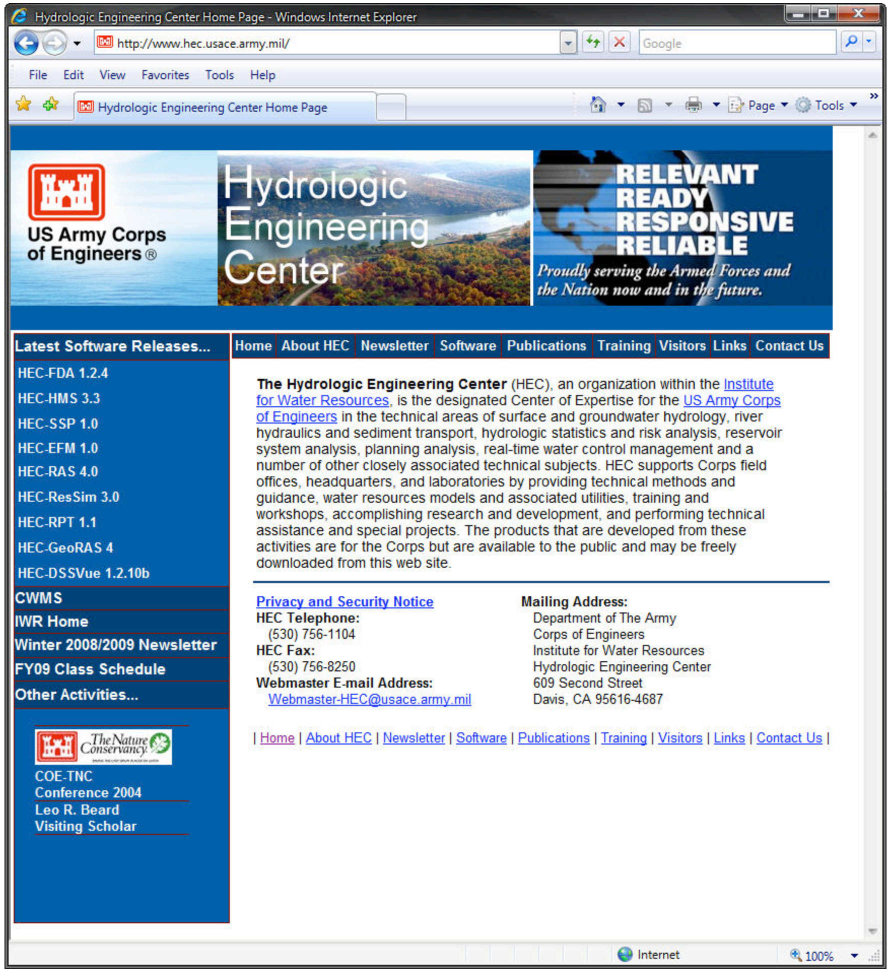
Where to get the Software and Documentation

http://www.hec.usace.army.mil/



Latest Software Releases...

- HEC-FDA 1.2.4
- HEC-HMS 3.3
- HEC-SSP 1.0
- HEC-EFM 1.0
- HEC-RAS 4.0
- HEC-ResSim 3.0
- HEC-RPT 1.1
- HEC-GeoRAS 4
- HEC-DSSVue 1.2.10b

CWMS
IWR Home
Winter 2008/2009 Newsletter
FY09 Class Schedule
Other Activities...

COE-TNC
Conference 2004
Leo R. Beard
Visiting Scholar

The Hydrologic Engineering Center (HEC), an organization within the Institute for Water Resources, is the designated Center of Expertise for the US Army Corps of Engineers in the technical areas of surface and groundwater hydrology, river hydraulics and sediment transport, hydrologic statistics and risk analysis, reservoir system analysis, planning analysis, real-time water control management and a number of other closely associated technical subjects. HEC supports Corps field offices, headquarters, and laboratories by providing technical methods and guidance, water resources models and associated utilities, training and workshops, accomplishing research and development, and performing technical assistance and special projects. The products that are developed from these activities are for the Corps but are available to the public and may be freely downloaded from this web site.

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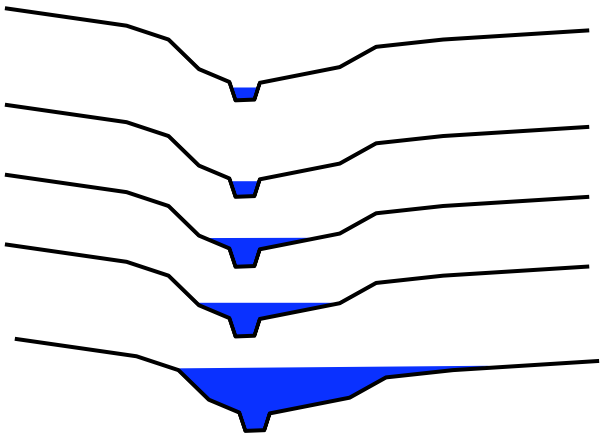
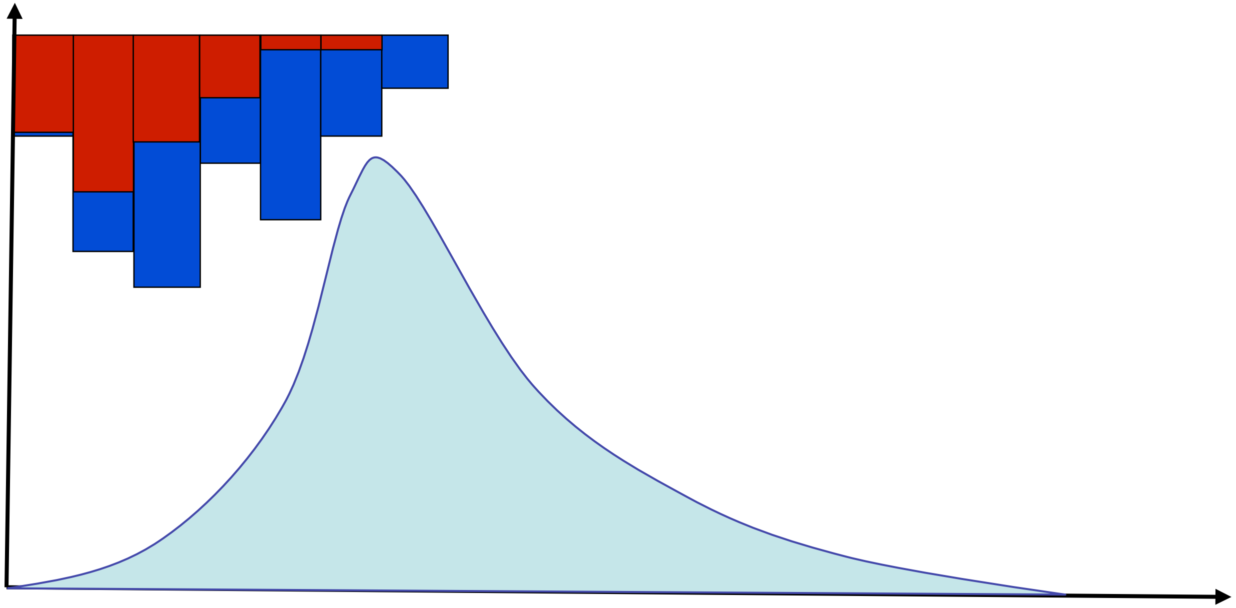
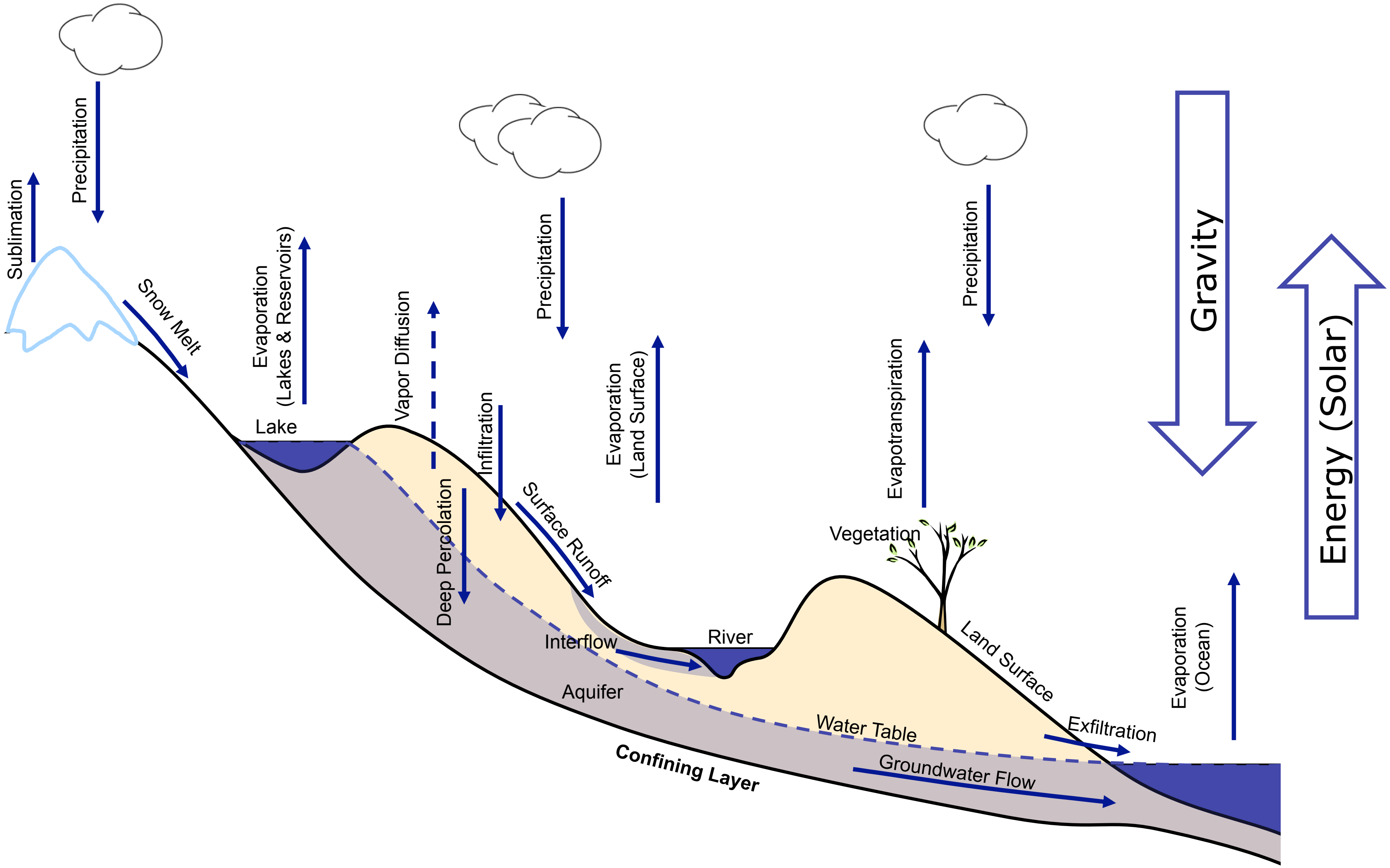
HMS: Hydrologic Modeling System
SSP: Statistical Software Package
EFM: Ecological Functions Model
RAS: River Analysis System
RES-SIM: Reservoir Systems Simulation
DSS-Vue: Data Storage System Viewer

Flood, Fargo Moorhead (ND, 2001)

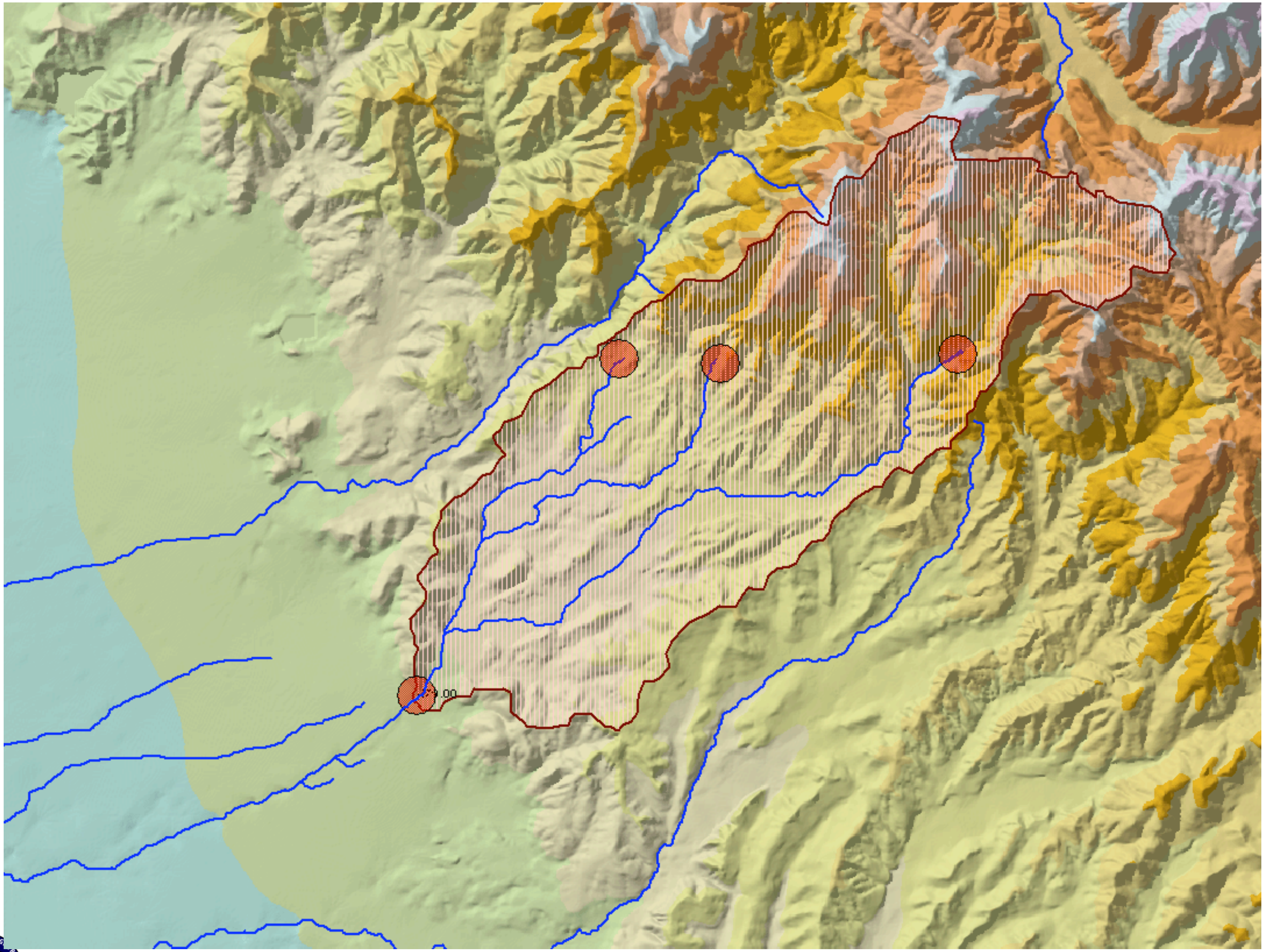




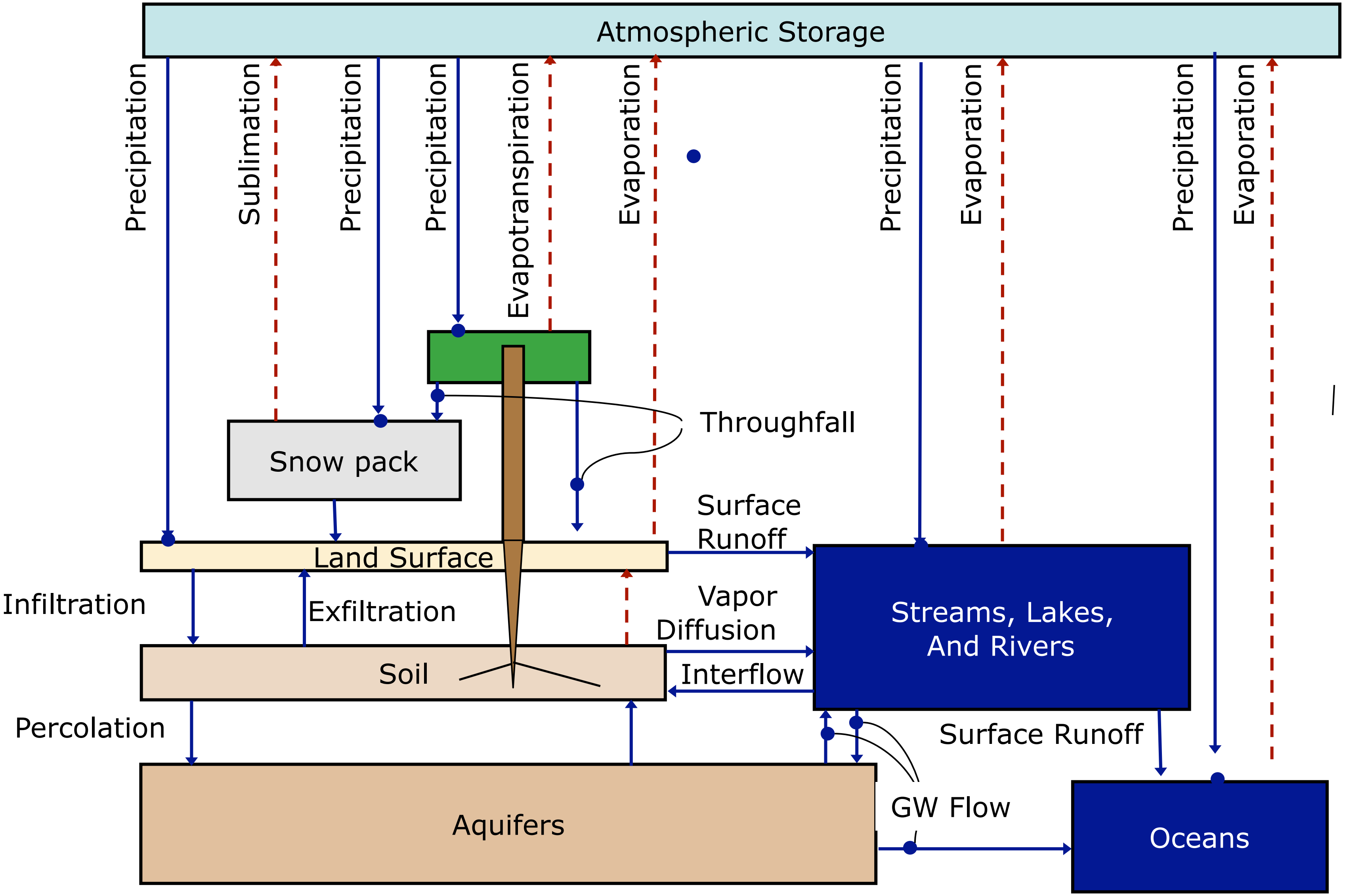

Sublimation
Precipitation
Snow Melt
Evaporation (Lakes & Reservoirs)
Lake
Vapor Diffusion
Precipitation
Infiltration
Deep Percolation
Surface Runoff
Evaporation (Land Surface)
Interflow
River
Aquifer
Confining Layer
Evapotranspiration
Precipitation
Vegetation
Land Surface
Water Table
Exfiltration
Groundwater Flow
Evaporation (Ocean)
Gravity
Energy (Solar)

