Florida Department of Environmental Protection

Hydrology – 4b: Runoff and Flow Hydrographs

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- The ***Unit Hydrograph*** is a generalized way of defining the flood producing characteristics of a watershed
- A ***Unit Hydrograph*** is defined as a surface runoff versus time function which is generated from a unit depth of ***Excess Rainfall*** uniformly distributed over the watershed and occurring within a specified time duration
- It can be derived from a measured ***Flood Hydrograph*** knowing the equivalent uniform depth of the rainfall
- The following example illustrates the computation of the ***Unit Hydrograph*** from a recorded ***Flood Hydrograph***

The Unit Hydrograph

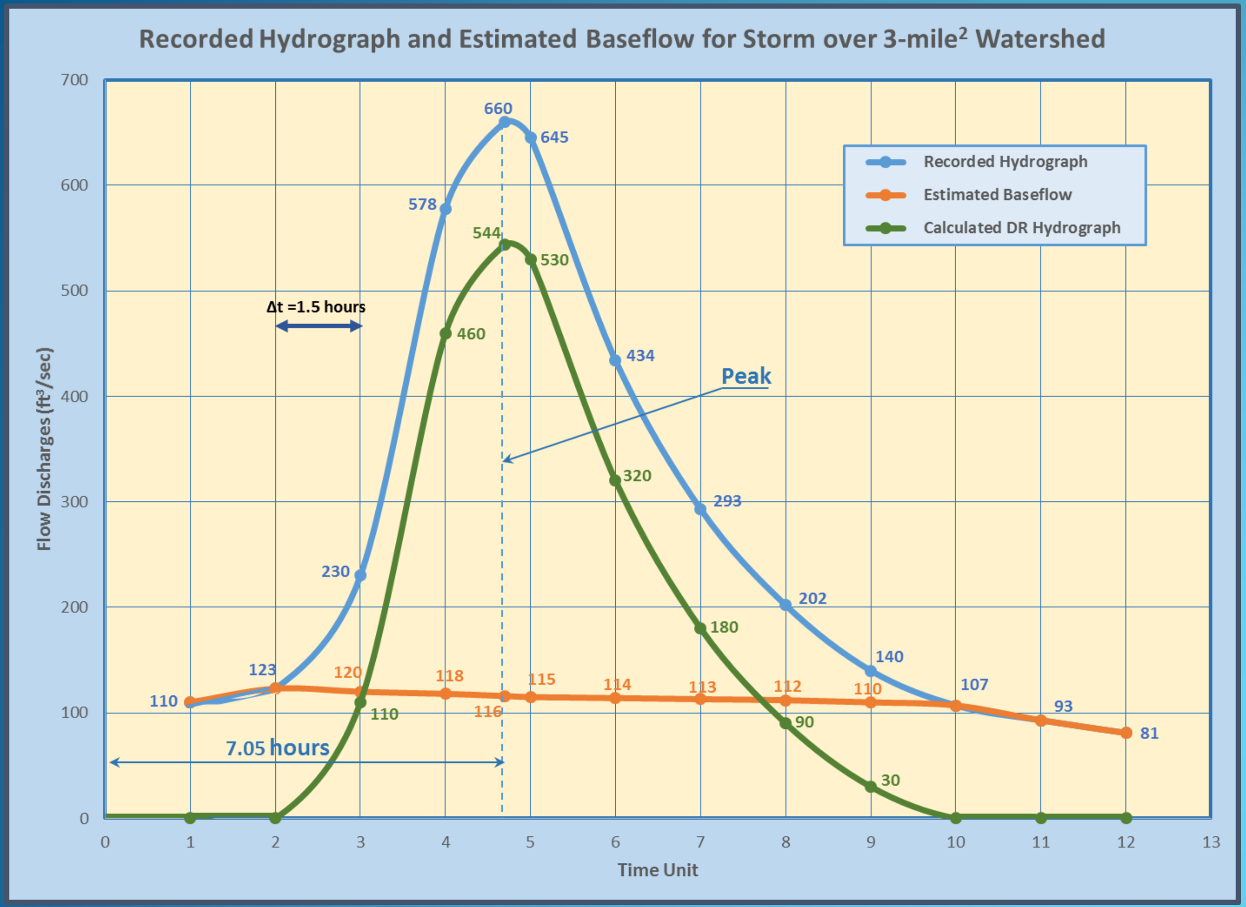
- **PROBLEM 4:** A ***Flood Hydrograph*** has been measured for a 18-hour flood in time intervals of 1.5 hours for a contributing watershed of 3-mile^2. its peak flow was 660 ft^3/sec at 7.05 hours. The ***Baseflow*** was estimated and T_B is 12 hours. Find the ***Unit Hydrograph (DR)***

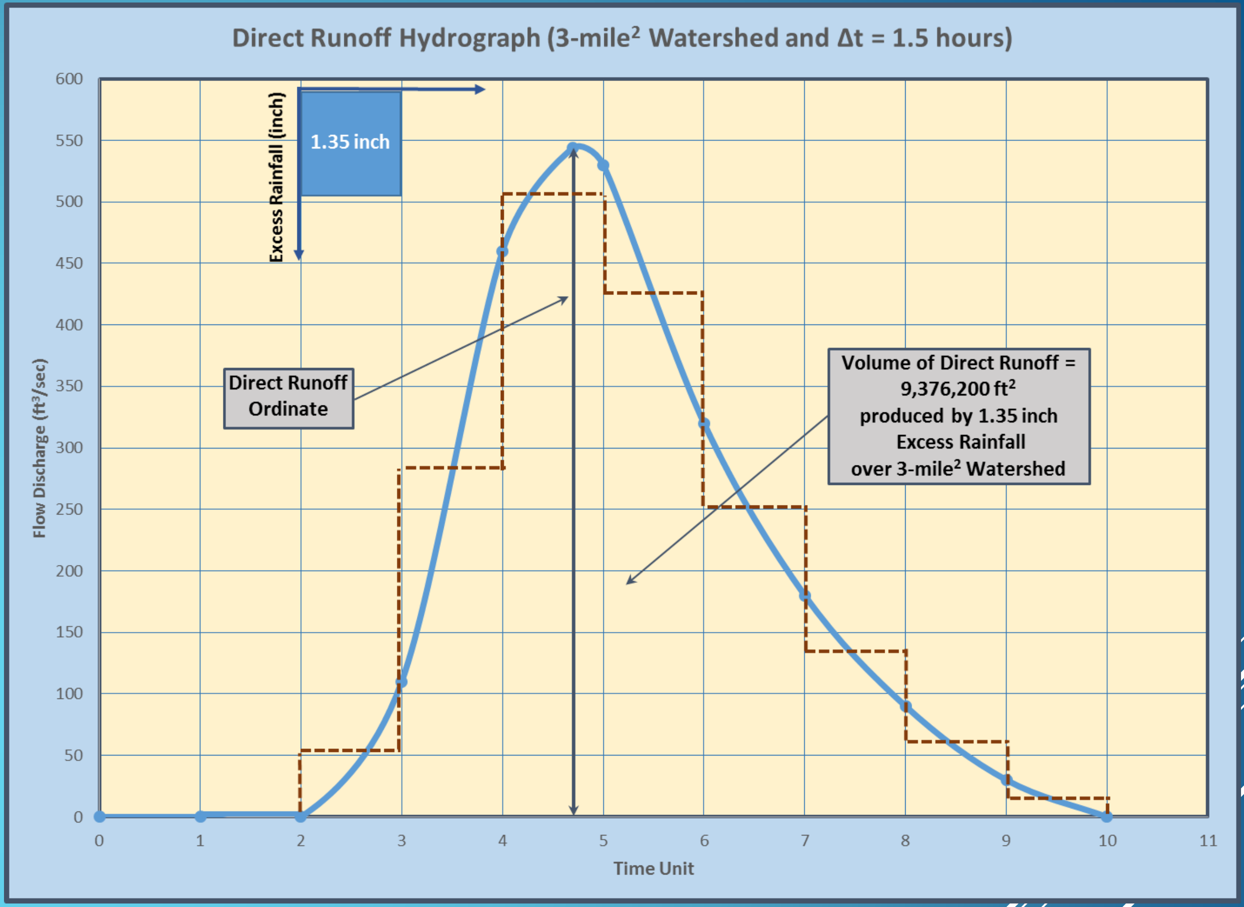
Computation of Direct Runoff Hydrograph from Measured Flood Hydrograph and Estimated Baseflow

Time Unit	1	2	3	4	4.7	5	6	7	8	9	10	11	12
Flood Hydrog., Q (ft^3/sec)	110	123	230	578	660	645	434	293	202	140	107	93	81
Baseflow (ft^3/sec)	110	123	120	118	116	115	114	113	112	110	107	93	81
DR Hydrograph (ft^3/sec)	0	0	110	460	544	530	320	180	90	30	0	0	0

- The following figure depicts the hydrographs and baseflow from the above table

The Unit Hydrograph





The Unit Hydrograph

Computation of Volume by integration of DR Hydrograph = Excess Rainfall over the Watershed

