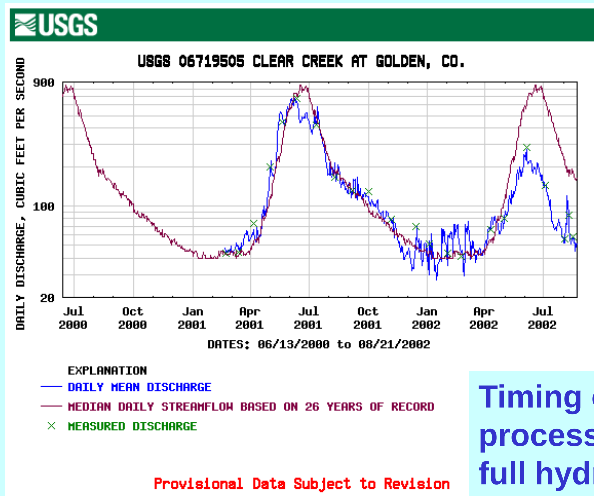
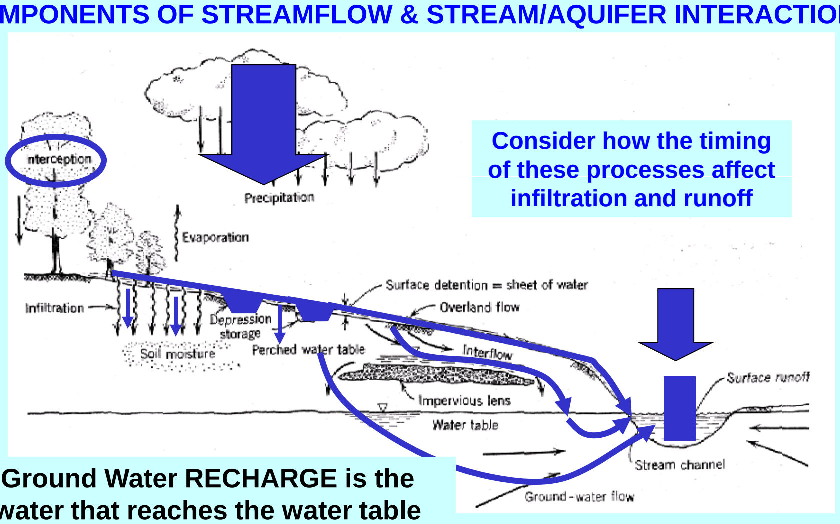
STREAM HYDROGRAPH - PLOT OF DISCHARGE VS TIME AT ONE LOCATION
DISCHARGE - VOLUME OF WATER FLOWING PAST A POINT OVER A TIME



Timing of each process forms the full hydrograph

The RUNOFF CYCLE - Events During Precipitation
COMPONENTS OF STREAMFLOW & STREAM/AQUIFER INTERACTION