Ponce, 1989

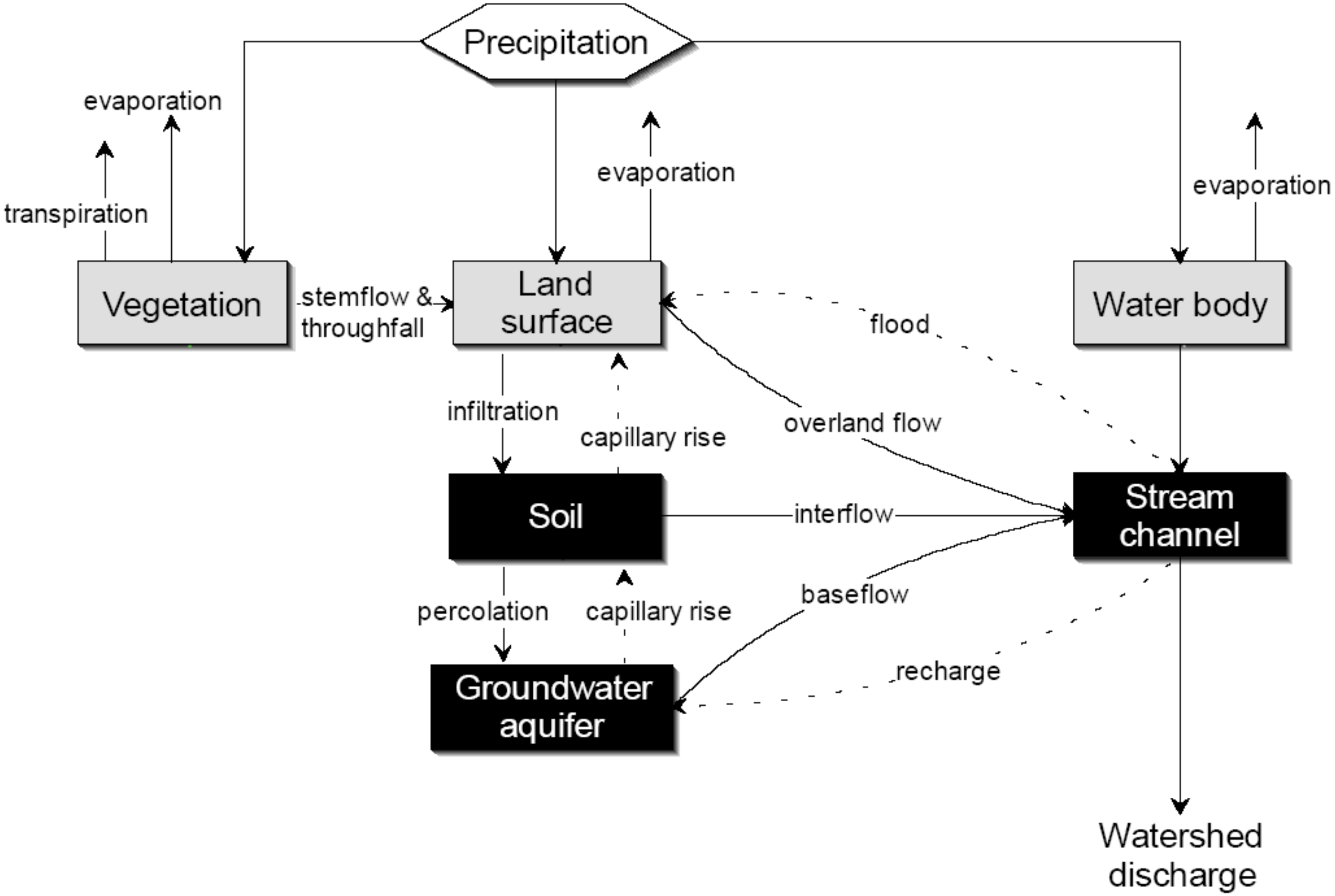
Trace The Water Drop



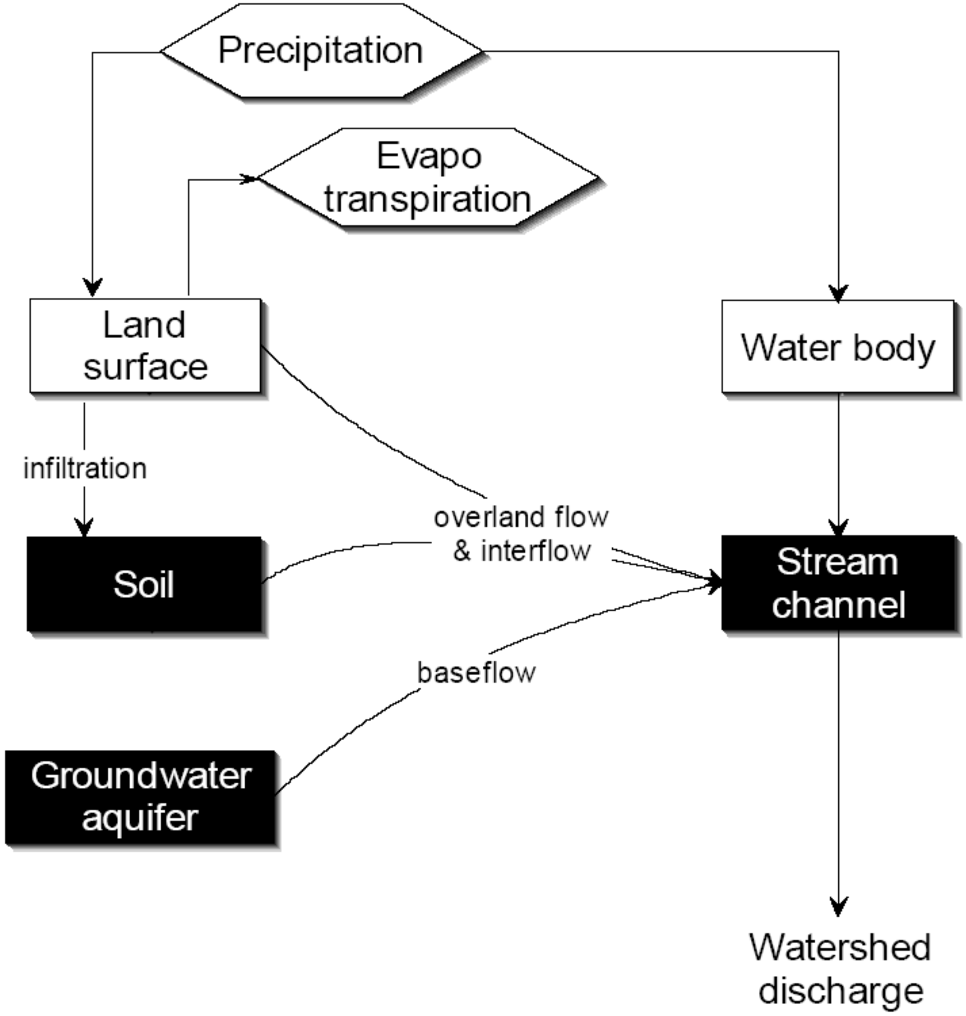
The Hydrologic Cycle: Compartments

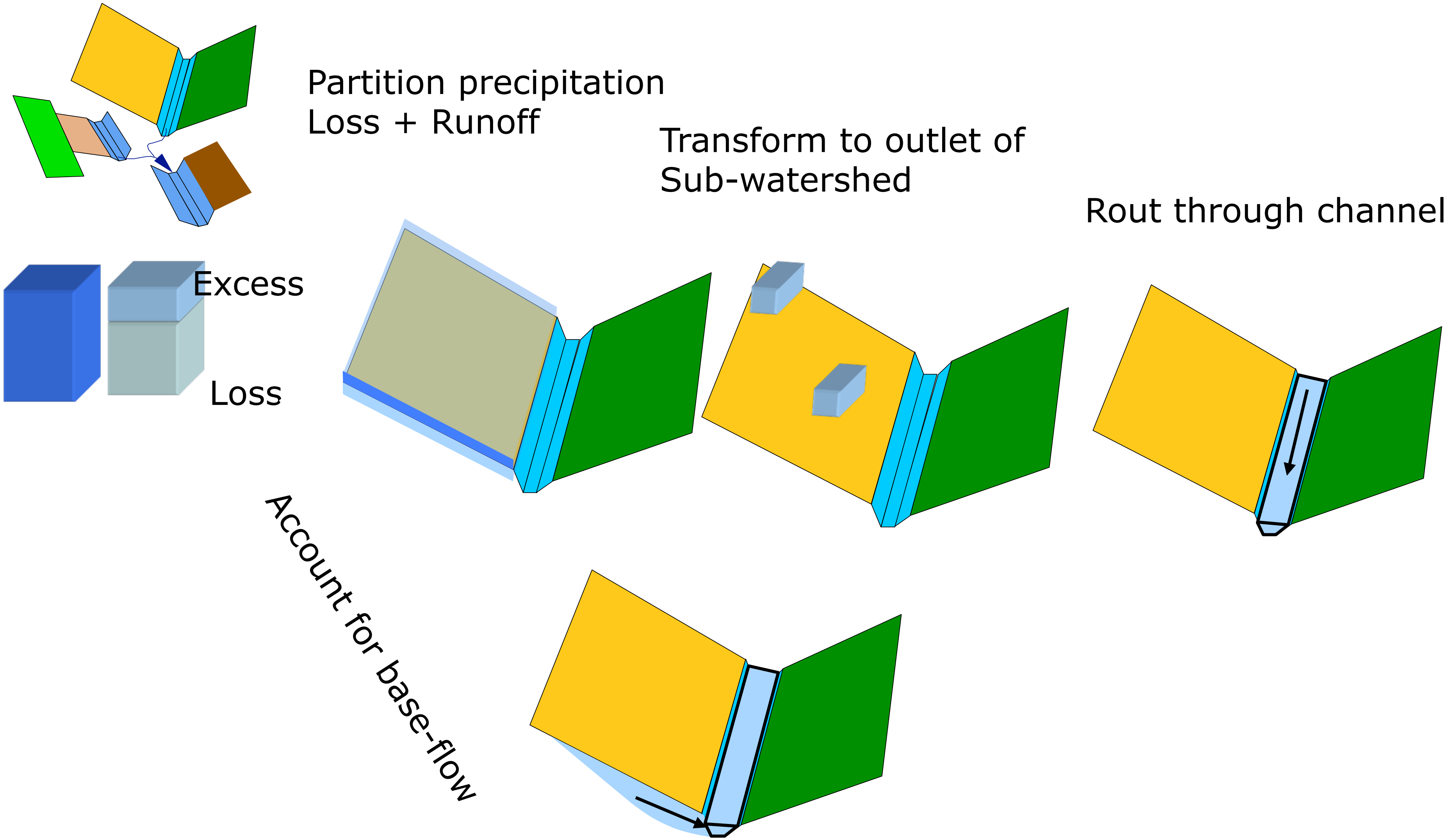


System representation



HEC's System representation





Partition precipitation
Loss + Runoff

Excess

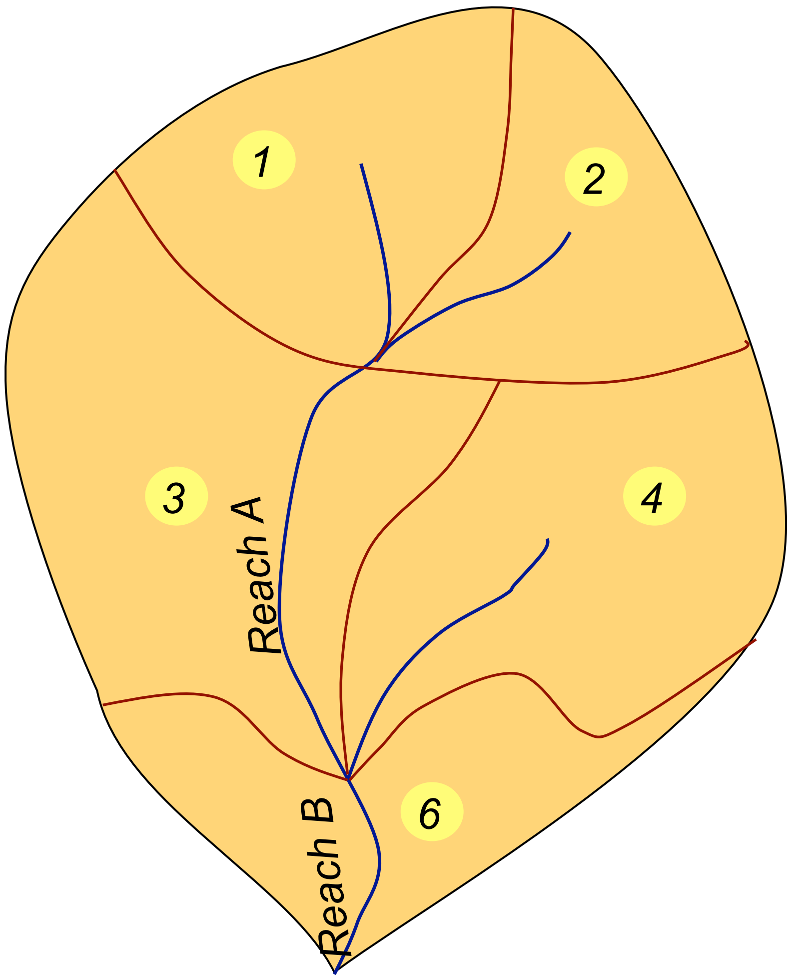
Loss

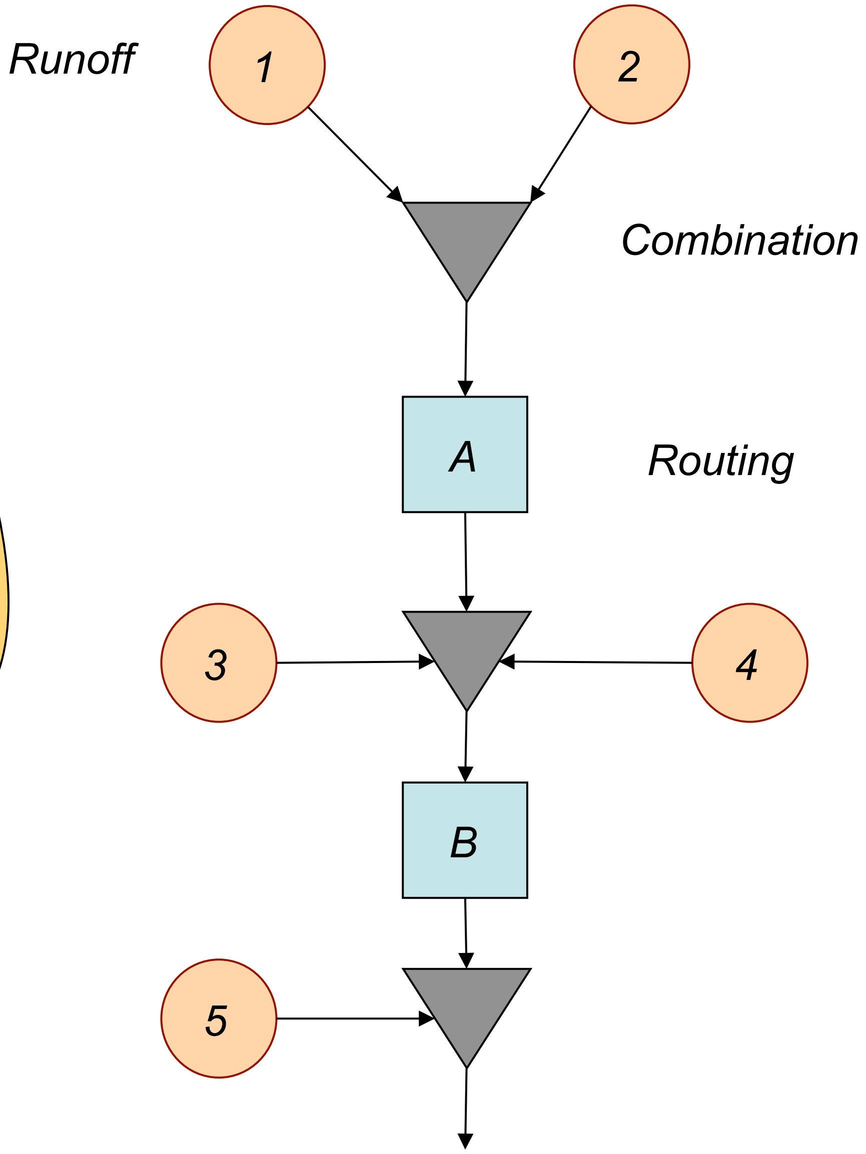
Transform to outlet of
Sub-watershed

Rout through channel

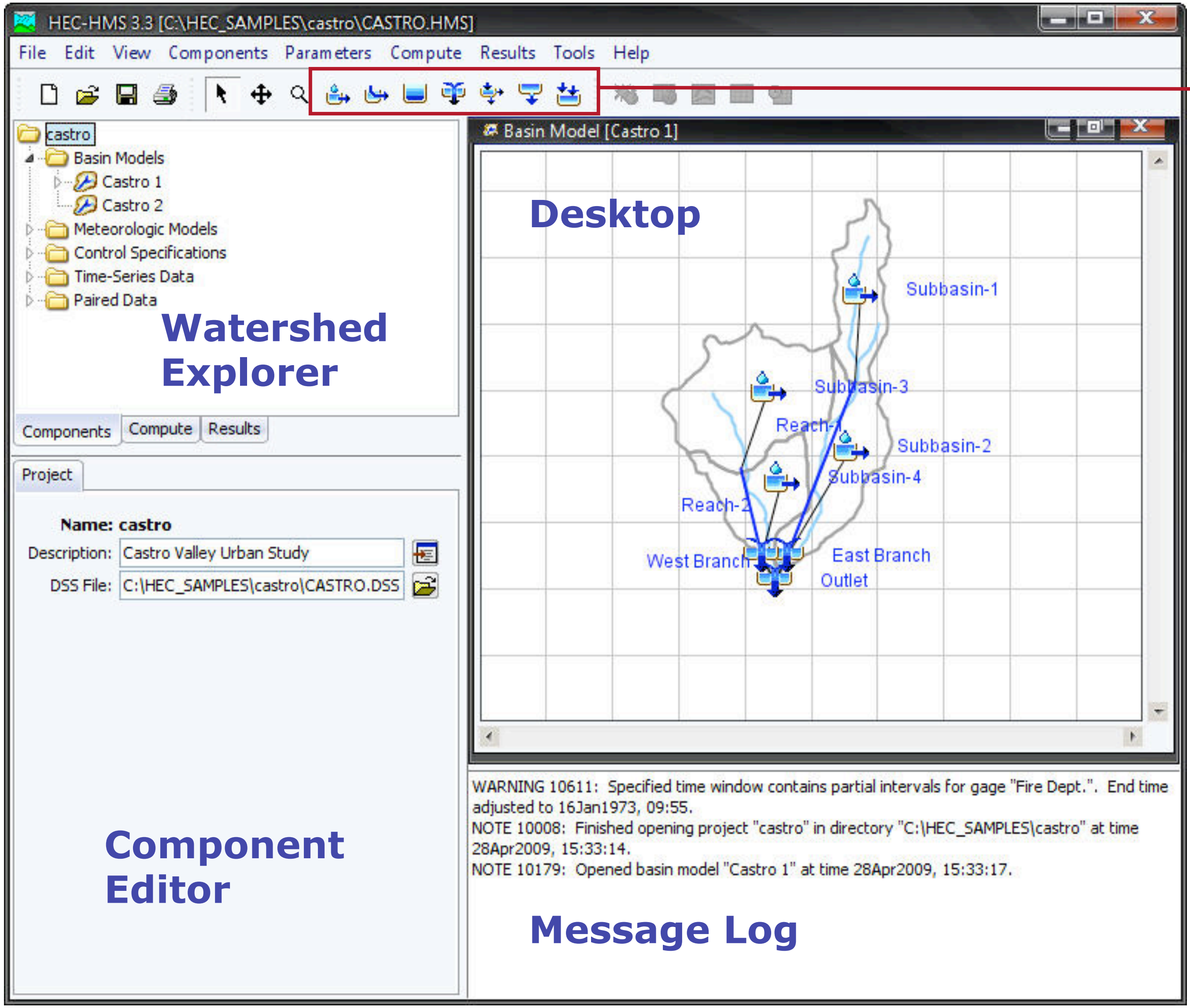
Account for base-flow

Watershed Elements





HEC-HMS Overview



Name: castro

Description: Castro Valley Urban Study

DSS File: C:\HEC_SAMPLES\castro\CASTRO.DSS

```
WARNING 10611: Specified time window contains partial intervals for gage "Fire Dept.". End time
adjusted to 16Jan1973, 09:55.
NOTE 10008: Finished opening project "castro" in directory "C:\HEC_SAMPLES\castro" at time
28Apr2009, 15:33:14.
NOTE 10179: Opened basin model "Castro 1" at time 28Apr2009, 15:33:17.
```

Basin Model Components

Desktop

Watershed Explorer

Component Editor

Message Log

Project Elements in the Watershed Explorer

Merteorologic Model

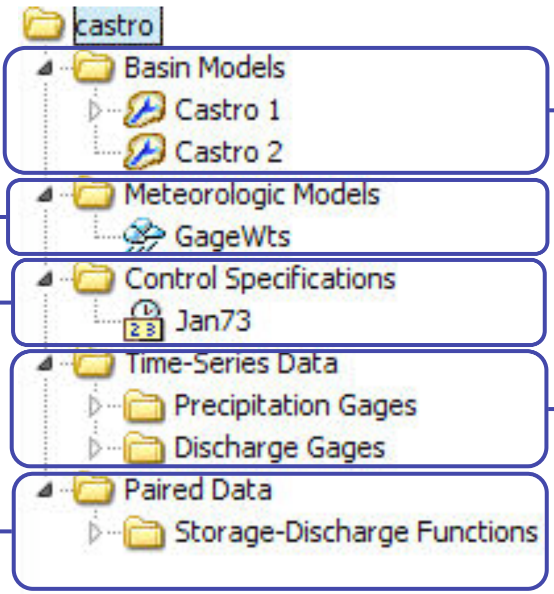
- Defines what type of model input to be used
- Connect model input (Time-series) to basin model
  - Methods of averaging input
  - Which gauge affects which sub-basin,

Control Specification

- Defines simulation time frame

Paired Data

- Provide data needed by reservoirs channels, and control structures
  - Stage Discharge
  - Storage discharge



Basin Models

- Provide physical watershed description
  - Hydrologic elements
    - Sub-basins
    - Reaches
    - Junctions (connectivity)
    - Reservoirs, sinks, sources and diversions
  - Define Selected calculation methods for each element
  - Define parameters for calculation methods

Time-Series Data

- Provide time dependent variables
  - Model input
    - precipitation,
    - temperature
    - solar radiation
    - Evapotranspiration
    - Source and sinks
  - Observation for calibration

Data
- Manual entry
- Connection to HEC-DSS files

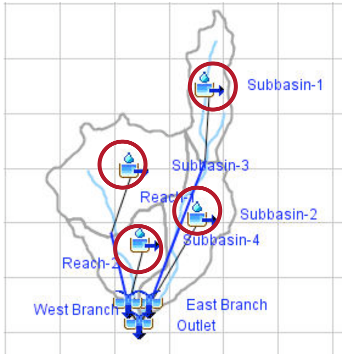
Basin Model Components (Sub-basin)

Sub-basin:
- Represents the physical watershed

- Basic element in rainfall-runoff modeling and loss calculations

- Runoff is routed internally to the outlet of the sub-basin

- Baseflow (GW contribution) is added



Loss

Deficit and constant rate (DC)
Exponential
Green and Ampt
Gridded DC
Gridded SCS CN
Gridded SMA
Initial and constant rate
SCS curve number (CN)
Smith Parlange
Soil moisture accounting (SMA)

Transform

Clark's UH
Kinematic wave
ModClark
SCS UH
Snyder's UH
User-specified s-graph
User-specified unit hydrograph (UH)

Transform

Bounded recession
Constant monthly
Linear reservoir
Nonlinear Boussinesq
Recession

Basin Model Components (Reach)

Reach

- Represents channels and pipes
- Conveys streamflow downstream in the basin model
- inflow can come from any hydrologic element
- Outflow is computed by accounting for translation + attenuation of inflow hydrograph

Routing

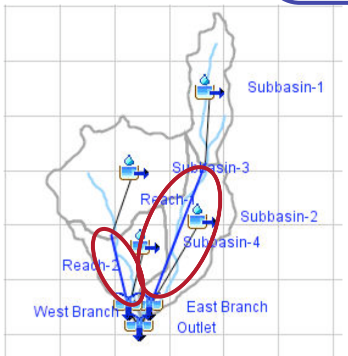
Kinematic wave

Lag

Modified Puls

Muskingum

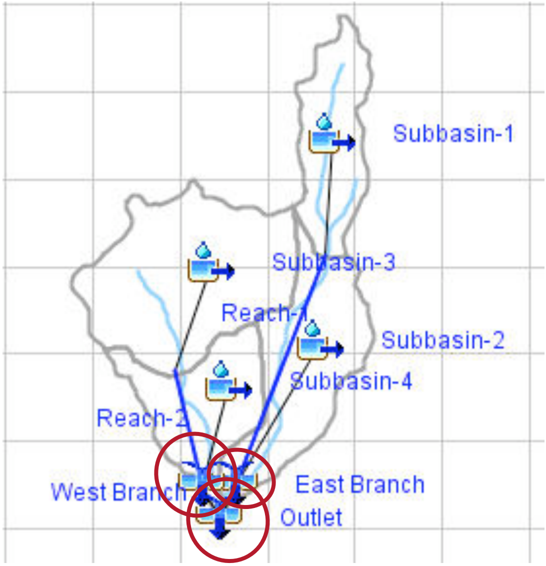
Muskingum-Cunge



Basin Model Components (Junction)

Junction

- Represents confluences and other flow combination
- Connects upstream elements to downstream elements
- inflow can come from any hydrologic element
- Outflow is computed by summing up all inflows



Basin Model Components (Others)

Reservoir

- Model detention and attenuation
- Receives inflow from any/or many hydrologic elements upstream
- Outflow is computed from
  - Storage | outflow relationship
  - Elevation | storage | outflow
  - Elevation | area | outflow
- User can define outlet structure

Diversion

- Models flow leaving main channel
- Receives inflow from any/or many hydrologic elements upstream
- Outflow consists of diverted and non-diverted flow, with diverted flow specified by user
- Both flows can be connected D/S

Source

- Introduce external flow
- Has no inflow, but outflow is pre-defined

Sink

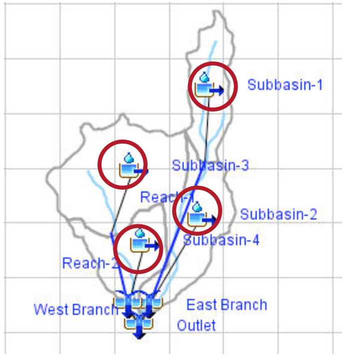
- Introduce external flow
- Has no inflow, but outflow is pre-defined

Sub-basin: Loss | Rainfall Runoff Relationship

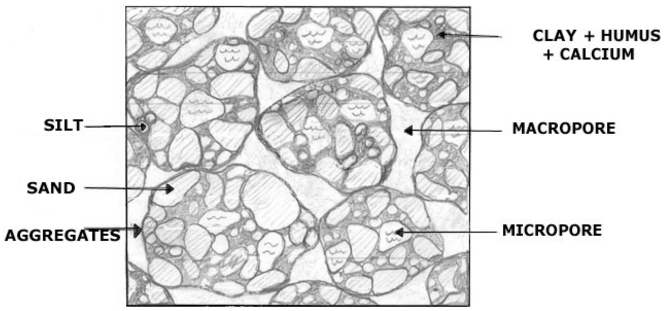
Sub-basin:
- Represents the physical watershed
- Basic element in rainfall-runoff modeling and loss calculations
- Runoff is routed internally to the outlet of the sub-basin
- Baseflow (GW contribution) is added

Loss

- Deficit and constant rate (DC)
- Exponential
- Green and Ampt
- Gridded DC
- Gridded SCS CN
- Gridded SMA
- Initial and constant rate
- SCS curve number (CN)
- Smith Parlange
- Soil moisture accounting (SMA)

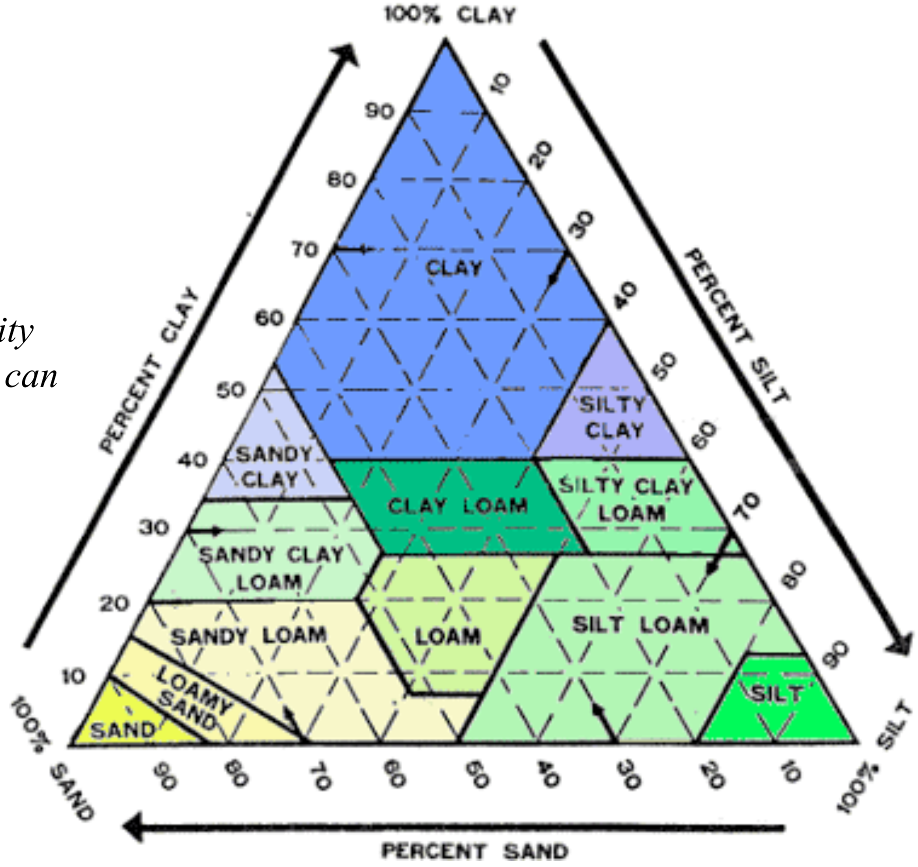


Soil Profile (Detailed)



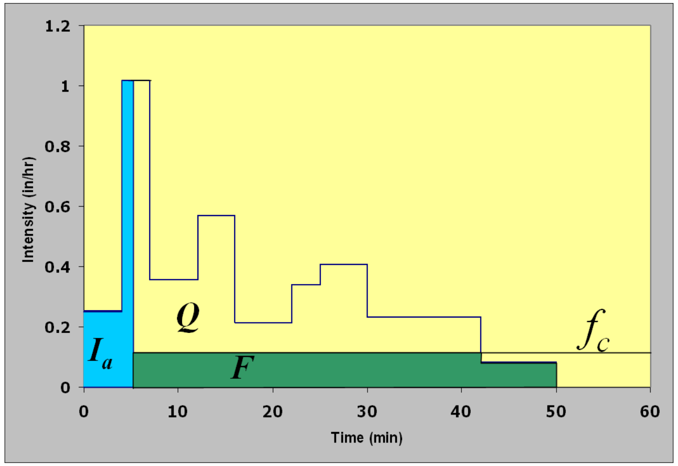
Porosity: Voids in the soil profile
Field Capacity: Amount of water held against gravity
Wilting Point: amount of water below which plants can not extract water from the soil
Hydraulic conductivity: Rate of water flow in soil

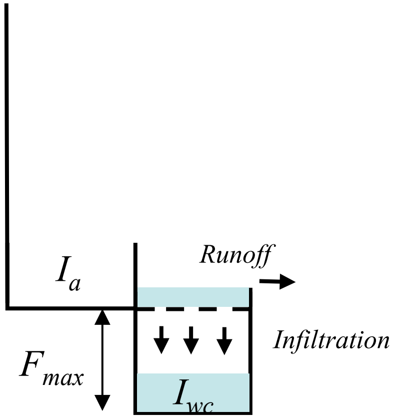
Values depend, among other factors, on soil texture



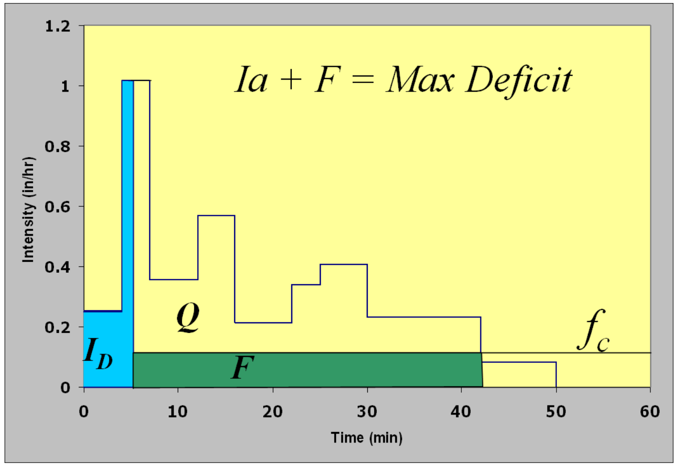
Constant Infiltration Rate Models

Initial and constant loss





Initial , constant and maximum loss



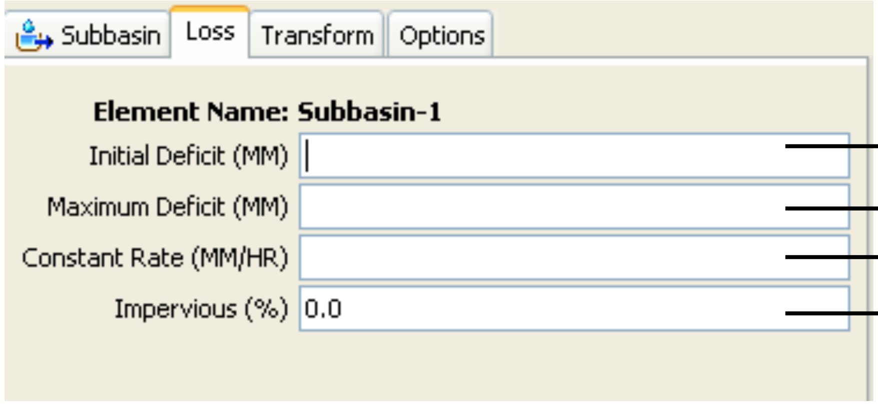
Soil group	Description	Range of loss rates (in/hr)
A	Deep sand, deep loess, aggregated silts	0.30-0.45
B	Shallow loess, sandy loam	0.15-0.30
C	Clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay	0.05-0.15
D	Soils that swell significantly when wet, heavy plastic clays, and certain saline soils	0.00-0.05

$$pe_t = \left\{ \begin{array}{ll} 0 & if \sum p_i < I_a \\ p_t - f_c & if \sum p_i > I_a \ and \ p_t > f_c \\ 0 & if \sum p_i > I_a \ and \ p_t < f_c \end{array} \right\}$$

When Maximum Soil Storage is considered

$$p_{et}=p_t \, if \ F_t \geq F_{max}$$

Parameters for Deficit Constant Model



Element Name: Subbasin-1

Initial Deficit (MM)

Maximum Deficit (MM)

Constant Rate (MM/HR)

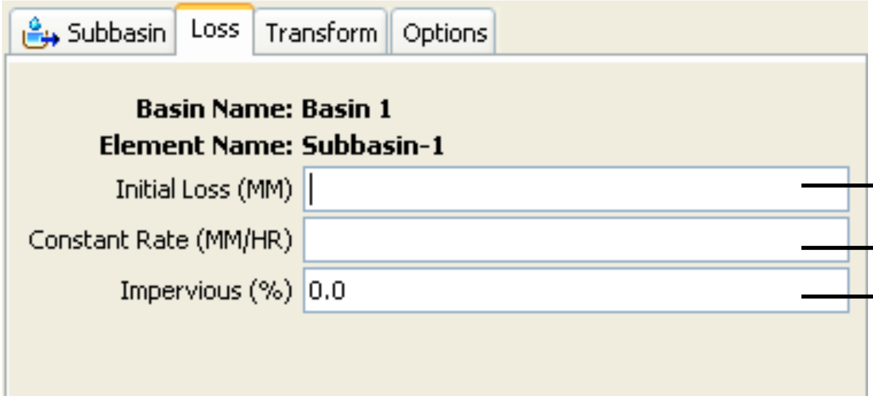
Impervious (%) 0.0

Depends on initial conditions $(q_s - q_i)$

Depends on Soil (Integrated field capacity)

Depends on soil. (# Sat. Conductivity)

Depends on land cover.



Basin Name: Basin 1

Element Name: Subbasin-1

Initial Loss (MM)

Constant Rate (MM/HR)

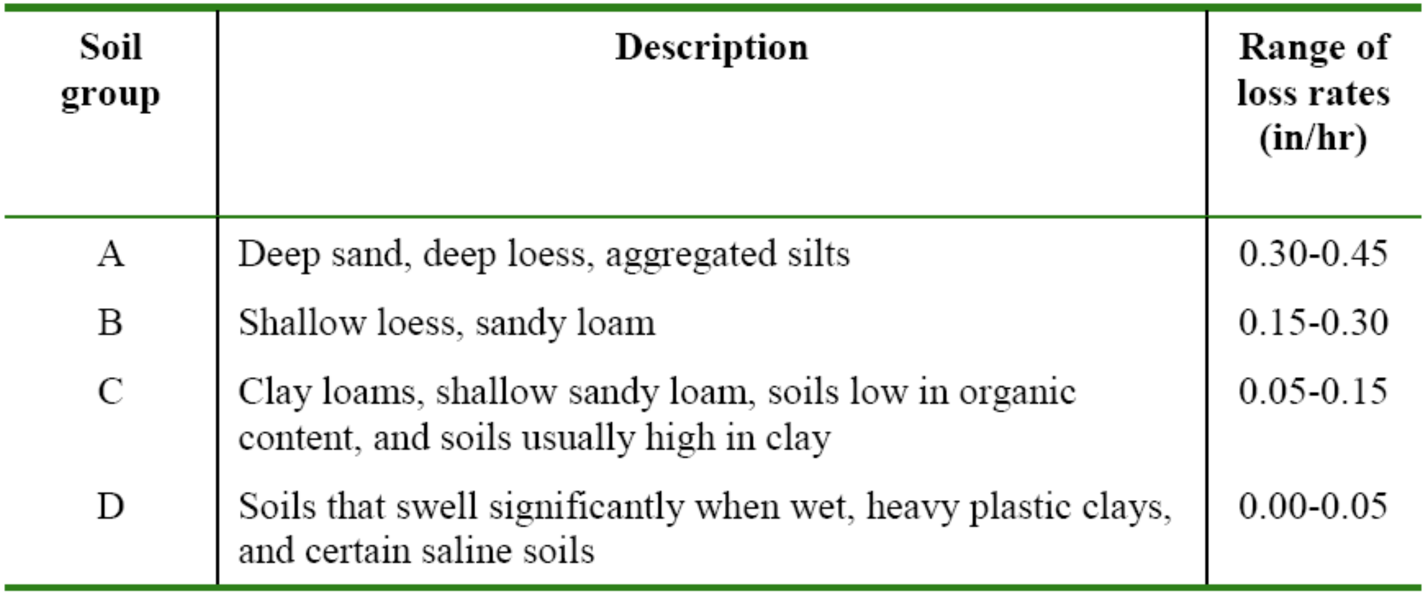
Impervious (%) 0.0

Depends on initial conditions, Soil, and Land cover

Depends on Soil (Integrated field capacity)

Depends on land cover.

