Florida Department of Environmental Protection

Hydrology – 3b:
Hydrologic Abstractions

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Classification of Hydrologic Abstractions

- ✓ Infiltration
- ✓ Evaporation
- ❑ Transpiration
- ❑ Interception
- ❑ Depression Storage
- ❑ Detention Storage

- Transpiration is the transfer of soil moisture from the soil to the atmosphere by the action of plants and vegetation which transpire water vapor through their foliage
- The absorption of water begins at the root system of plants and its release as vapor to the atmosphere occurs through their pores in the leaf system
- Plants also lose water by other mechanisms, but usually this is negligible compared with that lost by transpiration
- Transpiration is controlled by the same factors as evaporation, mainly solar radiation, wind speed, temperature and pressure

Transpiration

Transpiration

- Evaporation and transpiration are commonly lumped in one variable called Evapotranspiration (ETP)
- It is important when dealing with crop irrigation to maintain the soil moisture between the wilting point (*WP*)and field capacity (*FC*) by controlling the water applied to balance the ETP (consumptive use). Over-irrigation (above *FC*) can be as detrimental to the survival of crops as under-irrigation (below *WP*)
- Transpiration has a minimal effect on individual storms and is usually taken into account in long-term hydrologic budgets and in continuous modeling simulations

- Transpiration can be measured in the laboratory by using tanks wherein evaporation is eliminated and water losses are estimated by weighing
- ETP records from field observations are frequently made by using lysimeters. They are big containers that replicate the site conditions (i.e., soils and crops/vegetation) and maintain a precise water budget with strict control on all inputs and outputs

Transpiration: Measurements

ETP Equations

- The ***Blaney-Criddle*** (H. F. Blaney and W. D. Criddle, 1950) equation has been widely used in western U.S. to determine consumptive use or ETP for a reference crop. Given its coarse accuracy, the periods should be one month or greater,

$$ETP_{rc} = \frac{K_{rc} \times t \times p}{100} \quad \ldots [3.15]$$

where $\boldsymbol{ETP_{rc}}$ is the monthly consumptive use (*inch*), $\boldsymbol{K_{rc}}$ is the consumptive use coefficient of the crop, $\boldsymbol{t}$ is the mean monthly temperature (*°F*) and $\boldsymbol{p}$ is the monthly daytime hours as percent of the year (monthly graphs as a function of latitude N/S)

ETP Equations

- The ***Thornthwaite*** (C. W. Thornthwaite, 1944) equation defines potential ETP as "the water loss which will occur if at no time there is a deficiency of water in the soil for the use of vegetation"

$$PET = 1.6 \times \left(\frac{10 \times t_i}{TE} \right)^a \ldots [3.16]$$

where $\boldsymbol{PET}$ is the monthly potential ETP (*cm*), $\boldsymbol{t_i}$ is the mean monthly temperature (°C), $\boldsymbol{TE}$ is the Thornthwaite's temperature-efficiency index,

$$TE = \sum_{i=1}^{12} I_i \ldots [3.17]$$

which is the sum of the 12 monthly values of heat index (I_i). The heat index for each month is computed as follows,

$$I_i = \left(\frac{t_i}{5}\right)^{1.514} \quad \ldots [3.18]$$

and the a exponent can be evaluated by the following third-degree polynomial equation as a function of TE,

$$a = 6.75\times10^{-7}\times TE^3 - 7.71\times10^{-5}\times TE^2 + 0.01792\times TE + 0.49239 \ldots [3.19]$$

- A following example will illustrate an application of this equation

ETP Equations

- The ***Penman*** (H. L. Penman, 1948) equation is an advanced model to compute potential ETP even at daily time periods. It is based on the diffusion energy evaluated from meteorological variables and resistances that are related to the pores in the leafs and aerodynamics of the crops. It requires temperature, air pressure, solar radiation, wind, and humidity data, and has the simplified form

$$ETP = \frac{A \times H + 0.27 \times E}{A + 0.27} \quad \ldots [3.20]$$

where $\boldsymbol{ETP}$ is the consumptive use for given period (*mm*), $\boldsymbol{A}$ is the slope of saturated-vapor-pressure curve of air at absolute temperature (*mm Hg/°C*), $\boldsymbol{E}$ is the daily evaporation (*mm*) and $\boldsymbol{H}$ is the accumulated degree-days above

