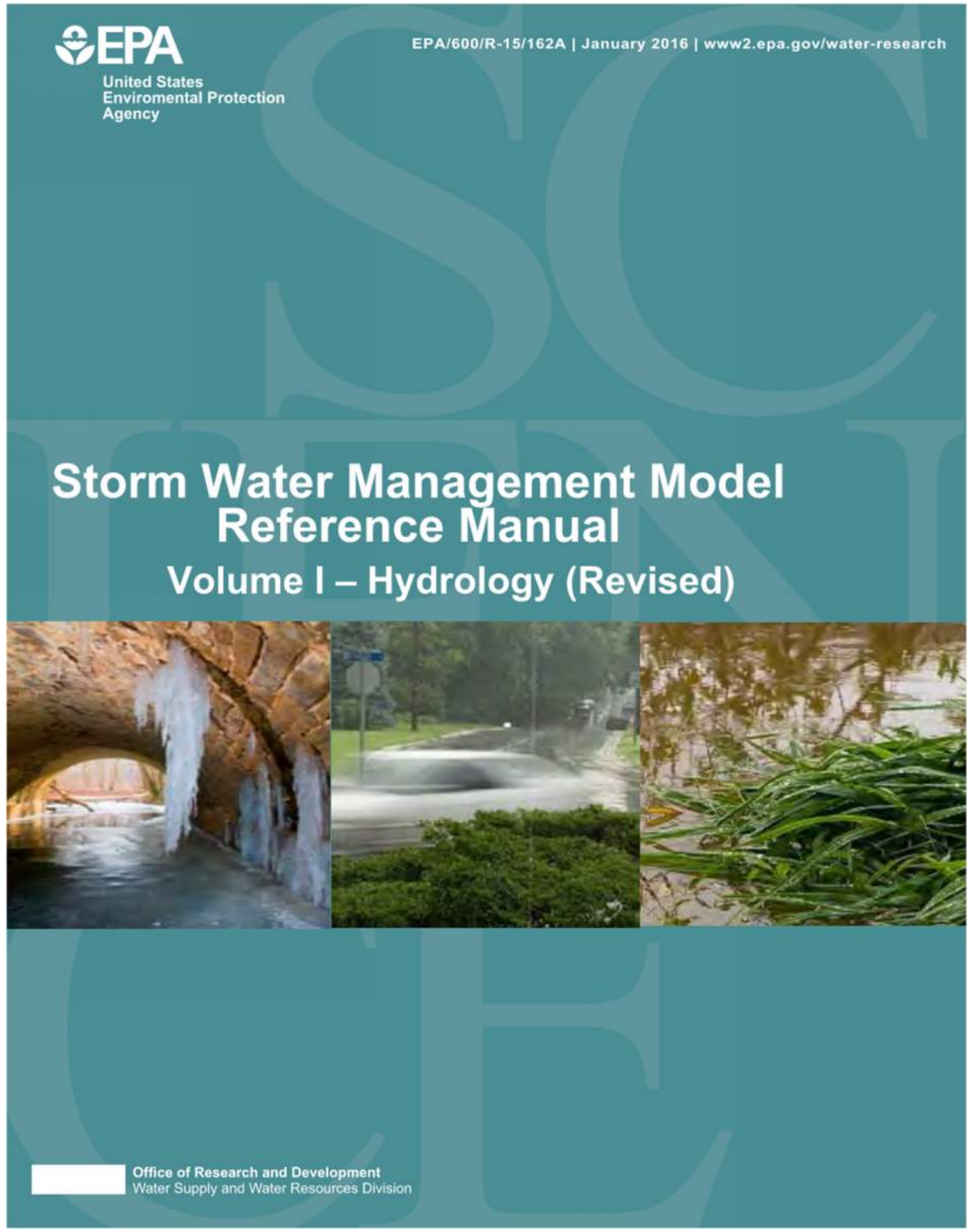
Stormwater
Modeling Committee
ASCE | EWRI

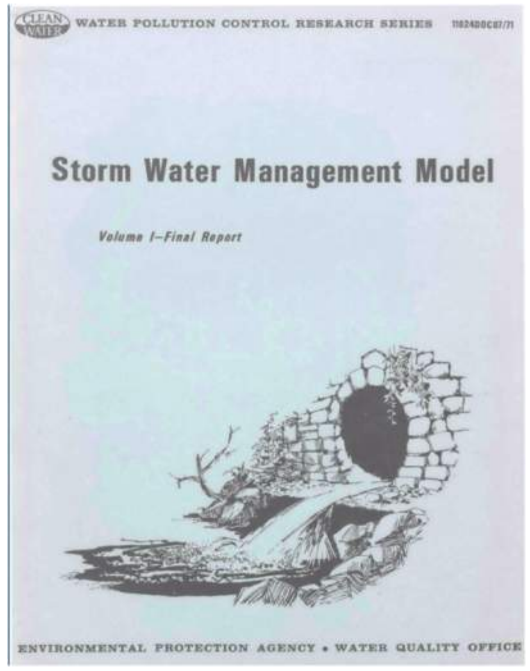
Hydrology

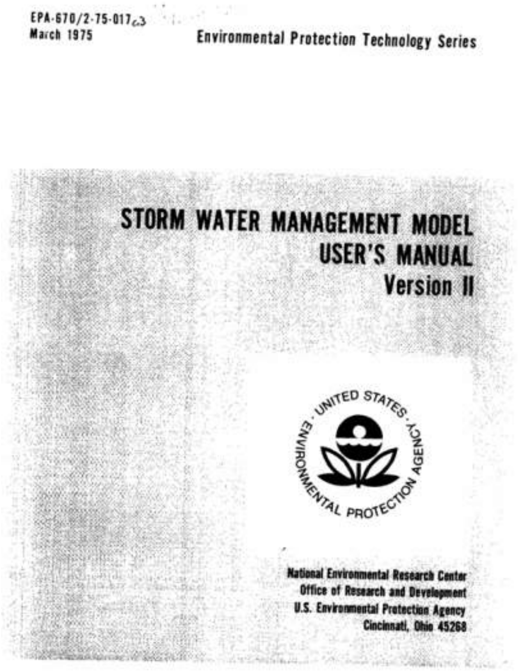
EWRI World Environmental & Water Resources Congress 2025
Workshop for the EPA Stormwater Management Model
May 18, 2025
Mitch Heineman, PE. BC.WRE, BCEE

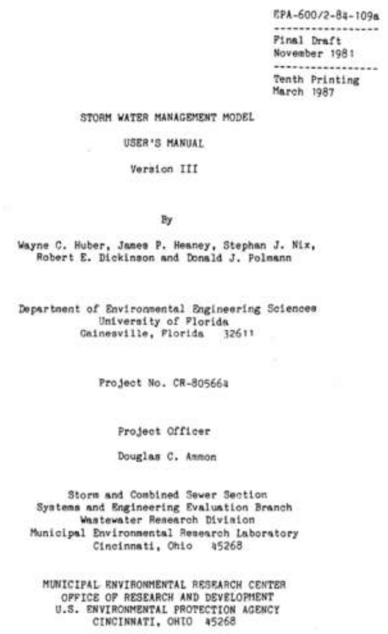
Topics

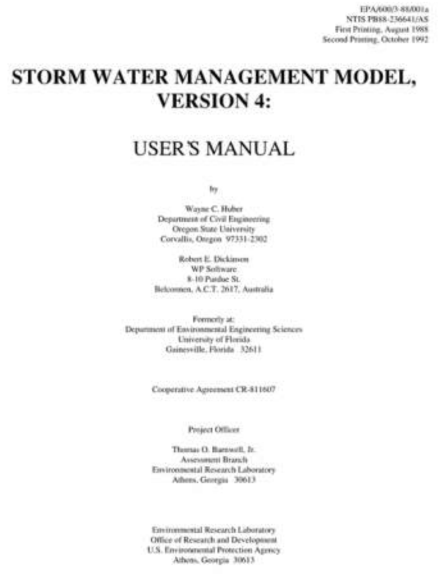
- Process models
- Nonlinear reservoir runoff
- Sanitary flow
- Infiltration methods
  - Patterns and timeseries
  - Unit hydrographs
  - Groundwater modeling





