HOW MUCH WATER DO WE NEED?
Take a moment to consider and estimate volume per person per day

One Person?

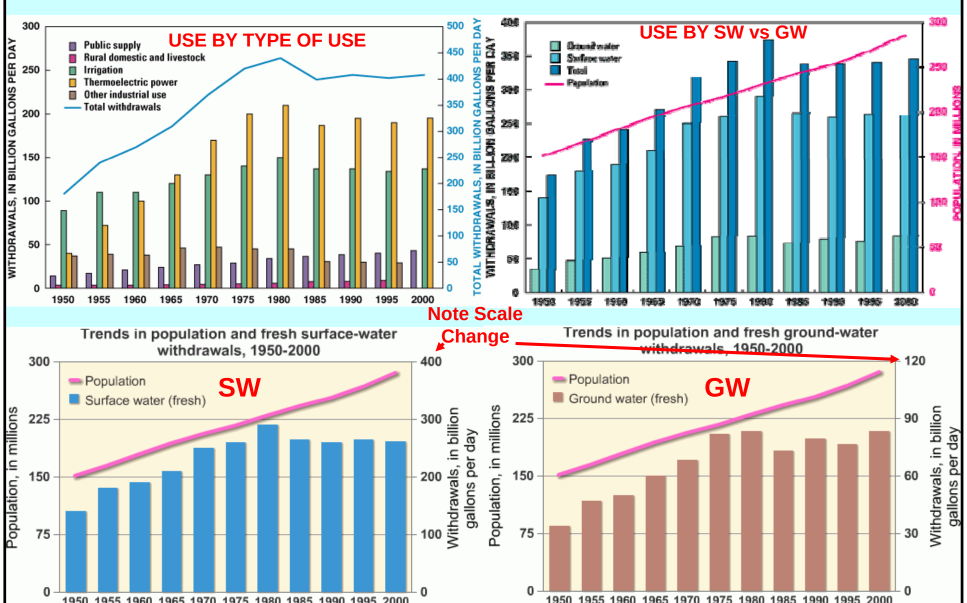
Flushing Toilet?

USA Personal Use?

Add Industrial, Municipal, Commercial ?

Add Energy And Food Production?

Images from http://ga.water.usgs.gov/edu/totrendbar.html



A Water Budget can be calculated for any defined domain

some may be easier than others

INFLOW = OUTFLOW + CHANGE IN STORAGE

Here an INCREASE in storage is taken as a POSITIVE CHANGE

BALANCE CAN APPLY TO THE EARTH's ENTIRE SPHERE,
OR TO ANY SUB-DOMAIN of the HYDROLOGIC SYSTEM

e.g.
Atmosphere
Ocean
Continent
Watershed
Stream Segment
Lake
Even anthropogenic objects: Processing Tank or a Pool
Or Political Entities: Counties, States, Nations

COMPONENTS OF A BASIN WATER BUDGET

INFLOW = OUTFLOW + CHANGE IN STORAGE

IN'S
PRECIPITATION + SW INFLOW + GW INFLOW + IMPORTED WATER =

OUT'S
ET + EVAPORATION + SW OUT + GW OUT + EXPORT + CONSUMPTION

STORAGE
+ INCREASE IN SW STORAGE + INCREASE IN GW STORAGE

FOR BALANCE TO BE MEANINGFUL,
ALL INPUTS, OUTPUTS, AND CHANGES IN STORAGE MUST BE IDENTIFIED

IN ALL PRACTICAL HYDROLOGIC PROBLEMS,
A ROUGH CHECK ON BALANCE IS ESSENTIAL
TO MAKE SURE YOU HAVE
APPROACHED AND EVALUATED THE PROBLEM CORRECTLY

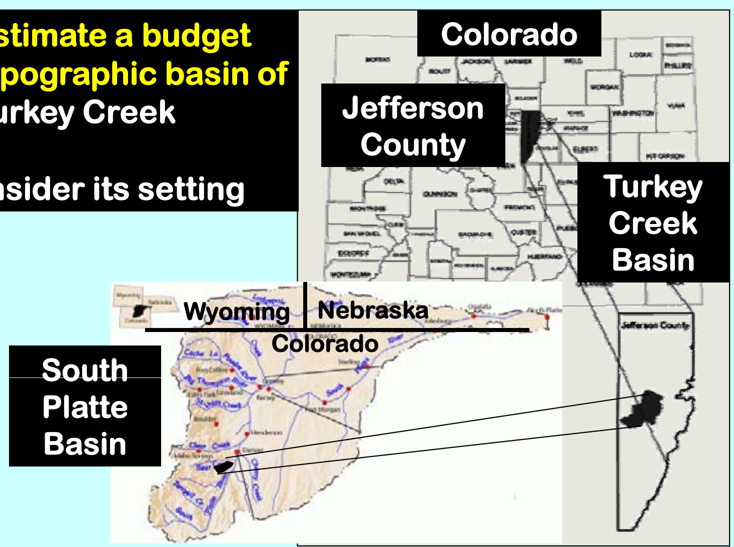
The process is simple and
much like accounting for your finances

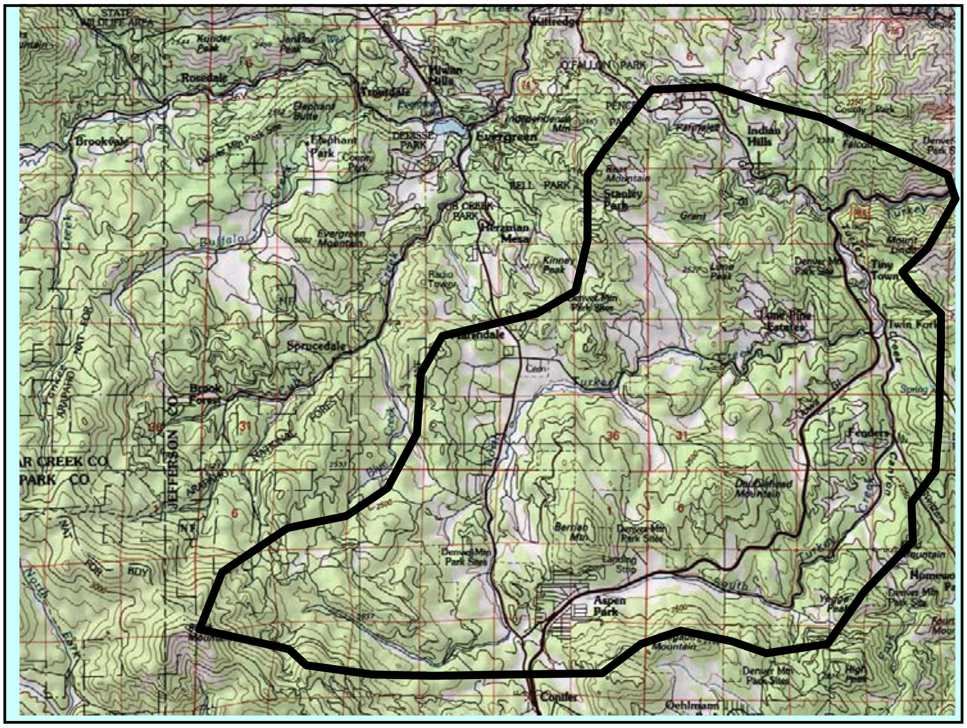
You track your income, expenditures
They differ in their type and character
For some you add or subtract one value
For others you must calculate a percentage
or
multiply a rate by a number of hours or items
then add and subtract the income and expenditure to find the
change in storage in your account