Time Unit	Direct Runoff Hydrograph (ft^3/sec)
2	0
3	110
4	460
4.7	544
5	530
6	320
7	180
8	90
9	30
10	0

Time Interval Δt	Average DR Hydrograph (ft^3/sec)	Volume DR Hydrograph (ft^3)
2 – 3	55	297,000
3 – 4	285	1,539,000
4 – 5	511	2,761,200
5 – 6	425	2,295,000
6 – 7	250	1,350,000
7 – 8	135	729,000
8 – 9	60	324,000
9 – 10	15	81,000
Σ	1736	9,376,200

Excess Rainfall Depth from the Storm over the Watershed

$$A_{watershed} = 3\ mile^2\ x\ (2.788x10^7\ ft^2/mile^2) = 83.64x10^6\ ft^2$$

$$Depth_{ER} = \frac{Vol_{DR}}{A_{watershed}} = \frac{9.3762x10^6\ ft^3}{83.64x10^6\ ft^2}\ x\,(12\,inch/\,ft) = 1.35\,inch$$

The ***Unit Hydrograph*** can be developed by dividing all the ordinates of the ***DR Hydrograph*** by 1.35 inch. Therefore the volume of the ***Unit Hydrograph*** divided by the watershed area will yield and ***Excess Rainfall*** depth of 1-inch

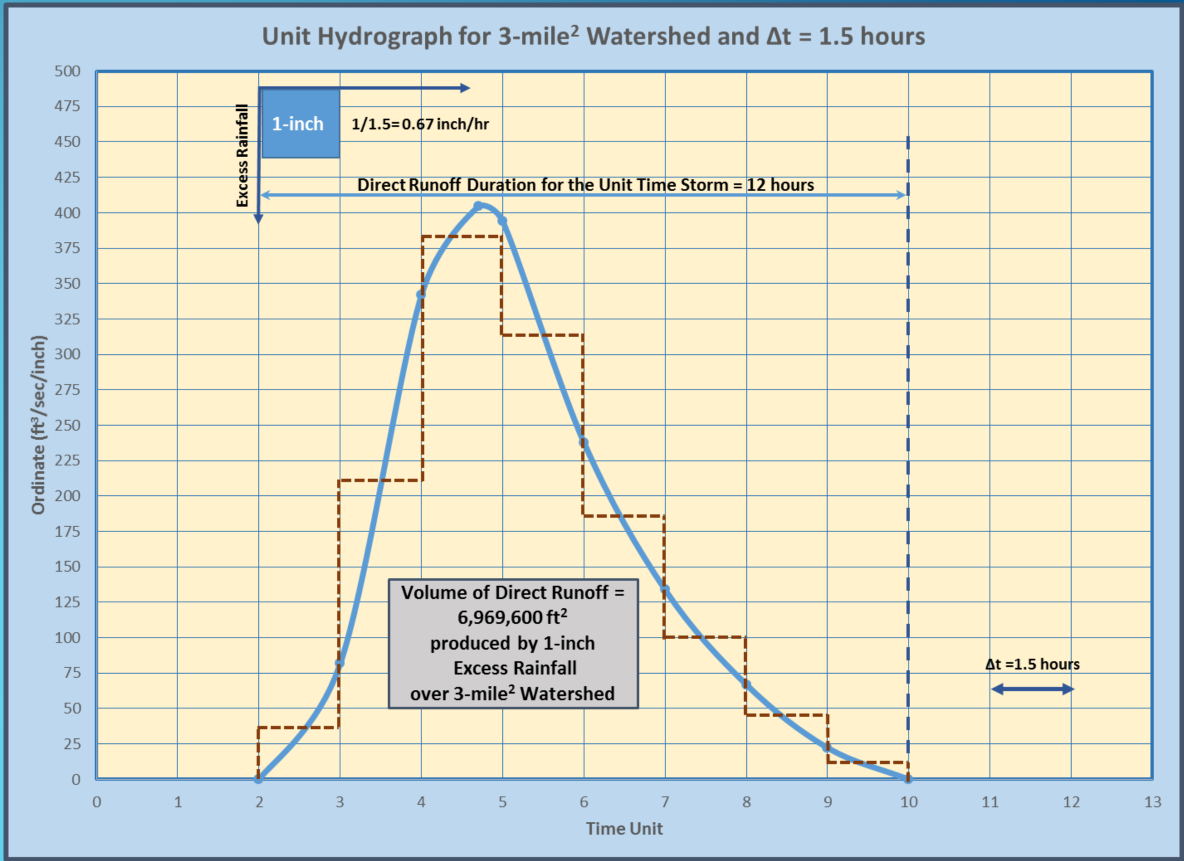
The Unit Hydrograph

Computation of the Unit Hydrograph and Verification

Time Unit	Direct Runoff Hydrograph (ft^3/sec)	Unit Hydrograph (ft^3/sec)
2	0	0.0
3	110	81.8
4	460	341.9
4.7	544	404.4
5	530	394.0
6	320	237.9
7	180	133.8
8	90	66.9
9	30	22.3
10	0	0.0

Time Interval Δt	Average U Hydrograph (ft^3/sec)	Volume U Hydrograph (ft^3)
2 – 3	40.9	220,768.7
3 – 4	211.8	1,143,983.1
4 – 5	380.1	2,052,479.6
5 – 6	315.9	1,705,939.7
6 – 7	185.8	1,003,494.0
7 – 8	100.3	541,886.7
8 – 9	44.6	240,838.5
9 – 10	11.1	60,209.6
Σ	1290.7	6,969,600.0

$$Depth_{ER} = \frac{Vol_U}{A_{watershed}} = \frac{6.9696x10^6\ ft^3}{83.64x10^6\ ft^2} x(12\,inch/\ ft) = 1.0\ inch$$



The Unit Hydrograph

- As frequently happens when several periods of ***Excess Rainfall*** occur in sequence, the resulting surface ***DR Hydrograph*** is the result of the superposition of a series of hydrographs each initiated by its own respective occurrence of ***Excess Rainfall***
- The problem consists of decomposing the measured composite ***Flood Hydrograph*** into its component hydrographs and then of deriving the ***Unit Hydrograph***
- The following equation represents the successive ordinates of the recorded surface ***DR Hydrograph***

The Unit Hydrograph

$$\boxed{Q_k = U_1 \times ER_i + U_2 \times ER_{i-1} + U_3 \times ER_{i-2} + \dots U_n \times ER_{i-n+1} \dots [4.9]}$$

where $\boldsymbol{Q_k}$ is the k^{th} ordinate of the ***DR Hydrograph***, $\boldsymbol{U_n}$ is the n^{th} ordinate of the ***Unit Hydrograph*** and $\boldsymbol{ER_i}$ is the ith value of ***Excess Rainfall***

- The ***Unit Hydrograph*** solution has the following form and can be solved by a Matrix Method

$$\boxed{\begin{aligned} Q_1 &= ER_1 \times U_1 \\ Q_2 &= ER_1 \times U_2 + ER_2 \times U_1 \\ Q_3 &= ER_1 \times U_3 + ER_2 \times U_2 + ER_3 \times U_1 \\ Q_4 &= ER_1 \times U_4 + ER_2 \times U_3 + ER_3 \times U_2 + ER_4 \times U_1 \end{aligned}}$$

And in general matrix form is: $\boxed{Q = ER \cdot U \dots [4.10]}$

The Unit Hydrograph

- The ***Excess Rainfall*** is a square (lower triangular) matrix, the ***Unit Hydrograph*** and the surface ***DR Hydrograph*** are both column vectors, as follows

$$\begin{bmatrix} ER_1 & 0 & 0 & 0 & . & . & 0 \\ ER_2 & ER_1 & 0 & 0 & & & 0 \\ ER_3 & ER_2 & ER_1 & 0 & & & 0 \\ . & & & & & & \\ ER_i & ER_{i-1} & & & & & ER_1 \end{bmatrix} \quad \begin{bmatrix} U_1 \\ U_2 \\ U_3 \\ . \\ U_j \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \\ . \\ Q_k \end{bmatrix}$$

with $k = i+j-1$…[4.11]

when the surface ***DR Hydrograph*** is known, the matrix solution become Eq. 4.10

- A numerical solution is expressed as a transformation of the ***Excess Rainfall***, which is an inexact duplication of the ***DR Hydrograph***

The Unit Hydrograph

$$U = (ER^T \ ER)^{-1} \ ER \cdot Q \ldots [4.12]$$

where ER^T is the transpose matrix of the ***Excess Rainfall*** and $(ER^T \ ER)^{-1}$ represents the inverse matrix of the product of the ***Excess Rainfall*** transpose matrix and its matrix

- By adjusting the ***Unit Hydrograph,*** the duplication effect may be improved. An optimization scheme can be applied to the ***Unit Hydrograph***
- There are many numerical schemes that facilitate these computations even available in standard calculators
- The following example illustrate an approximate solution to the ***Unit Hydrograph*** based on the simultaneous equations derived from Eq. 4.10

