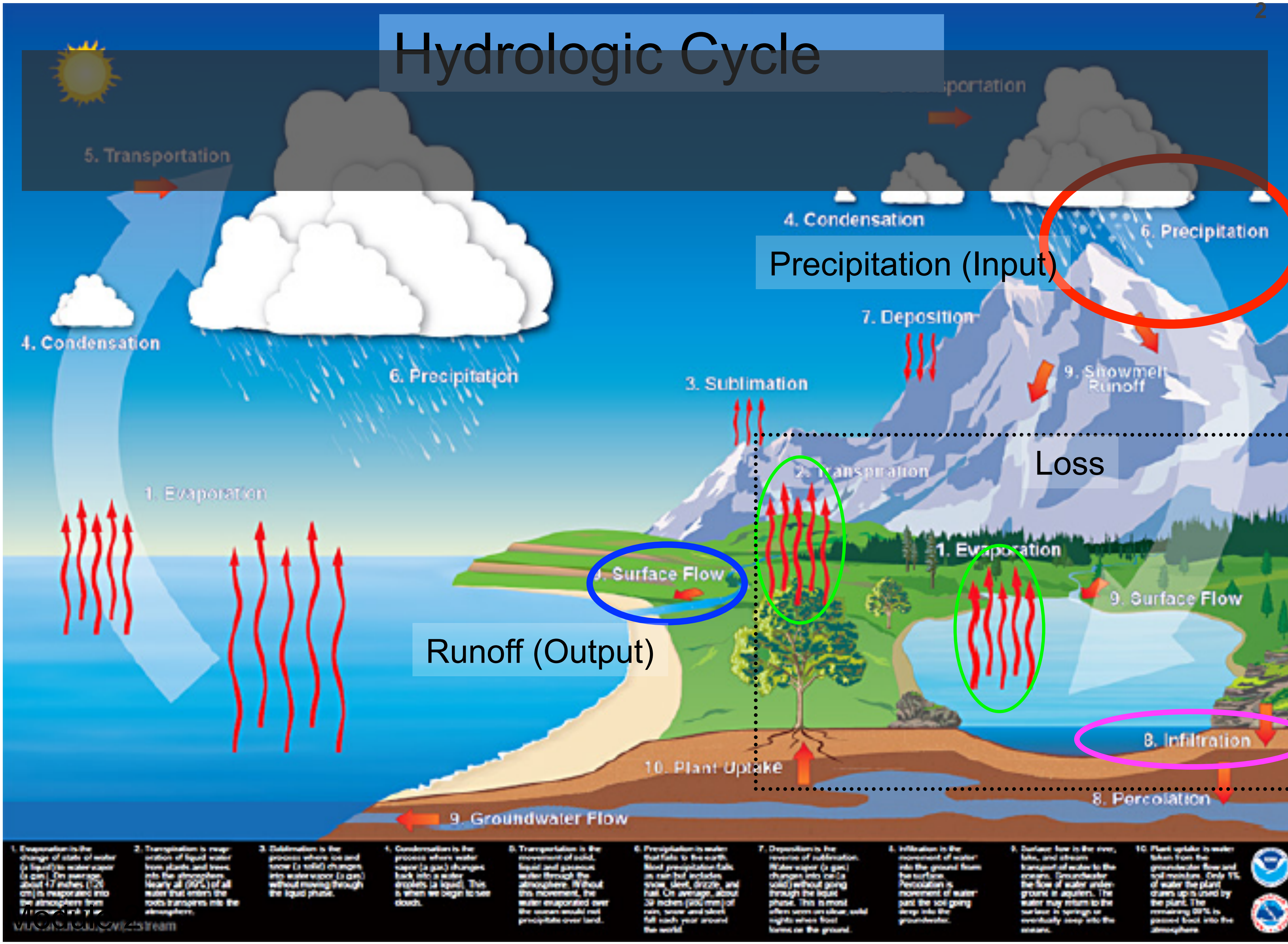
CE 5361 SURFACE WATER HYDROLOGY

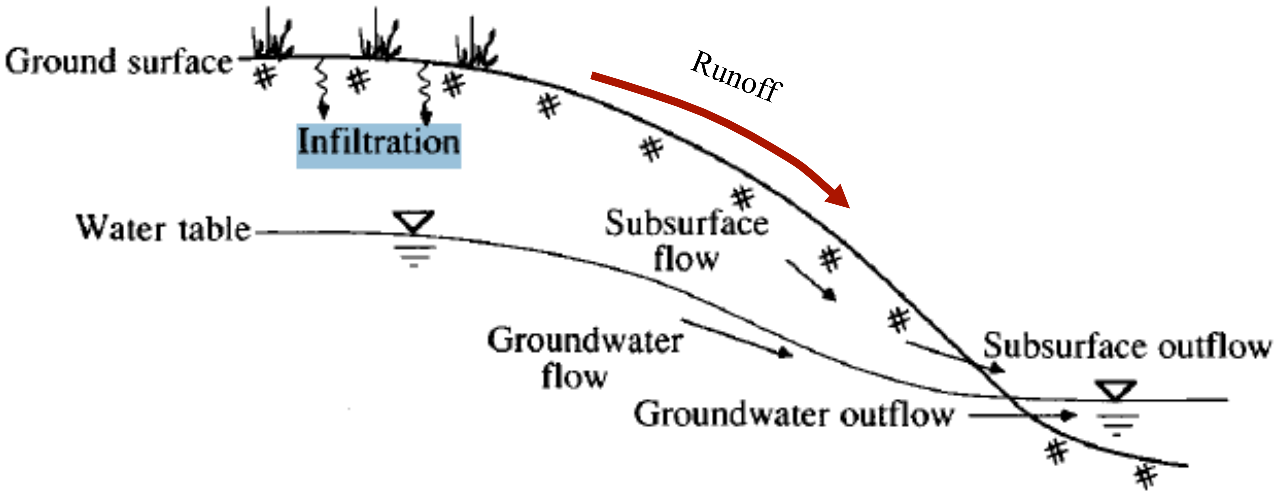
WATERSHED PROCESS: INFILTRATION

Hydrologic Cycle



LOSS MECHANISMS – INFILTRATION

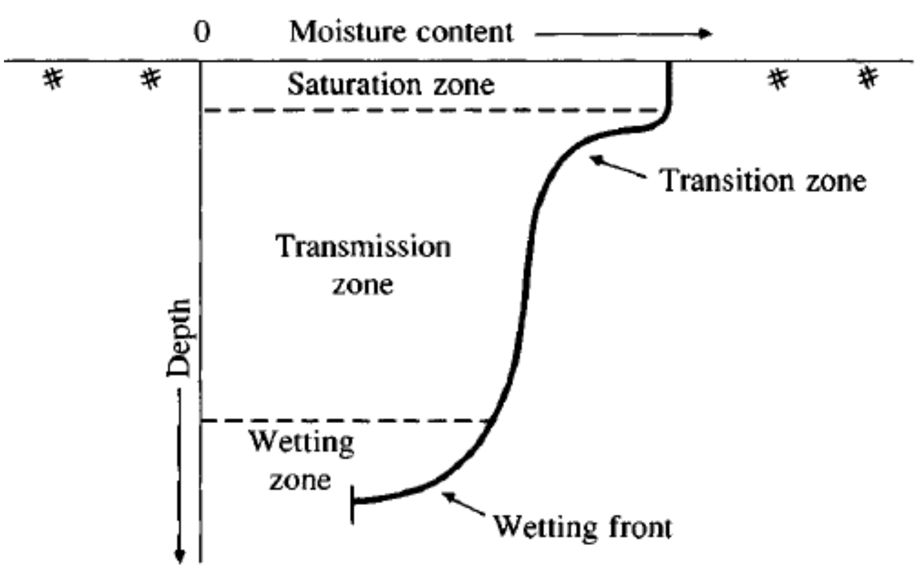
- Infiltration is water that soaks into the ground. This water is considered removed from the runoff process.