ETP Equations

minimum growing temperature. Both calculated from the equations

$$E = 0.35 \times (e_a - e_d) \times (1 + 0.0098 \times w_2) \ldots [3.21]$$

$$H = R \times (1 - r) \times (0.18 + 0.55 \times S) - B \times \left(0.56 - 0.092 \times \sqrt{e_d}\right) \times (0.1 + 0.9 \times S) \ldots [3.22]$$

where e_a is the saturation vapor pressure at mean air temperature (*mm Hg*), e_d is the saturation vapor pressure at dew point (= e_a x R_h in *percent*), w_2 is the mean wind speed at 2 m above the ground (miles/d), R is the mean daily radiation (*mm*), r is the albedo (*ratio of reflected and incoming radiations*), S is the ratio of actual to maximum possible durations of bright sunshine and B is a coefficient depending on temperature

ETP Equations

ETP Tornthwaite Example

- Estimate the mean monthly ETP potential values for Tallahassee using the ***Thornthwaite*** equation [3.16]

Mean Monthly Temperatures for Tallahassee

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T (°F)	51.3	54.7	60.4	66.2	74.3	80.2	82.4	81.9	78.3	69.4	60.8	53.2

$$PET = 1.6 \times \left(\frac{10 \times t_i}{TE} \right)^a \ldots [3.16]$$

$$TE = \sum_{i=1}^{12} I_i \ldots [3.17]$$

$$I_i = \left(\frac{t_i}{5} \right)^{1.514} \ldots [3.18]$$

$$a = 6.75 \times 10^{-7} \times TE^3 - 7.71 \times 10^{-5} \times TE^2 + 0.01792 \times TE + 0.49239 \ldots [3.19]$$

Computation of Potential ETP for Tallahassee

Month	Mean Temperature (°F)	Mean Temperature (°C)	I_i	PET (cm)	PET (inch)
Jan	51.3	10.7	3.16	1.83	0.72
Feb	54.7	12.6	4.05	2.63	1.03
Mar	60.4	15.8	5.71	4.33	1.70
Apr	66.2	19.0	7.55	6.49	2.56
May	74.3	23.5	10.41	10.36	4.08
Jun	80.2	26.8	12.70	13.84	5.45
Jul	82.4	28.0	13.58	15.24	6.00
Aug	81.9	27.7	13.36	14.89	5.86
Sep	78.3	25.7	11.92	12.62	4.97
Oct	69.4	20.8	8.66	7.92	3.12
Nov	60.8	16.0	5.82	4.45	1.75
Dec	53.2	11.8	3.67	2.27	0.90
Σ		TE =	100.59	96.87	38.14