The Unit Hydrograph

- **PROBLEM 5:** A surface ***DR Hydrograph*** has been estimated from a ***Flood Hydrograph*** (after subtracting the ***Baseflow***) as well as the ***Excess Rainfall*** from the ***Hyetograph***. Their values are shown in the following table. The time interval is 1-hour. Compute the ***Unit Hydrograph*** for the storm

Estimated Direct Runoff Hydrograph (*from Flood Hydrograph*) *and excess rainfall* (*from Hyetograph*)

Time Unit	1	2	3	4	5	6	7	8	9	10
DR Hydrograph, Q (ft^3/sec)	66	390	678	419	572	318	173	94	24	5
Excess Rainfall (inch)	1.27	0	0.53							

- From Eq. 4.12, j (index of Unit Hydrograph ordinates) = $k - i + 1$ = 10 – 3 +1 = **8**

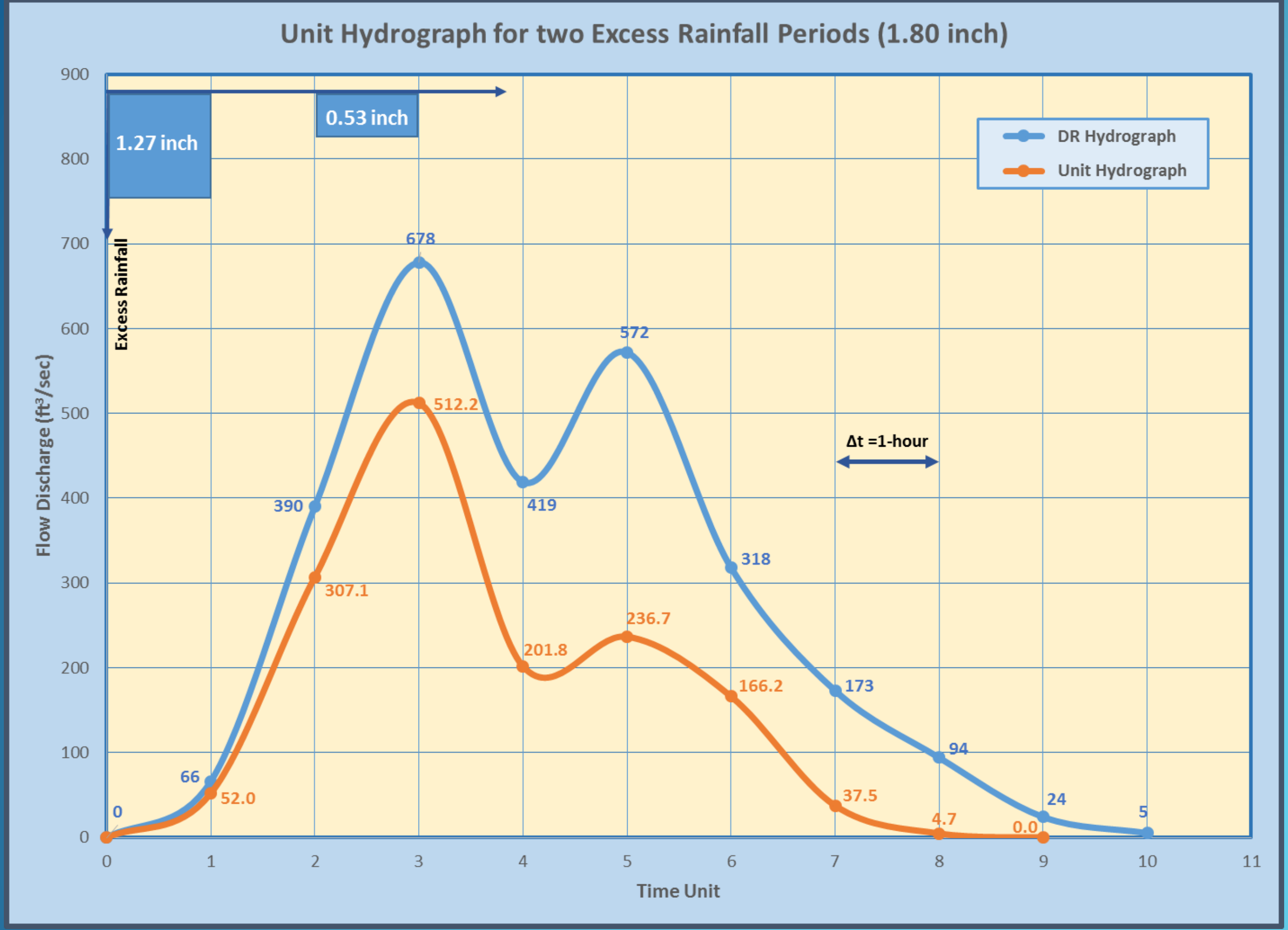
  It means that the ***Unit Hydrograph*** will have 8 ordinates

The Unit Hydrograph

Calculation of Unit Hydrograph (Consecutive Excess Rainfall Periods from Storm Hyetograph)

Excess Rainfall4.7	(inch)	1.27	0	0.53	Equation to Compute U_j	U_j	U (ft^3/sec/inch)
Q_k	(ft^3/sec)	$ER_1 U_i$	$ER_2 U_{i-1}$	$ER_3 U_{i-2}$			
Q_0	0					U_0	0.0
Q_1	66	$ER_1 U_1$	$ER_2 U_0$	$ER_3 U_0$	$Q_1 = ER_1 U_1 + ER_2 U_0 + ER_3 U_0$	U_1	52.0
Q_2	390	$ER_1 U_2$	$ER_2 U_1$	$ER_3 U_0$	$Q_2 = ER_1 U_2 + ER_2 U_1 + ER_3 U_0$	U_2	307.1
Q_3	678	$ER_1 U_3$	$ER_2 U_2$	$ER_3 U_1$	$Q_3 = ER_1 U_3 + ER_2 U_2 + ER_3 U_1$	U_3	512.2
Q_4	419	$ER_1 U_4$	$ER_2 U_3$	$ER_3 U_2$	$Q_4 = ER_1 U_4 + ER_2 U_3 + ER_3 U_2$	U_4	201.8
Q_5	572	$ER_1 U_5$	$ER_2 U_4$	$ER_3 U_3$	$Q_5 = ER_1 U_5 + ER_2 U_4 + ER_3 U_3$	U_5	236.7
Q_6	318	$ER_1 U_6$	$ER_2 U_5$	$ER_3 U_4$	$Q_6 = ER_1 U_6 + ER_2 U_5 + ER_3 U_4$	U_6	166.2
Q_7	173	$ER_1 U_7$	$ER_2 U_6$	$ER_3 U_5$	$Q_7 = ER_1 U_7 + ER_2 U_6 + ER_3 U_5$	U_7	37.5
Q_8	94	$ER_1 U_8$	$ER_2 U_7$	$ER_3 U_6$	$Q_8 = ER_1 U_8 + ER_2 U_7 + ER_3 U_6$	U_8	4.7
Q_9	24	$ER_1 U_9$	$ER_2 U_8$	$ER_3 U_7$		U_9	0.0
Q_{10}	5	$ER_1 U_{10}$	$ER_2 U_9$	$ER_3 U_8$			
Q_{11}	0	$ER_1 U_{11}$	$ER_2 U_{10}$	$ER_3 U_9$			