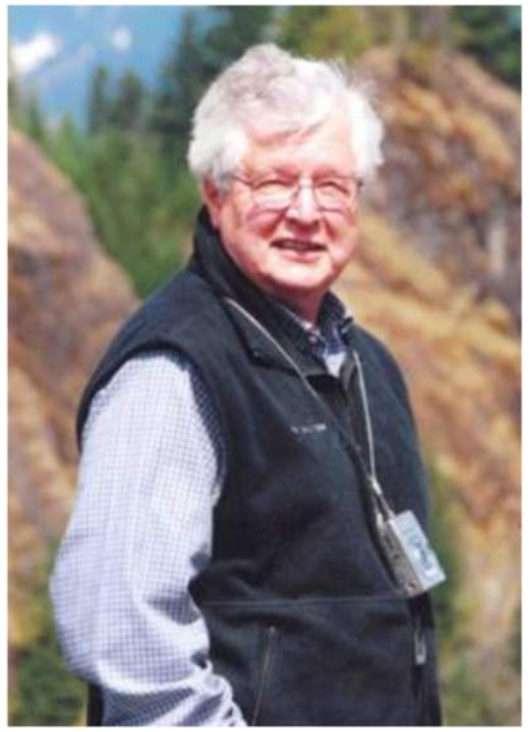




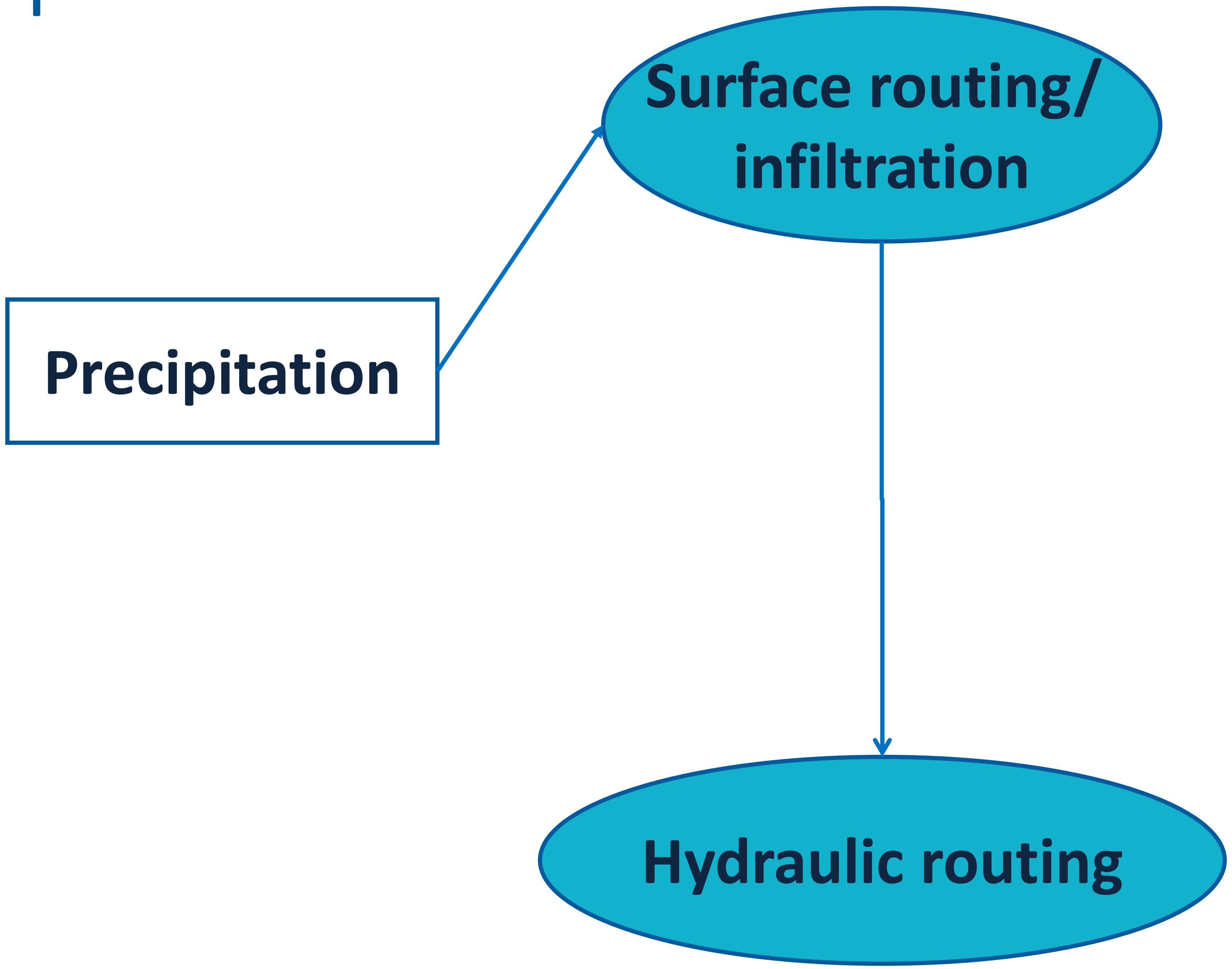


EPA Storm Water Management Model

- 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

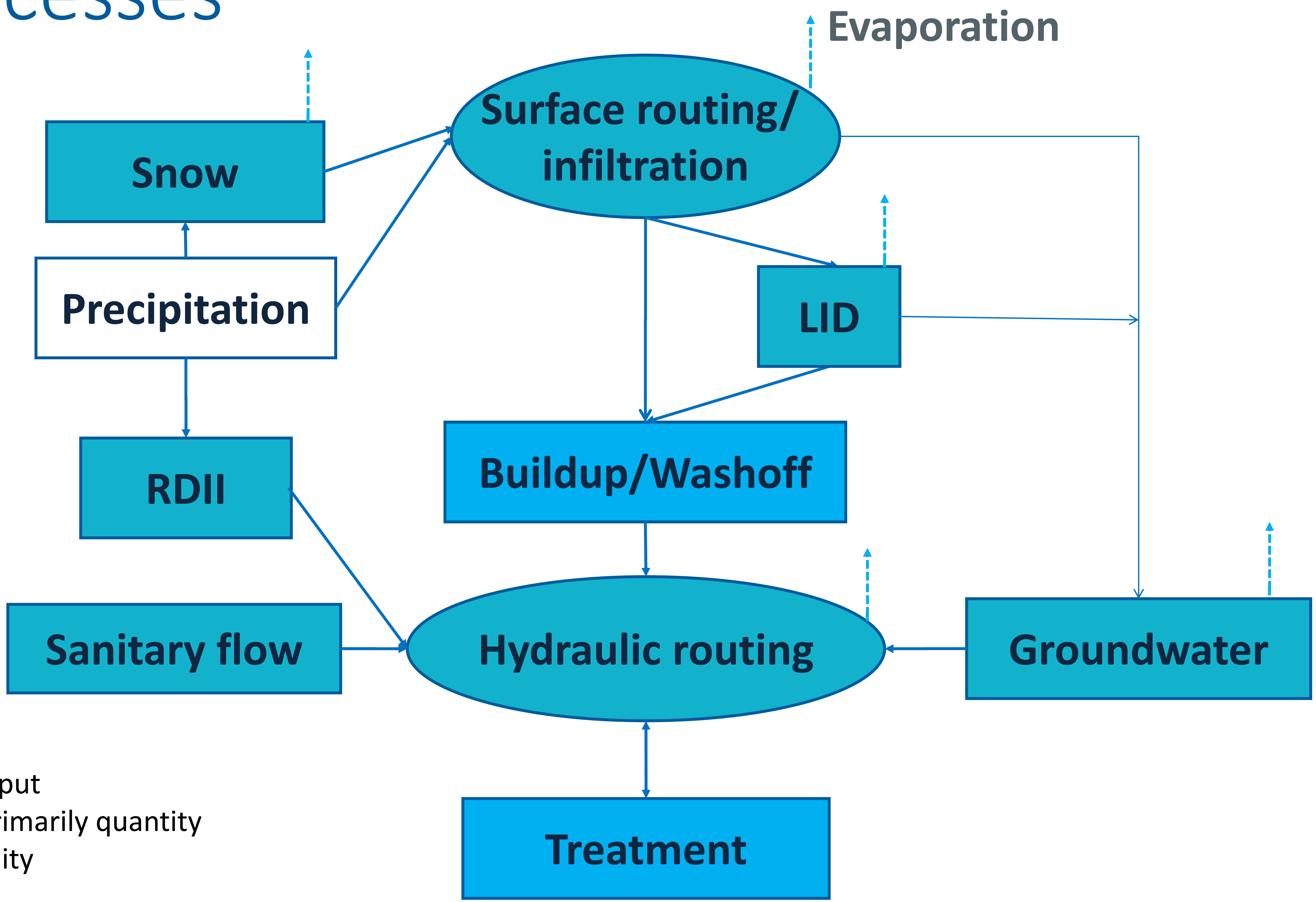


Typical processes



White – input
Green – primarily quantity
Blue - quality

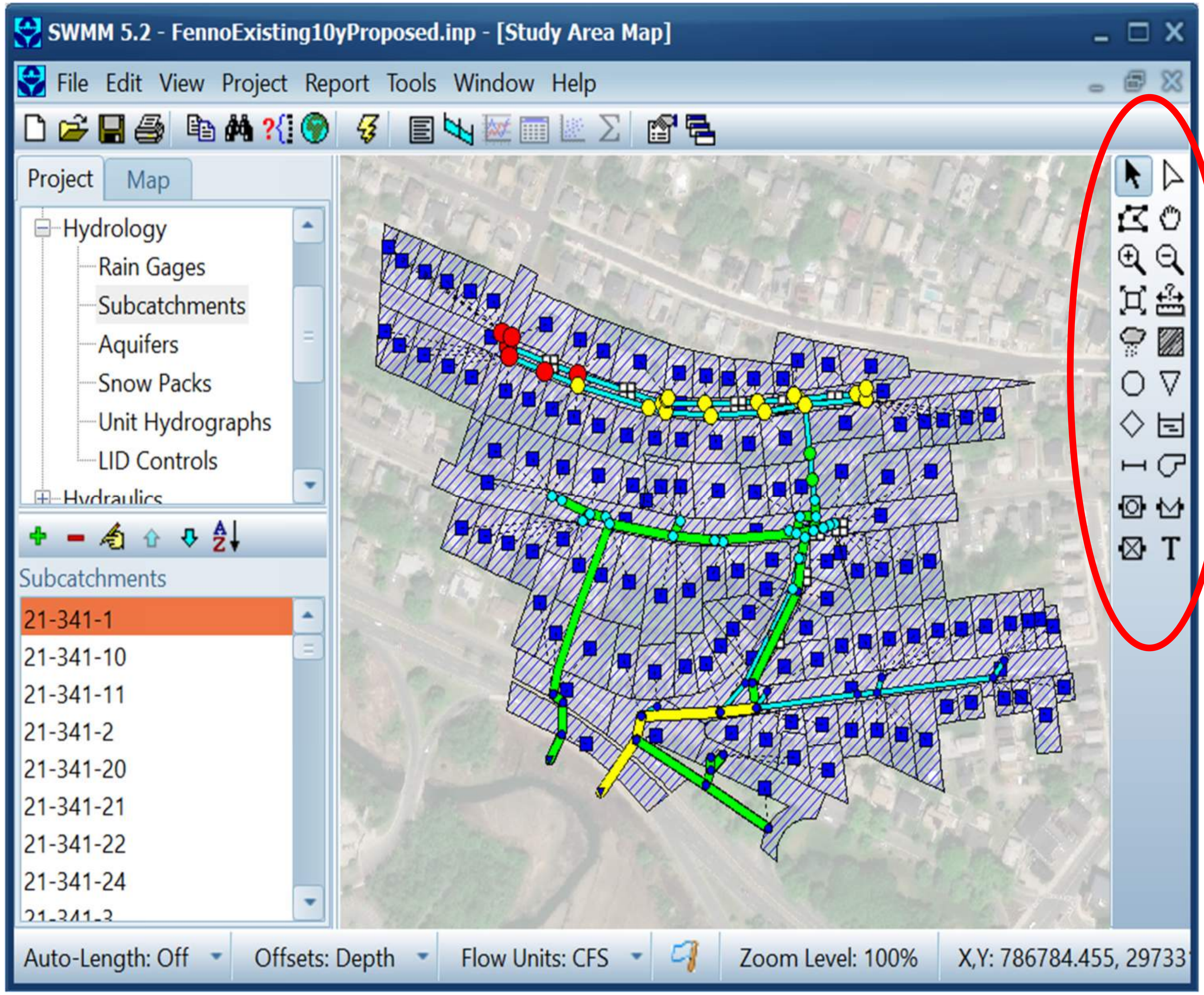
All processes



White – input
Green – primarily quantity
Blue - quality

Adapted from [SWMM hydrology manual]() Figure 1-3

Object toolbar

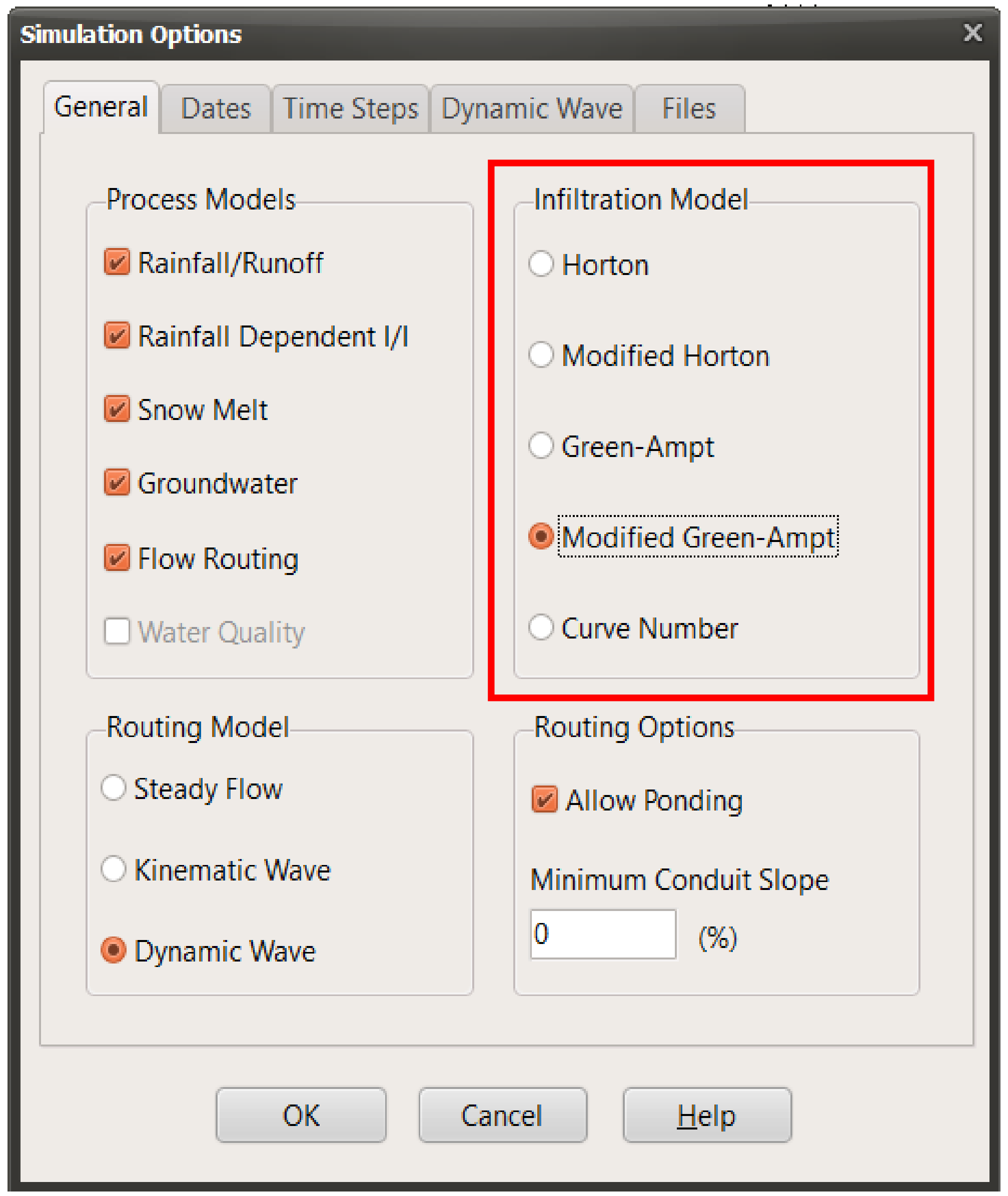


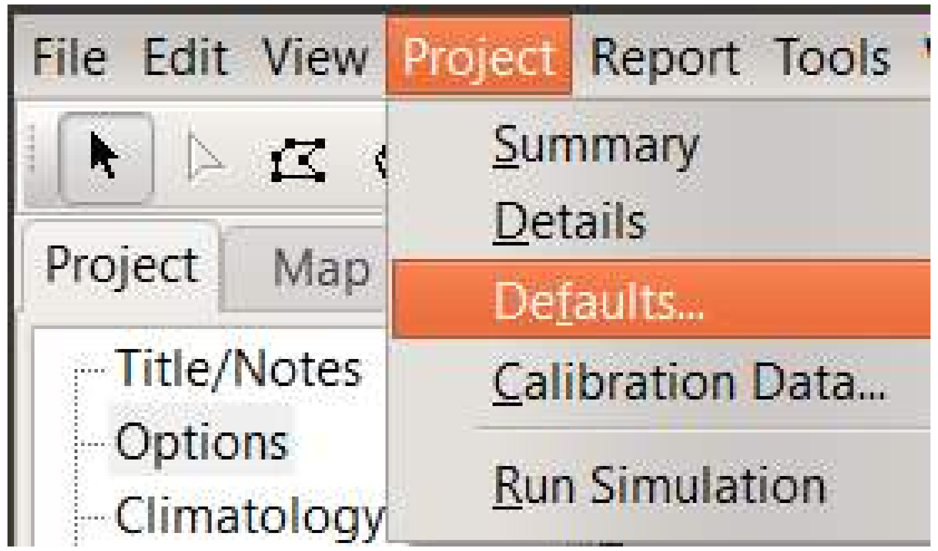
Select
Vertices
Select region
Pan
Zoom in
Zoom out
Full extent
Measure

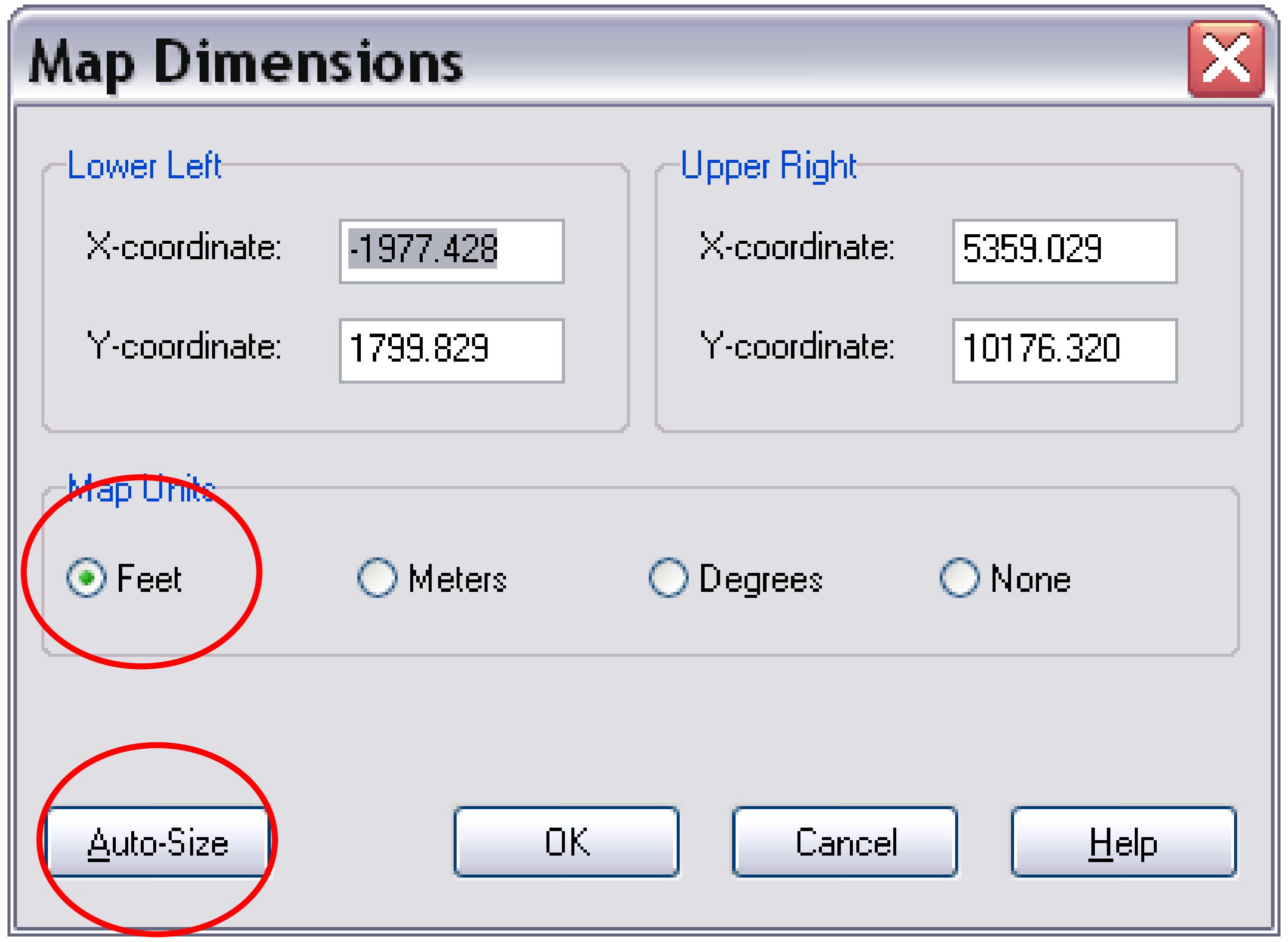
Rain gage
Subcatchment
Junction
Outfall
Divider
Storage
Link
Pump
Orifice
Weir
Outlet

