Unit Hydrographs (Streamflow Estimation)

Transforming the Runoff from Rainfall

Unit Hydrograph Theory

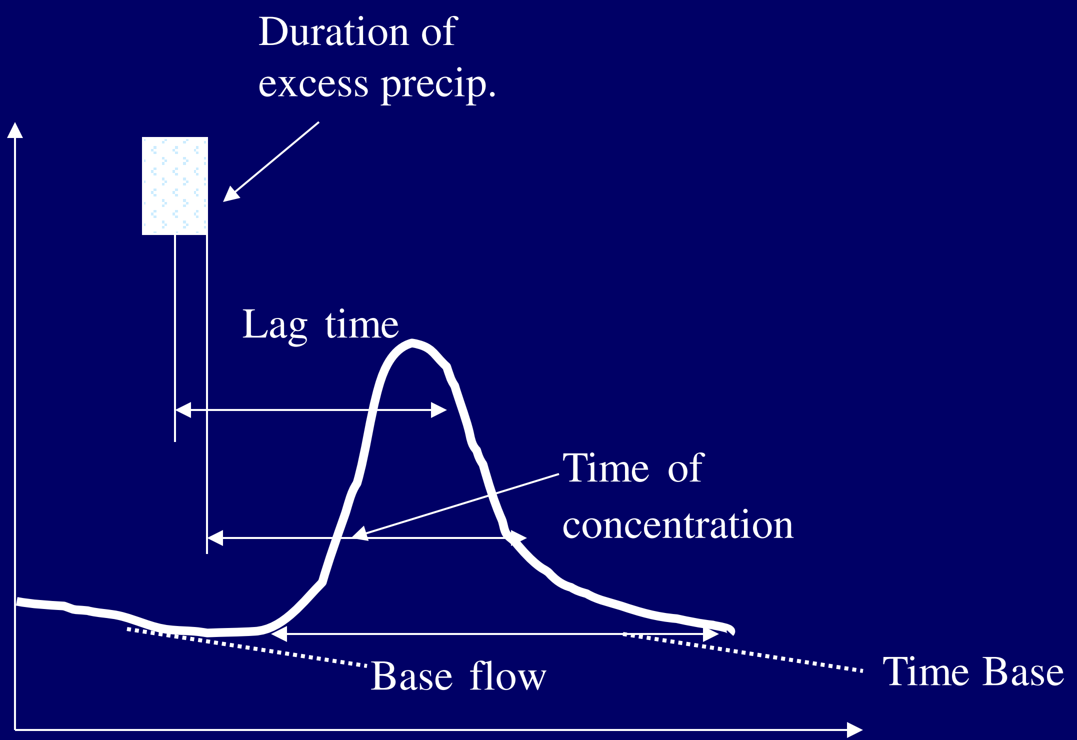
- Moving water off of the watershed…
- A mathematical concept (based on linearity)
- Linear in nature

Some History behind Unit Hydrograph Theory

- Sherman – 1932(first to propose the concept of ‘Unit Hydrograph’)
- Horton - 1933
- Wisler & Brater - 1949 - “*the hydrograph of surface runoff resulting from a relatively short, intense rain, called a unit storm.”*
- The runoff hydrograph may be “made up” of runoff that is generated as flow through the soil (Black, 1990).

Unit Hydrograph Components

- Duration
- Lag Time
- Time of Concentration
- Rising Limb
- Recession Limb (falling limb)
- Peak Flow
- Time to Peak (rise time)
- Recession Curve
- Separation
- Base flow



