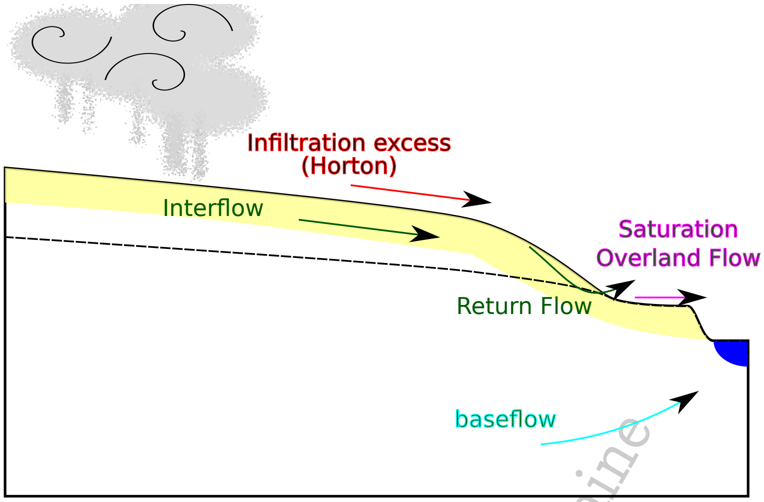
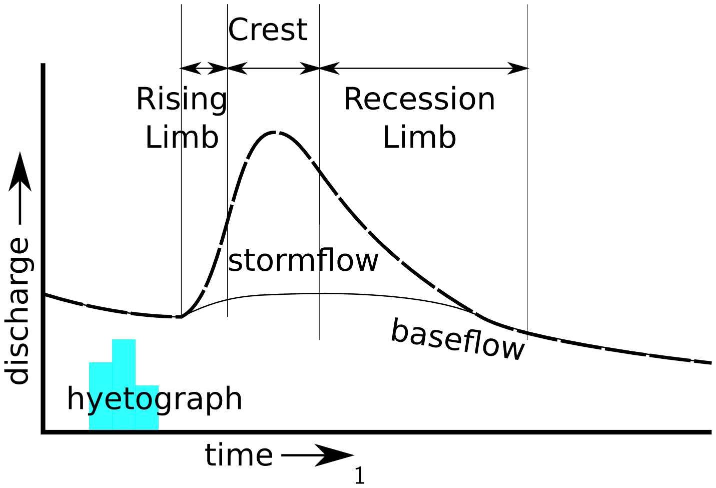
Runoff Mechanisms



Runoff Mechanisms

- Infiltration Excess
  - Horton Model
  - Arid,Semiarid, low permeability soils, etc.
  - Entire basin contributes
- Subsurface stormflow (interflow)
  - humid, vegetated areas
  - most flow through interflow
- Saturation Overland Flow
  - runoff from saturated soils
  - variable contributing area
  - small contributing area
- Combinations of Above Mechansims
- Baseflow supplied during and between storms

Hydrograph



Hydrograph

- hydrograph shape
  - basin properties
  - precip. distribution/intensity/duration
- crest, between inflection points
- recession limb
  - no direct runoff
  - interflow, detention storage, groundwater
  - $Q(t) = Q_0 K^t$

Baseflow Separation (Recession Curve)

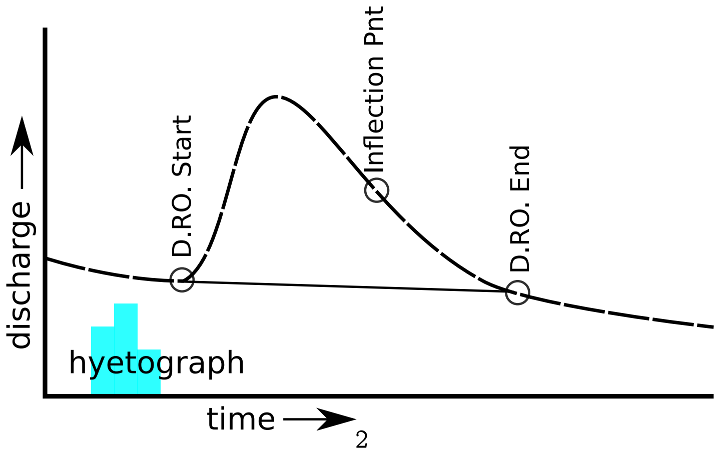
- Baseflow removed from discharge
- Direct Runoff Hydrograph