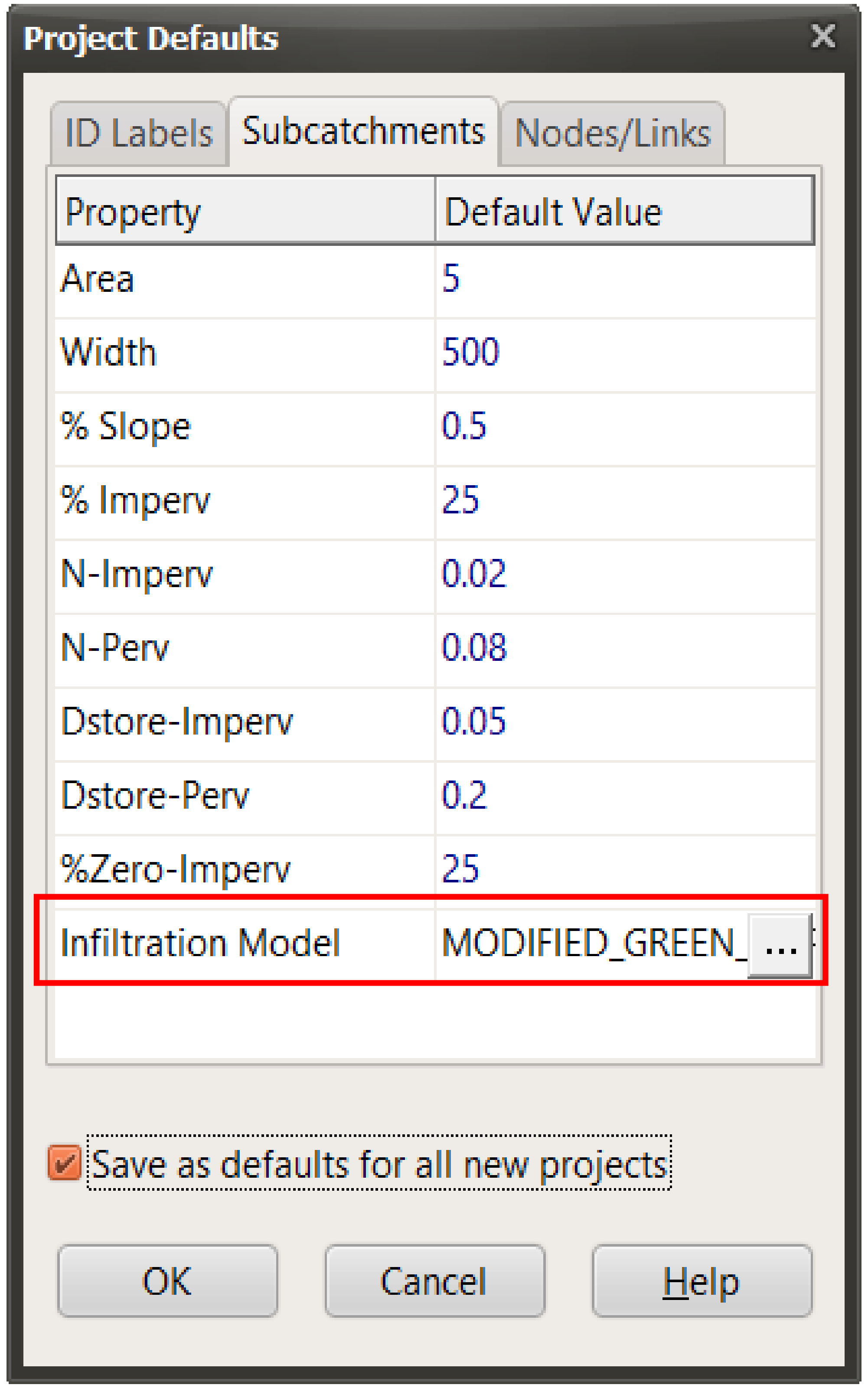
Label

Global settings and defaults



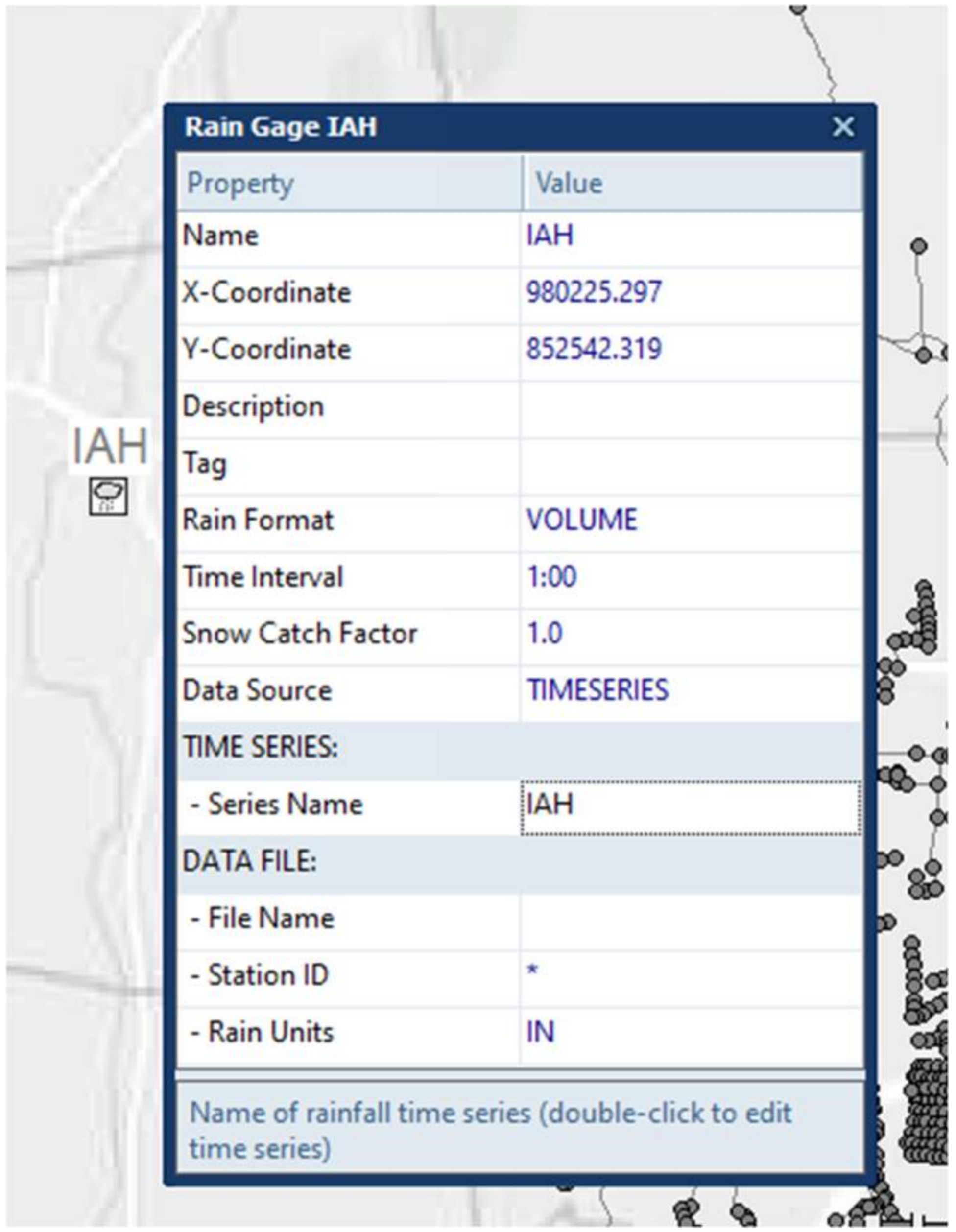


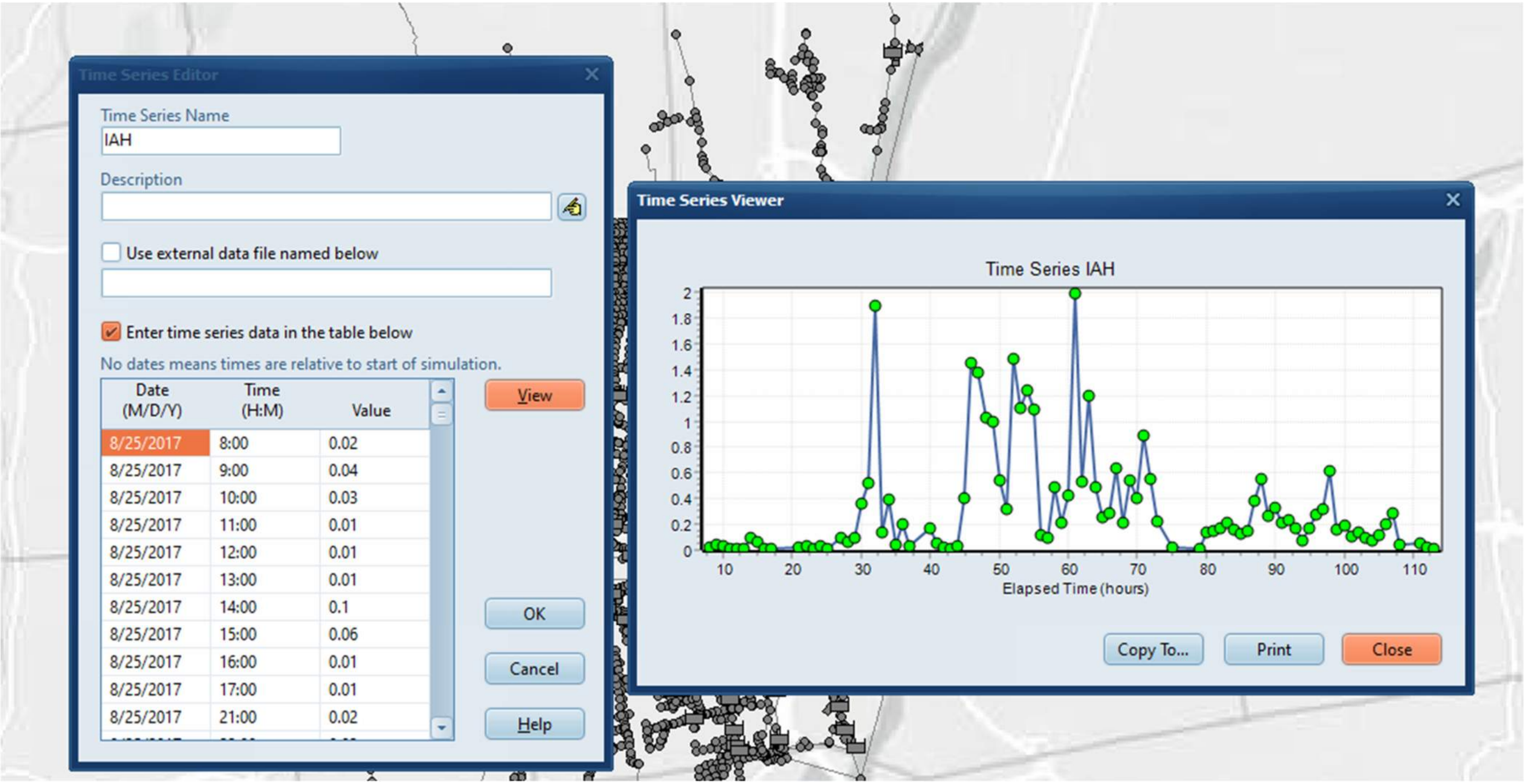




SWMM User's Manual Section 5.4

Rainfall data



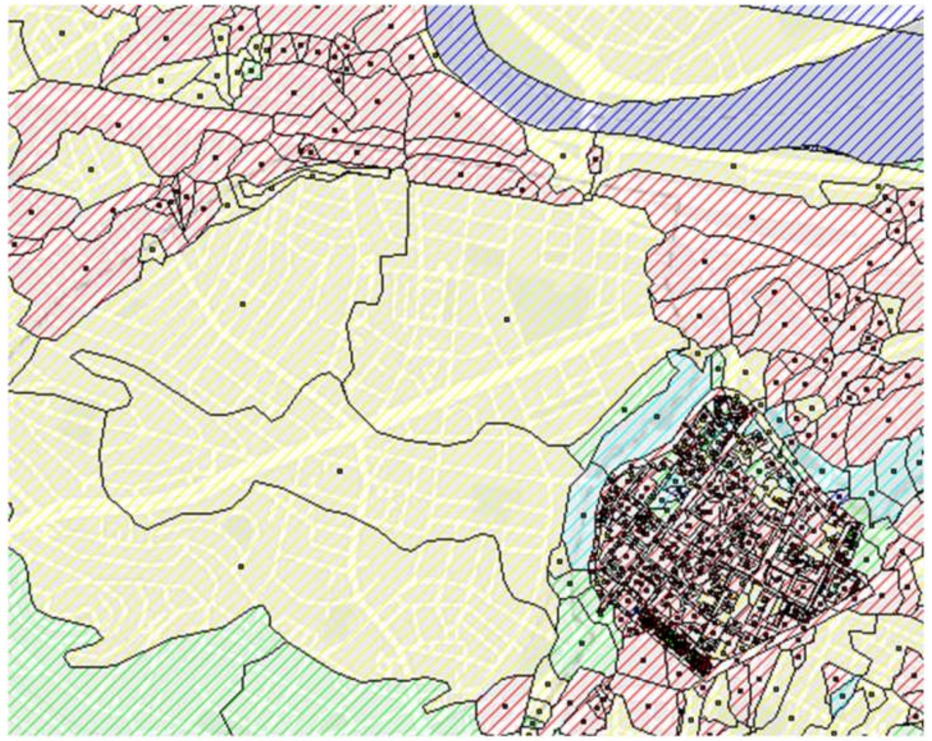


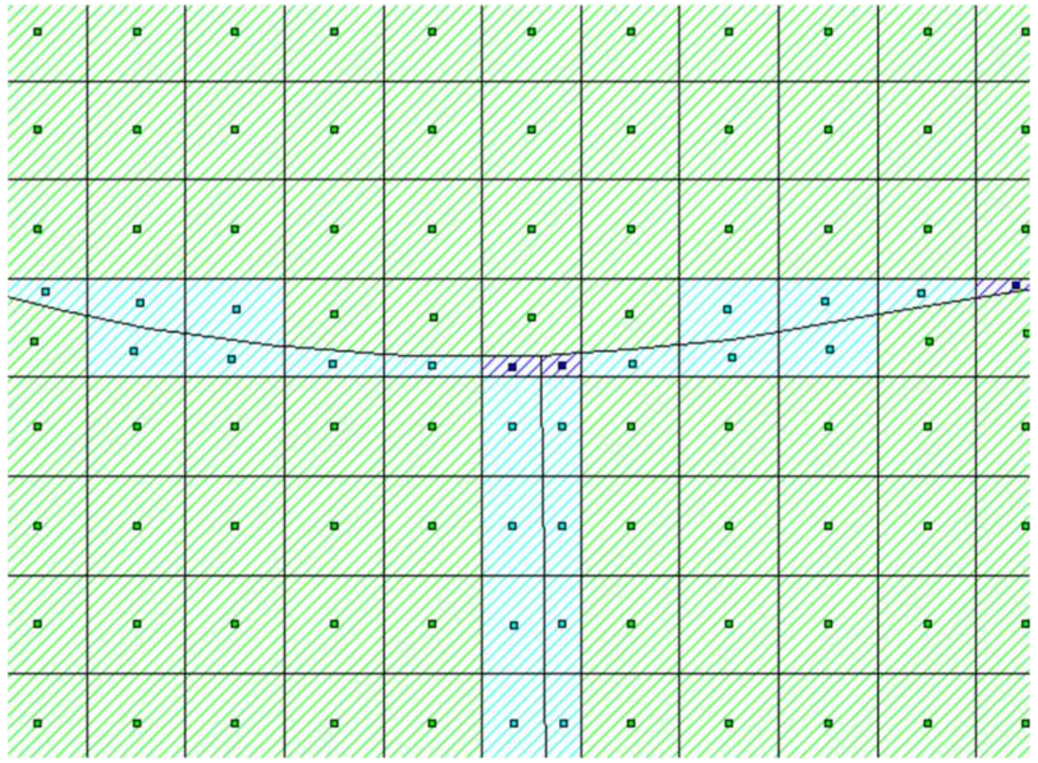

```
[RAINGAGES]
;;Name           Format    Interval SCF      Source
;;-------------- --------- -------- -------- ----------
Bradley          VOLUME    0:05     1        FILE       "BDL5m.dat" BDL     IN
```

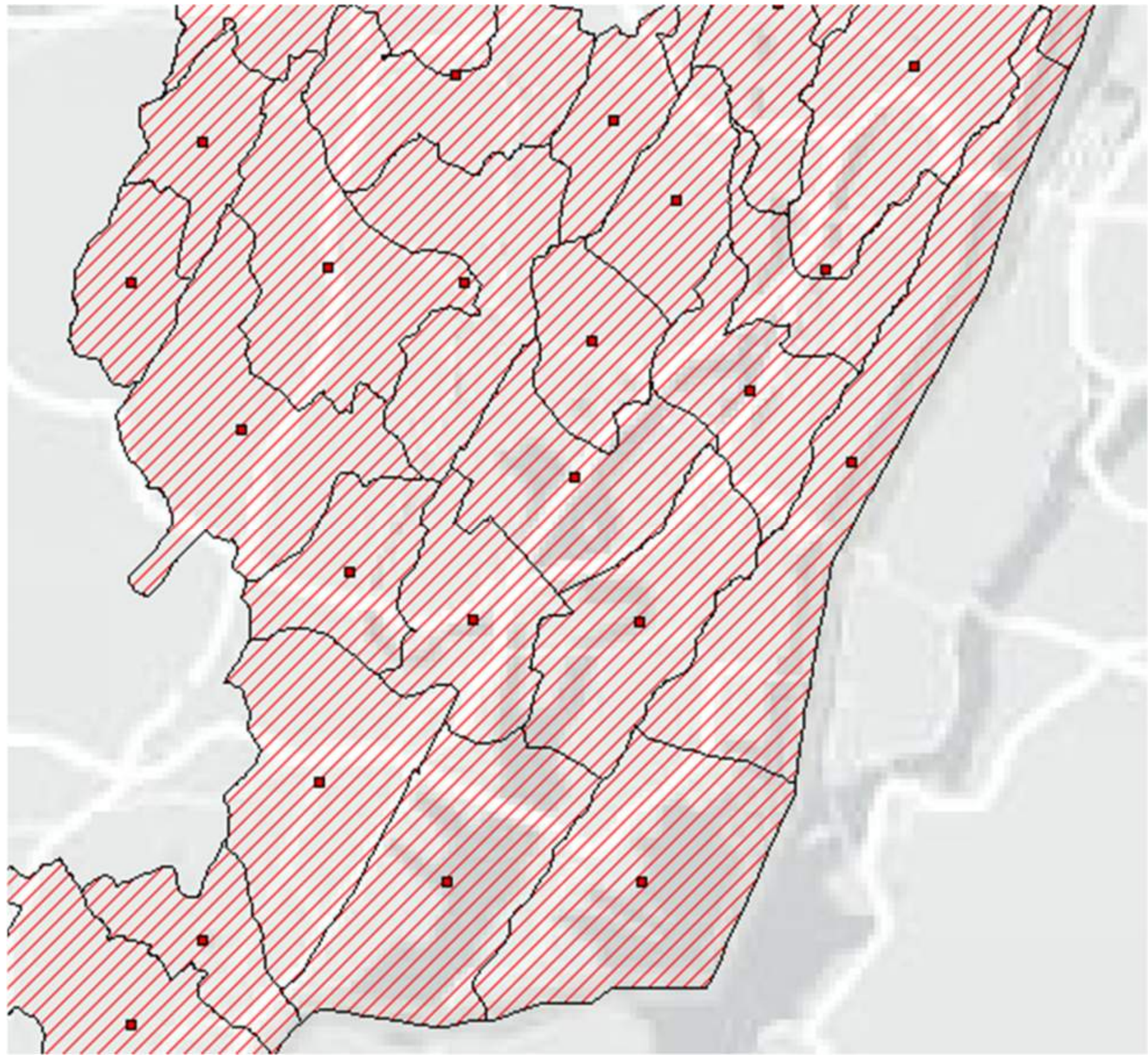
openswmm.org/Topic/11495/precipitation-input-formats

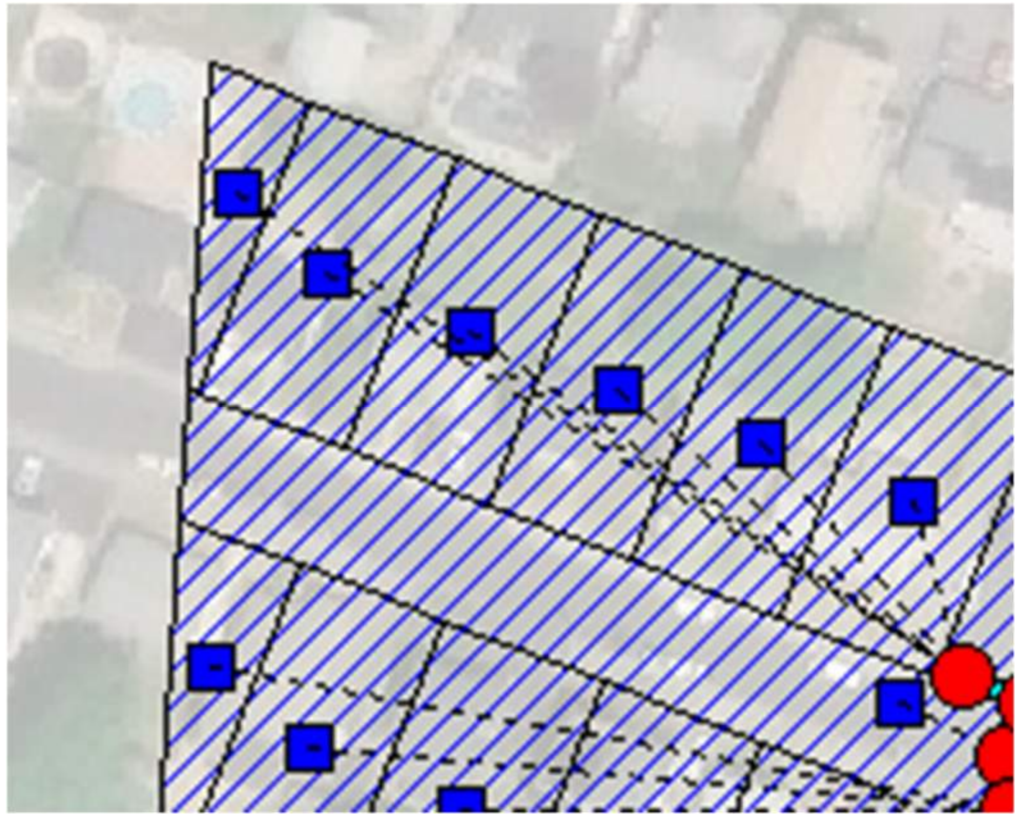
Subcatchments

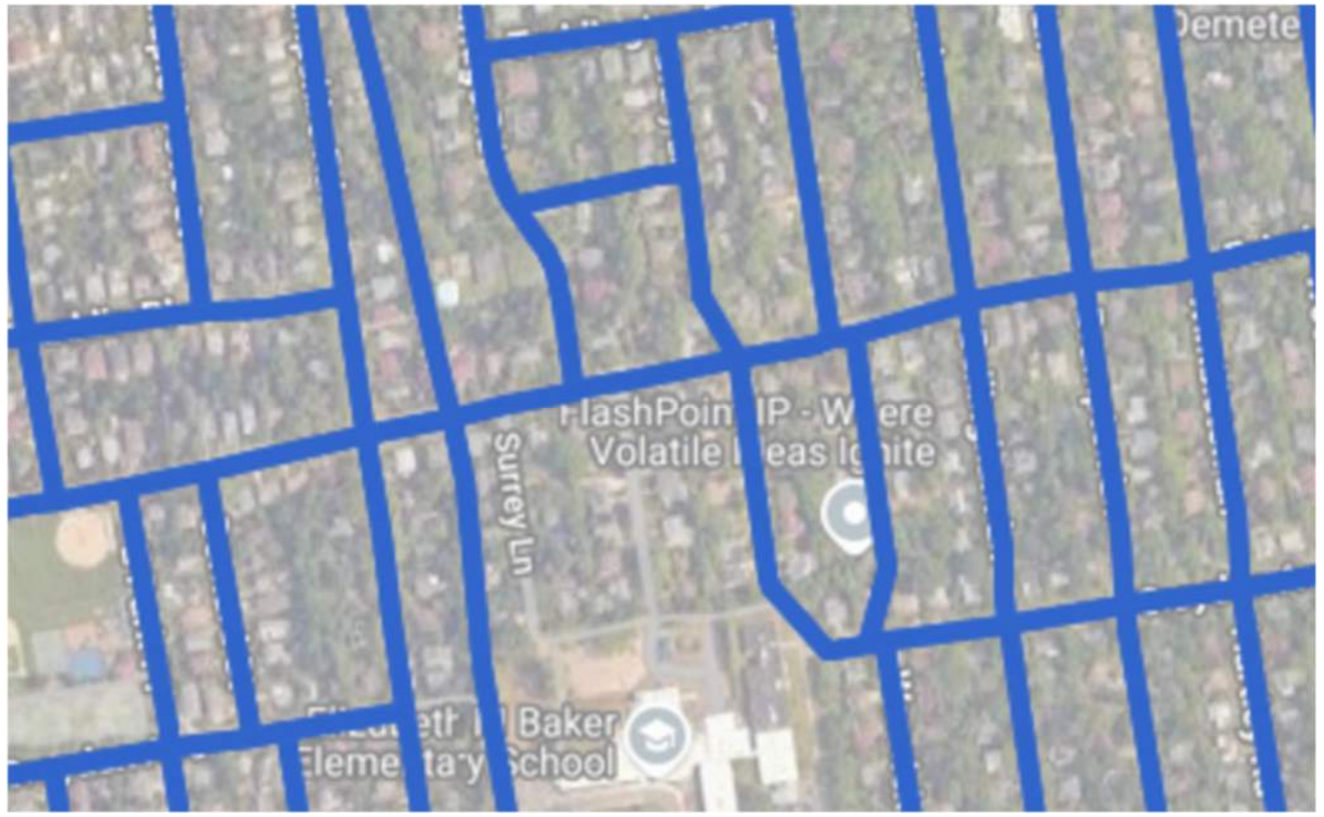
- A subcatchment can be defined using
  - Any size grid cell (e.g., 10 m × 10 m)
  - Parcels
  - Thiessen polygons
  - Topographically-defined polygons
  - Census blocks
  - Watershed Boundary Dataset hydrologic units









