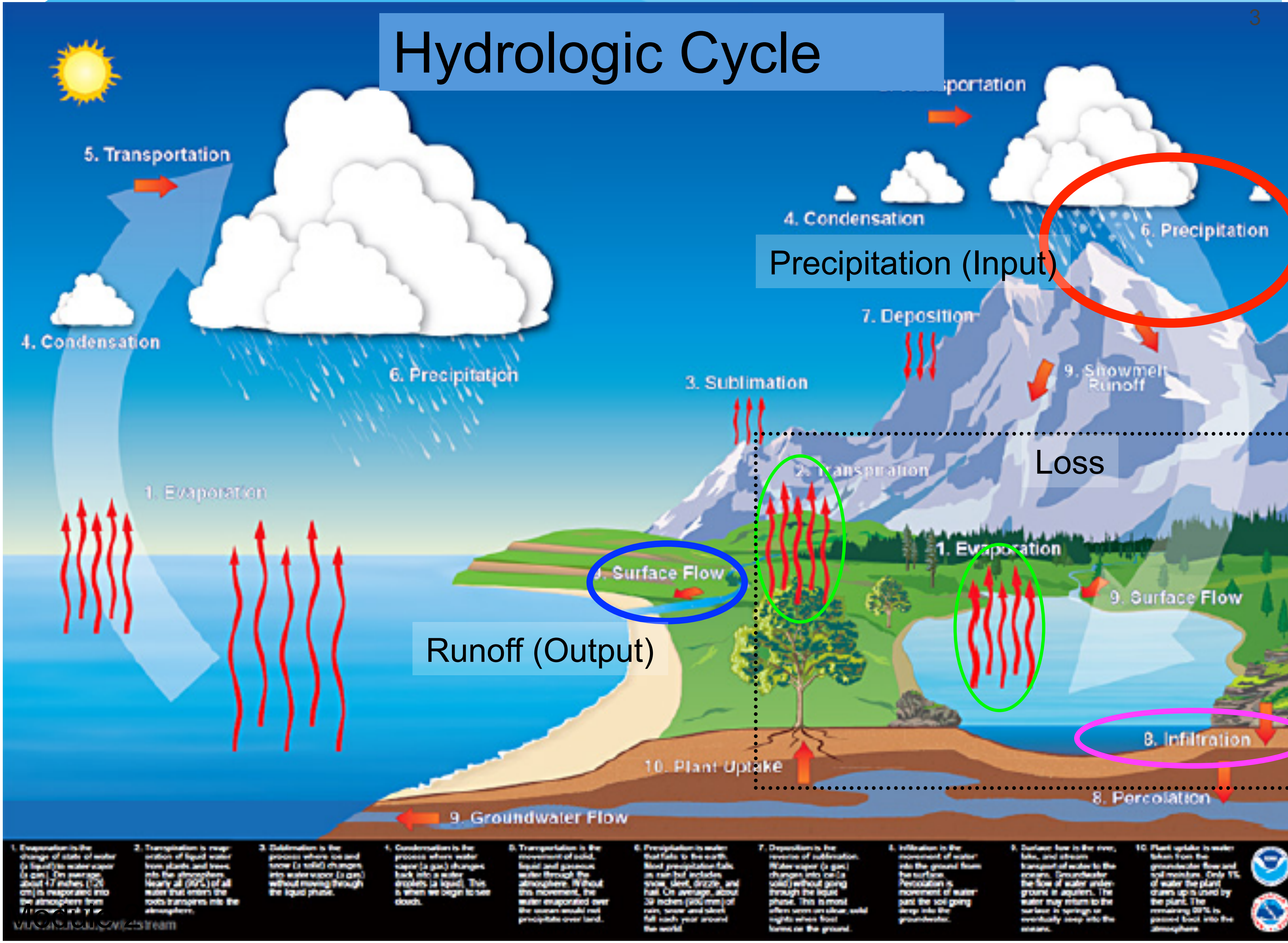
CE 3354 Engineering Hydrology

Lecture 12: Watershed Loss Processes
Infiltration

Outline

- Loss Processes
  - Infiltration
- HEC-HMS Representations

Hydrologic Cycle

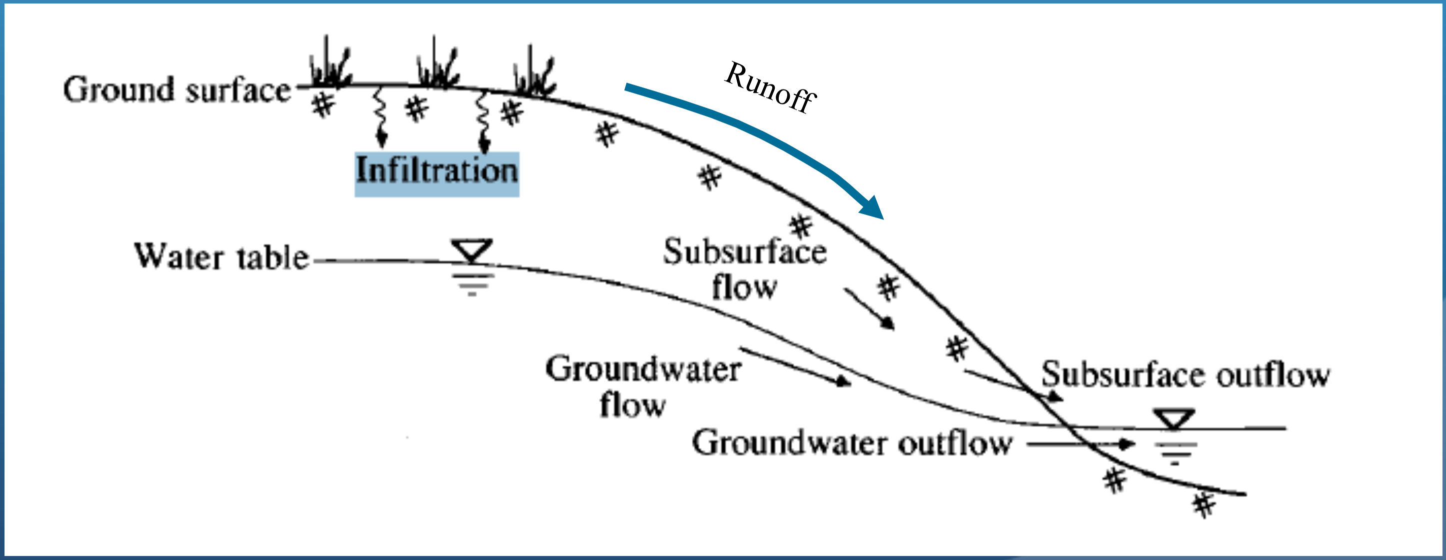


Loss Processes – Infiltration

- Infiltration
  - Process Concepts
  - Models:
    - Hortonian Loss Model
    - Green-Ampt Loss Model
    - NRCS Runoff Generation Model
    - Initial Abstraction, Constant Rate Model

Infiltration