Recession Curve Approach:

- Measure recession constant
  - portion of hydrograph with no stormflow
  - straight segments on semilog plot
  - measure Q's at start and end of several intervals
  - $K = \frac{Q_{end}}{Q_{start}}$
  - Calculate baseflow using $Q(t) = Q_0 K^t$
- projection method (no extended dry periods)
  - Project straight segments (semilog plot)
  - extend straight line backwards from end of hydrograph to point beneath recession inflection point
  - then connect to start of stormflow

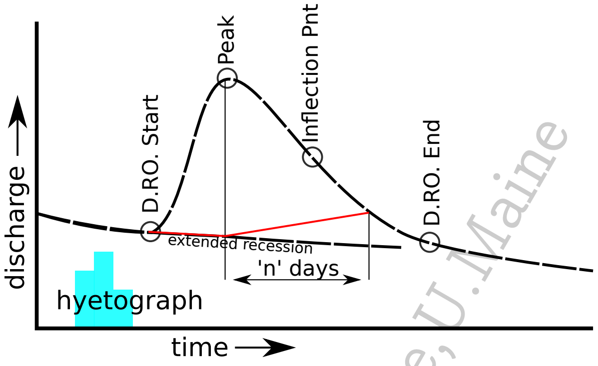
Baseflow Separation

- Method 1
  - straight line connecting start and end of direct runoff
  - alternatively, horizontal line from start of direct runoff



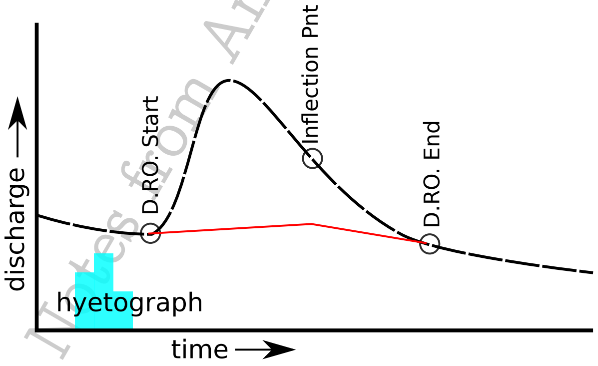
Baseflow Separation

- Method 2
  - extend recession to peak-flow time
  - connect point from end of extended recession to 'n' days past peak
  - $n = a \cdot A^{0.2}$
  - A=drainage area, a=.8 (A in sq.km) or 1.0 (A in sq.miles)



Baseflow Separation

- Method 3
  - extend recession backwards below inflection
  - connect point below inflection to start of direct runoff

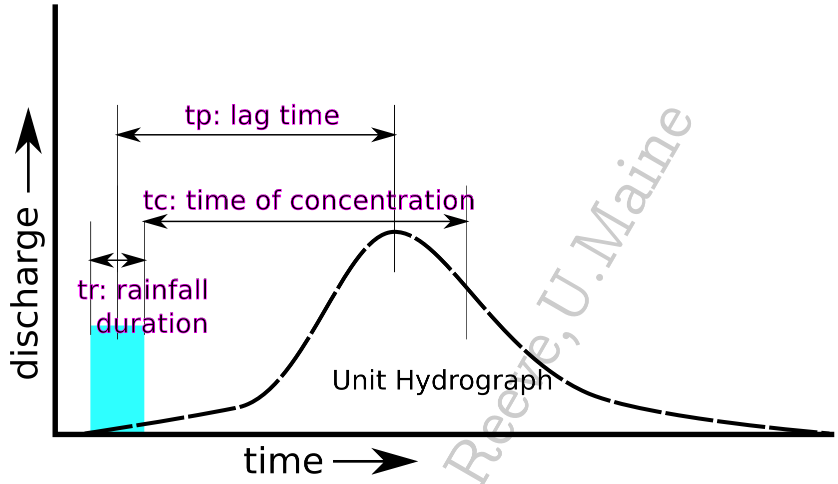


Unit Hydrograph

- Direct Runoff Hydrograph
- unit of rainfall
- specified duration (t_r)
  - longer duration appropriate for larger catchments
  - should be less than time of concentration
  - 6 to 12 hours for areas of 100 to 1000 mi^2
  - $\frac{1}{3} \cdot t_c$ to $\frac{1}{4} \cdot t_c$ for basins smaller than 20 mi^2