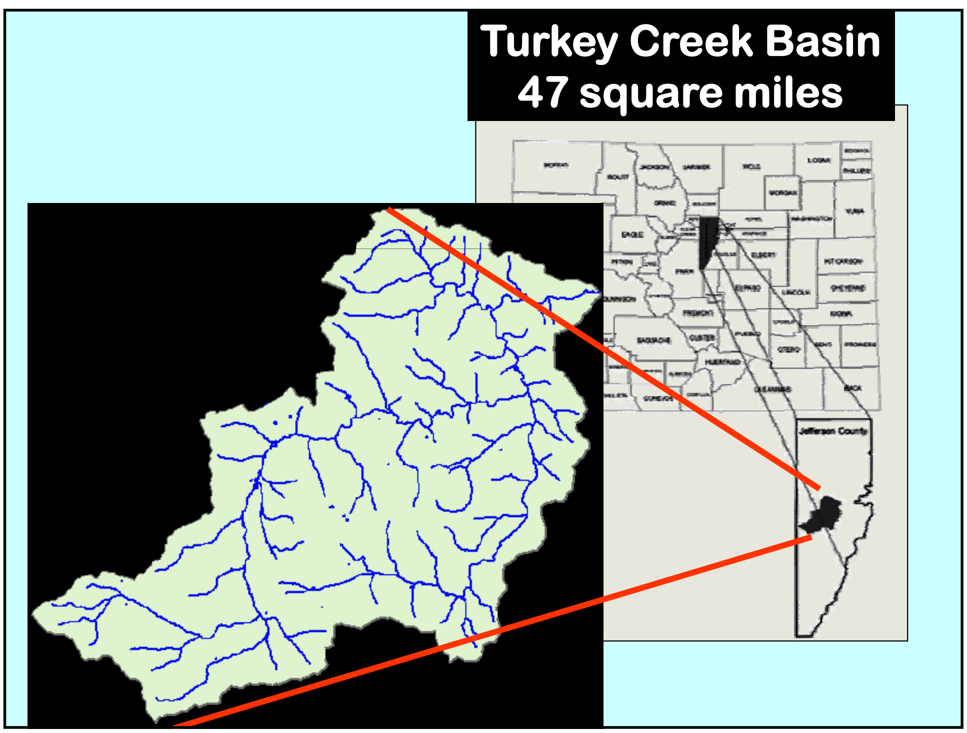
OFTEN WATER BUDGETS ARE PREPARED FOR A TOPOGRAPHIC BASIN
An area Surrounded by a Topographic Divide

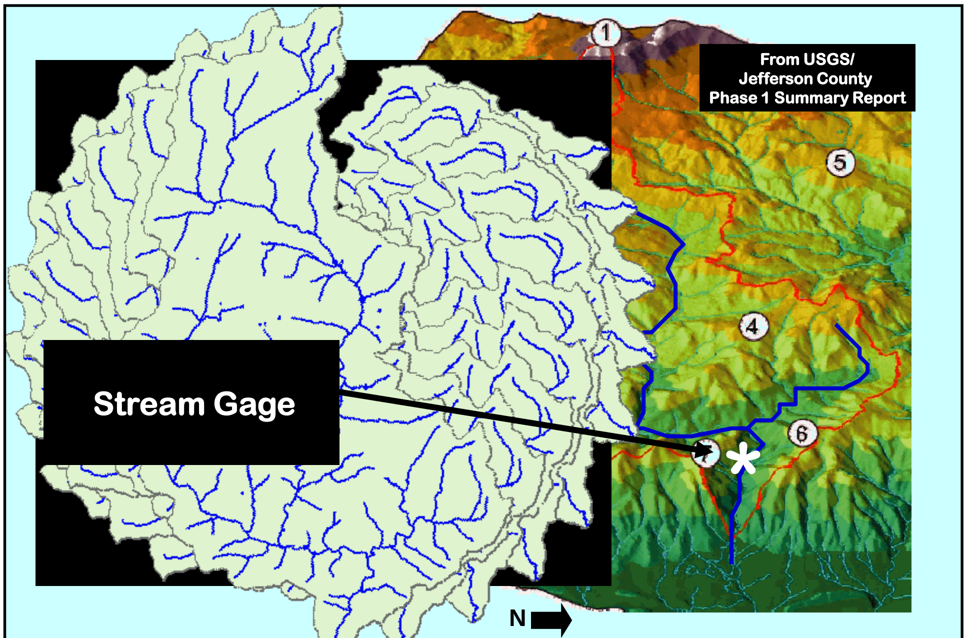
Let's estimate a budget
for the topographic basin of
Turkey Creek

1st consider its setting






Turkey Creek Basin
47 square miles
Jefferson County



1) Black Mountain 2) Be[illegible]ian Mountain 3) Double Head Mountain 4) Lone Peak 5) Evergreen Mountain 6) Mount Falcon 7) Mount Lindo 8) Yegge Peak 9) Crow Hill

COMPONENTS OF A BASIN WATER BUDGET

INFLOW = OUTFLOW + CHANGE IN STORAGE

IN'S

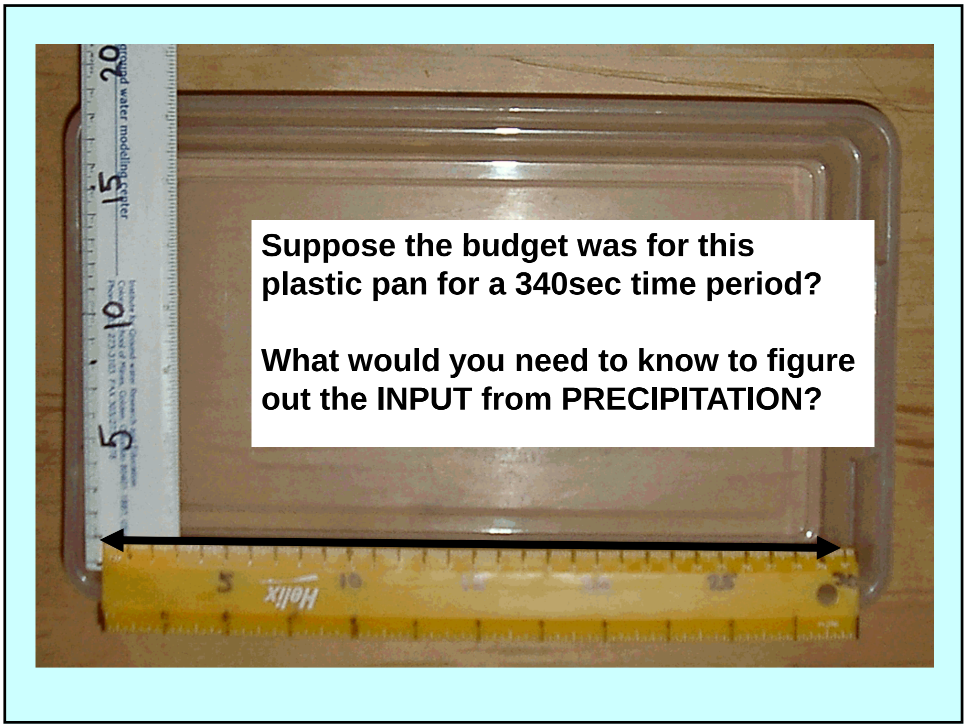
PRECIPITATION + SW INFLOW + GW INFLOW + IMPORTED WATER =

