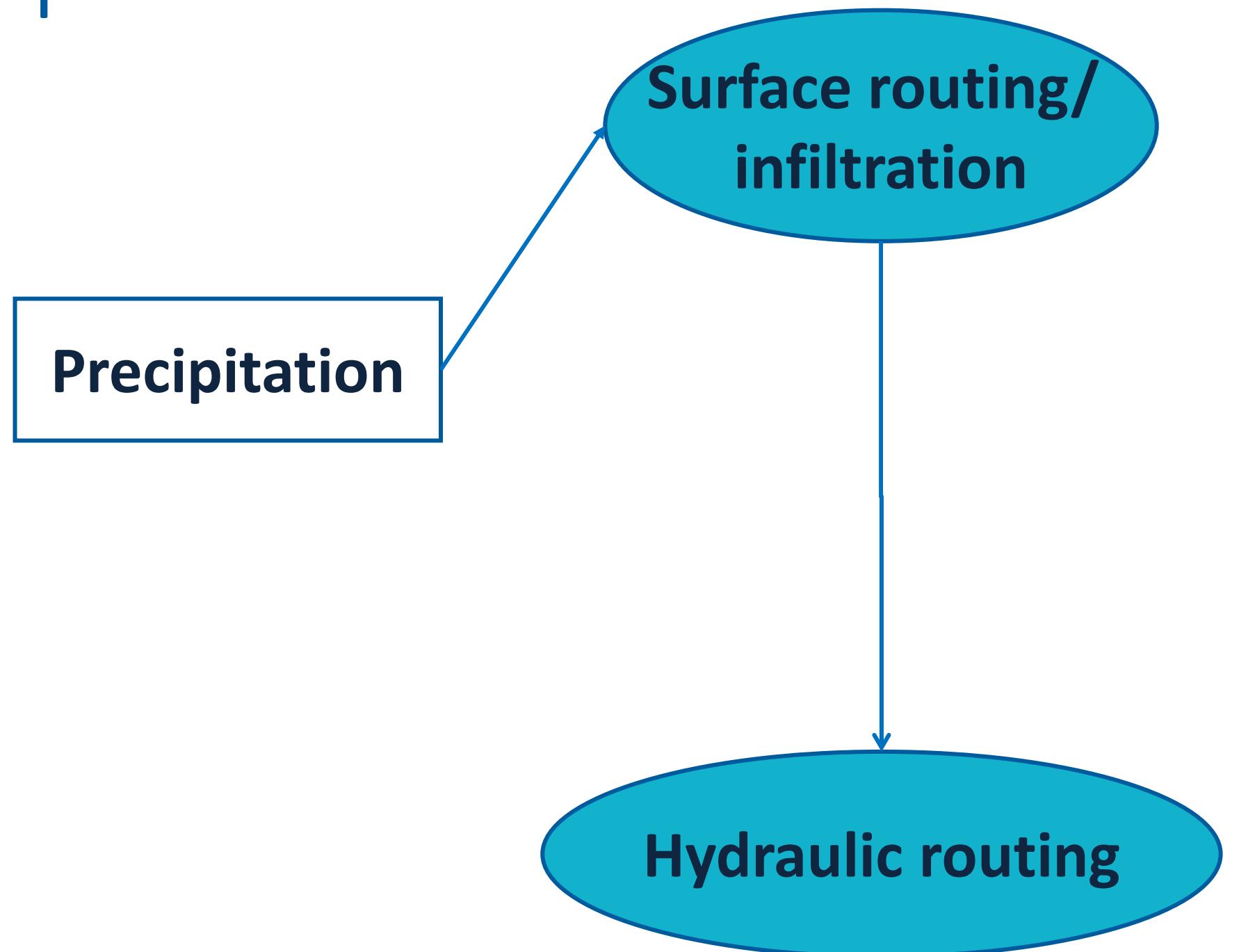


EPA Storm Water Management Model

- Dynamic urban rainfall-runoff simulation model
 - event or continuous simulation
 - runoff quantity and quality
- Runoff component operates on a collection of subcatchments that receive precipitation and generate runoff and pollutant loads
- Routing component conveys flow through pipes, channels, storage/treatment devices, pumps, and control structures
- During multiple time step simulation, model tracks:
 - quantity and quality of runoff within each subcatchment
 - discharge, depth, and quality of water in hydraulic elements



Typical processes

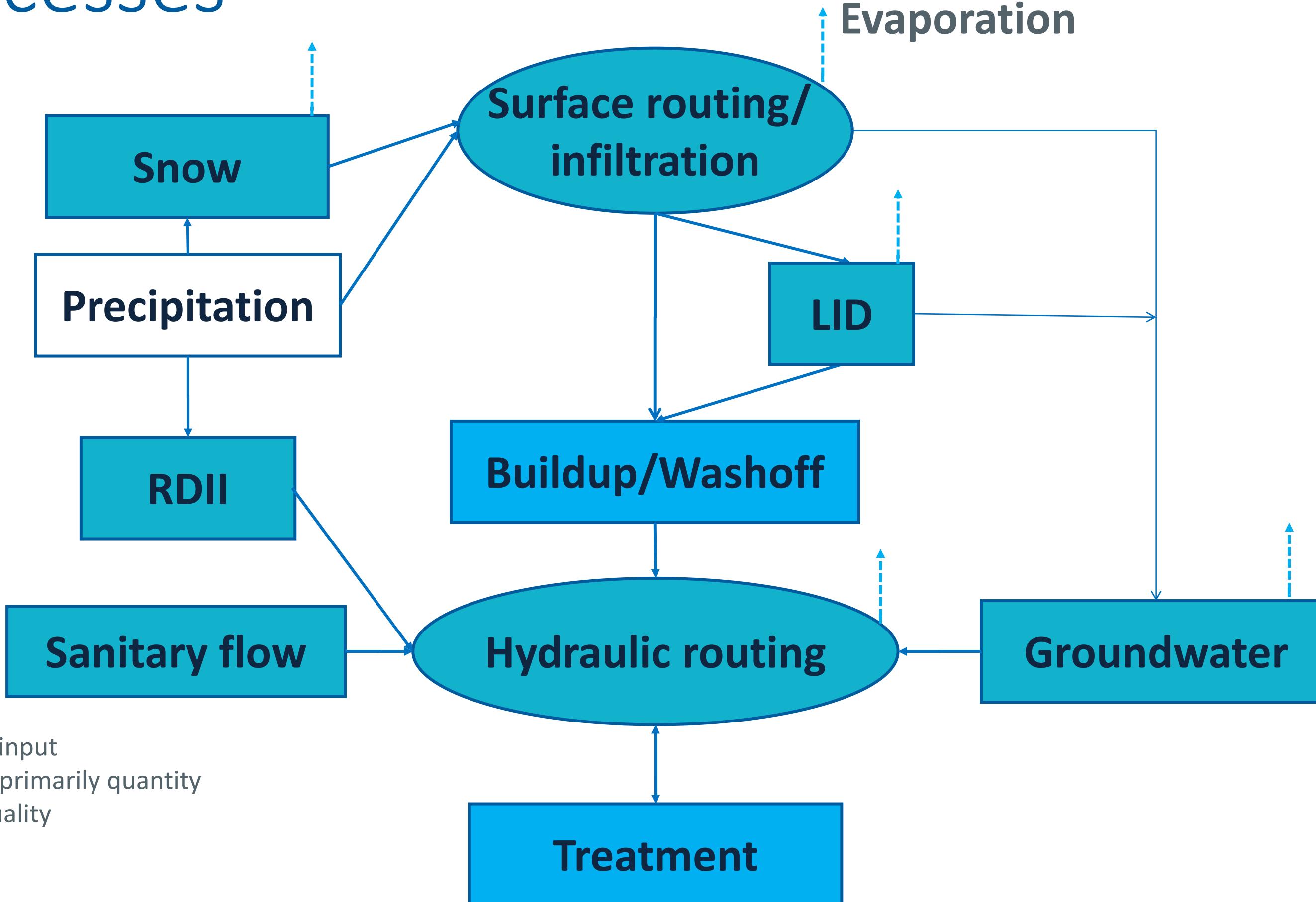


White – input

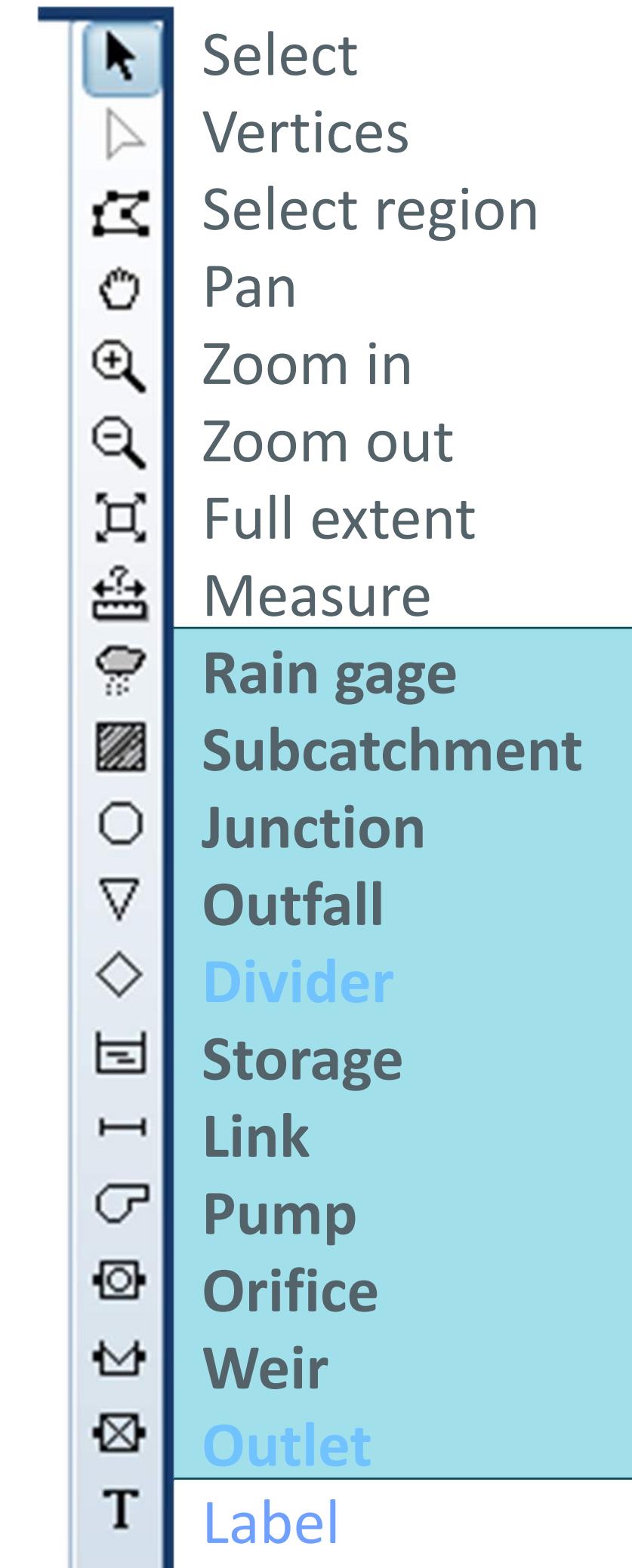
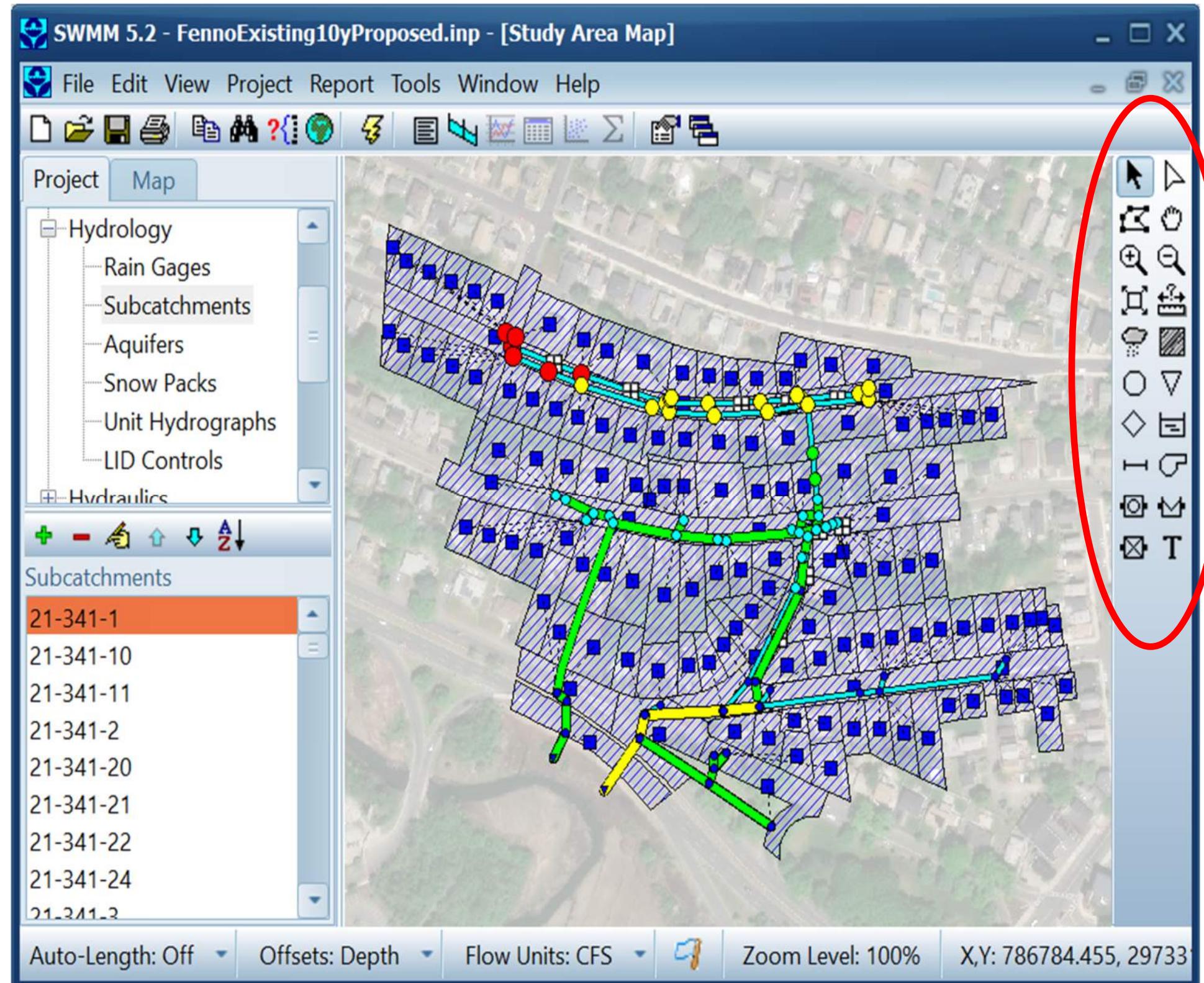
Green – primarily quantity