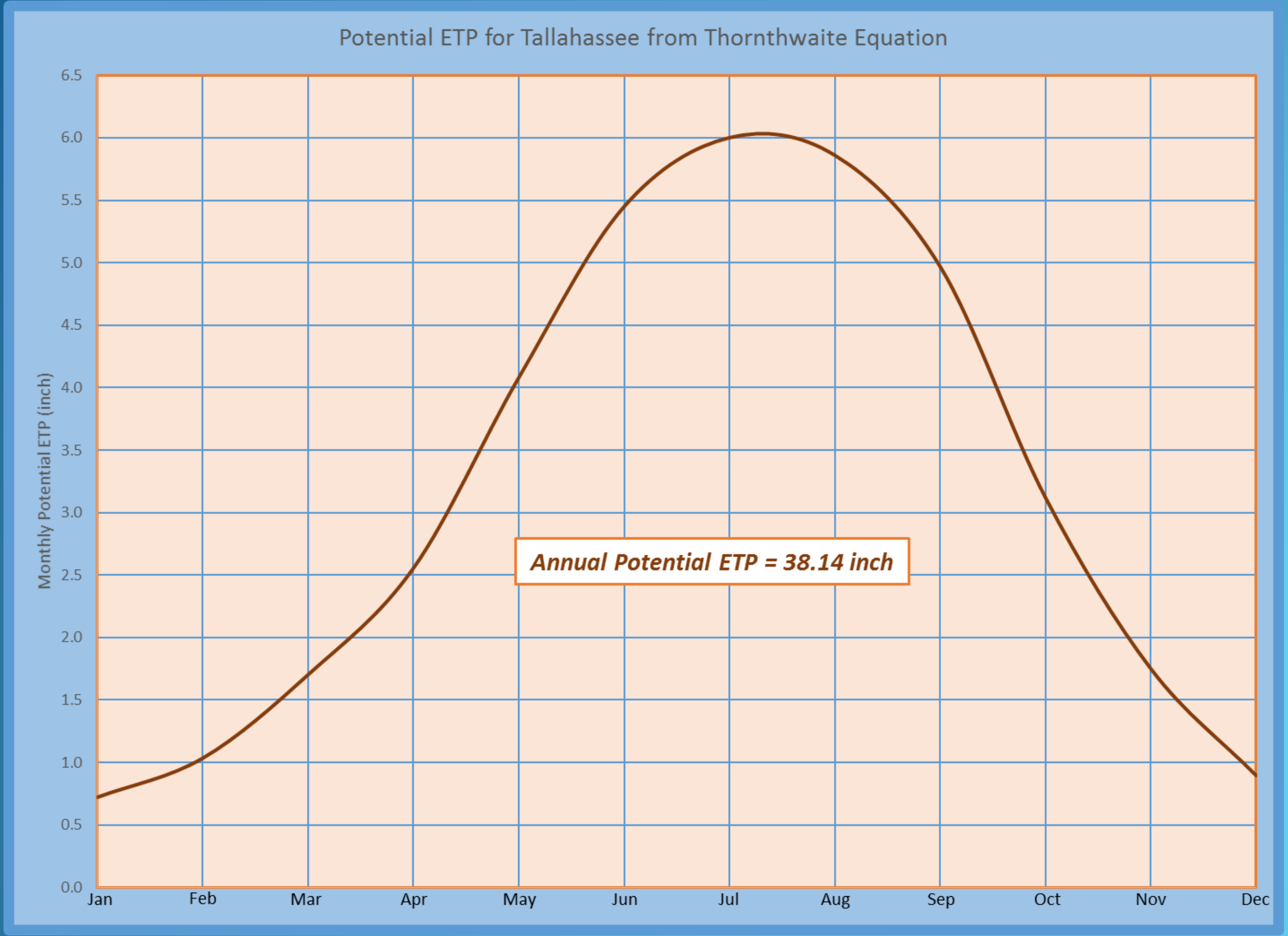
$$a = 6.75\times10^{-7}\times(100.59)^3 - 7.71\times10^{-5}\times(100.59)^2 + 0.01792\times(100.59) + 0.49239 = 2.2018 \quad \textit{from Eq. [3.19]}$$

$$I_5 = \left(\frac{23.5°C}{5}\right)^{1.514} = 10.41 \quad \textit{from Eq. [3.18]}$$

$$PET = 1.6\times\left(\frac{10\times28}{100.59}\right)^{2.2018} = 15.24\,cm \quad \textit{from Eq. [3.16]}$$

$$TE = 100.59 \quad \textit{from Eq. [3.17]}$$

ETP Thornthwaite Example



ETP Thornthwaite Example

Interception

- Interception is a portion of a storm precipitation that is captured by plant foliage, vegetation, buildings and other forms of cover on the drainage area
- Part of the rainfall wets and adheres to building walls, above ground objects or civil structures; is retained on leaves or blades of grass or vegetation; flows down the stems of plants until is either returned to the atmosphere through evaporation or eventually is transmitted to the ground surface
- The amount of water intercepted is a is a function of (1) the storm characteristics, (2) the species and density of plants and trees, and (3) the season of the year

Interception

- Losses by interception may be significant and play an important role in management of water resources of watersheds containing dense closed forest stands, and it can be
  - as much as 25% of the annual precipitation
  - usually about 10 to 20% of the precipitation during the growing season
  - about 24% of the annual precipitation in Douglas fir stands in western Oregon and Washington
  - approximately 14% for pine plantations in Georgia
  - about 12% for Ponderosa pine forest in California

- During a single storm event, interception removes about 0.02 inch (0.51 mm). Values as high as 0.06 inch (1.5 mm) can be used
- Estimation of interception is quite difficult however some equations have been developed for this purpose

$$L_i = S_i + K \times E \times t \ldots [3.23]$$

where L_i is the amount of water intercepted (*inch*), S_i is the interception storage that will be retained on the foliage against the forces of wind and gravity (it varies between *0.01* and *0.05 inch*), K is the ratio of the surface area occupied by foliage by over the entire area, E is the amount of water (*inch*) evaporated per hour during the precipitation period and t is time (*hr*)