The Unit Hydrograph



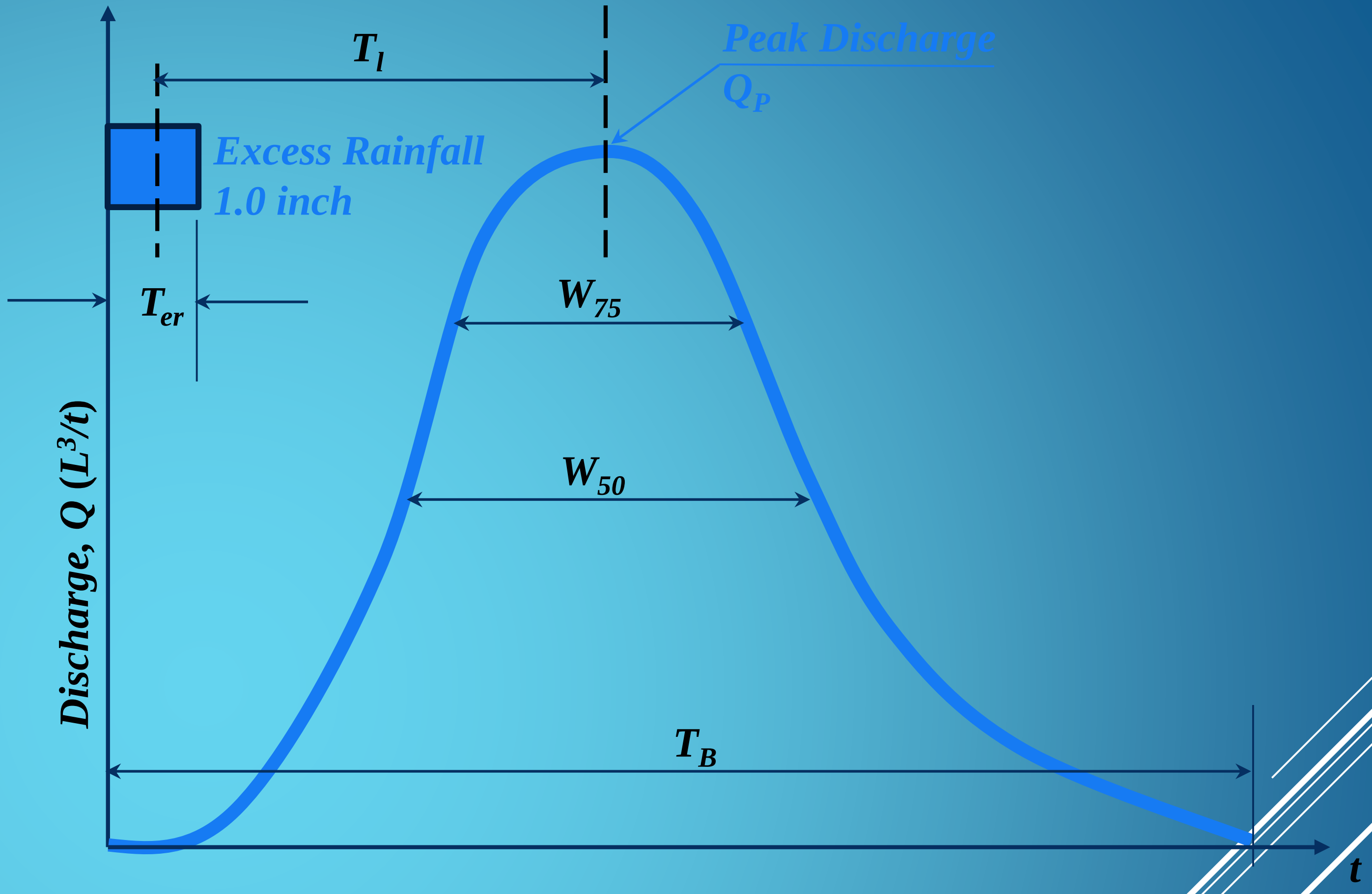
The Unit Hydrograph

- The ***Synthetic Unit Hydrograph*** is a procedure developed to allow the application of the ***Unit Hydrograph*** concept in a design problem where direct measurements of a ***Flood Hydrograph*** are missing
- The linear characteristics of ***Unit Hydrographs*** for a watershed as they are generated by superposition of successive excess rainfall impulses are a definite advantage in constructing more complex storm discharge hydrographs
- Synthetic techniques (in some cases applicable to specific sites and locations) have evolved continuously providing significant tools to analyzed a wide range of water resources projects

Synthetic Unit Hydrographs (*SUH*)

SUH: Snyder's Method

- The ***Snyder's Method*** has been widely employed by the US COE. Even though this method does not provide a complete time distribution of the discharge hydrograph, it allows computation of ***Lag Time***, ***Excess Rainfall*** and ***Base Time*** durations, ***Peak Discharge***, and hydrograph time widths at 50 and 75% of the ***Peak Discharge***



- Snyder developed a ***Lag time***, T_l relationship for watersheds ranging from 10 to 10,000 miles[2] located in the Appalachian Highlands as follows,

$$\boxed{T_l = C_t \times \left(L \times L_{ca}\right)^{0.3} \ldots [4.13]}$$

where T_l is the ***Lag Time*** (hr), C_t is a coefficient for the slope and storage of the watershed, L is the length of the main stream channel (miles) and L_{ca} is the length along the main channel to a point nearest the watershed centroid (miles). C_t accounts for a wide variation in topography, from plains to mountains with values ranging from 1.8 to 2.2 with an average of 2.0 indicating no major changes for similar study areas

SUH: Snyder's Method

Further analysis showed much larger variation with slopes. Steeper slopes yielded lower values of C_t as 0.4 in southern California and flatter slopes did higher values of C_t as 8.0 along the Gulf of Mexico

- The following equation relates the duration of ***Excess Rainfall*** as a function of ***Lag Time***

$$\boxed{T_{er} = \frac{T_l}{5.5} \ldots [4.14]}$$

where T_{er} is the duration of the unit ***Excess Rainfall*** (hr)

- This method defines initially a value of T_l and its associated value of T_{er} from Eq. 4.14. If the duration of the unit ***Excess Rainfall*** has to be changed, the ***Lag Time*** T_l will change as well, and it will have to be recalculated by the following equation

SUH: Snyder's Method

$$T_L = T_l + 0.25 \times (T_{ER} - T_{er}) \ldots [4.15]$$

where T_L is the adjusted ***Lag Time*** (hr) and T_{ER} is the desired duration of ***Excess Rainfall*** that replaces T_{er} (hr)

- The ***Peak Discharge*** is computed as follows

$$Q_P = \frac{640 \times C_p \times A}{T_l} \ldots [4.16]$$

where Q_P is the ***Peak Discharge*** (ft^3/sec), C_p is the peak coefficient varying from 0.56 to 0.69 with an average value of 0.60 and A is the area of the watershed ($miles^2$)

- The ***Base Time***, T_B of the ***SUH*** by the Snyder's Method is

SUH: Snyder's Method

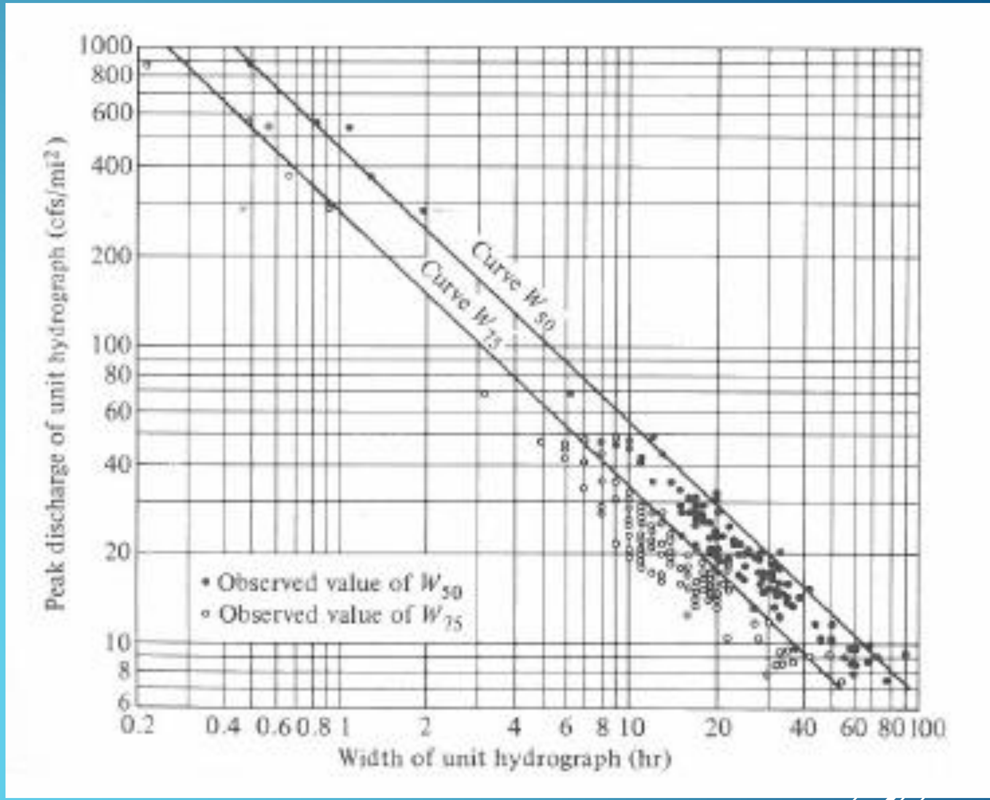
SUH: Snyder's Method

$$T_B = 3 + \frac{T_l}{8} \ldots [4.17]$$

where T_B is the ***Base Time*** of the ***SUH*** (days) and T_l is the ***Lag Time*** (hr)