Blue - quality

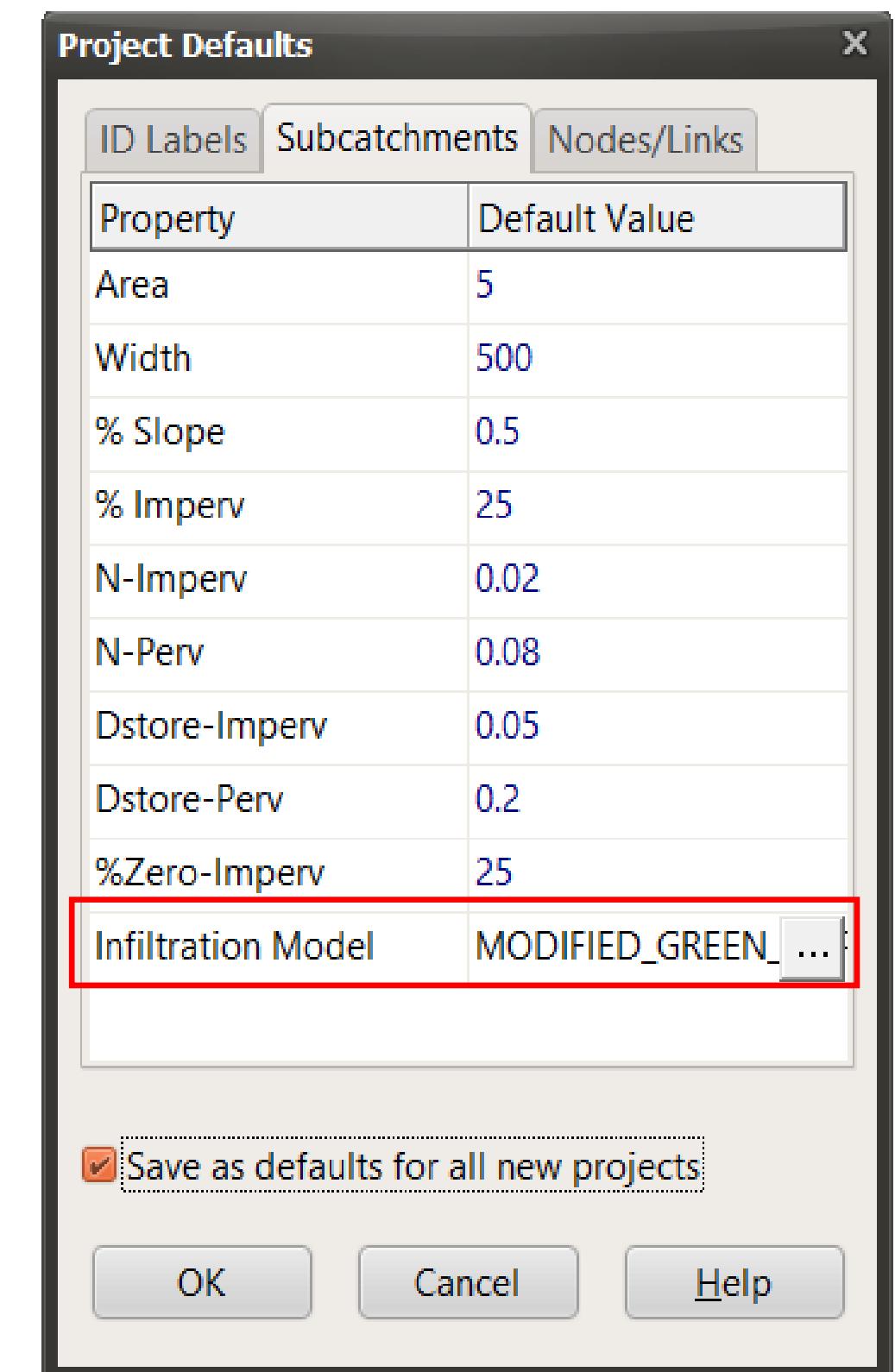
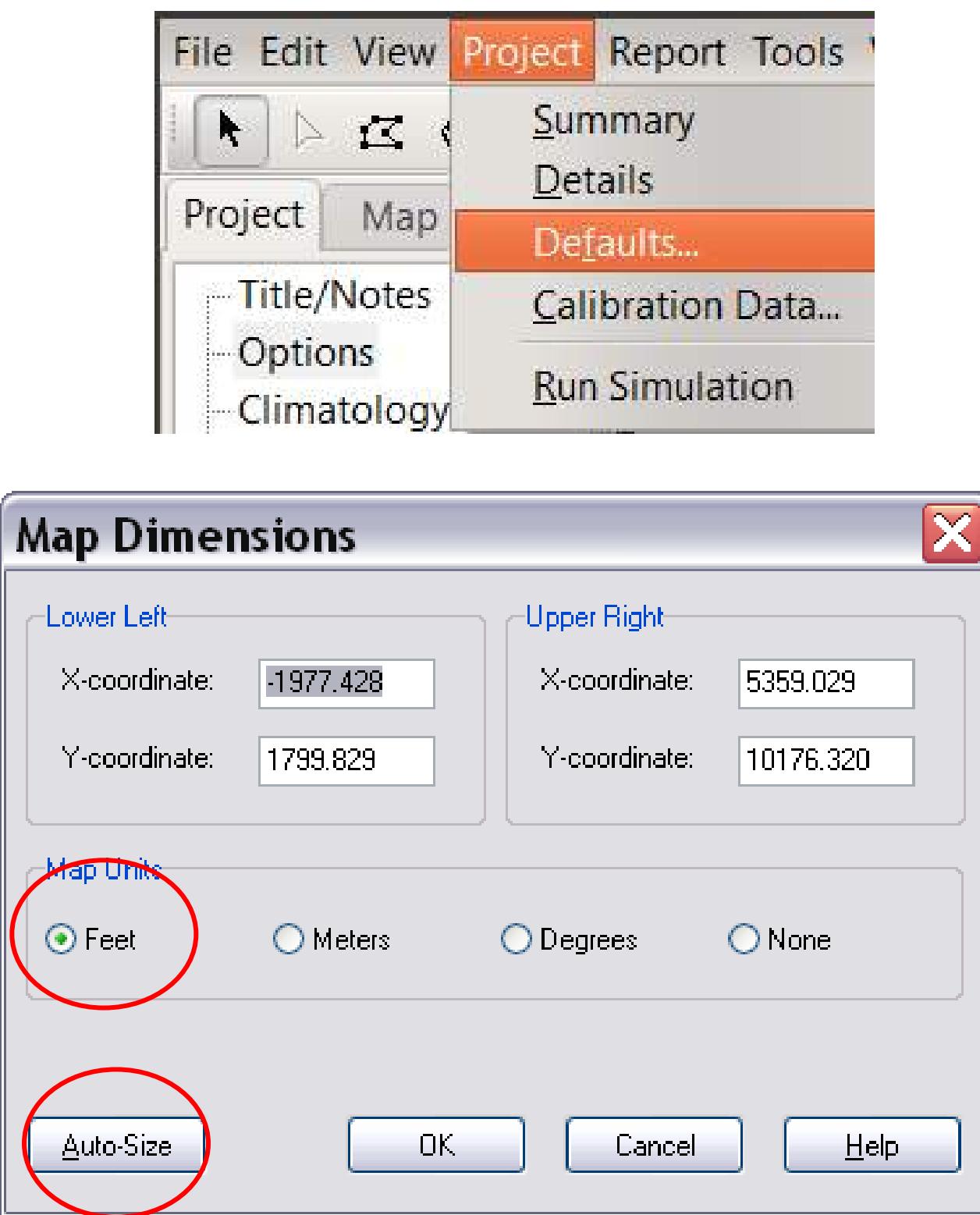
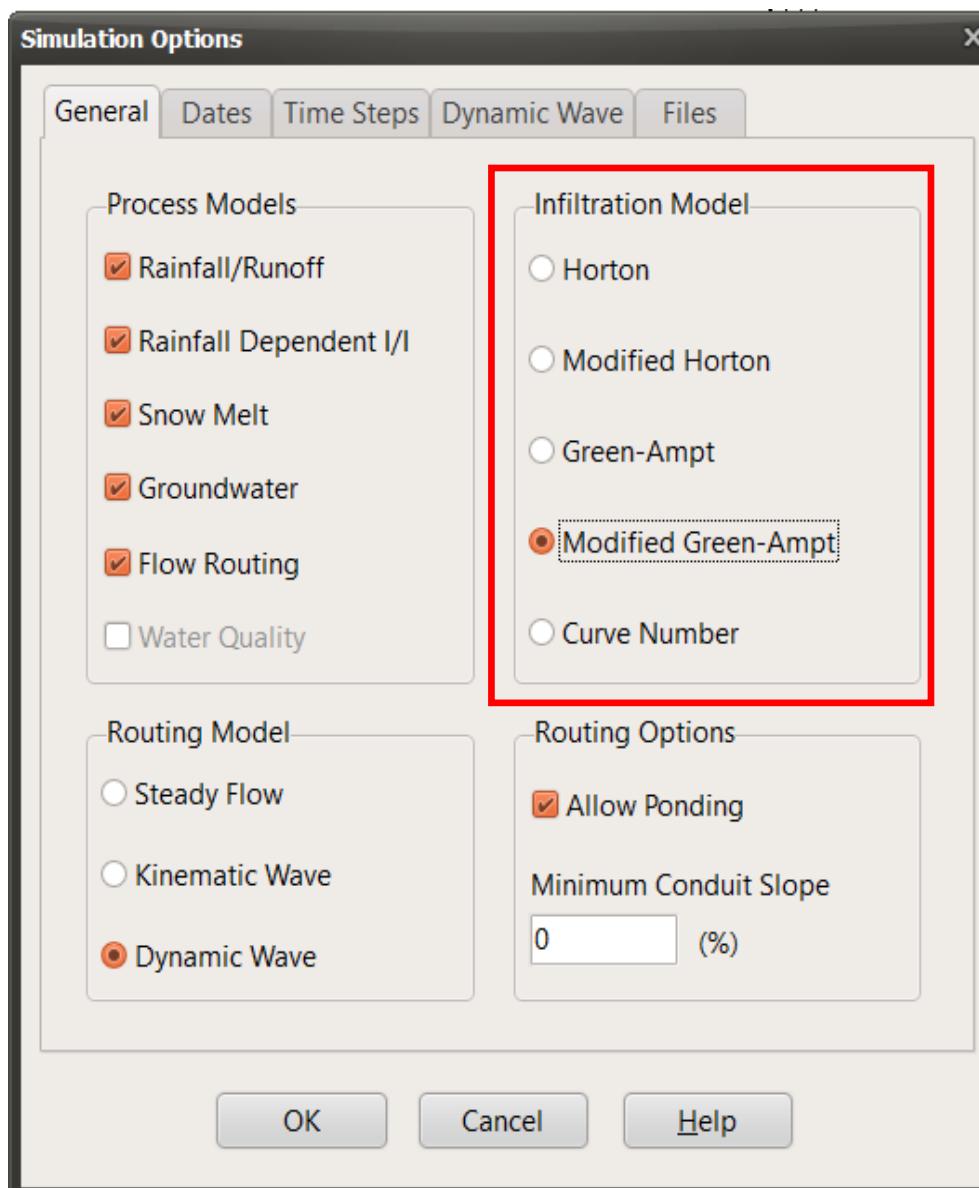
All processes



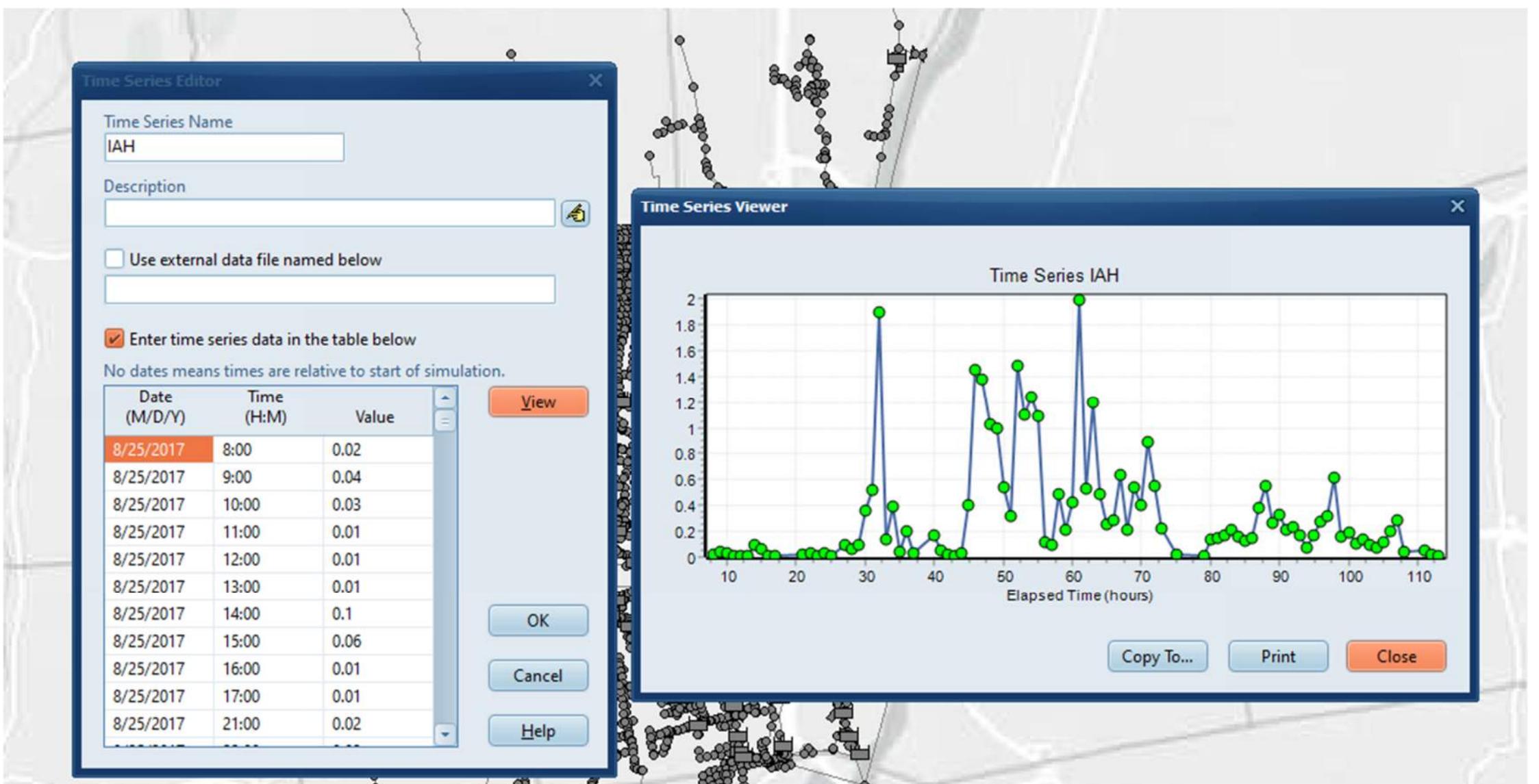
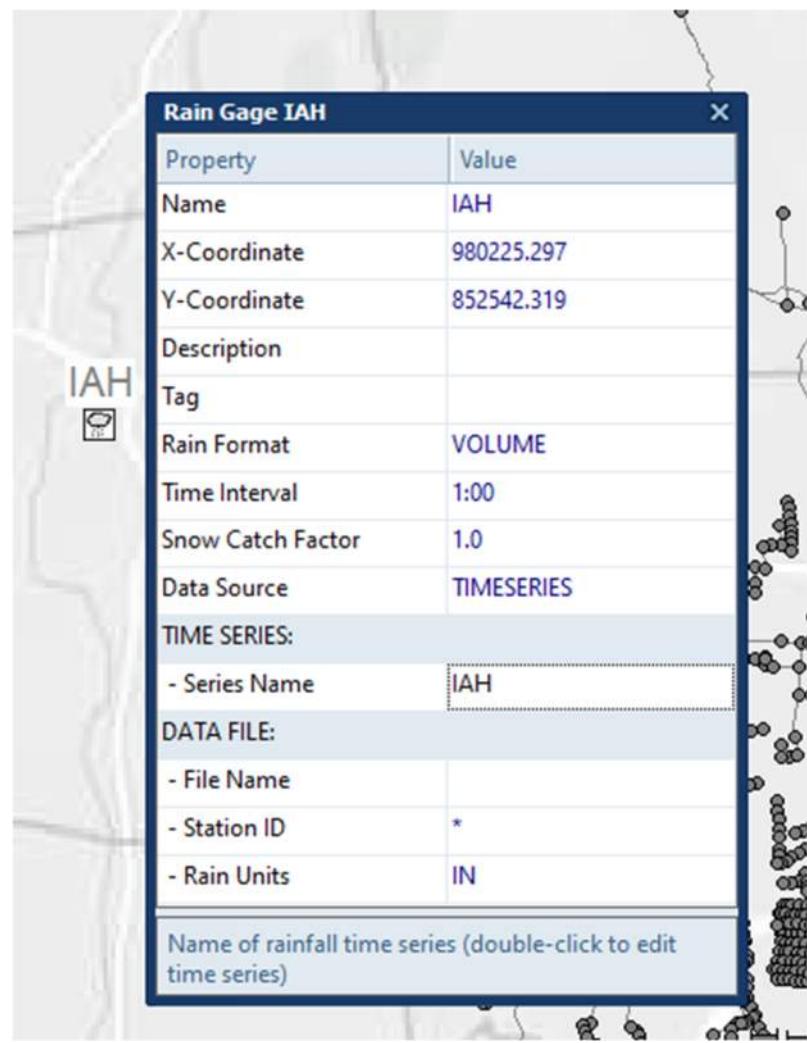
Object toolbar