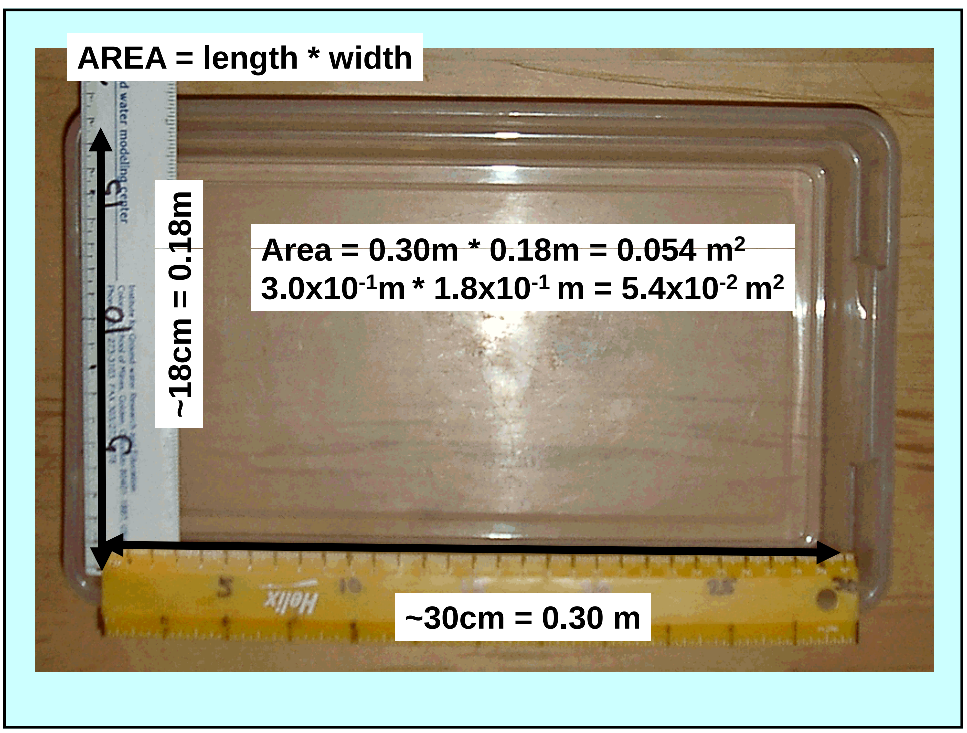
OUT'S

ET + EVAPORATION + SW OUT + GW OUT + EXPORT + CONSUMPTION

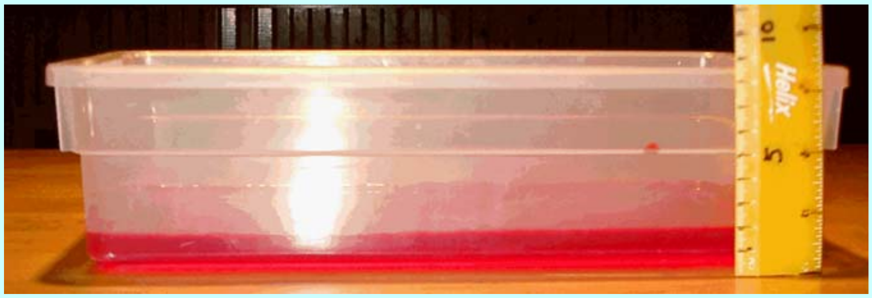
STORAGE

+ INCREASE IN SW STORAGE + INCREASE IN GW STORAGE


Suppose the budget was for this plastic pan for a 340sec time period?
What would you need to know to figure out the INPUT from PRECIPITATION?


AREA = length * width
~18cm = 0.18m
Area = 0.30m * 0.18m = 0.054 m^2
3.0x10^{-1}m * 1.8x10^{-1} m = 5.4x10^{-2} m^2
~30cm = 0.30 m

Usually we measure
"rain" depth over a period of time
Generally a day or year, but
this time, 340 sec
… see next for close up



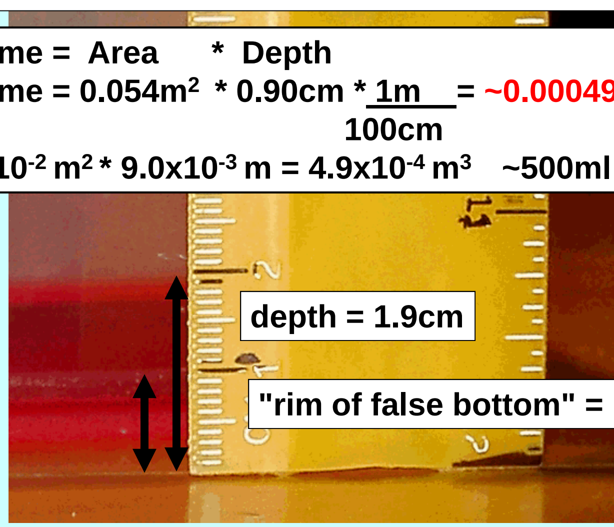
"rain" depth over area

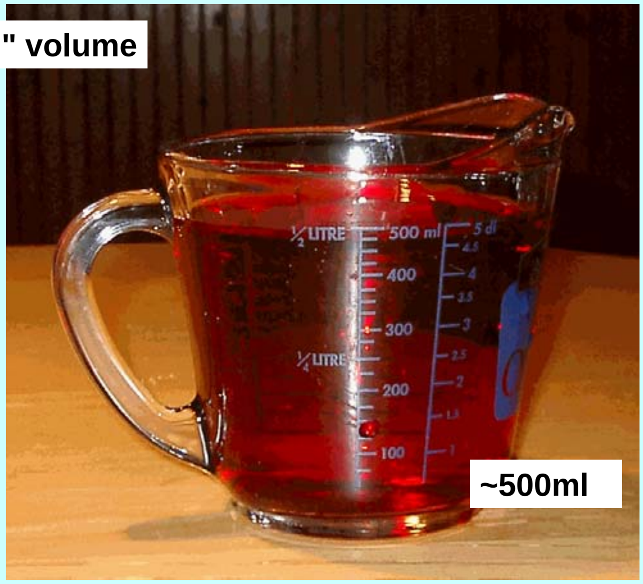
depth = measured - "rim of false bottom"
depth = 1.9cm - 1.0cm = 0.90cm

Volume = Area * Depth

$$\text{Volume} = 0.054\,m^2 * 0.90\,cm * \frac{1\,m}{100\,cm} = \sim 0.00049\,m^3$$

$$5.4\times10^{-2}\,m^2 * 9.0\times10^{-3}\,m = 4.9\times10^{-4}\,m^3 \quad \sim 500\,ml$$