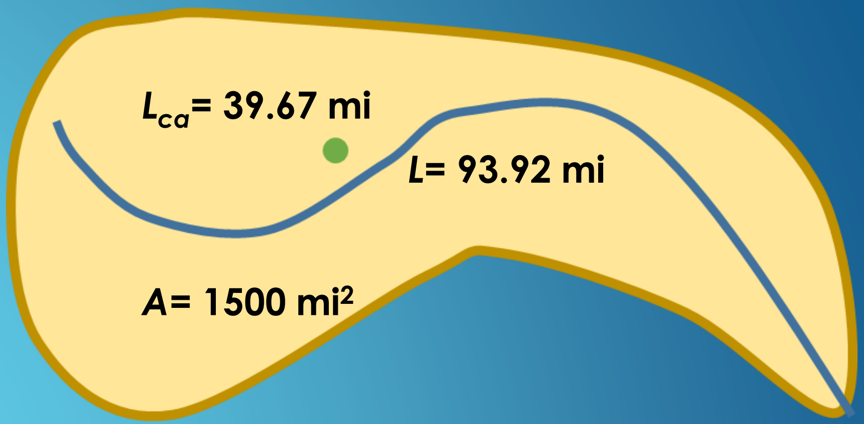
- Once all computations from Eqs. 4.13 to 4.17 have been done, it is necessary to estimate W_{50} and W_{75}. These two time widths are obtained from the graph with the Peak Discharge of Unit Hydrograph as

$$q_P = \frac{Q_P}{A} \ldots [4.18]$$



As a rule of thumb, the time width at W_{50} and W_{75} ordinates should be distributed at 1/3 and 2/3 to the left and right-hand sides of the **Snyder's *SUH***, respectively

- **PROBLEM 6:** An analysis on the depicted 1500-mi² watershed has given the shown results. The duration of the ***Excess Rainfall*** (T_{ER}) was 6.0 hr. Plot the ***SUH*** using the Snyder's Method for average conditions of slope and storage of the watershed as well as of its discharge



For average conditions: C_t = **2** and C_p = **0.60**

From Eq. 4.13 → T_l = **2**x(**93.92**x**39.67**)$^{0.3}$ = **23.57 hr**

From Eq. 4.14 → T_{er} = **23.57 hr** / **5.5** = **4.29 hr**

It is necessary to recalculate T_L for the desired duration of 6.0 hr for the ***Excess Rainfall*** (T_{ER}), so

From Eq. 4.15 → T_L = **23.57 hr** + **0.25**x(**6 – 4.29**) **hr** = **24 hr**

From Eq. 4.16 → Q_P = **640**x**0.60**x**1500** / **24** = **24,000 ft³/sec**

SUH: Snyder's Method

From Eq. 4.17 → T_B = 3 + 24/8 = 6 days = 144 hr

From Eq. 4.18 → q_P = 24,000 ft³/sec/1500 mi² = 16 cfs/mi²

With q_P = 16 cfs/mi², the time widths are obtained from the graph

W_{50} = 40 hr and W_{75} = 23 hr

Time to Rise (T_R) = 24 hr+6 hr /2 = 27 hr → Q_P = 24,000 cfs

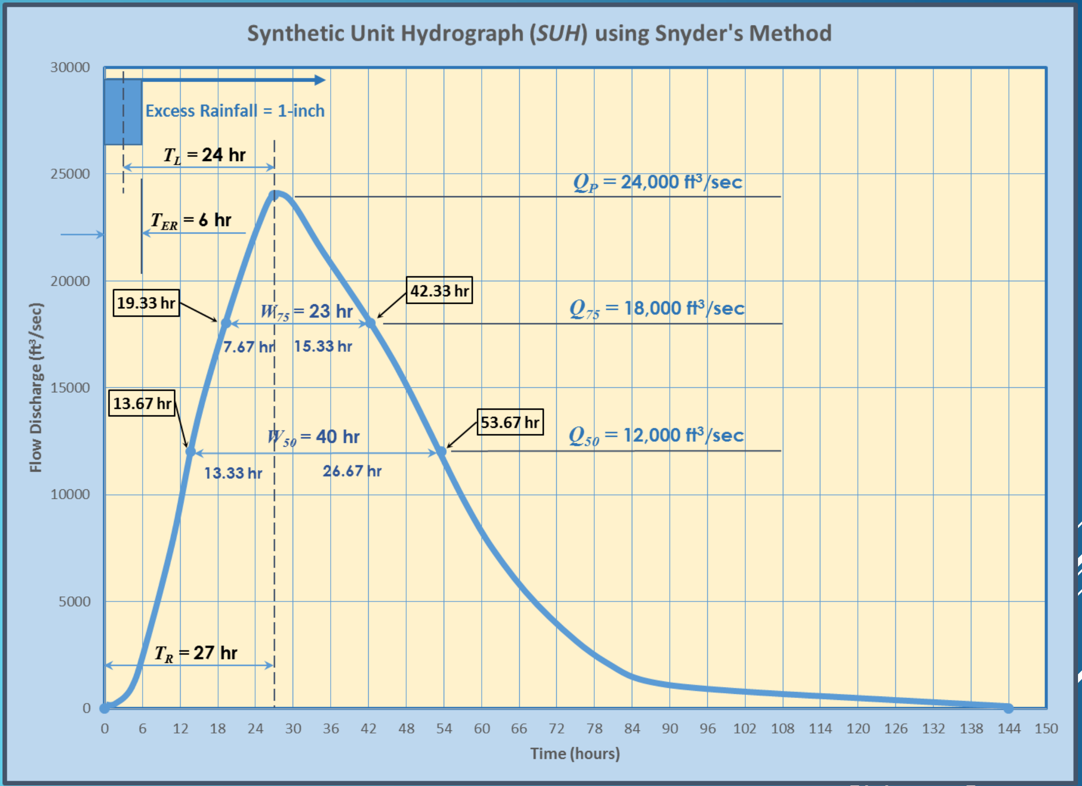
Q_{50} = 12,000 cfs → T_{left} = 27 hr – 40 hr x (1/3) = 13.67 hr

T_{right} = 27 hr + 40 hr x (2/3) = 53.67 hr

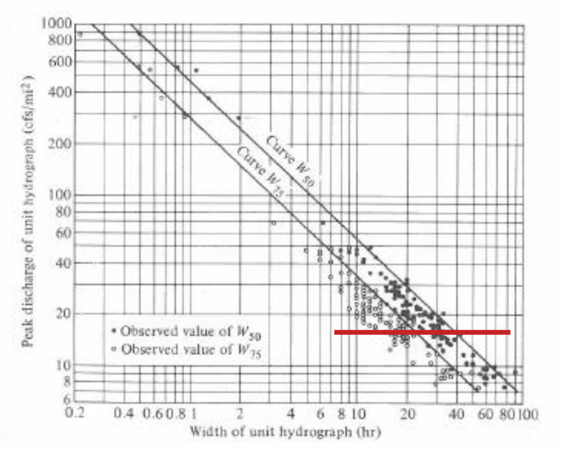
Q_{75} = 18,000 cfs → T_{left} = 27 hr – 23 hr x (1/3) = 19.33 hr

T_{right} = 27 hr + 23 hr x (2/3) = 42.33 hr

Base Time (T_B) = 144 hr → Q = 0



SUH: Snyder's Method



- The Soil Conservation Service (***SCS***)method for constructing ***SUH*** was developed based on dimensionless hydrographs analyzed of a large range of watersheds in size and geographical locations
- This method requires only the determination of T_R (***Time to Rise***) and Q_P (***Peak Discharge***)
- The ***Lag Time*** is calculated by the following equation

$$\boxed{T_l = \frac{L^{0.8} \times (S+1)^{0.7}}{1900 \times \sqrt{Y}} \ldots [4.19]}$$

where L is the length of the main stream channel (ft), S is the potential maximum retention (inch) and Y is the average watershed slope (%)

SUH: SCS Dimensionless Method

- The potential maximum retention is calculated by the SCS proposed equation

$$\boxed{S = \frac{1000}{CN} - 10 \ldots [4.20]}$$

where ***CN*** is the ***Curve Number*** a defined value based on the soil type of the watershed

- The ***Peak Discharge*** is computed as follows

$$\boxed{Q_P = \frac{484 \times A}{T_R} \ldots [4.21]}$$

where $\boldsymbol{Q_P}$ is the ***Peak Discharge*** (ft^3/sec), $\boldsymbol{A}$ is the area of the watershed ($miles^2$), and $\boldsymbol{T_R}$ is the ***Time to Rise***, calculated by the following equation