- Largest contribution to losses during a storm event, hence most loss models are some form of an infiltration accounting

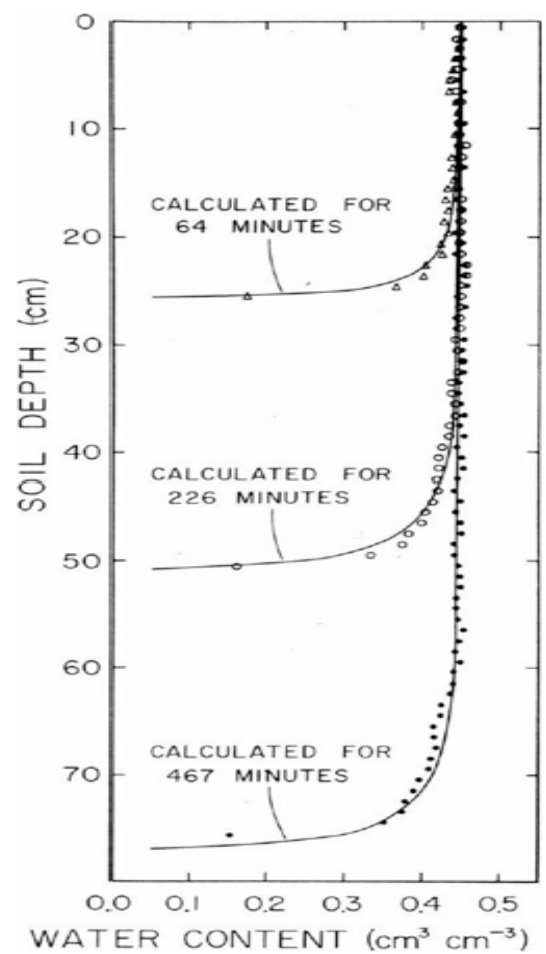


SOIL MOISTURE PROFILE

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

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





INFILTRATION EXCESS

- Infiltration excess concept (frequently called Hortonian overland flow)