- Infiltration is water that soaks into the ground. This water is considered removed from the runoff process.
- Largest contribution to losses during a storm event, hence most loss models are some form of an infiltration accounting



Soil Moisture Profile

- Infiltration defined by soil properties and ground cover.
  - Soil type (sand, clay, silt, etc.)

$$F(t) = \int_0^t f(\tau)\, d\tau \qquad (4.2.1)$$

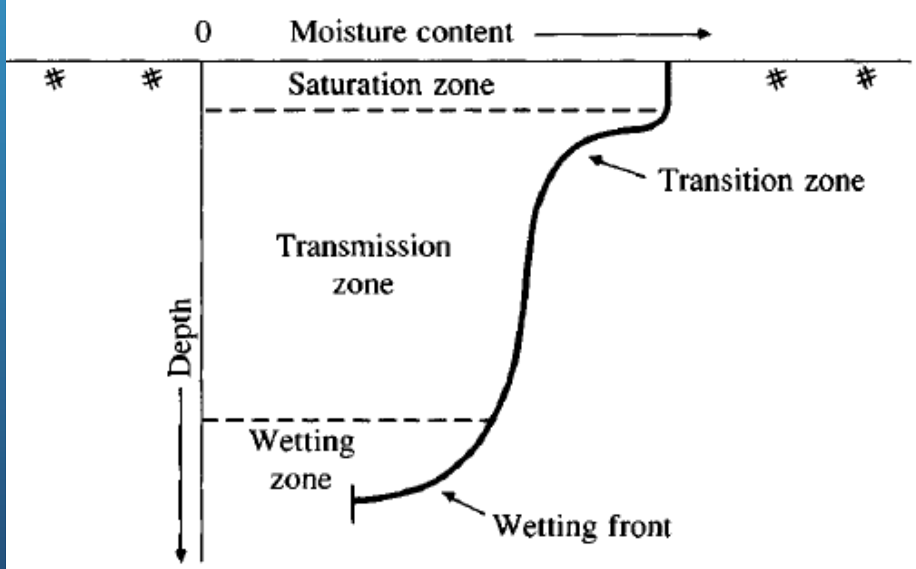


FIGURE 4.2.1
Moisture zones during infiltration.