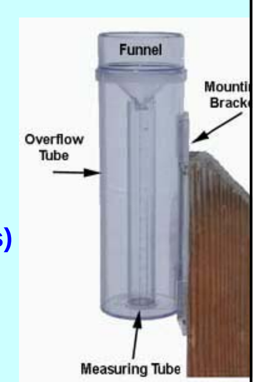
How do we Measure PRECIPITATION in the field?
Open Container
Location Is Critical
Need Average over Basin
but Measured at Discrete Points (e.g. NOAA)
Example of a locally initiated program

try 8/20/2010 http://new.cocorahs.org/
http://new.cocorahs.org/Maps/ViewMap.aspx

RULES OF THUMB:
Rising & Convergent - More Precipitation
Falling & Divergent - Less Precipitation

CONSIDER IF DATA ARE
Representative
Long Enough Record to Be Useful
Proper Distribution (Area & Types of Storms)

<u>HOMOGENEITY</u> OF PRECIPITATION DATA
moving stations
change of equipment
change of observer



to check for homogeneity:

compute ratio of values at stations at same times

compare - a break in constant ratio indicates a change

if only 1 year it is an error

otherwise, adjust early data to match later data

either multiply or divide early values at the station by the new ratio depending on whether the stationary station is in the denominator or the numerator of the ratio (see example)

HOMOGENEITY CORRECTION EXAMPLE:

YR	A	B	A:B	B:A
1	11	22		
2	10	21		
3	12	23		
4	6	23		
5	4	20		
6	5	21		

to check for homogeneity:

compute ratio of values at stations at same times

compare - a break in constant ratio indicates a change

if only 1 year it is an error

otherwise, adjust early data to match later data

either multiply or divide early values at the stationary station by the new ratio depending on whether the stationary station is in the denominator or the numerator of the ratio (see example)

HOMOGENEITY CORRECTION EXAMPLE:

YR	A	B	A:B	B:A
1	11	22	.50	2.00
2	10	21	.48	2.08
3	12	23	.52	1.92
4	6	23	.26	3.85
5	4	20	.20	5.00
6	5	21	.24	4.17

to check for homogeneity:

compute ratio of values at stations at same times
compare - a break in constant ratio indicates a change
if only 1 year it is an error
otherwise, adjust early data to match later data
either multiply or divide early values at the stationary station by the new ratio depending on whether the stationary station is in the denominator or the numerator of the ratio (see example)

HOMOGENEITY CORRECTION EXAMPLE:

YR	A	B	A:B	B:A	Corrected
1	11	22	.50	2.00	5.06 ~5
2	10	21	.48	2.08	4.83 ~5
3	12	23	.52	1.92	5.29 ~5
4	6	23	.26	3.85	6
5	4	20	.20	5.00	4
6	5	21	.24	4.17	5

FOR A:B B x 0.23 = CORRECT A VALUE FOR 1,2,3
FOR B:A B / 4.3 = CORRECT A VALUE FOR 1,2,3

If data are missing, the most likely value is:

$$P_x = \frac{1}{n}\left[\frac{A_x}{A_1}P_1 + \frac{A_x}{A_2}P_2 + \ldots + \frac{A_x}{A_n}P_n\right]$$

where: n = number of stations near station x which has the missing value
P_x = missing value of precipitation @ station of interest "x" for given year
A_x = average annual preciptation at station of interest "x"
$P_\#$ = precipitation at n nearby stations identified by # for given year
$A_\#$ = average annual precipitation at each of n stations identified by #

TAKE 5 MINUTES

homogeneity_missing.xls, sheets = "homogeneity" and "missing"

http://inside.mines.edu/~epoeter/_GW/02Budget1/BudgetPrecipEvap.htm

ONCE YOU ARE CONFIDENT IN THE DATA
COMPUTE EUD (EFFECTIVE UNIFORM DEPTH)

ARITHMETIC AVERAGE
Unweighted Average of All Point Values

THIESSEN WEIGHTING weighted by fraction of area closest to each point
Connect Each Station with Straight Line
Draw Perpendicular Bisectors to Each Line
3 Bisectors Meet at a Point
Yields Polygon Everywhere Closer to That Point
Express the Polygon Areas as % of Total Area
Avg Precipitation = Sum of (P @ Each Station X %Area)

ISOHYETAL WEIGHTING weighted by contoured area representing each point
Contour Lines (Isohyets) of Equal Precipitation
Draw to Conform to Other Features
Measure Area of Polygon Between Isohyets
Express the Polygon Areas as % of Total Area
Avg Precipitation = Sum of (avg P of the 2 contours X %Area)

ESTIMATE VOLUME OF PRECIPITATION IN TURKEY CREEK BASIN

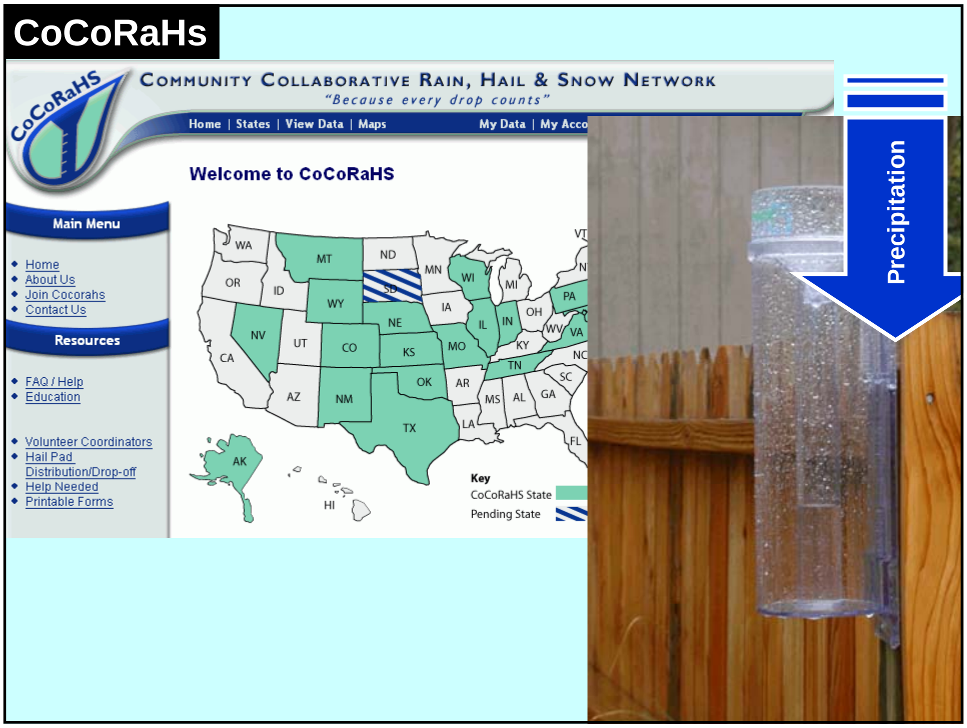
What is the depth of water that falls on Turkey Creek Basin in a year?