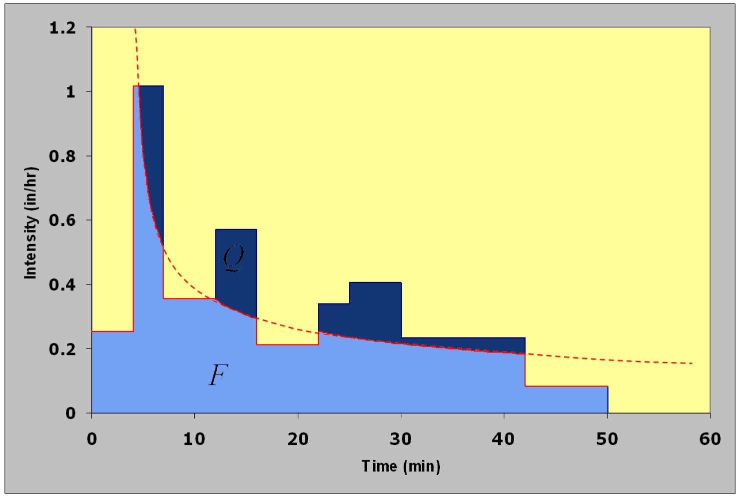
Initial Value of Loss Rate Parameter



Soil group	Description	Range of loss rates (in/hr)
A	Deep sand, deep loess, aggregated silts	0.30-0.45
B	Shallow loess, sandy loam	0.15-0.30
C	Clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay	0.05-0.15
D	Soils that swell significantly when wet, heavy plastic clays, and certain saline soils	0.00-0.05

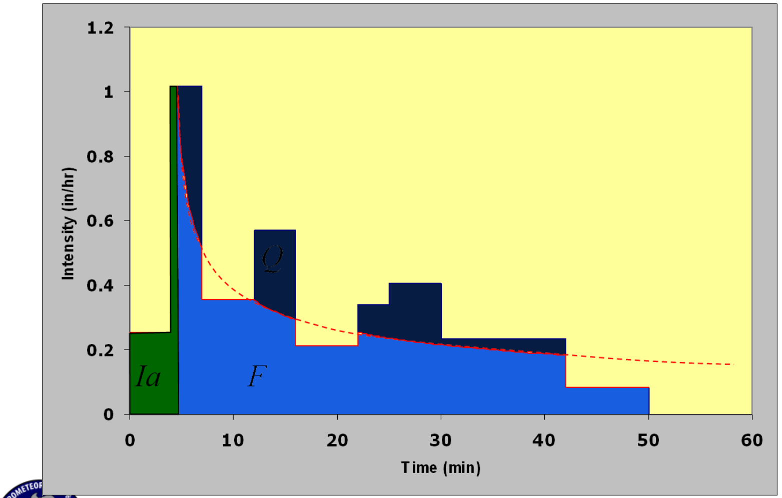
Infiltration Rate Decay Models

This type of models consider a more "realistic" infiltration approximation. Infiltration starts with the beginning of the storm at a very high rate, and it decays exponentially and almost asymptotically to a constant rate by the end of the storm. At any point, the infiltration rate depends on the amount of water that has already infiltrated.



$$pe_t = \begin{cases} 0 & \text{if } p_t \leq f_t \\ p - f_t & \text{if } p_t > f_t \end{cases}$$

$$f_t \propto \frac{1}{F_t} \Leftrightarrow \frac{1}{\sum_{t=0}^{t} f_t}$$



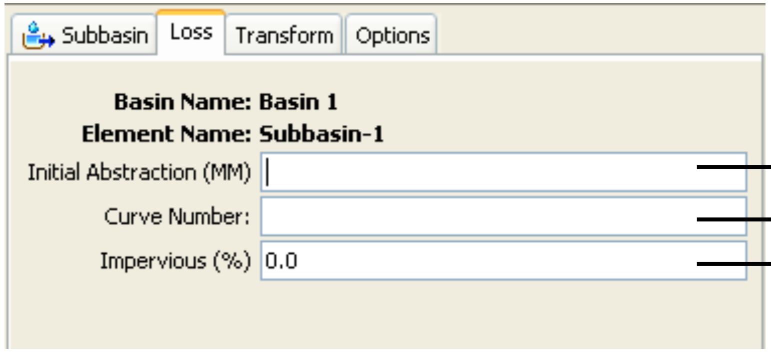
$$p_e = 0 \qquad If\, P_{Cumulative} \leq Ia$$

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \qquad If\, P_{Cumulative} > Ia$$

$$S = \begin{cases} \dfrac{1000 - 10\,CN}{CN} & (\text{foot} - \text{pound system}) \\ \dfrac{25400 - 254\,CN}{CN} & (\text{SI}) \end{cases}$$

$$I_a = 0.2\,S$$

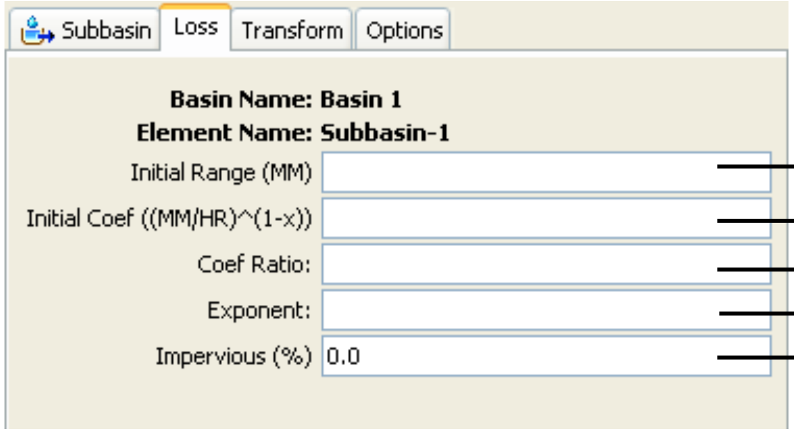
CN method Parameters in HEC-HMS



Basin Name: Basin 1
Element Name: Subbasin-1
Initial Abstraction (MM)
Curve Number:
Impervious (%) 0.0

Depends on initial conditions, Soil, and Land cover
If left blank, it will be set to 0.2S from CN
Depends on Soil (Integrated field capacity)
Depends on land cover.

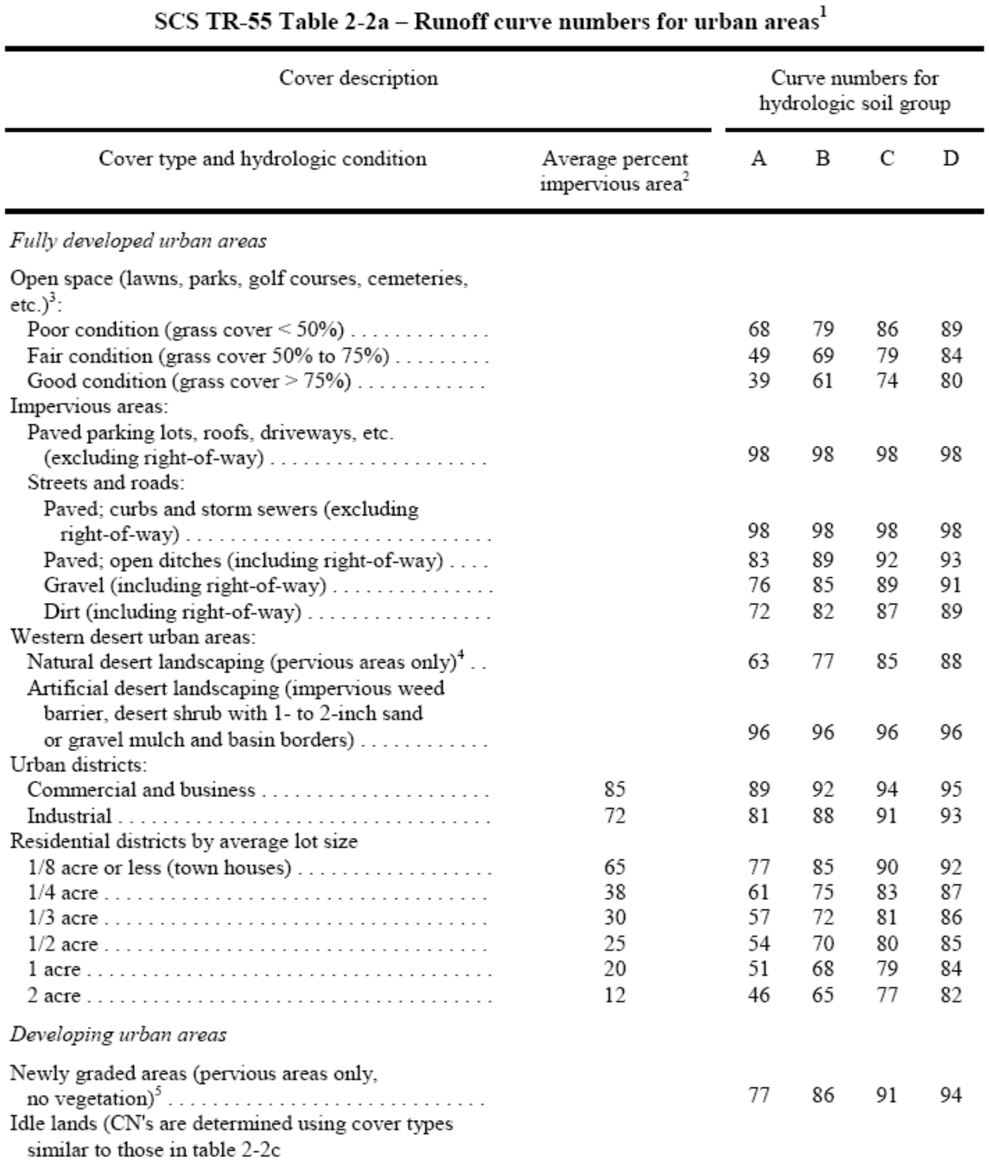
Exponential Infiltration model:
Only if calibrated, and only in event based



Basin Name: Basin 1
Element Name: Subbasin-1
Initial Range (MM)
Initial Coef ((MM/HR)^(1-x))
Coef Ratio:
Exponent:
Impervious (%) 0.0

Amount accumulated during initial phase of increasing infiltration. Function of antecedent conditions
Initial infiltration coefficient (starting loss rate)
The rate of subsequent exponential decrease (basin related)
Exponential decay of infiltration rate
Depends on land cover.

Example Land Use Table for CN



SCS TR-55 Table 2-2a – Runoff curve numbers for urban areas[1]

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area[2]	A	B	C	D
Fully developed urban areas					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acre	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)[5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c					

Semi-physically-based Infiltration

Volumetric Water Content

Capillary Suction

$$\frac{\partial \theta}{\partial z} = -\frac{\partial}{\partial z}\left[K(\theta)\frac{\partial \Psi(\theta)}{\partial z}\right] - \frac{\partial K(\theta)}{\partial z}$$

Hydraulic Conductivity

Distance from the Surface

Green Ampt Model

$$f_t = K\left[\frac{1+(\phi-\theta_i)S_f}{F_t}\right]$$

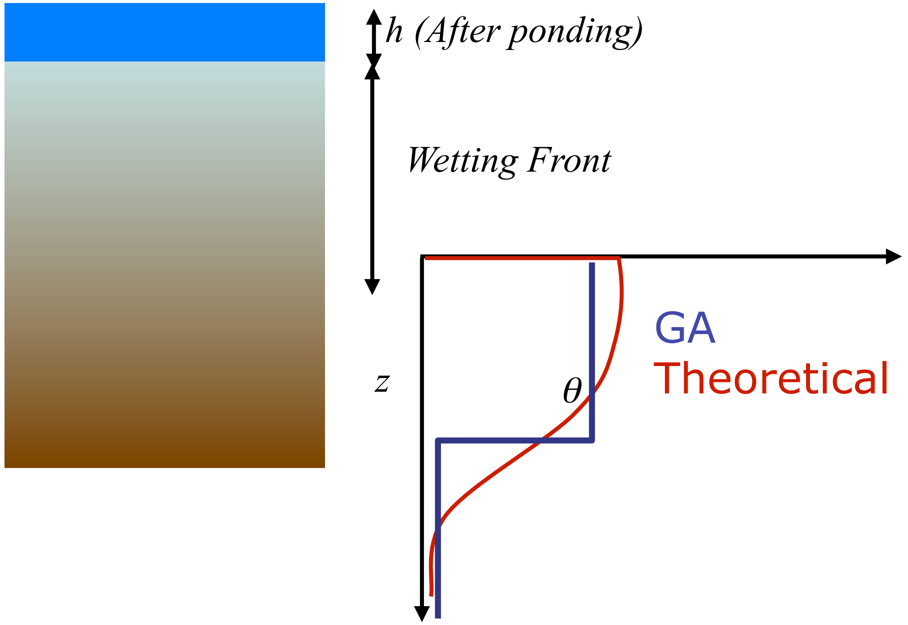
f_t = loss during period t;

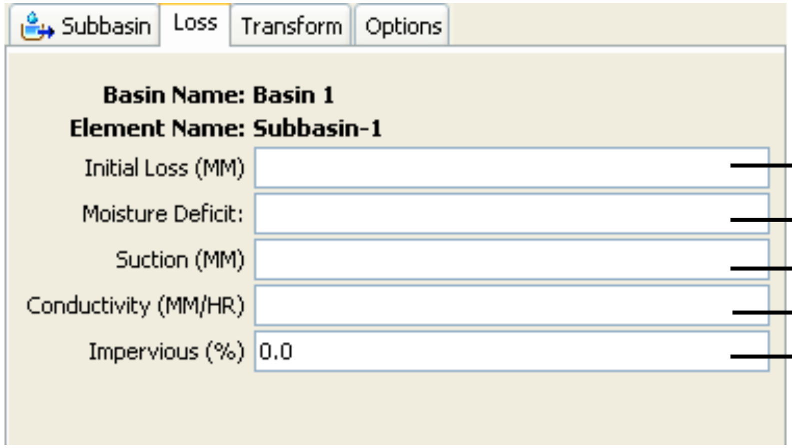
K = saturated hydraulic conductivity

$(\phi - \theta_i)$ = volumetric moisture deficit;

S_f = wetting front suction;

F_t = cumulative loss at time t.





Basin Name: Basin 1
Element Name: Subbasin-1
Initial Loss (MM)
Moisture Deficit:
Suction (MM)
Conductivity (MM/HR)
Impervious (%) 0.0

Loss before ponding occures , should include interception

Initial soil moisture defecit

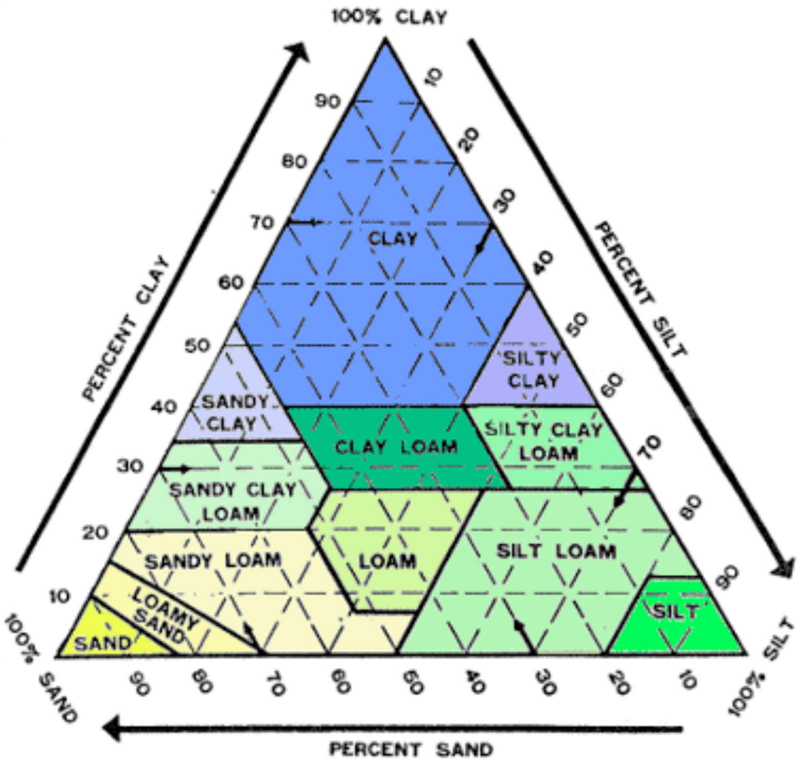
Soil parameter, identified from soil texture

Saturated hydraulic conductivity (soil dependent)

Depends on land cover.

Soil Classification and model parameters

Texture class	Porosity, ϕ (cm^3/cm)	Hydraulic conductivity, θ_i, saturated (cm/hr)	Wetting front suction (cm)
Sand	0.437	21.00	10.6
Loamy sand	0.437	6.11	14.2
Sandy loam	0.453	2.59	22.2
Loam	0.463	1.32	31.5
Silt loam	0.501	0.68	40.4
Sandy clay loam	0.398	0.43	44.9
Clay loam	0.464	0.23	44.6
Silty clay loam	0.471	0.15	58.1
Sandy clay	0.430	0.12	63.6
Silty clay	0.479	0.09	64.7
Clay	0.475	0.06	71.4



Porosity = Volume of Voids/Volume of Solids

Or Using Soil Texture

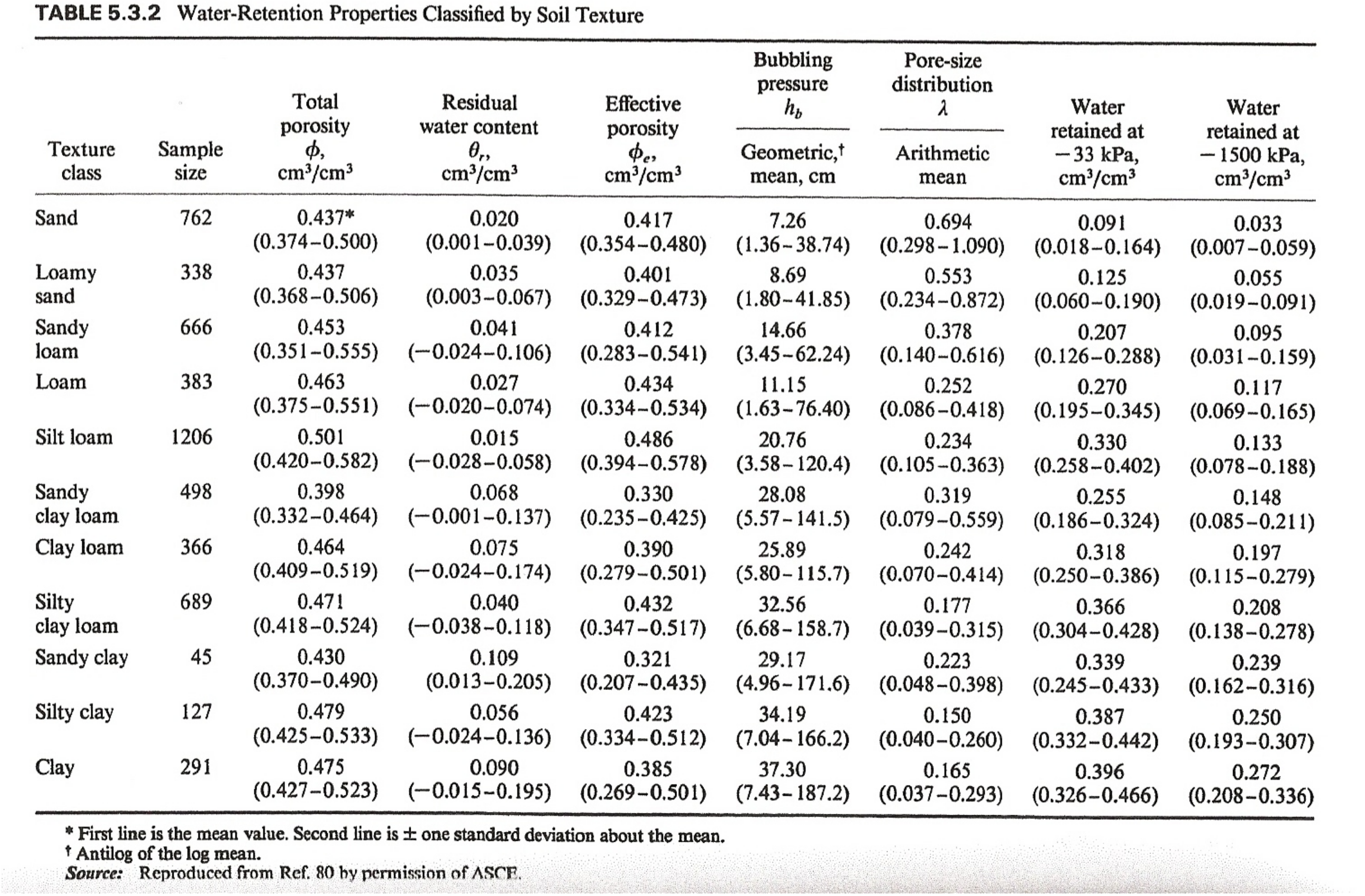


TABLE 5.3.2 Water-Retention Properties Classified by Soil Texture

Texture class	Sample size	Total porosity ϕ, cm^3/cm^3	Residual water content θ_r, cm^3/cm^3	Effective porosity ϕ_e, cm^3/cm^3	Bubbling pressure h_b Geometric,† mean, cm	Pore-size distribution λ Arithmetic mean	Water retained at −33 kPa, cm^3/cm^3	Water retained at −1500 kPa, cm^3/cm^3
Sand	762	0.437* (0.374–0.500)	0.020 (0.001–0.039)	0.417 (0.354–0.480)	7.26 (1.36–38.74)	0.694 (0.298–1.090)	0.091 (0.018–0.164)	0.033 (0.007–0.059)
Loamy sand	338	0.437 (0.368–0.506)	0.035 (0.003–0.067)	0.401 (0.329–0.473)	8.69 (1.80–41.85)	0.553 (0.234–0.872)	0.125 (0.060–0.190)	0.055 (0.019–0.091)
Sandy loam	666	0.453 (0.351–0.555)	0.041 (−0.024–0.106)	0.412 (0.283–0.541)	14.66 (3.45–62.24)	0.378 (0.140–0.616)	0.207 (0.126–0.288)	0.095 (0.031–0.159)
Loam	383	0.463 (0.375–0.551)	0.027 (−0.020–0.074)	0.434 (0.334–0.534)	11.15 (1.63–76.40)	0.252 (0.086–0.418)	0.270 (0.195–0.345)	0.117 (0.069–0.165)
Silt loam	1206	0.501 (0.420–0.582)	0.015 (−0.028–0.058)	0.486 (0.394–0.578)	20.76 (3.58–120.4)	0.234 (0.105–0.363)	0.330 (0.258–0.402)	0.133 (0.078–0.188)
Sandy clay loam	498	0.398 (0.332–0.464)	0.068 (−0.001–0.137)	0.330 (0.235–0.425)	28.08 (5.57–141.5)	0.319 (0.079–0.559)	0.255 (0.186–0.324)	0.148 (0.085–0.211)
Clay loam	366	0.464 (0.409–0.519)	0.075 (−0.024–0.174)	0.390 (0.279–0.501)	25.89 (5.80–115.7)	0.242 (0.070–0.414)	0.318 (0.250–0.386)	0.197 (0.115–0.279)
Silty clay loam	689	0.471 (0.418–0.524)	0.040 (−0.038–0.118)	0.432 (0.347–0.517)	32.56 (6.68–158.7)	0.177 (0.039–0.315)	0.366 (0.304–0.428)	0.208 (0.138–0.278)
Sandy clay	45	0.430 (0.370–0.490)	0.109 (0.013–0.205)	0.321 (0.207–0.435)	29.17 (4.96–171.6)	0.223 (0.048–0.398)	0.339 (0.245–0.433)	0.239 (0.162–0.316)
Silty clay	127	0.479 (0.425–0.533)	0.056 (−0.024–0.136)	0.423 (0.334–0.512)	34.19 (7.04–166.2)	0.150 (0.040–0.260)	0.387 (0.332–0.442)	0.250 (0.193–0.307)
Clay	291	0.475 (0.427–0.523)	0.090 (−0.015–0.195)	0.385 (0.269–0.501)	37.30 (7.43–187.2)	0.165 (0.037–0.293)	0.396 (0.326–0.466)	0.272 (0.208–0.336)

* First line is the mean value. Second line is ± one standard deviation about the mean.

† Antilog of the log mean.

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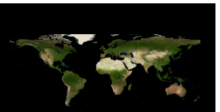
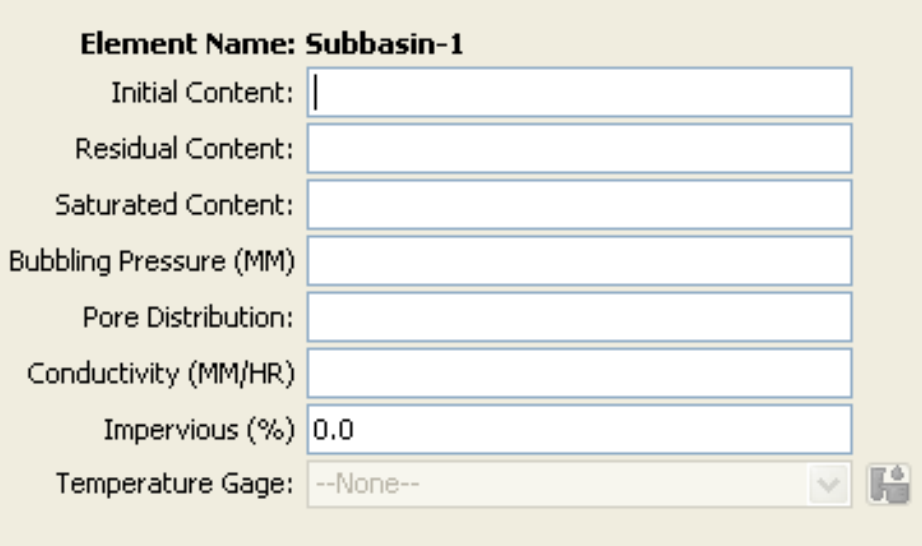
Smith-Parlange Model



$$f_t = K[\frac{C_o}{KF_t} + 1]$$

$$f_t = K\frac{e^{F_t/C_0}}{e^{F_t/C_0} - 1}$$

$$C_o = [2S_f K(\phi - \theta_i)]$$



Element Name: Subbasin-1
Initial Content:
Residual Content:
Saturated Content:
Bubbling Pressure (MM)
Pore Distribution:
Conductivity (MM/HR)
Impervious (%) 0.0
Temperature Gage: --None--

f_t = loss during period t;

K = saturated hydraulic conductivity

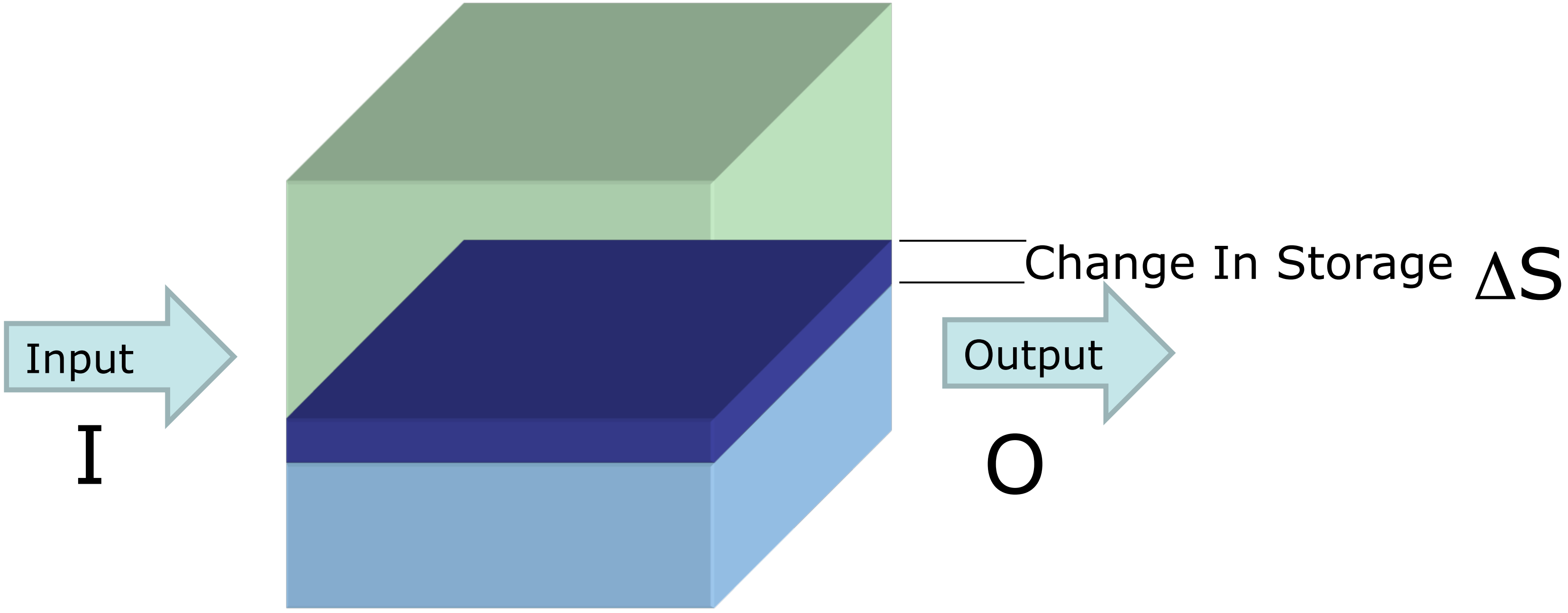
$(\phi - \theta_i)$ = volume moisture deficit;

S_f = wetting front suction;

F_t = cumulative loss at time t.