Hortonian Infiltration

- Infiltration Excess Concept
  - Rate has an initial and asymptotic value.
  - Integral of rate is total depth (volume) lost

$$q(t) = f_c + (f_o - f_c)e^{-kt}$$

$$I(t) = \int_0^t q(\tau)d\tau$$

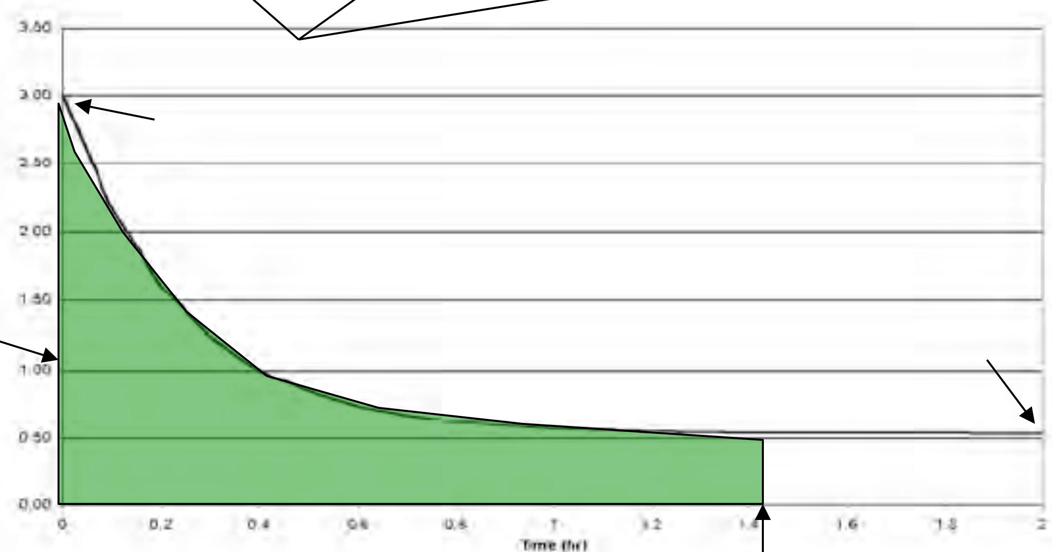


Figure 1: Horton's model using supplied parameters

- CMM pp 108-110

Loss Models

- Detailed Discussion
  - NRCS Curve Number
  - Green-Ampt
  - Initial Abstraction, Constant Loss
- Other Methods
  - Exponential Model
  - Phi-Index (and proportional rainfall)
  - Soil Moisture Accounting
  - Deficit/Constant

Loss Model: NRCS CN

- NRCS Runoff Curve Number (CMM pp 110-122)
- Precipitation = Excess + Initial Loss + Continuing Loss

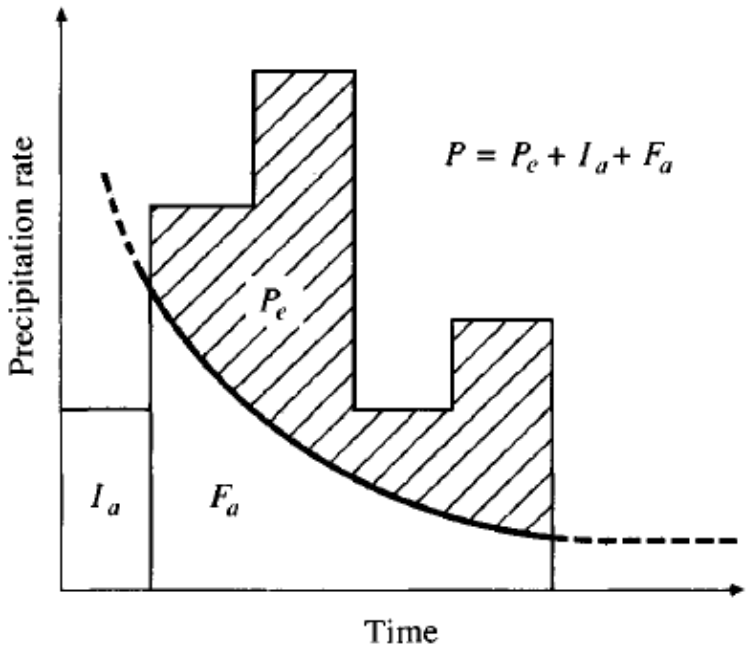


FIGURE 5.5.1
Variables in the SCS method of rainfall abstractions: I_a = initial abstraction, P_e = rainfall excess, F_a = continuing abstraction, P = total rainfall.

