Hydrological Modeling

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GI Studio Guest Lecture

9/16/16

Goals

- Increase familiarity with urban hydrological cycle
- Introduce advantages and shortcomings of urban hydrological modeling
- Build working knowledge of a lumped-parameter design storm model

Overview

- Why model?
- What are we trying to model?
- Approaches to modeling
- Types of models relevant to Green Stormwater Infrastructure
- Creating Hydrographs Using the SCS method
- HydroCAD demo

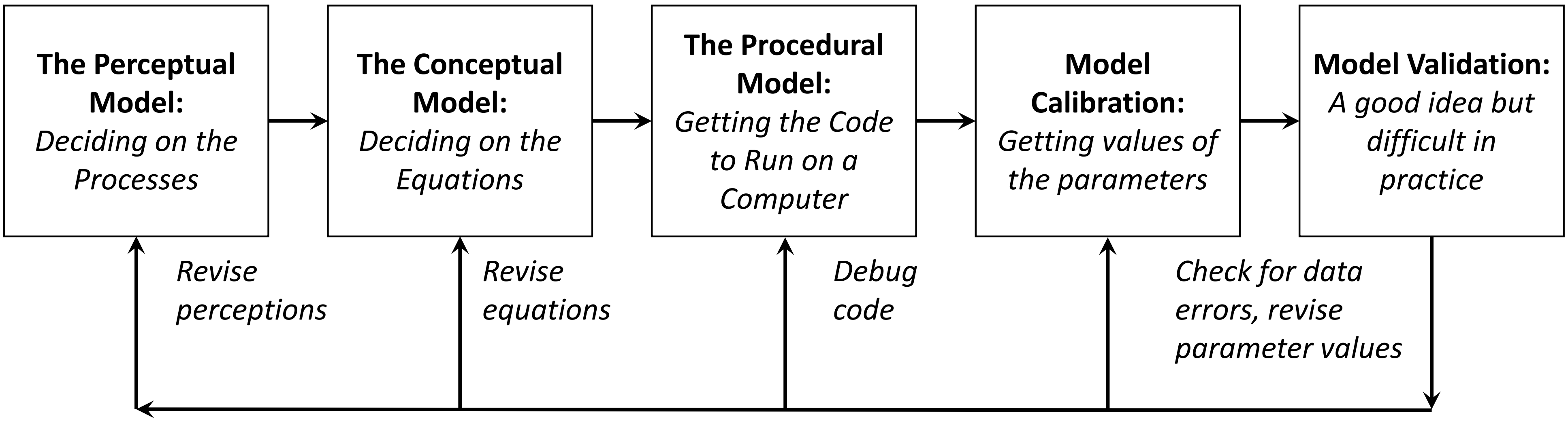
Why Model?

"All models are wrong, but some are useful" – George Box, statistician

Who models and when?

- Infrastructure managers/planners → regulatory agencies
- Infrastructure managers/planners → investment decision-making
- Site designers/developers/engineers → compliance and site permitting (usually involved after Schematic Design)
- Regional environmental planners and watershed managers → regulatory body
- Academics and researchers → publications, policies, new knowledge

The Overall Modeling Process



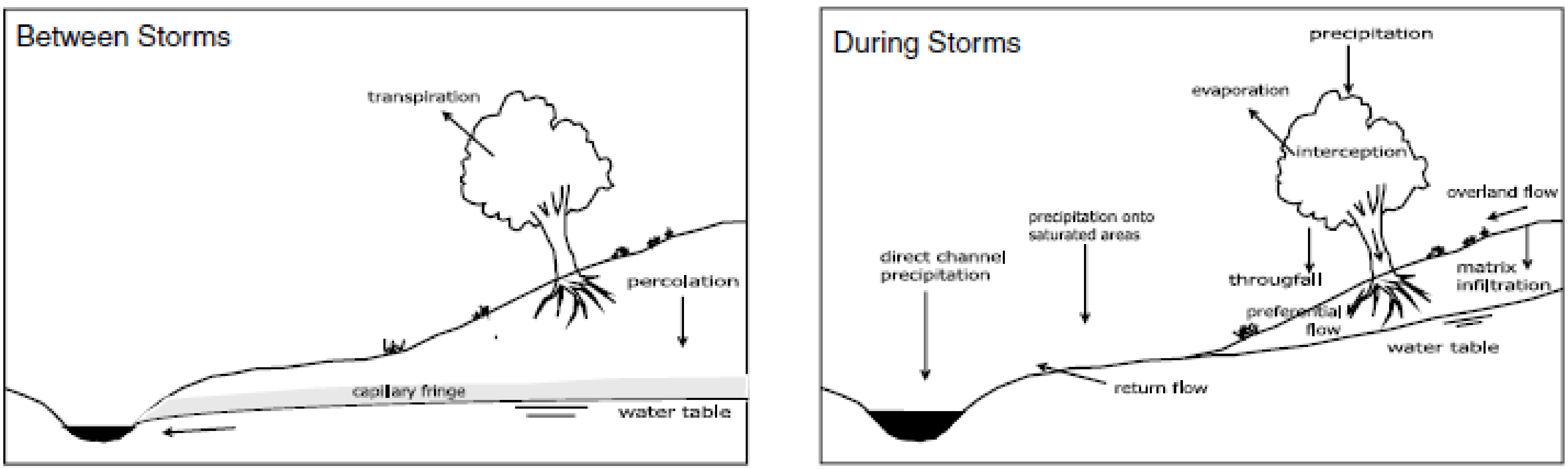
Adapted from Beven 2012

Modeling in the Site Design Process

- Conceptual Design
- Schematic Design
- Detailed Design
- Construction Documents

What are we trying to model?