- lag time (t_p): time from center of rainfall duration to peak of hydrograph
- time of concentration (t_c)
  - represents longest travel time for runoff
  - time from center of rainfall duration to falling limb inflection point

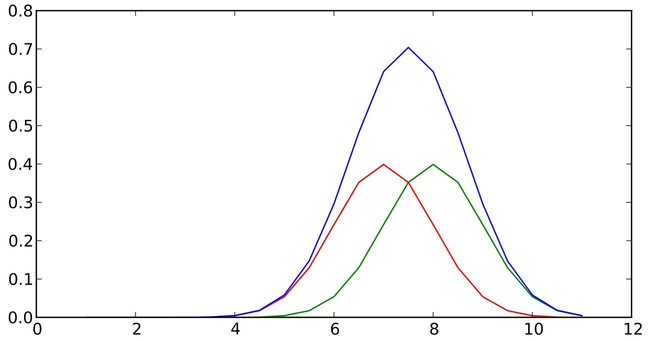
Unit Hydrograph



Unit Hydrograph

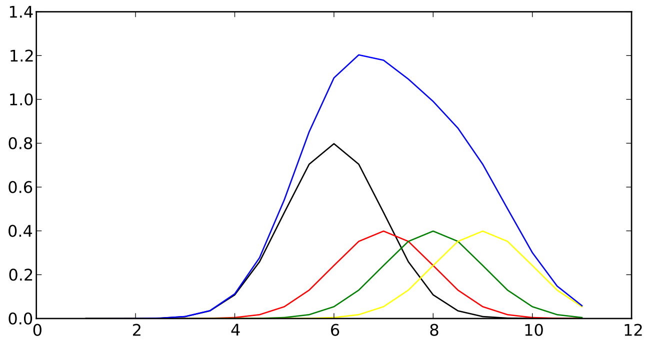
- Complex hydrographs produced by combining unit hydrographs
  - superposition
  - linear relationship between unit and more complex hydrographs
  - my need several unit hydrographs for a large basin (different behavior in different parts of basin)
- Concept not applicable to very large (2000 mi^2) basins (too much spatial variability)
- if only daily data available, should only apply unit hydrograph concept to larger basins

Superposition



- Add together unit hydrographs to predict storm response
- Each unit hydrograph separated by rainfall duration

Superposition



- Can add unit hydrographs at same time
- Multiple 'units' of rain over rainfall duration

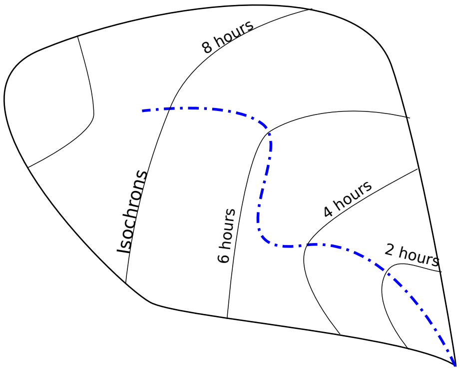
Unit Hydrograph

Calculation by Inverse Procedure:

- Identify 'simple' hydrograph in basin (ideally)
  - short duration
  - temporally isolated
  - uniform spatial distribution
  - uniform temporal duration
- subtract baseflow, creating direct runoff hydrograph (DRH)
- Calculate area under curve (volume of water)
- convert to length (divide by basin area)
- use this length to normalize original DRH (divide discharges by length)

Instantaneous Unit Hydrograph

- basin response to instantaneous unit recharge event
- assumes unique IUH for each basin
- assumes linearity for IUH
- eliminates effect of duration on UH shape