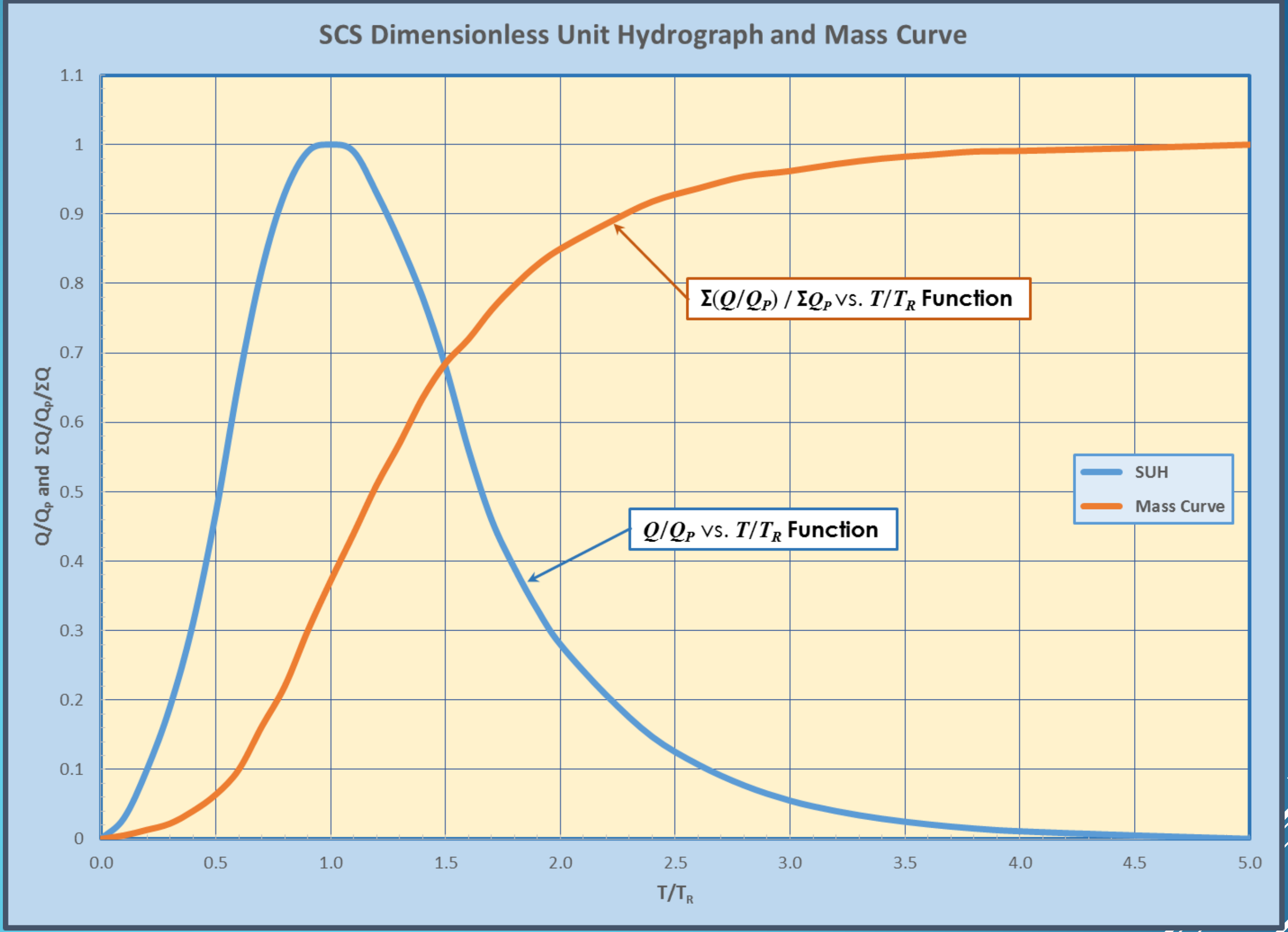
SUH: SCS Dimensionless Method

SUH: SCS Dimensionless Method

$$T_R = \frac{D}{2} + T_l \ldots [4.22]$$

where D is the duration of the ***Excess Rainfall*** (hr) and T_R is ***Time to Rise*** (hr)

- The adjacent graph depicts the values to calculate the time and discharge ordinates after computation of Q_P and T_R for the ***SUH*** developed by the ***SCS***



- **PROBLEM 7:** A woodland is in "fair hydrologic conditions" with soils of the C-type (Hydrologic Soil Group) and has drainage area of 70 mi^2. Its main stream channel is 15.5 mi and the average watershed slope has been estimated as 3.12%. Compute the ***SUH*** of D = 4 hour from the SCS Dimensionless Method

For the given characteristics of the watershed and its soils, $\boldsymbol{CN = 73}$

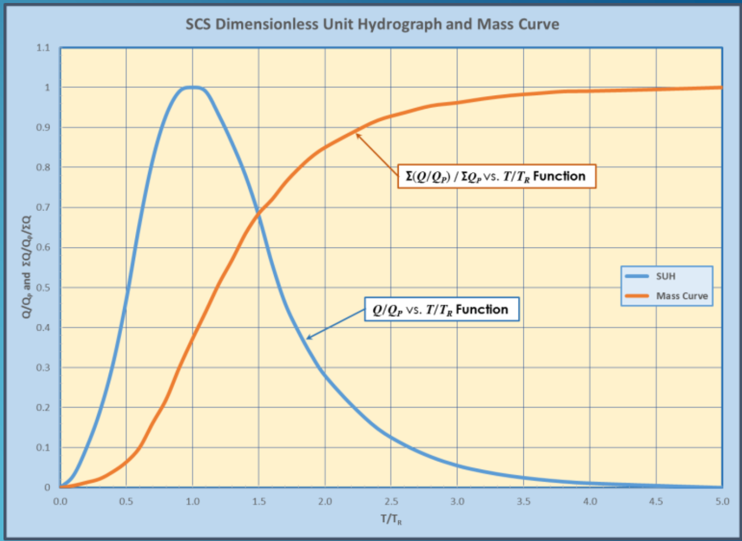
From Eq. 4.20 → $\boldsymbol{S = 1000/73 + 10 = 3.70\ inch}$

From Eq. 4.19 → $T_l = \dfrac{81{,}840^{0.8}\ ft \times (3.7\,inch + 1)^{0.7}}{1900 \times \sqrt{3.12}} = 7.5\,hr$

From Eq. 4.22 → $T_R = \dfrac{4\,hr}{2} + 7.5\,hr = 9.5\,hr$

SUH: SCS Dimensionless Method

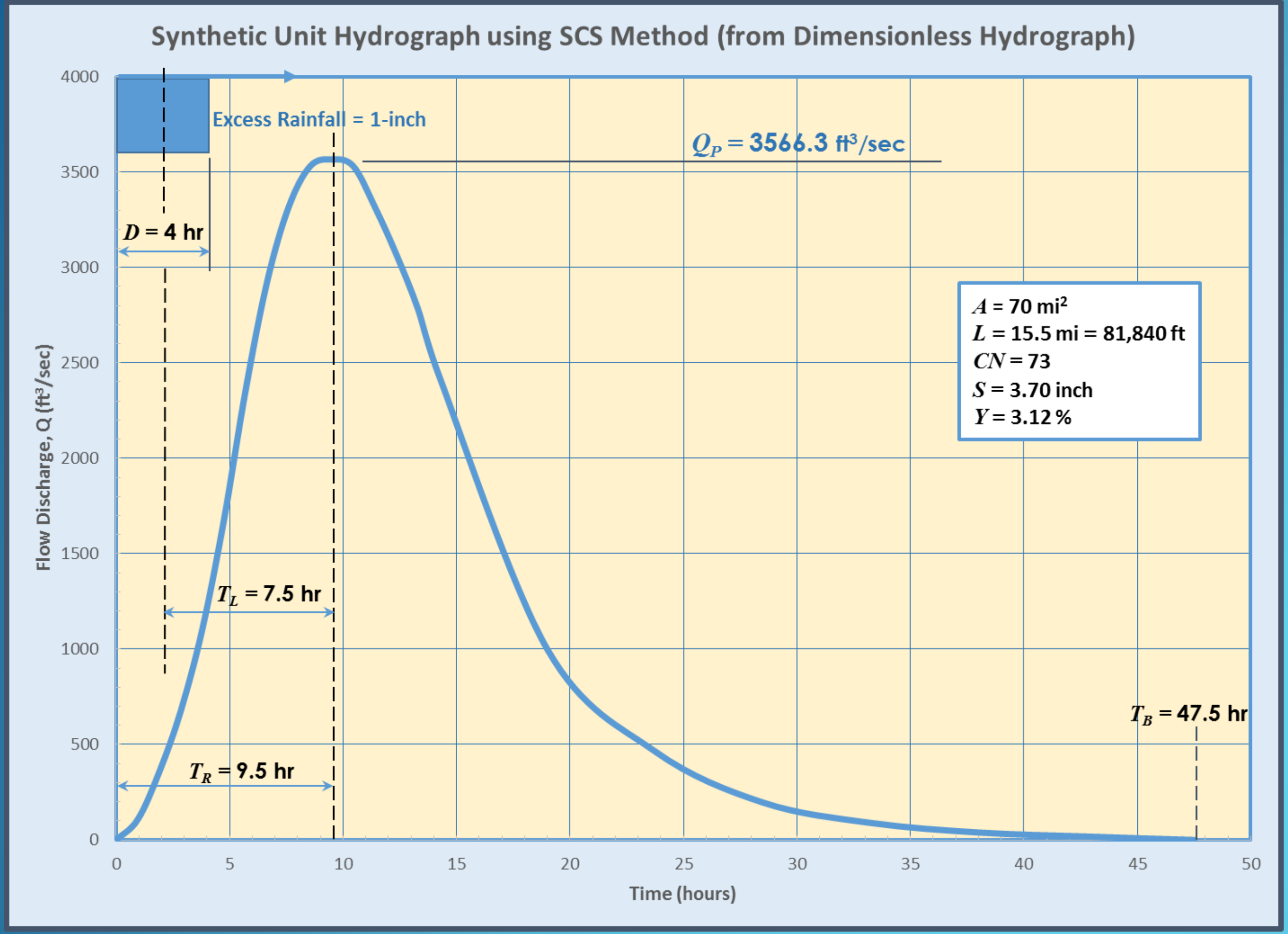
From Eq. 4.21 → $Q_P = \dfrac{484 \times 70\, mi}{9.5\, hr} = 3566.3\ ft^3/\sec$