Dominant processes in un-urbanized catchments in humid climates

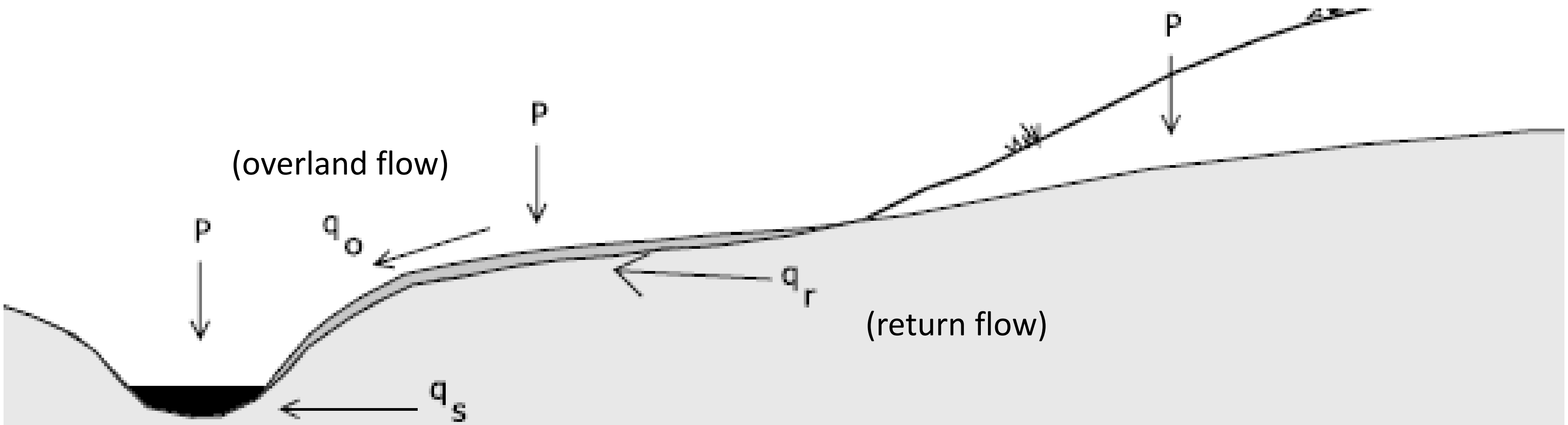


Source: Beven 2012

What are we trying to model?

Dominant processes in un-urbanized catchments in humid climates

Note: “Q” is the conventional variable for flow [$L^3 T^{-1}$]



(subsurface flow)

Source: Beven 2012

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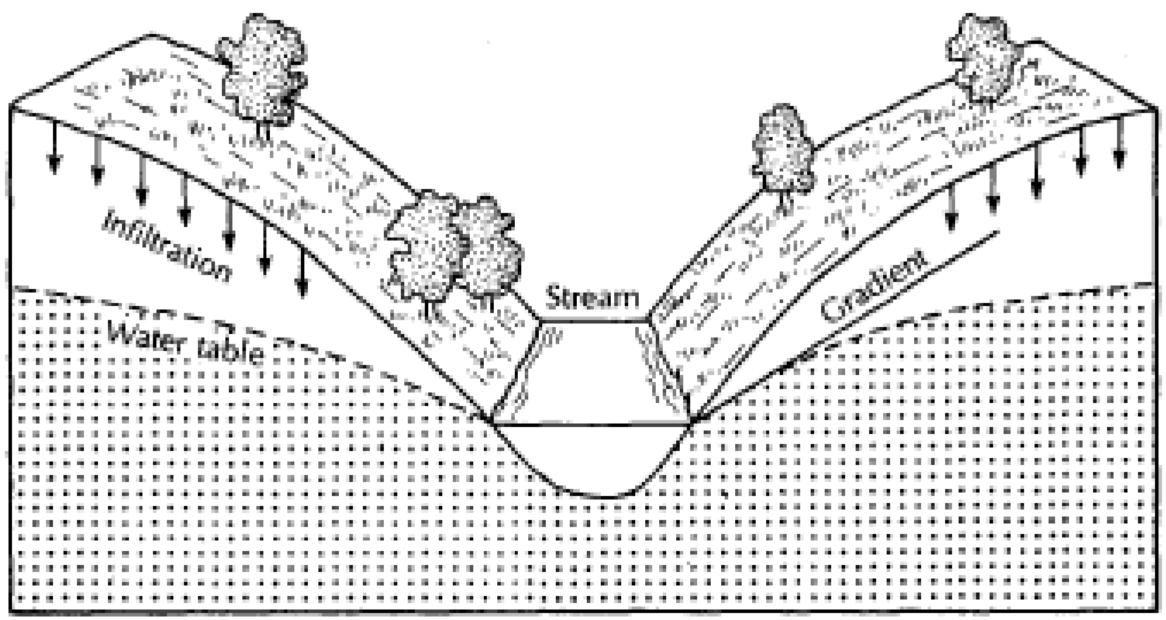
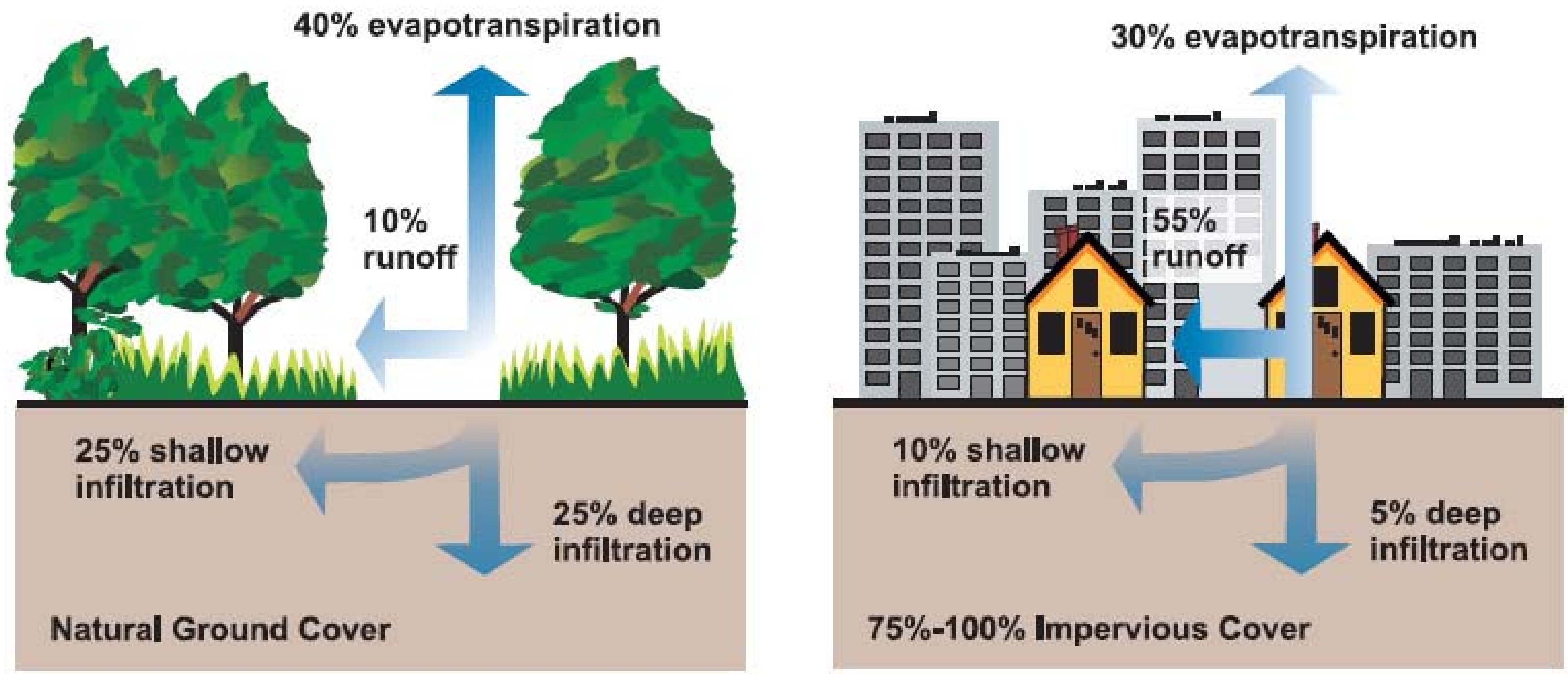


Source: Fetter 2001

What are we trying to model?