Unit Hydrograph

Calculation by using Instantaneous Unit Hydrograph

- based on water balance concept, and estimated lag time for storm water
- assuming inflow is constant with time to a 'stream reservoir'

$$I - \frac{O_{t2} + O_{t1}}{2} = \frac{\Delta S}{\Delta t}$$

$$S = K \cdot O$$

$$I - \frac{O_{t2} + O_{t1}}{2} = K \frac{O_{t2} - O_{t1}}{t}$$

$$K = -\frac{Q}{\frac{Q}{t}} \quad \text{from hydrograph at inflection}$$

$$O_i = C \cdot I + (1 - C)O_{i-1}$$

$$C = \frac{2\Delta t}{2 \cdot K + \Delta t}$$

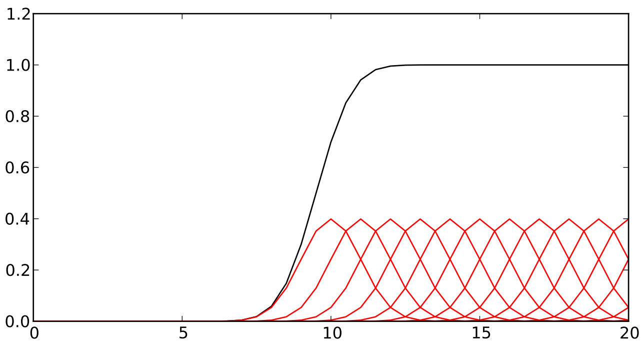
- O_i is IUH discharge and Δt is rainfall duration
- Q for UH based on average outflow $Q = \frac{O_i + O_{i-1}}{2}$

Unit Hydrograph

Calculation of Instantaneous Unit Hydrograph

- K is 'attenuation const.' (using DRO hydrograph)
- subdivide drainage basin into 5 to 10 zones defined by isochrones (areas with similar travel times)
- plot travel time vs. cumulative contributing area (based on isochrons map of basin)
- Using this graph, and a desired rainfall duration, determine incremental areas (a) at different times after the storm (step size(Δt) is desired rainfall duration)
- Calculate discharges(I): $I_i = \frac{a_i}{\Delta t}$
- use C and I to calculate O
- plot of O vs time provides IUH
- plot of Q (average O's) vs time provides UH

S Curve



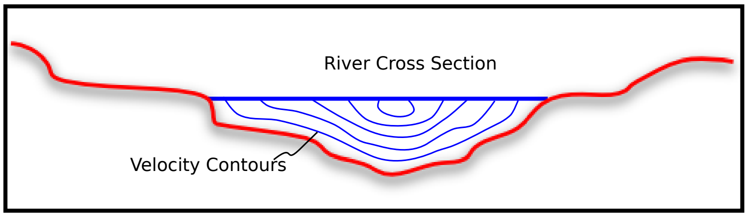
- Developed by superposing multiple unit hydrographs
  - add unit hydrographs, lagged by rainfall duration
  - scale S curve, multiply by duration,converts to unit rain per unit time
- Used to create hydrograph of arbitrary duration
  - Subtract S-curves offset by needed rainfall duration
  - rescale by dividing by duration of new hydrograph, converts from unit rain per unit time to unit of rain over entire duration

Measuring Streamflow

- Measure Velocity
  - Current Meters
    - ∗ propeller, EM, Acoustic Doppler
  - Floats
  - Tracer Dilution
- Measure Stage
  - staff gage
  - float gage
  - pressure transducer
- Weir, Flume, orifice (stage-discharge equations)