Interception

- Precipitation that reaches the ground may infiltrate, flow over the surface or been ponded in land surface hollows which accounts for depression storage.
- The water from a precipitation event that becomes trapped in shallow depressions or ground irregularities can escape either by infiltration or evaporation
- This component of the hydrologic abstractions is quite difficult to estimate because the nature, number and size of depressions within the watershed, many soil parameters, vegetation cover and the land use practices

Depression Storage

- Measurements from field experiments are practically not feasible due to spatial variability
- However some attempts have been made to quantify the water from precipitation being retained in shallow depressions

$$V_s = S_d \times \left(1 - e^{-P_e/S_d}\right) \ldots [3.24]$$

where $\boldsymbol{V_s}$ is the water in depression storage (*inch*), $\boldsymbol{S_d}$ is the depression storage capacity (*inch*) and $\boldsymbol{P_e}$ is the rainfall excess (i.e., gross rainfall minus infiltration, evaporation and interception). Eq. 3.24 neglects evaporation from depression storage during a storm. Typical values of $\boldsymbol{S_d}$ range from 0.4 to 2.0 inch depending on the terrain slope and its topography

Depression Storage

- Depression storage may be treated as a calibration parameter, precisely to adjust runoff flow from continuous model simulations
- Precipitation over large waterbodies (e.g., lakes, reservoirs or ponds) within a watershed is not considered as depression storage. Such a rainfall is called "blind drainage"
- Depression storage is inversely proportional to the slope of the basin
- Typical values of depression storage for storms of high intensity are 0.20 *inch* for sand, 0.15 *inch* for loam and 0.10 *inch* for clay (5.1, 3.8 and 2.5 *mm*, respectively). Also values of 0.25 inch (6.4 *mm*) in impervious urban areas and 0.06 *inch* (1.6 *mm*) for pavement