Global settings and defaults



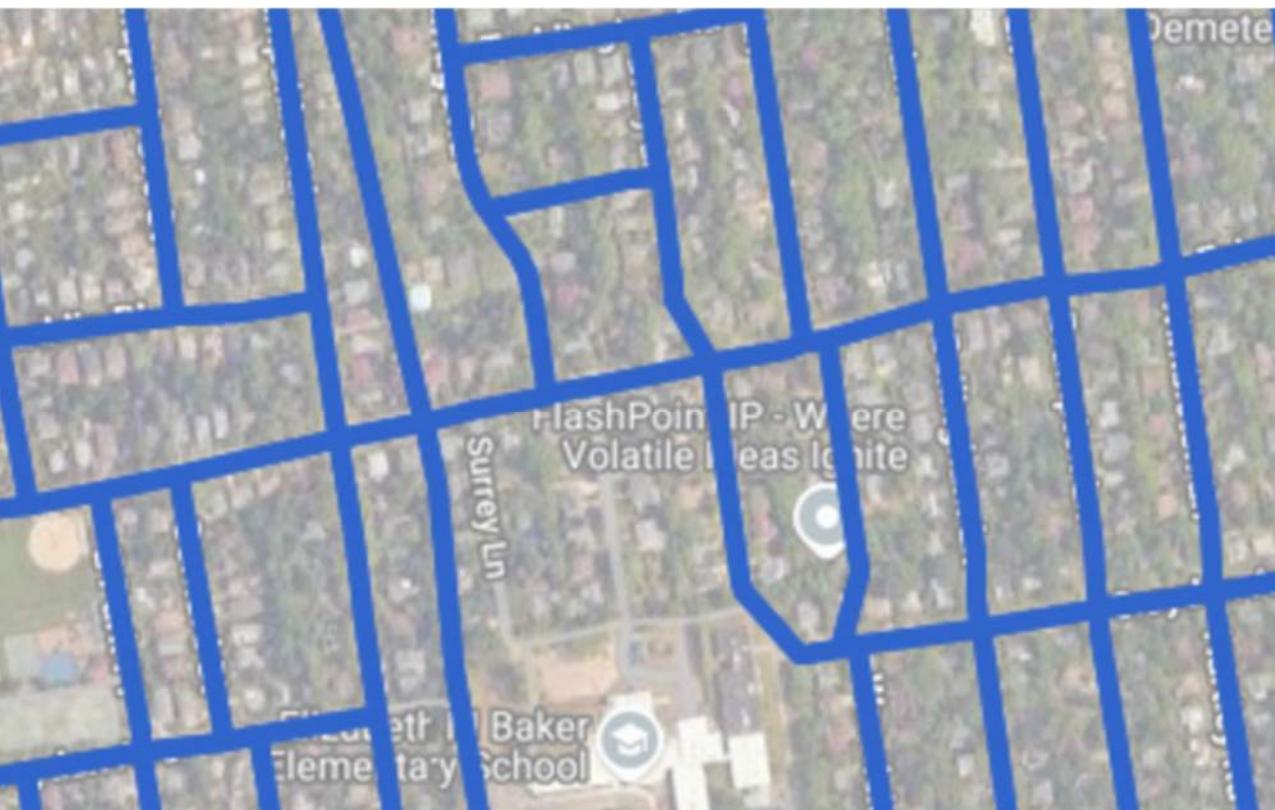
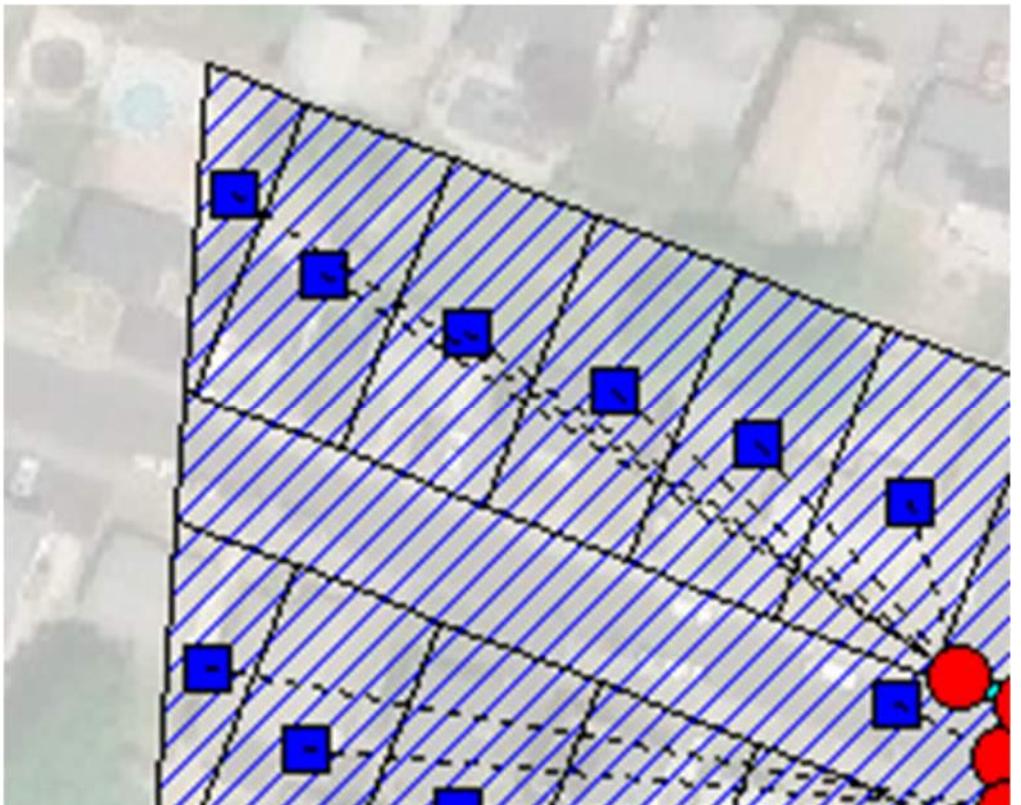
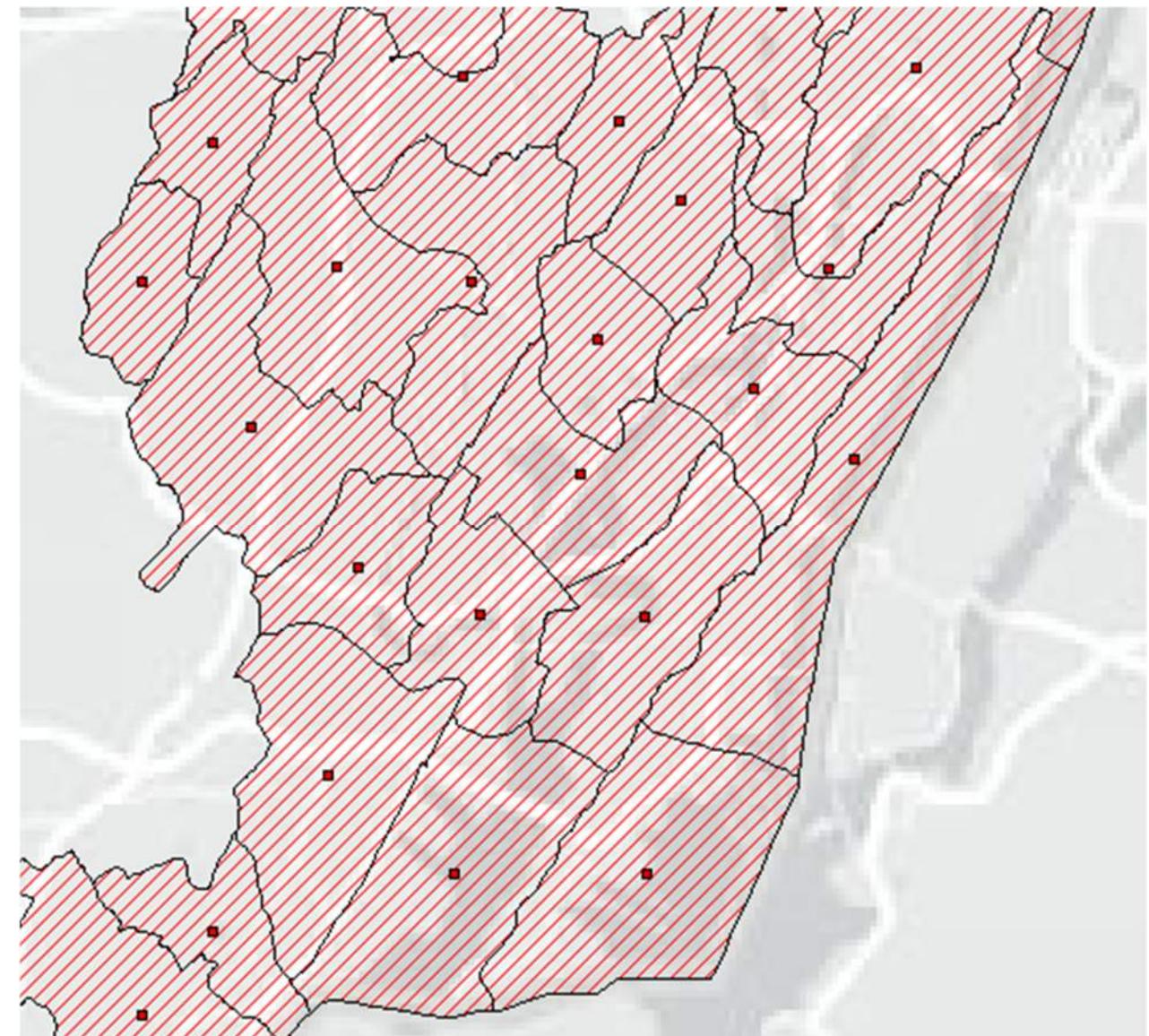
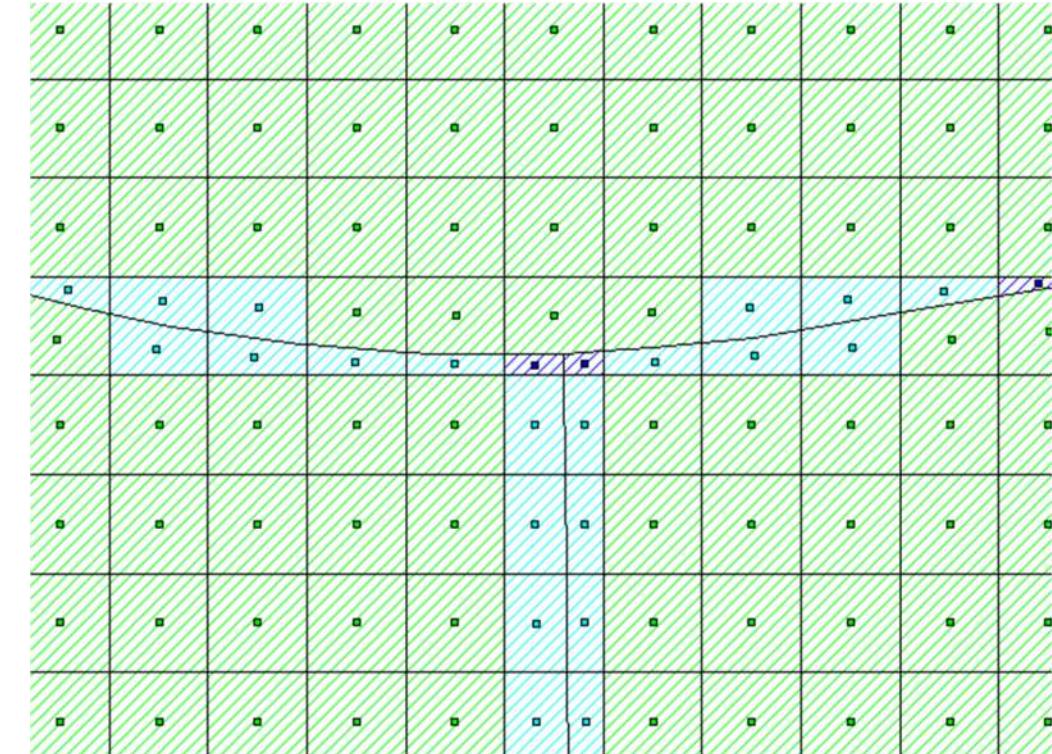
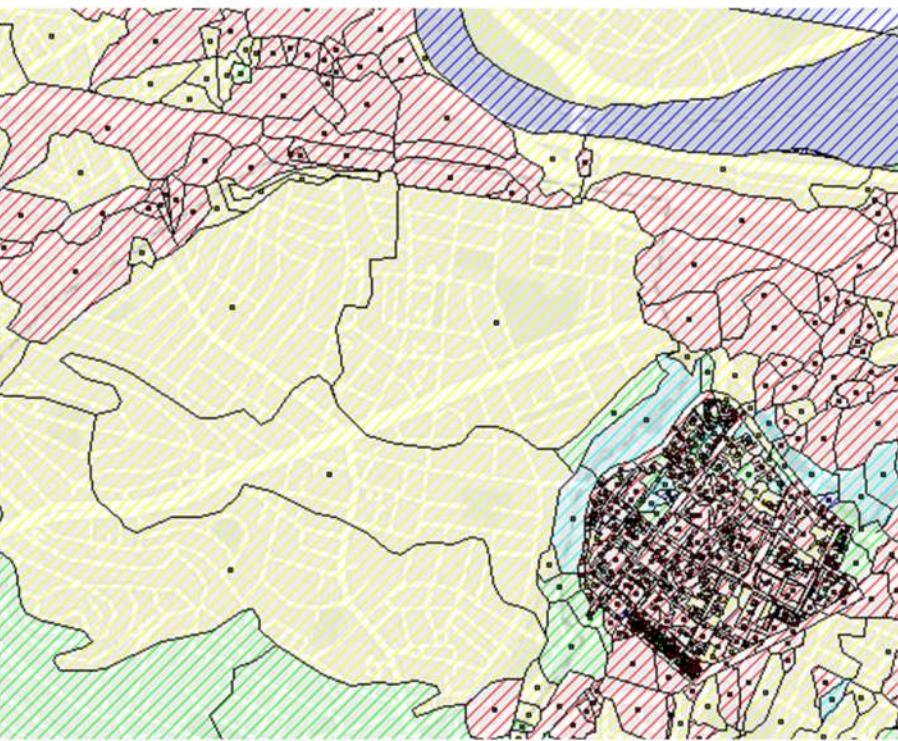
Rainfall data



```
[RAINGAGES]
;;Name      Format    Interval SCF      Source
;;-----
Bradley    VOLUME    0:05     1        FILE      "BDL5m.dat" BDL    IN
```