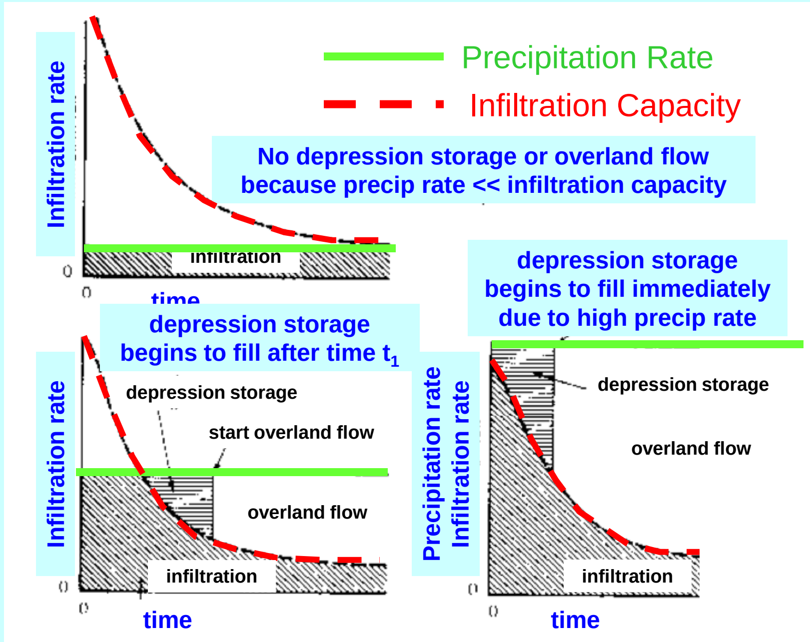


Consider how the timing of these processes affect infiltration and runoff

Ground Water RECHARGE is the water that reaches the water table

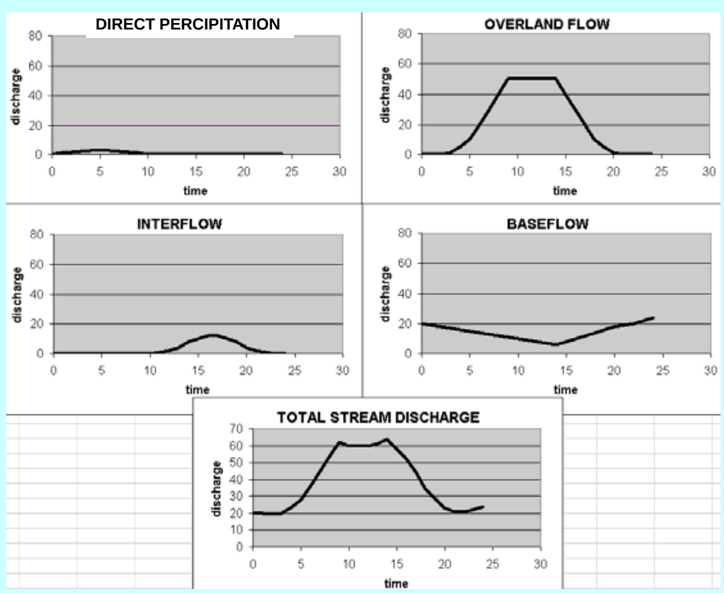
Base Flow is the portion of stream flow from Ground Water that discharges to the stream

RELATIONSHIP BETWEEN PRECIPITATION AND INFILTRATION



HYDROGRAPH FOR ONE STORM

@ one point



To Manage Water, We Want to Know How Often a Flow Is Equaled or Exceeded

DURATION CURVE - % of Time a Flow Is Equaled or Exceeded

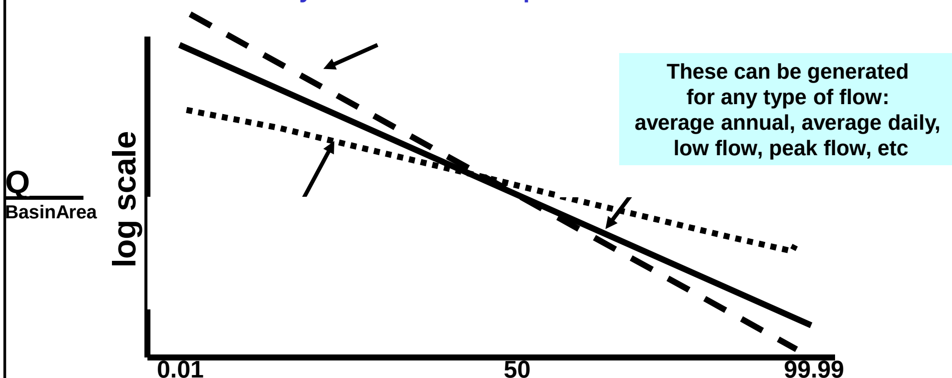
Plot of Discharge vs Probability of Occurrence

To create: Rank Flows, as m, From Highest to Lowest 1 to N

If 2 Values Are Equal, Assign Separate Rank

$P = 100 * (m/(n+1))$

Normalize flow by basin area to compare basins of different size



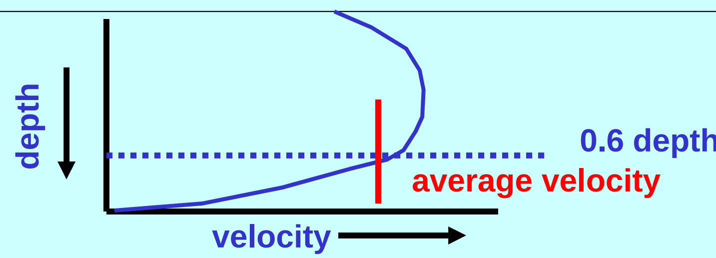
Probability that Flow is Equaled or exceeded

HOW IS STREAM DISCHARGE MEASURED?