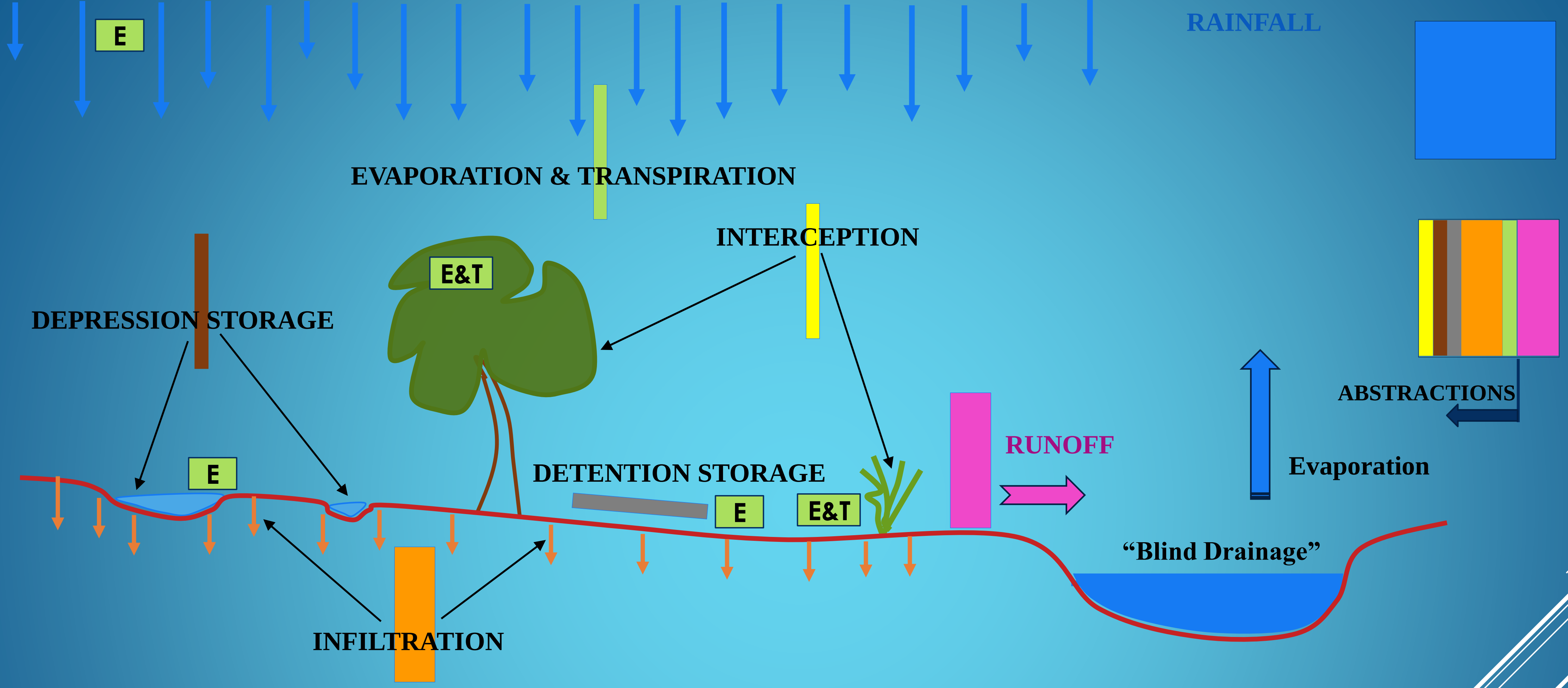
Depression Storage

- Detention storage is the volume of water that remains in temporary storage during the beginning of a storm
- As soon as a finite depth is established and accrues sufficient energy (initially potential and then kinetic), flow begins. This surface flow is called overland flow or "*sheet flow*" and begins the runoff process. Overland flow is then conveyed to streams, canals or stormwater systems prior to their discharge from outfalls
- Detention storage depends on watershed conditions such as slope, land use, soil types and saturation (due to antecedent storms), vegetation, and rainfall intensity