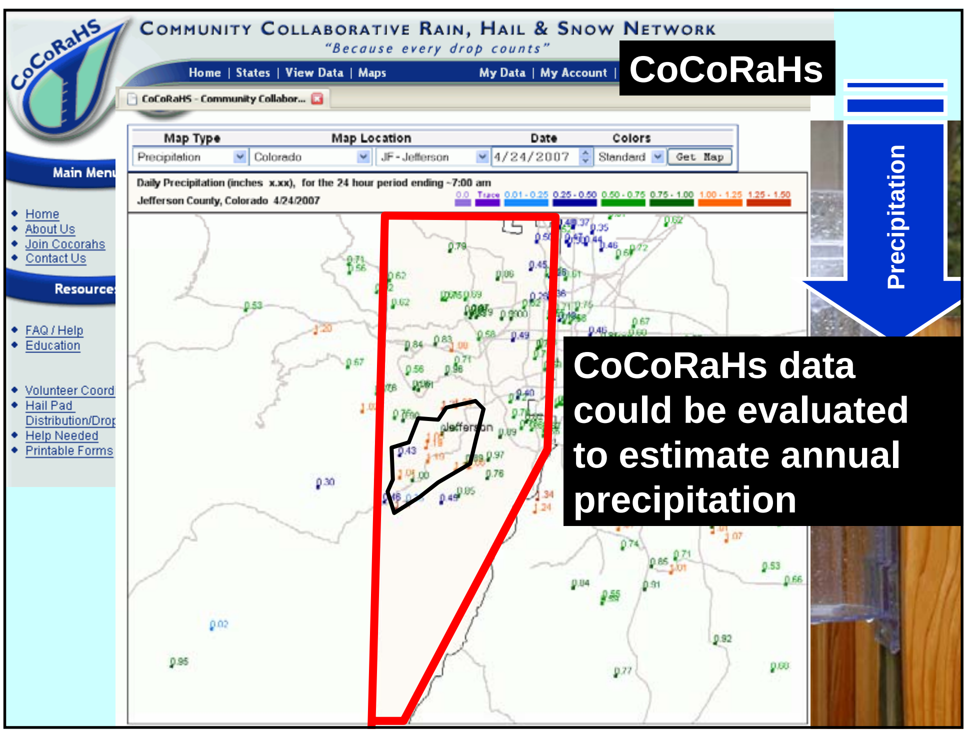
Surf the web? NOAA? USGS? Denver Airport? CoCoRAHS?

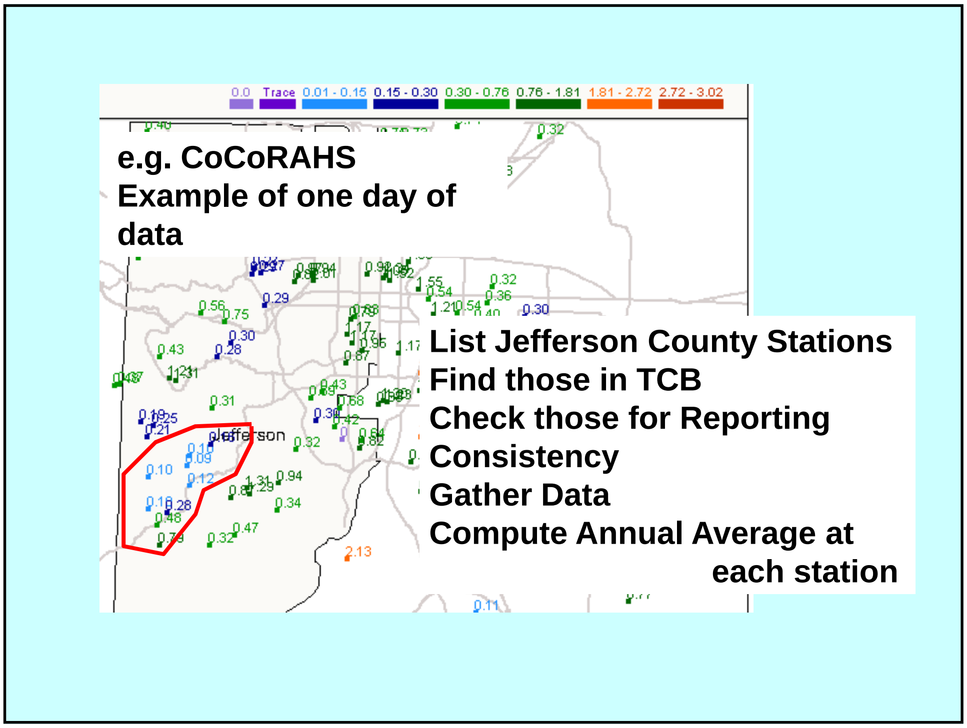
What will you trust?
How will you deal with the uncertainty?

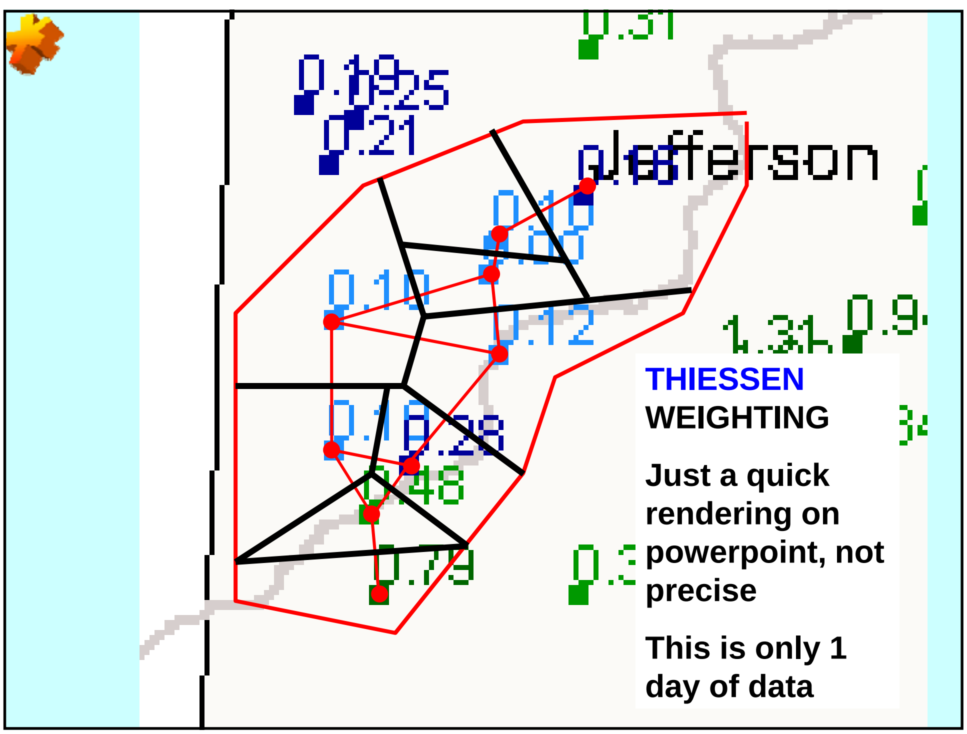
Reliability of Data – Longevity of Record – Effort Required