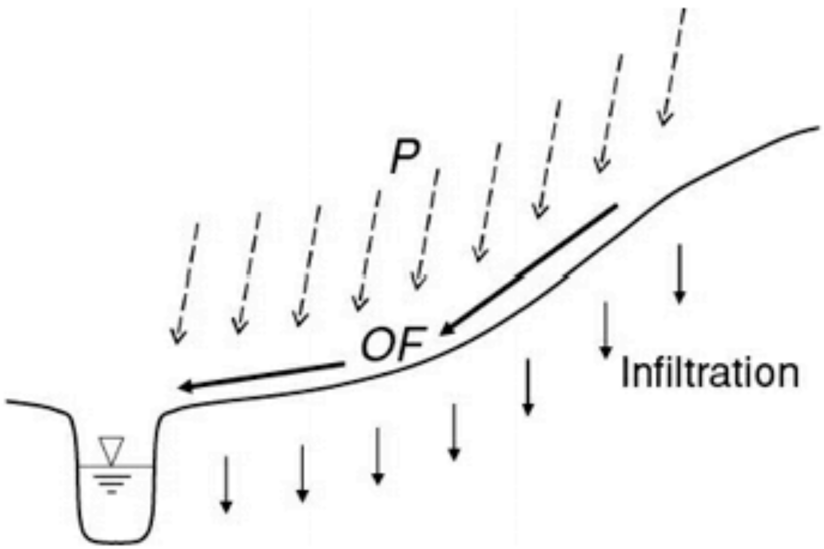


Fig. 11.2 Illustration of the overland flow (OF) mechanism as infiltration excess. The precipitation rate *P* exceeds infiltration capacity, and the water table is at the ground surface.

INFILTRATION EXCESS (HORTONIAN OVERLAND FLOW)

This type of flow occurs when the rainfall rate is larger than the infiltration capacity, so that there is an excess which runs off over the surface. Although this flow generation concept is sometimes associated with the name of Horton (1933), it goes back much earlier. It was already the basis of the well-known rational method, introduced 150 years ago by Mulvany (1850), and of the various runoff routing procedures subsequently derived from it by Hawken and Ross (1921) and others (see also Dooge, 1957; 1973). It is also implicit in the unit hydrograph, as originally proposed by Sherman (1932a; b). In these and other early studies concerned with maximal rates of runoff in problems of flooding and erosion, it was assumed that the infiltration rate is smaller than the precipitation rate over the entire catchment. In the rational method, the infiltration is taken as a fraction of the precipitation, whereas in the unit hydrograph approach and in Horton's work, the infiltration capacity or a related index is subtracted from the precipitation. Thus it was assumed that the infiltrated water is "lost" and that virtually all stormflow results from the overland flow of the precipitation excess (see Figure 11.2). In the prediction of extreme flows for design purposes in disaster situations, this assumption of overland flow was not unreasonable.

Brutsaert, Wilfried. Hydrology . Cambridge University Press. Kindle Edition.

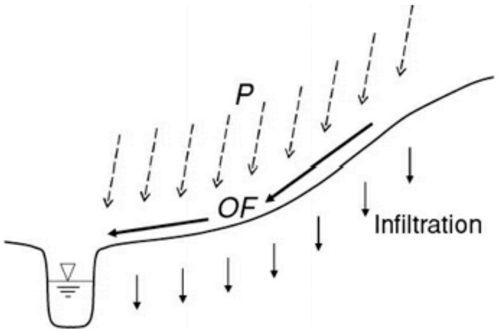


Fig. 11.2 Illustration of the overland flow (OF) mechanism as infiltration excess. The precipitation rate *P* exceeds infiltration capacity, and the water table is at the ground surface.

HORTONIAN INFILTRATION

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

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

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

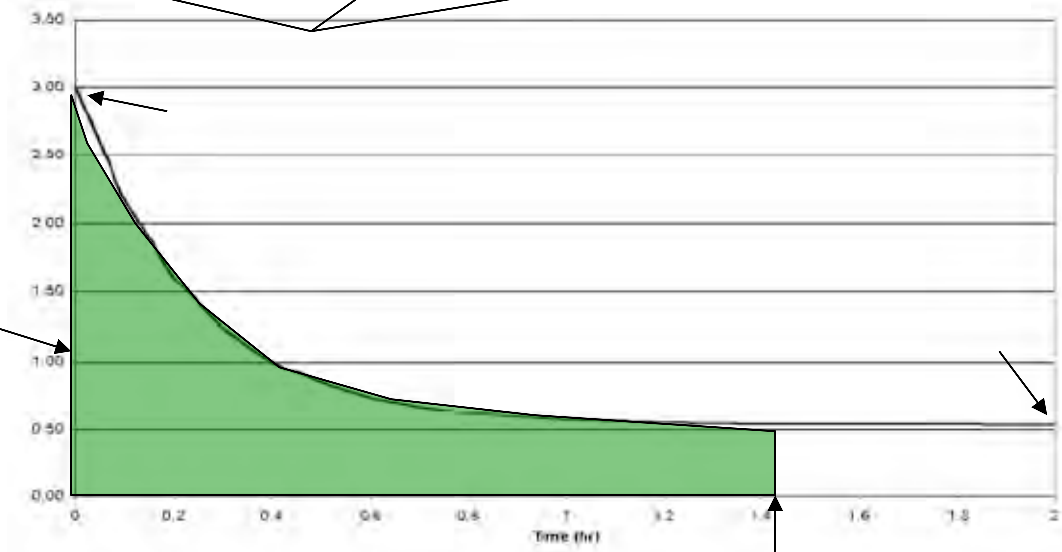


Figure 1: Horton's model using supplied parameters

- CMM pp 108-110

SATURATION EXCESS

- Saturation excess concept
  - Dunne overland flow
- Saturation zone moves upward
- Flow when saturation reaches land surface