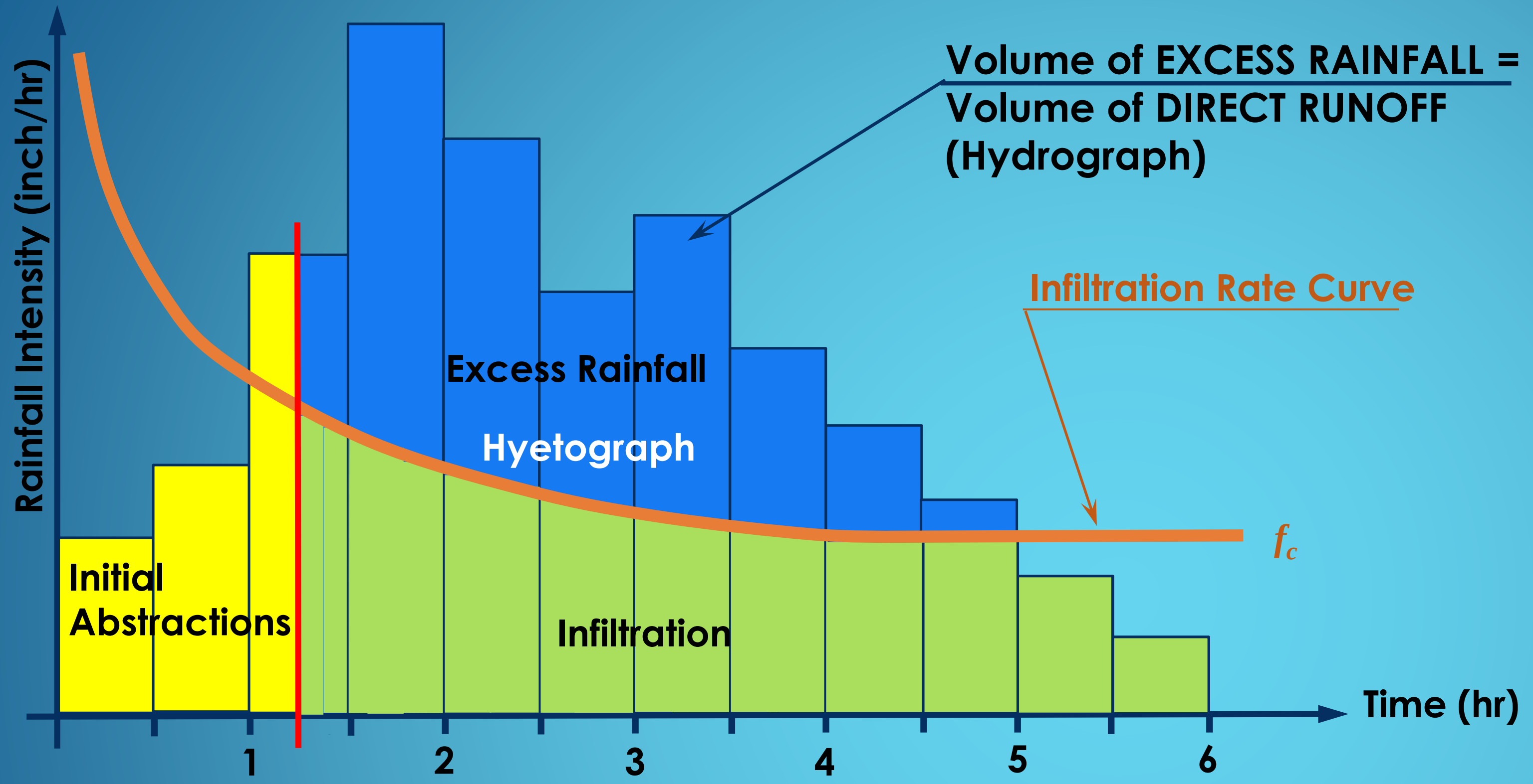
Detention Storage

- Slopes of the watershed influence significantly its detention storage. As the slope increases, additional energy is created for the static water in detention to begin the movement (i.e., overland flow) initiating the runoff process
- Rural and undeveloped areas with relative permeable soils can accumulate larger detention storage than urban areas with significant impermeable areas
- Interception, depression storage and detention storage are commonly added together in rainfall/runoff events as “initial abstractions”
- Typical values range from 0.1 to 0.4 inch (2.5 to 10 mm)

Detention Storage



Rainfall/Runoff Event Abstractions



Rainfall/Runoff Event Relationship

- A 8-hour storm has produced a total precipitation of 21.7 inch, with the following distribution over a watershed of 30 miles^2

Recorded Rainfall for an 8-hour Storm

t (hours)	1	2	3	4	5	6	7	8
Rainfall Intensity, P_i (inch/hr)	0.55	2.40	3.00	3.85	5.11	4.10	1.78	0.91

- Calculate the Volume of Runoff generated
  - E = **0.04 inch/hr**; For Eq. 3.23 (Interception): S_i = **0.33 inch** & K = **0.30**
  - For Eq. 3.2 (Philip Infiltration): S = **7 inch/hr$^{1/2}$** & A = **0.60 inch/hr**
  - V_s = **0.20 inch** (Depression Storage) & V_{ds} = **0.40 inch** (Detention Storage)

Rainfall/Runoff Event Problem

Computation of Excess Rainfall

t (hr)	P_i	f	I_a	I_a^*	f^*	ER
	(inch/hr)					
1	0.55	4.10	0.55	0.55	0	0
2	2.40	3.07	0.80	2.40/0.33	1.60**	0
3	3.00	2.62			2.62	0.38
4	3.85	2.35			2.35	1.50
5	5.11	2.17			2.17	2.94
6	4.10	2.03			2.03	2.07
7	1.78	1.92			1.78	0
8	0.91	1.84			0.91	0
Σ (inch)	21.70	20.10	1.35	1.35	13.46	6.89

1.60 1.6 = 2.4 "/hr @ 2/3 hr (40 min)**

$$f(t) = \frac{S}{2\sqrt{t}} + A \ldots [3.2]$$

S = 7 inch/hr$^{1/2}$
A = 0.6 inch/hr

$$L_i = S_i + K \times E \times t \ldots [3.23]$$

S_i = 0.33 inch
E = 0.04 inch/hr
K = 0.30

L_i = 0.33 inch + 0.30 x 0.04 inch/hr x 8 hr = **0.43 inch**
E_S = 0.04 inch/hr x 8 hr = **0.32 inch**