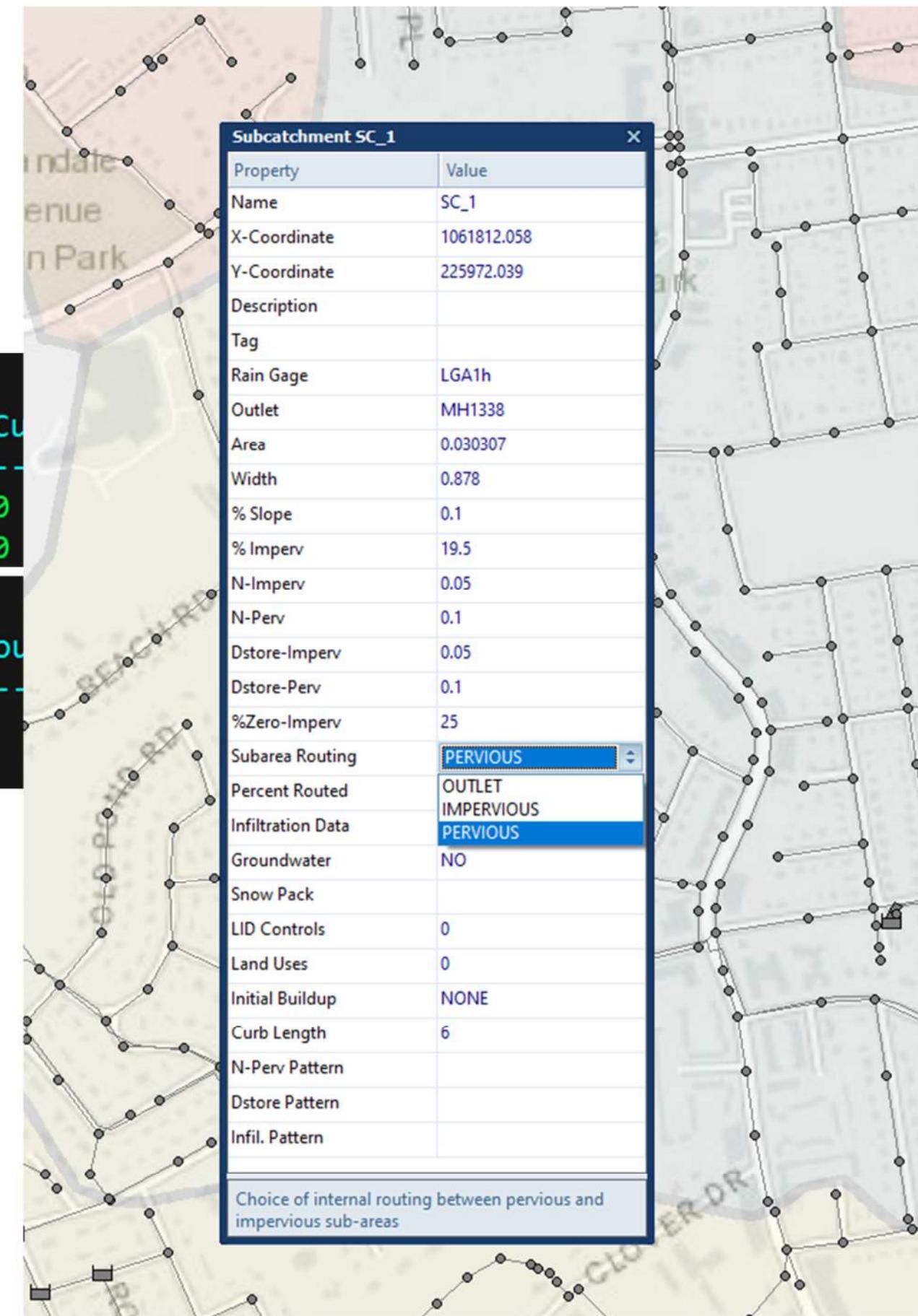
Subcatchments

- A subcatchment can be defined using
 - Any size grid cell (e.g., 10 m × 10 m)
 - Parcels
 - Thiessen polygons
 - Topographically-defined polygons
 - Census blocks
 - Watershed Boundary Dataset hydrologic units



Subcatchment dialog

[SUBCATCHMENTS]							
;;Name	Rain Gage	Outlet	Area	%Imperv	Width	%Slope	Cu
4401_01	MDC-RG-1	BASS10875	942	30	6278.4	0.1	0
4401_02	MDC-RG-1	BASS05154	409	30	4840.2	0.1	0
[SUBAREAS]							
;;Subcatchment	N-Imperv	N-Perv	S-Imperv	S-Perv	PctZero	RouteTo	PctRou
4401_01	0.02	0.2	0.05	0.2	25	PERVIOUS	25
4401_02	0.02	0.2	0.05	0.2	25	PERVIOUS	25
[INFILTRATION]							
;;Subcatchment	Param1	Param2	Param3	Param4	Param5		
4401_01	6.57	0.45	0.17	0	0		
4401_02	8.6	0.25	0.14	0	0		
4401_03	6.57	0.39	0.17	0	0		

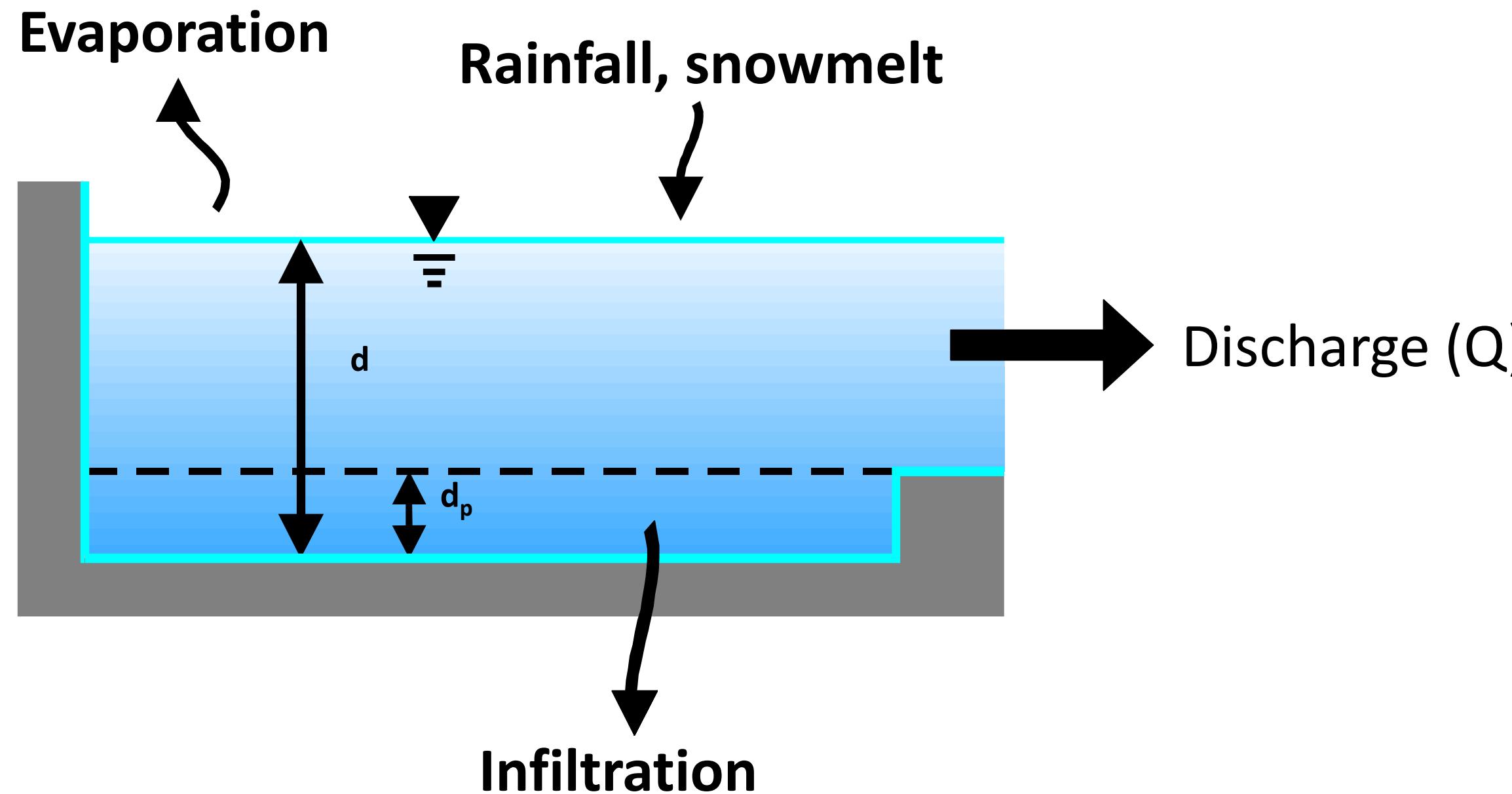


Nonlinear reservoir runoff

- Subcatchment area
- Volume parameters
 - Imperviousness
 - Subarea routing
 - Depression storage
 - Infiltration
- Shape parameters
 - Width
 - Slope
 - Roughness



Surface runoff calculation



SWMM conceptualizes a subcatchment as a rectangular surface that has a uniform slope S and a width W that drains to a single outlet channel (Hydrology manual Section 3.2)

Surface runoff calculation

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

Where:

Q = discharge (ft^3/s)

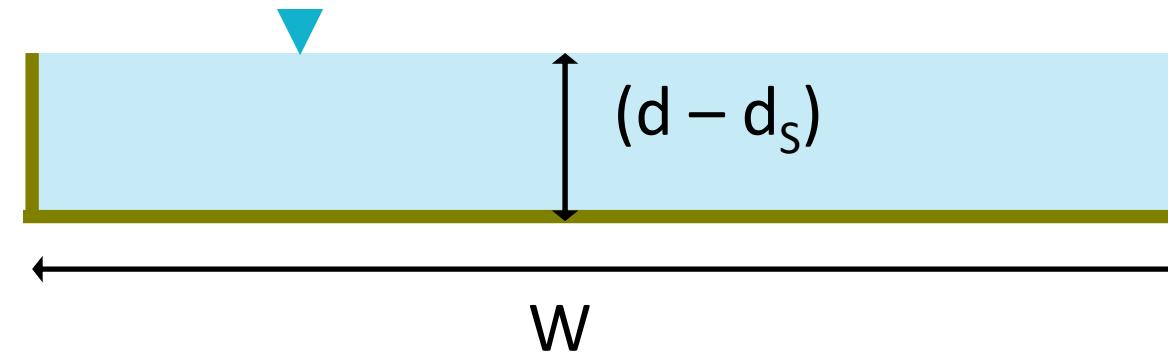
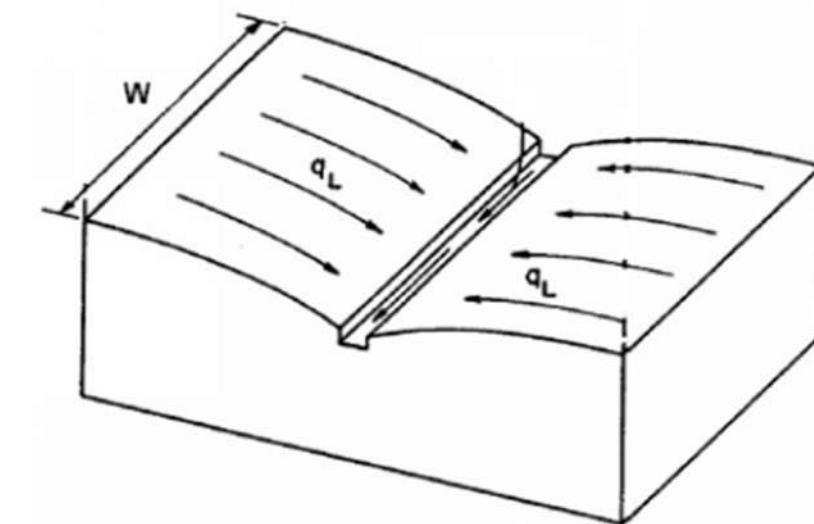
W = flow width (ft)

n = Manning's roughness coefficient

d = ponded depth = precipitation – evaporation – infiltration (ft)

d_s = depression storage (ft)

S = ground slope



Surface runoff calculation

- Constant

$$K = \frac{1.49}{n} W \sqrt{S}$$

- Volume

$$V_t = V_{t-1} - Q_{t-1} \Delta t + iA \Delta t$$

- Discharge

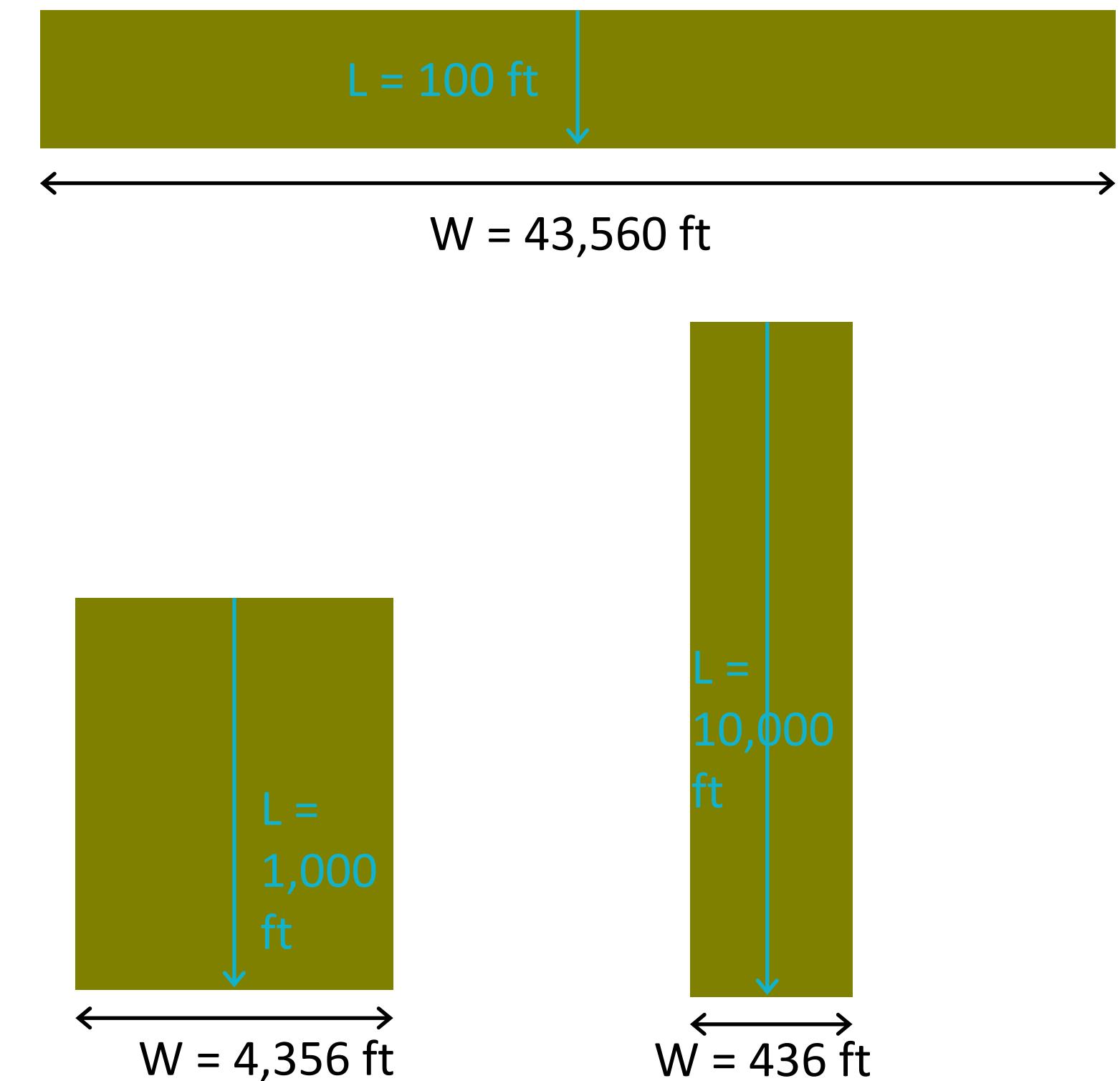
$$Q_t = K (d - d_s)^{5/3} = K \left(\frac{V_t}{A} \right)^{5/3}$$

Width estimation methods

Simple

- Area \div 200 ft typical overland flow length
- $250 A^{0.6}$ (Mitch's rule of thumb)
- Curb length
- $2 \times$ main drainage channel length
- Area \div mean overland flow length
- Guo and Urbonas (Denver UDFCD/MHFD) method

Complex



Guo and Urbonas skew method

- $Y = 2X(1.5 - Z)(2K - X)/(2K - 1)$
- $W = YL$
- where
 - L = main drainage channel length
 - $X = A/L^2$
 - A_m = larger area to one side of main drainage channel
 - $Z = A_m/A$ (skew factor between 0.5 and 1)
 - K : watershed shape factor between 4 and 6 (4 for Denver)