Loss Model: NRCS CN

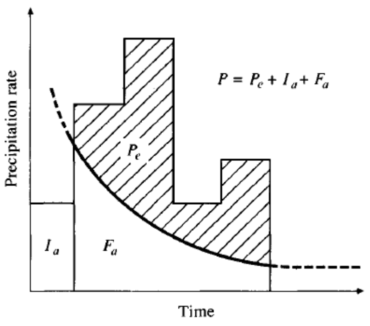


FIGURE 5.5.1
Variables in the SCS method of rainfall abstractions: I_a = initial abstraction, P_e = rainfall excess, F_a = continuing abstraction, P = total rainfall.

- NRCS Runoff Curve Number
- Precipitation = Excess + Initial Loss + Continuing Loss

$$P_e = \frac{(P - I_a)^2}{P - I_a + S}$$

Maximum Retention

$$I_a = 0.2S$$

$$P_e = \frac{(P - 0.2S)^2}{P + 0.8S}$$

Loss Model: NRCS CN

- NRCS Runoff Curve Number
- Precipitation = Excess + Initial Loss + Continuing Loss

$$P_e = \frac{(P - 0.2S)^2}{P + 0.8S}$$

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

Loss Model: NRCS CN

- NRCS Runoff Curve Number
  - Is really a runoff generation model, but same result as a loss model.
- Uses tables for soil properties and land use properties.
- Each type (A,B,C, or D) and land use is assigned a CN between 10 and 100

Loss Model: NRCS CN

- The CN approaches 100 for impervious
  - The CN approaches zero for no runoff generation.
- Reminder:
  - The CN is NOT a percent impervious.
  - The CN is NOT a percent of precipitation.

Loss Model: NRCS CN

- NRCS CN method
  - Separate computation of impervious cover then applied to pre-development land use or
  - Use a composite CN that already accounts for impervious cover.
  - Composite CN described in TxDOT Hydraulic Design Manual (circa 2009)
- Composite common in TxDOT applications

Loss Model: NRCS CN

Table 9–1 Runoff curve numbers for agricultural lands[1/]

Cover description: cover type	Cover description: treatment[2/]	Cover description: hydrologic condition[3/]	CN for hydrologic soil group: A	B	C	D
Fallow	Bare Soil	---	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C & T)	Poor	66	74	80	82
		Good	62	71	78	81

- Rural: Table from NEH-630-Chapter 9

Loss Model: NRCS CN

(c) Urban and residential land

Several factors, such as the percentage of impervi-
ous area and the means of conveying runoff from

(1) Connected impervious areas

An impervious area is considered connected if runoff from it flows directly into the drainage system. It is also considered connected if runoff from it occurs as ...ncentrated flow that runs over a pervious ...hen into a drainage system.

...e impervious area is directly connected to ...ge system, but the impervious area per... ...n table 9–5 or the pervious land use as... ...are not applicable, use equation 9–1 or ...to compute a composite CN.

$$CN_c = CN_p + \left(\frac{P_{imp}}{100}\right)(98 - CN_p) \qquad [9\text{–}1]$$

Composite CN equation

Table 9–5 Runoff curve numbers for urban areas [1/]

Cover description cover type and hydrologic condition	Average percent impervious area [2/]	-- CN for hydrologic soil group -- A	B	C	D
Fully developed urban areas (vegetation established)					
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

- Urban: Table from NEH-630-Chapter 9

Loss Model: NRCS CN

- Runoff generated by

$$q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

where,

q = depth of direct runoff (inches)

P = precipitation depth (inches)