Computation of the ordinates of the SUH from SCS Method (Dimensionless)

T/T_R $T_R = 9.5$ hr	Q/Q_P $Q_P = 3566.3$ cfs	T (hr)	Q (cfs)	T/T_R $T_R = 9.5$ hr	Q/Q_P $Q_P = 3566.3$ cfs	T (hr)	Q (cfs)
0.0	0.0	0.00	0.0	1.5	0.68	14.25	2425.1
0.1	0.03	0.95	107.0	2.0	0.28	19.00	998.6
0.2	0.1	1.90	356.6	2.5	0.13	23.75	463.3
0.5	0.47	4.75	1676.2	3.0	0.055	28.50	196.1
0.7	0.82	6.65	2924.4	3.5	0.025	33.25	89.2
0.8	0.93	7.60	3316.7	4.0	0.011	38.00	39.2
1.0	1.0	9.50	3566.3	4.5	0.005	42.75	17.8
1.2	0.93	11.40	3316.7	5.0	0.0	47.50	0.0

SUH: SCS Dimensionless Method



SUH: SCS Dimensionless Method

- This method of generating ***SUH*** was developed initially for midwestern watersheds by D.M. Gray in 1961
- Gray's Method is based on dimensionalizing the incomplete Gamma Distribution and analyzing results in dimensionless form
- An approximate upper limit of watershed area for application of this method to the geographic areas of Central Iowa, Missouri, Illinois and Wisconsin is 100 mi^2
- Watershed and Storage Factors are determined by the following equations

SUH: Gray's Method

$$WF = \frac{L}{\sqrt{S}} \quad \ldots [4.23]$$

$$SF = \frac{T_R}{\gamma'} \quad \ldots [4.24]$$

$$SF = a \times WF^b \quad \ldots [4.25]$$

where WF is the ***Watershed Factor***, L and S are the length and slope of the stream channel, respectively (mi and %), SF is the ***Storage Factor***, T_R is the ***Time to Rise*** (min), and a and b are site-specific regression factors

- The ***Storage Factor*** is related to ***Time to Rise*** as follows

$$SF = \frac{1}{\frac{2.676}{T_R} + 0.0139} \quad \ldots [4.26]$$

Once T_R has been calculated the flow discharge can be calculated for any value of the fraction T/T_R

SUH: Gray's Method

$$Q_{T/T_R} = \frac{25 \times (\gamma')^{q}}{\Gamma(q)} \times (e^{-\gamma' \times T/T_R}) \times \left(\frac{T}{T_R}\right)^{q-1} \quad \text{... [4.27]}$$

where $\boldsymbol{Q_{T/T_R}}$ is the dimensionless discharge for $\boldsymbol{T/T_R}$ (%), $\boldsymbol{q}$ is a ***Shape Parameter*** = $\mathbf{1} + \boldsymbol{\gamma'}$, and $\boldsymbol{\Gamma}$ is the ***Gamma Function*** = $(\boldsymbol{q} - \mathbf{1})!$ and $\boldsymbol{e}$ is the base of the natural logarithms

- The volume of the unit hydrograph is calculated as follows, considering an ***Excess Rainfall*** of 1.0 inch

$$V = 1.0\,inch \times A\,mi^2 \times 640\,\frac{acre}{mi^2} \times 0.0833\,\frac{ft}{inch} \times 43{,}560\,\frac{ft^2}{acre} \quad \text{... [4.28]}$$

- The above volume, $\boldsymbol{V}$ ($\boldsymbol{ft^3}$) has to match the volume for the dimensionless hydrograph, which is

SUH: Gray's Method

$$V_D = \sum cfs \times 0.25 \times T_R \times 60 \frac{\text{sec}}{\text{min}} \quad \ldots [4.29]$$

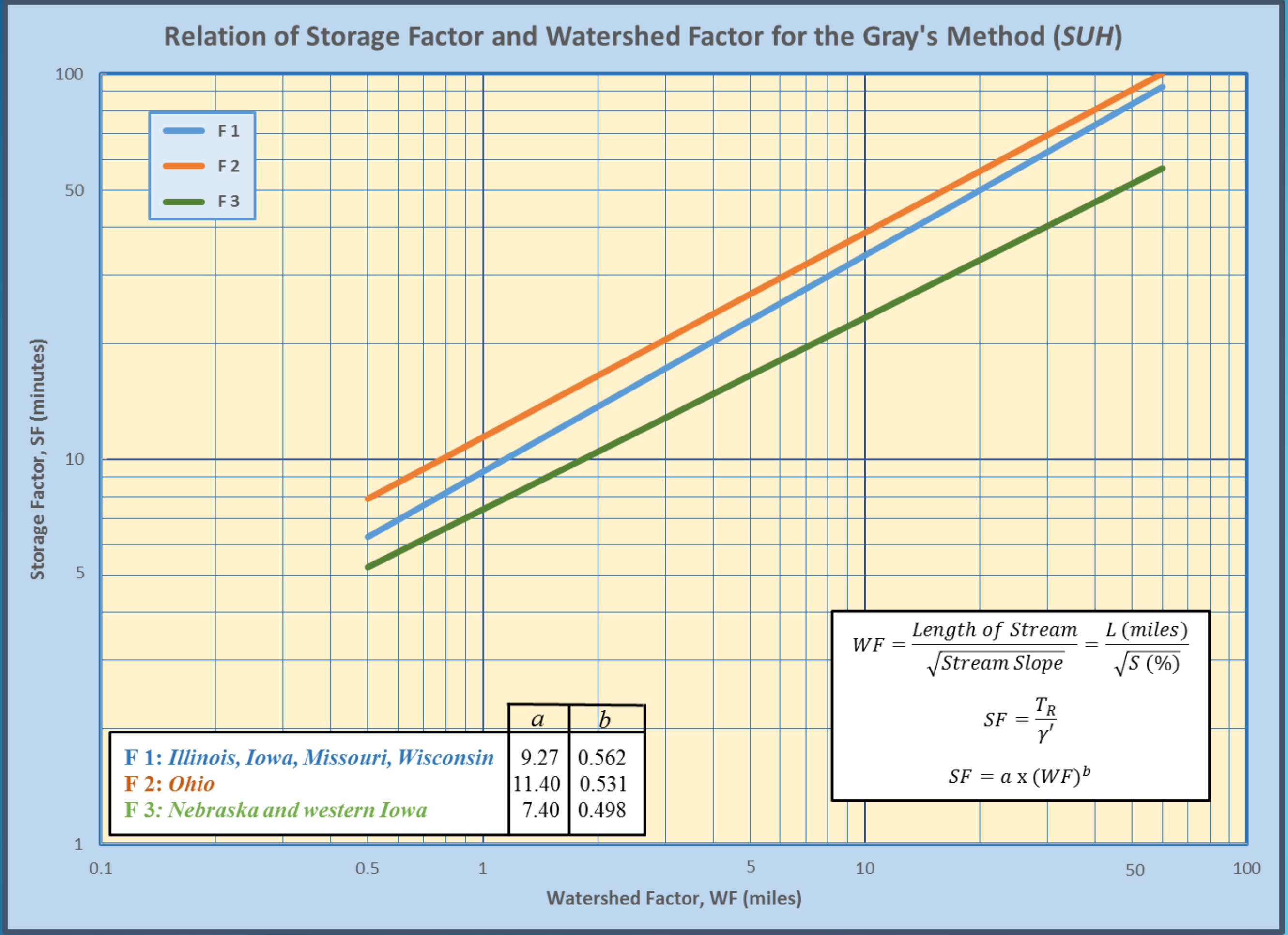
by equating $\boldsymbol{V}$ and $\boldsymbol{V_D}$ (Eqs. 4.28 and 4.29), the term $\boldsymbol{\Sigma cfs}$ is calculated

- The Unit Hydrograph ordinates are calculated by the following equation

$$Q_u = \frac{Q_{T/T_R}}{100} \times \sum cfs \quad \ldots [4.30]$$

- $\boldsymbol{T}$ of the dimensionless ***Hydrograph*** is converted to absolute time by multiplying $\boldsymbol{T/T_R}$ x $\boldsymbol{T_R}$ for each flow discharge ($\boldsymbol{Q_u}$). It is important to realize that ***Runoff*** does not begin until the centroid of rainfall has been reached, or $\boldsymbol{T_R/8}$

SUH: Gray's Method



SUH: Gray’s Method

- **PROBLEM 8:** A watershed has a drainage area of 0.62 mi^2, its stream channel is 0.98 mi long with an average slope of 1.45%. Its storage factor coincides with those from F 1 (i.e., a = 9.27 and b = 0.562). Apply Gray's Method to calculate the ***SUH***. Note that this method results in a ***SUH*** with a duration of ***Excess Rainfall*** equal to $T_R/4$