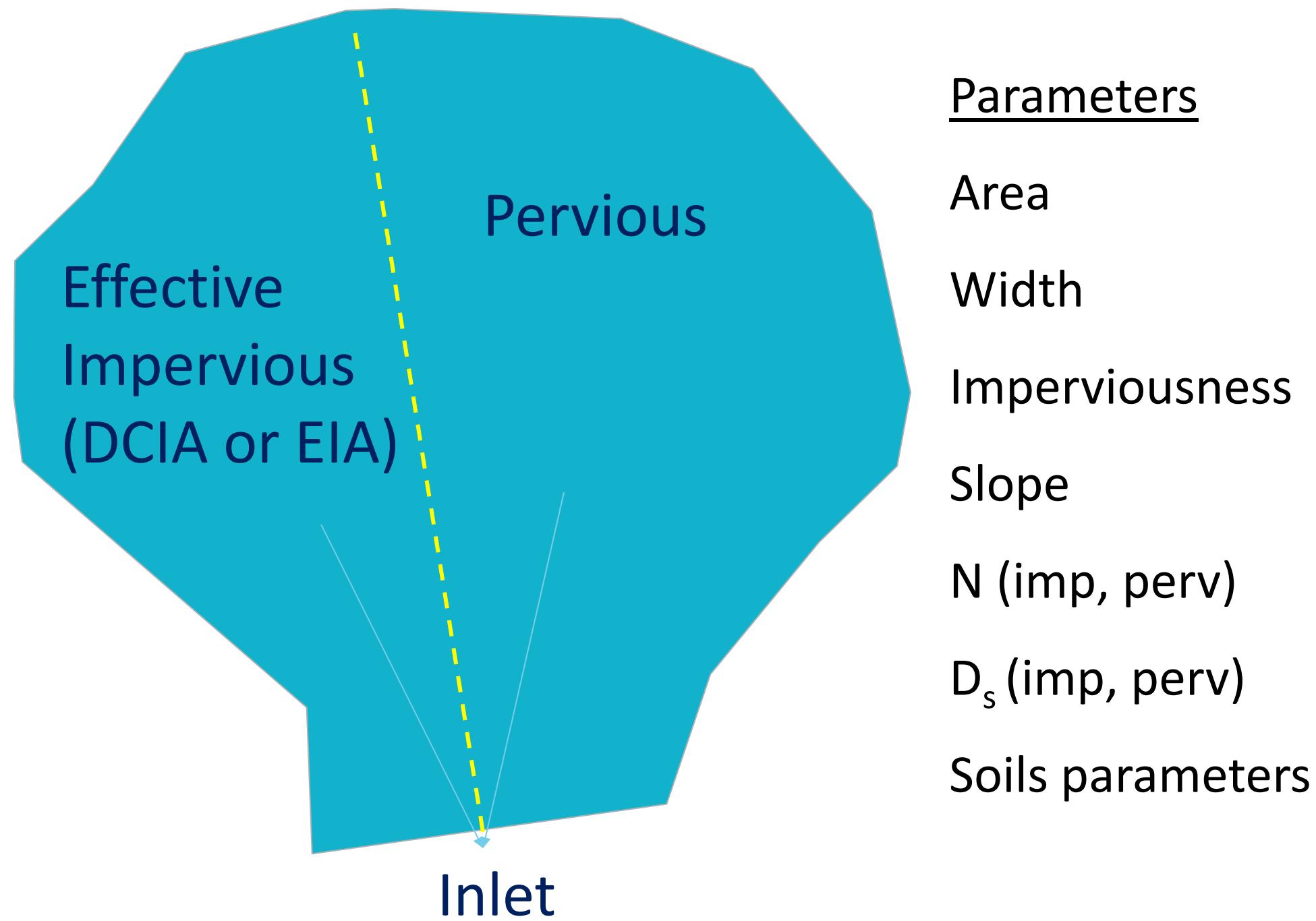
Example width calculation for 1.67 acres

- Denver UDFCD method
- $Y = 2X(1.5 - Z)(2K - X) / (2K - 1)$
- $W = YL$
- $X = A/L^2$
- $Z = A_m/A$
- $K = 4$
- $L = 360 \text{ ft}$
- $X = 43560 * 1.67 / 360^2 = 0.56$
- $A_m = 1.19 \text{ ac}$
- $Z = 1.19 / 1.67 = 0.71$
- $Y = 2x0.56(1.5-0.71)(2*4-0.56)/(2x4-1) = 0.94$
- $W = 0.94 \times 360 = 338 \text{ ft}$
- Twice main drainage channel
- $L = 360 \text{ ft}$
- $W = 2 \times 360 = 720 \text{ ft}$
- 200-foot overland flow
- $W = 1.67 \text{ ac} / 200 \text{ ft} = 364 \text{ ft}$
- Mitch's rule of thumb
- $W = 250 A^{0.6}$
- $W = 250 (1.67)^{0.6} = 340 \text{ ft}$

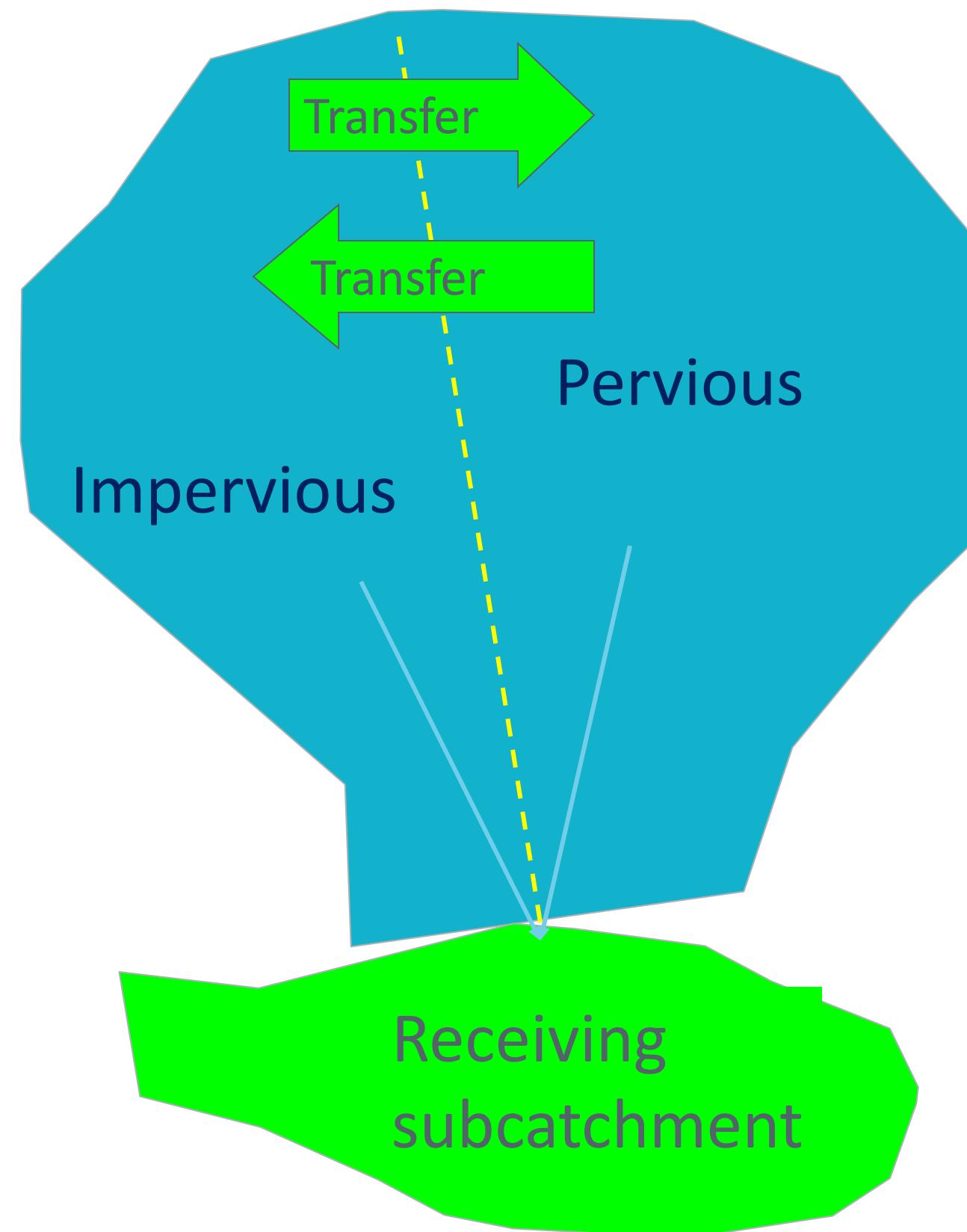
Width parameter summary

- Controls hydrograph shape
- Key calibration term
- Accounts for overland flow as well as omitted shallow channel and conduit flow
- Area ÷ overland flow length alone can yield too sharp a hydrograph