DISCHARGE - Q = VOL flowing past a point PER UNIT TIME $Q = V A$

AREA – cross sectional area of the stream

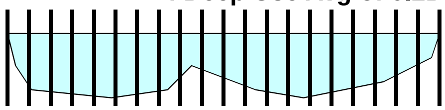
AVERAGE V - varies in channel due to friction losses



HOW DO WE DETREMINE VELOCITY?

1) Measure Velocity With Current Meter

Price or Pygmy Vanes – Electromagnetic- Ultrasonic
Use a Straight, Clear Reach
Divide Width in Segments (Wi)
Record Depth in Middle of Each (Di)
Meas V at 0.6Di in Middle of Segment
If Deep Use Avg of 0.2D & 0.8D



Q = SUM (V_i W_i D_i)

or 2) Estimate Velocity with a Rating Curve

Measure Q & Stage
Plot Stage vs Q
Use Stable Portion of Channel
Typically Stilling Well and Continuous Recorder

or 3) Measure Velocity With A Weir

Opening with Flow Calibrated to Height of Back Water

OR, possibly

or 4) Estimate Velocity With Manning Equation (empirical)

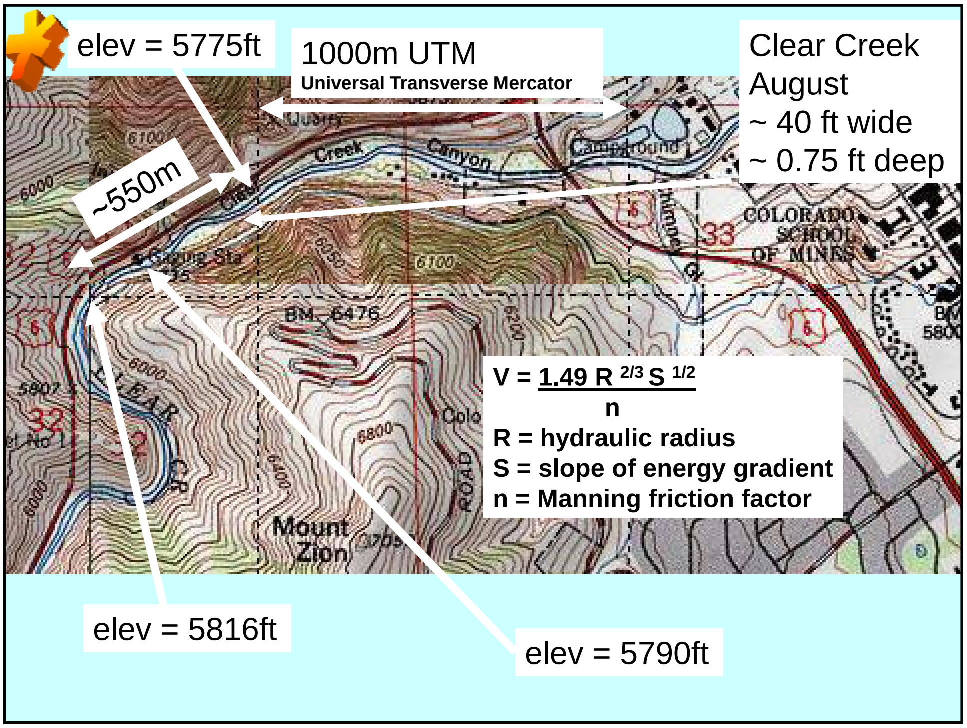
$$V = \frac{1.49\, R^{2/3}\, S^{1/2}}{n}$$

where: V = average velocity in fps
R = hydraulic radius (flow area [ft^2]/wetted perimeter[ft])
S = slope of energy gradient
n = Manning friction factor