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

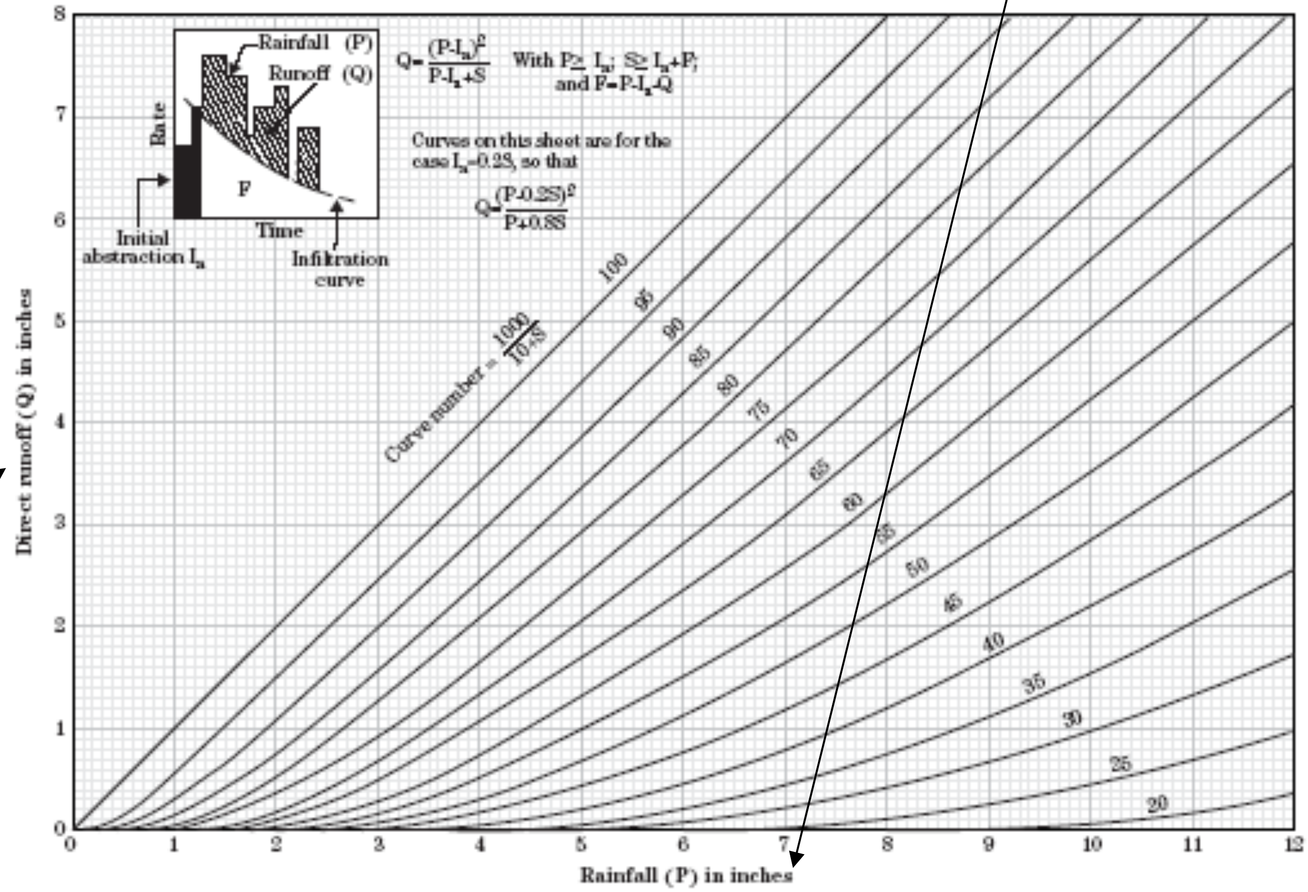
Loss Model: NRCS CN

- Graphical runoff generation model
- From NEH-630-Chapter 10

Depth

Depth

Figure 10–2 ES–1001 graphical solution of the equation $Q = \frac{(P-0.2S)^2}{P+0.8S}$



Note: Appendix A gives the tabular solution to this equation for P and Q up to 40 inches. In most cases use of this appendix gives a more exact solution than reading from the figure.

Loss Model: NRCS CN

- Parameter Estimation
  - NEH 630 Chapters 9 and 10
    - Detailed development of the model, Chapter 10
    - Estimation of CN, Chapter 9
  - FHWA-NHI-02-001 (Highway hydrology)
  - Most hydrology textbooks
  - TxDOT Hydraulics Design Manual (circa 2009)

Loss Model: NRCS CN

- Advantages
  - Simple, documented approach
  - Widely used and established across the USA
- Disadvantages
  - Losses approach zero for moderate duration storms
  - Same loss for given rainfall regardless of duration.
- HEC-HMS User Manual 3.5 pg 137

Loss Model: Green-Ampt

- Infiltration model based on constant head or constant vertical flux into a porous medium.
  - Assumes soil behaves like a permeameter.
  - Uses Darcy's law (adjusted for soil suction).
- Four parameters:
  - Initial and saturated water content
  - Soil suction and saturated hydraulic conductivity
- CMM pp 110-122