Subcatchment routing – traditional approach



Subcatchment routing options

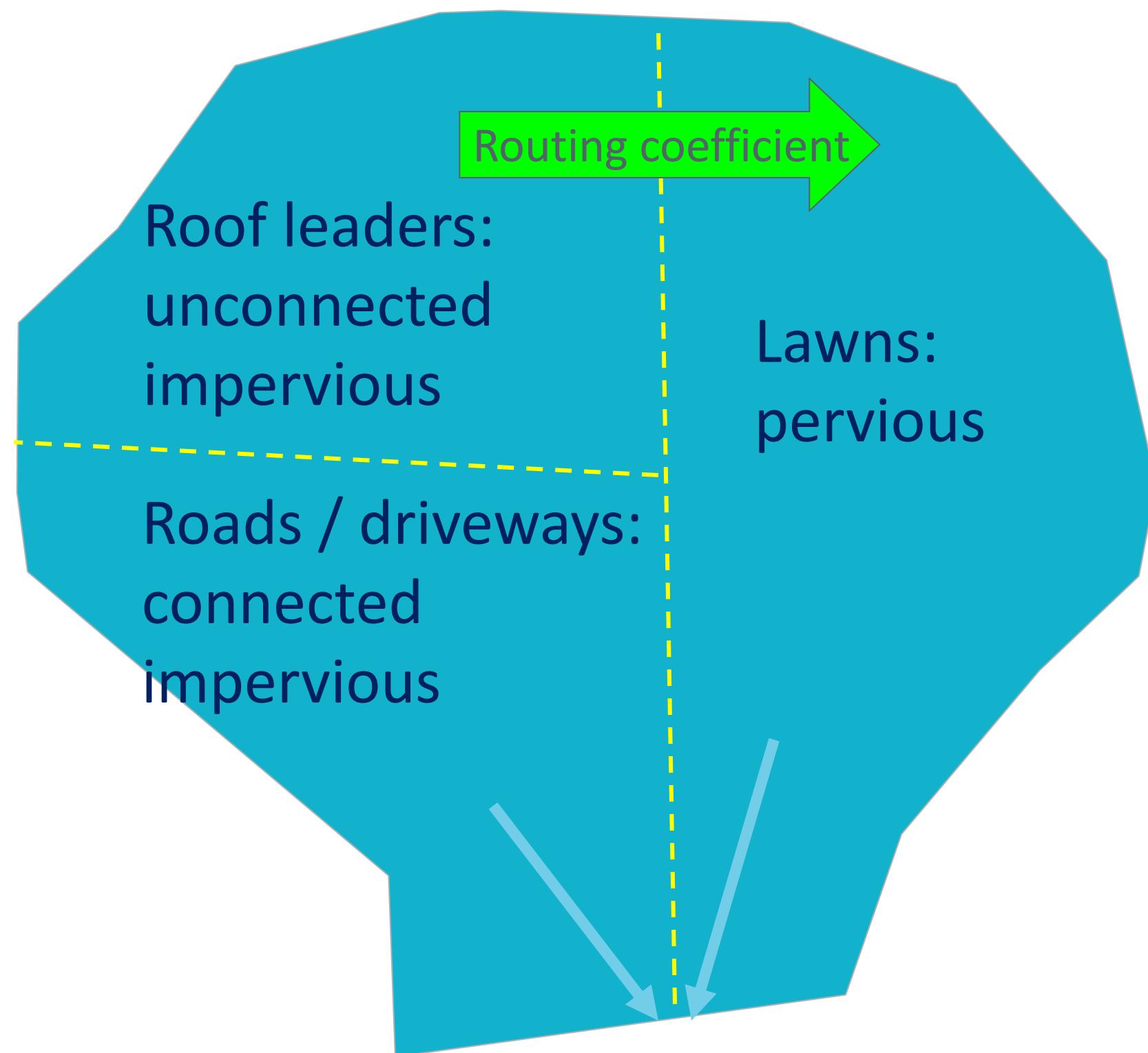


Optional Parameters

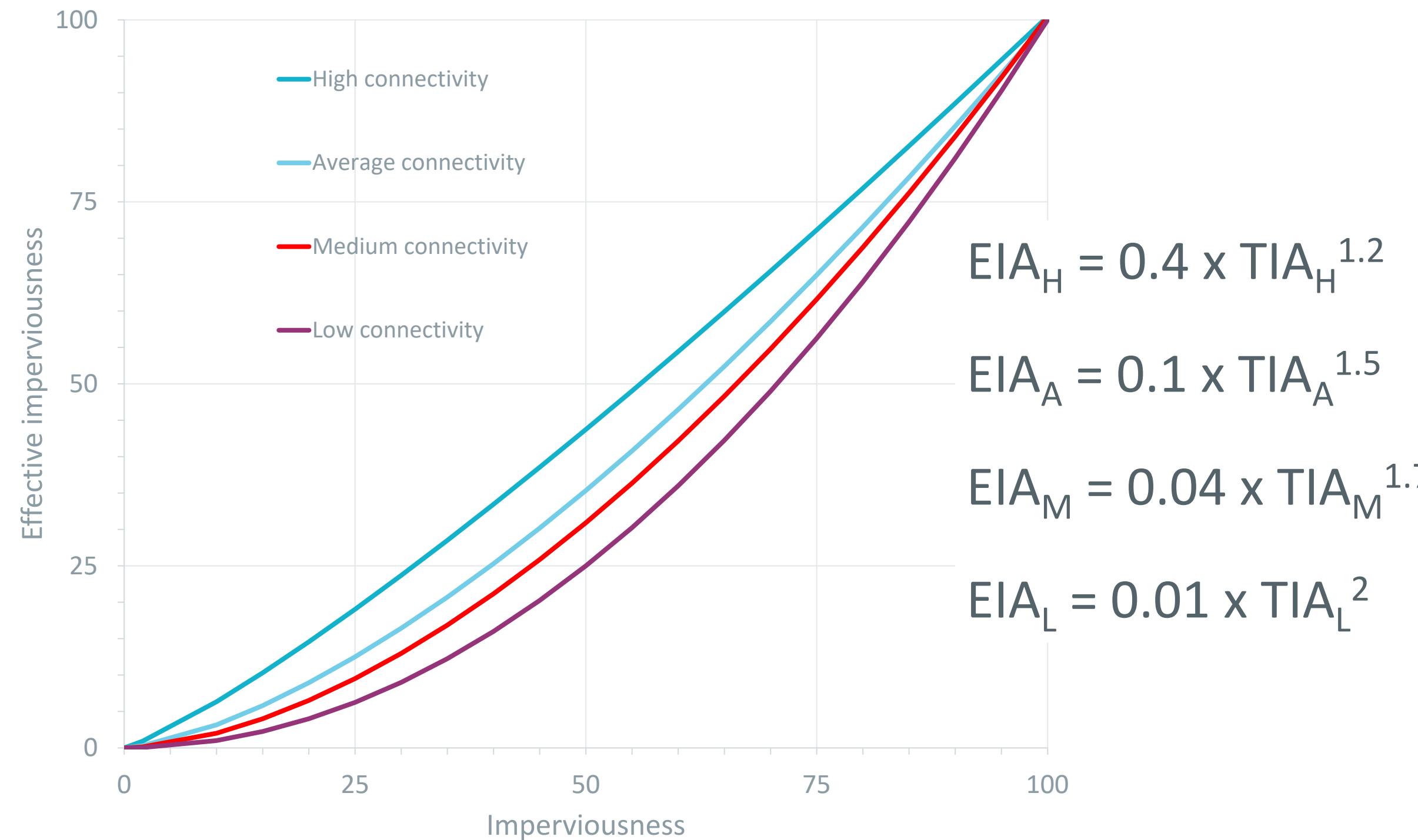
Internal transfer direction

Internal transfer fraction

Urban routing paradigm

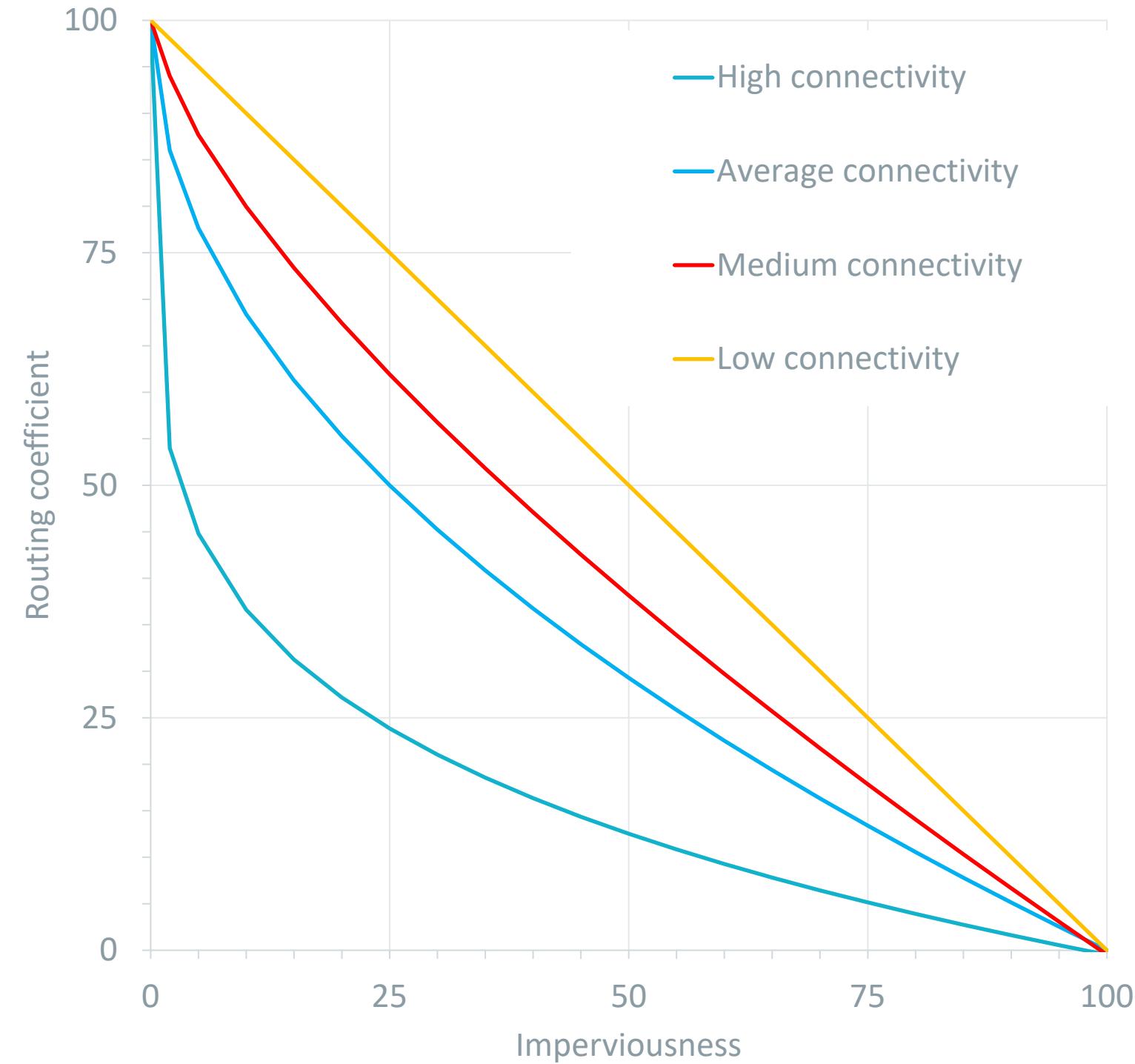


Total and effective imperviousness



SWMM hydrology manual Section 3.8.3

Routing coefficient using Sutherland equations



Routing coefficient for
low connectivity
condition:

$$R = 100 - TIA$$

Pervious area infiltration equations

- Green-Ampt / Modified Green-Ampt
- Horton / Modified Horton
- NRCS (SCS)

$$f_p = k_s \left(1 + \frac{S_\theta \theta_t}{F_t} \right)$$

$$f_p = f_c + (f_0 - f_c) e^{-kt}$$

Horton infiltration

$$f_p = f_c + (f_0 - f_c) e^{-kt}$$

f_p = infiltration capacity (in/hr)

f_c = minimum infiltration (in/hr)

f_0 = initial infiltration (in/hr)

k = decay coefficient (s^{-1})

t = time since beginning of storm (s)

Green-Ampt infiltration

$$f_p = k_s \left(1 + \frac{S_\theta \theta_t}{F_t} \right)$$

f_p = infiltration capacity, (in/hr)

k_s = saturated hydraulic conductivity (in/hr)

S_θ = capillary suction (in)

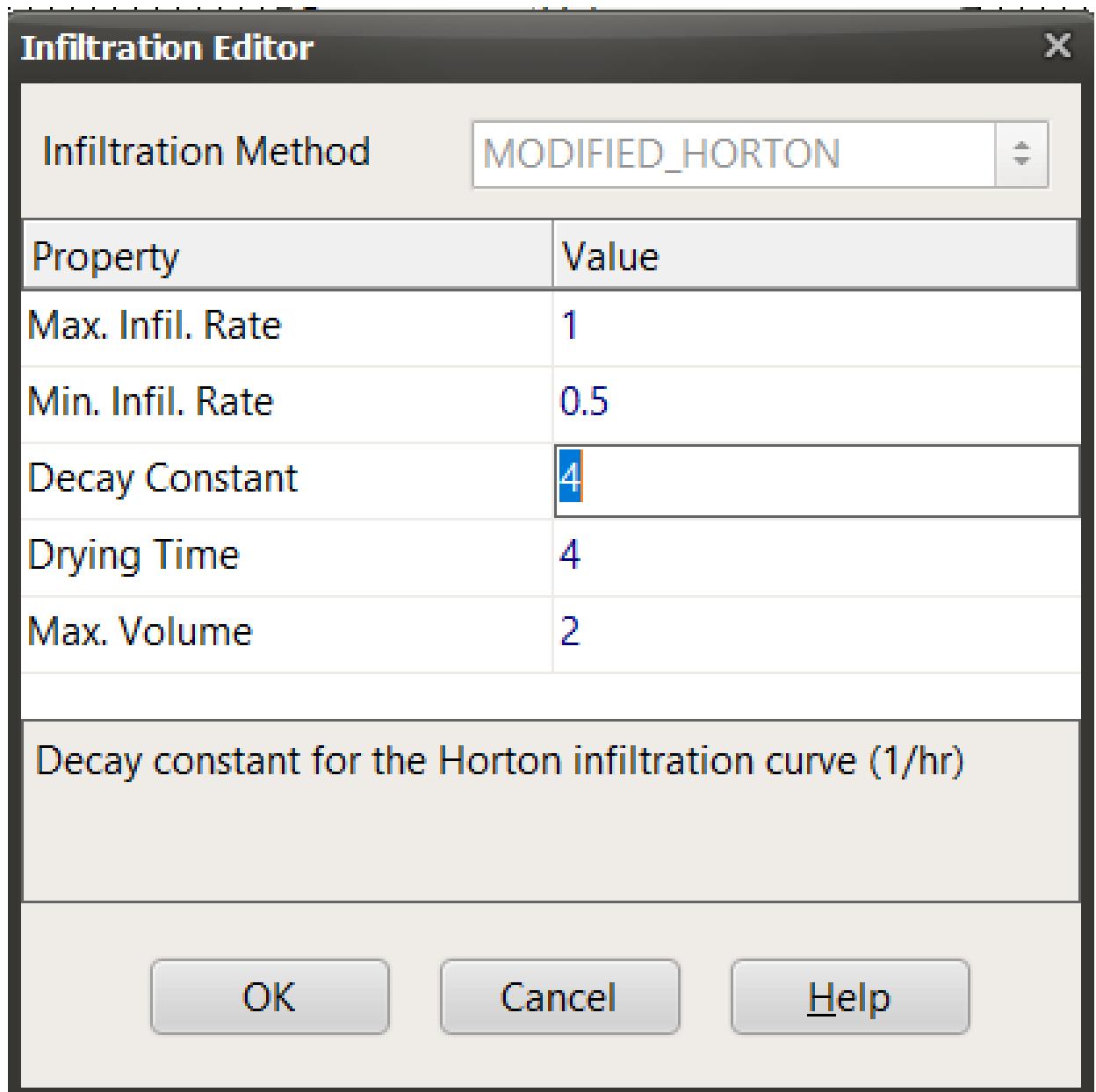
θ_t = initial moisture deficit

F = cumulative infiltration volume (in)

Sample Green-Ampt parameters

Soil class	Suction	Conductivity	Initial Deficit
Sand	1.95	4.74	0.34
Loamy sand	2.41	1.18	
Sandy loam	4.33	0.43	0.33
Loam	3.50	0.13	0.31
Silt loam	6.57	0.26	0.32
Sandy clay loam	8.60	0.06	
Clay loam	8.22	0.04	0.24
Silty clay loam	10.75	0.04	
Sandy clay	9.41	0.02	
Silty clay	11.50	0.02	
Clay	12.45	0.01	0.21

Infiltration dialog



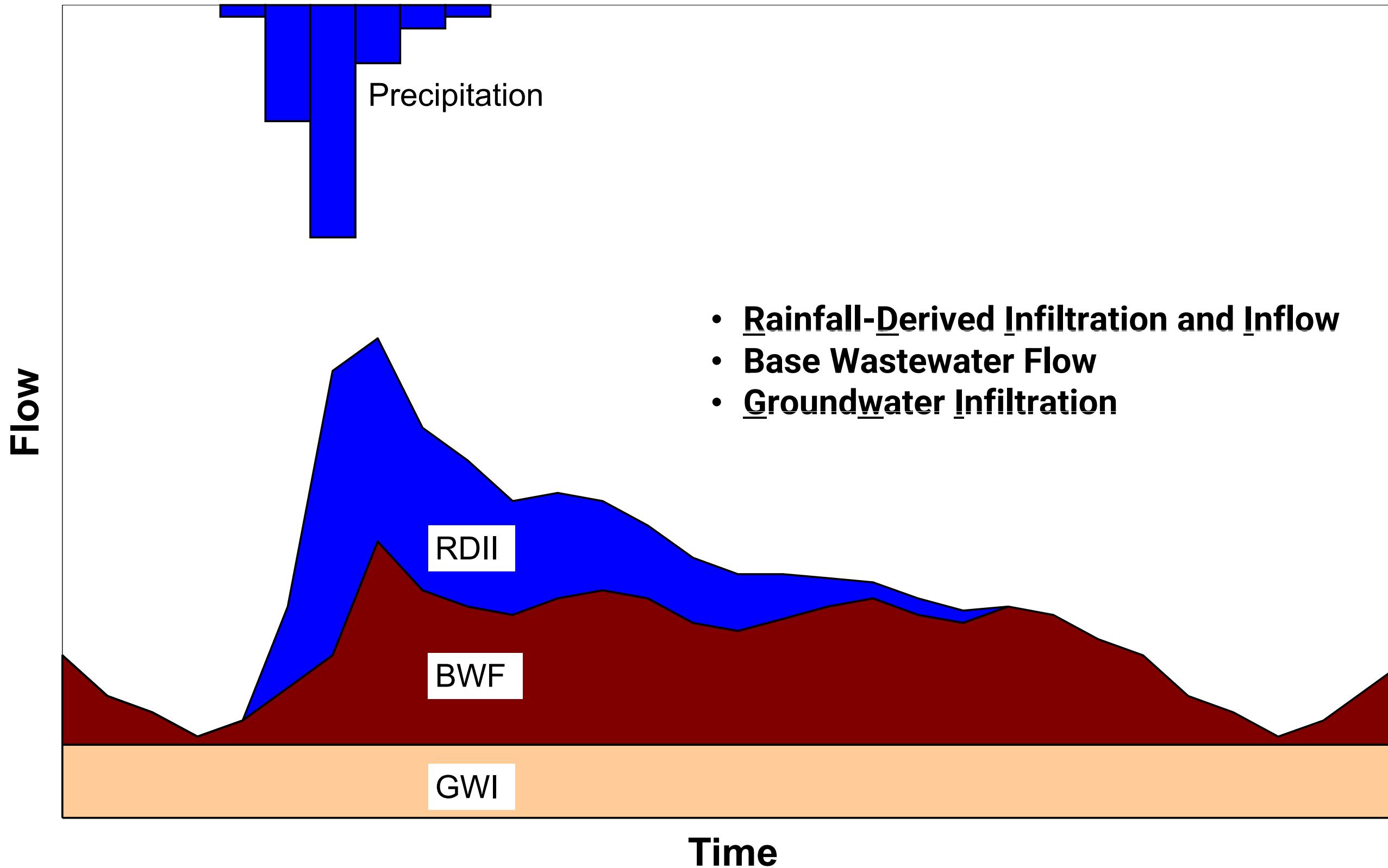
Infiltration Editor	
Infiltration Method MODIFIED_GREEN_AMPT	
Property	Value
Suction Head	7
Conductivity	1
Initial Deficit	0.25

Infiltration Editor	
Infiltration Method CURVE_NUMBER	
Property	Value
Curve Number	92
Conductivity	0.3
Drying Time	7

```
[INFILTRATION]
;;Subcatchment Param1 Param2 Param3 Param4 Param5
;;----- -----
4401_01      6.57   0.45   0.17    0     0
4401_02      8.6    0.25   0.14    0     0
4401_03      6.57   0.33   0.17    0     0
```

This property has been deprecated and its value is ignored.

Sewer flow components



Sanitary flow

[DWF]

;	;	Average	Time
;	Node	Parameter	Value
;	SITE4	FLOW	680
			"H1" "d4" "m4"

[PATTERNS]

;	Name	Type	Multipliers					
;								
H1		HOURLY	1.01	0.85	0.69	0.62	0.55	0.5
H1			0.55	0.72	0.95	1.16	1.25	1.45
H1			1.25	1.1	1.0	1.1	1.13	1.2
H1			1.3	1.45	1.3	1.2	1.10	1.05
d4		DAILY	1.10	0.96	0.90	0.91	0.95	1.02
m4		MONTHLY	0.88	0.89	0.99	1.14	1.19	1.24
m4			1.30	1.30	0.96	0.85	0.63	0.67

Per capita sanitary flow paradigm

Inflows for Node GIS2002947

Direct Dry Weather RDII

Inflow = (Average Value) x (Pattern 1) x
 (Pattern 2) x (Pattern 3) x (Pattern 4)

Constituent	FLOW
Average Value (MGD)	5500
Time Patterns	90_GPCD SystemwideHourly

If Average Value is left blank its value is 0. Any Time Pattern left blank defaults to a constant value of 1.0.