Methods of Developing UH’s

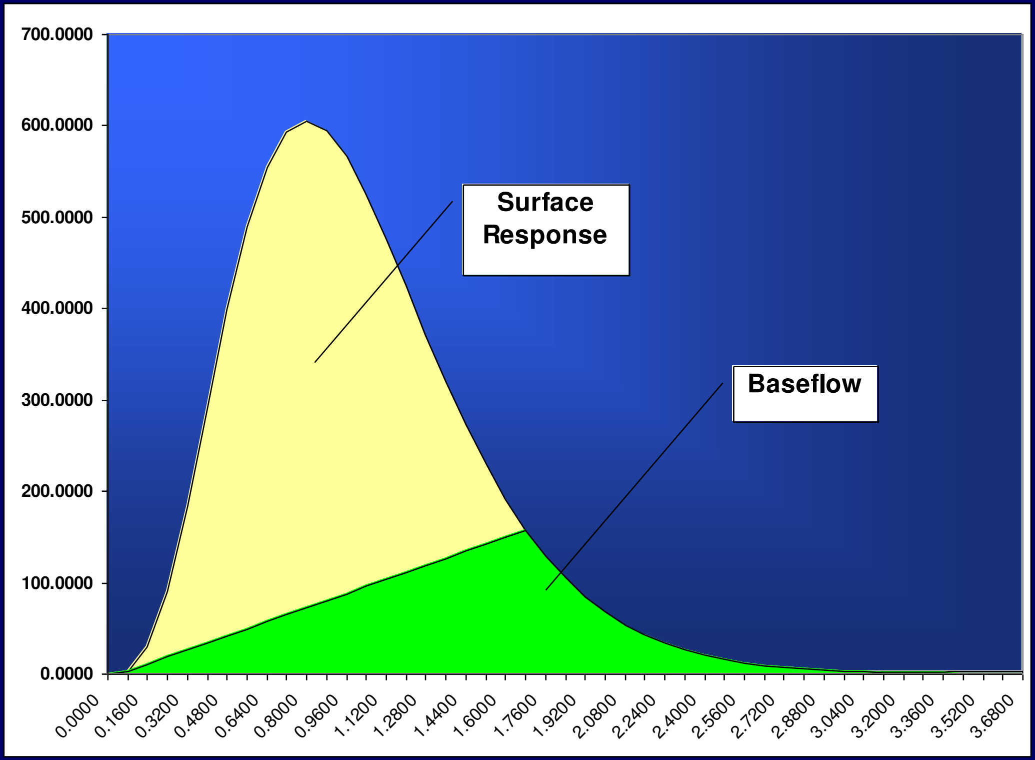
- From Streamflow Data
- Synthetically
  - Snyder (for CEE4420 – just know the formula for calculating lag and concentration times that are in the Gupta book
  - SCS
  - Time-Area (Clark, 1945)
- “Fitted” Distributions

Unit Hydrograph

- ***The hydrograph of direct runoff that results from 1-inch (or 1 unit) of excess precipitation spread uniformly in space and time over a watershed for a given duration.***

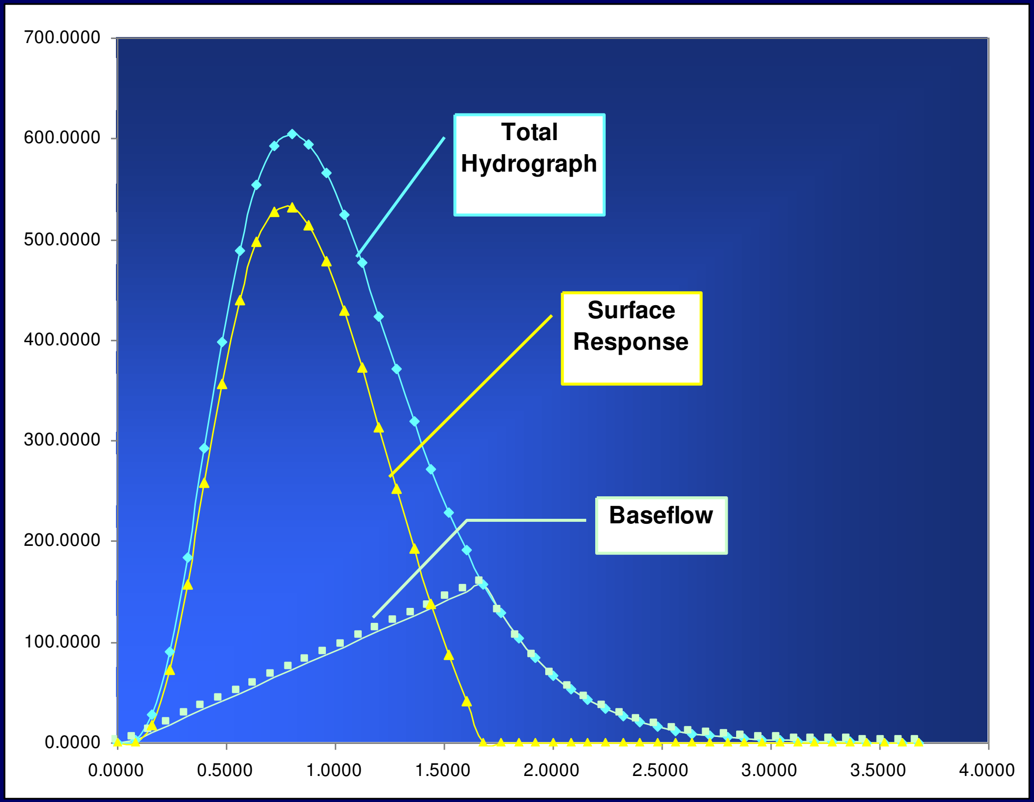
- The key points :
  - ✓ 1-inch of EXCESS precipitation
  - ✓ Spread uniformly over space - evenly over the watershed
  - ✓ Uniformly in time - the excess rate is constant over the time interval
  - ✓ There is a given duration pertaining to the storm – NOT the duration of flow!