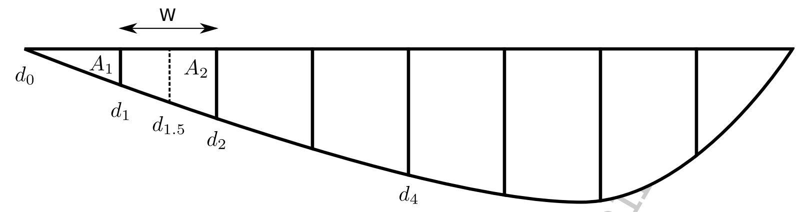
Discharge Measurement

- velocity in a stream varies with location
- lateral and horizontal variability



Discharge Measurement: lateral variablity

- $Q = \sum v \cdot A$
- Divide stream into segments
- measure area and velocity of each segment
  - midsection depth method: $A_2 = d_{1.5} \cdot w$
  - mean depth method: $A_2 = w\frac{d_1+d_2}{2}$



Discharge Measurement: vertical variablity

- zero velocity at streambed
- velocity increases from bed to stream surface
- Three zones (from bottom to top)
  - laminar boundary layer
  - log velocity distribution
  - velocity defect
- zones mark shift from laminar to turbulent flow
- for rough (natural) streambeds $v = \bar{v} + \frac{1}{K}\sqrt{g \cdot d \cdot s}\left(1 + \ln\left(\frac{y}{d}\right)\right)$

  d=total depth, y=vertical position (from bottom), K=von Karman coef. (about 0.4), s=channel slope

- velocity profile approximated by: $v = V_0\left(\frac{y}{y_a}\right)^{\frac{1}{m}}$

  y_0 is vertical position where V_0 is known,y=vertical position (from bottom), m=depends on reynolds number (6 to 10, typically 7)

Discharge Measurement: vertical variablity

- by manipulating previous equation, can develop various ways of determining average stream velocity over depth
- $\bar{v} = v(.4 \cdot d)$ (one point method, six-tenths-depth method)
- $\bar{v} = \frac{v(.2 \cdot d)+v(.8 \cdot d)}{2}$ (two point method)
- plot curve based on many measurements, $\bar{v} = \frac{area\ under\ curve}{d}$ (velocity curve method)
- smoothly lower and raise current meter through water column, collect average velocity over time.
- $\bar{v} = 0.87 \cdot v(.8 \cdot d)$ (two-tenths depth)
- $\bar{v} = 0.85 \cdot v(1. \cdot d)$ (surface velocity)

Continuous Discharge Measurement

- Need nearly continuous record of discharge
- Direct measurement of velocity expensive or not practical
  - utrasonic methods
  - electomagnetic methods
- Stage-discharge relationships
  - construct hydraulic structure
  - create rating curve
  - measuring stage
    - measure pressure
    - ultrasound
    - floats

Stage-Discharge Relationship

- relationship may shift with time, require periodic correction
- relationship stablized by certain controls
  - section control: physical feature at point in stream (bridge, rocks, culvert)
  - channel control: downstream features, stabalize stream bed (slope, constriction, ...)
- Simple Relationship
  - parabolic pattern
  - fit curve (or equation) to measured data
  - $Q = A \cdot (h + a)^n$

Stage-Discharge Relationship

- Log. Rating curve
  - based on taking log of simple equation (above)
  - Q vs. stage plots as straight line on log-log graph
  - easier to use/evaluate straight line relationship
- finding 'a', stage at zero flow
  - plot Q vs stage on log-log plot
  - adjust a to get straight line
    - trial and error
  - adjust a to get straight line
    - Solution to power-law equation
    - pick two points (Q_1,h_1) and (Q_2,h_2)
    - $Q_3 = \sqrt{Q_1 \cdot Q_2}$
    - find h_3 from graph
    - $a = \frac{h_1 \cdot h_2 - h_3^2}{h_1 + h_2 + 2 \cdot h_3}$

Slope-Stage-Discharge Rating

- Stage-Discharge may be influenced by variable backwater conditions
- compensate with slope
- measure stage (elevation) and discharge at two points
- $Q_r = \frac{Q}{F^n}$ n=constant(.4 to .6), F=change in level between stations, Q's are discharges at stations
- calculate Q_r and plot against base gage height, fit curve
- Plot $\frac{Q}{Q_r}$ vs. fall (elevation change), use best-fit-curve to estimate Q_r, fit curve
- use measured stage at two points to estimate discharge
  - stage at base -> Q_r (from first plot)
  - fall -> Q (from second plot)
  - Q from equation