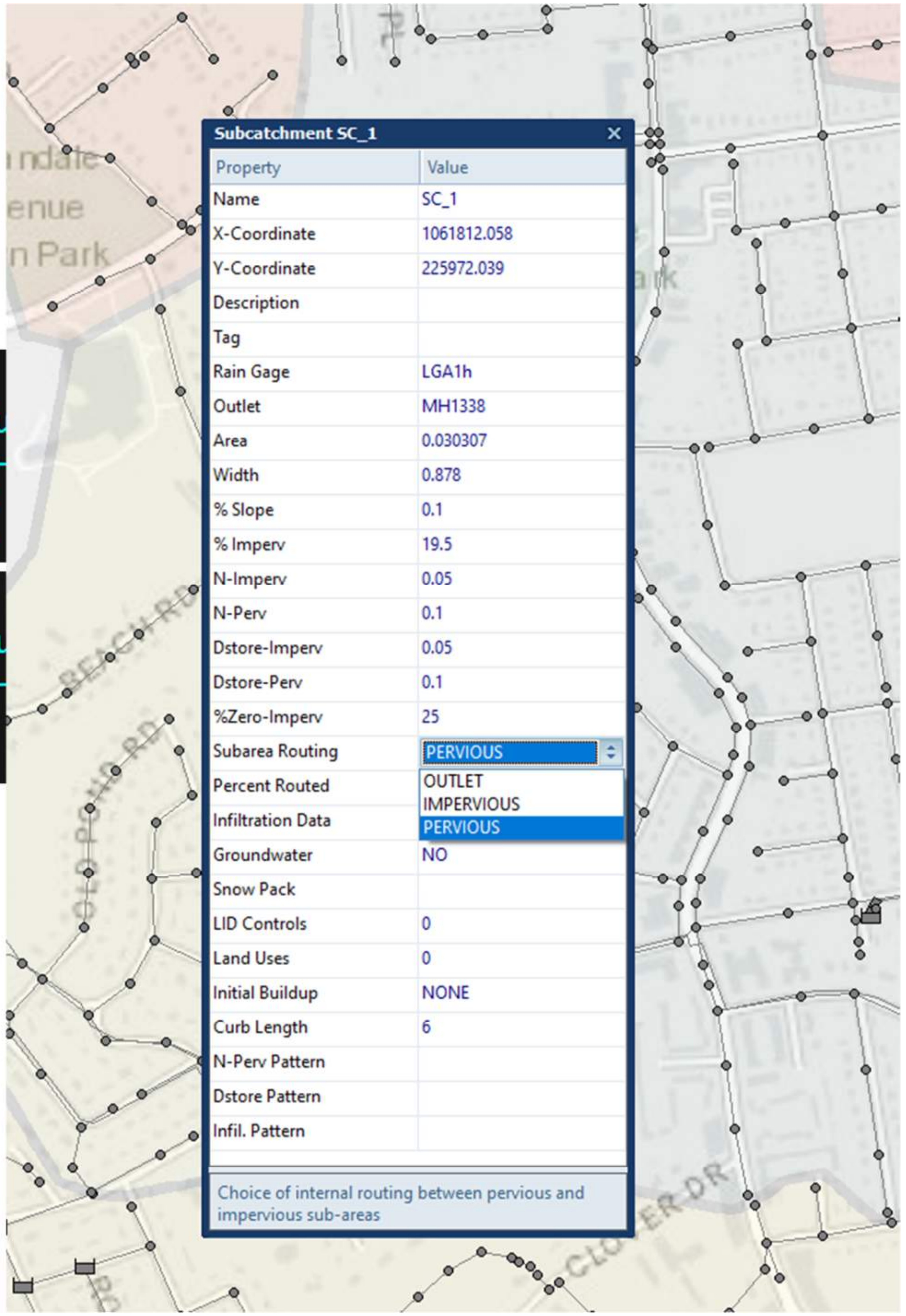


Subcatchment dialog

```
[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
```

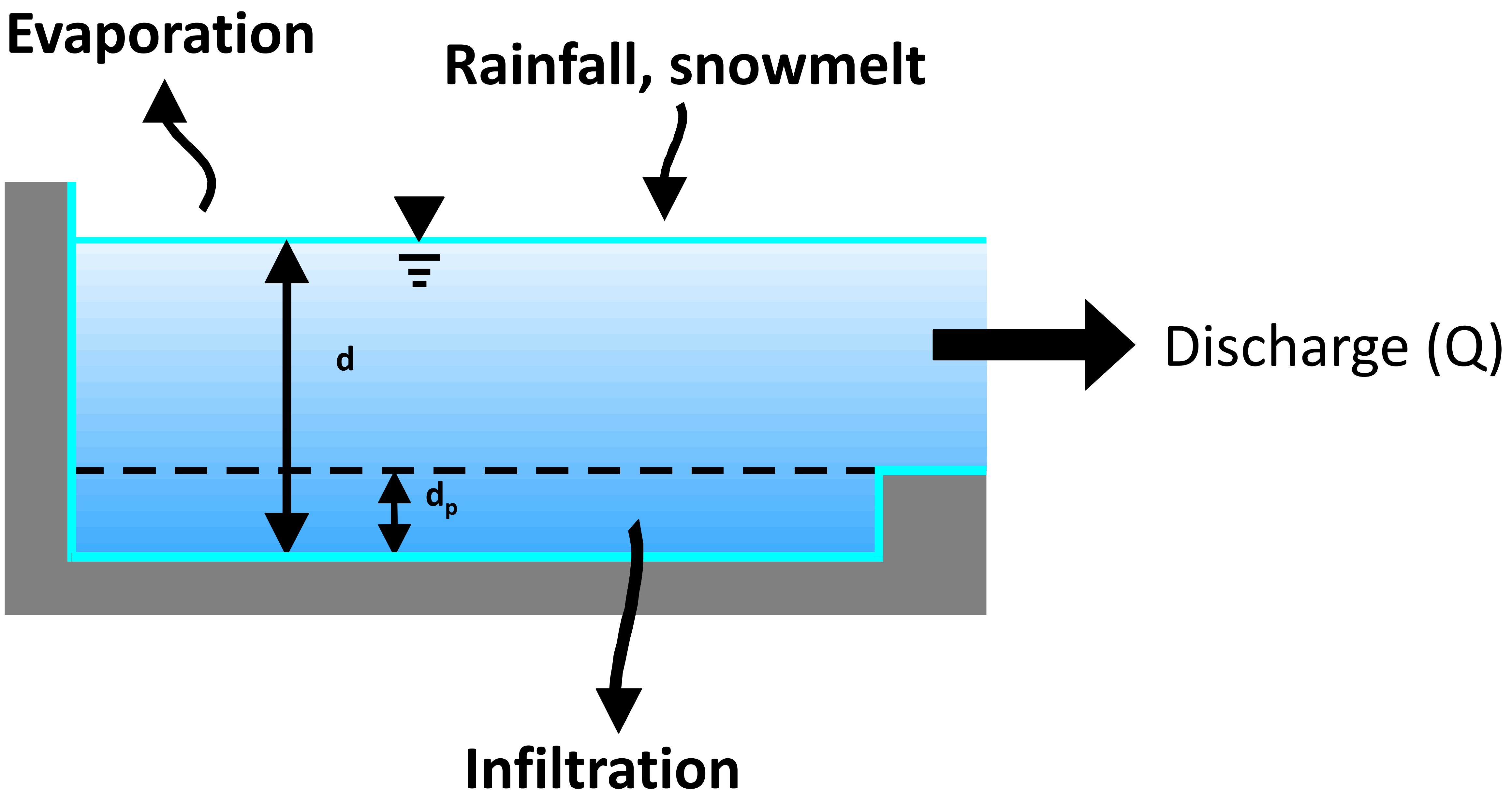
```
[INFILTRATION]
;;Subcatchment   Param1     Param2     Param3     Param4     Param5
;;-------------- ---------- ---------- ---------- ---------- ----------
4401_01          6.57       0.45       0.17       0          0
4401_02          8.6        0.25       0.14       0          0
```



Nonlinear reservoir runoff

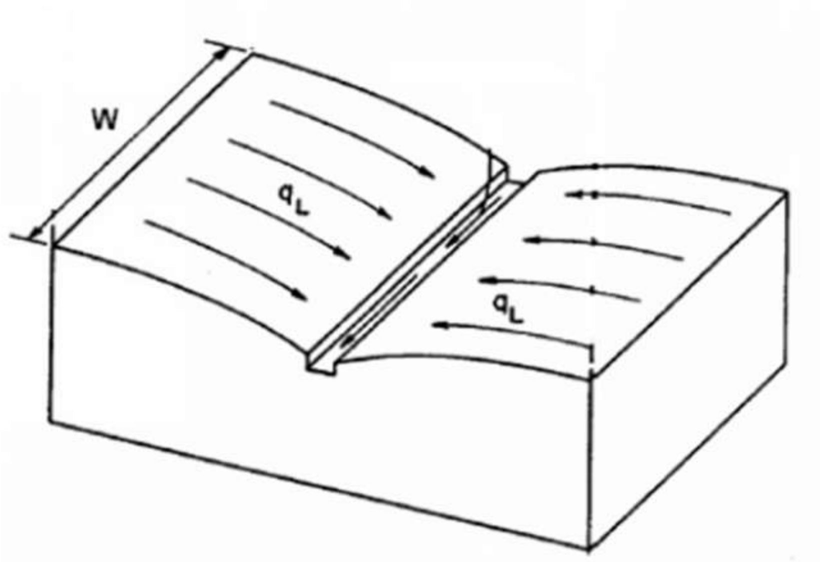
- Subcatchment area
- Volume parameters
  - Imperviousness
  - Subarea routing
  - Depression storage
  - Infiltration
- Shape parameters
  - Width
  - Slope
  - Roughness

Surface runoff calculation



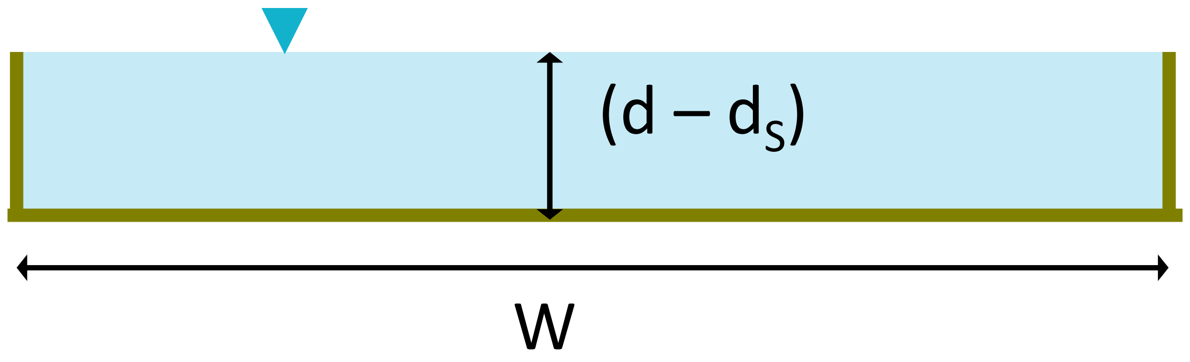
SWMM conceptualizes a subcatchment as a rectangular surface that has a uniform slope ***S*** and a width ***W*** that drains to a single outlet channel (Hydrology manual Section 3.2)

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

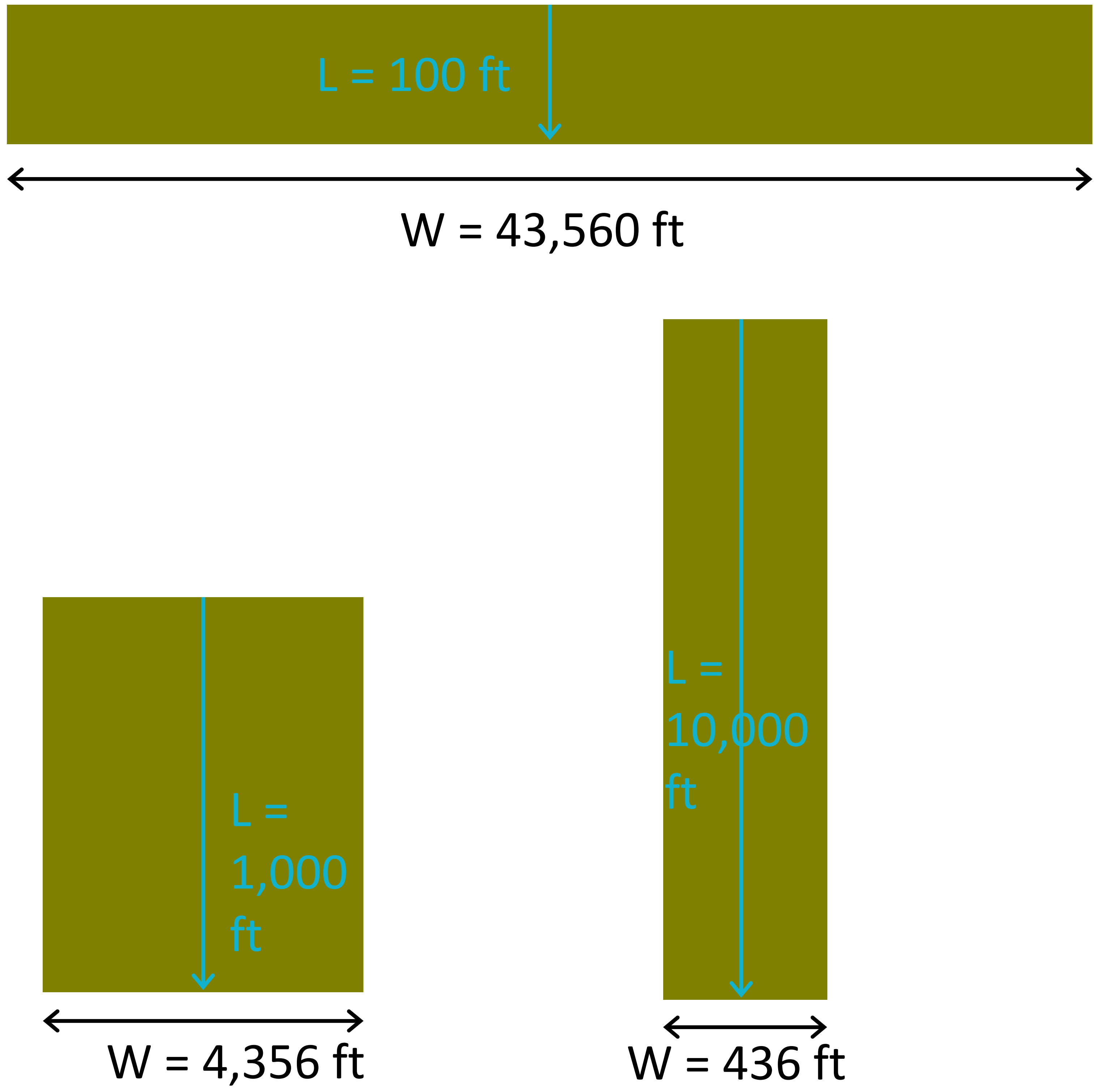
- Discharge $$Q_t = K(d - d_s)^{5/3} = K\left(\frac{V_t}{A}\right)^{5/3}$$

Width estimation methods

Simple

Complex

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



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)

SWMM hydrology manual Section 3.8.4

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 ft
- $X = 43560*1.67 / 360^2 = 0.56$
- A_m = 1.19 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 x 360 = 338 ft

- Twice main drainage channel
- L = 360 ft
- W = 2 x 360 = 720 ft

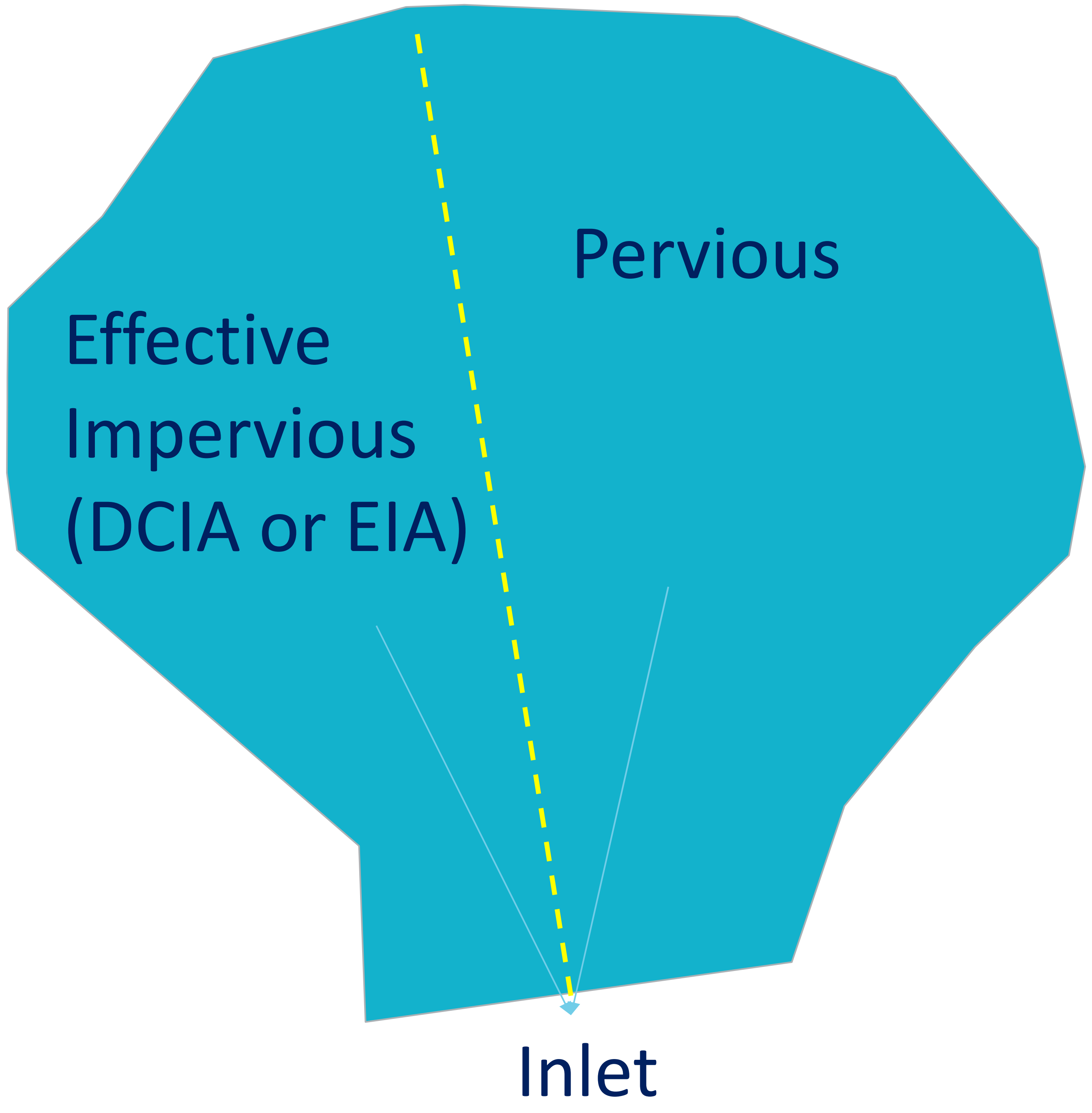
- 200-foot overland flow
- W = 1.67 ac / 200 ft = 364 ft