Loss Model: Green-Ampt

- Infiltration model based on constant head or constant vertical flux into a porous medium.

$$F(t) = \int_0^t f(\tau)\, d\tau \qquad (4.2.1)$$

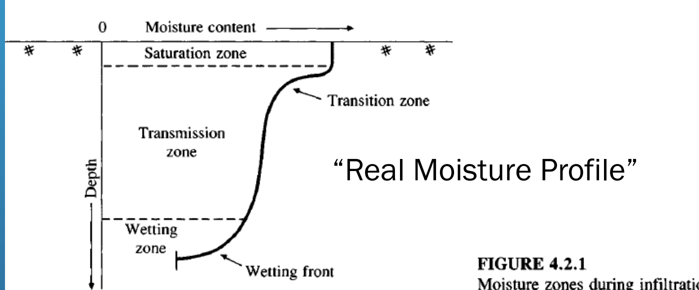


FIGURE 4.2.1
Moisture zones during infiltration.

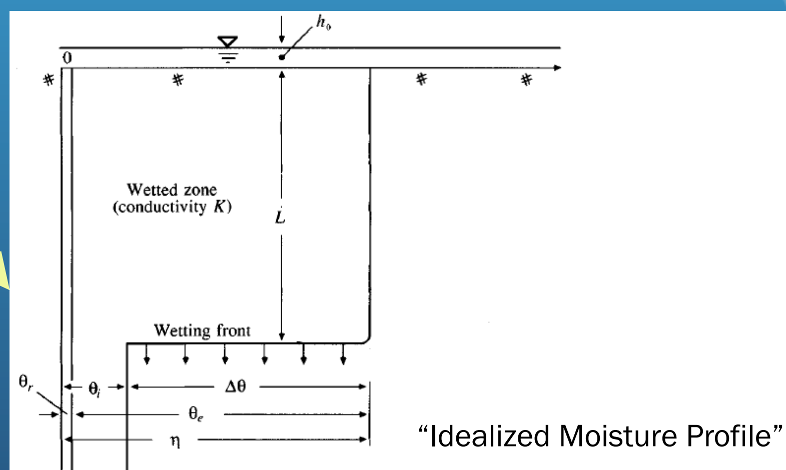


FIGURE 4.3.1
Variables in the Green-Ampt infiltration model. The vertical axis is the distance from the soil surface, the horizontal axis is the moisture content of the soil.

Loss Model: Green-Ampt

Flux (infiltration rate); Governed by saturated hydraulic conductivity, soil suction, and accumulated infiltration.

Volume infiltrated over time; Governed by flux, change in water content.