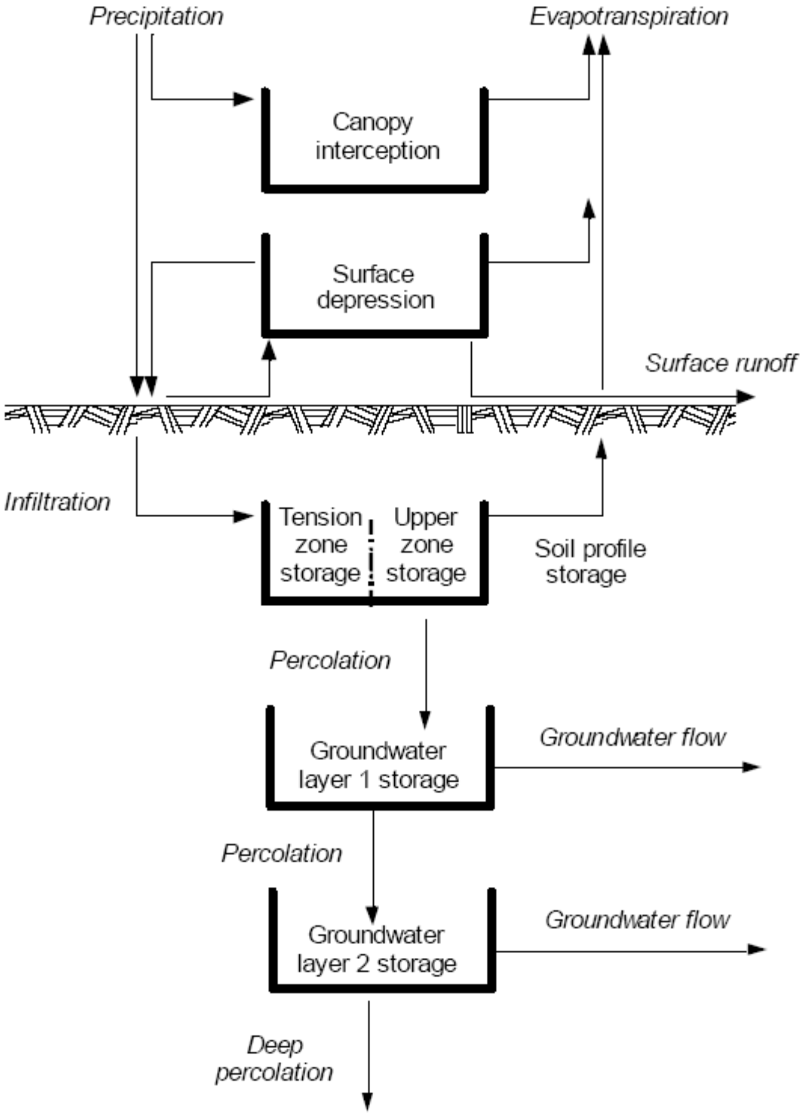
C_o= Sorptivity can also be estimated using other soil parameters

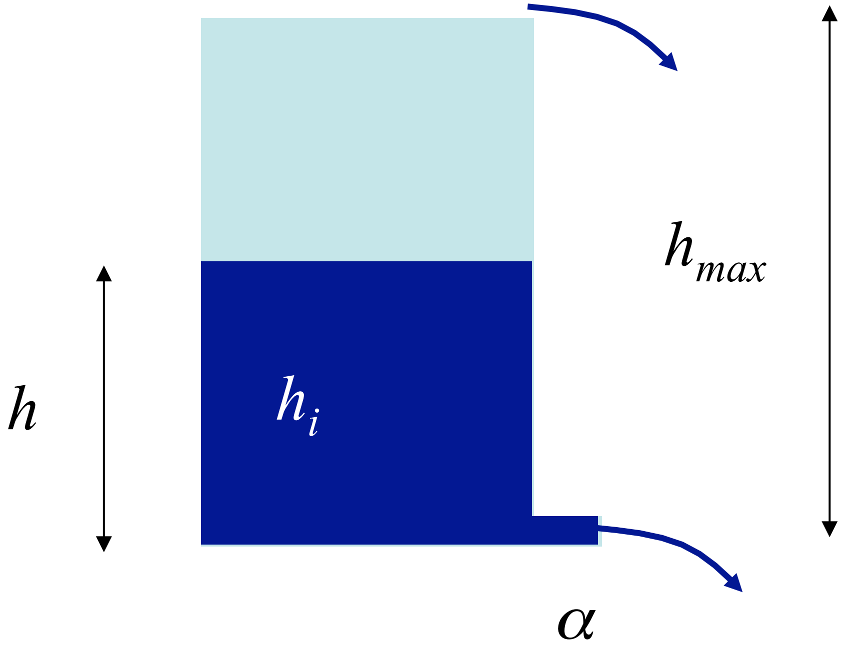
Conceptual Models



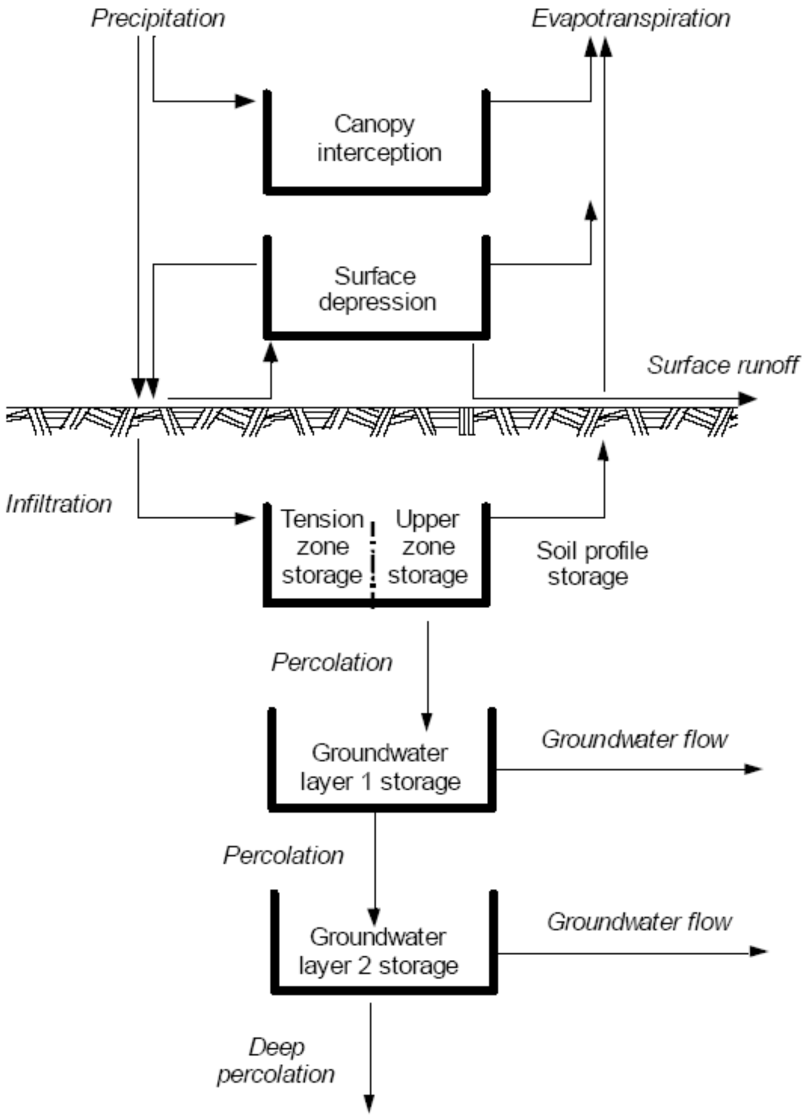
$$I - O = \Delta S$$

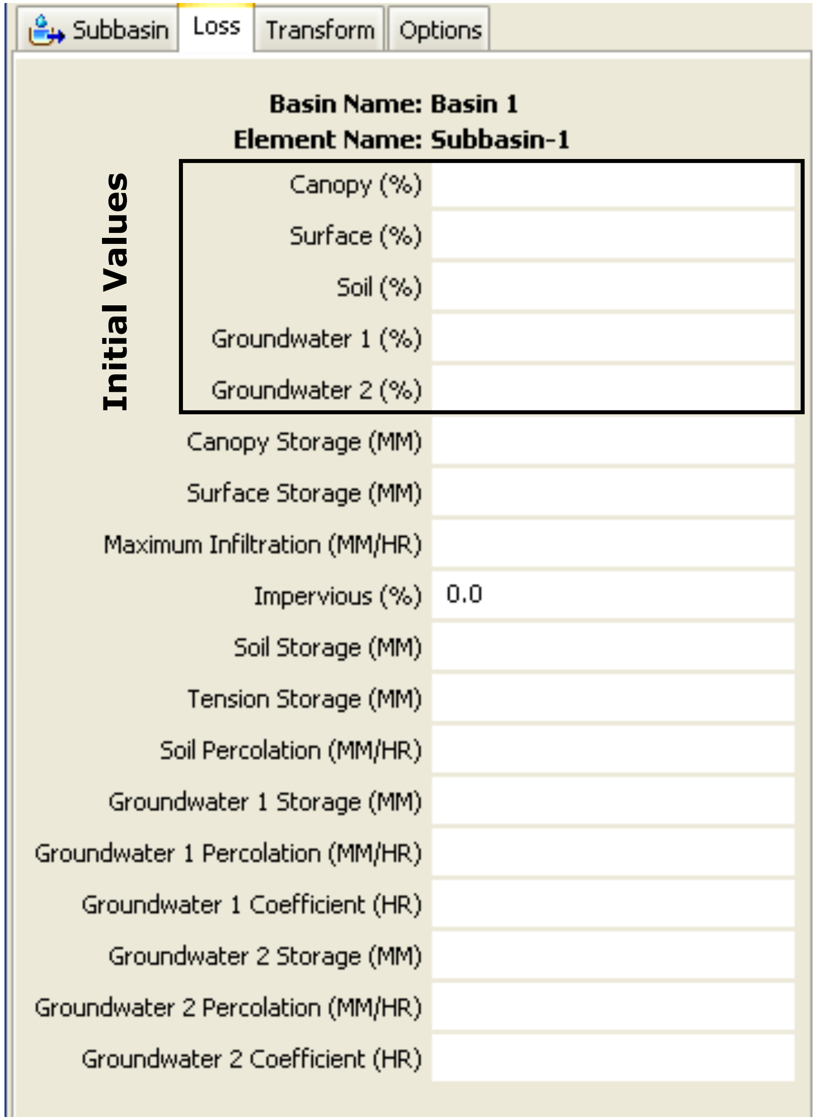
Conceptual Model (SMA)





Conceptual Model (SMA)



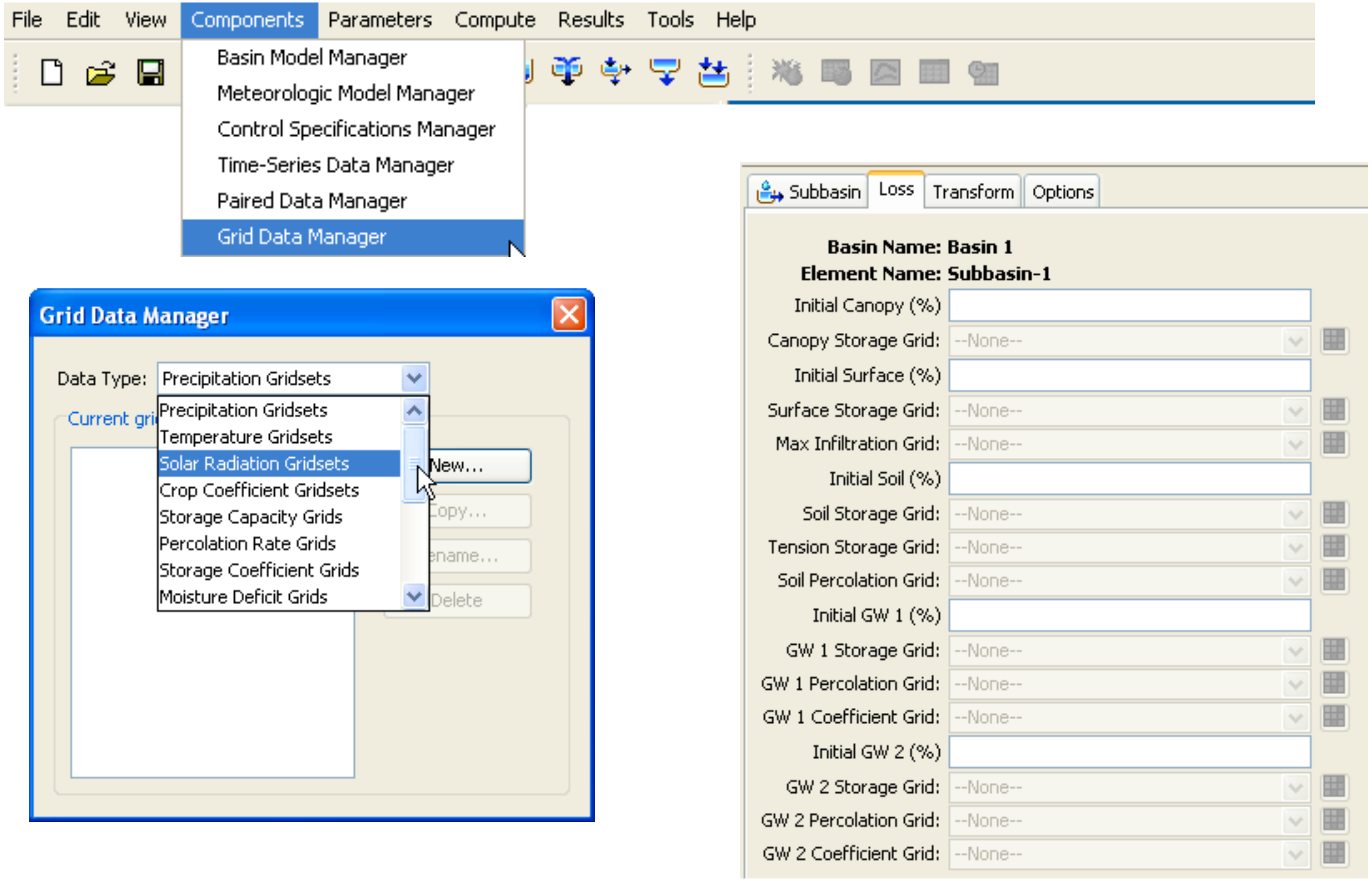


Basin Name: Basin 1
Element Name: Subbasin-1

Initial Values

Canopy (%)	
Surface (%)	
Soil (%)	
Groundwater 1 (%)	
Groundwater 2 (%)	
Canopy Storage (MM)	
Surface Storage (MM)	
Maximum Infiltration (MM/HR)	
Impervious (%)	0.0
Soil Storage (MM)	
Tension Storage (MM)	
Soil Percolation (MM/HR)	
Groundwater 1 Storage (MM)	
Groundwater 1 Percolation (MM/HR)	
Groundwater 1 Coefficient (HR)	
Groundwater 2 Storage (MM)	
Groundwater 2 Percolation (MM/HR)	
Groundwater 2 Coefficient (HR)	

Gridded Models



Data Type: Precipitation Gridsets

Basin Name: Basin 1

Element Name: Subbasin-1

Initial Canopy (%):

Canopy Storage Grid: --None--

Initial Surface (%):

Surface Storage Grid: --None--

Max Infiltration Grid: --None--

Initial Soil (%):

Soil Storage Grid: --None--

Tension Storage Grid: --None--

Soil Percolation Grid: --None--

Initial GW 1 (%):

GW 1 Storage Grid: --None--

GW 1 Percolation Grid: --None--

GW 1 Coefficient Grid: --None--

Initial GW 2 (%):

GW 2 Storage Grid: --None--

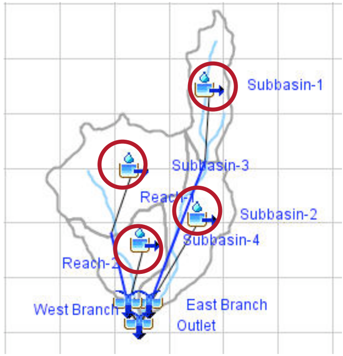
GW 2 Percolation Grid: --None--

GW 2 Coefficient Grid: --None--

Basin Model Components (Sub-basin)

Sub-basin:

- Represents the physical watershed
- Basic element in rainfall-runoff modeling and loss calculations
- Runoff is routed internally to the outlet of the sub-basin
- Baseflow (GW contribution) is added



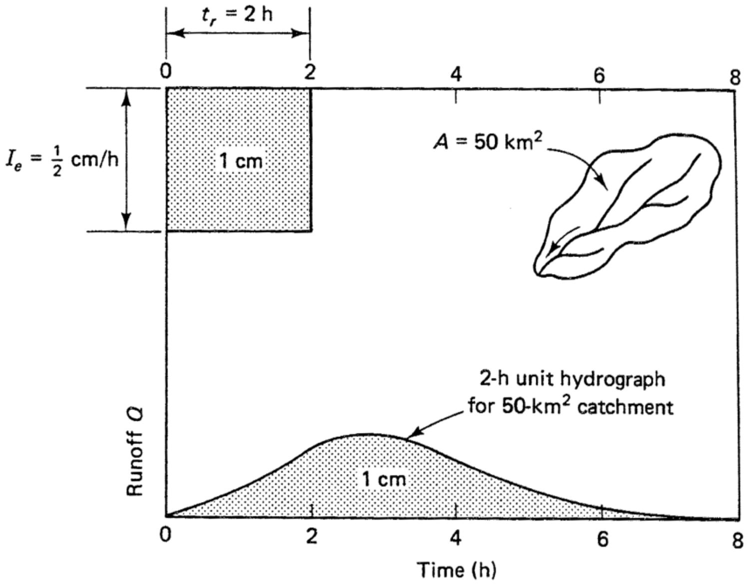
Transform

Clark's UH
Kinematic wave
ModClark
SCS UH
Snyder's UH
User-specified s-graph
User-specified unit hydrograph (UH)

Unit Hydrograph Concept

Basic Definition

Consider a unit depth of excess generated uniformly (spatially and temporally) over a watershed with area A, during time duration t_r. The resulting hydrograph is called the t_r Unit Hydrograph for the watershed. The intensity of the excess rain is given as $1/t_r$

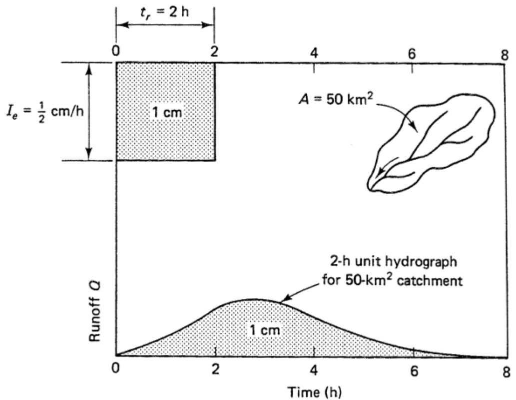


Main Assumptions

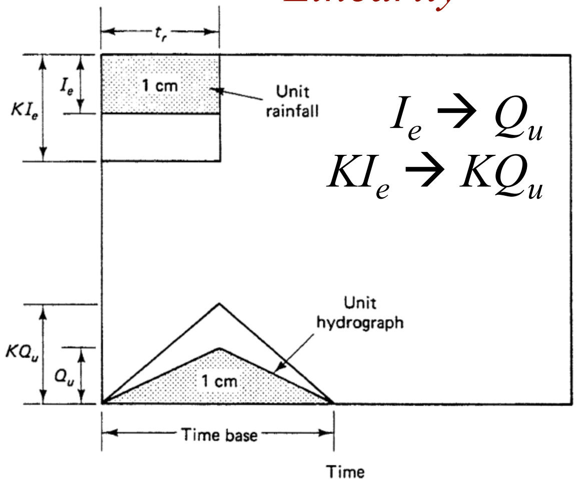
- The P_e is distributed uniformly spatially I_e is constant during each Dt.
- The direct runoff hydrograph resulting from a given increment of excess is independent of the time of occurrence of the excess and of the antecedent precipitation. This is the assumption of time-invariance.
- Precipitation excesses of equal duration are assumed to produce hydrographs with equivalent time bases regardless of the intensity of the precipitation.

If these assumptions are valid, then we can assume a linear system and the following properties are valid

Unit Hydrograph: Its application



Linearity

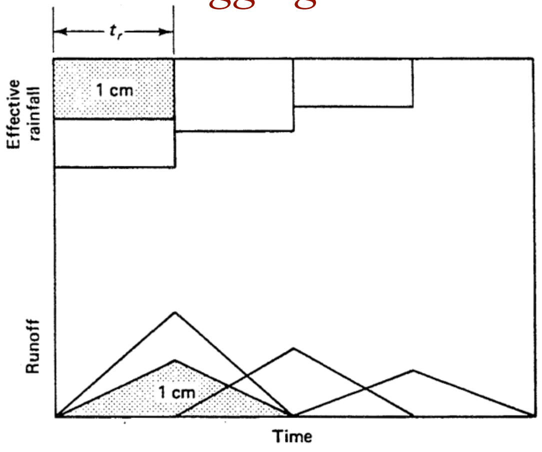


$$I_e \rightarrow Q_u$$

$$KI_e \rightarrow KQ_u$$

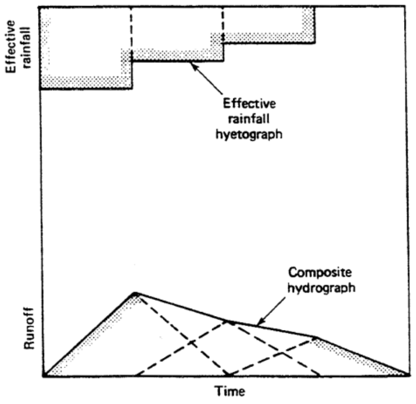
Allows us to identify hydrograph resulting from more/or less than one unit of excess rain

Lagging



Allows us to identify hydrographs for each rain interval in a sequence of excess rains

Superposition



Allows us to combine hydrograph resulting from non-unit rain intervals in a sequence of excess rain. That is the event hydrograph

Discrete Convolution: The combination of all three properties

$$Q_n = \sum_{m=1}^{n \leq M} P_m U_{n-m+1}$$

where Q_n = storm hydrograph ordinate at time nDt;

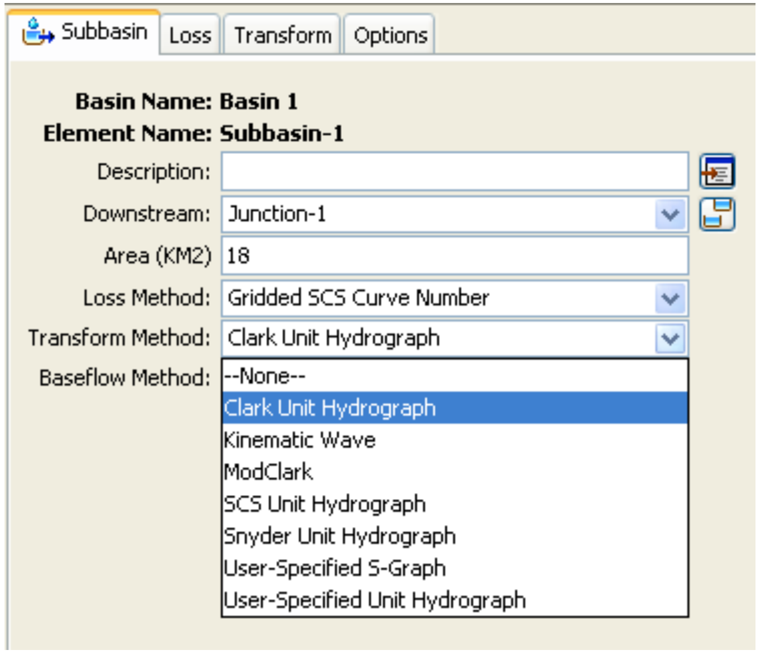
P_m = rainfall excess depth in time interval mDt to $(m+1)\Delta t$;

M = total number of discrete rainfall pulses; and

U_{n-m+1} = UH ordinate at time $(n-m+1)\Delta t$

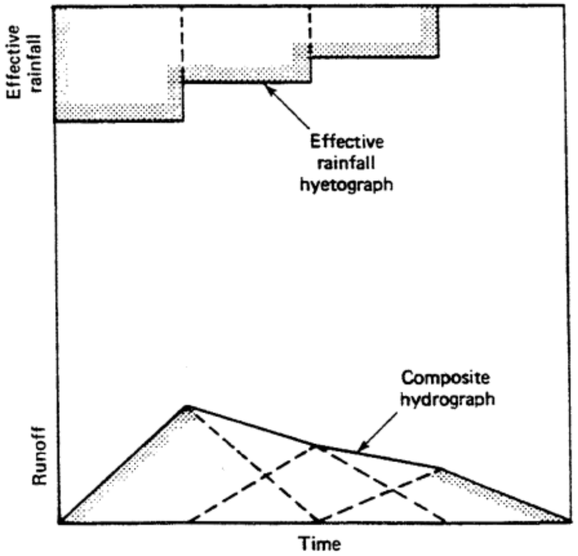
Q_n and P_m are expressed as flow rate and depth respectively,

U_{n-m+1} (flow rate per unit depth).