- Mitch's rule of thumb
- $W = 250 A^{0.6}$
- $W = 250 (1.67)^{0.6} = 340$ 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



<u>Parameters</u>

Area

Width

Imperviousness

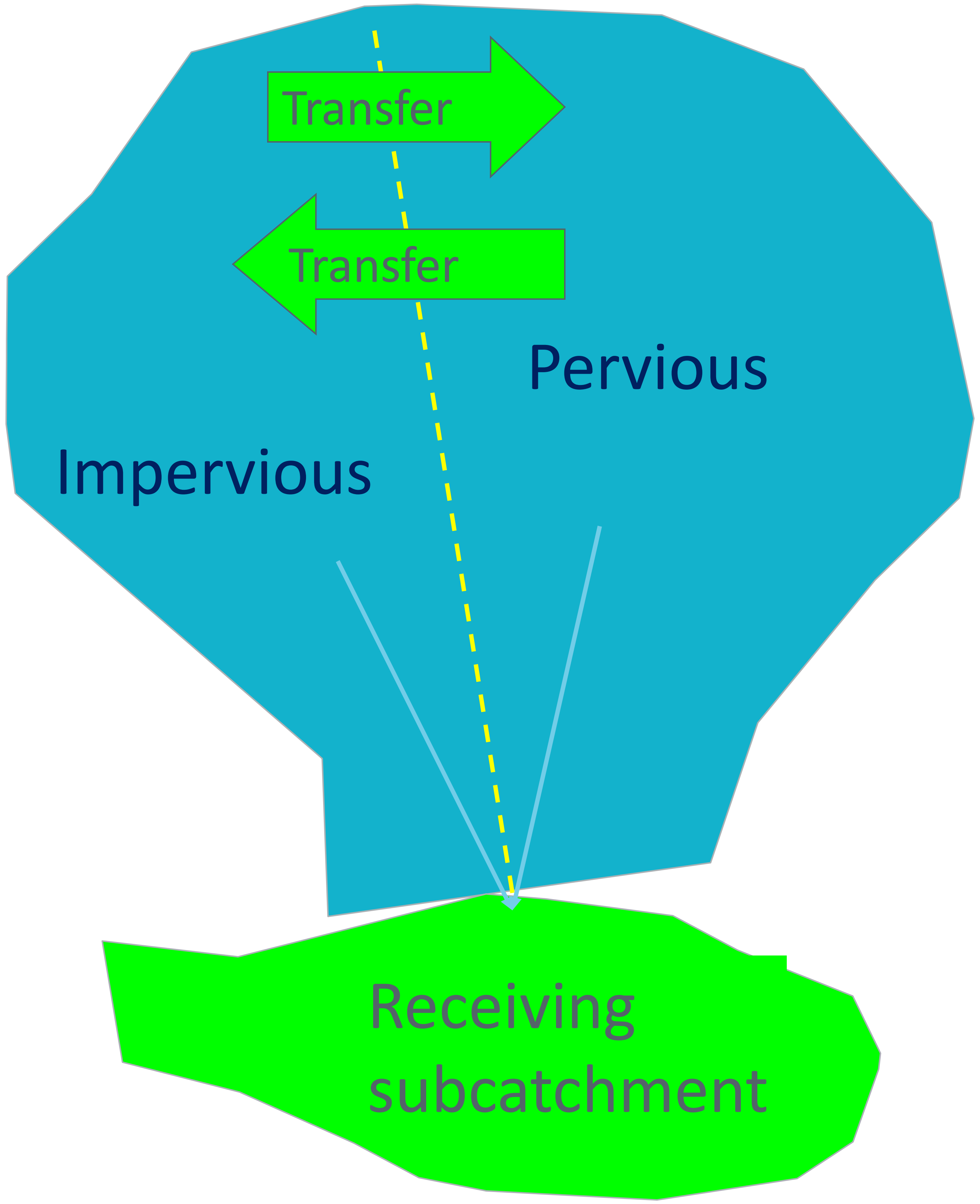
Slope

N (imp, perv)

D_s (imp, perv)

Soils parameters

Subcatchment routing options

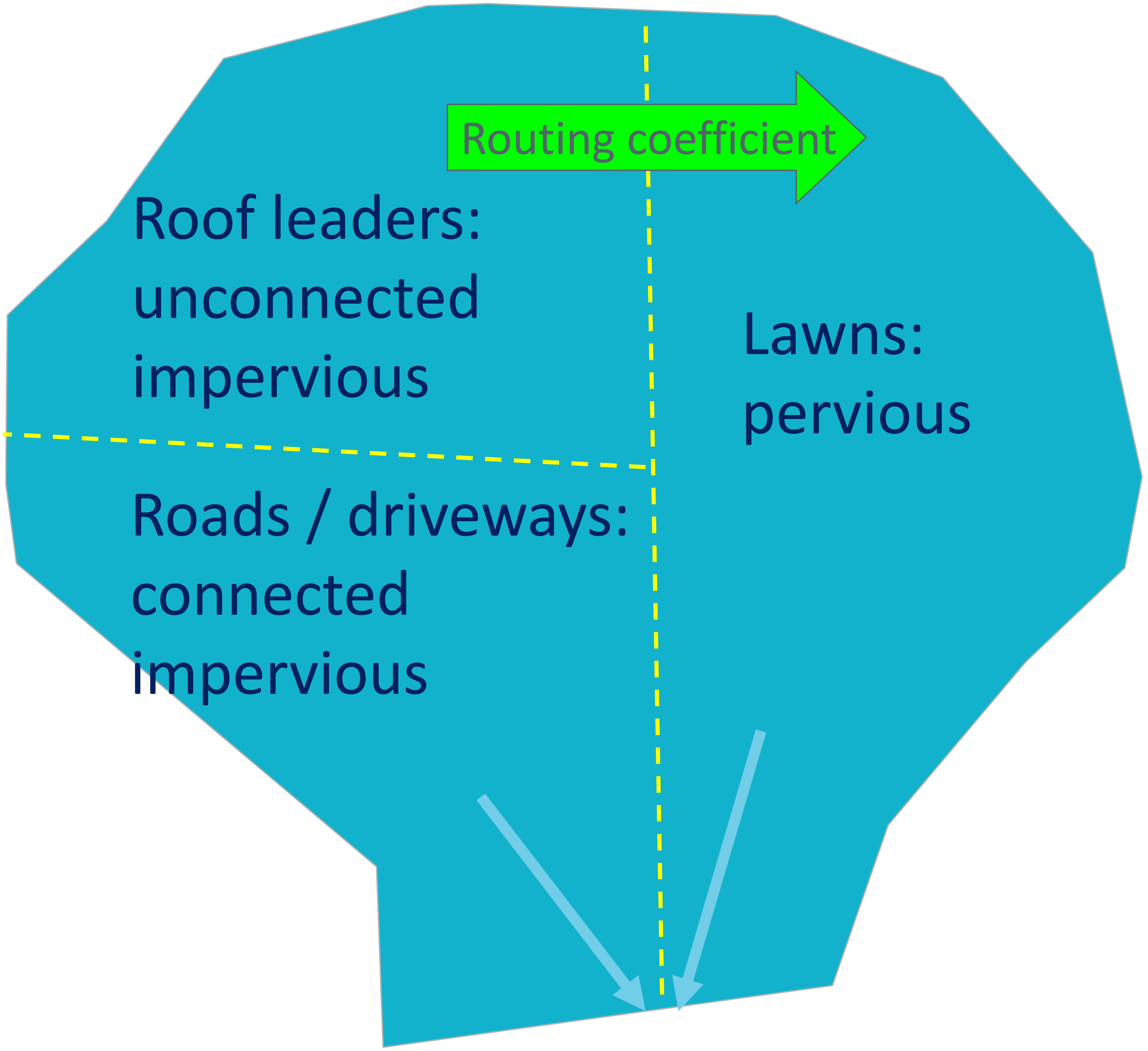


<u>Optional Parameters</u>

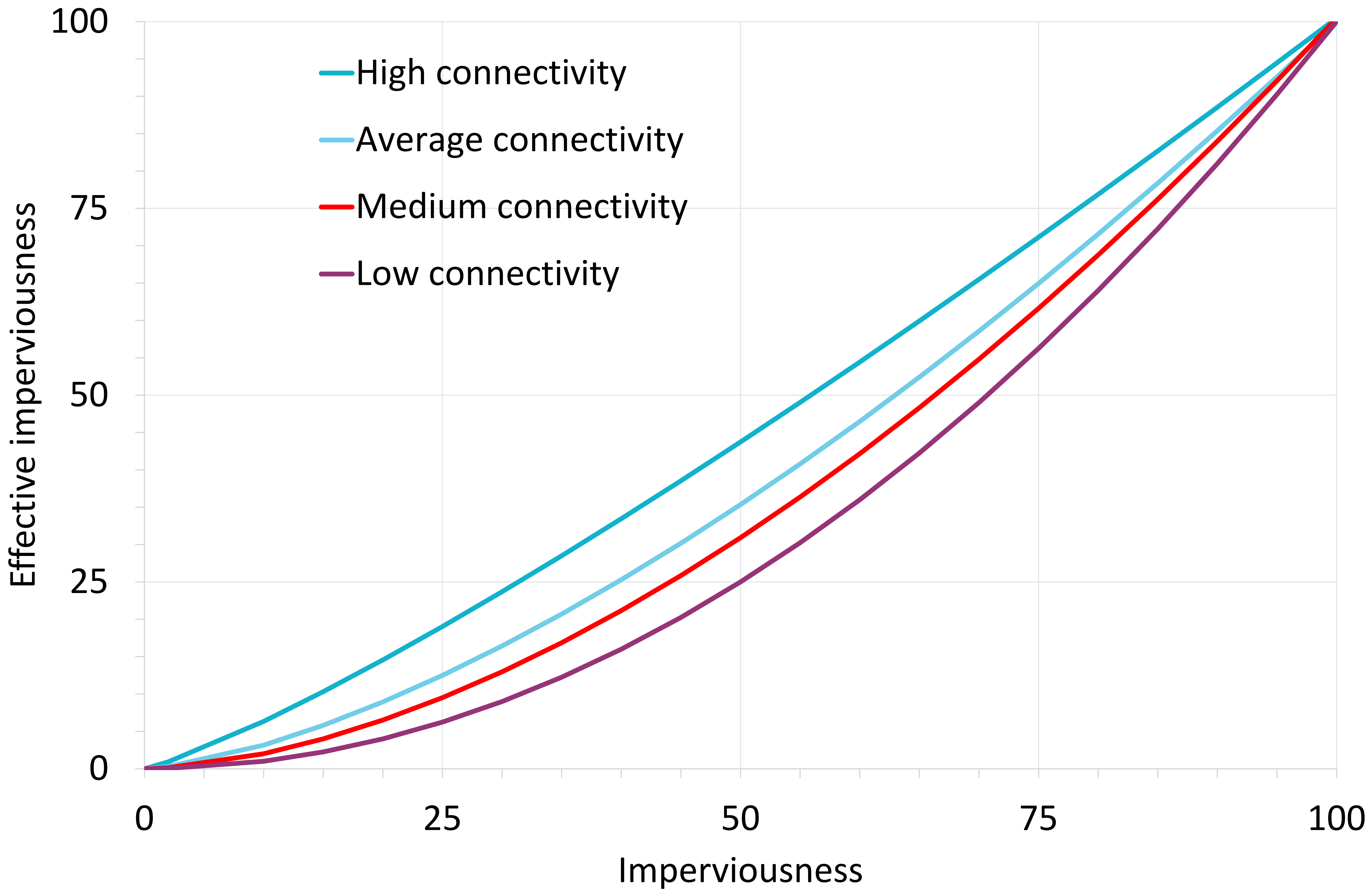
Internal transfer direction

Internal transfer fraction

Urban routing paradigm



Total and effective imperviousness



$EIA_H = 0.4 \times TIA_H^{1.2}$

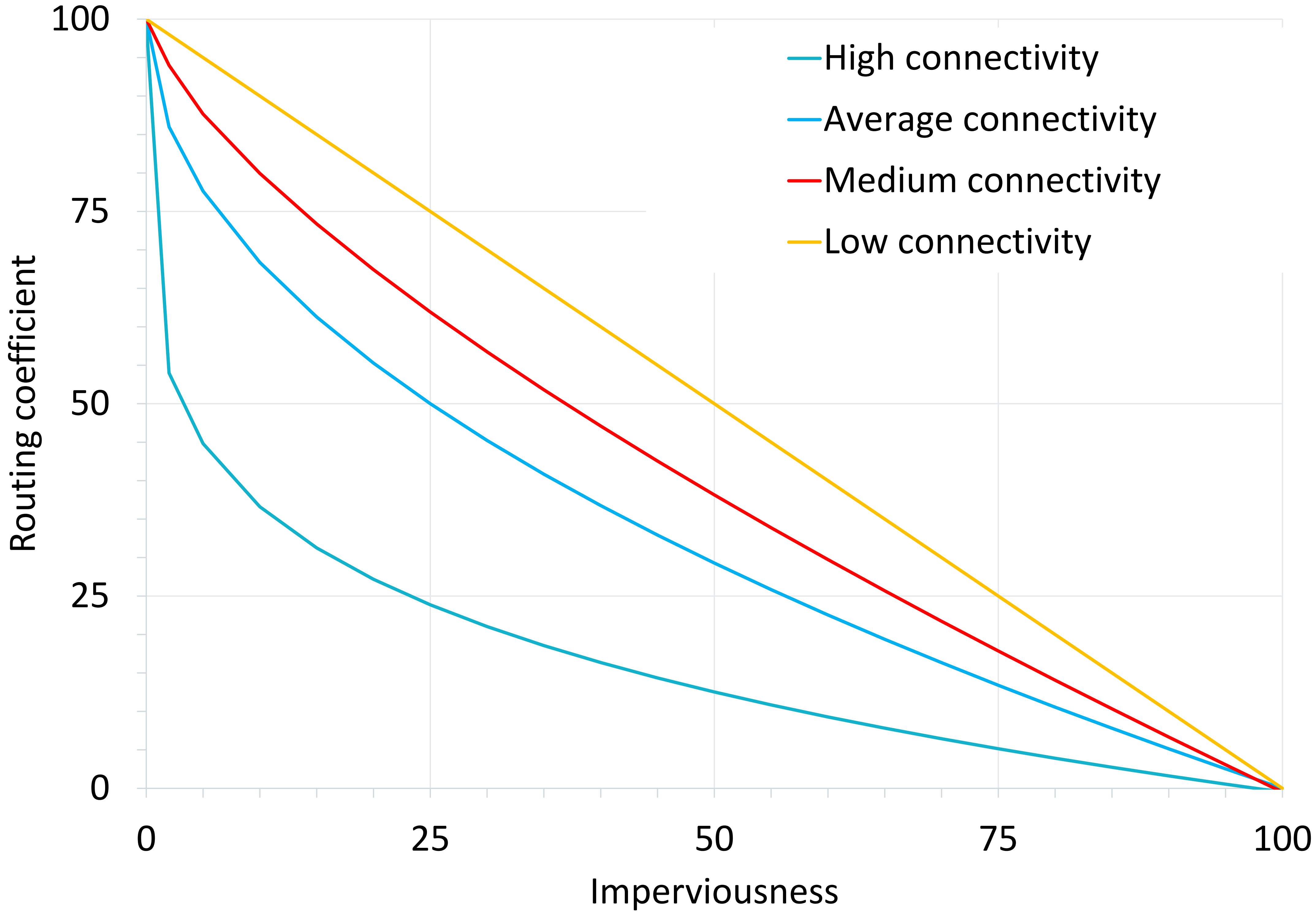
$EIA_A = 0.1 \times TIA_A^{1.5}$

$EIA_M = 0.04 \times TIA_M^{1.7}$

$EIA_L = 0.01 \times TIA_L^{2}$

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

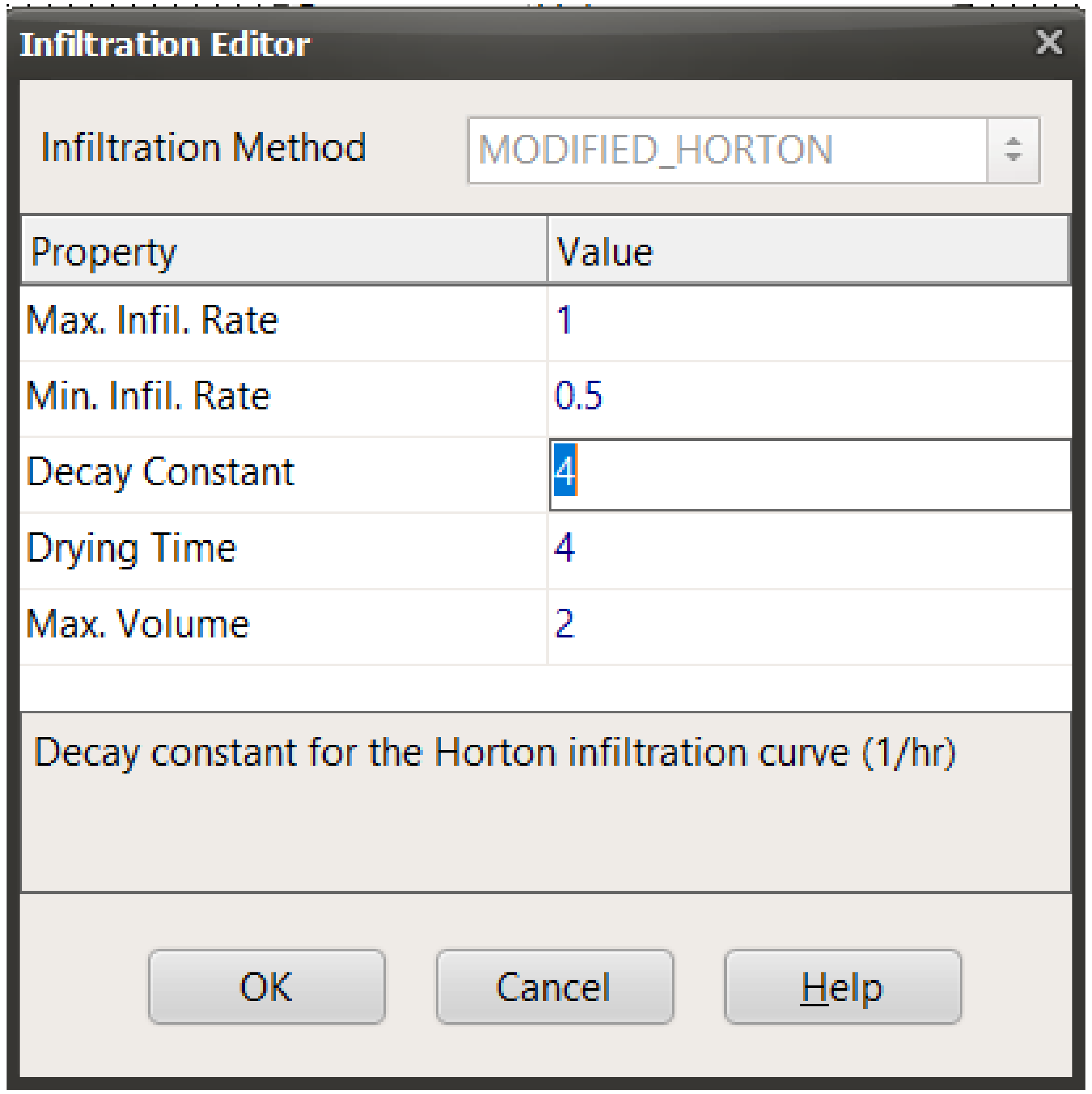
F = cumulative infiltration volume (in)