Dominant processes in URBANIZED catchments in humid climates



Source: US EPA 2003

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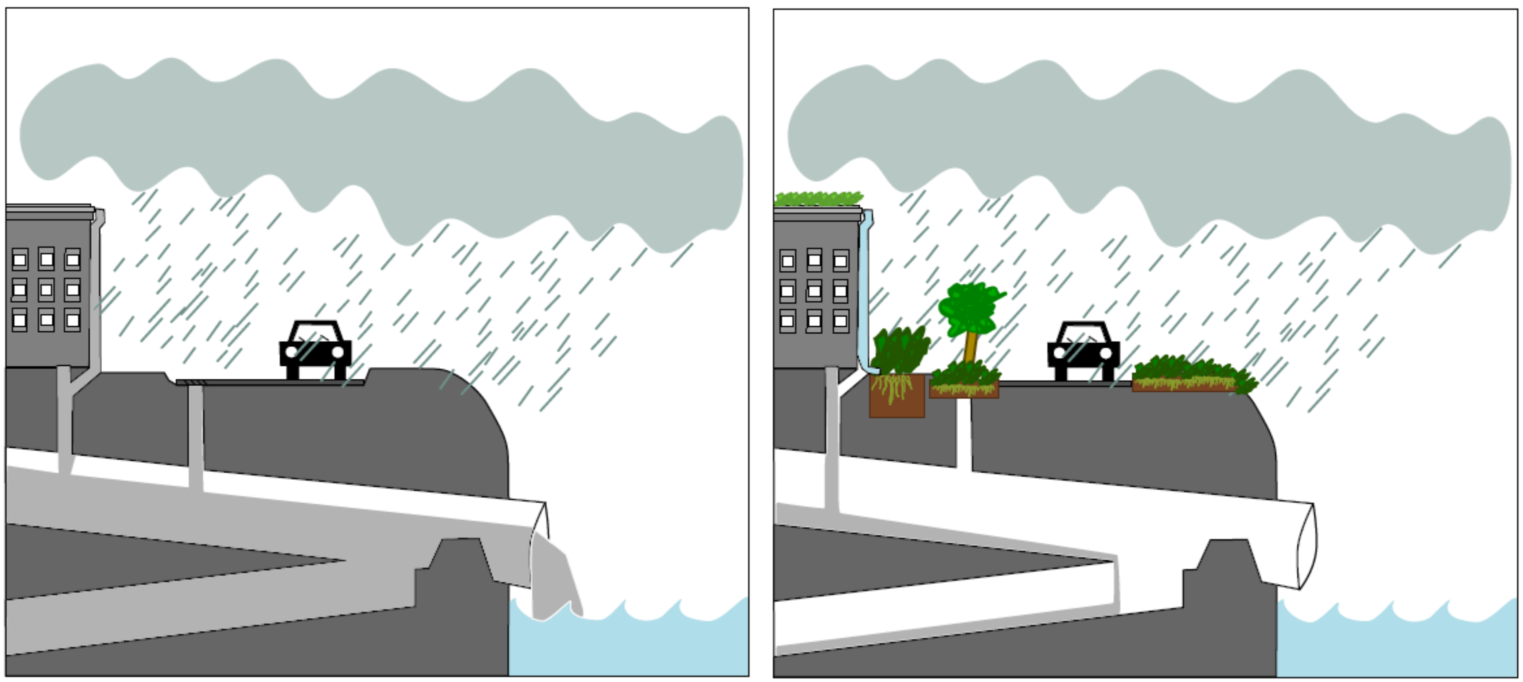
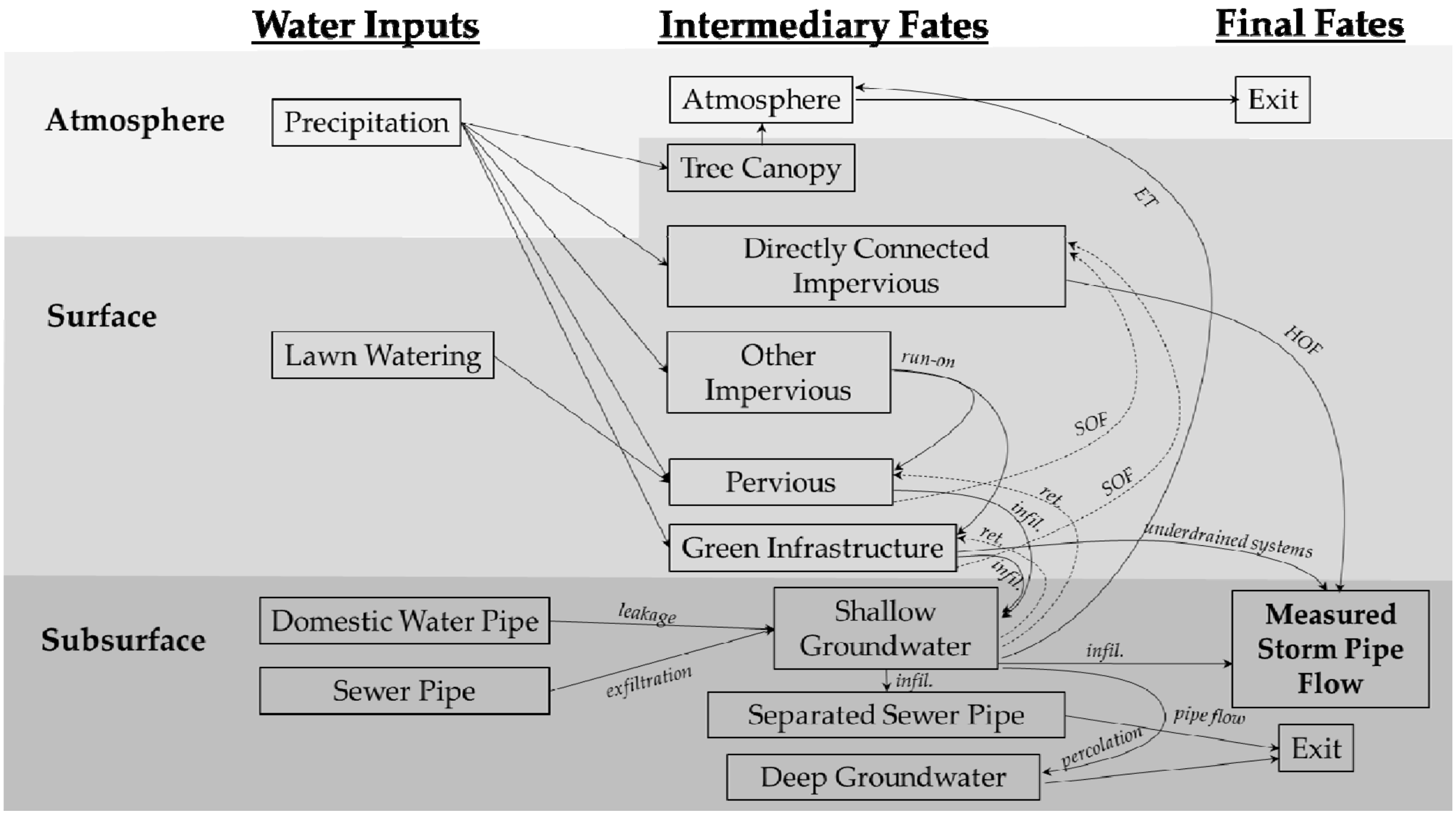