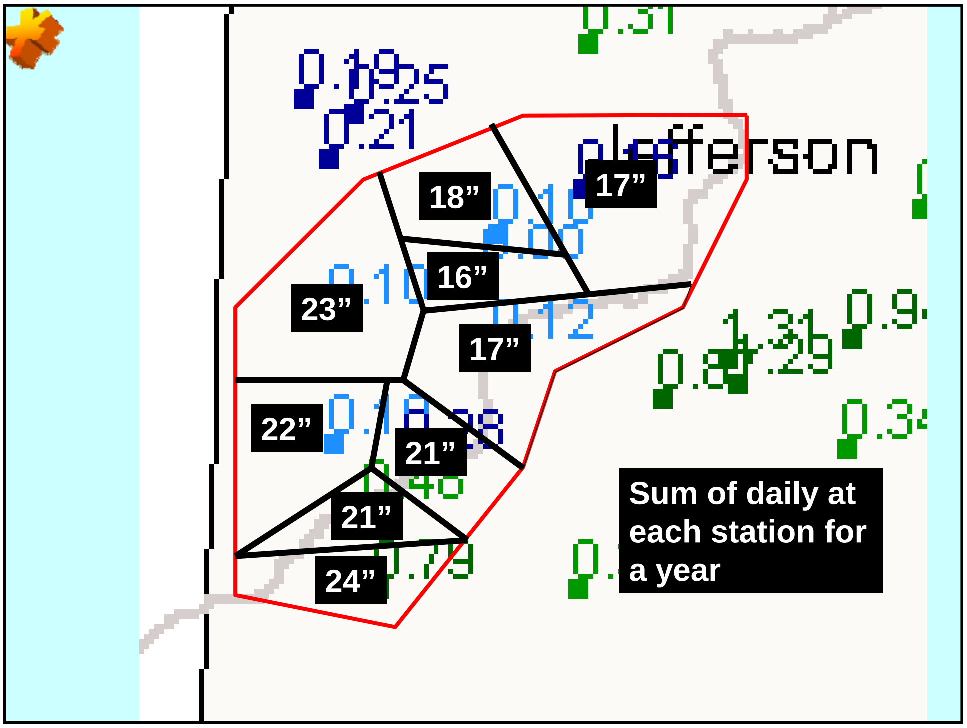
How critical is the question? How accurate must the estimate be?

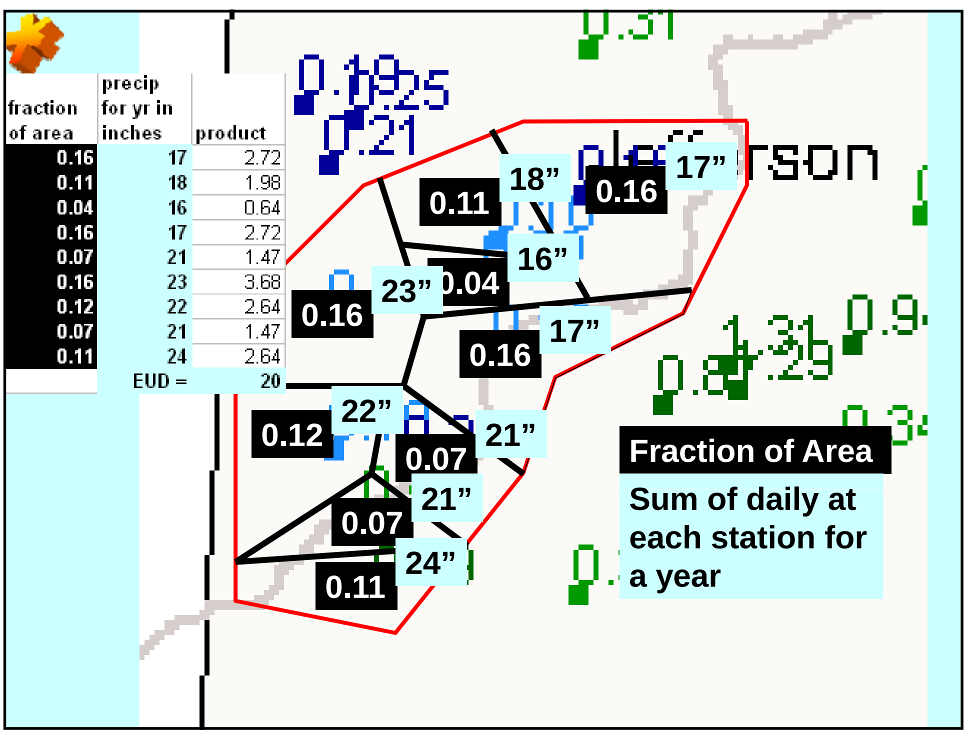

CoCoRaHs
CoCoRaHS
Community Collaborative Rain, Hail & Snow Network
"Because every drop counts"
Home | States | View Data | Maps
My Data | My Acco
Welcome to CoCoRaHS
Main Menu
Home
About Us
Join Cocorahs
Contact Us
Resources
FAQ / Help
Education
Volunteer Coordinators
Hail Pad
Distribution/Drop-off
Help Needed
Printable Forms
Key
CoCoRaHS State
Pending State
Precipitation


CoCoRaHS
Community Collaborative Rain, Hail & Snow Network
"Because every drop counts"
Home | States | View Data | Maps
My Data | My Account |
CoCoRaHs
Map Type
Map Location
Date
Colors
Precipitation
Colorado
JF - Jefferson
4/24/2007
Standard
Get Map
Daily Precipitation (inches x.xx), for the 24 hour period ending ~7:00 am
Jefferson County, Colorado 4/24/2007
Main Menu
Home
About Us
Join Cocorahs
Contact Us
FAQ / Help
Education
Hail Pad
Help Needed
Printable Forms
Precipitation
CoCoRaHs data could be evaluated to estimate annual precipitation

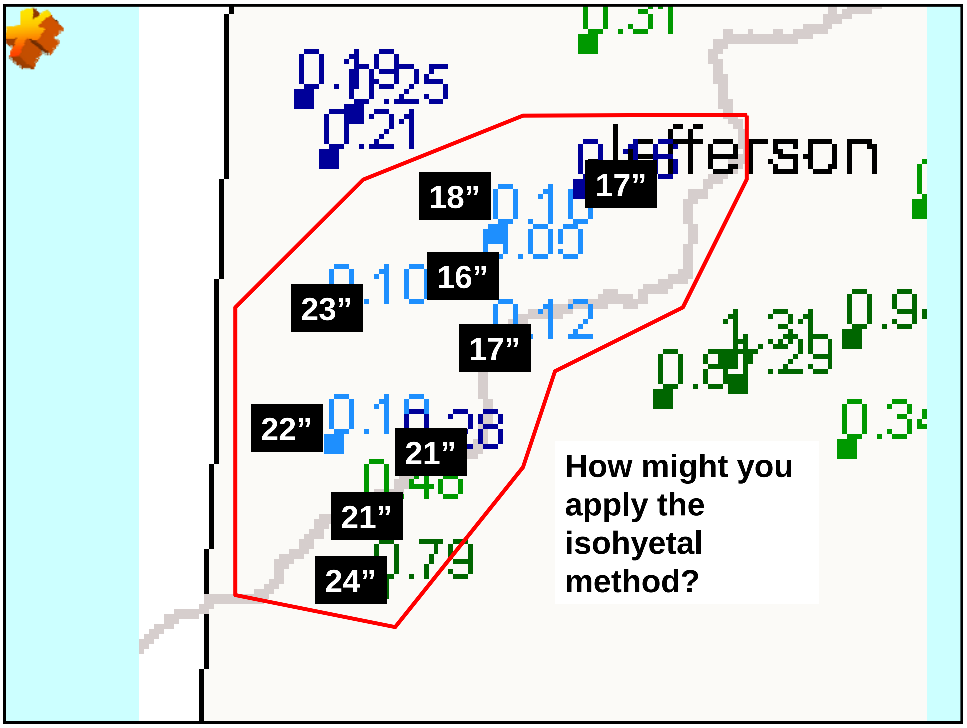

0.0
Trace
0.01 - 0.15
0.15 - 0.30
0.30 - 0.76
0.76 - 1.81
1.81 - 2.72
2.72 - 3.02
e.g. CoCoRAHS
Example of one day of data
List Jefferson County Stations
Find those in TCB
Check those for Reporting Consistency
Gather Data
Compute Annual Average at each station
Jefferson