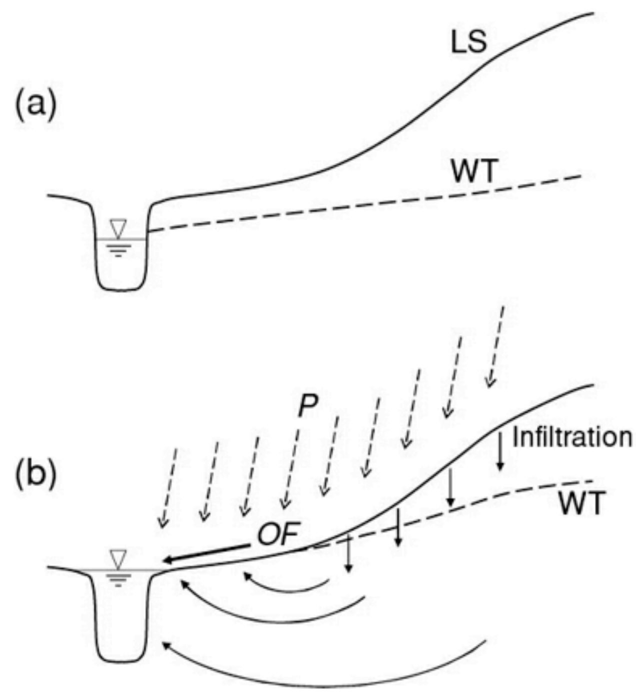


Fig. 11.3 Schematic illustration of the overland flow (OF) mechanism as saturation excess: (a) the position of the water table (WT) prior to the onset of precipitation and (b) during the precipitation event. The precipitation rate *P* is smaller than the infiltration capacity over the unsaturated portion of the land surface; overland flow takes place where the water table has risen to the ground surface.

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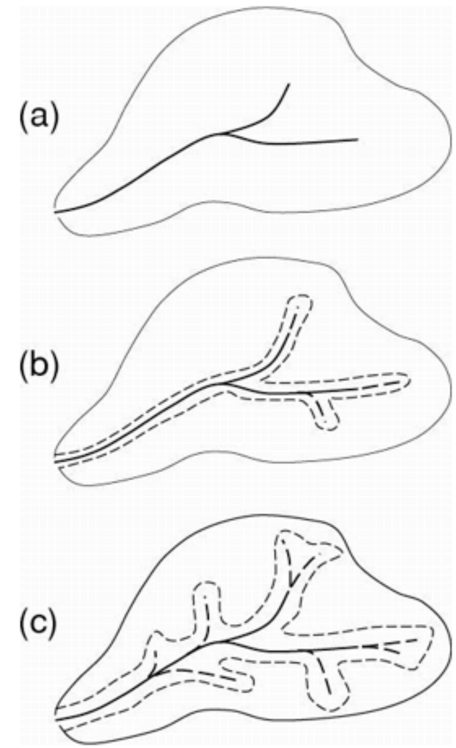
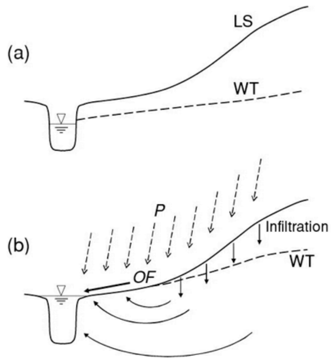


Fig. 11.4 Schematic plan view of a second-order catchment illustrating the extent of the variable source areas (inside the dashed line) on which overland flow takes place: (a) under drought flow conditions; (b) and (c) after the onset of precipitation. The stream channels and the saturated areas near the stream channels expand as the precipitation continues.

SATURATION EXCESS

This type of surface runoff occurs over land surfaces that are saturated by emerging subsurface outflow from below and perched water tables, regardless of the intensity of the rainfall (or snowmelt) (see Figure 11.3). It is a rapid and almost immediate transport mechanism to the stream channel, for the seepage outflow water and for the rainwater falling (or snow melting) on such areas. It usually takes place in conjunction with subsurface flow to the channel, but the relative magnitudes of surface and subsurface flows into the channel depend largely on the nature of the catchment and the precipitation. It is most often observed over limited areas in the immediate vicinity of the river channel where downslope subsurface flows emerge, and in wetlands, where the water table can rise rapidly to the surface; but it can also occur higher up in slope hollows, where elevation contours display strong curvature, thus forcing convergence of the flow paths. Outside of these saturated areas all the precipitation and other input can generally enter the soil surface.

Brutsaert, Wilfried. Hydrology . Cambridge University Press. Kindle Edition.