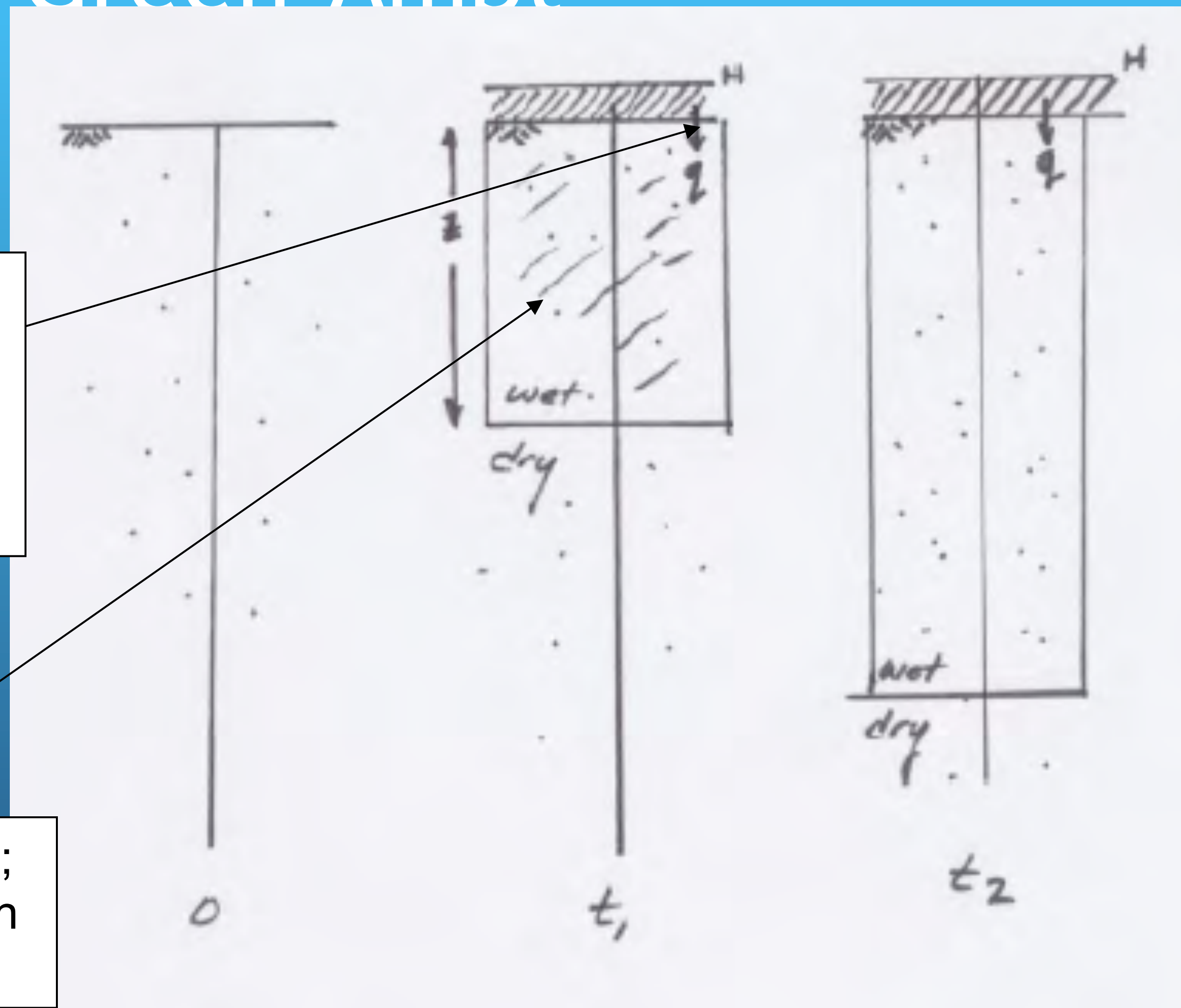


Figure 4: Watershed infiltration schematic

Loss Model: Green-Ampt

- Parameter estimation
  - Initial water content
    - wilting point is a good lower bound for modeling
  - Saturated water content
    - porosity is a good approximation
  - Saturated hydraulic conductivity
    - Infiltrometer measurements
  - Soil suction
    - Textural description
    - Hanging column measurements
- Local guidance
  - (e.g. Harris County has suggested GA parameter values)