From Eq. 4.23 → $WF = \mathbf{0.98}\ mi\ /\ (\mathbf{1.45}\ \%)^{1/2} = \mathbf{0.814}$

From Eq. 4.25 → ***SF*** = **9.27** x (**0.814**) $^{0.562}$ = **8.26**

From Eq. 4.26 → $\mathbf{8.26} \times (\mathbf{2.676}/T_R + \mathbf{0.0139}) = 1 \rightarrow T_R = \mathbf{24.96}\ min$

From Eq. 4.24 → $\mathbf{8.26} = T_R\ /\ \gamma' \rightarrow \gamma' = \mathbf{3.02}$, and

Shape parameter, $q = 1 + \gamma' = \mathbf{4.02}$

SUH: Gray's Method

- Now, we have to use Eqs. 4.28 and 4.29 to calculate the volumes of the unit hydrograph and the dimensionless hydrograph respectively, which have to be equal

V = **1** $\boldsymbol{inch}$ x **640** $\boldsymbol{acre/mi^2}$ x **0.0833** $\boldsymbol{ft/inch}$ x **43,560** $\boldsymbol{ft^2/acre}$ = **1,439,807.85** $\boldsymbol{ft^3}$

V_D = **1.43981**x**10**^{6} $\boldsymbol{ft^3}$ = **0.25**x**24.96** $\boldsymbol{min}$x**60** $\boldsymbol{sec/min}$x $\boldsymbol{\Sigma cfs \rightarrow \Sigma cfs}$ = **3845.74** $\boldsymbol{ft^3/sec}$

- The values of time ($\boldsymbol{T}$) are calculated knowing that there will be four points for $\boldsymbol{T/T_R}$ between 0 and 1.0 at 0.25 x $\boldsymbol{T_R}$ intervals with the exception of the first point that it will be 0.125 x $\boldsymbol{T_R}$ ($\boldsymbol{T_R}$/8). The following table illustrate the procedure and the calculation of the dimensionless hydrograph (Eq. 4.27) and of the ***SUH*** from the Gray's Method (Eq. 4.30)

The Gamma Function of $\boldsymbol{q}$ is: $\boldsymbol{\Gamma}$(**4.02**) = **3.02** x **2.02** x **1.02** x $\boldsymbol{\Gamma}$(**1.02**) = **6.152992**

SUH: Gray's Method

Computation of dimensionless Hydrograph and SUH from Gray's Method (Γ Function)

T/T_R	T (min) 1)	Q_{T/T_R} (%) 2)	$\Sigma Q_{T/T_R}$ (%) 3)	Q_u (cfs) 4)	T/T_R	T (min) 1)	Q_{T/T_R} (%) 2)	$\Sigma Q_{T/T_R}$ (%) 3)	Q_u (cfs) 4)
0	0.00	0.00	0.00	0.00	1.875	46.80	8.04	85.42	309.21
0.125	3.12	0.44	0.44	17.08	2.125	53.04	5.51	90.93	212.01
0.375	9.36	5.78	6.22	222.11	2.375	59.28	3.62	94.55	139.37
0.625	15.60	12.71	18.93	488.65	2.625	65.52	2.30	96.86	88.58
0.875	21.84	16.50	35.43	634.63	2.875	71.76	1.42	98.28	54.77
1	24.96	16.93	—	651.21	3.125	78.00	0.86	99.14	33.10
1.125	28.08	16.57	52.00	637.16	3.375	84.24	0.51	99.65	19.62
1.375	34.32	14.27	66.27	548.89	3.625	90.48	0.30	99.95	11.44
1.625	40.56	11.11	77.38	427.16		Σ	99.95		3843.79

1) Values in first column (T/T_R) multiplied by T_R = **$24.96\ min$**

2) Ordinates of dimensionless hydrograph from **Eq. 4.27**. The value for T_R = **16.93%** is included only for the purpose of computing the peak discharge for the ***SUH*** = **$651.21\ ft^3/sec$**

3) Accumulated dimensionless hydrograph. It approaches 100%

4) Ordinates of the ***SUH*** from **Eq. 4.30**, values of Q_{T/T_R} multiplied by Σcfs = **$3845.74\ \ ft^3/sec$** from **Eq. 4.29**. Note its match with the sum of values in the Table (Q_u *peak* at T_R is excluded from sum)

Integration of the ***SUH*** over the watershed will yield the ***Excess Rainfall***

Time interval = $T_R/4 = 6.24\ min$ (or 9.36 — 3.12, or 3.12 x 2)

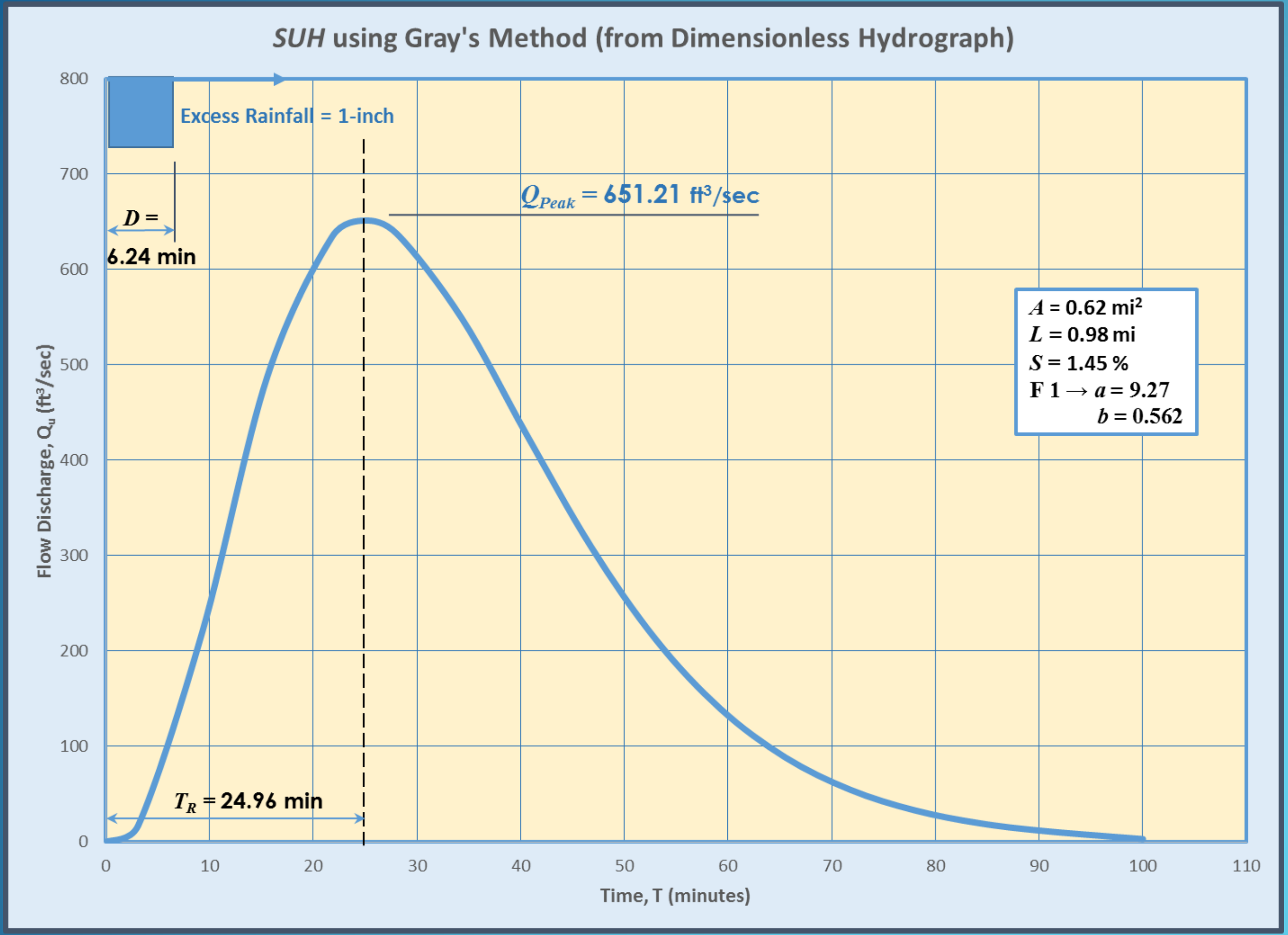
V_D = **$3843.79\ cfs$ x $6.24\ min$ x 60= $1{,}439{,}115\ ft^3$**

A = **$0.62\ mi^2 = 2.788\text{x}10^7\ ft^2/mi^2 = 17{,}285{,}600\ ft^2$**

V_D/A = **$0.08326\ ft$ = $\underline{1.0\ inch}$**

This proves that the ***SUH*** is correct. As expected ***Excess Rainfall*** is **1.0 *inch***

SUH: Gray's Method



SUH: Gray's Method

Florida Department of Environmental Protection

Questions?

Thank you!