The velocity of flow is dependent upon the amount of friction between the water and the stream channel. Smoother channels will have less friction and, hence, faster flow. Channel roughness contributes to turbulence, which dissipates energy and reduces flow velocity. The following values for *n* are typical:

mountain streams with rocky beds:	0.04–0.05
winding natural streams with weeds:	0.035
natural streams with little vegetation:	0.025
straight, unlined earth canals:	0.020
smoothed concrete:	0.012

The U.S. Geological Survey has published a series of photographs of rivers for which the value of the Manning roughness coefficient has been computed (24). Field measurements of velocity, slope, area and wetted perimeter were made and the value of *n* computed



HYDROLOGISTS NEED
TO PREDICT
PEAK RUNOFF FROM STORMS

for example, for small areas:
RATIONAL METHOD

Q = C I A

Q - PEAK DISCHARGE
(CFS, that's ft^3/sec)
C - RUNOFF COEF
I - RAIN INTENSITY (in/hr)
A - DRAINAGE AREA (acres)

Empirical: cfs results from in/hr & acres.

Valid after rain has continued at least as long as the time of concentration

Description of Area	C
Business	
Downtown	0.70–0.95
Neighborhood	0.50–0.70
Residential	
Single-family	0.30–0.50
Multiunits, detached	0.40–0.60
Multiunits, attached	0.60–0.75
Residential suburban	0.25–0.40
Apartment	0.50–0.70
Industrial	
Light	0.50–0.80
Heavy	0.60–0.90
Parks, cemeteries	0.10–0.25
Playgrounds	0.20–0.35
Railroad yard	0.20–0.35
Unimproved	0.10–0.30
Character of surface	
Pavement	
Asphalt and concrete	0.70–0.95
Brick	0.70–0.85
Roofs	0.75–0.95
Lawns, sandy soil	
Flat, up to 2% grade	0.05–0.10
Average, 2%–7% grade	0.10–0.15
Steep, over 7%	0.15–0.20
Lawns, heavy soil	
Flat, up to 2% grade	0.13–0.17
Average, 2%–7% grade	0.18–0.22
Steep, over 7%	0.25–0.35

SOURCE: American Society of Civil Engineers, Manuals and Reports of Engineering Practice No. 37, 1970.

TIME OF CONCENTRATION - TIME IT TAKES FOR DROP OF WATER FROM MOST DISTANT PART OF BASIN TO REACH OUTLET

Simplest SCS EMPIRICAL FORMULA FOR APPROX t_c
see SCS for more involved methods of estimating

$$t_c = \frac{L^{1.15}}{7700\ H^{0.38}}$$

where: t_c - time in hours
L - length of mainstream in feet
H - difference in elevation from most distant divide to outlet in ft

IF RAINFALL DURATION LESS THAN t_c
RATIONAL METHOD PREDICTS TOO HIGH A PEAK

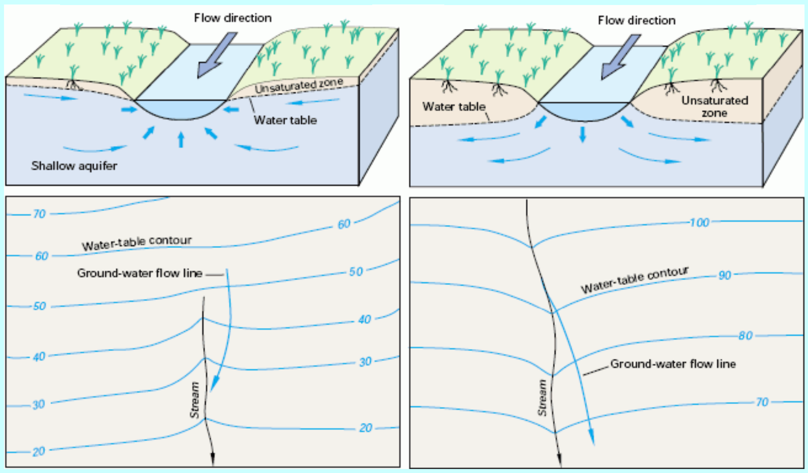
OTHER METHODS of Estimating Surface Water Discharge
(topics of surface water flow course)