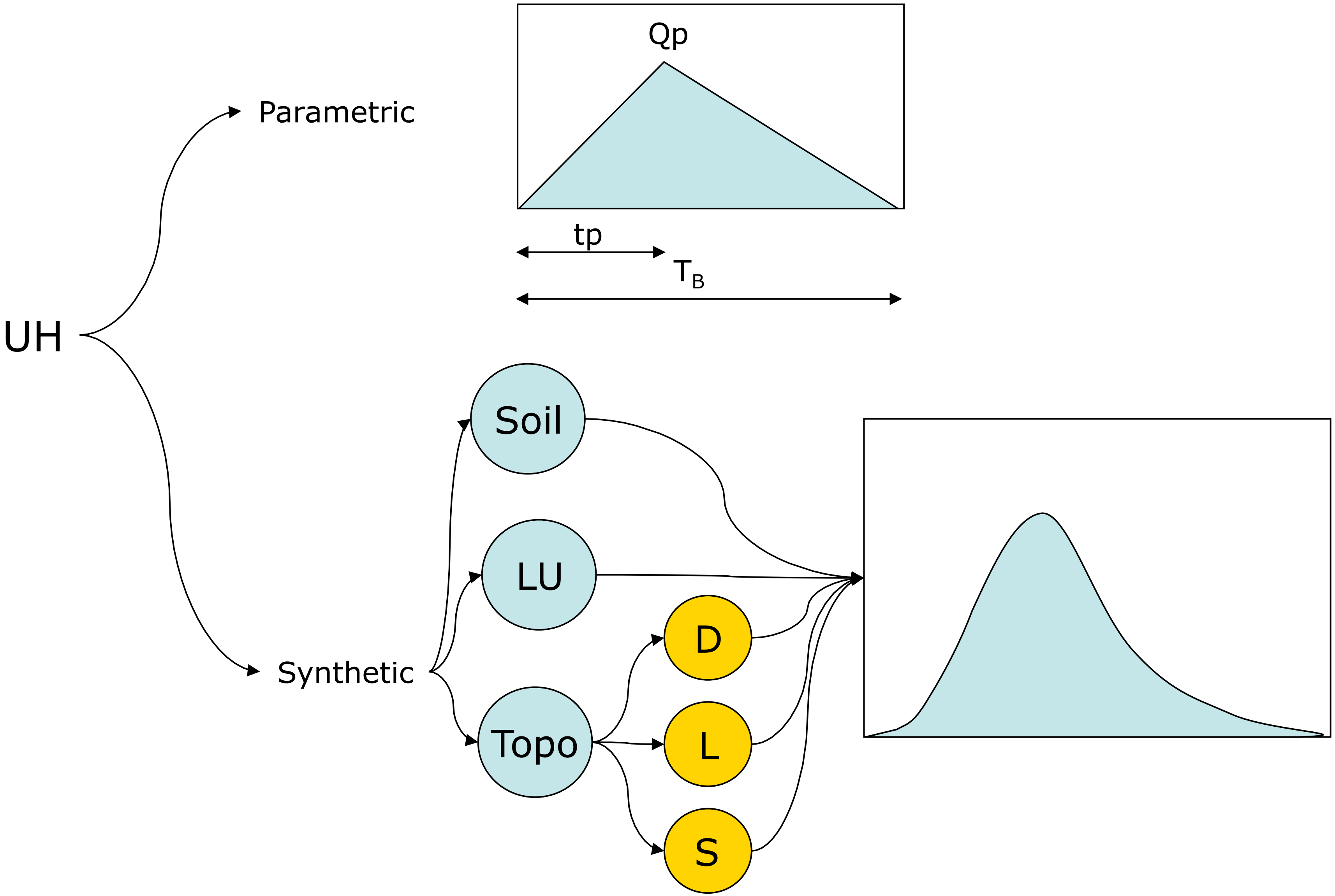


Basin Name: Basin 1
Element Name: Subbasin-1

Description:
Downstream: Junction-1
Area (KM2) 18
Loss Method: Gridded SCS Curve Number
Transform Method: Clark Unit Hydrograph
Baseflow Method:



Types of Unit Hydrographs



Snyder UH: 1938 (Parameters)

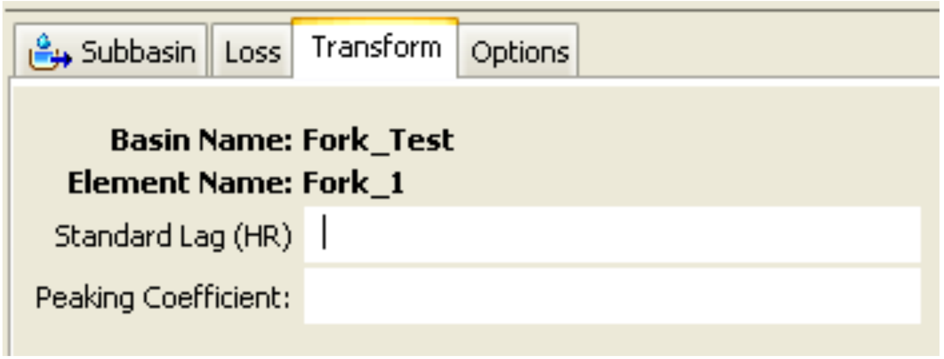
Snyder's observations →

$$t_p = C_t (LL_c)^{0.3}$$

$km : C_t$ [1.35 → 1.65]

$$t_p = C_t (LL_c)^{0.3}$$

$mile : C_t$ [1.8 → 2.2]



Basin Name: Fork_Test
Element Name: Fork_1
Standard Lag (HR)
Peaking Coefficient:

LA District (USACE) →

0.75 for SI, 1 for E.

$$t_p = CC_t \left(\frac{LL_c}{\sqrt{S}}\right)^N$$

0.33

C_t [1.8 → 2.2]

Slope of longest flow path

Ct = basin coefficient;
L = length of the main stream from the outlet to the divide;
Lc = length along the main stream from the outlet to a point nearest the watershed centroid

SCS UH: Dimensionless UH (Concept)

$$U_P = C\frac{A}{T_P}$$

Watershed Area

Time to peak
From starting of Pe

Duration of Pe

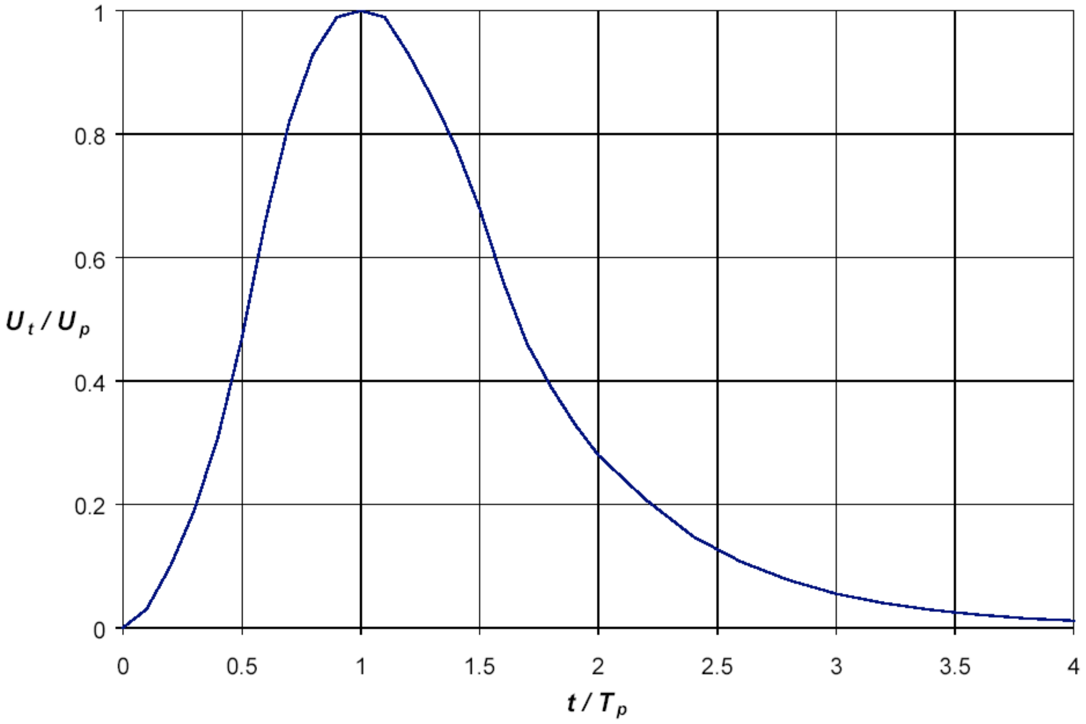
$$T_p = \frac{\Delta t}{2} + t_{lag}$$

Lag Time
Pe Centroid to Qp

$$t_{lag} = 0.6\, t_c$$

Time of Concentration

Dimensionless form (Stored in HEC-HMS)



SCS UH: Parameters (Parameters –First Approach)

$$t_{lag} = 0.6\, t_c$$

$$t_c = t_{sheet} + t_{shallow} + t_{channel}$$

$$t_{sheet} = \frac{0.007(NL)^{0.8}}{(P_2)^{0.5} S^{0.4}}$$

$$V = \begin{cases} 16.1345\sqrt{S} & \text{for unpaved surface} \\ 20.3282\sqrt{S} & \text{for paved surface} \end{cases}$$

$$t_{shallow} = \frac{L - 200}{V_{shallow}}$$

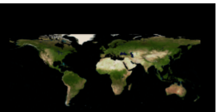
P_2: 2 yr/24 hr rainfall depth

N: Overland Roughness Coefficient
L: Longest Flow Path
S: Hydraulic slope, approximate with slope

$$t_{channel} = \frac{L}{V}$$

$$V = \frac{CR^{2/3} S^{1/2}}{n}$$

Overland flow roughness coefficient



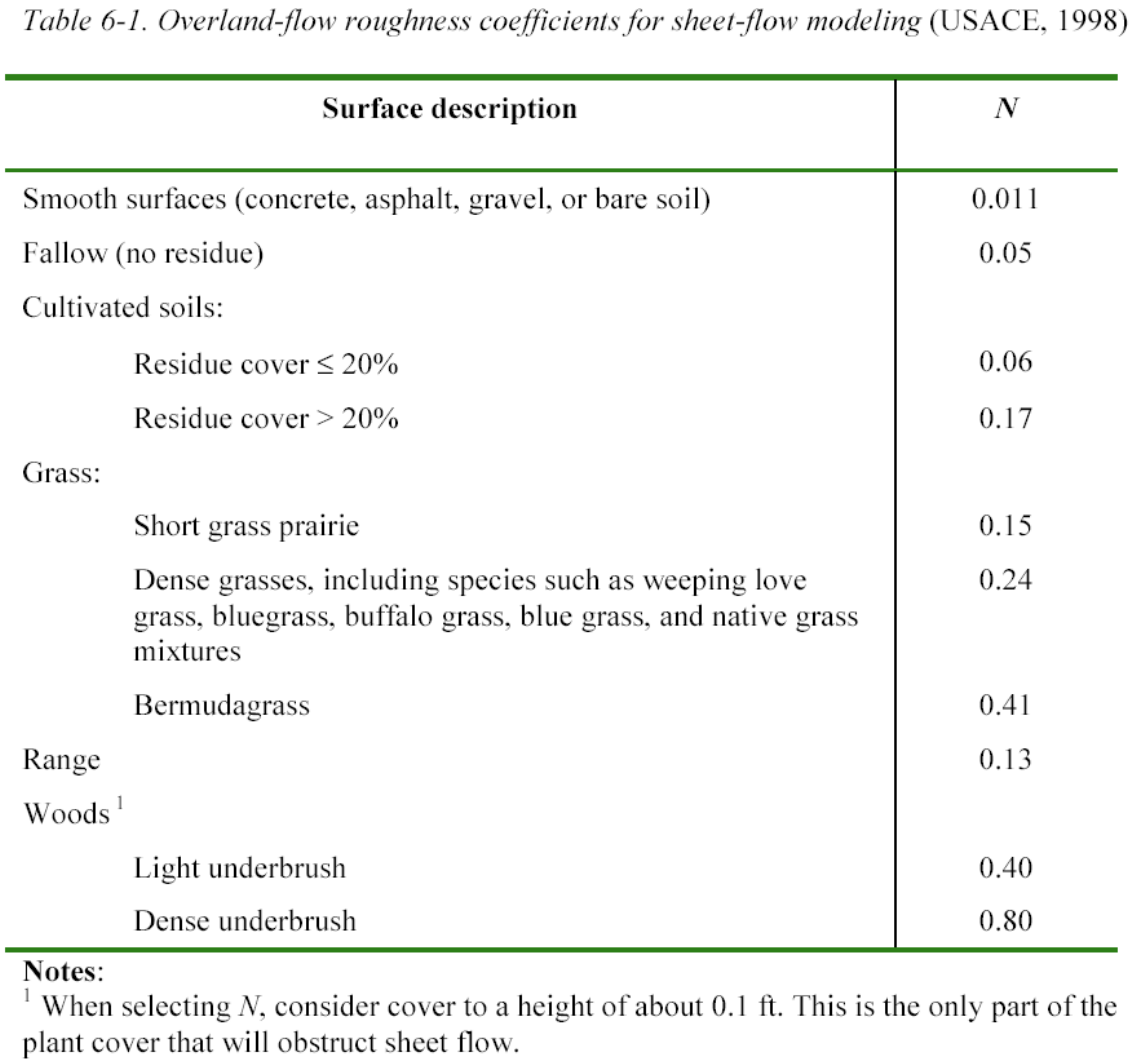


Table 6-1. Overland-flow roughness coefficients for sheet-flow modeling (USACE, 1998)

Surface description	***N***
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤ 20%	0.06
Residue cover > 20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses, including species such as weeping love grass, bluegrass, buffalo grass, blue grass, and native grass mixtures	0.24
Bermudagrass	0.41
Range	0.13
Woods[1]	
Light underbrush	0.40
Dense underbrush	0.80

Notes:

[1] When selecting N, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

SCS UH: Parameters (small catchments < 8 km²)

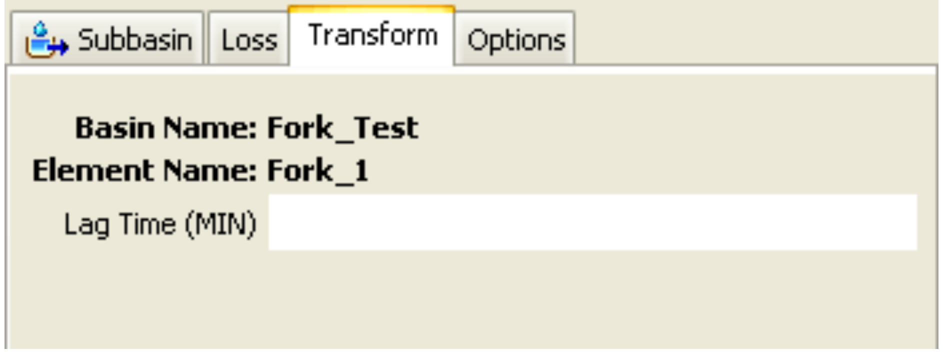
$$t_{lag} = 0.6\, t_c$$

$$t_{lag} = \frac{L^{8}(2540 - 22.86CN)^{0.7}}{14104CN^{0.7}Y^{0.5}}$$

L: Longest flow path (meters)
Y: Average slope (meter/meter)
CN: Basin curve number
t_{lag}: *lag time in hours*

$$t_{lag} = \frac{L^{0.8}(1000 - 9CN)^{0.7}}{1900CN^{0.7}Y^{0.5}}$$

L: Longest flow path (ft)
Y: Average slope (%)
CN: Basin curve number
t_{lag}: *lag time in hours*



Basin Name: Fork_Test
Element Name: Fork_1
Lag Time (MIN)

Clark's UH

Translation *or movement of the excess from its origin throughout the drainage to the watershed outlet*

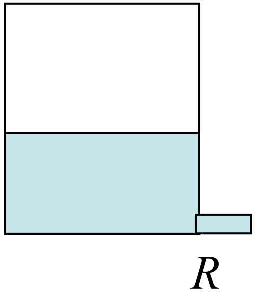
Attenuation *or reduction of the magnitude of the discharge as the excess is stored throughout the watershed.*

$$\frac{dS}{dt} = I_t - O_t$$

$$S_t = RO_t$$

$$O_t = C_A I_t + C_B O_{t-1}$$

$$\frac{A_t}{A} = \left\{ \begin{array}{ll} 1.414\left(\frac{t}{t_c}\right)^{1.5} & for\ t \le \frac{t_c}{2} \\ 1 - 1.414\left(1 - \frac{t}{t_c}\right)^{1.5} & for\ t \ge \frac{t_c}{2} \end{array} \right\}$$



where

At = cumulative watershed area contributing at time t;

A = total watershed area

tc = time of concentration of watershed =

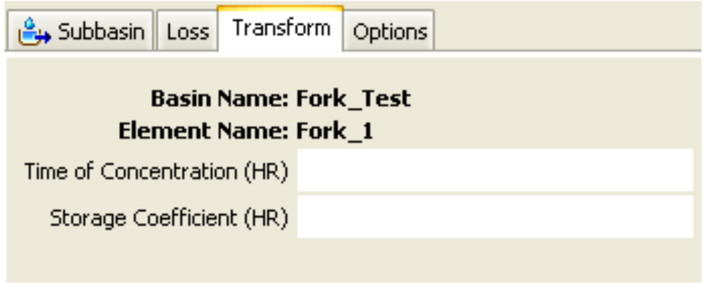
In HEC-HMS ← Calibration or using SCS approach

Routing coefficients

$$C_A = \frac{\Delta t}{R + 0.5\Delta t}$$

$$C_B = 1 - C_A$$

$$\overline{O}_t = \frac{O_{t-1} + O_t}{2}$$



Basin Name: Fork_Test
Element Name: Fork_1

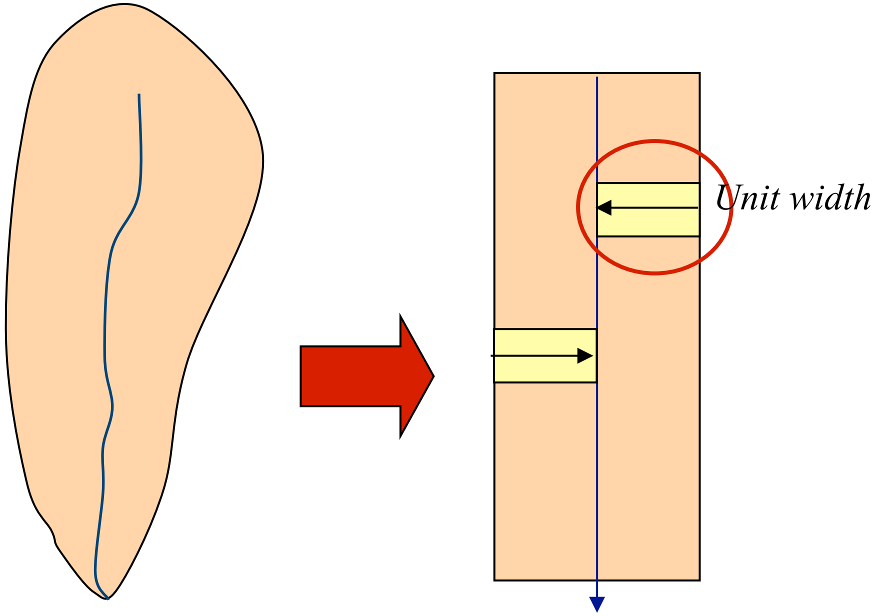
Time of Concentration (HR)
Storage Coefficient (HR)

Limitations (Data)

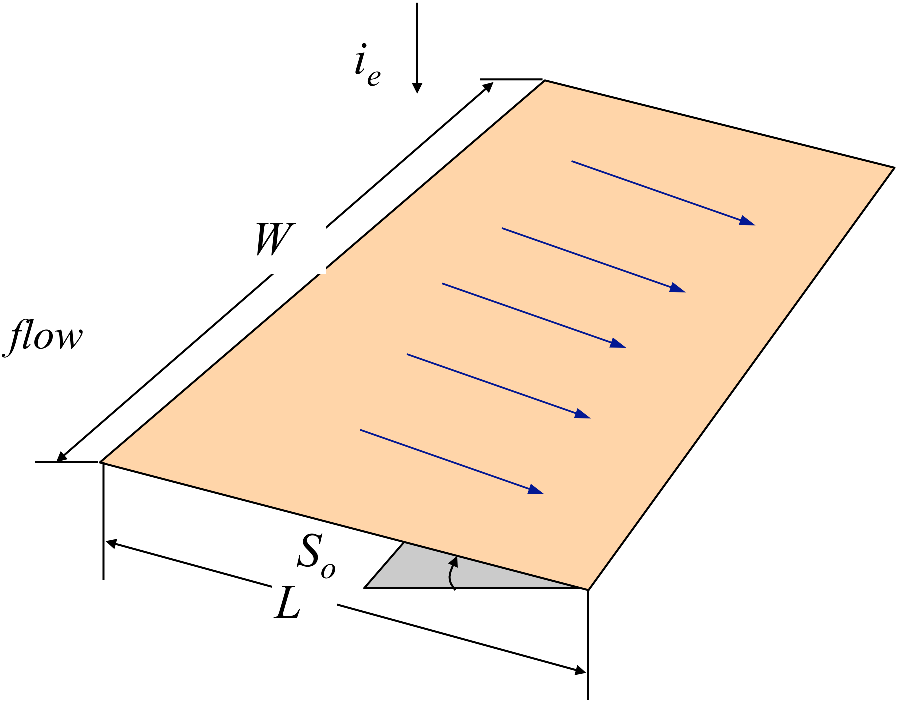
Availability of information for calibration or parameter estimation.

- Parametric UH models requires model parameters.
- Empirical parameter predictors
- Optimal source of these parameters is calibration,
- If calibration in an urban watershed is not available, then use the kinematic-wave model

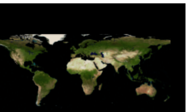
Physically Based Models of Overland Flow Theory



Watershed → Flow plains
i_e : *Rainfall excess ← treated as lateral flow*
W: Plane width
S_o: *Slope*
L: Flow length



Approximations



$$S_f = S_0 - \frac{\partial y}{\partial x} - \frac{V}{g}\frac{\partial V}{\partial x} - \frac{1}{g}\frac{\partial V}{\partial t}$$

$S_f = S_o$ *Kinematic Wave* → *HEC-HMS*

Overland

Channel

$S_f = S_0 - \frac{\partial y}{\partial x}$ *Diffusion Wave* → *HEC-HMS*

Basis for Muskingum

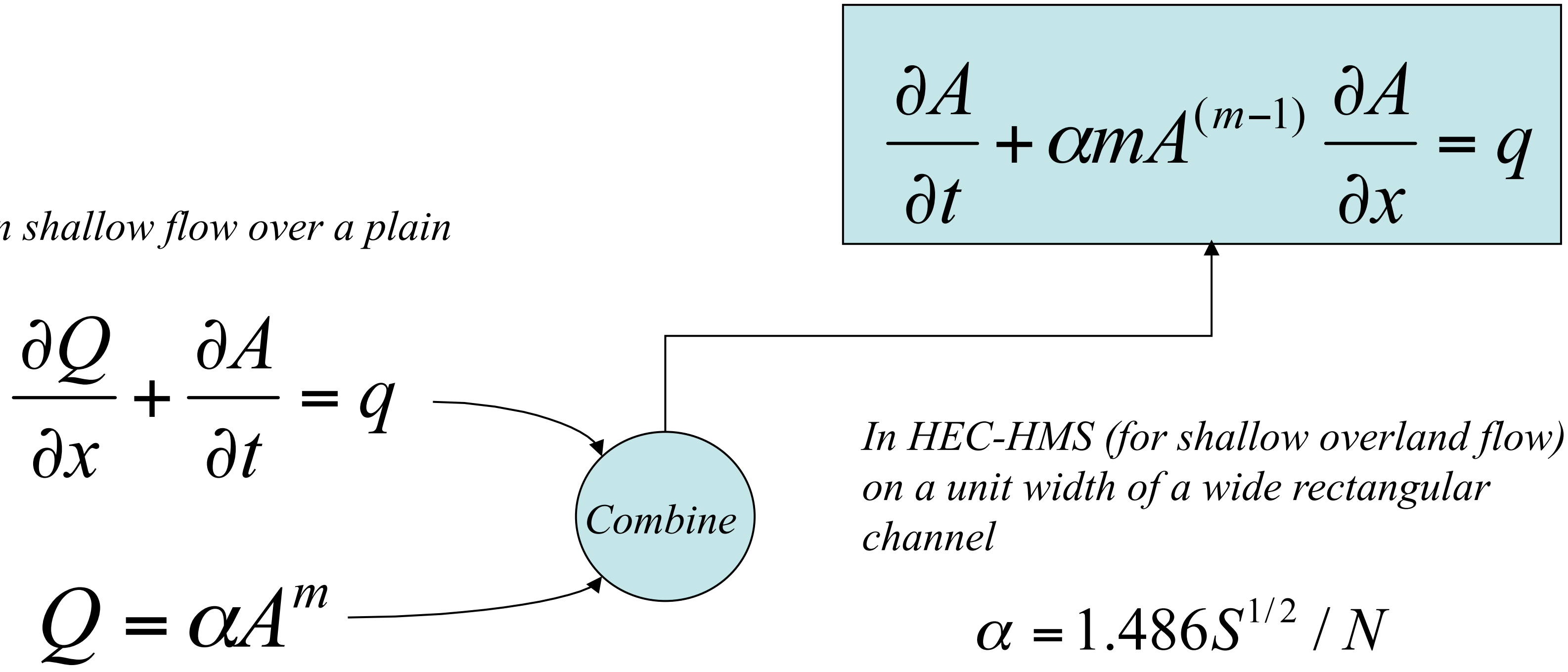
$S_f = S_0 - \frac{\partial y}{\partial x} - \frac{V}{g}\frac{\partial V}{\partial x}$ *Quasi Steady State Dynamic Wave* → *HEC-RAS*

Steady flow

$S_f = S_0 - \frac{\partial y}{\partial x} - \frac{V}{g}\frac{\partial V}{\partial x} - \frac{1}{g}\frac{\partial V}{\partial t}$ *St. Venant /Dynamic Wave* → *Unsteady/Gradually varied Flow*

Many numerical models

Kinematic Wave: Combine Simplifications



In shallow flow over a plain

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=q$$

$$Q=\alpha A^{m}$$

$$\frac{\partial A}{\partial t}+\alpha m A^{(m-1)}\frac{\partial A}{\partial x}=q$$

In HEC-HMS (for shallow overland flow) on a unit width of a wide rectangular channel

$$\alpha=1.486S^{1/2}/N$$

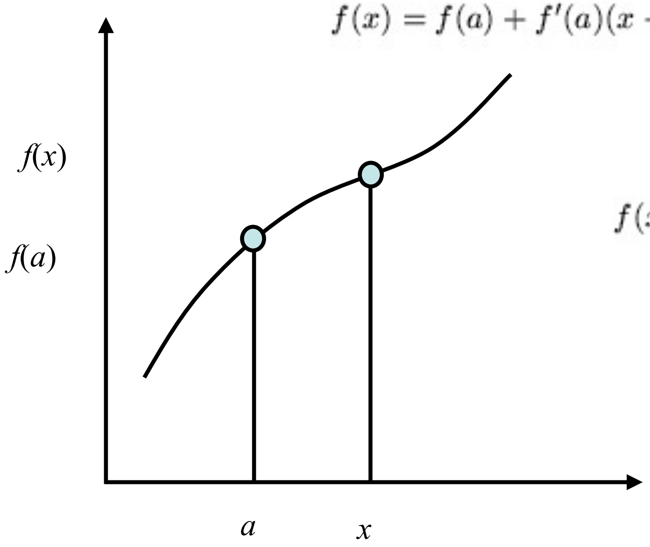
and

$$m=\frac{5}{3}$$

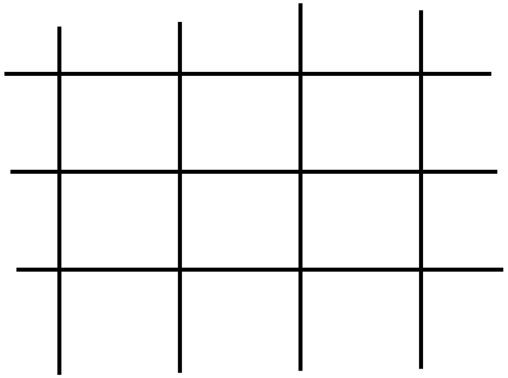
Basic Concept of Finite Difference Method

Taylor Series

$$f(x) = f(a) + f'(a)(x-a) + \frac{f''(a)}{2!}(x-a)^2 + \cdots + \frac{f^{(n)}(a)}{n!}(x-a)^n + \cdots,$$



$$f(x) = \sum_{n=0}^{\infty} \frac{(x-a)^n}{n!} f^{(n)}(a),$$



Needs boundary conditions

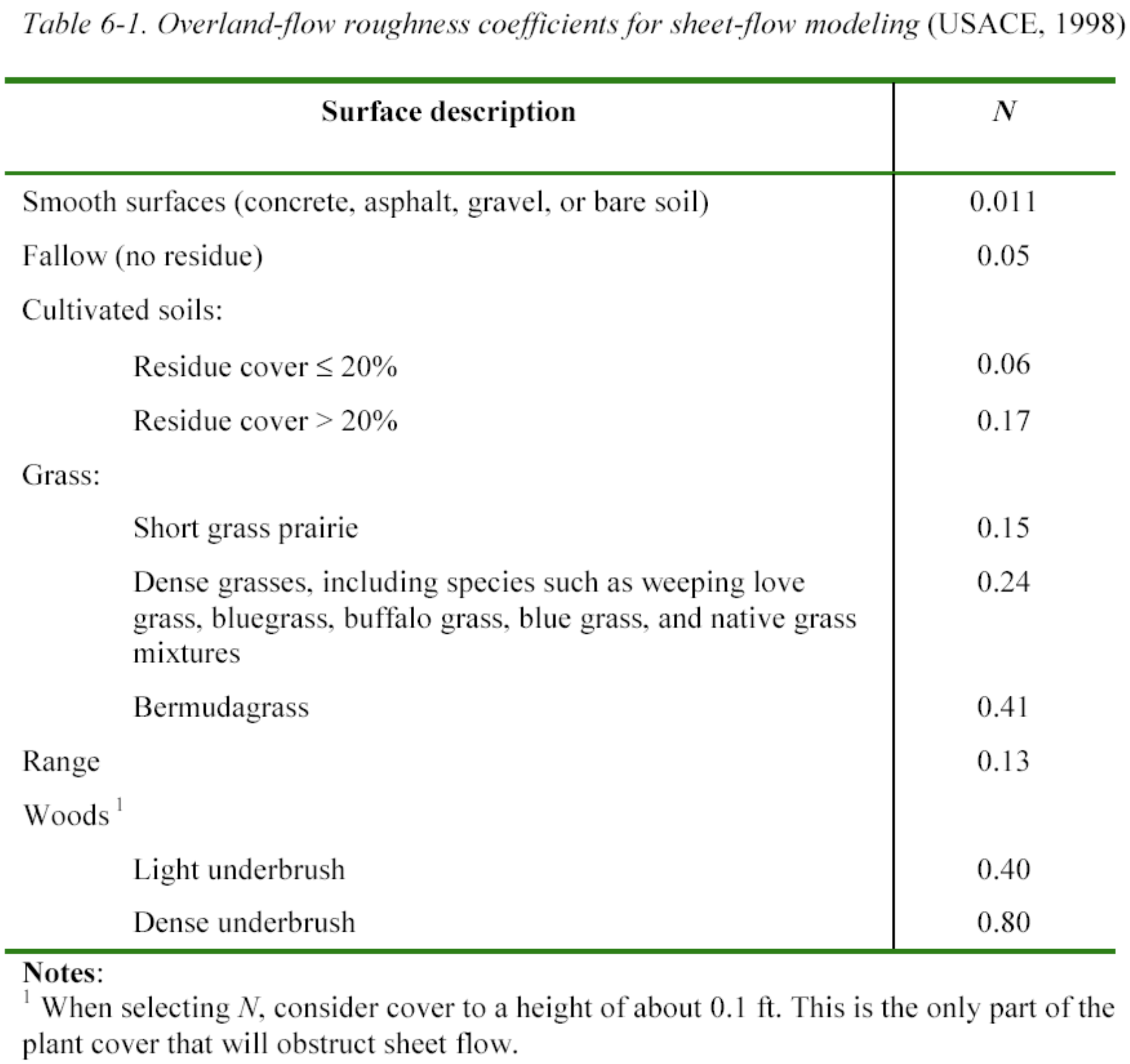
Needs method to approximate $f^{(n)}$ → *How many neighboring points will you consider*