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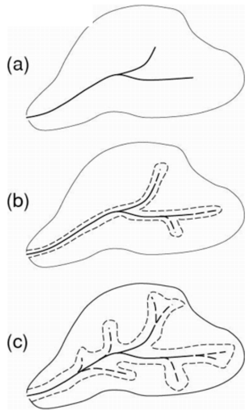
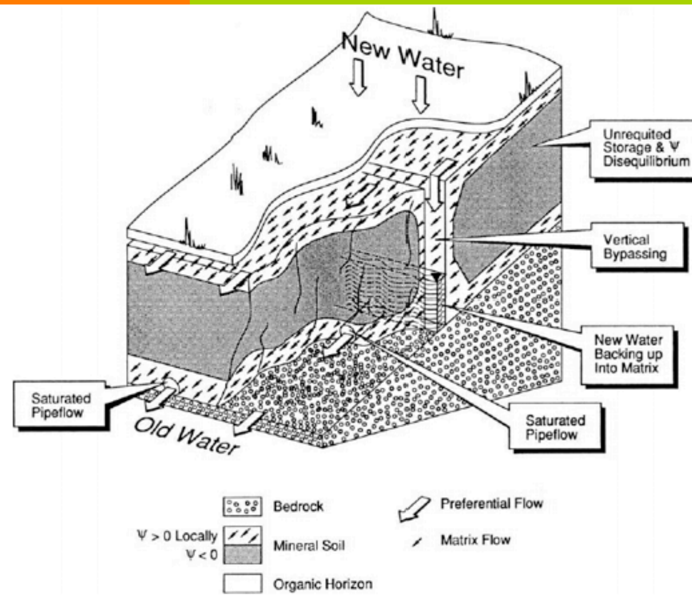


Fig. 11.4 Schematic plan view of a second-order catchment illustrating the extent of the variable source areas (inside the

SUBSURFACE STORMFLOW

In many catchments under natural conditions infiltration is never exceeded, and the precipitation and other input can readily enter into the ground surface; thus the subsequent flow to the stream channel takes place below the surface, presumably through the soil mantle of the catchment. Lowdermilk (1934) and Hursh (1936) appear to have been among the first to propose subsurface flow as the main streamflow generation mechanism in forested hill slopes (see also Hewlett, 1974). It was later confirmed in several experimental investigations that subsurface flow can even be the only mechanism under certain conditions (see Roessel, 1950; Hewlett and Hibbert, 1963; Whipkey, 1965; Weyman, 1970).

Brutsaert, Wilfried. Hydrology . Cambridge University Press. Kindle Edition.



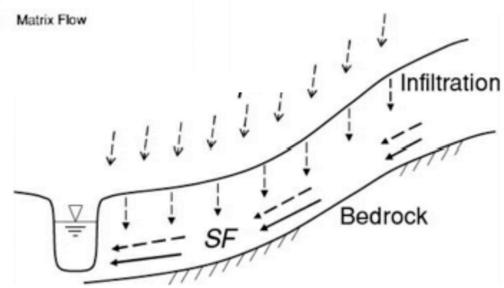


Fig. 11.11 Schematic illustration of the rapid subsurface storm flow (SF) through various types of preferential flowpath-s,pipes and macropores. The relative amounts of new (dashed arrows) and old water (solid arrows) in the mixing process depend mainly on the precipitation intensity and on the pre-storm soil moisture conditions.

COMPUTATIONAL HYDROLOGY CONSIDERATIONS

- Scale is the appropriate criterion to classify the different methodologies.
  - distributed models, also called runoff routing models, the computational scales are much smaller than the flow domain characterizing the catchment,
  - lumped models the computational scale is essentially of the same order as that of the catchment.
- Importance of scale justifies efforts at delineation
- Some distributed models are collections of lumped models (perhaps most) connected by hydraulic mechanisms

LOSS MODELS

- Consider the tools
  - Homebrew
  - HEC-HMS
  - SWMM
- Consider the model question
  - Select what we attempt to explain by the various process explanations

LOSS MODELS

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

Loss Model: NRCS CN

- NRCS Runoff Curve Number (CMM pp 110-122)