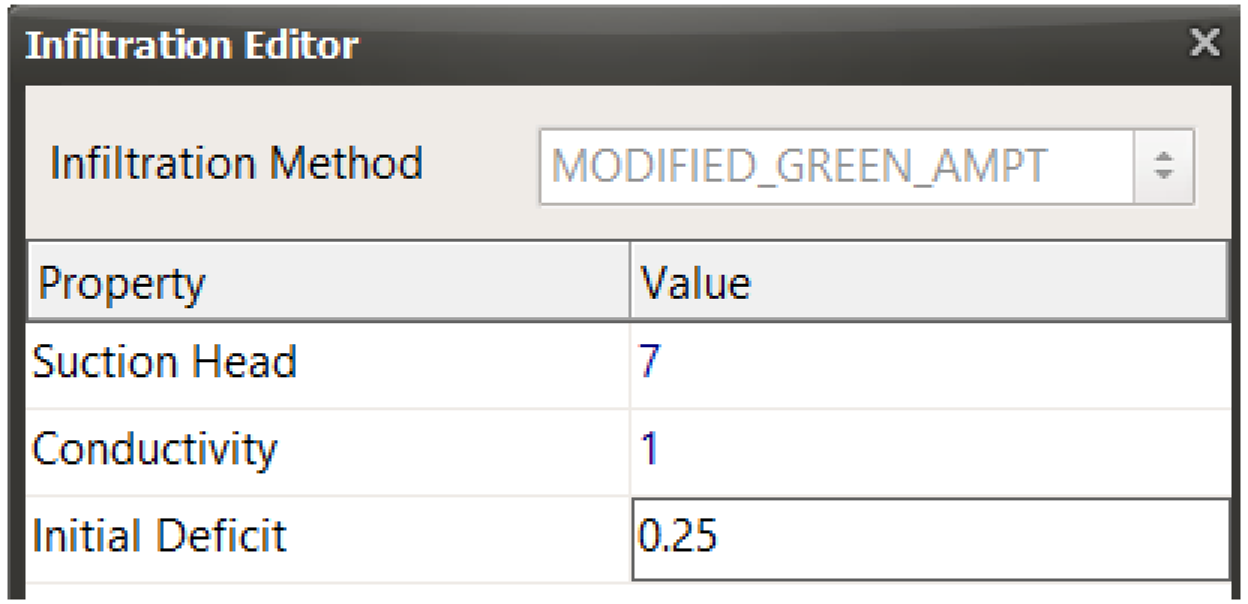
Sample Green-Ampt parameters

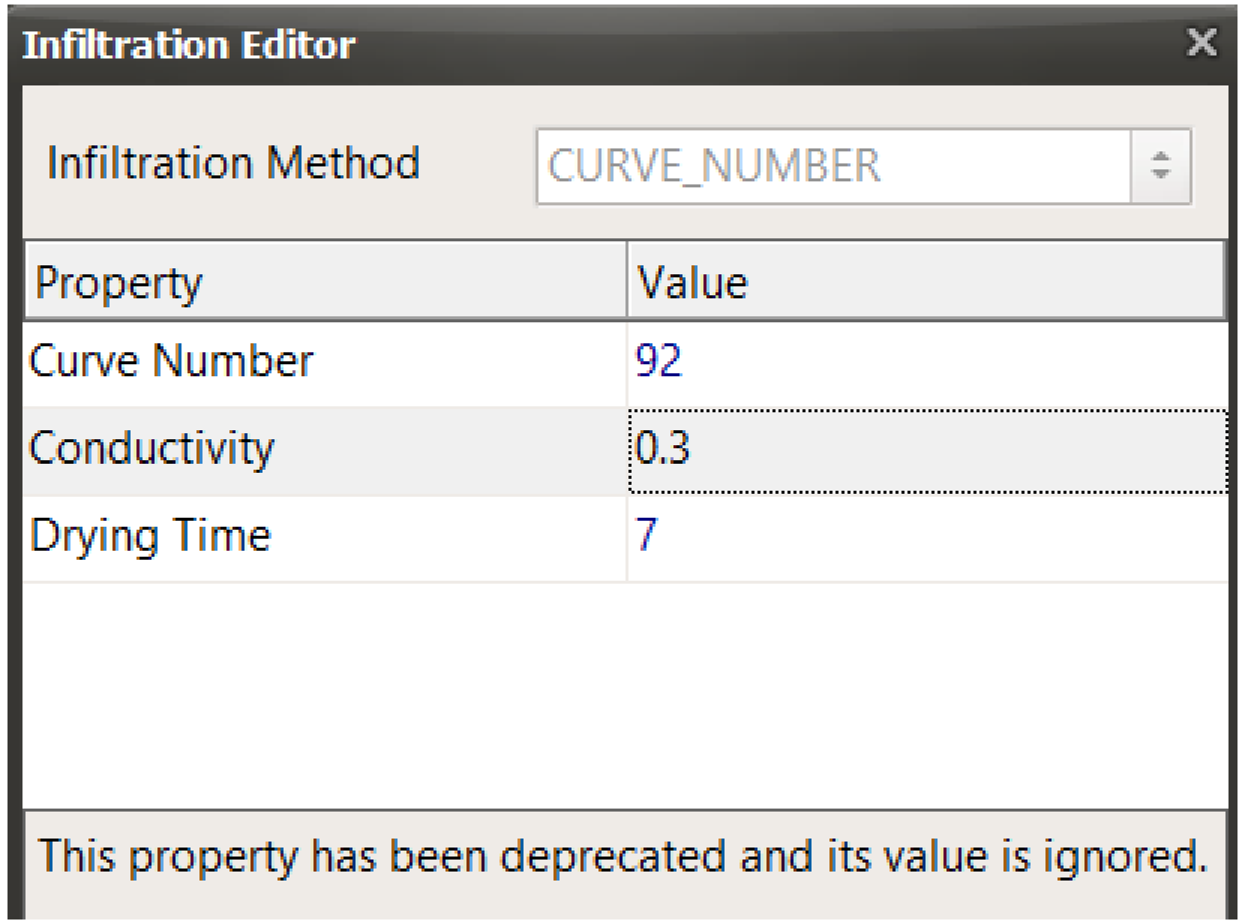
Soil class	Suction	Conductivity	Initial Deficit
Sand	1.95	4.74	0.34
Loamy sand	2.41	1.18	
Sandy loam	4.33	0.43	0.33
Loam	3.50	0.13	0.31
Silt loam	6.57	0.26	0.32
Sandy clay loam	8.60	0.06	
Clay loam	8.22	0.04	0.24
Silty clay loam	10.75	0.04	
Sandy clay	9.41	0.02	
Silty clay	11.50	0.02	
Clay	12.45	0.01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

SWMM hydrology manual Table 4.7 & 4.8

Infiltration dialog

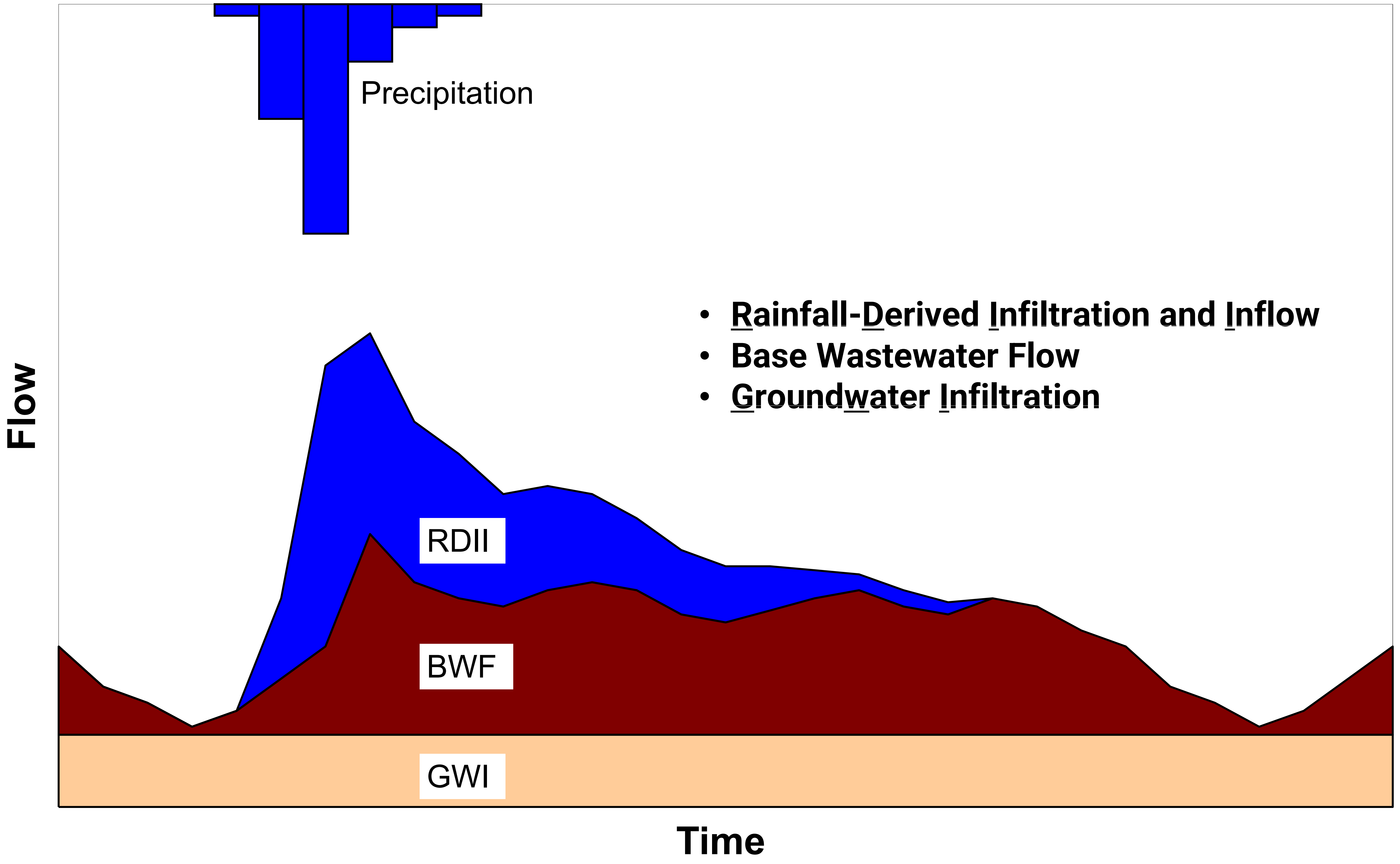







```
[INFILTRATION]
;;Subcatchment   Param1     Param2     Param3     Param4     Param5
;;-------------- ---------- ---------- ---------- ---------- ----------
4401_01          6.57       0.45       0.17       0          0
4401_02          8.6        0.25       0.14       0          0
```