Source: Lim 2014

Elements of the Urban Hydrologic Cycle



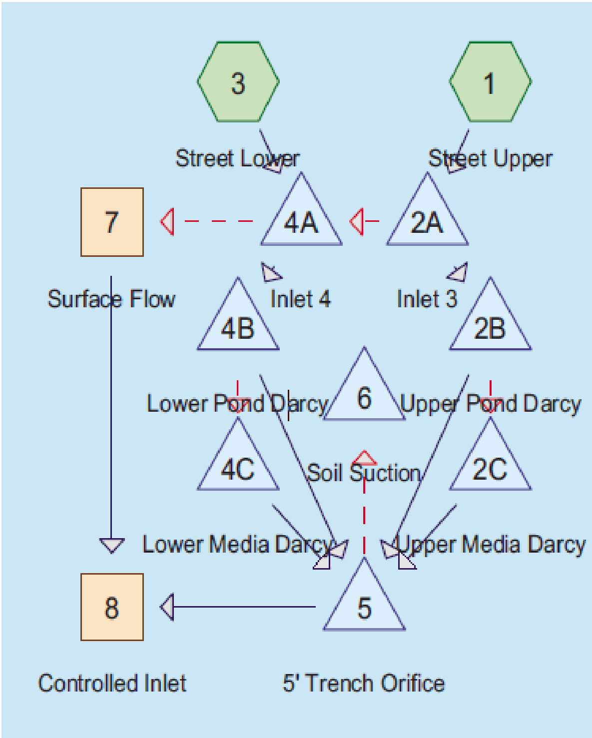
Source: Lim 2015

Approaches to Modeling

LUMPED: Treats catchment as a single unit, state variables represent catchment averages over the entire area

DISTRIBUTED: Discretizes catchment into grid cells, state variables are assigned to each grid and related to each other through physical process equations, sometimes called “process-based” or “physically-based” models

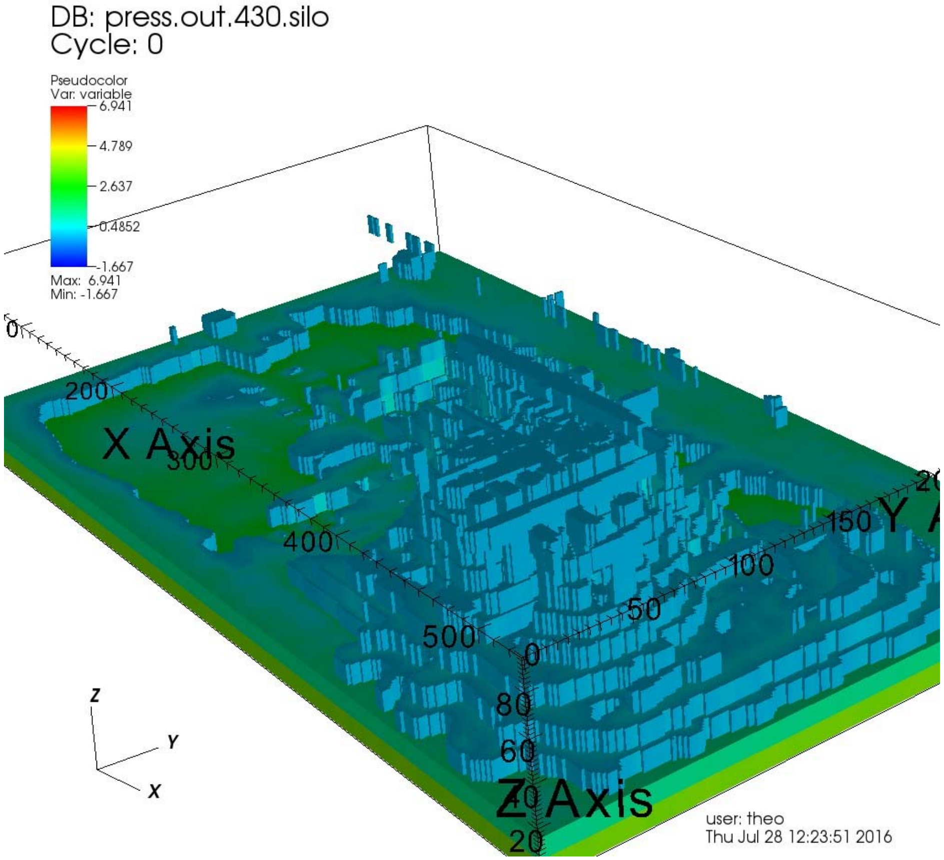
Approaches to Modeling



HydroCAD is an example of a **lumped parameter**, edge-node model. Each node represents a "catchment" with its own storage, porosity, conductivity etc parameters

Source: Lucas 2010

Approaches to Modeling



ParFlow-CLM is an example of a **fully-distributed**, finite-difference model model. In this example, the horizontal gridding is 1.5m x 1.5m, with variable dz discretization in the z dimension. Continuous solutions to Richards equation for the pressure field are solved using a numerical solver, called KINSOL.