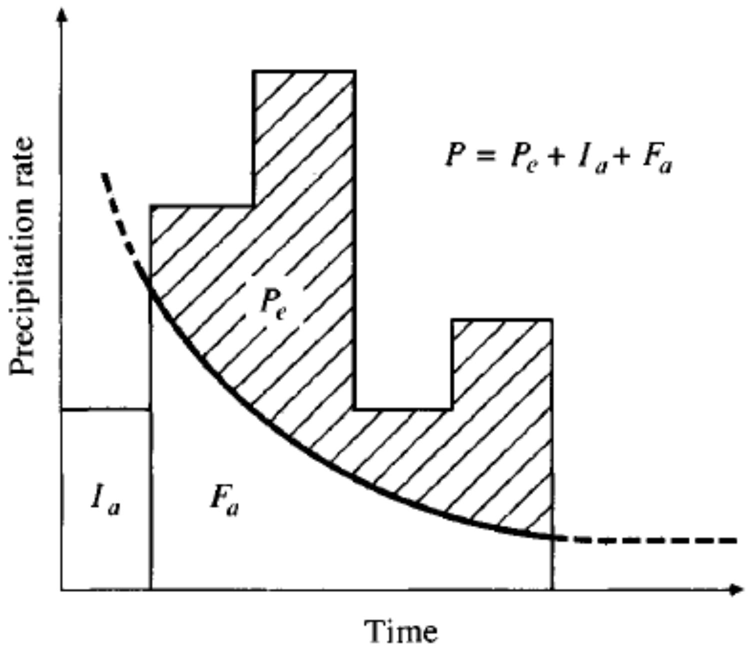


FIGURE 5.5.1
Variables in the SCS method of rainfall abstractions: I_a = initial abstraction, P_e = rainfall excess, F_a = continuing abstraction, P = total rainfall.

Loss Model: NRCS CN

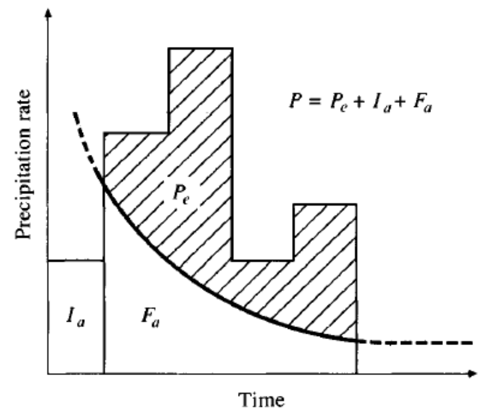
- NRCS Runoff Curve Number
- Precipitation = Excess + Initial Loss + Continuing Loss

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

$$I_a = 0.2S$$

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

Maximum Retention



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Loss Model: NRCS CN

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

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

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

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 many 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 impervious 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 ...en into a drainage system.