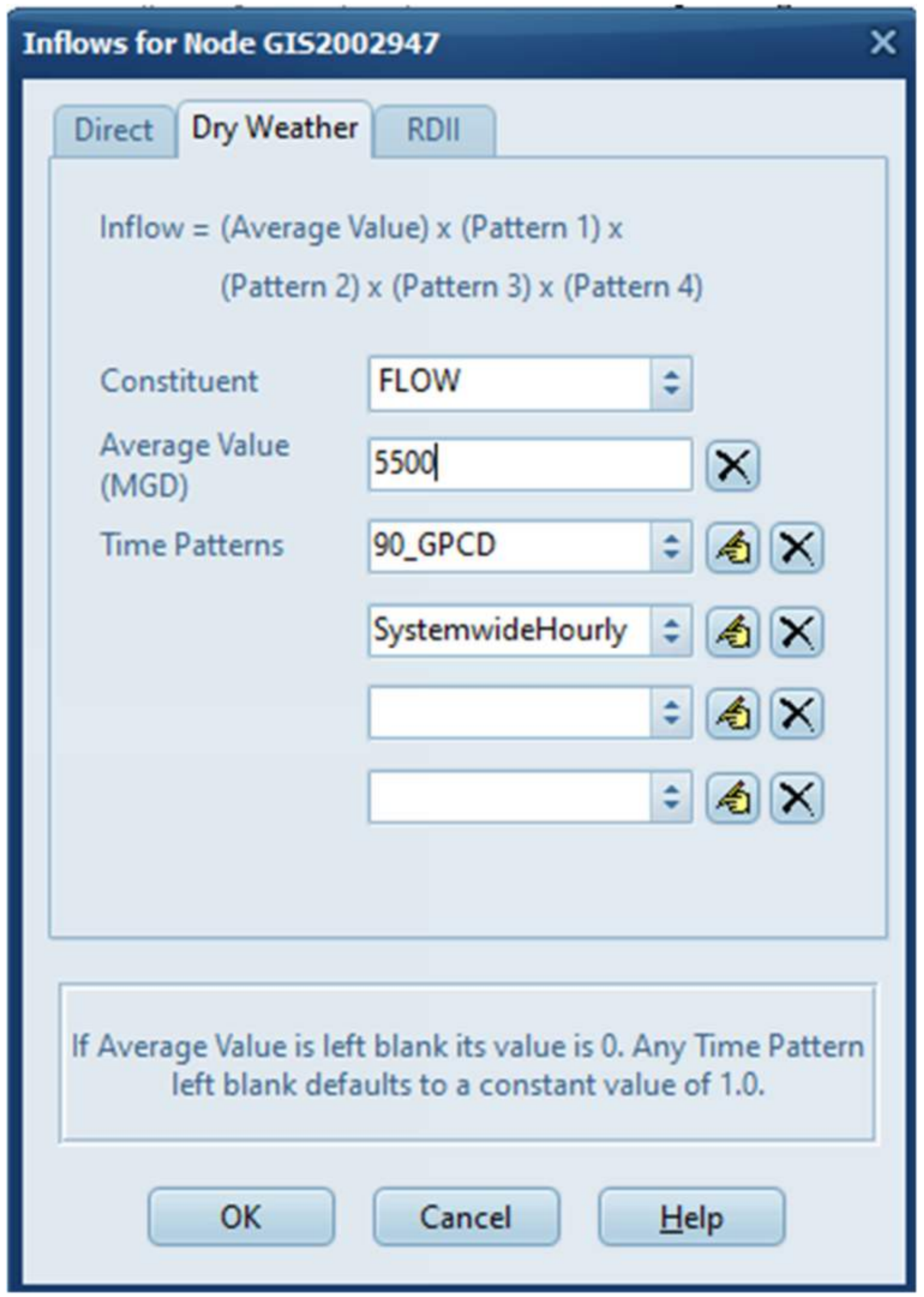
Sewer flow components

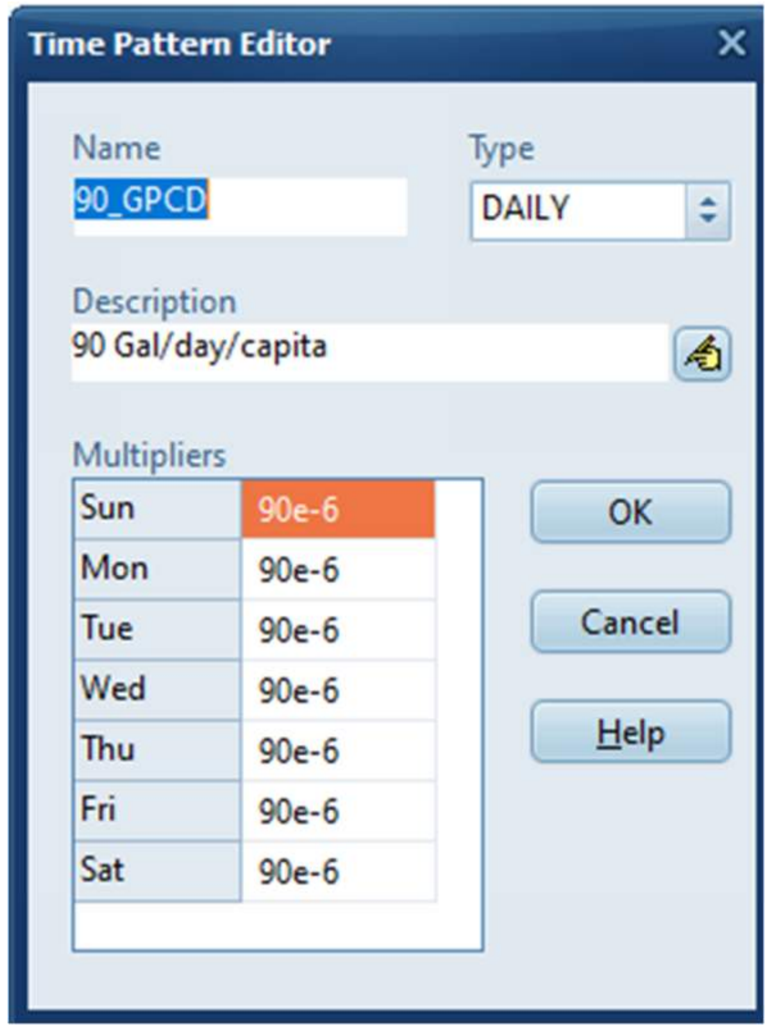


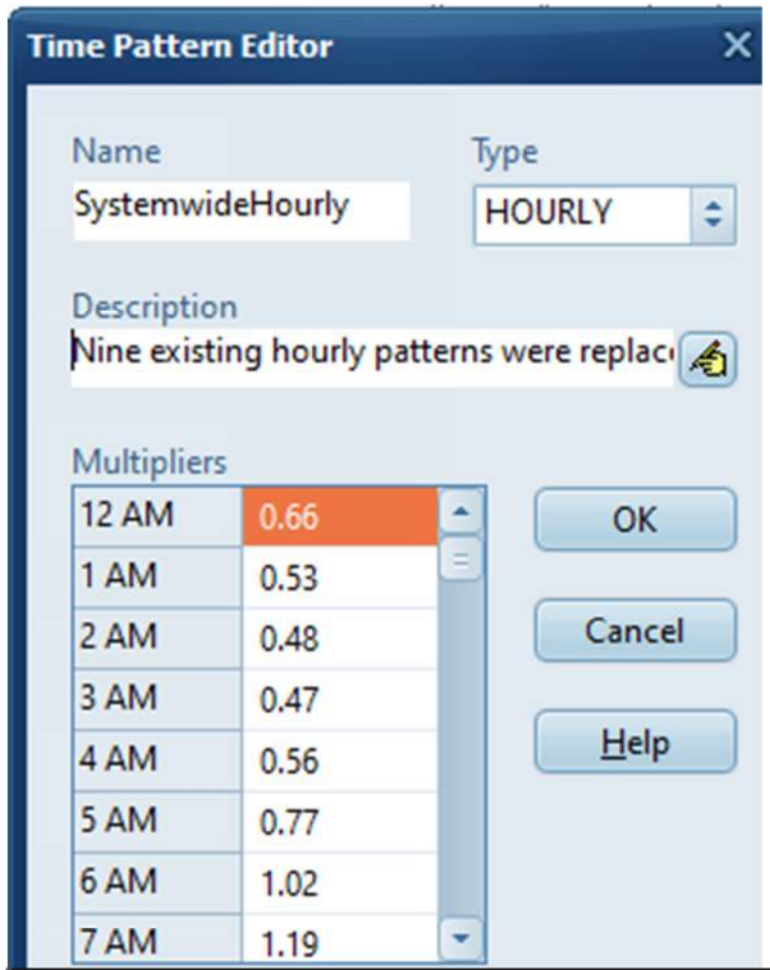
Sanitary flow

```
[DWF]
;;                                     Average    Time
;;Node           Parameter             Value      Patterns
;;-------------- ---------------- ---------- ----------
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  1.11

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





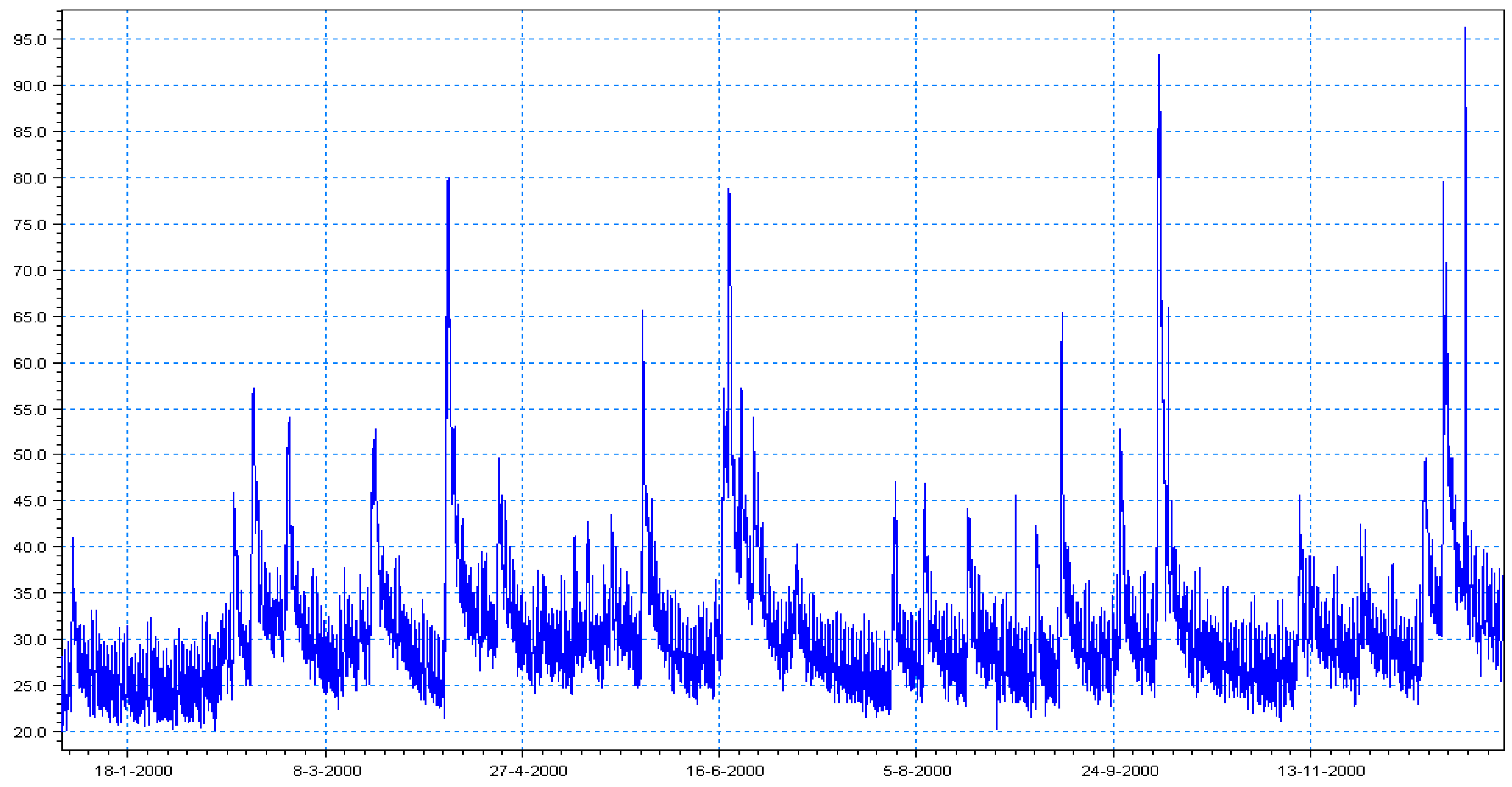


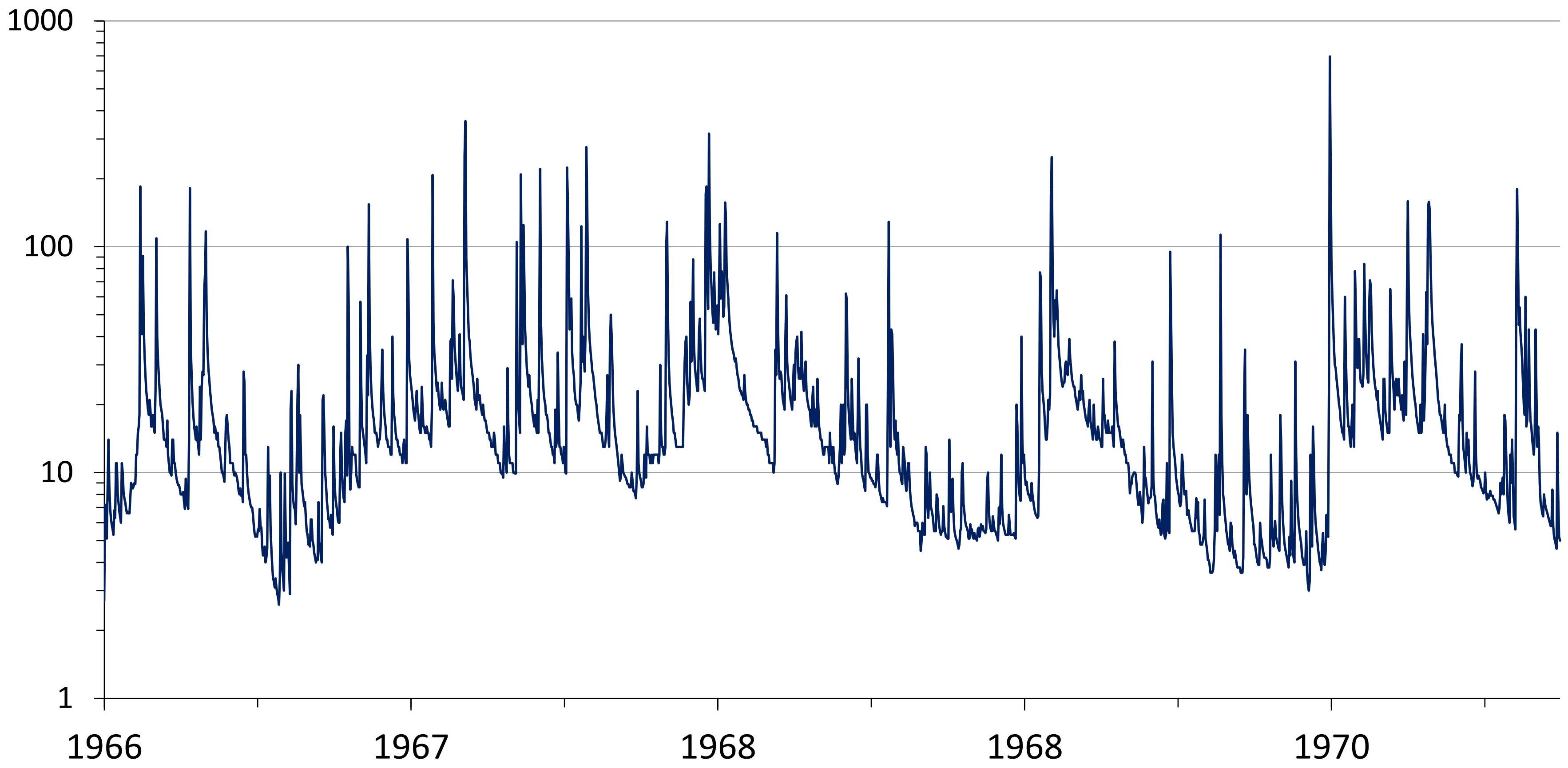

```
[DWF]
;;Node           Constituent      Baseline   Patterns
;;-------------- ---------------- ---------- ----------
GIS2002947       FLOW             5500       "90_GPCD" "SystemwideHourly" "" ""
CDM140           FLOW             95         "90_GPCD" "SystemwideHourly" "" ""
```

```
[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 75e-6
90_GPCD          DAILY      90e-6 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 100e-6
110_GPCD         DAILY      11e-5 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

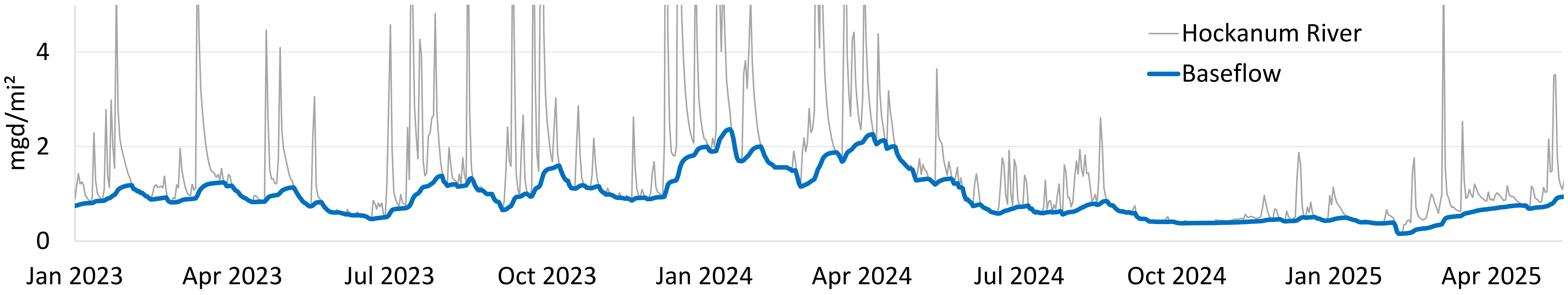




Infiltration modeling using timeseries

```
[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
```

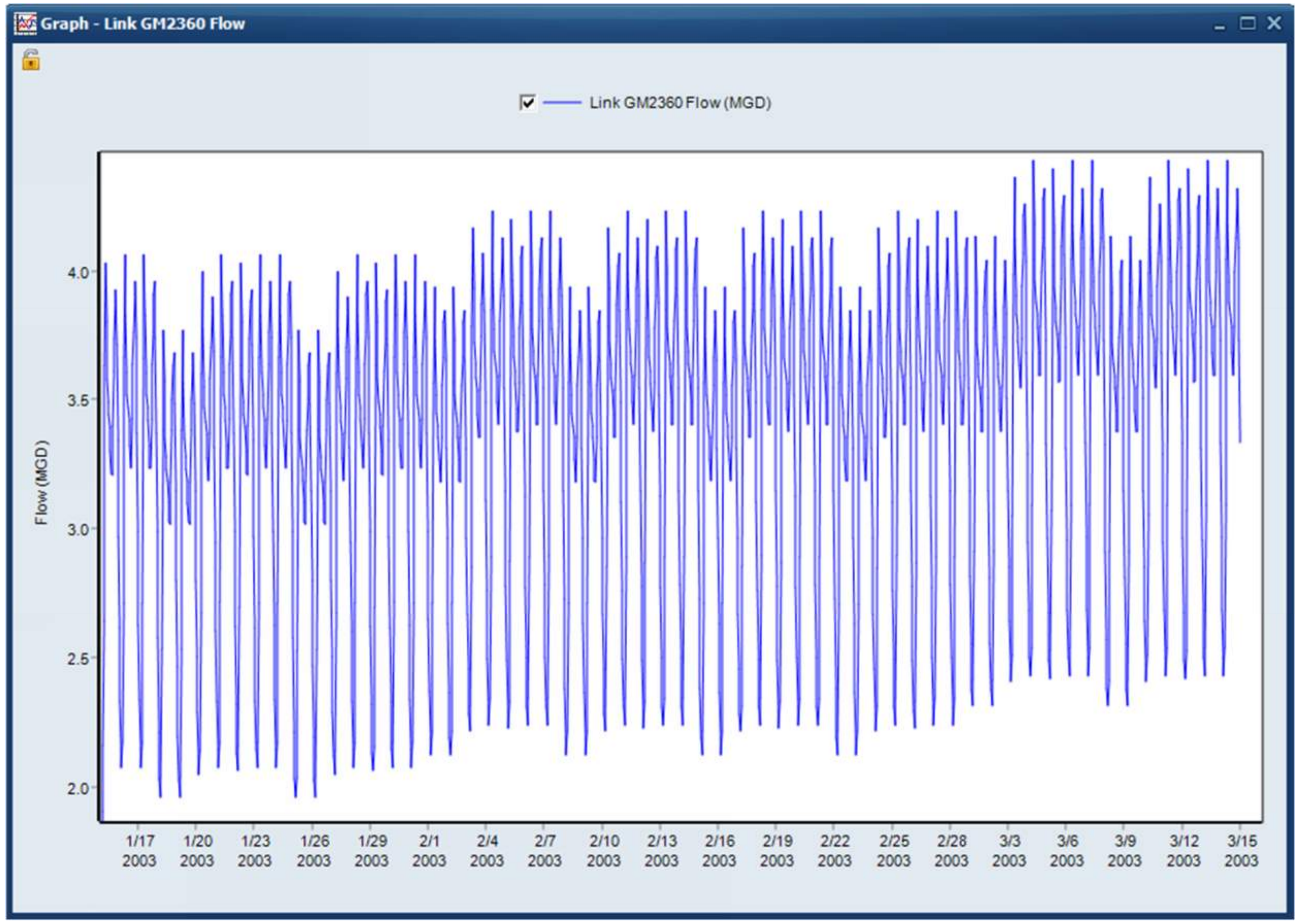


Infiltration modeling using patterns

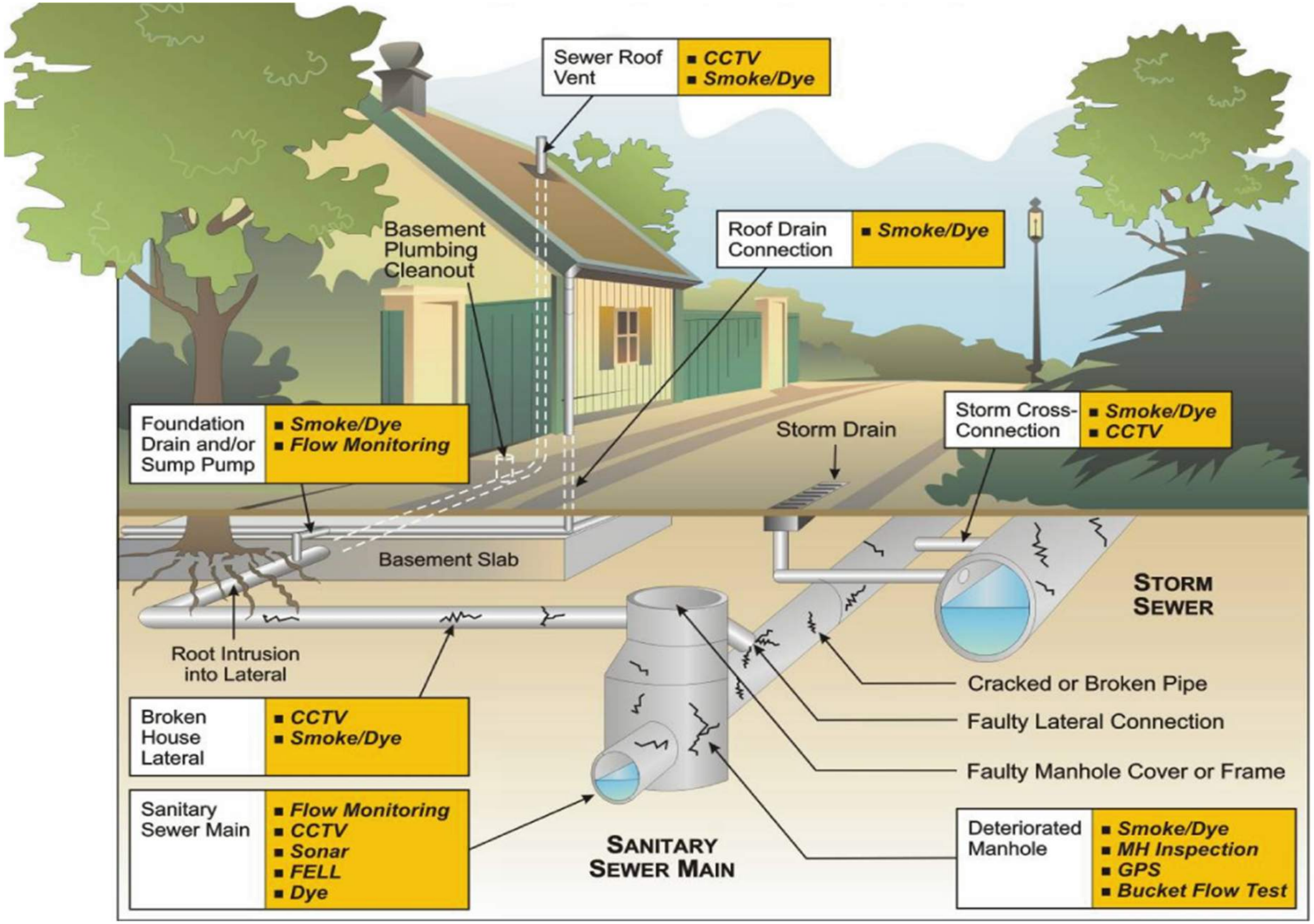
```
[INFLOWS]
;;                                                      Param    Units    Scale    Baseline Baseline
;;Node           Parameter        Time Series          Type     Factor   Factor   Value    Pattern
;;-------------- ---------------- ---------------- -------- -------- -------- --------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