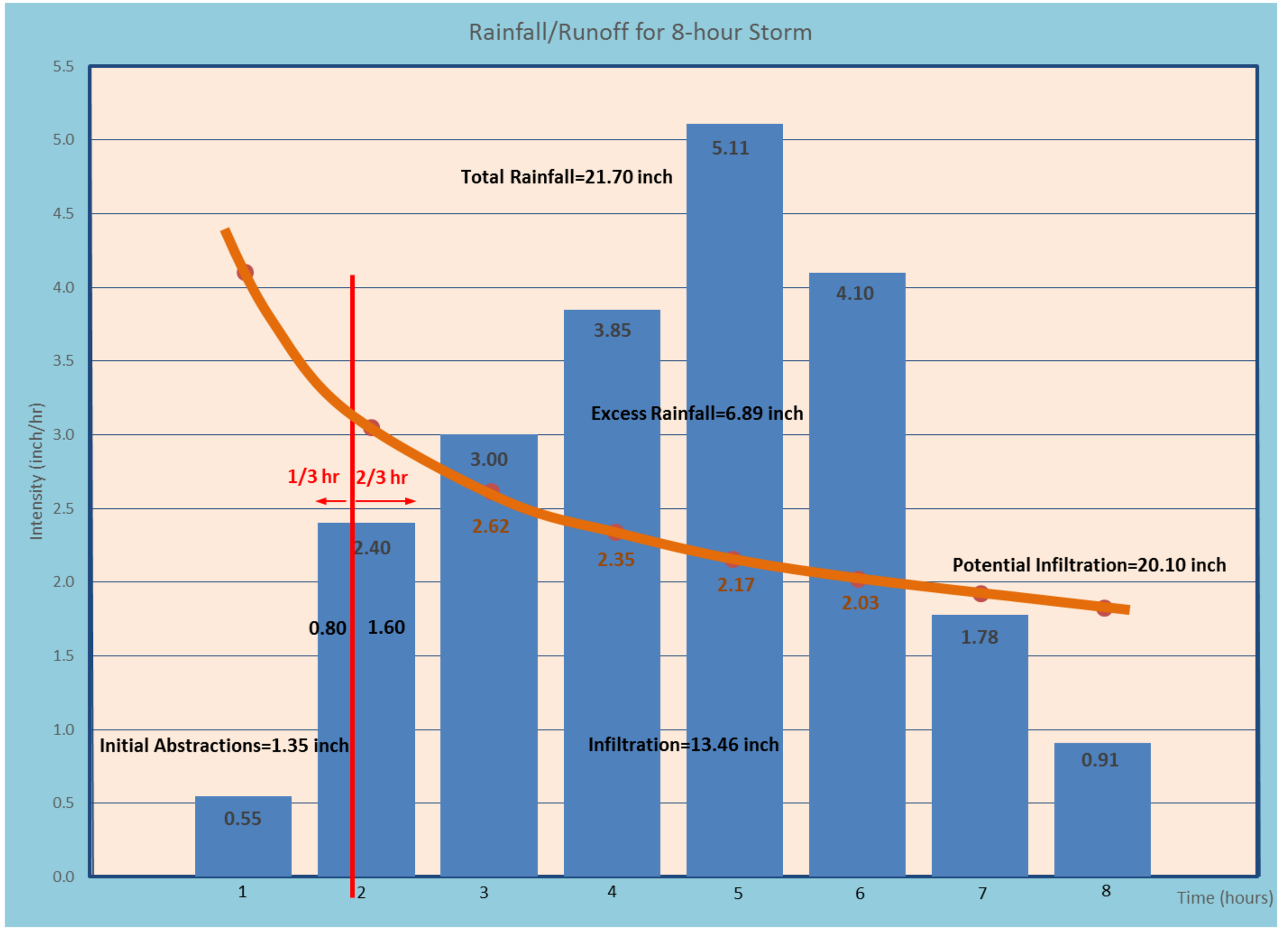
$I_a = L_i + E_S + V_s + V_{ds}$ = 0.43 + 0.32 + 0.20 +0.40 = **1.35 inch**

Volume of Runoff (Hydrograph) = A_{WS} x ER
30 miles^2 = 19,200 ac

Volume of Runoff (Hydrograph)=19,200 ac x (6.89/12)ft =

Volume of Runoff (Hydrograph) = **<u>11,024 ac-ft</u>**

Rainfall/Runoff Event Problem



Rainfall/Runoff Event Problem

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Questions?

Thank you!