Jefferson
THIESSEN WEIGHTING
Just a quick rendering on powerpoint, not precise
This is only 1 day of data





fraction of area	precip for yr in inches	product
0.16	17	2.72
0.11	18	1.98
0.04	16	0.64
0.16	17	2.72
0.07	21	1.47
0.16	23	3.68
0.12	22	2.64
0.07	21	1.47
0.11	24	2.64
	EUD =	20



PRISM is another source of precipitation estimates:

http://www.prism.oregonstate.edu/

"Internet Map Server" link under quicklinks
Conifer is 39.521N. The *longitude* is -105.304W
"TimeSeries" returns a table by month
"Normals" returns averages 1971-2000
Morrison is 39.666N. The *longitude* is -105.206W

"Normals" for precipitation in inches:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Conifer	0.83	0.92	2.35	2.98	3.23	2.07	2.67	2.8	1.53	1.41	1.44	1.01	23.23
Morrison	0.79	0.7	2.13	2.4	2.63	1.88	1.73	2.11	1.32	1.02	1.14	0.96	18.81

Alternatively grids of spatial data representing specified time periods can be downloaded

Volume of Precipitation on Turkey Creek Basin in a year?
Use 20 inches/yr for the average to facilitate moving along in class

Area of Turkey Creek Basin? = 47.2 mi^2

Take a few minutes to estimate the
volume input to the Basin via precipitation (work together)

COMPONENTS OF A BASIN WATER BUDGET

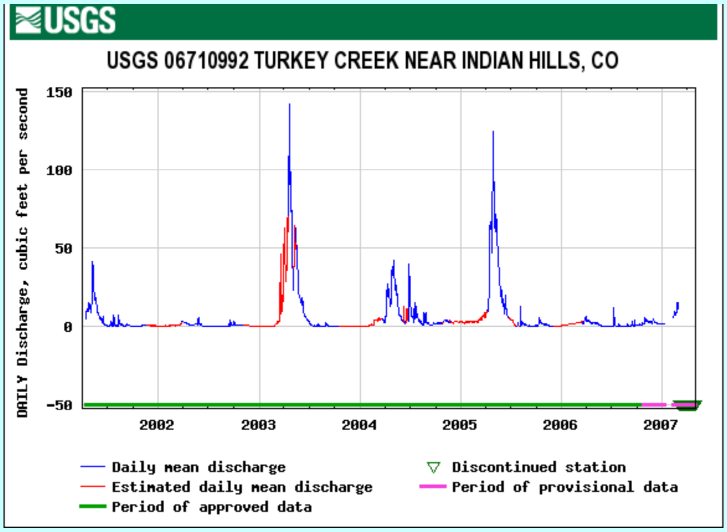
INFLOW = OUTFLOW + CHANGE IN STORAGE

IN'S
PRECIPITATION + SW INFLOW + GW INFLOW + IMPORTED WATER =
TCB 50000 AF
PAN 500 ml

OUT'S
ET + EVAPORATION + SW OUT + GW OUT + EXPORT + CONSUMPTION

STORAGE
+ INCREASE IN SW STORAGE + INCREASE IN GW STORAGE

Do we see $\underline{70\ \frac{ft^3}{sec}}$ (cubic feet per second cfs) flowing at the stream gage?



WE WILL ESTIMATE SURFACE WATER OUTFLOW DURING OUR NEXT CLASS, BUT CLEARLY IT IS << 70CFS, HOWEVER STREAMFLOW IS NOT THE ONLY, NOR THE LARGEST OUTFLOW

COMPONENTS OF A BASIN WATER BUDGET

INFLOW = OUTFLOW + CHANGE IN STORAGE

IN'S

PRECIPITATION + SW INFLOW + GW INFLOW + IMPORTED WATER =

TCB 50000 AF

PAN 500 ml

OUT'S

ET + EVAPORATION + SW OUT + GW OUT + EXPORT + CONSUMPTION

STORAGE

+ INCREASE IN SW STORAGE + INCREASE IN GW STORAGE

To Estimate EVAPORATION AND EVAPOTRANSPIRATION

FROM METEOROLOGICAL DATA

First some basic concepts:

ABSOLUTE HUMIDITY - Grams of Water Per Cubic Meter of Air

SATURATION HUMIDITY - Max Moisture Content @ a Given Temp

RELATIVE HUMIDITY - Absolute Humid / Sat Humid at a Given Temp

EVAPORATION STOPS AT RELATIVE HUMID = 100%

CONDENSATION OCCURS AT RELATIVE HUMID = 100%

DEW POINT - TEMP AT WHICH CONDENSATION OCCURS WHEN A PACKET OF AIR IS COOLED

To Measure EVAPORATION
Shallow Pan
Monitor Volume
Pan Coefficient < 1
Some data on EVAP & PAN COEFFICIENTS are available in Water Atlases

TO ESTIMATE EVAPORATION IF NO DATA AVAILABLE:

Nomograph from US National Weather Service
(Fetter Applied Hydrogeology)
need:
Mean Temp
Mean Dew Point Temp
Solar Radiation
Wind Movement

Take 5 min to get the evaporation rate

Mean Temp = 75 F
Mean Dew Point Temp = 50 F
Solar Radiation = 500 langley's
Wind Movement = 200 mi/day

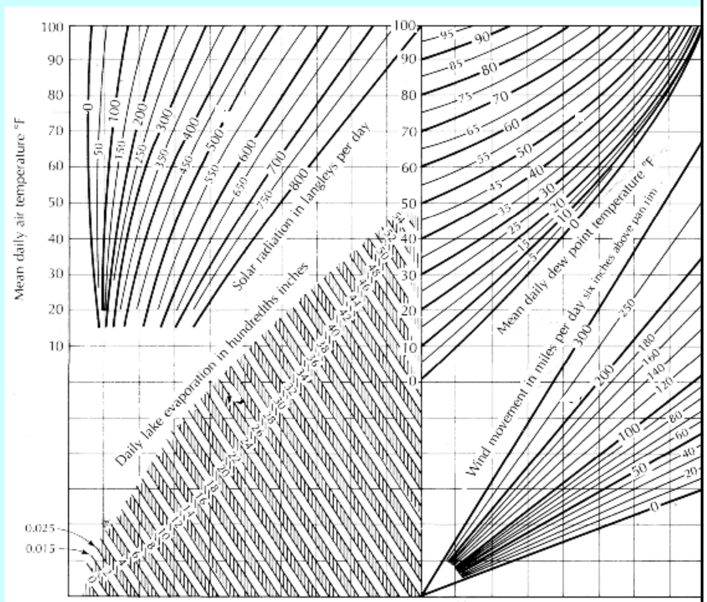


FIGURE 2.1 Nomograph used to determine the value of daily lake evaporation for shallow lakes if solar radiation, mean daily air temperature, mean daily dew point temperature, and wind movement are known. Source: Roberts & Stall 1967.