Source: Lim 2016

Approaches to Modeling

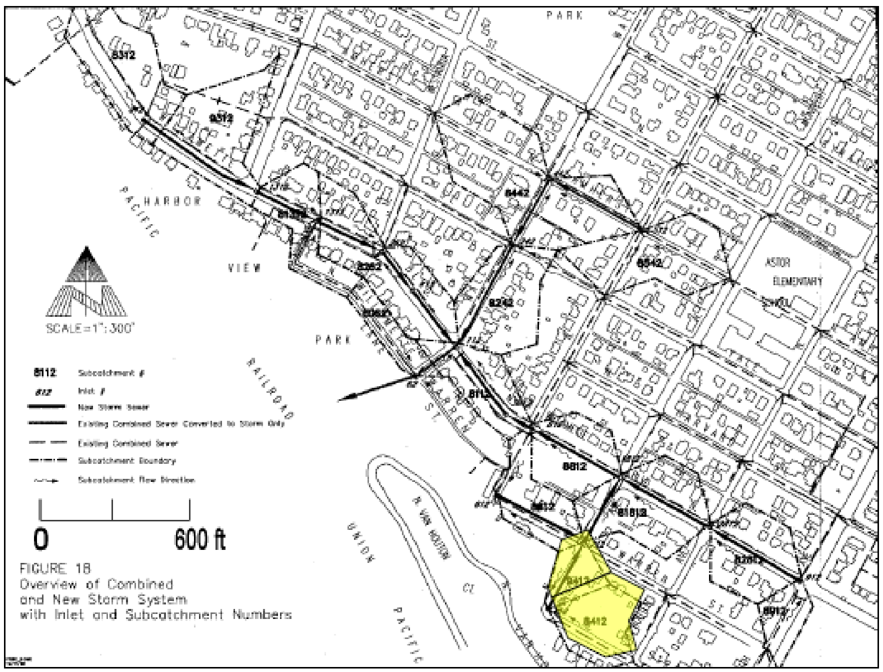


Figure 3-6 Fisk B catchment, Portland, Oregon (Portland BES, 1996).

SWMM is generally classified as a lumped parameter model, but what would happen if you make the "catchments" really small?

Source: Rossman 2015

Discussion: What do we want out of modeling?

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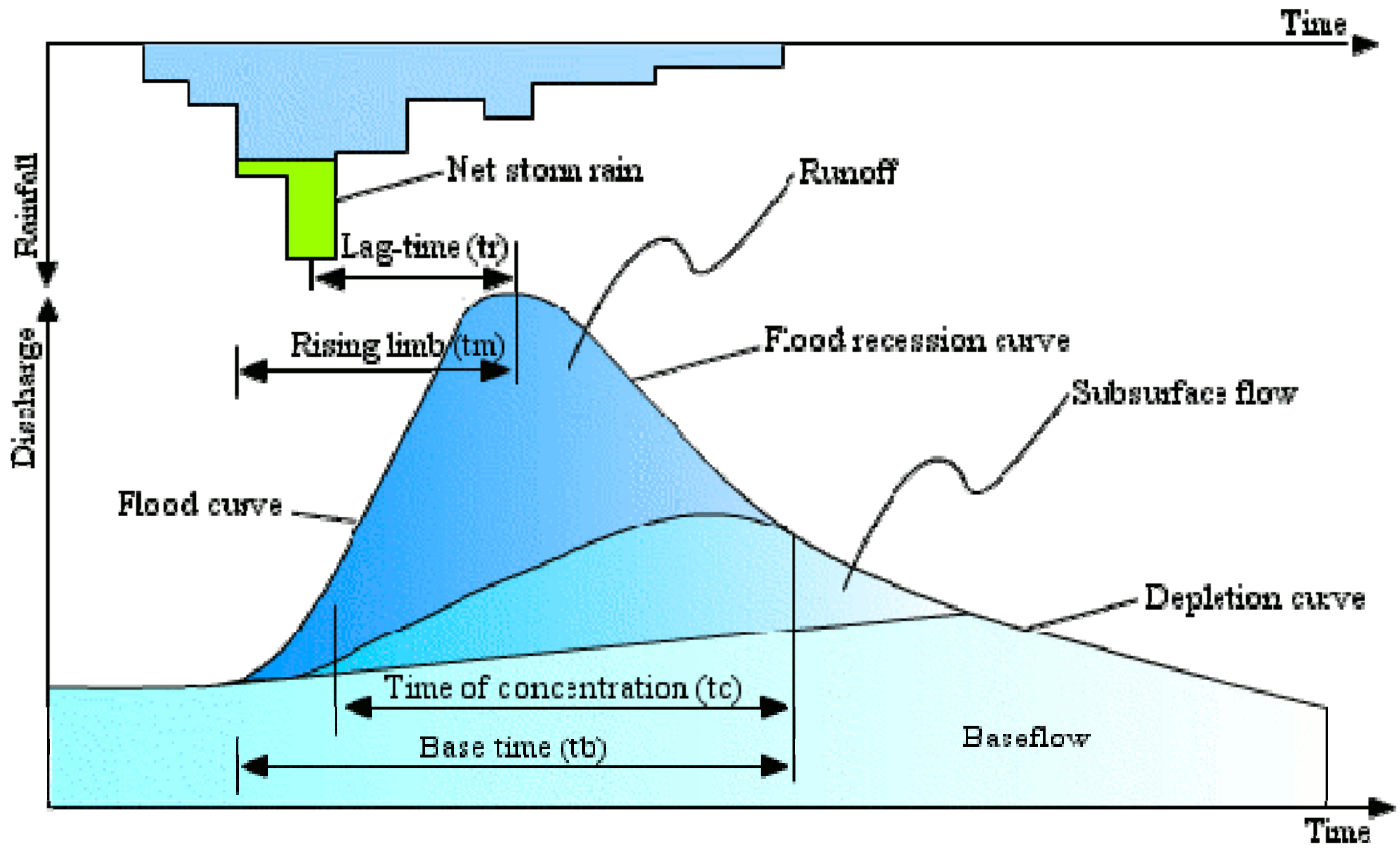


Approaches to Modeling

BOTTOM-UP: This is primarily what we have been talking about and what most people are referring to when they talk about "hydrological modeling." Modelers are interested in running simulations given known relationships between parameters (equations), given some actual or hypothetical scenarios.

TOP-DOWN: Another approach to determining if our perceptual models of hydrological function are supported by empirical evidence. When might we take a top-down modeling approach?