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

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

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

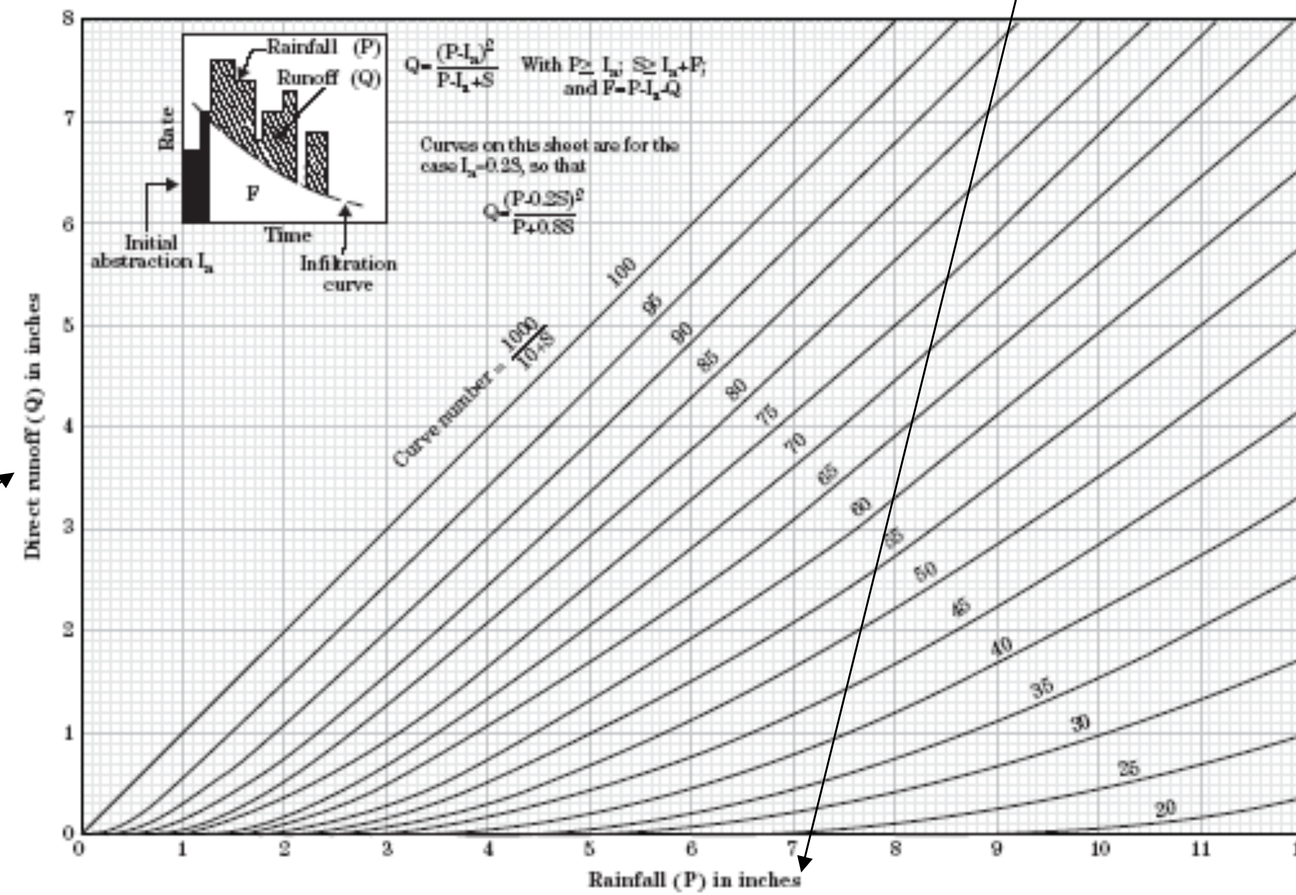
$$q = \frac{(P-0.2S)^2}{(P+0.8S)}$$

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

Loss Model: NRCS CN

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

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

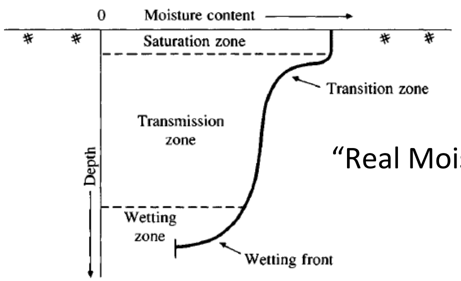
Loss Model: Green-Ampt

- 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

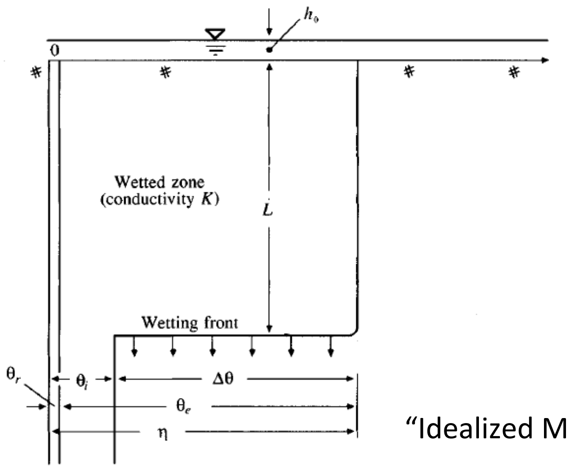
- Infiltration model based on constant head or constant vertical flux into a porous medium.

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



"Real Moisture Profile"

FIGURE 4.2.1
Moisture zones during infiltration.



"Idealized Moisture Profile"

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.