SYNTHETIC HYDROGRAPH
USGS METHOD
COOK SUMMATION W METHOD
OUTPUT-OUTPUT METHOD
COMPUTER SIMULATIONS OF RUNOFF PROCESSES

BASE FLOW IS THE COMPONENT OF GREATEST INTEREST TO GROUND WATER HYDROLOGISTS

Baseflow Occurs in Gaining Streams

Gaining Stream | **Losing Stream**

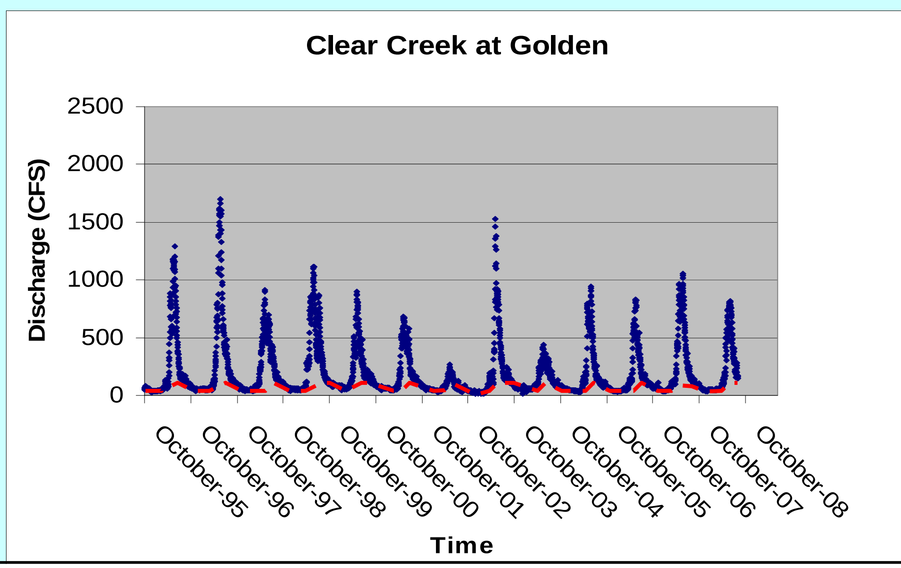


Winter et.al., USGS Circular 1139
Ground Water and Surface Water A Single Resource

BASE FLOW

PORTION OF STREAM DISCHARGE ATTRIBUTED TO GROUND WATER DISCHARGE TO THE STREAM

DIFFICULT TO DETERMINE



BASE FLOW

Measured as Difference in Stream flow at 2 Pts on Stream If There Are No Other Contributions to Flow along the Reach

But Records Include Other Components and often there is only ONE GAGE, therefore we attempt to estimate Baseflow from hydrographs

A Hydrograph with No Overland Flow Effects & No Intervening Recharge Will Exhibit an Exponential Decay

Let's convince ourselves (shots per second)

BASEFLOW RECESSION IS A FUNCTION OF:

TOPOGRAPHY
DRAINAGE PATTERN
SOIL TYPES
GEOLOGY

RECESSION CURVES FOR ONE BASIN ARE SIMILAR FROM YR TO YR

Sample Stream Hydrographs from Meyboom

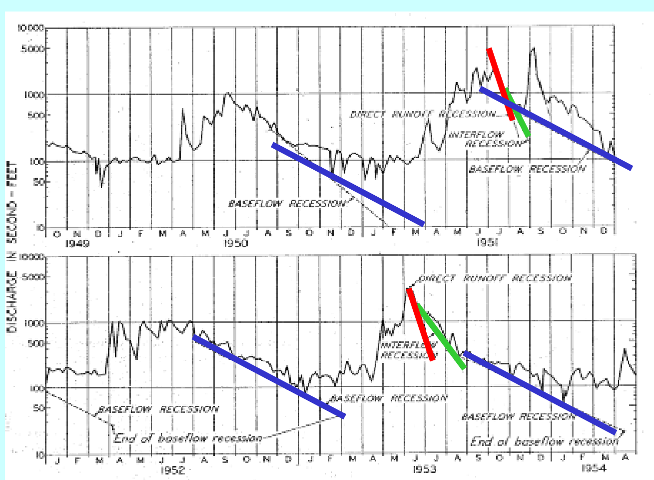


Fig. 5. Stream hydrograph of Elbow River, 1949-1954.