Approaches to Modeling

- More on top-down modeling later…
- Back to bottom-up types now…

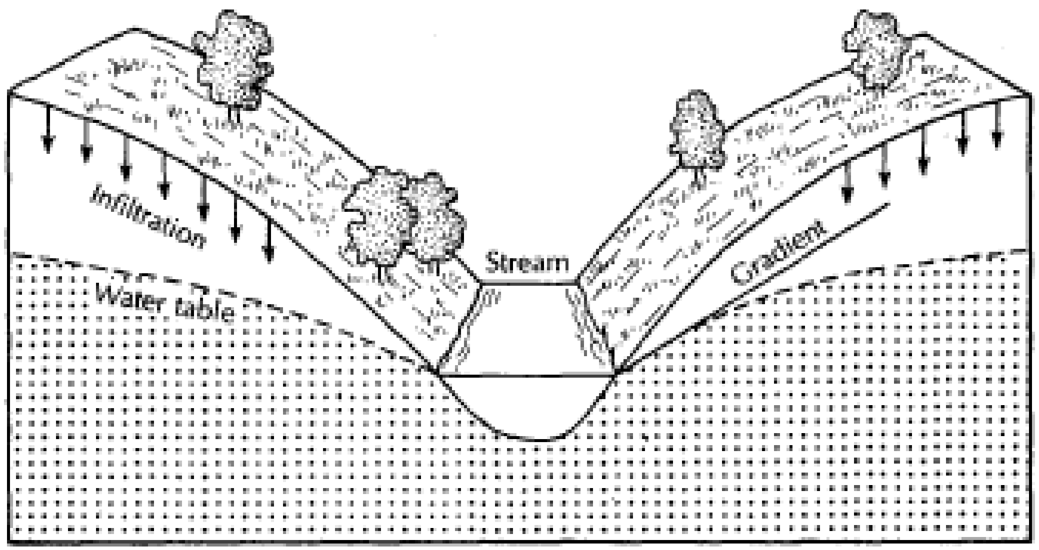
Approaches to Modeling

	Processes Modeled	Key Concepts	Examples
Rainfall-runoff calculation	peak flow, runoff volume, and hydrograph functions, only	Rainfall-runoff ratio	The Rational Method
Hydrologic	includes rainfall-runoff simulation plus reservoir/channel routing	Rainfall-runoff simulation plus reservoir/channel routing	TR-55, HEC-HMS (SCS method)
Hydraulic	water surface profiles, flow rates, and flow velocities through waterways, structures and pipes.	Flow rates, and flow velocities through waterways, structures and pipes	HEC-RAS
Combined Hydrologic-Hydraulic	rainfall-runoff results become input into hydraulic calculations	Hydrologic outputs used as inputs to hydraulic model	SWMM, HydroCAD
Water Quality	pollutant loading to surface waters or pollutant removal in a BMP	Mass loading, dispersion, advection, etc	WASP

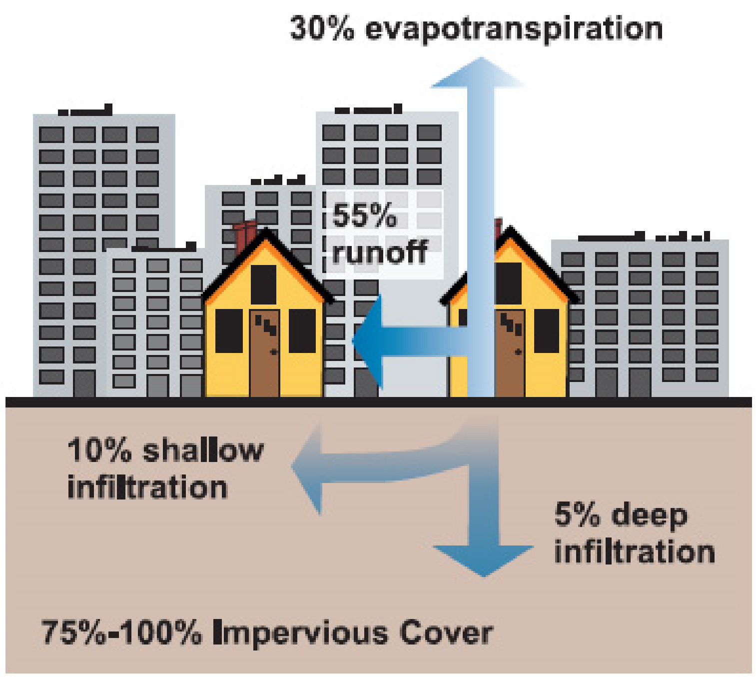
http://stormwater.pca.state.mn.us/index.php/Available_stormwater_models_and_selecting_a_model

Back to: What are we trying to model?

Dominant processes in in response to rainfall



Source: Fetter 2001



Source: US EPA 2003

Back to: What are we trying to model?

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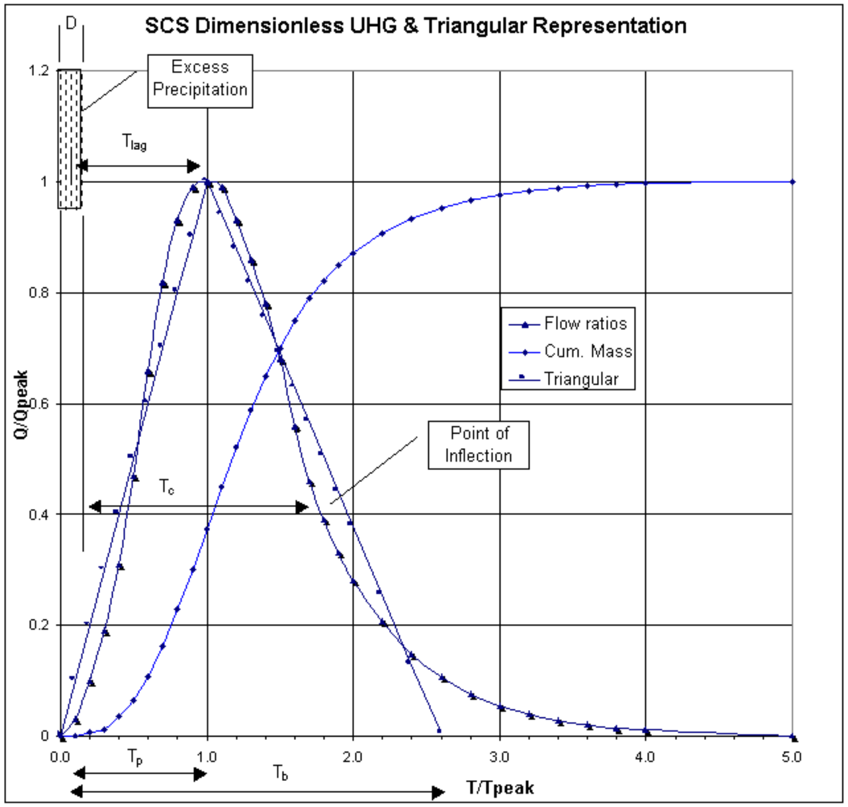
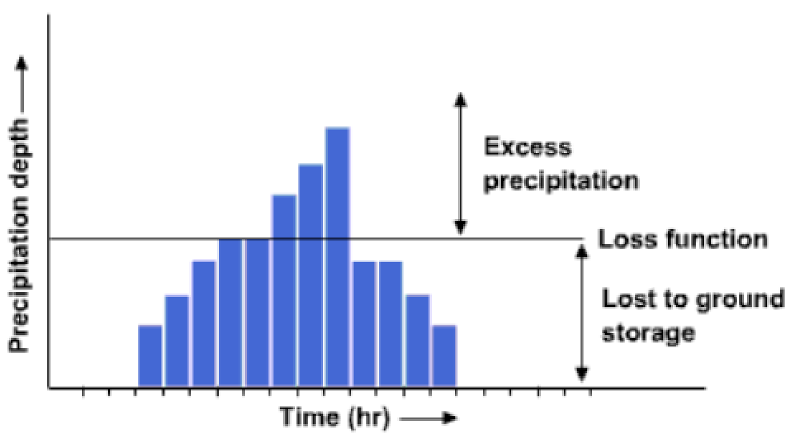
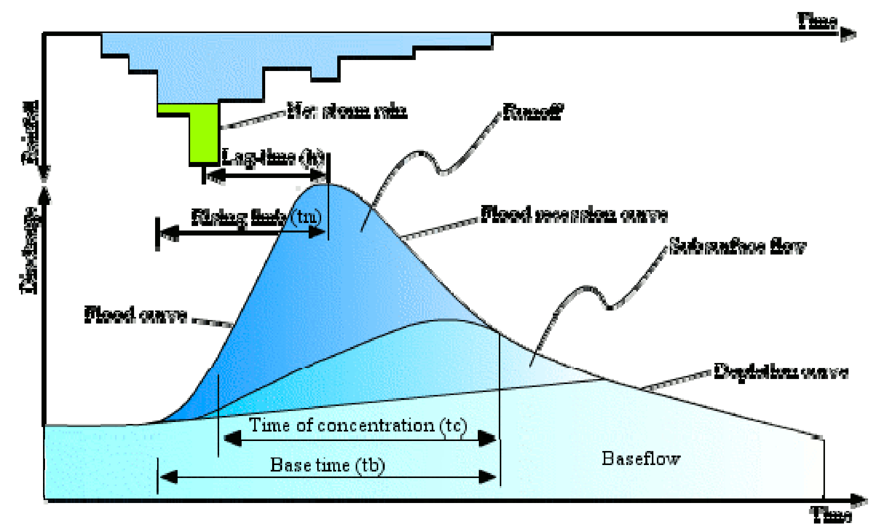