Central

Implicit

Explicit

Overland flow roughness coefficient



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Dense underbrush	0.80

Notes:

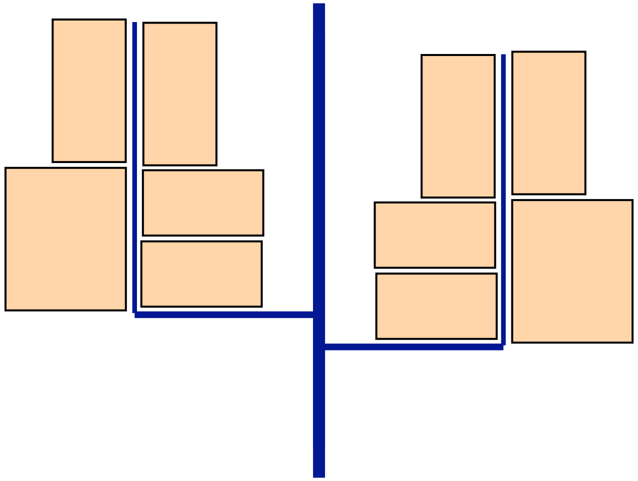
[1] When selecting *N*, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

HEC-HMS Implementation for Sub-basins

$\Delta x/\Delta t \approx c$ → Accurate and stable solution

c = average kinematic-wave speed over a distance increment Δx

Types of routing elements for KW (see pp 71 for details)



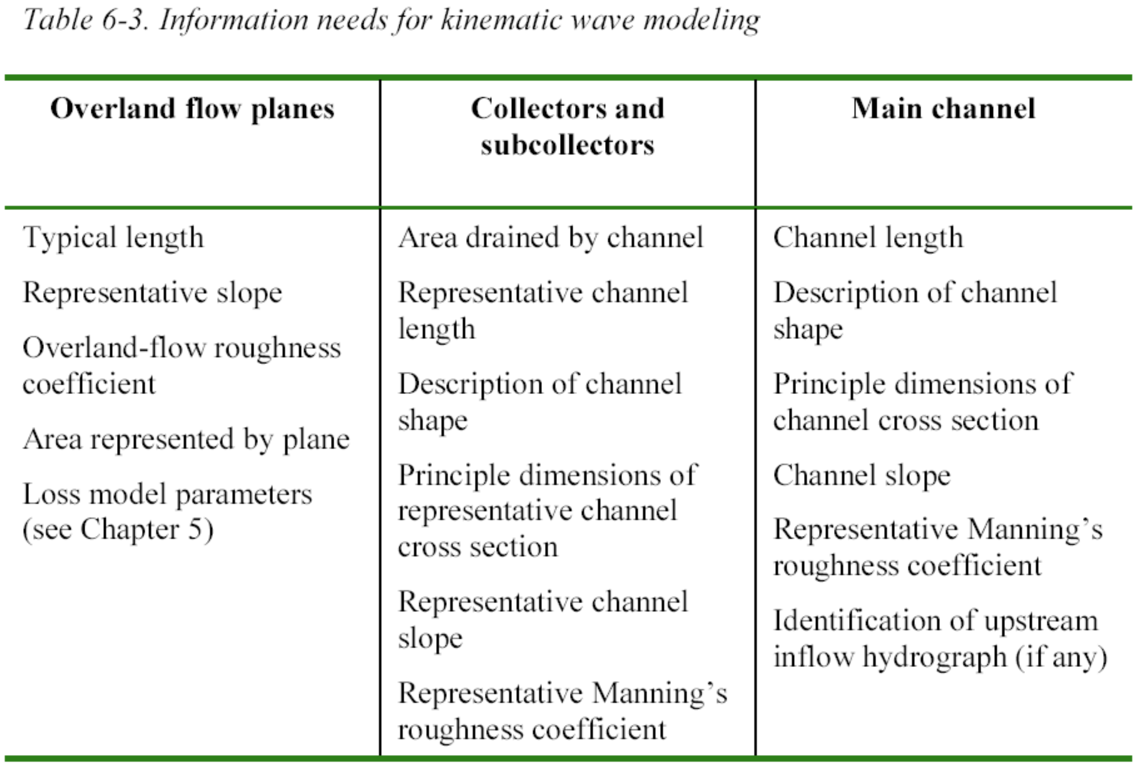
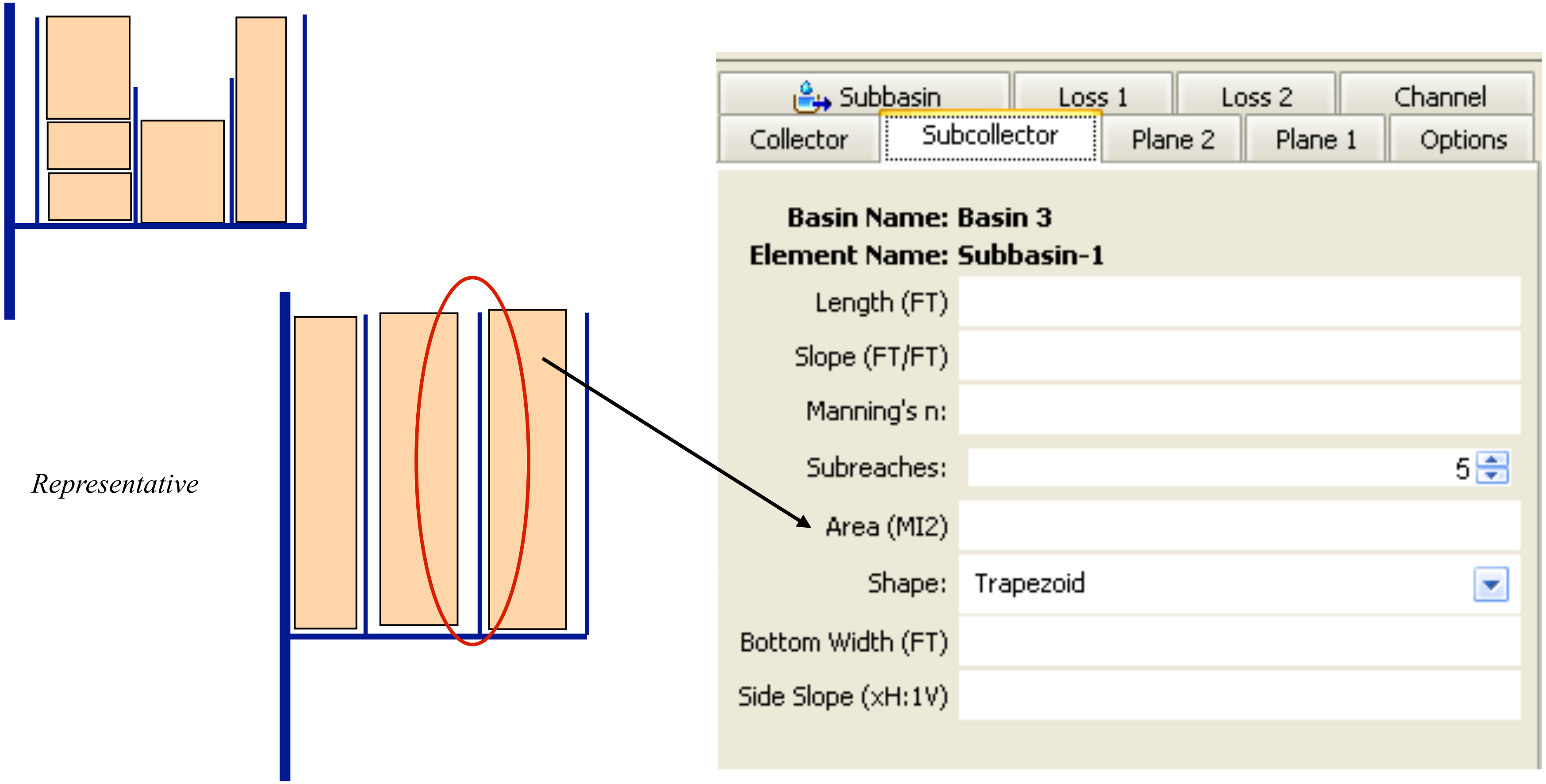


Table 6-3. Information needs for kinematic wave modeling

Overland flow planes	**Collectors and subcollectors**	**Main channel**
Typical length Representative slope Overland-flow roughness coefficient Area represented by plane Loss model parameters (see Chapter 5)	Area drained by channel Representative channel length Description of channel shape Principle dimensions of representative channel cross section Representative channel slope Representative Manning's roughness coefficient	Channel length Description of channel shape Principle dimensions of channel cross section Channel slope Representative Manning's roughness coefficient Identification of upstream inflow hydrograph (if any)

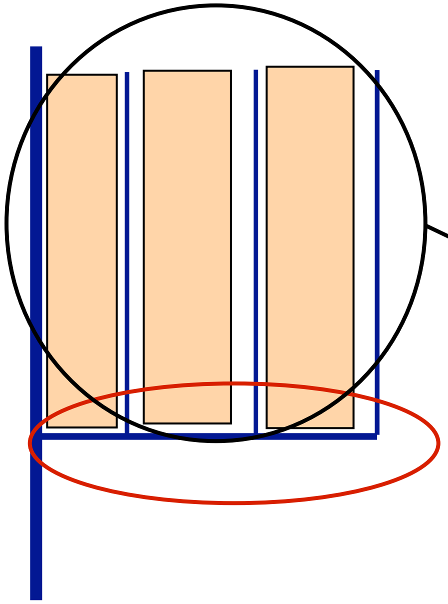
Sub-Collectors

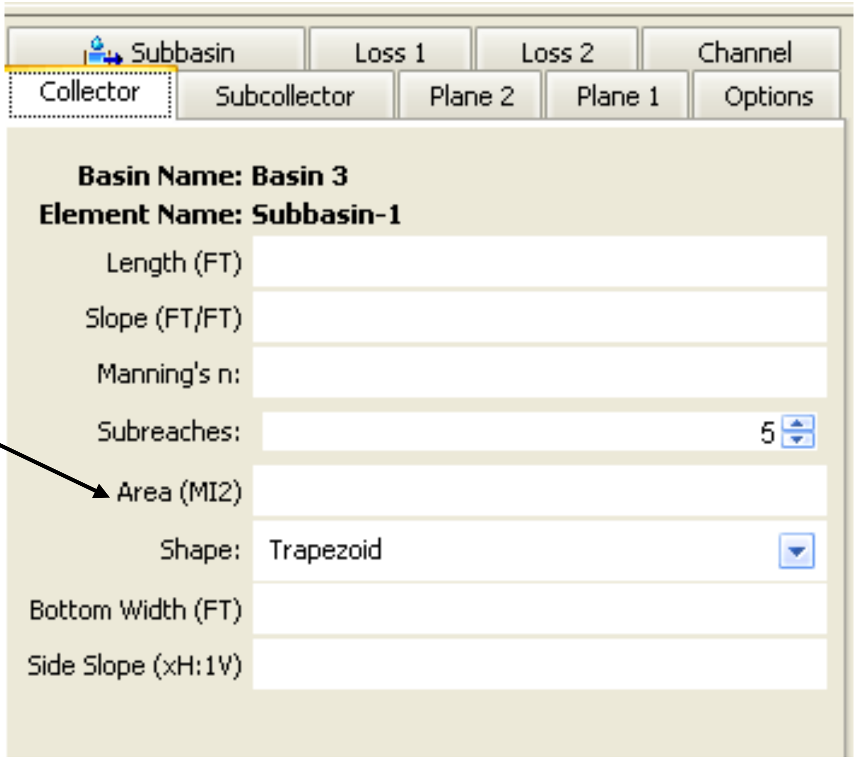


Basin Name: Basin 3
Element Name: Subbasin-1
Length (FT)
Slope (FT/FT)
Manning's n:
Subreaches: 5
Area (MI2)
Shape: Trapezoid
Bottom Width (FT)
Side Slope (xH:1V)

Small feeder pipes or channels,
Principle dimension < 18 inches,
They might service area < 10 acres.
Flow is assumed to enter the channel uniformly along its length.

Collectors

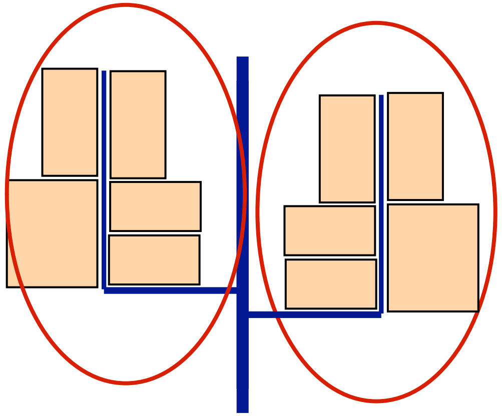


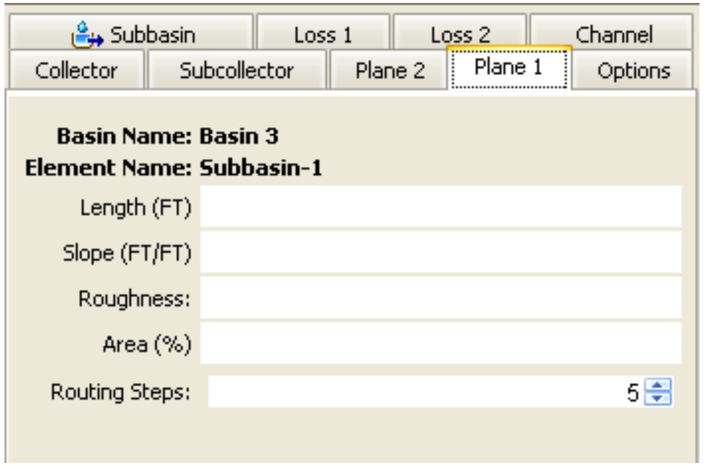


Basin Name: Basin 3
Element Name: Subbasin-1
Length (FT)
Slope (FT/FT)
Manning's n:
Subreaches: 5
Area (MI2)
Shape: Trapezoid
Bottom Width (FT)
Side Slope (xH:1V)

These are channels, with
Principle dimension 18-24 inches,
Collect flows from sub-collectors
Convey flow to main channel.
Flow enters latterally

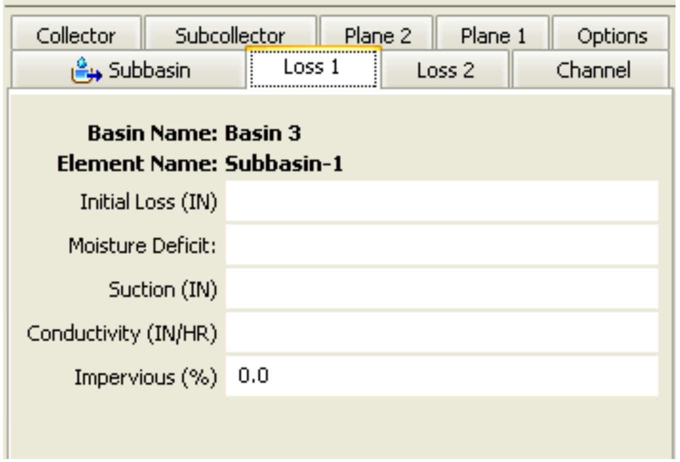
Planes





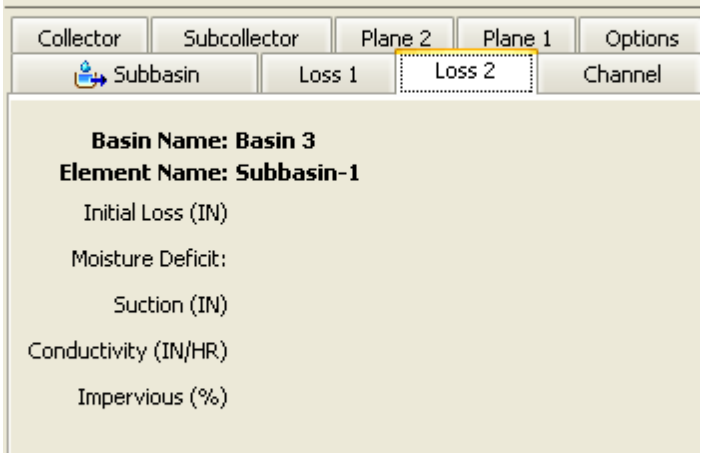
Basin Name: Basin 3
Element Name: Subbasin-1

Length (FT)
Slope (FT/FT)
Roughness:
Area (%)
Routing Steps: 5



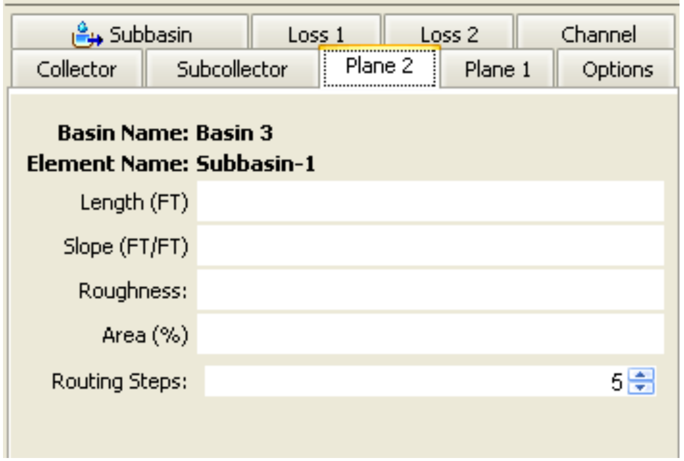
Basin Name: Basin 3
Element Name: Subbasin-1

Initial Loss (IN)
Moisture Deficit:
Suction (IN)
Conductivity (IN/HR)
Impervious (%) 0.0



Basin Name: Basin 3
Element Name: Subbasin-1

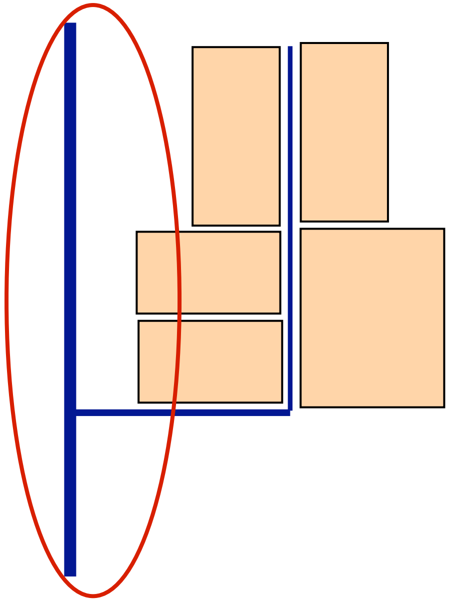
Initial Loss (IN)
Moisture Deficit:
Suction (IN)
Conductivity (IN/HR)
Impervious (%)



Basin Name: Basin 3
Element Name: Subbasin-1

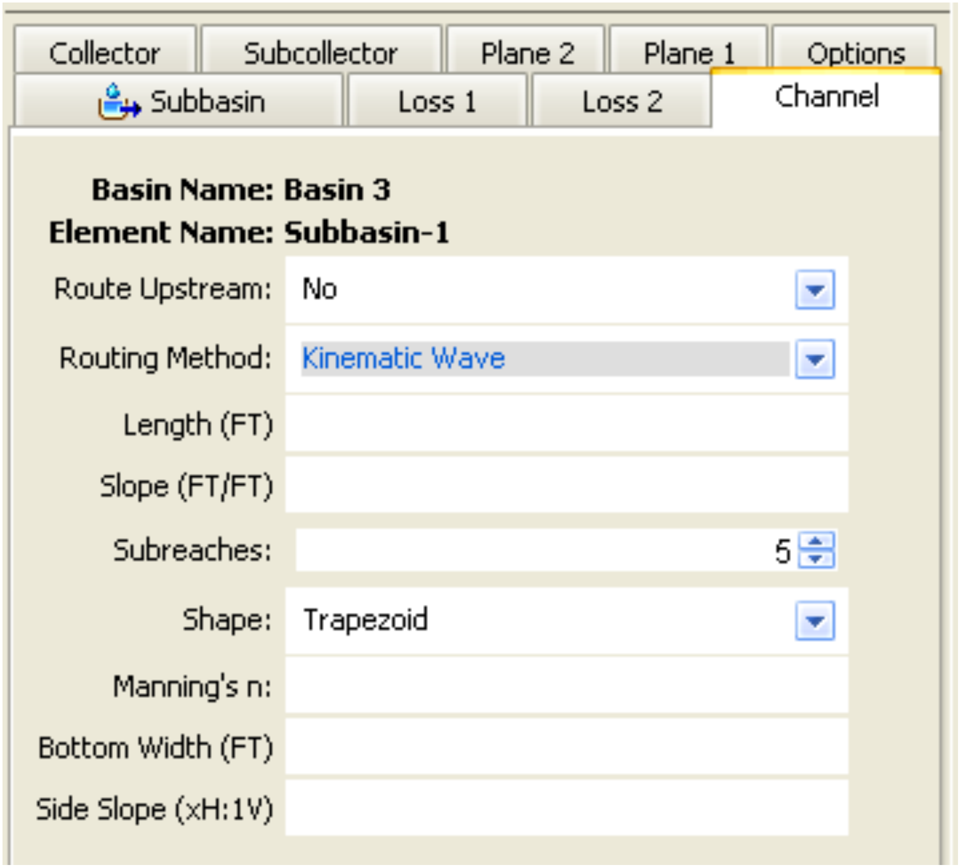
Length (FT)
Slope (FT/FT)
Roughness:
Area (%)
Routing Steps: 5

Channel



Conveys flow from upstream sub-watersheds

Convey flows that enter from the collector channels or overland flow planes



Basin Name: Basin 3

Element Name: Subbasin-1

Route Upstream: No

Routing Method: Kinematic Wave

Length (FT)

Slope (FT/FT)

Subreaches: 5

Shape: Trapezoid

Manning's n:

Bottom Width (FT)

Side Slope (xH:1V)

Basin Model Components (Sub-basin)

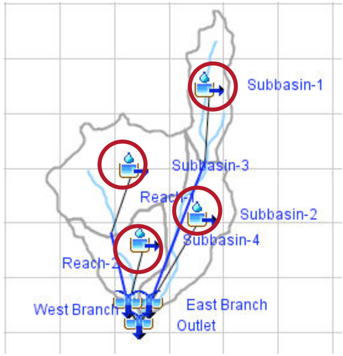
Sub-basin:

- Represents the physical watershed

- Basic element in rainfall-runoff modeling and loss calculations

- Runoff is routed internally to the outlet of the sub-basin

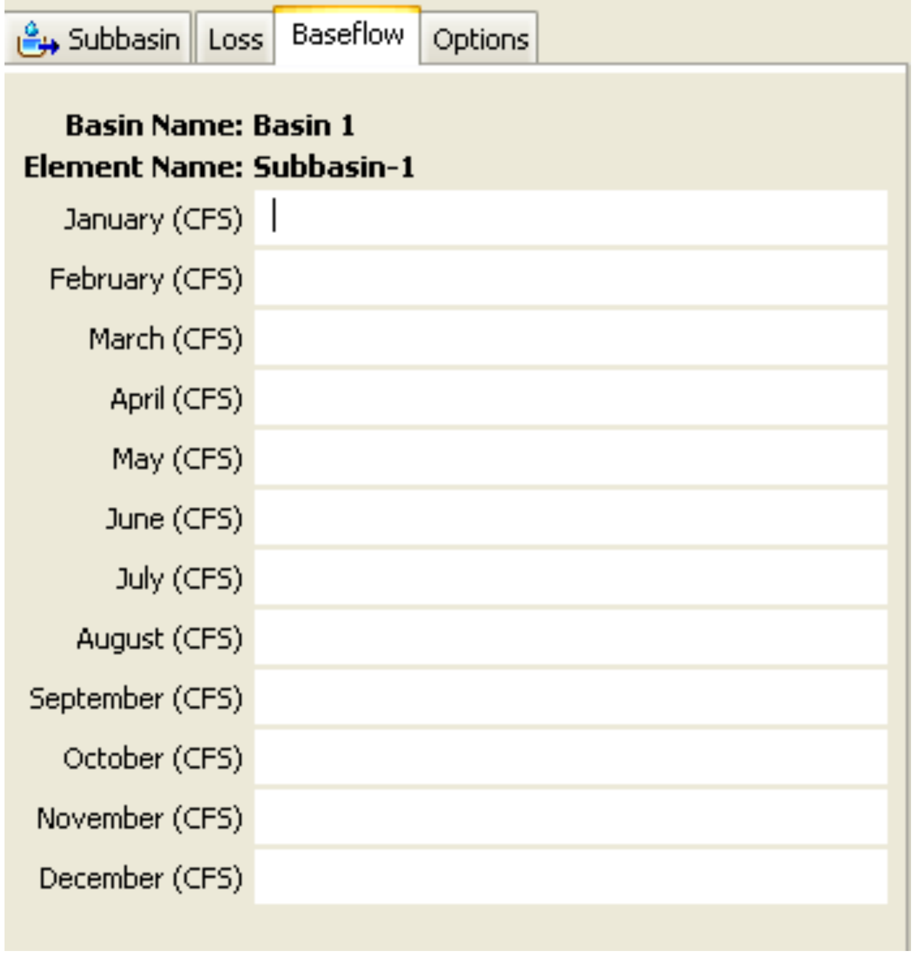
- Baseflow (GW contribution) is added



Transform

Bounded recession
Constant monthly
Linear reservoir
Nonlinear Boussinesq
Recession

Constant Monthly



Basin Name: Basin 1
Element Name: Subbasin-1

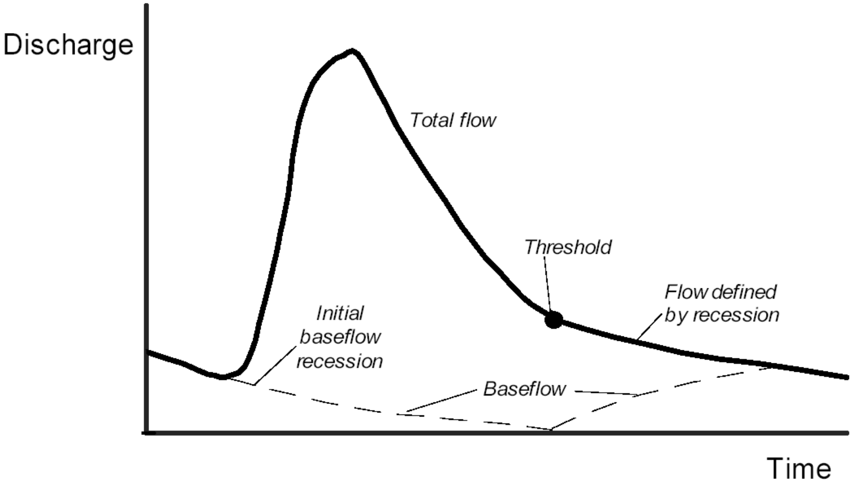
January (CFS)	
February (CFS)	
March (CFS)	
April (CFS)	
May (CFS)	
June (CFS)	
July (CFS)	
August (CFS)	
September (CFS)	
October (CFS)	
November (CFS)	
December (CFS)	