MATHEMATICAL DESCRIPTION OF RECESSION

EXPONENTIAL DECAY FUNCTION

$$Q = Q_o e^{-at}$$

Q - DISCHARGE AT TIME, t, AFTER RECESSION BEGINS

Q_o - DISCHARGE AT START OF RECESSION

a - RECESSION CONSTANT FOR BASIN

t - TIME SINCE RECESSION STARTED

NORMALLY WE HAVE DISCHARGE DATA & WANT TO SOLVE FOR "a" TO MAKE FUTURE PREDICTIONS

$$Q = Q_o e^{-at}$$

Divide by Q_o

$$\frac{Q}{Q_o} = e^{-at}$$

Take the log of both sides:

$$\ln Q - \ln Q_o = -at$$

Multiply both sides by -1:

$$\ln Q_o - \ln Q = at$$

Re-arrange: (to solve for slope of the log plot)

$$a = \frac{\ln(Q_o/Q)}{t}$$

a is 1 over the time for Q to decrease 1 natural log cycle

$$a = \frac{1}{t_{ln}}$$

“a” is the slope of the recession

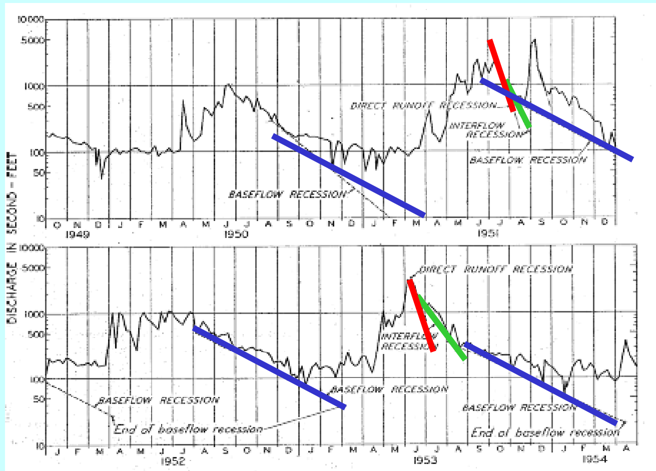


Fig. 5. Stream hydrograph of Elbow River, 1949–1954.

In base 10

$$\frac{Q}{Q_o} = 10^{-at}$$

Take the log of both sides:

$$\log Q - \log Q_o = -at$$

Multiply both sides by -1:

$$\log Q_o - \log Q = at$$

Re-arrange: **(to solve for slope of the log plot)**

$$a = \frac{\log(Q_o/Q)}{t}$$

a is 1 over the time for Q to decrease 1 base ten log cycle

$$a = \frac{1}{t_{log}}$$

One Problem Is How to Compute Q_o
(i.e. Q When Recession Begins & Overland Ends)

RULE OF THUMB $D = A^{0.2}$ **FOR A IN** MI^2

D - # DAYS BETWEEN PEAK & END OVERLAND FLOW
A - DRAINAGE BASIN AREA

Debatable, let's discuss

What ever you decide to use, just be sure you clearly explain what you used and why

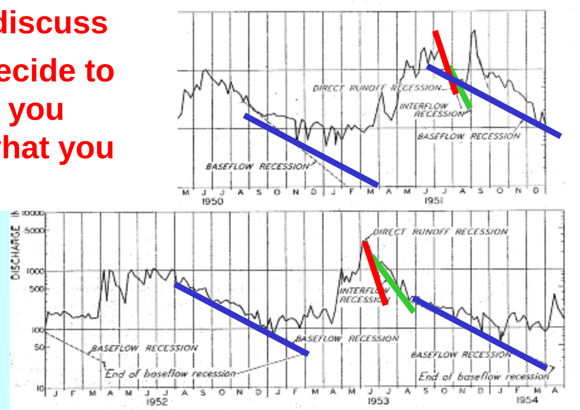


Fig. 5. Stream hydrograph of Elbow River, 1949-1954.