OK Cancel Help

Time Pattern Editor

Name: 90_GPCD Type: DAILY

Description: 90 Gal/day/capita

Multipliers	
Sun	90e-6
Mon	90e-6
Tue	90e-6
Wed	90e-6
Thu	90e-6
Fri	90e-6
Sat	90e-6

OK Cancel Help

Time Pattern Editor

Name: SystemwideHourly Type: HOURLY

Description: Nine existing hourly patterns were replaced

Multipliers	
12 AM	0.66
1 AM	0.53
2 AM	0.48
3 AM	0.47
4 AM	0.56
5 AM	0.77
6 AM	1.02
7 AM	1.19

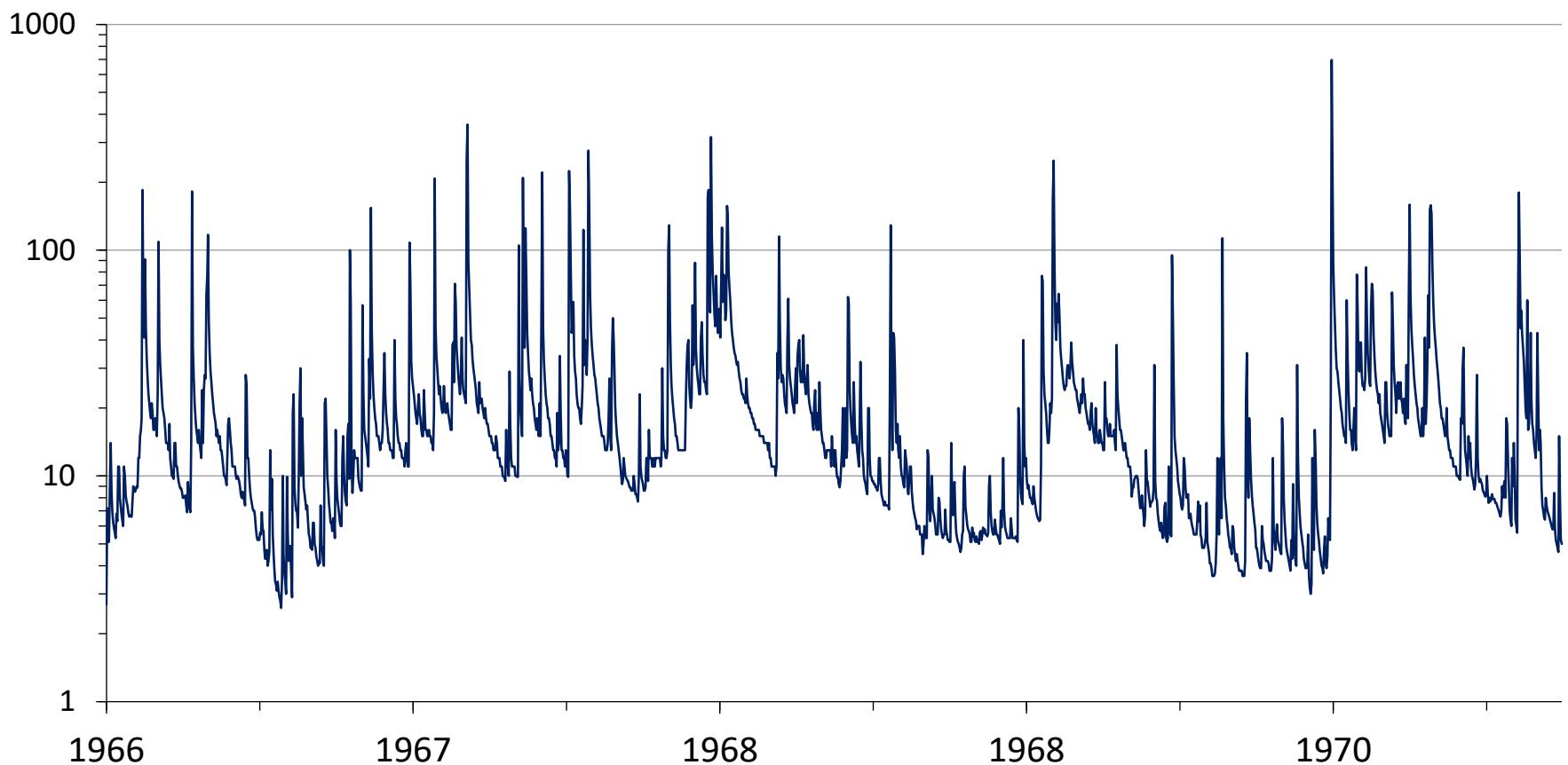
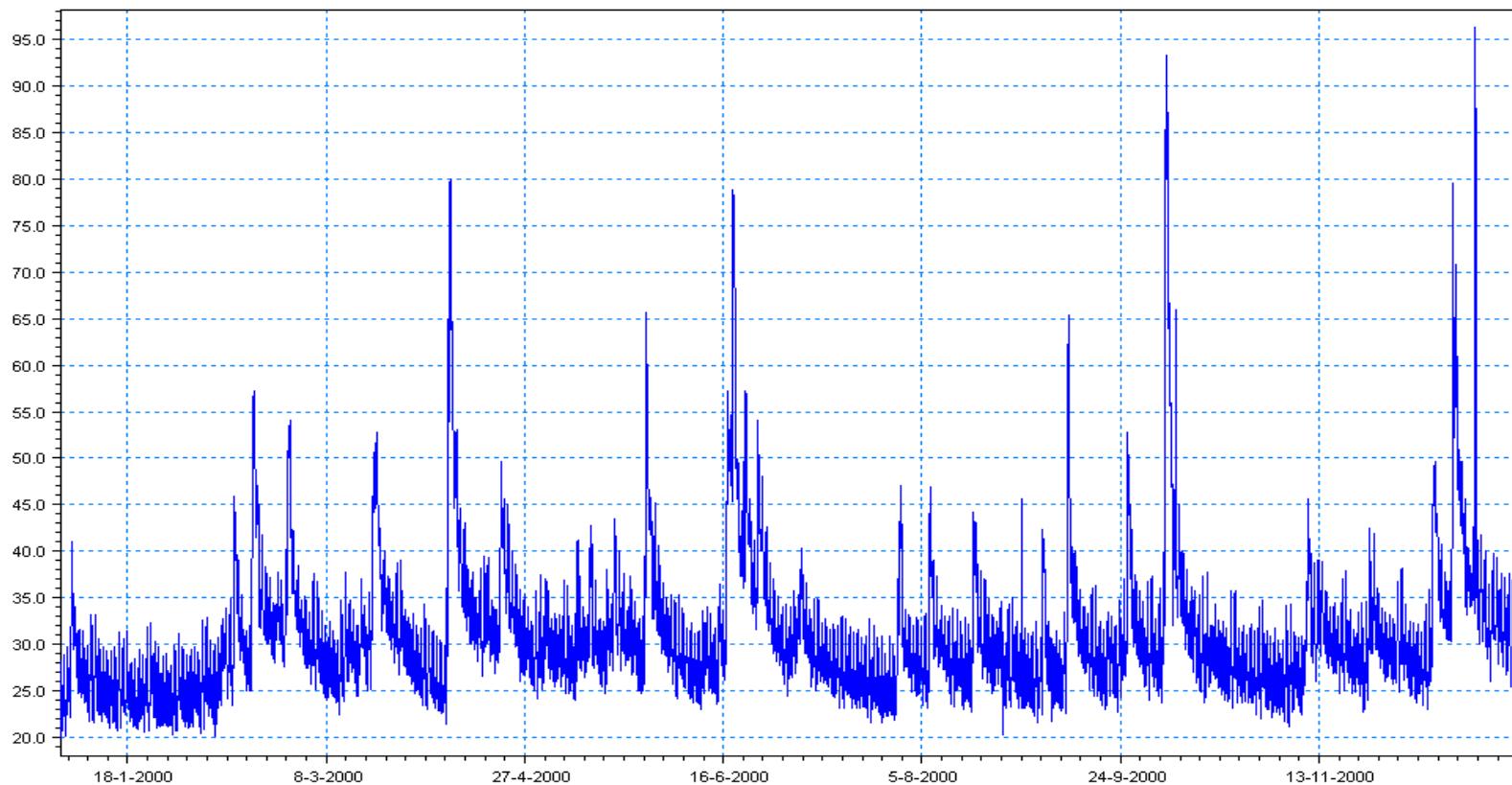
OK Cancel Help

```
[DWF]
;;Node          Constituent   Baseline   Patterns
;;-----
GIS2002947     FLOW         5500       "90_GPCD" "SystemwideHourly"   ""   ""
CDM140          FLOW         95        "90_GPCD" "SystemwideHourly"   ""   ""

[PATTERNS]
;;Name          Type      Multipliers
;;-----
;75 gallons per capita per day
75_GPCD        DAILY     75e-6   75e-6   75e-6   75e-6   75e-6   75e-6
90_GPCD        DAILY     90e-6   90e-6   90e-6   90e-6   90e-6   90e-6
100_GPCD       DAILY     100e-6  100e-6  100e-6  100e-6  100e-6  100e-6
110_GPCD       DAILY     11e-5   11e-5   11e-5   11e-5   11e-5   11e-5
;
SystemwideHourly HOURLY   0.66    0.53    0.48    0.47    0.56    0.77
SystemwideHourly   1.02    1.19    1.23    1.19    1.18    1.17
SystemwideHourly   1.15    1.12    1.12    1.12    1.15    1.20
SystemwideHourly   1.23    1.25    1.24    1.16    1.00    0.80
```

Infiltration modeling methods

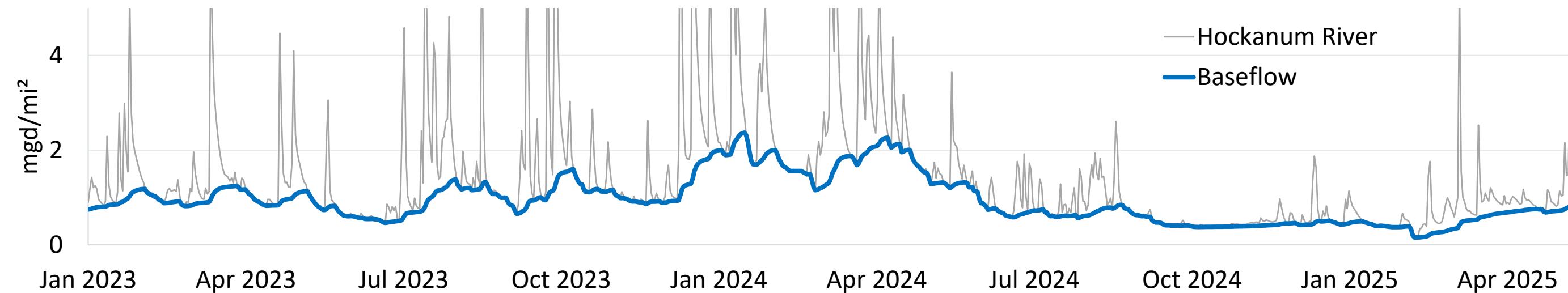
- Ignore / constant
- Monthly pattern or time series
- RTK
- Groundwater simulation



Infiltration modeling using timeseries

[INFLows]						
;;Node	Constituent	Time Series	Type	Mfactor	Sfactor	Baseline Pattern
CDM2378596	FLOW	ConnRiverFlow	FLOW	1.0	0.646	0
CDM425	FLOW	HockanumBaseflow	FLOW	1.0	0.116	0
CDM455	FLOW	HockanumBaseflow	FLOW	1.0	2.262	0

[TIMESERIES]			
;;Name	Date	Time	Value
ConnRiverFlow	FILE	ConnRiverFlow.dat	
HockanumBaseflow	FILE	HockanumBaseflow.dat	

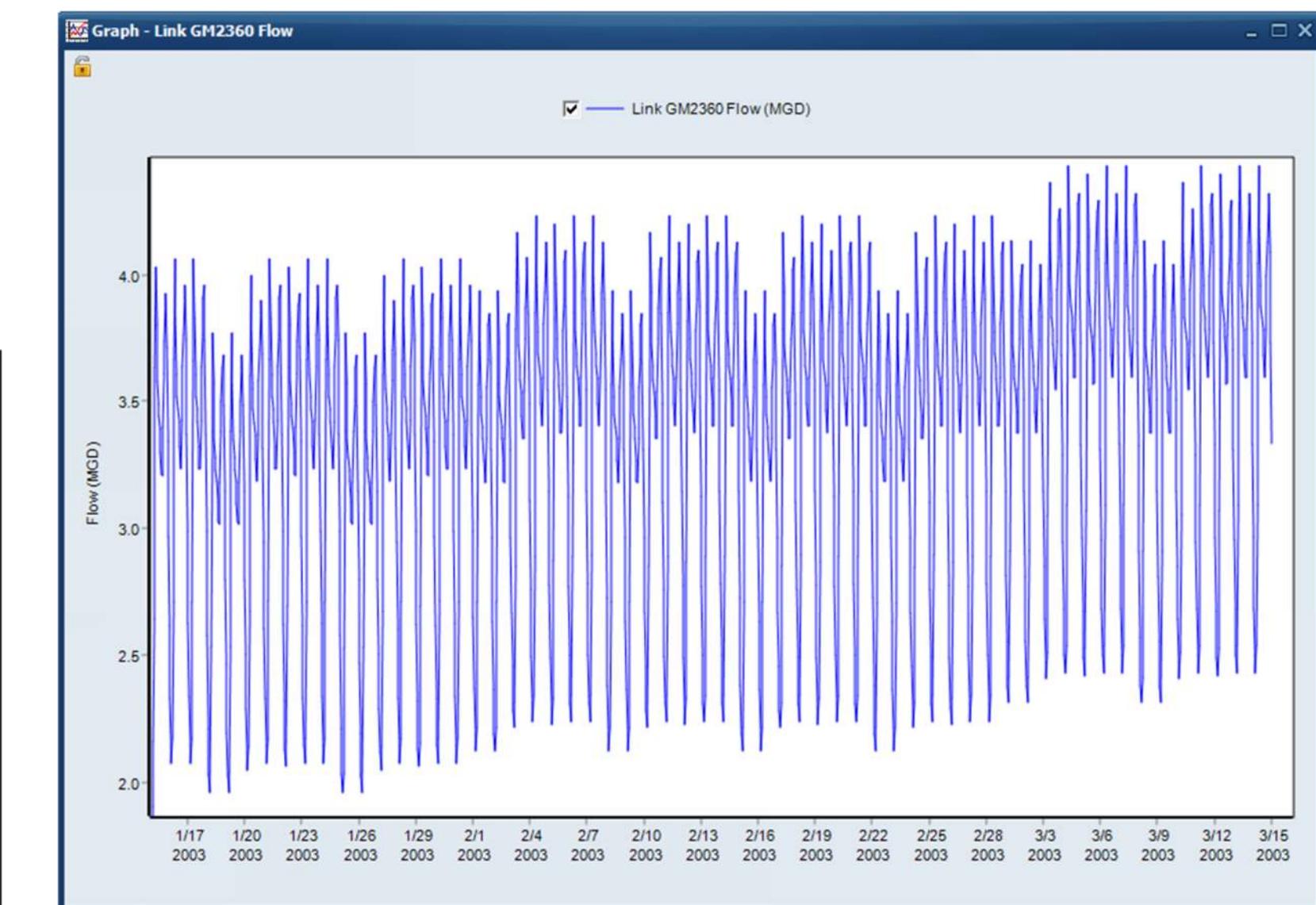


Infiltration modeling using patterns

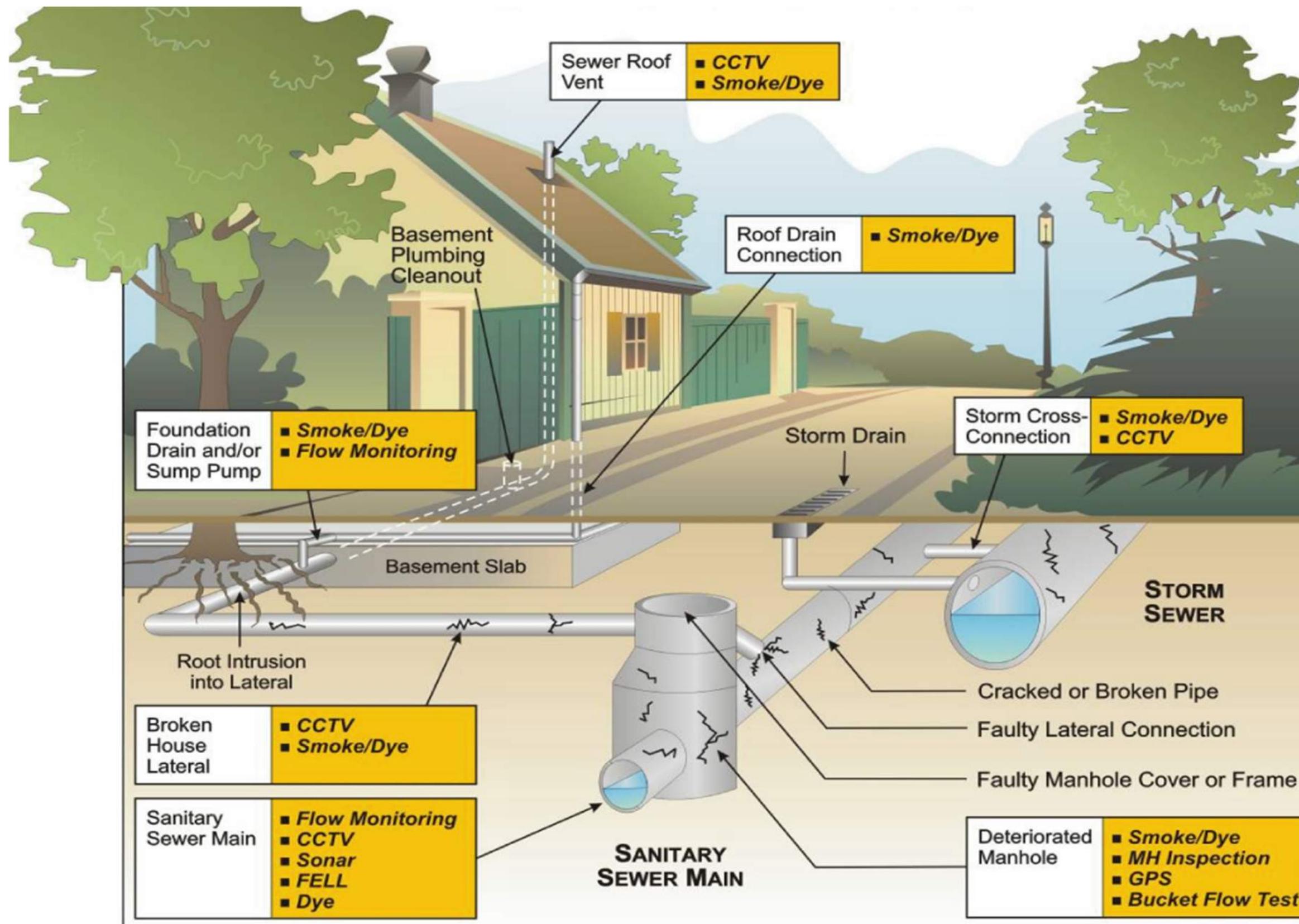
```
[INFLOWS]
;;
;;Node      Parameter    Time Series    Param   Units     Scale
;;-----  Type       Factor    Factor  Baseline Baseline
;;-----  FLOW        1.0      1        0.0001  Infiltration
CDM1      FLOW        1.0      1        0.000224 Infiltration
CDM10     FLOW        1.0      1        0.0001  Infiltration
CDM11     FLOW        1.0      1        0.0001  Infiltration
CDM12     FLOW        1.0      1        0.0001  Infiltration
```

```
[DWF]
;;
;;Node      Parameter    Average Value   Time Patterns
;;-----  FLOW        0.0003    "" "GNDaily" "DWF" ""
;;-----  FLOW        0.002618  "" "GNDaily" "DWF" ""
;;-----  FLOW        0.0003    "" "GNDaily" "DWF" ""
;;-----  FLOW        0.0003    "" "GNDaily" "DWF" ""
```

```
[PATTERNS]
;;Name      Type      Multipliers
;;-----  HOURLY
DWF       0.65  0.56  0.52  0.53  0.64  1.04
          1.37  1.3   1.13  1.12  1.08  1.08
          1.04  1    0.97  1.01  1.14  1.18
          1.23  1.3   1.26  1.1   0.95  0.78
GNDaily   DAILY    0.94  1.01  1.03  1.02  1.03  1.03  0.94
Infiltration MONTHLY 0.93  1.14  1.38  1.37  1.46  1.05
          0.74  0.8   0.78  0.72  0.72  0.92 |
```