Derived Unit Hydrograph



Note: The baseflow shown here (and separated in next slide) was identified using a different graphical method). For the course – keep the baseflow separation simple to 'flat rate deduction' or the N=Ad0.2 approach)

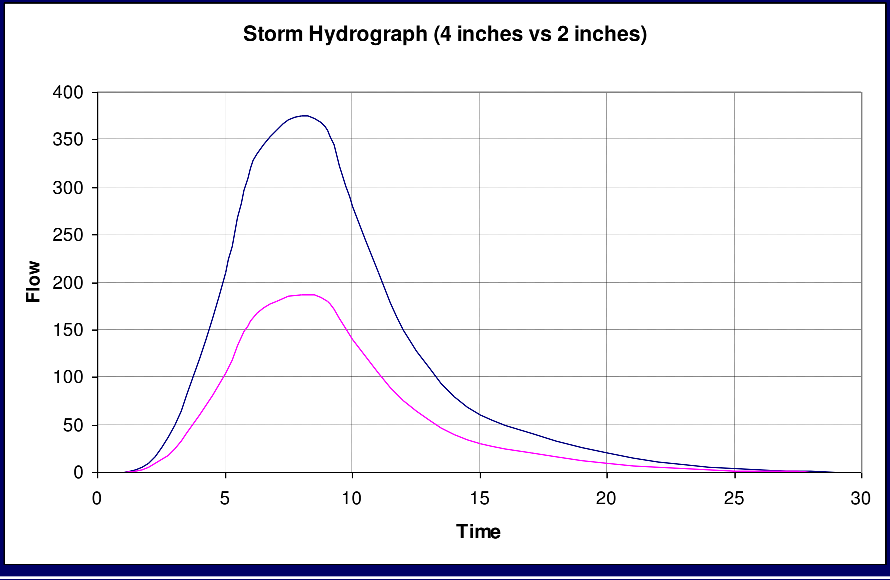
Derived Unit Hydrograph



Using a UH

- Remember what we covered in class last time on how to predict direct runoff from a storm of given duration and depth of excess precipitation provided you knew the UH for the same duration of the storm:

"The direct runoff from a 2 hour storm with 2 units of excess rainfall shall be twice as much as the direct runoff from a 2 hour storm with 1 unit of excess rainfall"