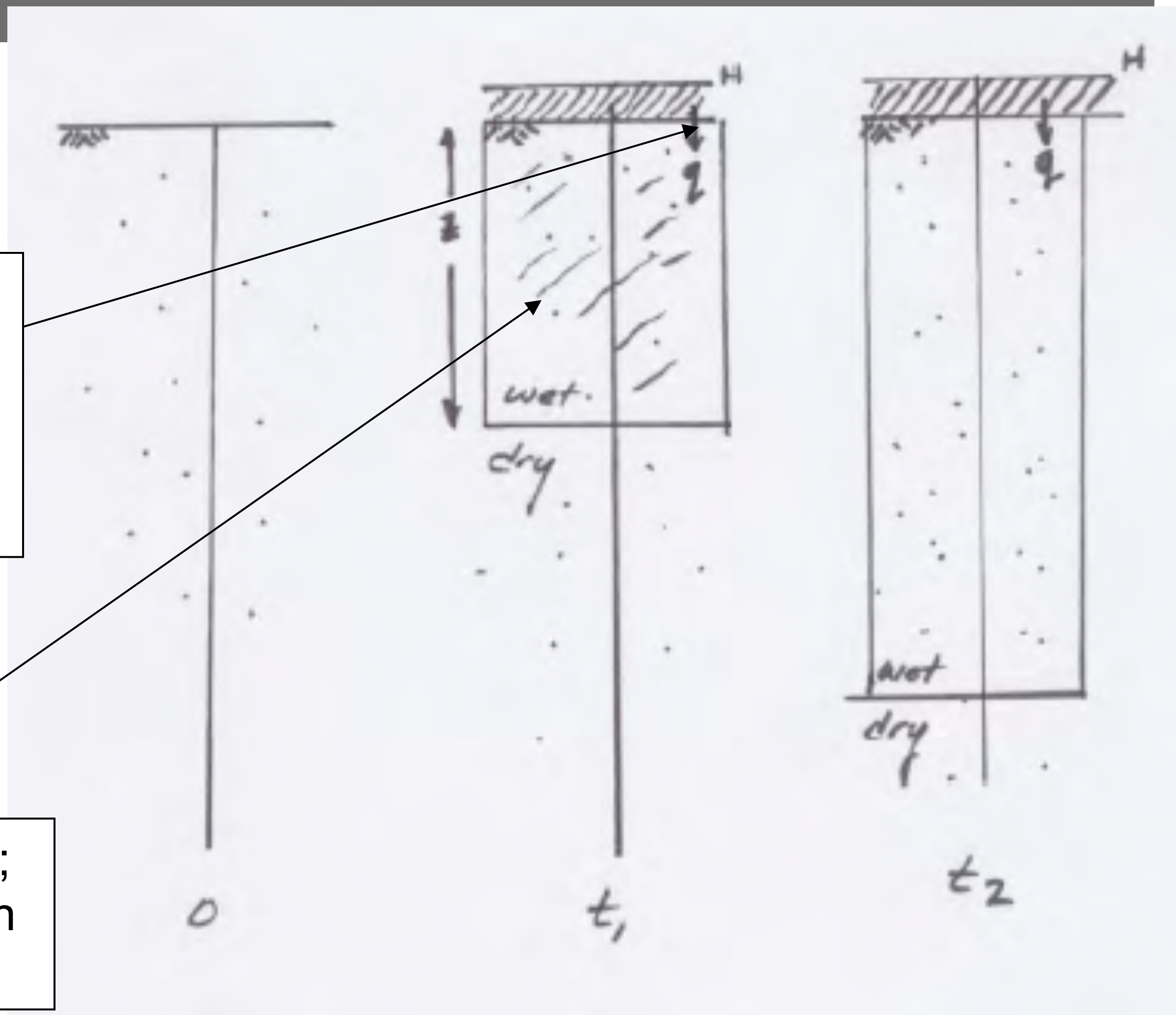


Figure 4: Watershed infiltration schematic

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)

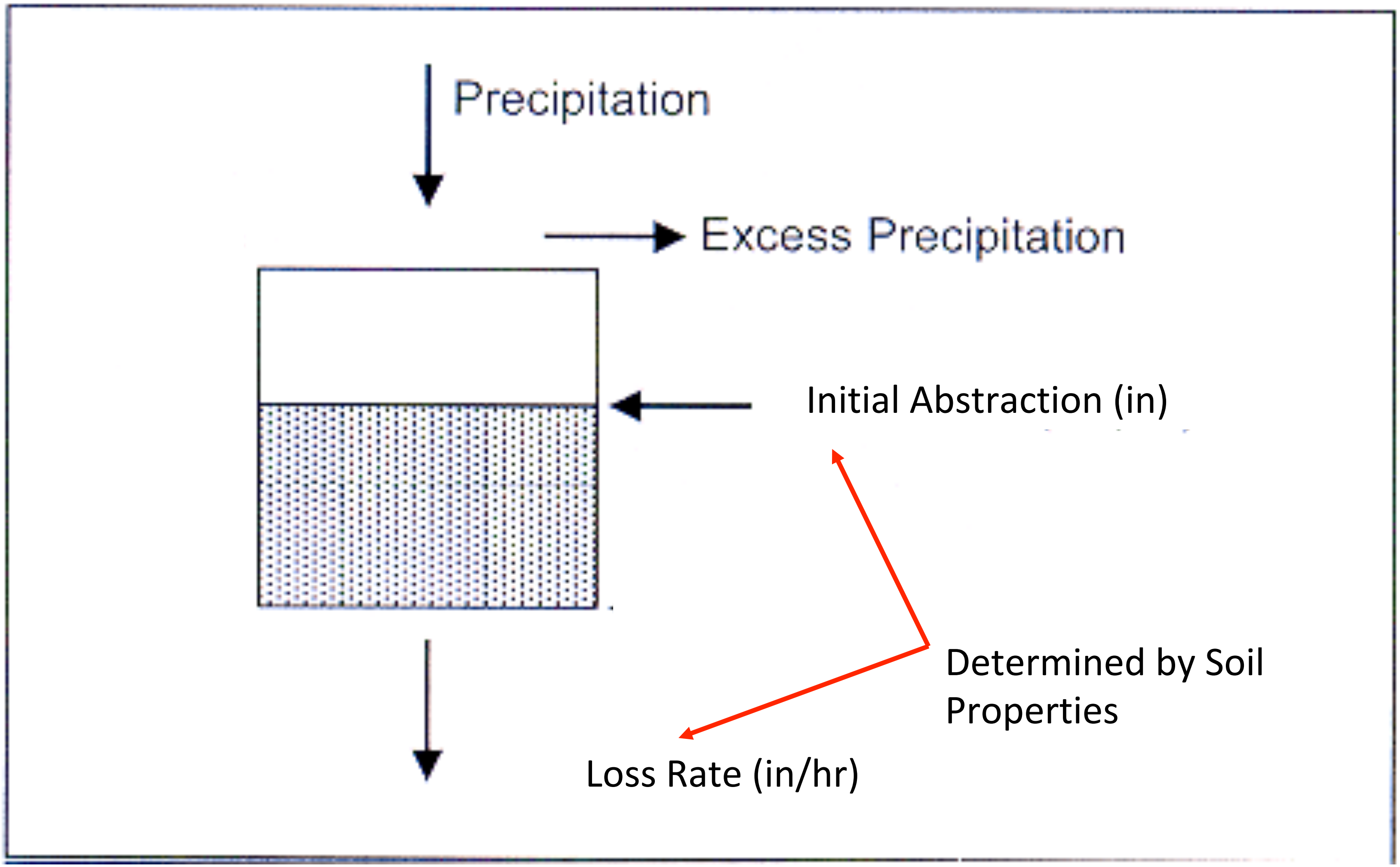
Loss Model: Green-Ampt

- 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 (HEC-HMS Example 2)
  - 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