In base 10

Given that

$$\frac{Q}{Q_o} = 10^{-at}$$

And

a is 1 over the time for Q to decrease 1 base ten log cycle

$$a = \frac{1}{t_{log}}$$

Then we know:

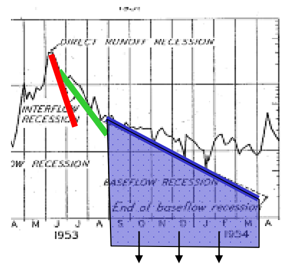
$$Q = Q_o\, 10^{\frac{-t}{t_{log}}}$$

where: $Q = Q_o$ when $t = 0$

$t = t_{log}$ when $Q = 0.1\, Q_o$

ESTIMATING GROUNDWATER DISCHARGE & RECHARGE FROM HYDROGRAPHS:

$$Q = Q_o\, 10^{\frac{-t}{t_{log}}}$$



VOL OF DISCHARGE OVER GIVEN TIME
= AREA UNDER CURVE

$$Vol = \int_{t_1}^{t_2} Q\,dt = Q_o \int_{t_1}^{t_2} 10^{\frac{-t}{t_{\log}}}\,dt$$

$$\int_{x_1}^{x_2} b^{ax}\,dx = \left.\frac{b^{ax}}{a \ln b}\right|_{x_1}^{x_2} \qquad b = 10, \quad a = \frac{-1}{t_{\log}}, \quad x = t$$

$$\int_{x_1}^{x_2} b^{ax}\,dx = \left.\frac{b^{ax}}{a \ln b}\right|_{x_1}^{x_2} \qquad b = 10, \quad a = \frac{-1}{t_{\log}}, \quad x = t$$

TOTAL POTENTIAL DISCHARGE AT START OF RECESSION, V_{tp}:

$$V_{tp} \textit{ is evaluated } \textit{ from } t = 0 \textit{ to } \infty \textit{ so } V_{tp} = Q_o \left(\frac{10^{\frac{-1}{t_{\log}}*\infty}}{\frac{-1}{t_{\log}}2.3} - \frac{10^{\frac{-1}{t_{\log}}*0}}{\frac{-1}{t_{\log}}2.3} \right) = \frac{Q_o t_{\log}}{2.3}$$

TOTAL POTENTIAL DISCHARGE AT END OF RECESSION, V_R:

$$V_R \textit{ is evaluated } \textit{ from } t = end(t) \textit{ to } \infty \text{ so } V_R = Q_o \left(\frac{10^{\frac{-1}{t_{\log}}*\infty}}{\frac{-1}{t_{\log}}2.3} - \frac{10^{\frac{-1}{t_{\log}}*t}}{\frac{-1}{t_{\log}}2.3} \right) = \frac{Q_o t_{\log}}{2.3\left(10^{\frac{t}{t_{\log}}}\right)}$$

Why might you want to know these volumes?
Consider management of groundwater pumping in a basin.
This would help you estimate availabilty of groundwater.

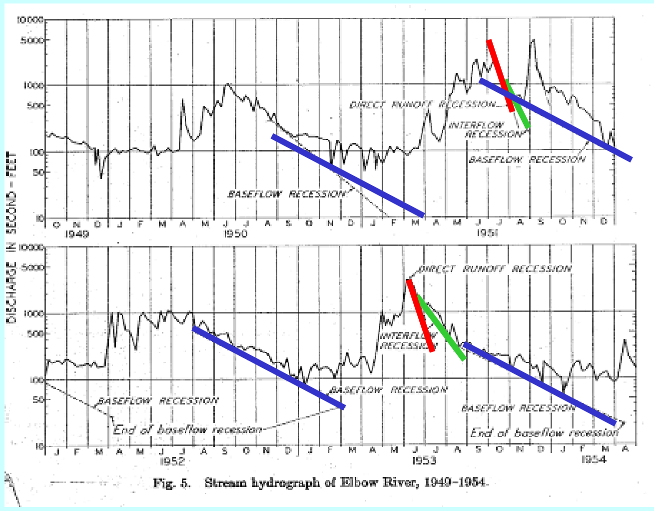


Fig. 5. Stream hydrograph of Elbow River, 1949–1954.