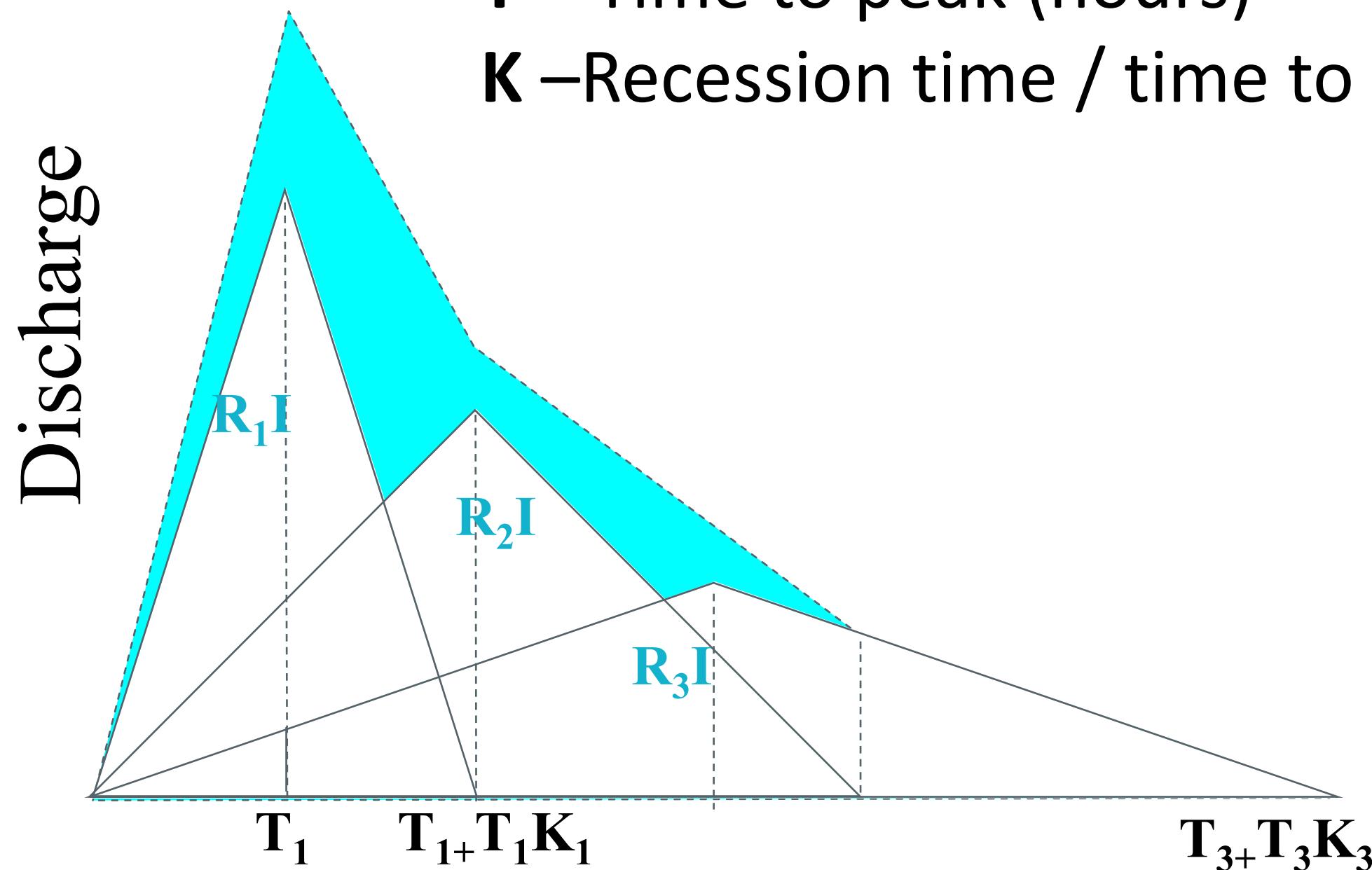
Sanitary sewer I/I



RTK method

I

R – Rainfall fraction entering sewers
T – Time to peak (hours)
K – Recession time / time to peak



Curve	T (hours)	K
Short	1 – 2	1 – 2
Medium	3 – 5	2 – 3
Long	5 – 10	3 – 5

Unit hydrograph parameters

Inflows for Node GIS2227729

Direct Dry Weather RDII

Unit Hydrograph Group: uN10

Sewersheds Area (acres): 233.7

Unit Hydrograph Editor

Name of UH Group: uN10

Rain Gage Used: MDC-RG-1

Hydrographs For: January (*)

Response	R	T	K
Short-Term	0.0096	1	1.5
Medium-Term	0.0193	3	2
Long-Term	0	0	0

R = fraction of rainfall that becomes runoff
T = time to hydrograph peak (hours)
K = falling limb duration / rising limb duration

Months with UH data have a (*) next to them.

OK Cancel Help

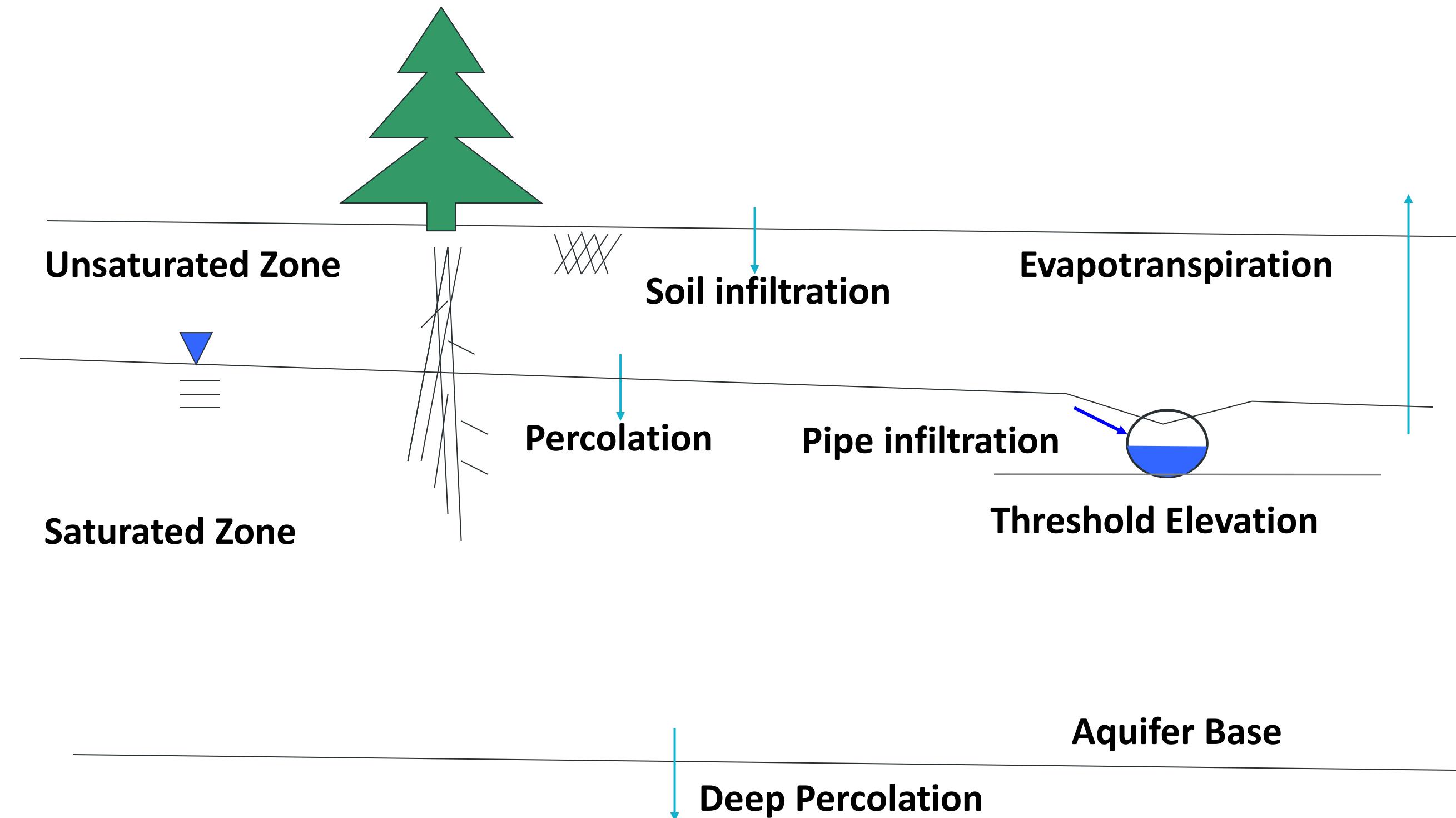
Response	Dmax	Drec	Do
Short-Term	0.2	0.1	0
Medium-Term	0.2	0.1	0
Long-Term	0	0	0

Dmax = maximum depth (inches)
Drec = recovery rate (in/day)
Do = starting depth (inches)

[HYDROGRAPHS]

```
;;Hydrograph Rain Gage/Month Response R T K Dmax Drecov Dinit
;:-
uN10 MDC-RG-1
uN10 Jan Short 0.0096 1 1.5 0.2 0.1 0
uN10 Jan Medium 0.0193 3 2 0.2 0.1 0
uN10 Jan Long 0 0 0 0 0 0
```

Groundwater processes



Simple groundwater paradigm

$$Q = A_1(H_{gw} - E)^{B^1} - \cancel{A_2(H_{sw} - E)^{B^2}} + \cancel{A_3(H_{gw} \times H_{sw})}$$

Q = unit groundwater flow

A, B = model parameters

H_{gw} = water table elevation

E = threshold elevation

~~H_{sw} = surface water elevation at receiving node~~

Groundwater inputs

Aquifer Editor

Property	Value
Aquifer Name	Newington
Porosity	0.45
Wilting Point	0.2
Field Capacity	0.33
Conductivity	2
Conductivity Slope	40
Tension Slope	0
Upper Evap. Fraction	0.5
Lower Evap. Depth	10
Lower GW Loss Rate	0.0005
Bottom Elevation	999
Water Table Elevation	999
Unsat. Zone Moisture	0.33
Inner Evap. Pattern	

User-assigned aquifer name

OK Cancel Help

Groundwater Flow Editor

Property	Value
Aquifer Name	4401
Receiving Node	BASS10875
Surface Elevation	45
A1 Coefficient	0.000115
B1 Exponent	2
A2 Coefficient	0
B2 Exponent	0
A3 Coefficient	0
Surface Water Depth	0
Threshold Water Table Elev.	29
Aquifer Bottom Elevation	20
Initial Water Table Elev.	31.44
Unsat. Zone Moisture	0.33
Custom Lateral Flow Equation	No
Custom Deep Flow Equation	Yes

Name of Aquifer object that lies below subcatchment. Leave blank for no groundwater.

OK Cancel Help

The standard equation for lateral groundwater flow is:

$$Q_L = A_1 * (H_{gw} - H_{cb})^{B1}$$

$$- A_2 * (H_{sw} - H_{cb})^{B2}$$

$$+ A_3 * H_{gw} * H_{sw}$$

where Q_L has units of cfs/ac (or cms/ha).

The standard equation for deep groundwater flow is:

$$Q_D = LGLR * H_{gw} / H_{gs}$$

where LGLR is the aquifer lower GW loss rate (in/hr or mm/hr).

[AQUIFERS]

;;Name	Por	WP	FC	Ksat	Kslope	Tslope	ETu	ETs	Seep	Ebot	Egw	Umc	ETupat
;;													
4401	0.45	0.25	0.33	0.32	40	0	0.3	6	0.0005	999	999	0.33	

[GROUNDWATER]

;;Subcatchment	Aquifer	Node	Esurf	A1	B1	A2	B2	A3	Dsw	Egwt	Ebot	Wgr	Umc
;;													
4000_24_2_R1	Hartford3	Meadow05800	56	9E-05	2	0	0	0	0	35	30	38.19	0.32

CDM develop a long-range sanitary sewer facility plan that will result in a cost-effective, phased improvement program to reduce weather overflows and to accommodate growth needs in the coming years.

CDM Smith
listen. think. deliver.

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Federal, State and Town offices, including the U.S. Environmental Protection Agency's SWMM-EXTRAN model was selected. "Application of this model to the trunk sewer system allows us to identify hydraulic bottlenecks that cause overflows, and to evaluate the effectiveness of various improvement alternatives in mitigating these overflows," notes Dave Zimmer, CDM associate and project manager.

CDM engineer Rick Carrier designed the innovative conversion of out-of-use polishing ponds to flow equalization basins at the McAlpine and Sugar Creek treatment plants. The 44-million-gallon flow equalization facility at McAlpine is scheduled to be completed in 1993. "B

Combined sewer overflows
(continued from previous page)

Computer models are now used to describe storm flow and pollution loads and to quickly screen a great many solutions for control alternatives to identify a few feasible solutions for a detailed study, Roesner said. STORM (Storage, Treatment, Overflow and Runoff Model) and the Environmental Protection Agency's SWMM (Stormwater Management Model) are two of the better known models developed for studying urban stormwater systems.

As was borne out in the Boston Harbor study, the capabilities to quickly process a large amount of information are important because CSO planning requires dealing with a variety of storm events as wide as nature will allow, Callahan said. Added to that is the individual nature of the sewer systems' size and performance, making management analysis more precise.

In developing a new system, it may not be the most cost-effective alternative to alter the existing system.

STORMWATER MANAGEMENT

MEET THE STATE-DEADLI
The largest South Carolina firm serves the Greenville area, encompassing seven surrounding districts within a 41-square-mile impact area. Impacts include water quality issues, flooding problems, and more.

CDM SMITH / CLIENT SOLUTIONS / EPA SWMM STORM WATER MANAGEMENT MODEL

INSIGHT

How SWMM Changed the Way Cities View Water

How a pioneering software model and the engineers behind it transformed U.S. urban water quality over the course of a half-century.

In the late 1960s, water quality in American cities was in crisis. Polluted water degraded urban infrastructure, ecosystems, and quality of life. Cleveland's Cuyahoga River caught fire at least 13 times before 1969, contaminated so severely with industrial waste that even leeches and sludge worms had no chance at survival. In a 1969 *Time* article on American sewer systems, a Cleveland citizen joked grimly, "Anyone who falls into the Cuyahoga does not drown. He decays." Philadelphia's waterways turned the paint of ships brown when they docked or traveled through. A dip in Miami's Biscayne Bay became hazardous in the

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