Infiltration and Surface Runoff

- Logic:

Precipitation Rate	Infiltration Capacity Models, sometimes called “loss models”	Precipitation Excess	Timing of Runoff, or creating of a streamflow hydrograph

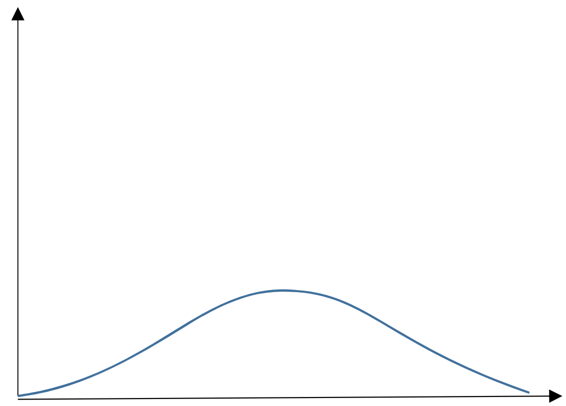


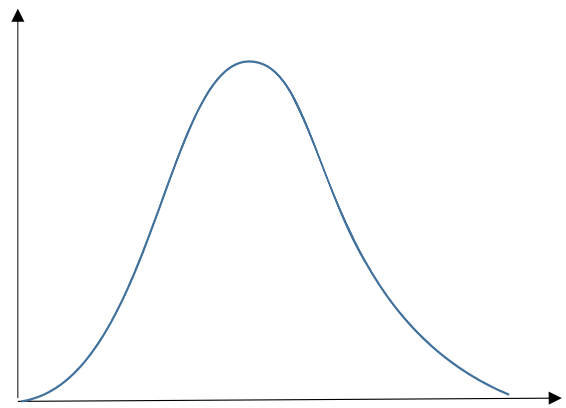


Infiltration and Surface Runoff

Thoughts on hydrographs

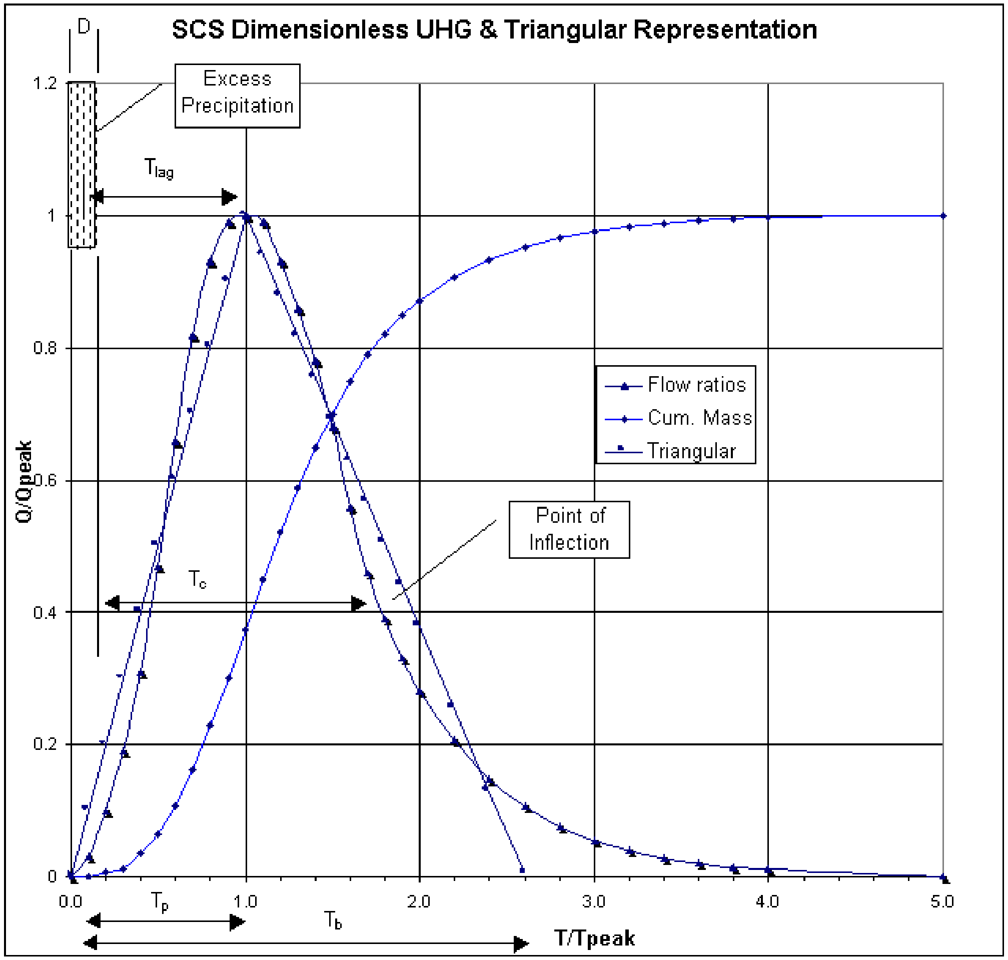
- What would be the effect of steeper slopes in the catchment area?
- What would be the effect of rougher surfaces?
- What would the effect of an elongated basin shape be?