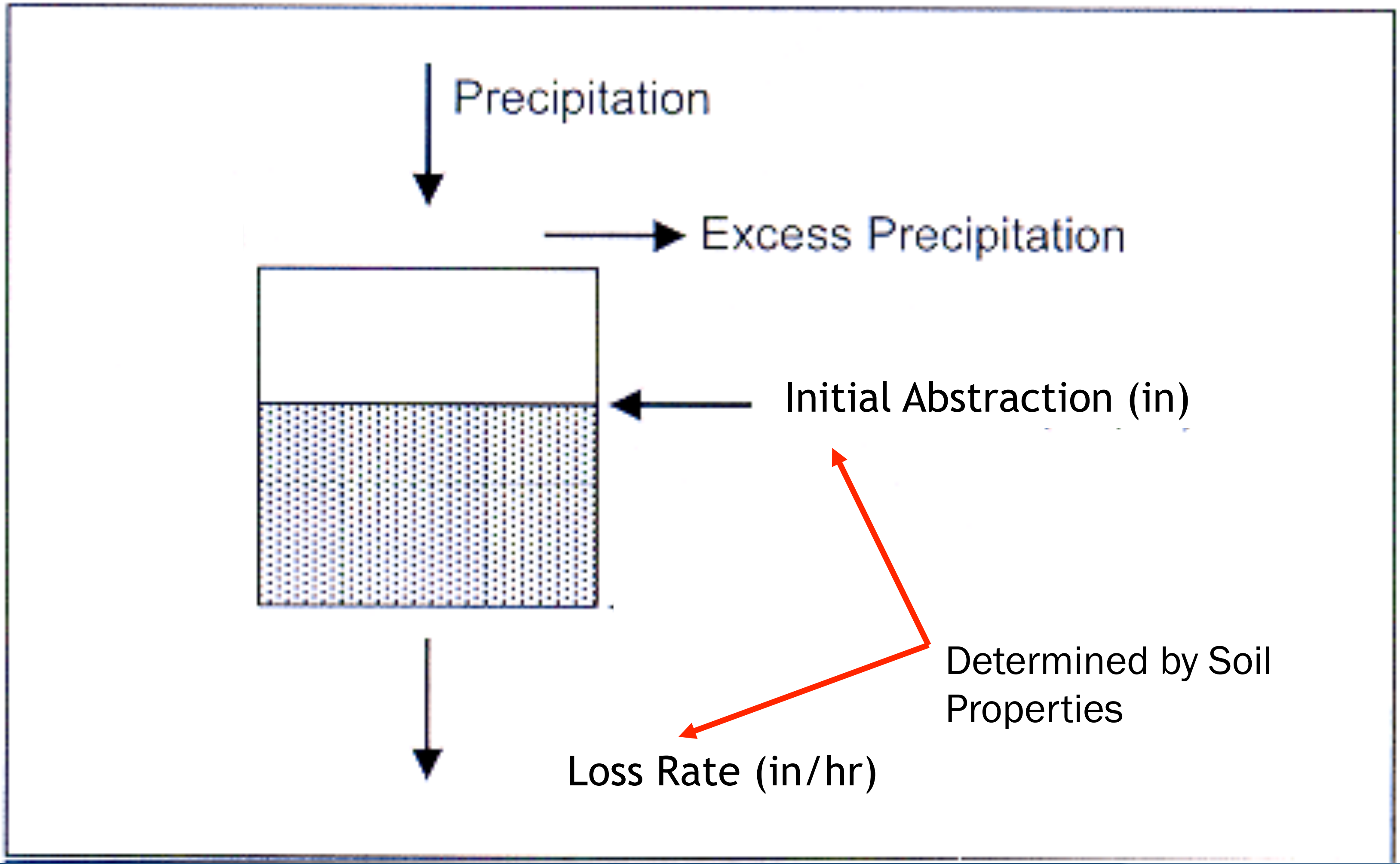
Loss Model: Green-Ampt

- Advantages
  - Documented soil saturation theory
  - Parameters can be estimated either by measurement or textural soils description
- Disadvantages
  - Parameter estimates NON-TRIVIAL.
  - More complex than rest of hydrologic model.
- HEC-HMS User Manual 3.5, pg 133

Loss Model: IaCl

- Assumes soil has an initial capacity to absorb a prescribed depth.
- Once the initial depth is satisfied, then a constant loss rate thereafter.
  - No recovery of initial capacity during periods of no precipitation.

Loss Model: IaCl



Loss Model: IaCl

- Typical values, Ia:
  - Sandy soils: 0.80 to 1.50 inches
  - Clay soils : 0.40 to 1.00 inches
- Typical values, Cl
  - Sandy soils: 0.10 to 0.30 inches/hour
  - Clay soils : 0.05 to 0.15 inches/hour

Loss Model: IaCl

- Two parameters, the initial abstraction and the constant loss rate.
- Parameter estimation:
  - Calibration
  - TxDOT 0-4193-7 (Additional Readings)
  - Local guidance (i.e. Harris County, circa 2003)

Loss Model: IaCl

- Advantages
  - Simple to set up and use
  - Complexity appropriate for many studies
- Disadvantages
  - Parameter estimation (outside of 0-4193-7)
  - May be too simplified for some studies
- HEC-HMS User Manual 3.5, pg 136
  - "Initial and Constant Loss"

Other Loss Models

- Deficit and Constant
- Exponential Model
- Smith Parlange
- Soil Moisture Accounting
- Phi-Index (and proportional rainfall)
  - Not in HEC-HMS, analyst prepares excess precipitation time series externally.
  - Documented in most hydrology textbooks.

Other Loss Models

- Deficit and Constant
  - Similar to IaCl. Ia "rebounds" after period of zero precipitation.
  - HEC-HMS User Manual 3.5 pg 130
- Exponential Model
  - Exponential decay of infiltration rate
  - Needs local calibration, popular in coastal communities (long history of calibration)
  - HEC-HMS User Manual 3.5 pg 130

Other Loss Models

- Smith Parlange
  - A soil science approach more complex than Green-Ampt, similar concepts.
  - Nine parameters
  - HEC-HMS User Manual 3.5, pg 138
- Soil Moisture Accounting
  - Three-layer soil storage model. Evapotranspiration used to dry upper layer.
  - 14 parameters
  - HEC-HMS User Manual 3.5, pg 139

Next Time

- Unit Hydrographs
  - CMM pp. 201-223