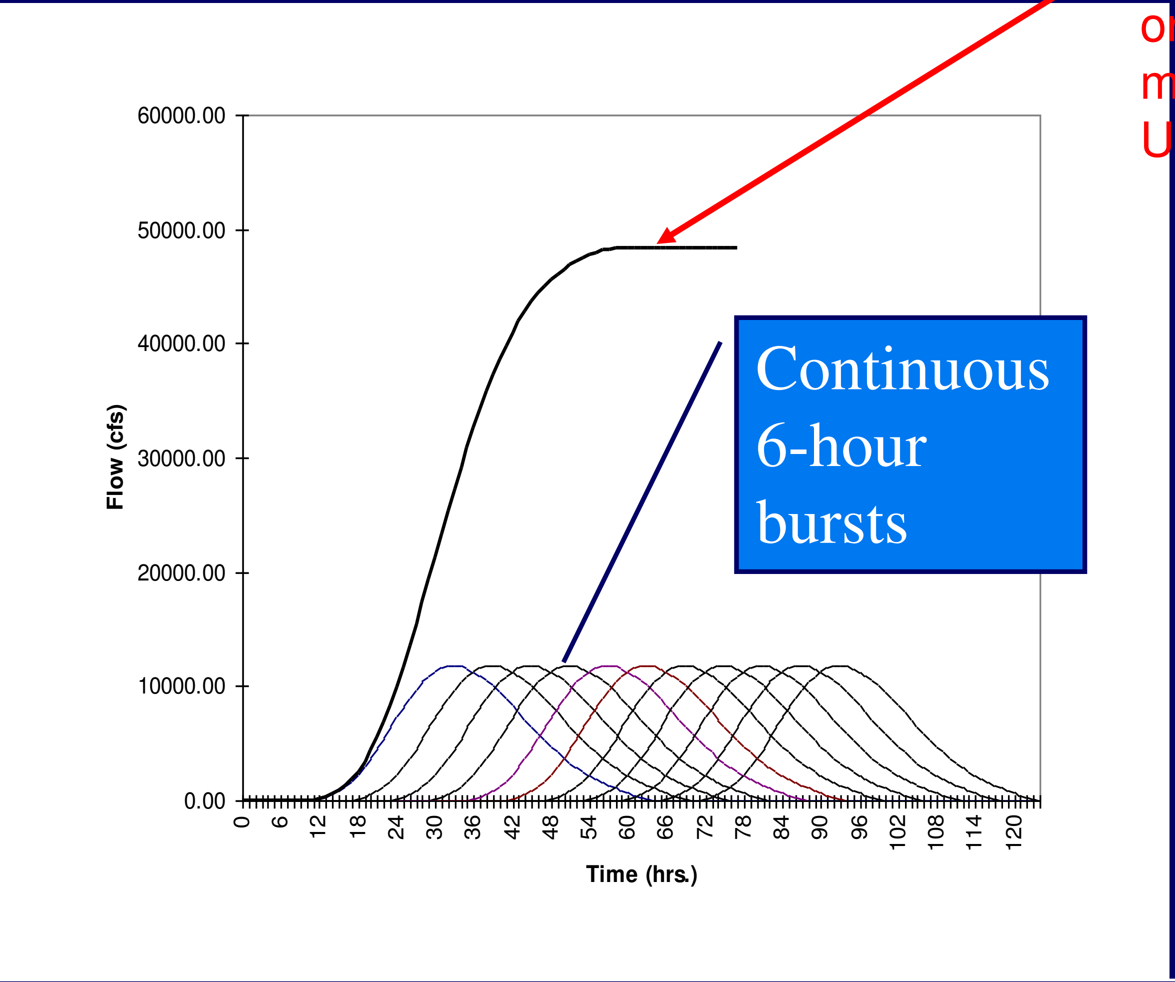


Changing the Duration of UH

- Very often, it will be necessary to change the duration of the unit hydrograph. Storms occur in all shapes (rainfall amount) and sizes (durations)
- The most common method of altering the duration of a unit hydrograph is by the S-curve method.
- The S-curve method involves continually lagging a unit hydrograph by its duration and adding the ordinates.
- For the present example, the 6-hour unit hydrograph is continually lagged by 6 hours and the ordinates are added.

Develop S-Curve

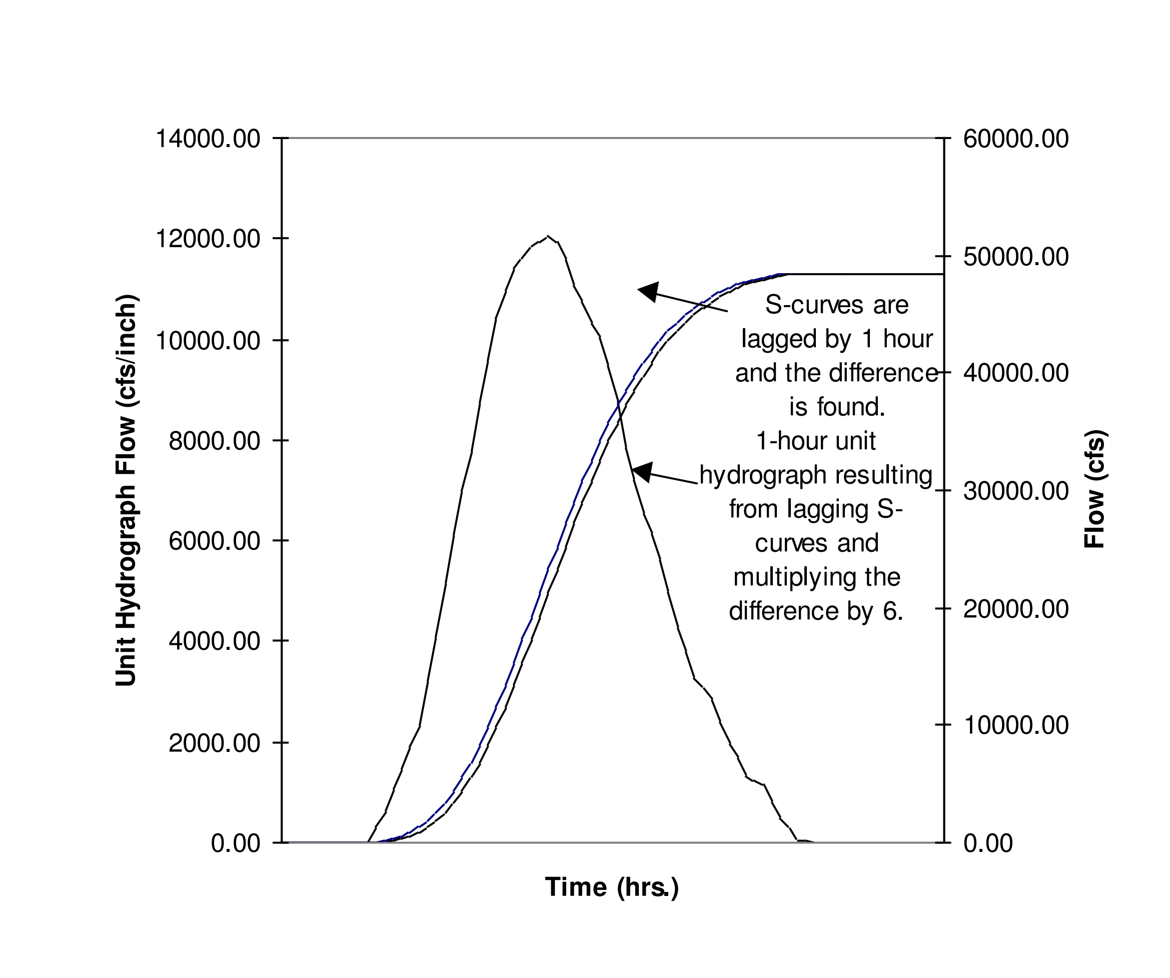
S-Curve: You get this by adding the ordinates of multiple 6 hr UHs below