The Unit Hydrograph

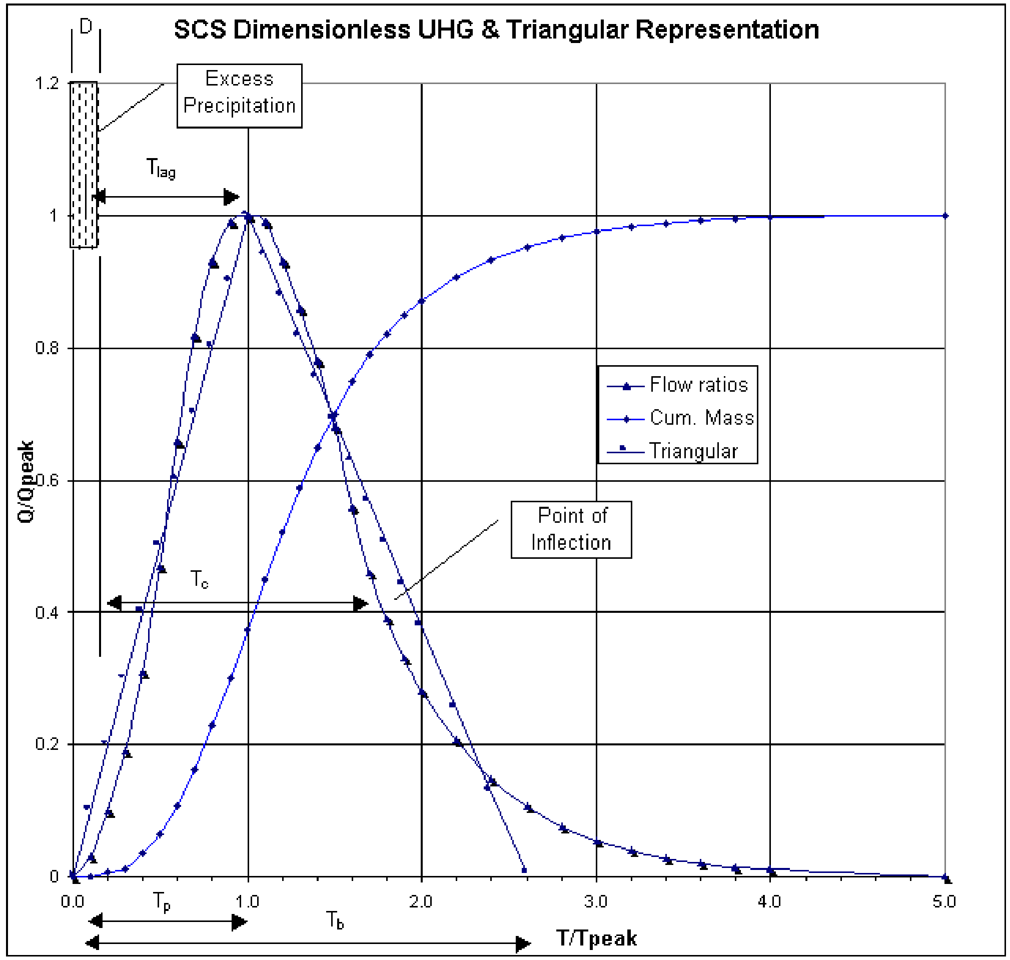
- This is like the "normal distribution" of surface runoff models
- Constructed from empirical data averaging the area and precipitation-normalized hydrographs from many (un-developed), small watersheds
- Easy to compute from geographic parameters -> define "lag time"
- Nice curvilinear shape



The Unit Hydrograph

- Time lag is calculated from geomorphic characteristics of the catchment area

$$t_L = \frac{L^{0.8}(S+1)^{0.7}}{1900Y^{0.5}}$$



L = Hydraulic length (ft)

Y = slope (%)

S = potential max retention (inches)

Calculating Peak Discharge

$$t_L = \frac{L^{0.8}(S+1)^{0.7}}{1900Y^{0.5}}$$

$$t_c = \frac{5}{3}t_L$$

$$t_P = 0.67t_c$$

$$P_e = Q$$

$$q_p = \frac{484AQ}{t_p}$$

Pe = Precipitation excess = 1” in UH case
Q = total runoff depth = 1” in UH case
A = watershed area (mi^2)
q_p = peak discharge (ft^3/s)

General Desc	Peaking Factor	Limb Ratio
Urban areas; steep slopes	575	1.25
Typical SCS	484	1.67
Mixed urban/rural	400	2.25
Rural, rolling hills	300	3.33
Rural, slight slopes	200	5.5
Rural, very flat	100	12.0

Getting Storage (S) from the Curve Number (CN)

$$S = \frac{1000}{CN} - 10$$

- Look CN up in a table. (https://en.wikipedia.org/wiki/Runoff_curve_number)
- CN ranges from 30 (low runoff potential) to 100 (high runoff). Paved parking lots are 98.
- It's a function of land cover/vegetation and soil type
- Can do a weighted average if several types within contributing area

Create a Unit Hydrograph Mini-Lab

Q1: For **one inch of rainfall excess**, what peak discharge would we expect to see from a medium density watershed with the following chracteristics:

Area = 3 sq mi
Hydraulic Length = 1.2 miles
Average Slope = 3%
CN = 86
Peaking Factor = 484

Q2: Use the provided spreadsheet to estimate discharge at time = 100 min

SCS Method Tradeoffs

PROS

- Computationally efficient
- Can be adjusted with peaking factor, limb ratio, and CN to calibrate to observed data
- Very widely used
- Good for "quick checks"

CONS

- Linearity assumption: assumes that 2" of rainfall excess produces a peak discharge twice as large as 1" of rainfall excess
- Ie, response is independent of rainfall intensity
- Ie, rainfall excess is uniformly distributed throughout the catchment.
- No physical mechanisms represented. Cannot assign sensitivity in the model, if some condition changes in the watershed, won't be able to calibrate
- Assumes overland surface runoff

A Top-Down Model Example for Urbanized Watersheds

Premise: Do not assume CN, Peaking Factor, Land Cover/vegetation type, and instead look at the relationship between rainfall depth and average runoff depth for many storms, and across many watersheds.

Instead: characterize the relationship between rainfall depth and runoff depth, and see what watershed characteristics best explain nonlinearity

A Top-Down Model Example for Urbanized Watersheds

Motivation: Many assume that hydraulic connectivity in urbanized watersheds (ie, flashy response) is primarily determined by imperviousness preventing infiltration into subsurface. Is this true?

Sources of Data

HydroCAD

- http://www.hydrocad.net/understanding.htm

Model verification and calibration