Recession Models

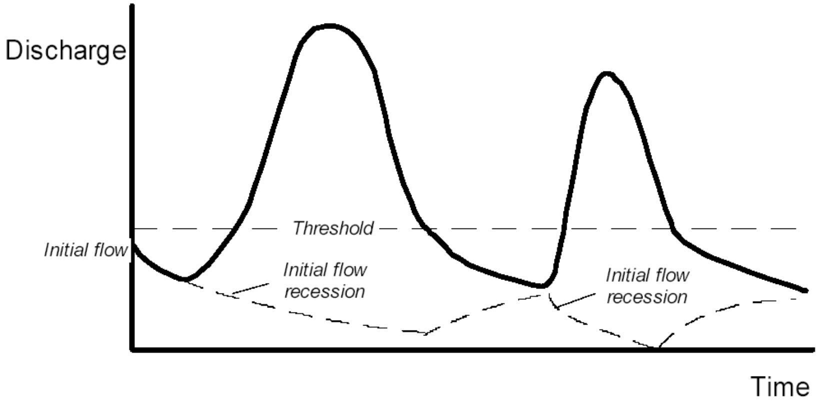
Initial Discharge

$$Q_t = Q_0 k^t$$

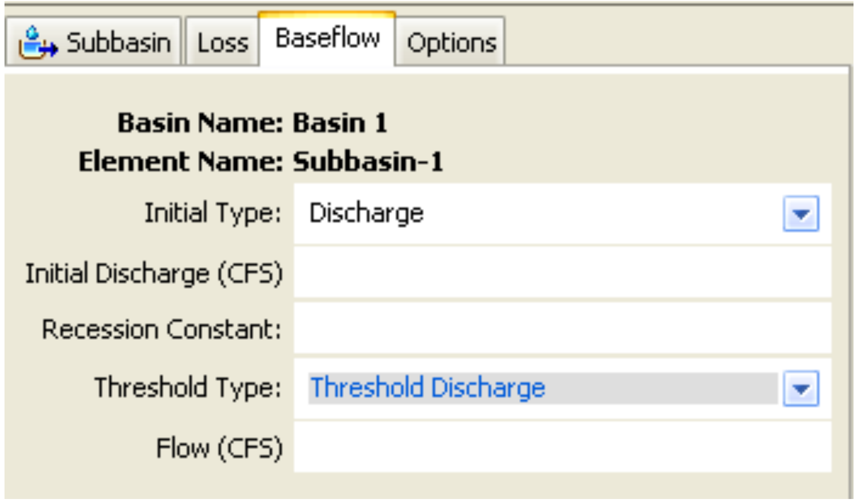
Recession Constant



You can also reset Q_o



Recession Model



Basin Name: Basin 1
Element Name: Subbasin-1

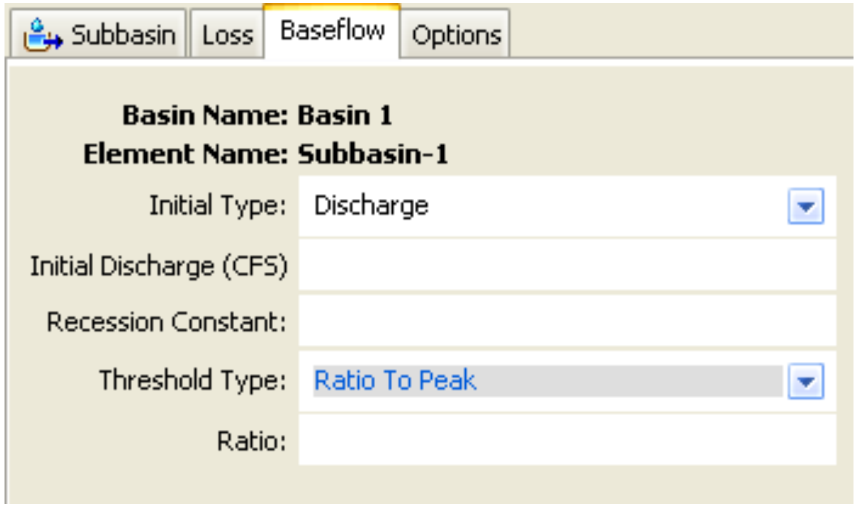
Initial Type: Discharge

Initial Discharge (CFS)

Recession Constant:

Threshold Type: Threshold Discharge

Flow (CFS)



Basin Name: Basin 1
Element Name: Subbasin-1

Initial Type: Discharge

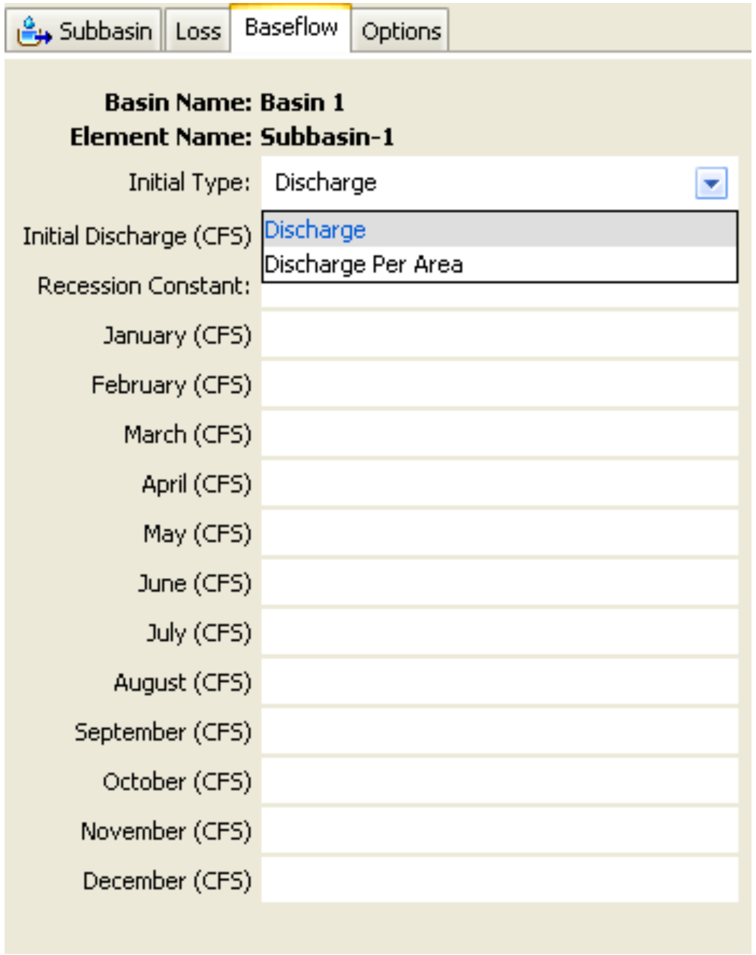
Initial Discharge (CFS)

Recession Constant:

Threshold Type: Ratio To Peak

Ratio:

Bounded Recession



Basin Name: Basin 1

Element Name: Subbasin-1

Initial Type: Discharge

Initial Discharge (CFS)

Recession Constant:

January (CFS)

February (CFS)

March (CFS)

April (CFS)

May (CFS)

June (CFS)

July (CFS)

August (CFS)

September (CFS)

October (CFS)

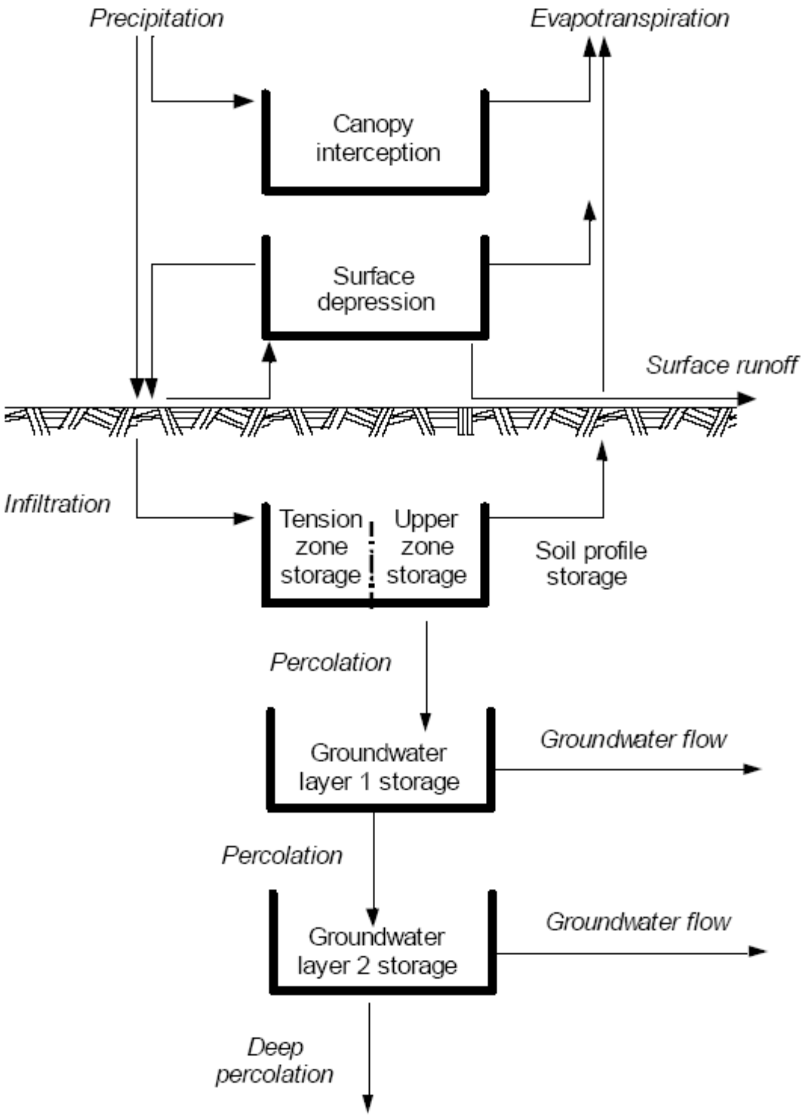
November (CFS)

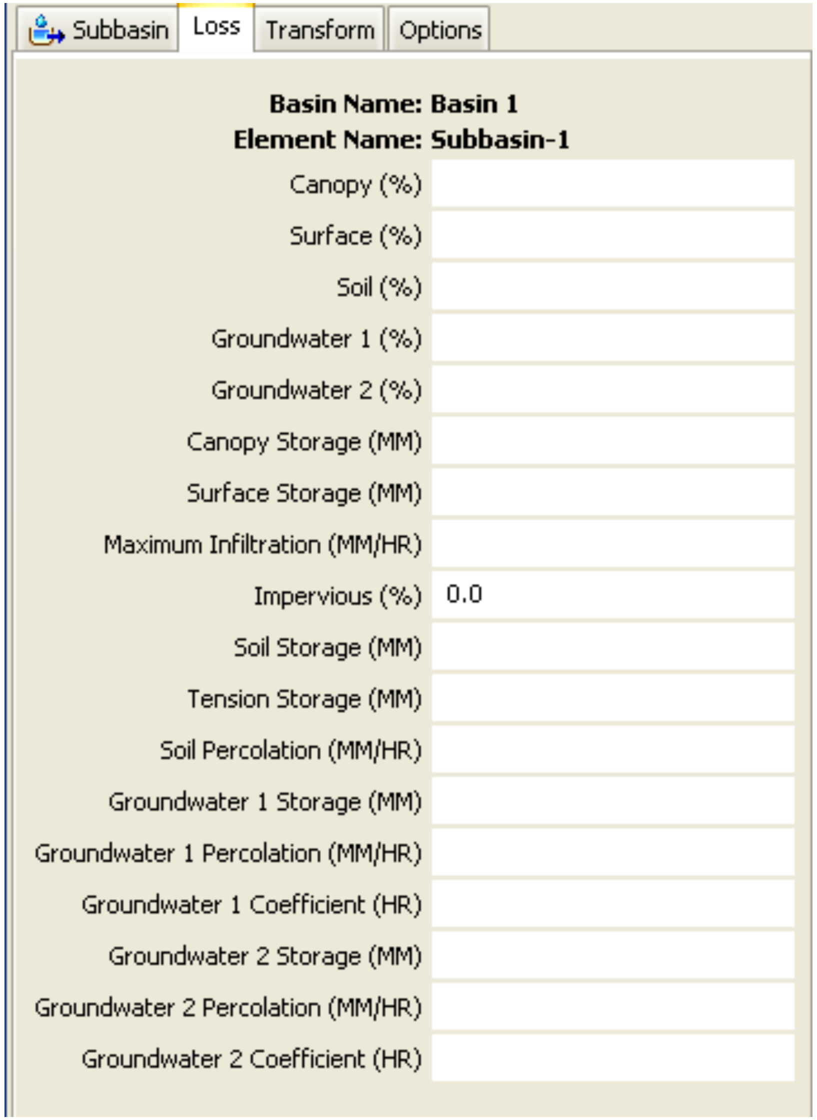
December (CFS)

Bounded recession is similar to recession method. The difference is mainly in selecting temporally varying threshold.

You can also identify the type of initial flow.

Linear Reservoir (Remember SAC-SMA)



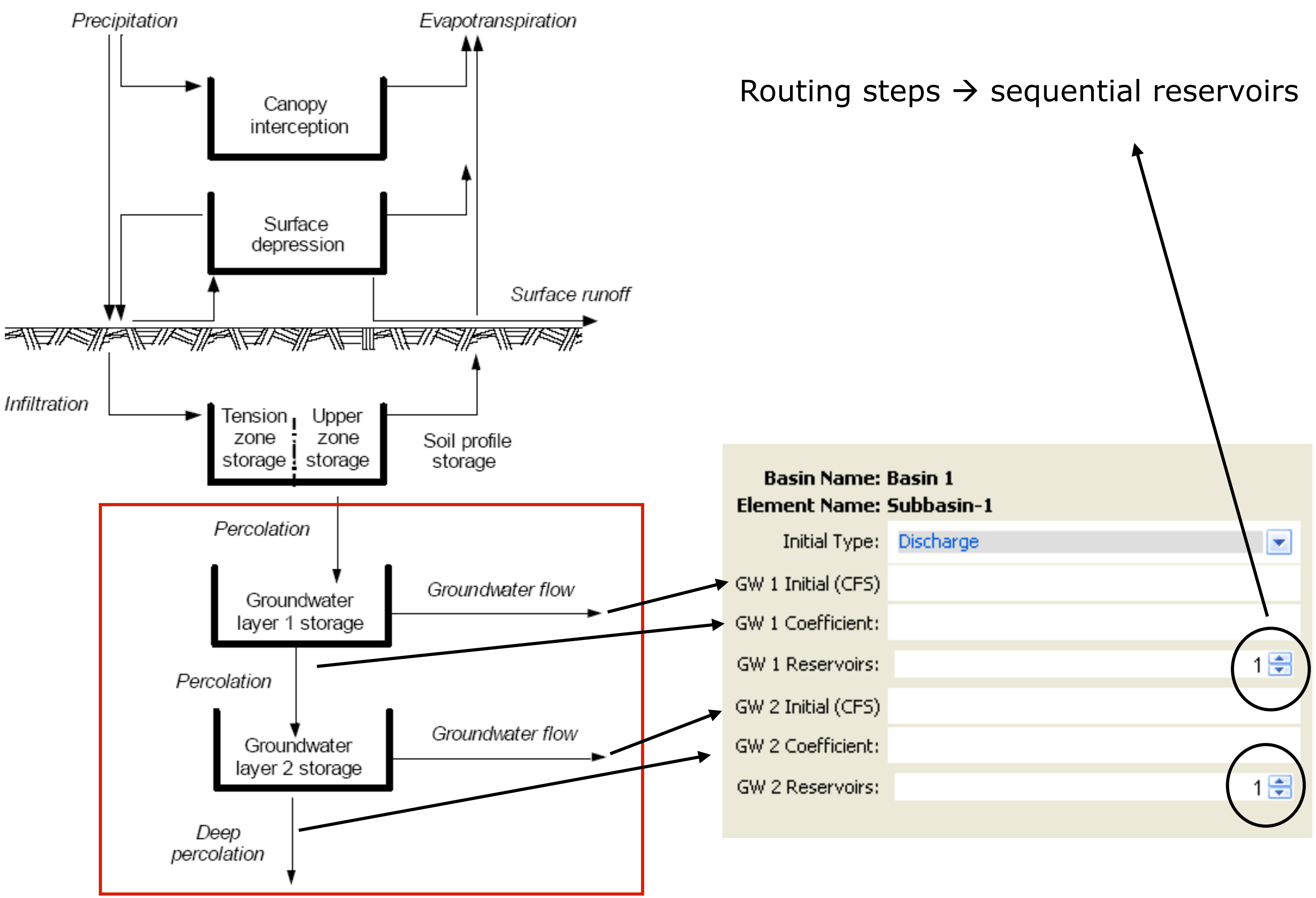


Basin Name: Basin 1
Element Name: Subbasin-1

Canopy (%)	
Surface (%)	
Soil (%)	
Groundwater 1 (%)	
Groundwater 2 (%)	
Canopy Storage (MM)	
Surface Storage (MM)	
Maximum Infiltration (MM/HR)	
Impervious (%)	0.0
Soil Storage (MM)	
Tension Storage (MM)	
Soil Percolation (MM/HR)	
Groundwater 1 Storage (MM)	
Groundwater 1 Percolation (MM/HR)	
Groundwater 1 Coefficient (HR)	
Groundwater 2 Storage (MM)	
Groundwater 2 Percolation (MM/HR)	
Groundwater 2 Coefficient (HR)	

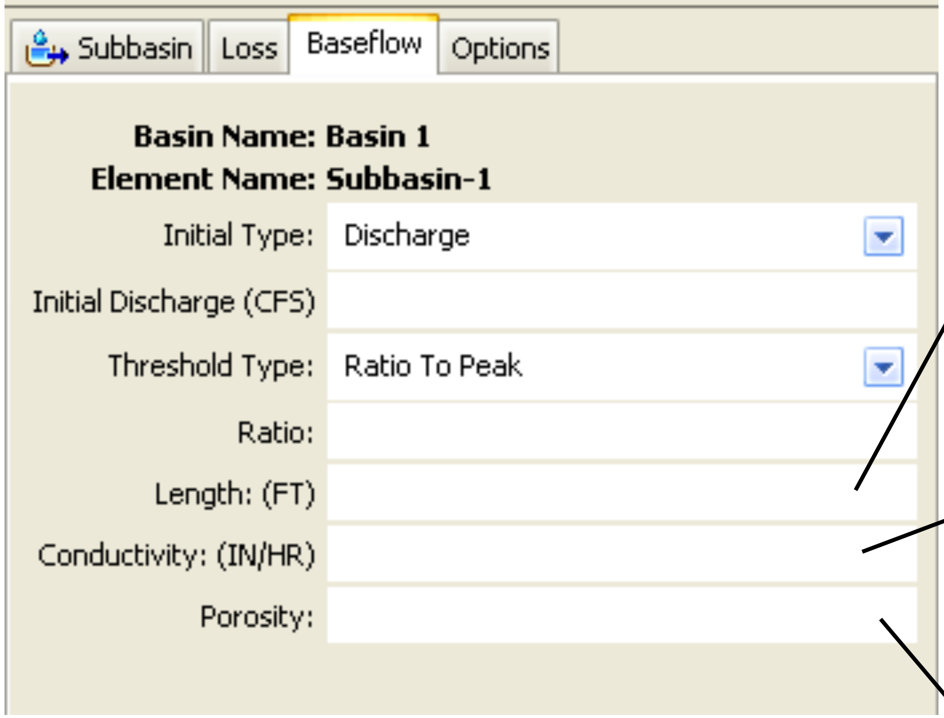
Linear Reservoir

Routing steps → sequential reservoirs



Basin Name: Basin 1
Element Name: Subbasin-1
Initial Type: Discharge
GW 1 Initial (CFS):
GW 1 Coefficient:
GW 1 Reservoirs: 1
GW 2 Initial (CFS):
GW 2 Coefficient:
GW 2 Reservoirs: 1

Non-Linear Boussinesq



Basin Name: Basin 1
Element Name: Subbasin-1
Initial Type: Discharge
Initial Discharge (CFS)
Threshold Type: Ratio To Peak
Ratio:
Length: (FT)
Conductivity: (IN/HR)
Porosity:

Characteristic subsurface flow length ← mean distance from the sub-basin boundary to the stream.

Soil conductivity ← estimated from
field tests
soil texture.

Drainable porosity (volume ratio) ←
max= total porosity - residual porosity.
Actual =f(local conditions)

Basin Model Components (Reach)

Reach

- Represents channels and pipes
- Conveys streamflow downstream in the basin model
- inflow can come from any hydrologic element
- Outflow is computed by accounting for translation + attenuation of inflow hydrograph

Routing

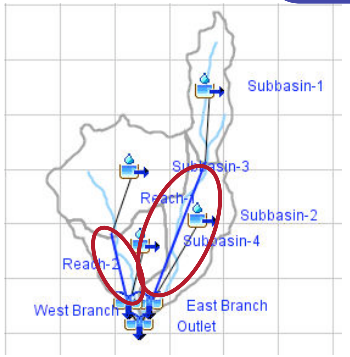
Kinematic wave

Lag

Modified Puls

Muskingum

Muskingum-Cunge



Channel Routing Requirements

Description of the Channel

- Width
- Bed-slope
- Cross-section shape

Energy loss model parameters

- Physically based: manning equation
- Others: parametric

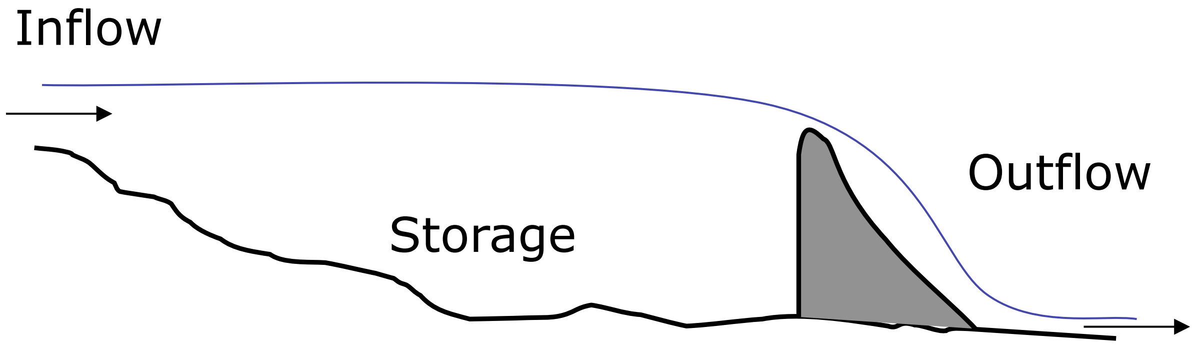
Initial conditions

- Flow or stage d/s. Example (use base-flow as estimate)

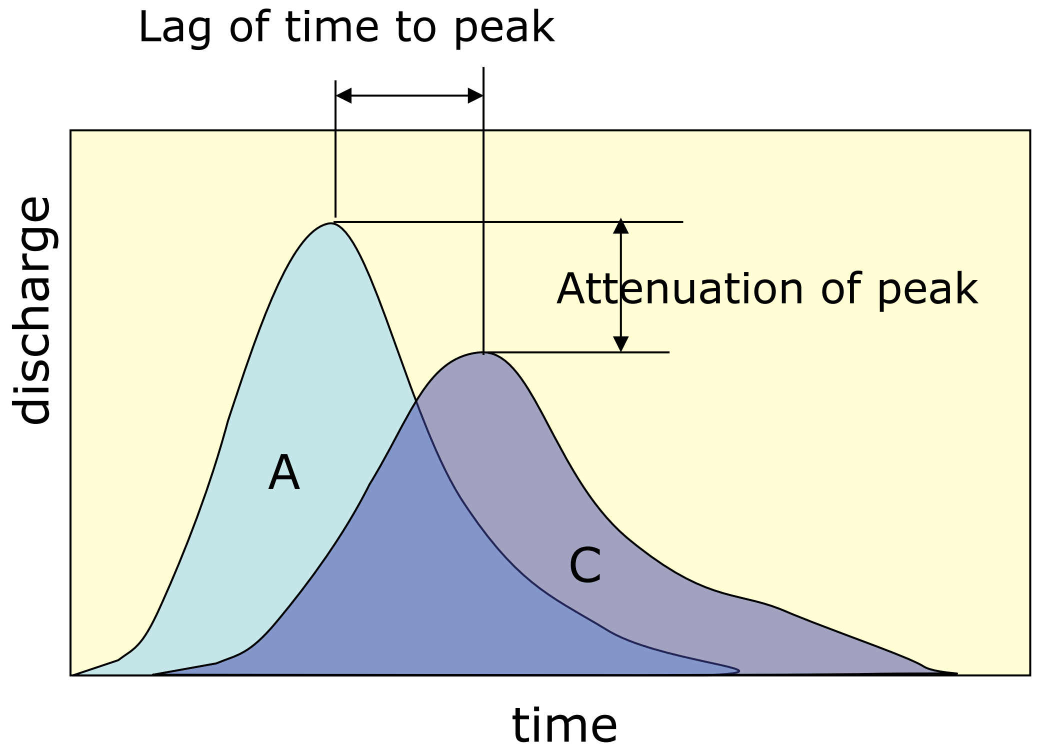
Boundary conditions

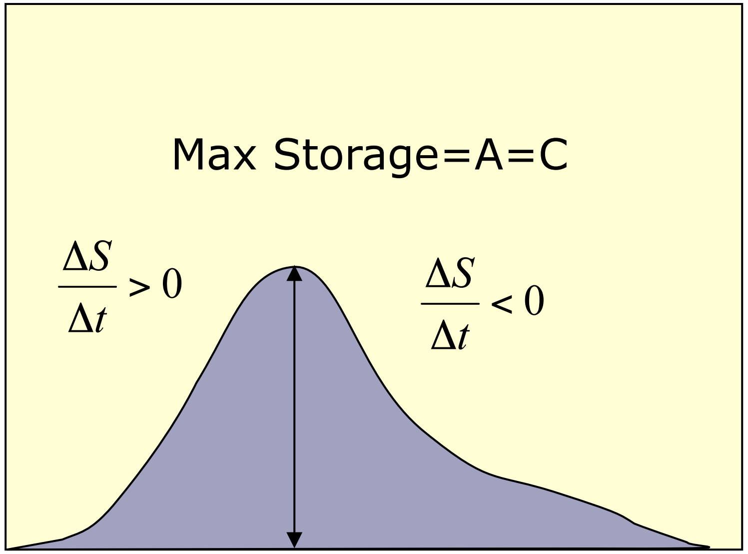
- Upstream inflow (determined by the direct runoff model)

Reservoir Storage Concept

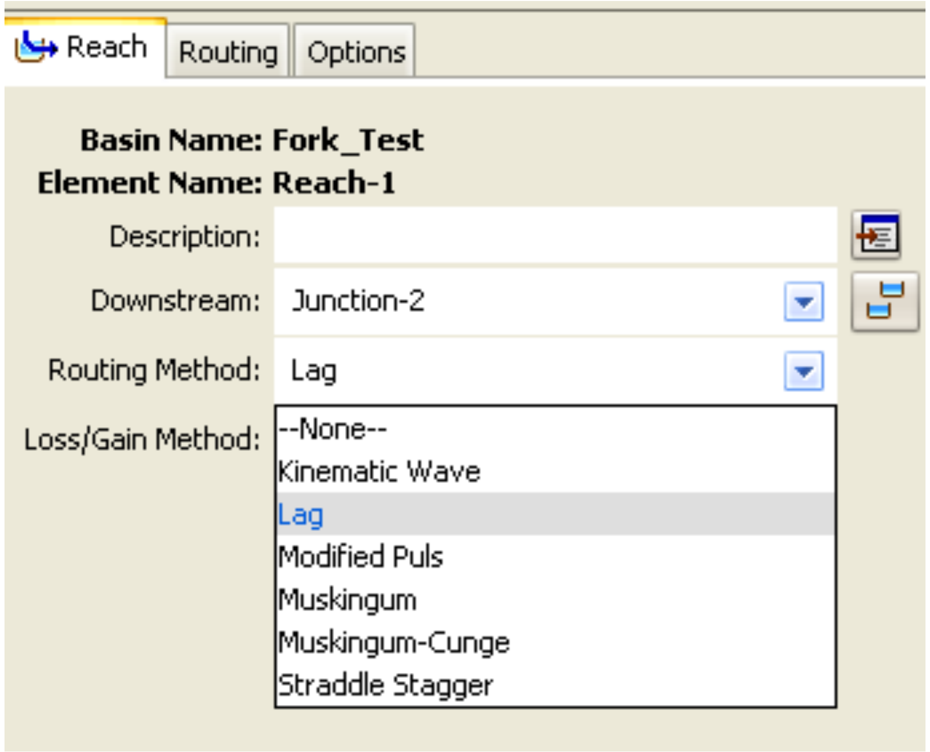


$$I - O = \frac{\Delta S}{\Delta t}$$





Channel Routing Models in HEC-HMS



Basin Name: Fork_Test
Element Name: Reach-1
Description:
Downstream: Junction-2
Routing Method: Lag
Loss/Gain Method:

- --None--
- Kinematic Wave
- Lag
- Modified Puls
- Muskingum
- Muskingum-Cunge
- Straddle Stagger

Modified Pulse Model: Simple Storage Routing

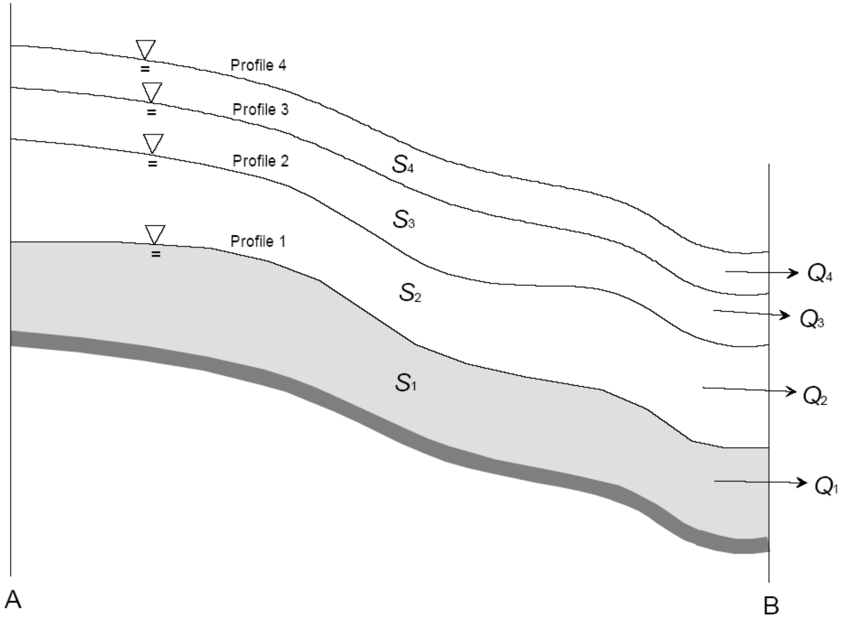
$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0$$

$$\bar{I}_t - \bar{O}_t = \frac{\Delta S}{\Delta t}$$

$$\frac{1}{2}(I_1 + I_2) - \frac{1}{2}(Q_1 + Q_2) = \frac{S_2 - S_1}{\Delta t}$$

$$\left(\frac{S_t}{\Delta t} + \frac{O_t}{2}\right) = \left(\frac{I_{t-1} + I_t}{2}\right) + \left(\frac{S_{t-1}}{\Delta t} - \frac{O_{t-1}}{2}\right)$$

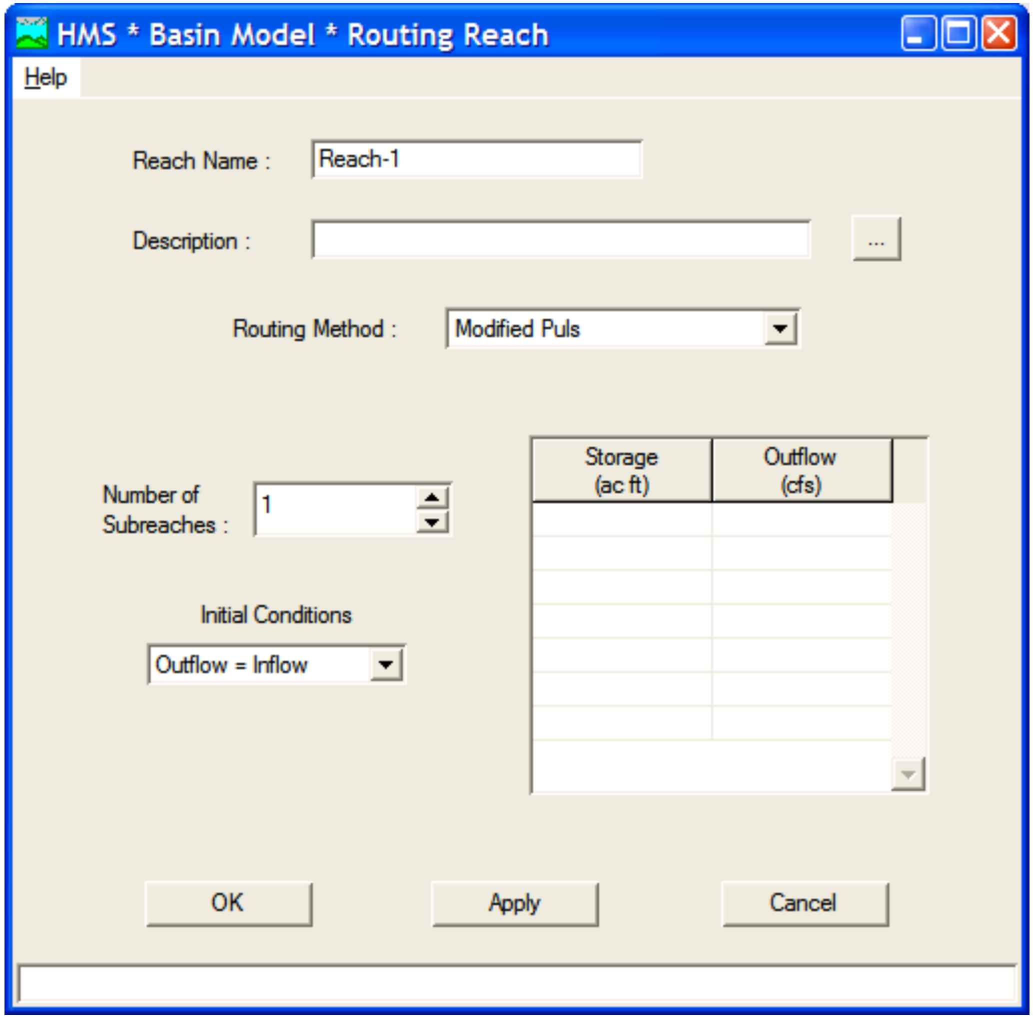
Unknown



Solution requires Discharge-Storage (Q|S) relationship

HEC-HMS Solves equation recursively using trial and error

Modified Pulse



Reach Name : Reach-1

Description :

Routing Method : Modified Puls

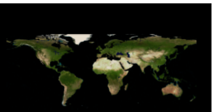
Number of Subreaches : 1

Initial Conditions: Outflow = Inflow

Storage (ac ft)	Outflow (cfs)

Notice Storage Outflow requirement

Muskingum Model: The starting point



$$\left(\frac{S_t}{\Delta t}+\frac{O_t}{2}\right)=\left(\frac{I_{t-1}+I_t}{2}\right)+\left(\frac{S_{t-1}}{\Delta t}-\frac{O_{t-1}}{2}\right)$$

Proposed S/I-O relationship

$$S=\frac{b\left[xI^{m/n}+(1-x)O^{m/n}\right]}{a^{m/n}}$$

$$(I,O)\propto ay^{n}\quad (Manning)$$

$$S_{reach}\propto by^{n}$$

$$a,b,m,n\ \ are\ constants$$

Assume m/n = 1 and b/a = K

$$S=K\left[xI+(1-x)O\right]$$

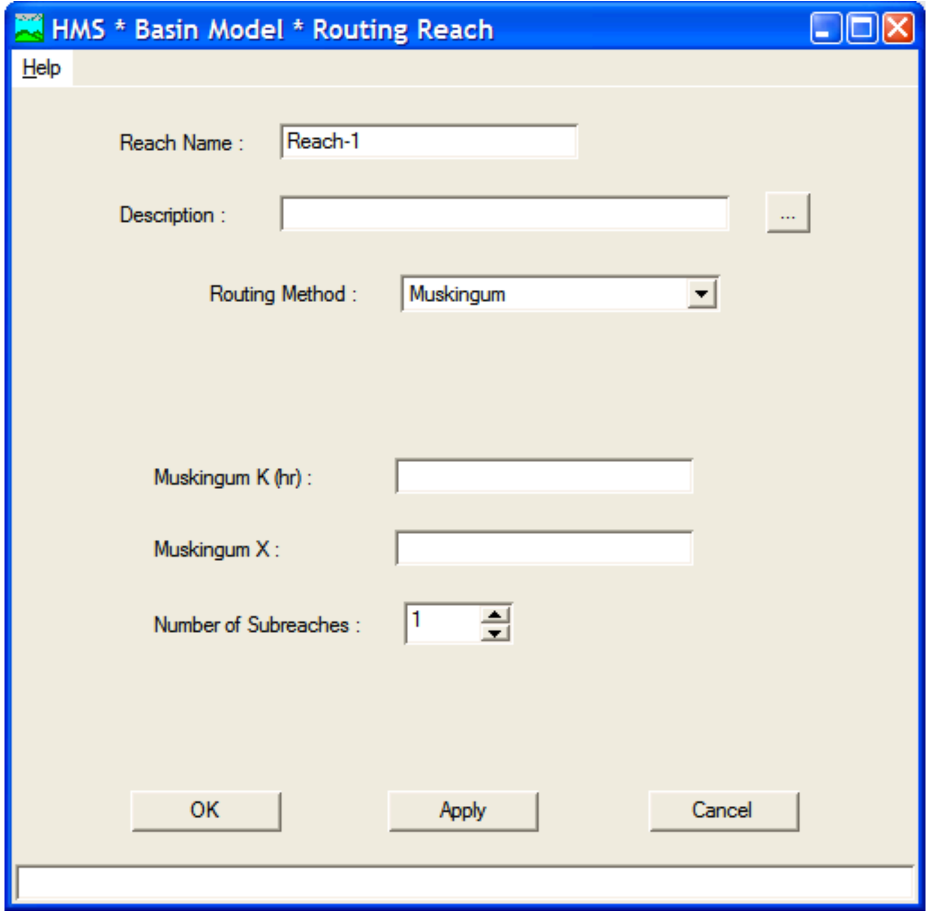
Muskingum Model (S/I-O) relationship

$$S_t = K\left[xI_t + (1-x)O_t\right]$$

K: Average travel time of flood wave through the routing reach

$x I_t + (1\text{-}x)\ O_t$ is a weighted discharge. When S is controlled by downstream conditions, thus storage and outflow are highly correlated and $x = 0.0$ and $S = KO$ (linear reservoir model)

If $x = 0.5$, equal weight is given to inflow and outflow, and the result is a uniformly progressive wave that does not attenuate as it moves through the reach.



Reach Name : Reach-1

Description :

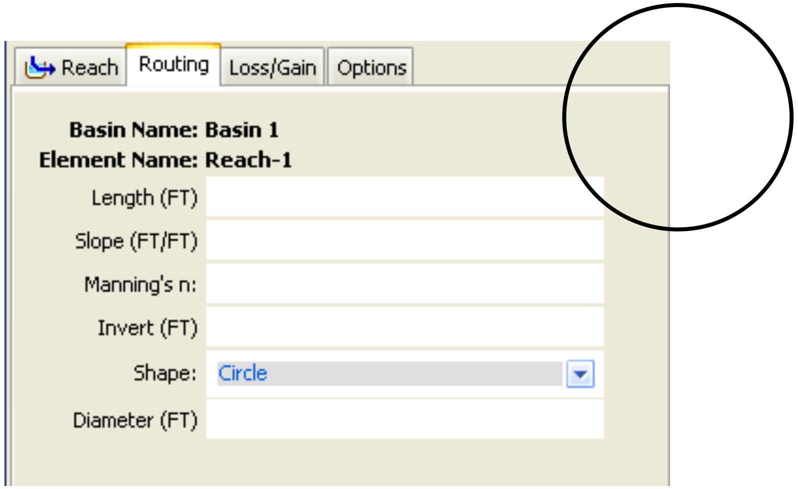
Routing Method : Muskingum

Muskingum K (hr) :

Muskingum X :

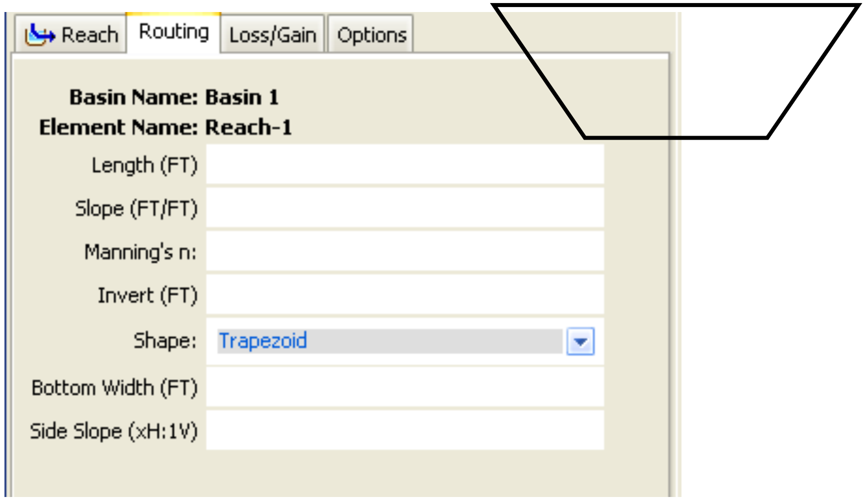
Number of Subreaches : 1

Muskingum Kung Standard



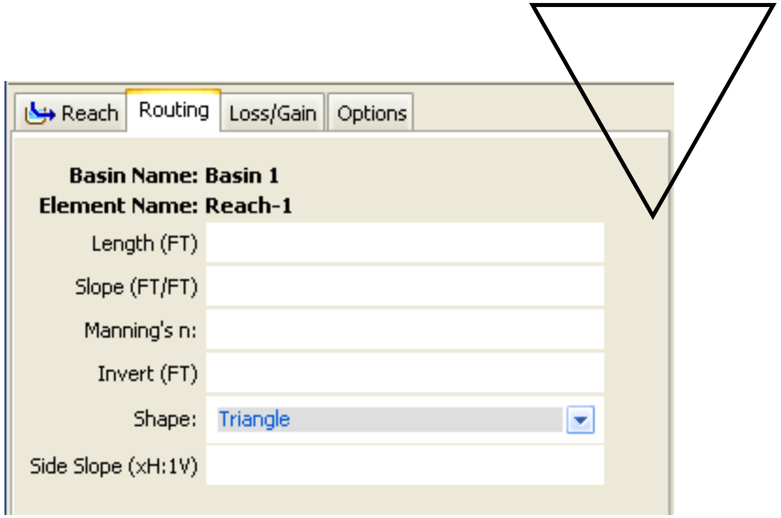
Basin Name: Basin 1
Element Name: Reach-1

Length (FT)
Slope (FT/FT)
Manning's n:
Invert (FT)
Shape: Circle
Diameter (FT)



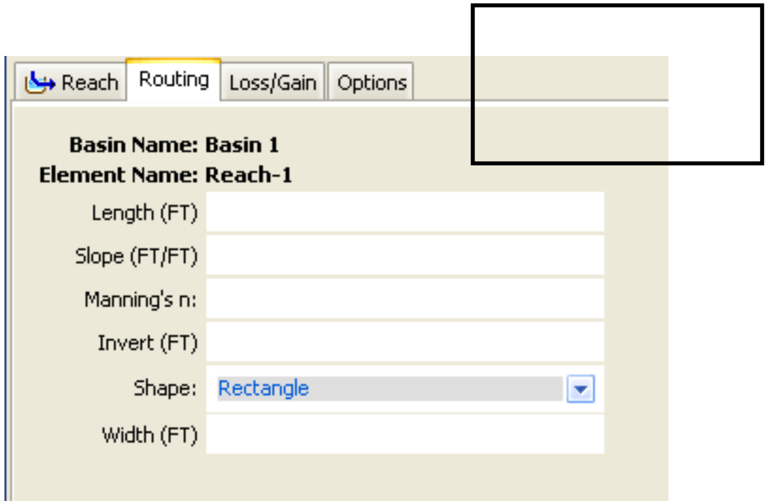
Basin Name: Basin 1
Element Name: Reach-1

Length (FT)
Slope (FT/FT)
Manning's n:
Invert (FT)
Shape: Trapezoid
Bottom Width (FT)
Side Slope (xH:1V)



Basin Name: Basin 1
Element Name: Reach-1

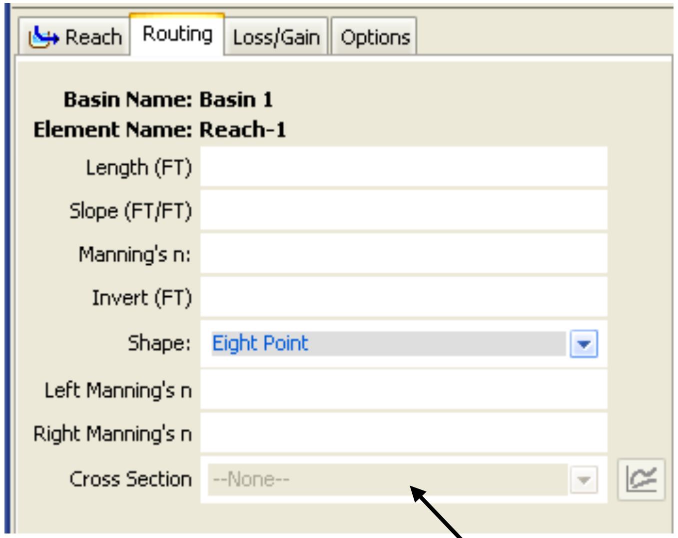
Length (FT)
Slope (FT/FT)
Manning's n:
Invert (FT)
Shape: Triangle
Side Slope (xH:1V)



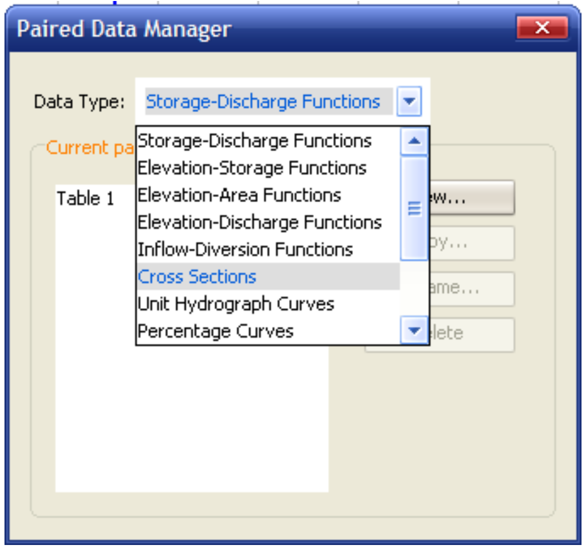
Basin Name: Basin 1
Element Name: Reach-1

Length (FT)
Slope (FT/FT)
Manning's n:
Invert (FT)
Shape: Rectangle
Width (FT)

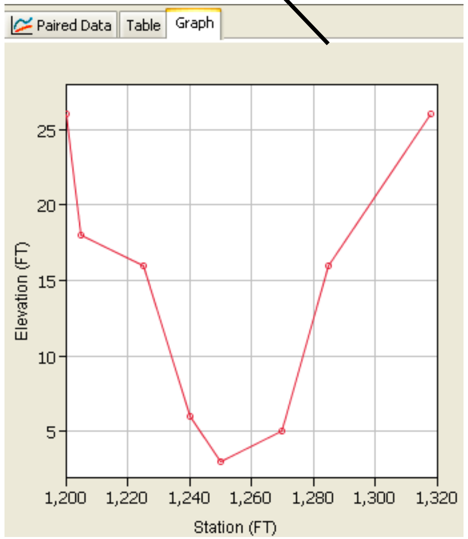
Muskingum Kung 8 Points



Basin Name: Basin 1
Element Name: Reach-1
Length (FT)
Slope (FT/FT)
Manning's n:
Invert (FT)
Shape: Eight Point
Left Manning's n
Right Manning's n
Cross Section --None--


Paired Data Manager

Data Type: Storage-Discharge Functions



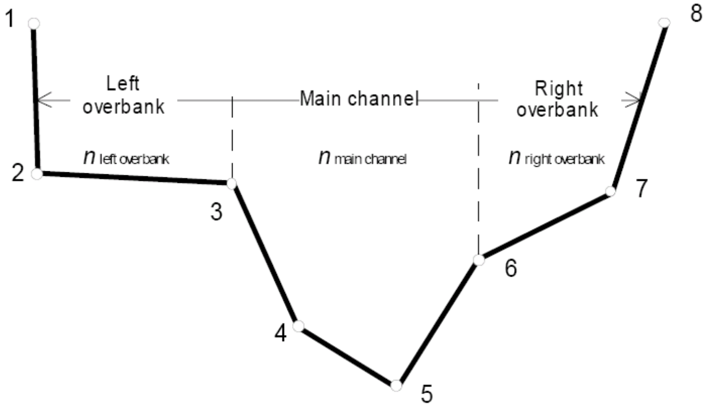
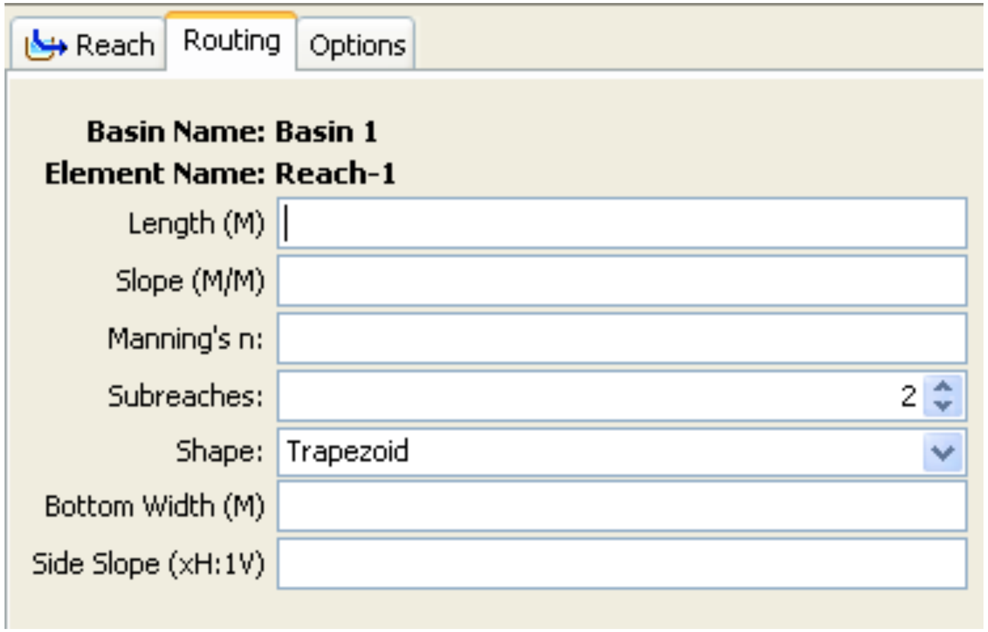
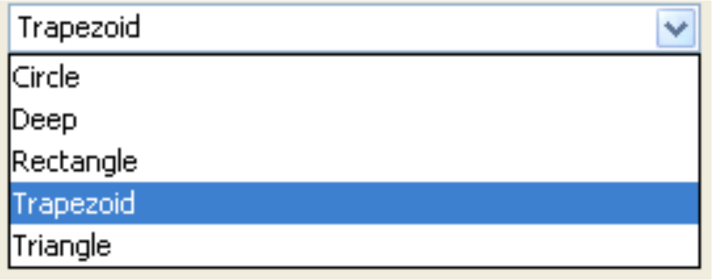


Figure 8-5. Format for describing channel geometry with 8 points

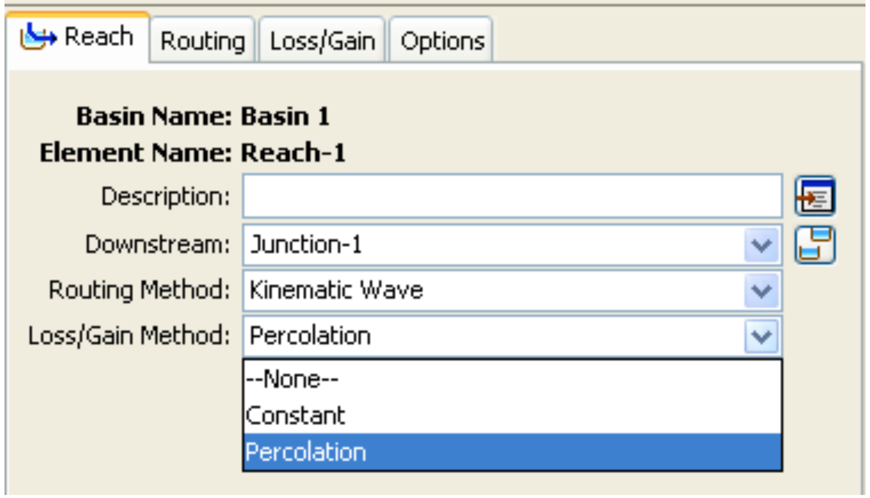
Kinematic Wave



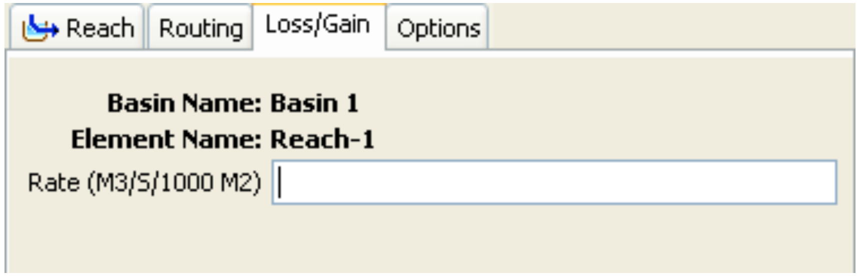
Basin Name: Basin 1
Element Name: Reach-1
Length (M)
Slope (M/M)
Manning's n:
Subreaches: 2
Shape: Trapezoid
Bottom Width (M)
Side Slope (xH:1V)


Trapezoid

Kinematic Wave

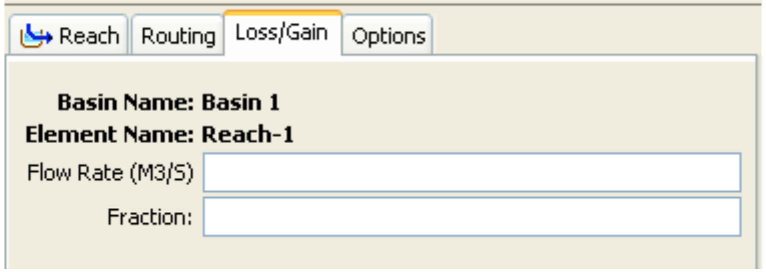


Basin Name: Basin 1
Element Name: Reach-1
Description:
Downstream: Junction-1
Routing Method: Kinematic Wave
Loss/Gain Method: Percolation



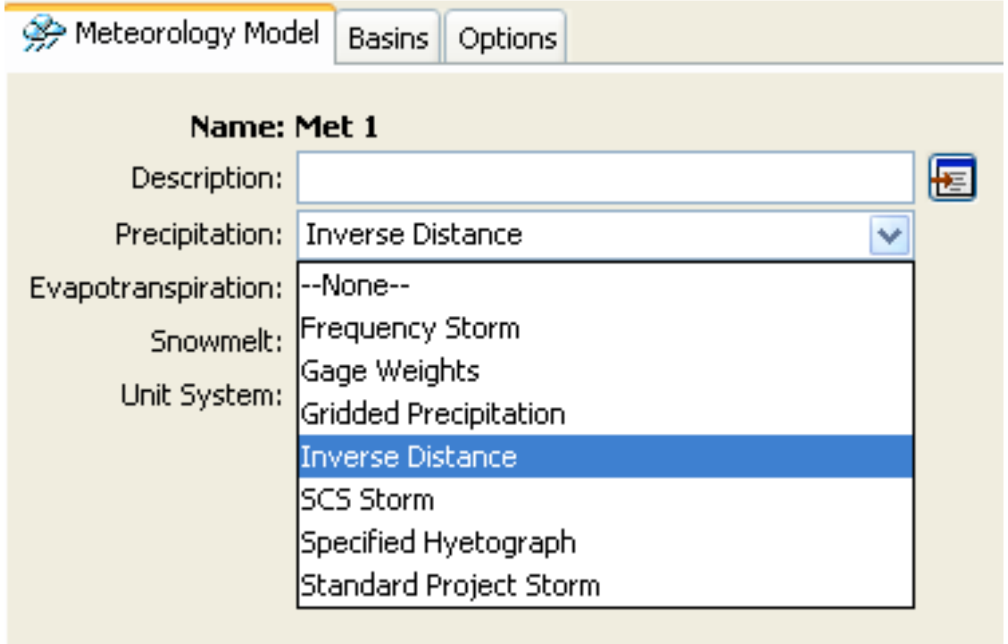
Basin Name: Basin 1
Element Name: Reach-1
Rate (M3/S/1000 M2)

Requires inundated area
Not compatible with all methods
Requires discharge/Elevation/Area relationships



Basin Name: Basin 1
Element Name: Reach-1
Flow Rate (M3/S)
Fraction:

After constant rate is subtracted
Remaining flow is further reduced by 1-fraction



Name: Met 1

Description:

Precipitation: Inverse Distance