Convert to 1-Hour Duration

1. To arrive at a 1-hour UH from a given 6 hour UH, two S-curves are lagged by 1 hour from each other and the difference between the two lagged S-curve (ordinates) is calculated for every timestep.
2. However, because the S-curve was formulated from unit hydrographs having a 6 hour duration of uniformly distributed precipitation, the hydrograph resulting from the subtracting the two S-curves will be the result of 1/6 of an inch of precipitation.
3. Thus the ordinates of the newly created 1-hour DR hydrograph in step 1must be multiplied by 6 in order to be a true unit hydrograph to get the final 1 hr UH.
4. The 1-hour UH should have a higher peak which occurs earlier than the 6-hour unit hydrograph. *Does this make sense ? You are having the same amount of excess rainfall but in a shorter period so the storm is more intense and hence creates runoff faster.*

Final 1-hour UHG



Steps for Changing duration of UH

Suppose you are asked to change the duration of a given 2 hour UH to a 6 hour UH. Let tr=2hr (original duration) and trb=6hr (required duration).

1. First lag a minimum of tb/tr number of 2 hour UHs. So suppose, tb (time base of flow) is 12 hours, then in this case you should lag at least 12/2=6 2 hour UHs. Round off this number to the nearest higher integer.
2. Next, add all the ordinates as a function of time. You should get an S-type shape where the flow will reach a steady-state and saturated value. In exam, step#1 is very handy to save time. And the moment you get your highest flow value, that can be your S-curve peak value that you can maintain from thereafter.
3. Now lag two S-curves (derived in step#2) by duration trb (6 hour). And then subtract the ordinates.
4. Step #3 will give you a DRH for a trb duration storm. Multiply the ordinates by tr/trb to get your 6 hour UH from the given 2 hr UH.

Synthetic UHs

- Snyder (this is good enough for course)
- SCS
- Time-area

Snyder

- Since peak flow and time of peak flow are two of the most important parameters characterizing a unit hydrograph, the Snyder method employs factors defining these parameters, which are then used in the synthesis of the unit graph (Snyder, 1938).
- The parameters are C_p, the peak flow factor, and C_t, the lag factor.
- The basic assumption in this method is that basins which have similar physiographic characteristics are located in the same area will have similar values of C_t and C_p.
- Therefore, for ungaged basins, it is preferred that the basin be near or similar to gaged basins for which these coefficients can be determined.