IN SHORT:

TOTAL GW THAT COULD DISCHARGE AT START OF RECESSION, V_{tp}:

$$V_{tp} \text{ is evaluated } \int_0^\infty \qquad V_{tp} = \frac{Q_o t_{\log}}{2.3}$$

TOTAL GW THAT COULD DISCHARGE AT END OF RECESSION, V_R:

$$V_R \text{ is evaluated } \int_{t@end}^\infty \qquad V_R = \frac{Q_o t_{\log}}{2.3\left(10^{\frac{t}{t_{\log}}}\right)}$$

By Determining the Total Potential Discharge at the Start of a Recession and the Remaining Potential Discharge at the End of That Recession, We Can Evaluate the Amount of Discharge

Volume-drained-during-recession = $V_{tp1} - V_{R1}$

By Determining the Total Potential Discharge at the Start of a Recession and the Total Potential Discharge at the End of the Previous Recession, We Can Evaluate the Amount of Recharge

Volume-recharged-before-next-recession = $V_{tp2} - V_{R1}$

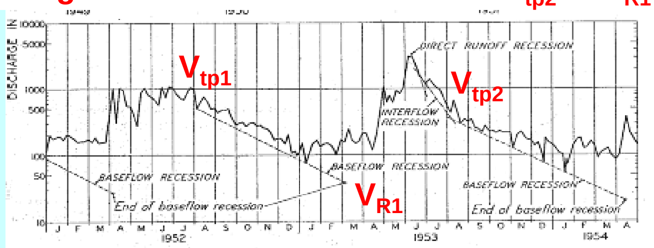
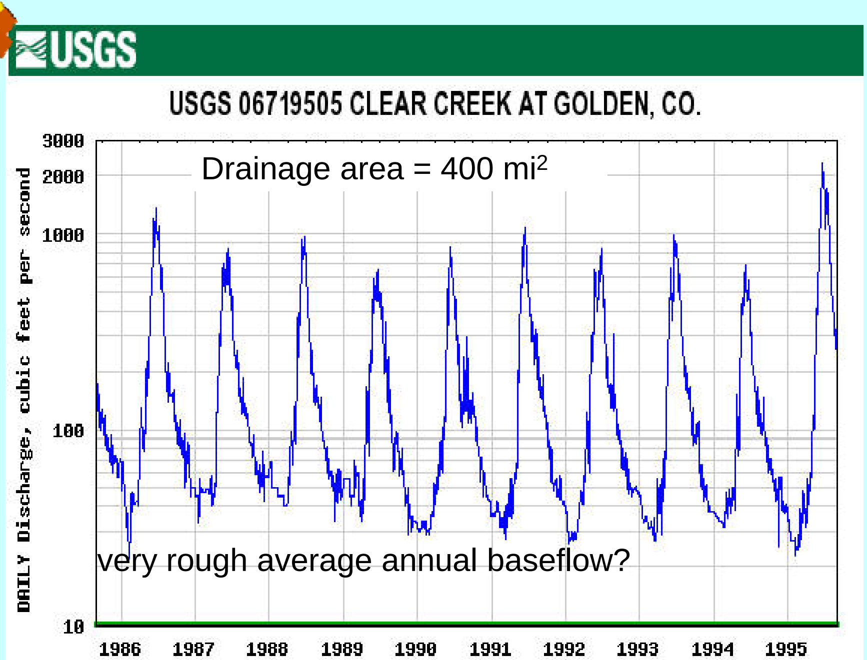


Fig. 5. Stream hydrograph of Elbow River, 1949–1954.



Methods in this class are only a beginning:

When called upon to do a task in your future career, look for new developments and options.

With respect to ground water / surface water interactions, one resource is the USGS Office of Ground Water:

http://water.usgs.gov/ogw/gwsw.html

Remember to visit the class web page

and

Try the old exam problems

Also you might explore the Drainage Experiment:

I allowed water to drain from a tub full of sand and measured the flow rate with time. The linked spreadsheet includes the data as well as a linear fit to the data and the resulting value of the "basin constant", a.

You are welcome to download, view, and manipulate the spreadsheet as you wish.

http://www.mines.edu/~epoeter/_GW/04Budget3/tank_baseflow.xls