```
[DWF]
;;                                Average    Time
;;Node           Parameter        Value      Patterns
;;-------------- ---------------- ---------- ----------
CDM1             FLOW             0.0003     "" "GNDaily" "DWF" ""
CDM10            FLOW             0.002618   "" "GNDaily" "DWF" ""
CDM11            FLOW             0.0003     "" "GNDaily" "DWF" ""
```

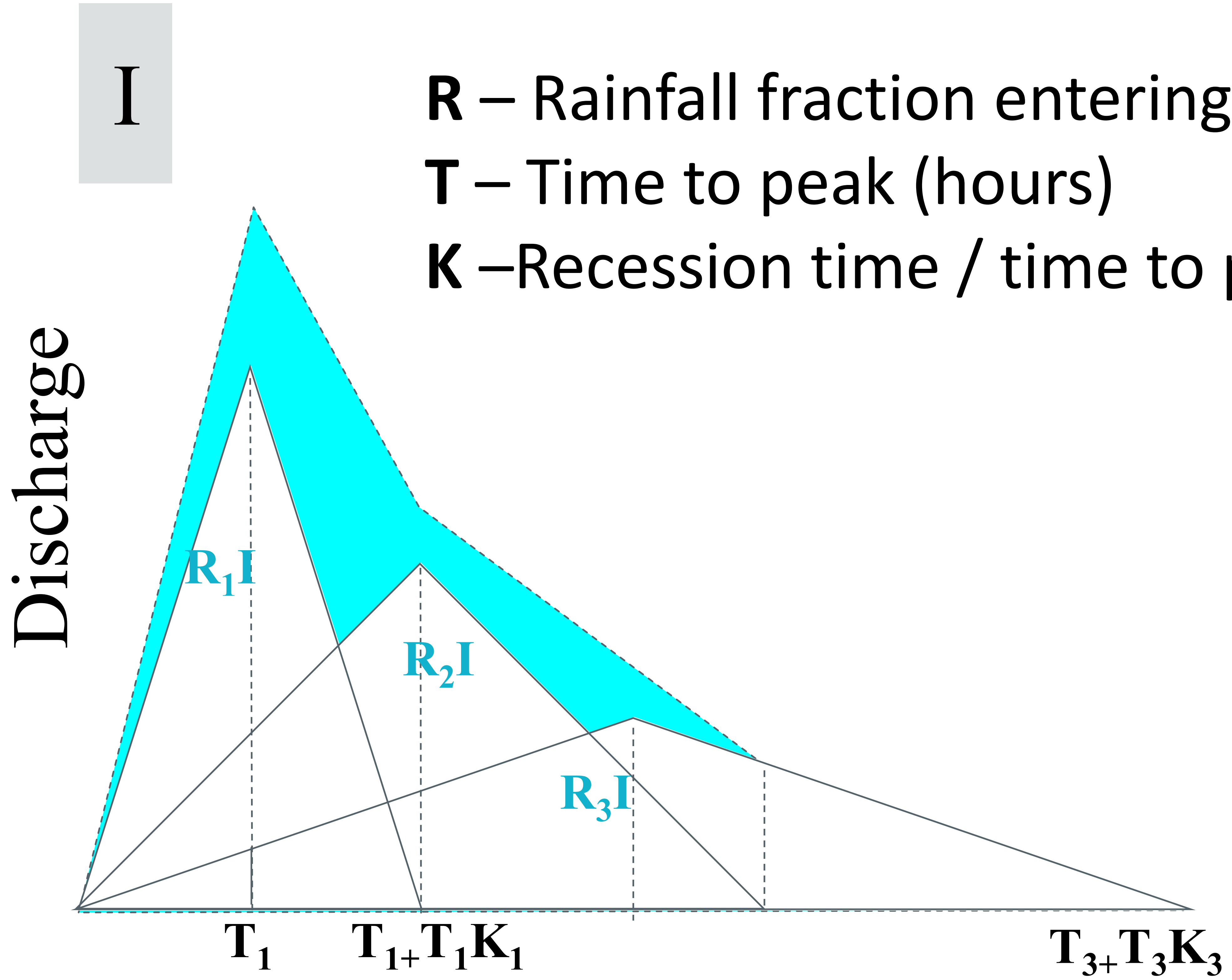
```
[PATTERNS]
;;Name           Type       Multipliers
;;-------------- ---------- ----------
DWF              HOURLY     0.65  0.56  0.52  0.53  0.64  1.04
DWF                          1.37  1.3   1.13  1.12  1.08  1.08
DWF                          1.04  1     0.97  1.01  1.14  1.18
DWF                          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
Infiltration                 0.74  0.8   0.78  0.72  0.72  0.92
```



Sanitary sewer I/I



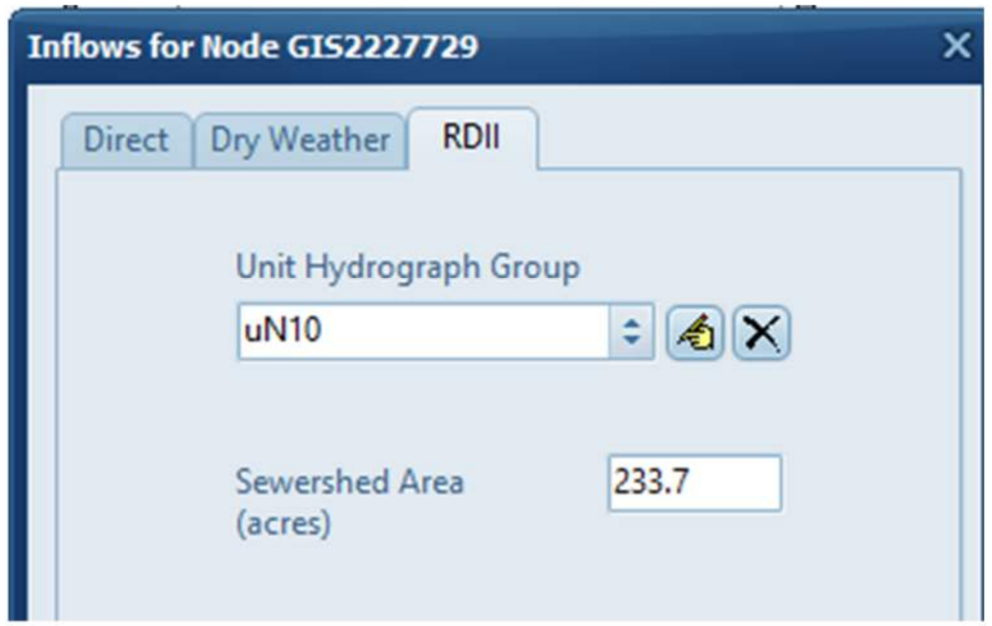
RTK method

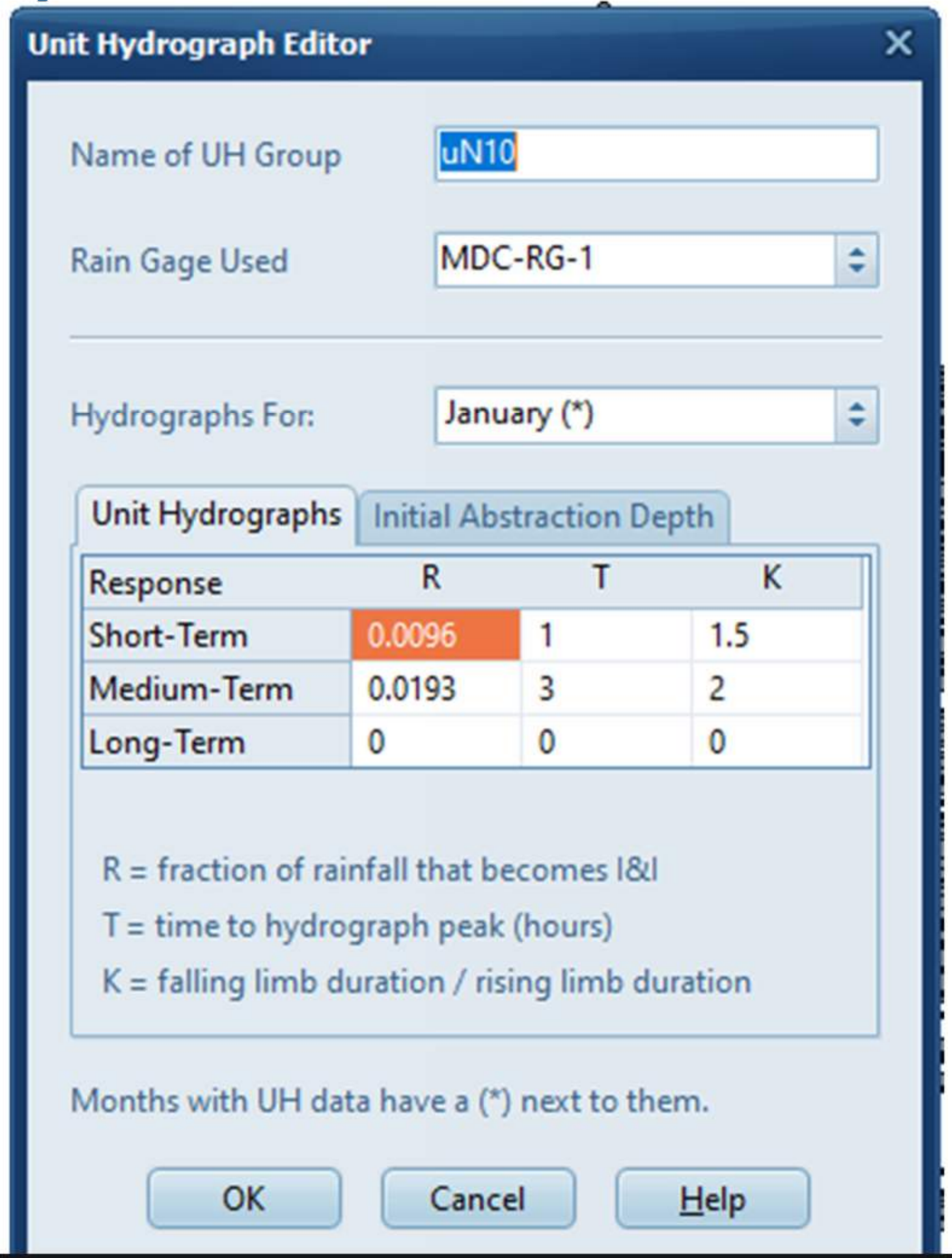


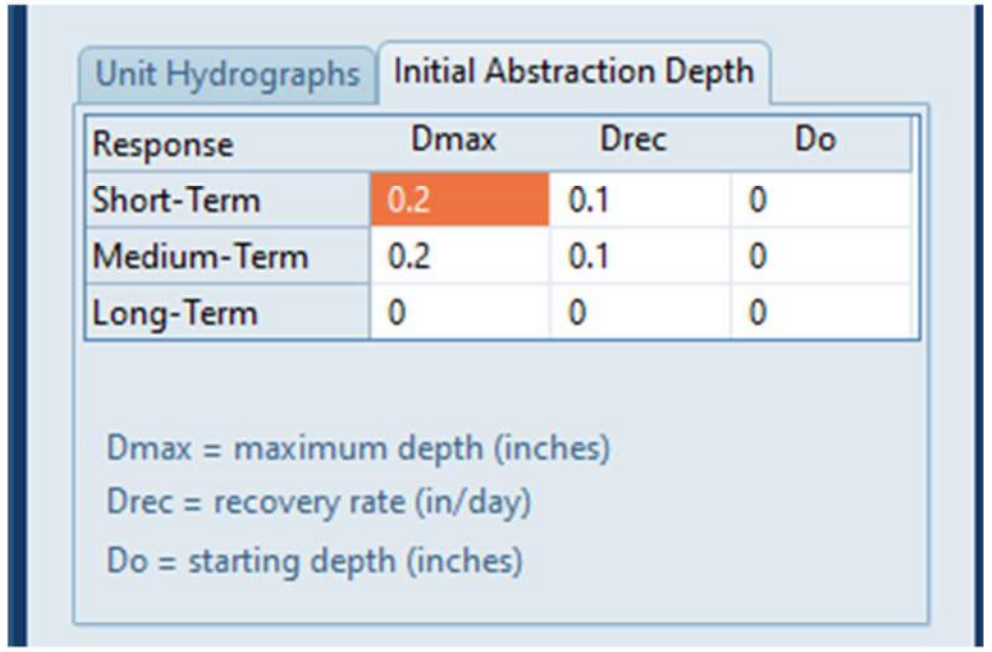
R – Rainfall fraction entering sewers
T – Time to peak (hours)
K –Recession time / time to peak

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

Unit hydrograph parameters

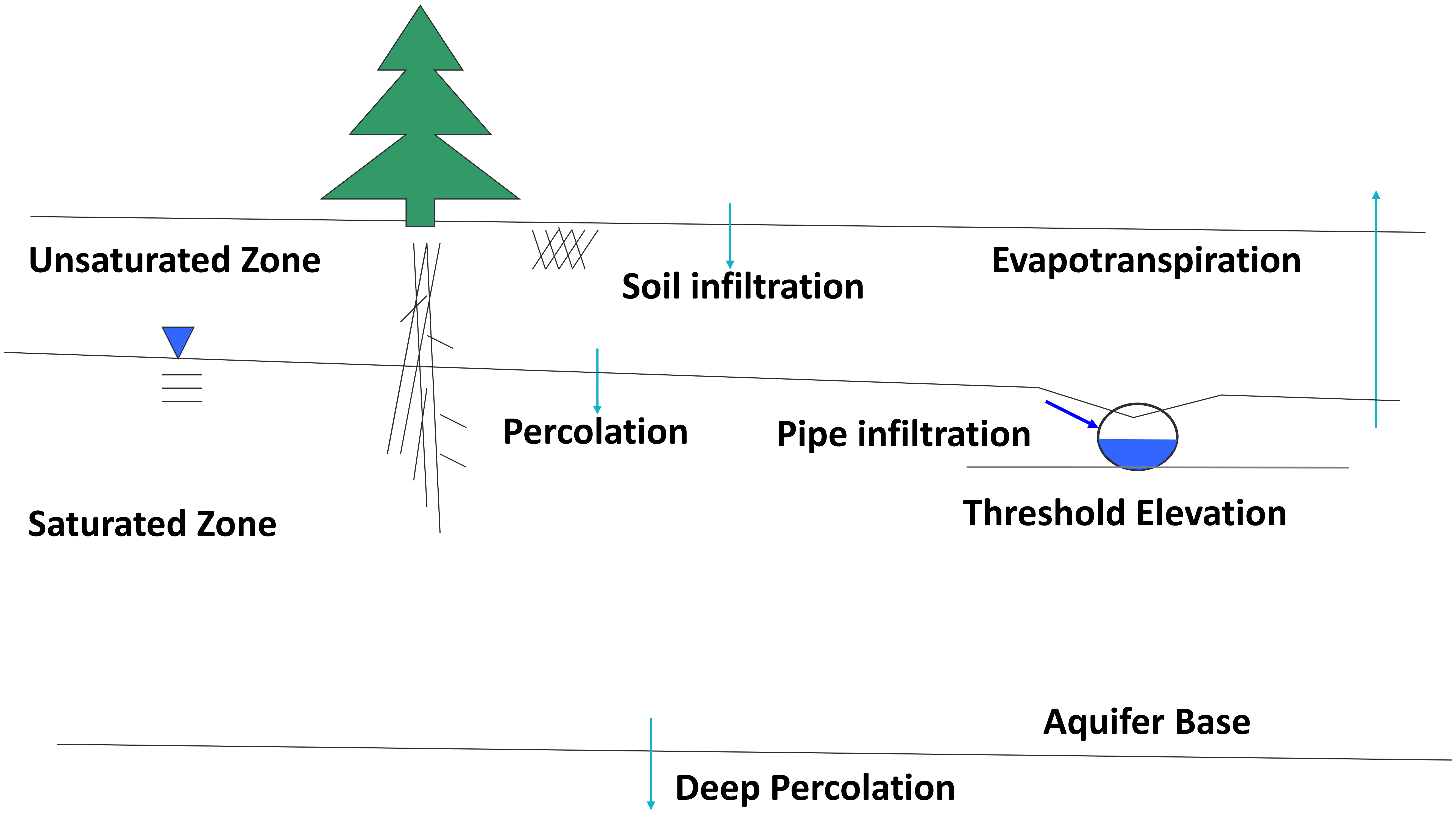







```
[HYDROGRAPHS]
;;Hydrograph      Rain Gage/Month  Response R        T        K        Dmax     Drecov   Dinit
;;-------------- ---------------- -------- -------- -------- -------- -------- -------- --------
uN10             MDC-RG-1
uN10             Jan              Short    0.0096   1        1.5      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

$$Q = A1(Hgw - E)^{B1} \cancel{- A2(Hsw - E)^{B2} + A3(Hgw \times Hsw)}$$

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
Upper Evap. Pattern	

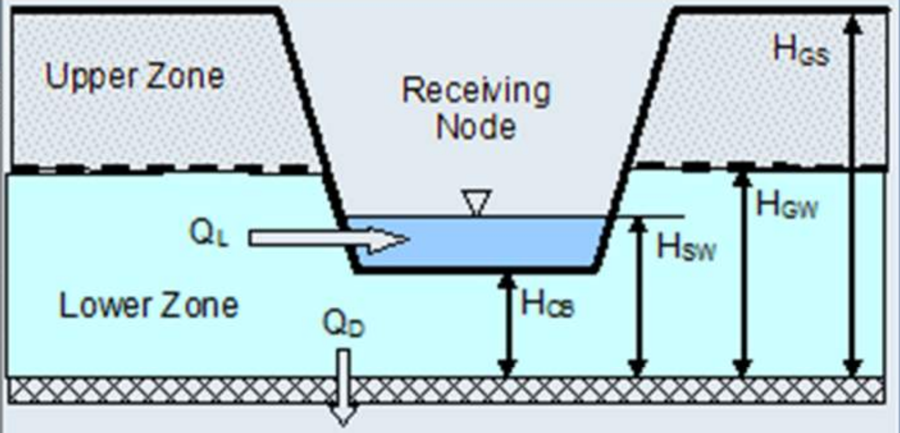
User-assigned aquifer name

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.



The standard equation for lateral groundwater flow is:

QL = A1 * (Hgw - Hcb)^B1
- A2 * (Hsw - Hcb)^B2
+ A3 * Hgw * Hsw

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

The standard equation for deep groundwater flow is:

QD = LGLR * Hgw / Hgs

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

OK Cancel Help

```
[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
```

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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