Basic Relationships

$$t_{LAG} = C_t (L \bullet L_{ca})^{0.3}$$

$$t_{duration} = {t_{LAG}}/{5.5}$$

$$t_{alt.lag} = t_{LAG} + 0.25(t_{alt.duration} - t_{duration})$$

$$t_{base} = 3 + \frac{t_{LAG}}{8}$$

$$q_{peak} = \frac{640 A C_p}{t_{LAG}}$$

Significance of Unit Hydrograph

- Watersheds response to a given amount of excess precipitation is just a multiplier of the unit hydrograph
- Use unit hydrograph as a basis to determine the storm hydrograph from any given rainfall distribution

Example

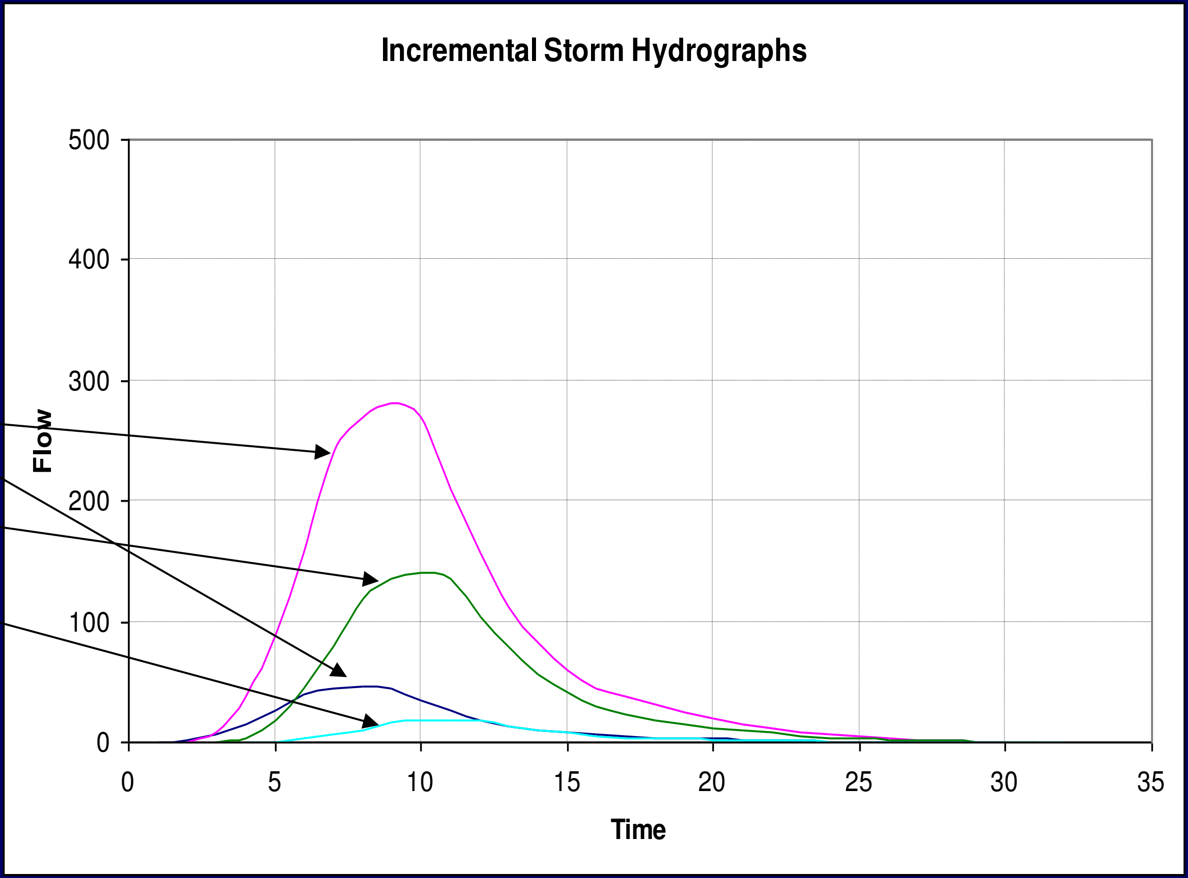
- Given the following rainfall distribution

Time	Precipitation
1	0.5
2	3
3	1.5
4	0.2

- The watershed will respond as follows

Example

Time (hr)	Precipitation
1	0.5
2	3
3	1.5
4	0.2



For hour 1: multiply your 1 hr UH by 0.5 and plot it starting at t=1hr

For hour 2: multiply your 1 hr UH by 3 and plot it starting at t=2hr…. And so on

You get four DRHs plotted for each hour as above

Example

Now add all your ordinates to get the final DRH – shown here by the tallest DRH.

This is the DRH you will get from the storm of 4 hours with variable intensity