TABLES of INTEREST

TABLE 2.1. Saturation humidity of air (grams per cubic meter)

Temperature °C	Humidity
−25	0.705
−20	1.074
−15	1.605
−10	2.358
−5	3.407
0	4.874
5	6.797
10	9.399
15	12.83
20	17.30
25	23.05
30	30.38

SOURCE: *Handbook of Chemistry and Physics* (Cleveland, Ohio: CRC Publishing Company, 1976).

TABLE 2.2. Class-*A* land pan coefficients for midwestern United States

January	0.62	July	0.76
February	0.72	August	0.75
March	0.77	September	0.73
April	0.77	October	0.69
May	0.78	November	0.63
June	0.77	December	0.58
Annual 0.75			

SOURCE: W. J. Roberts and J. B. Stall, Illinois State Water Survey Report of Investigation 57, 1967.

EVAPOTRANSPIRATION

TRANSPIRATION - Loss of Water From Plants

EVAPORATION - Loss of Water From Soil And Free Water Surfaces

EVAPOTRANSPIRATION ET
Total Water Loss, Free H_2O, Plant Transpiration And Soil Moisture Evaporation

POTENTIAL EVAPOTRANSPIRATION PET
Amt of Water Plants Can Transpire & Air Can Carry Away If No Water Deficiency
depends on: Temperature - Solar Radiation - Vegetation Type & Maturity
Wind Speed - Dew Point - Soil Texture And Permeability
see Thornthwaite / Mather and many others

ACTUAL ET AET < Potential --- AET When Soil Doesn't Have All The Water Required

FIELD CAPACITY - Volume of Water Soil Holds after Gravitational Water has Drained

AET < PET When Soil below field capacity

WILTING POINT - Soil Is So Dry, Osmotic Pressure of Roots No Longer Exceeds Surface Tension of H_2O in Soil (Osmotic Pressure < Surface Tension)

PHREATOPHYTES - Tap The Water Table

To estimate **EVAPOTRANSPIRATION (ET)**

Lysimeter

$$ET = SI + P + I - SF - D$$

ET - ET FOR PERIOD
SI - INITIAL VOL OF MOISTURE
P - PRECIPITATION INTO LYSIMETER
I - IRRIGATION WATER ADDED
SF - FINAL VOL OF MOISTURE
D - EXCESS MOISTURE DRAINED FROM SOIL

Calculate PET
From climatological variables and Energy balance equations

ET Dome measures AET at a point in space and time
Measures rate of accumulation of vapor density with wet/dry bulb thermometer

Correlation Eddy Tower continuous AET at a point in space
Measures vertical air velocity and vapor content ~30x per sec
To determine the net moisture flux, thus the evapotranspiration rate

SAMPLE SOIL MOISTURE BUDGET

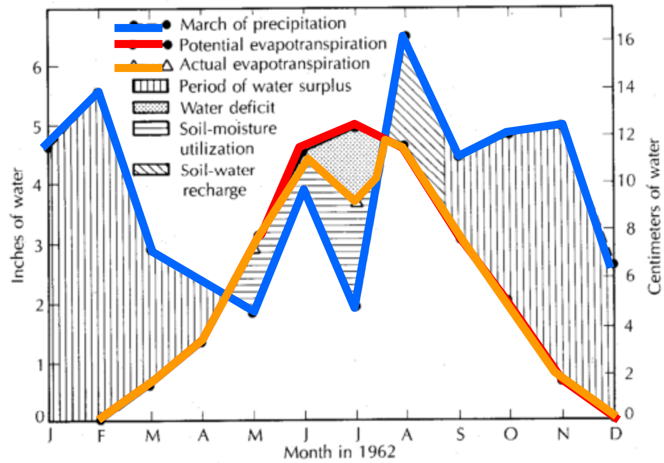
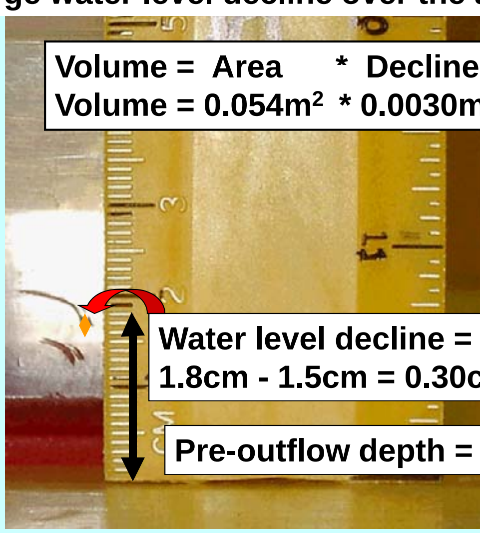


FIGURE 6.4 Soil-moisture budget for Bridgehampton, New York. The diagram is based o measured precipitation and computed potential and actual evapotranspiration. The Thorr thwaite method was used for evapotranspiration computations. Source: C. W. Fetter, Jr *Bulletin, Geological Society of America* 87 (1976): 401–6.

Suppose the budget was for the plastic pan for a 340sec time period?

So it is hot hot hot and windy and in that brief time We find a large water level decline over the area

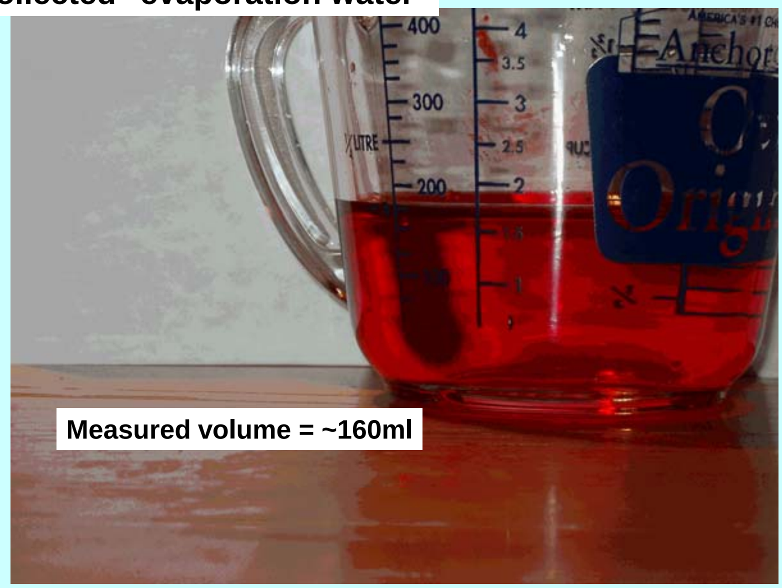


Volume = Area * Decline
Volume = $0.054m^2$ * $0.0030m$ = ~$0.00016m^3$

Water level decline = 1.8cm - 1.5cm = 0.30cm = 0.0030m

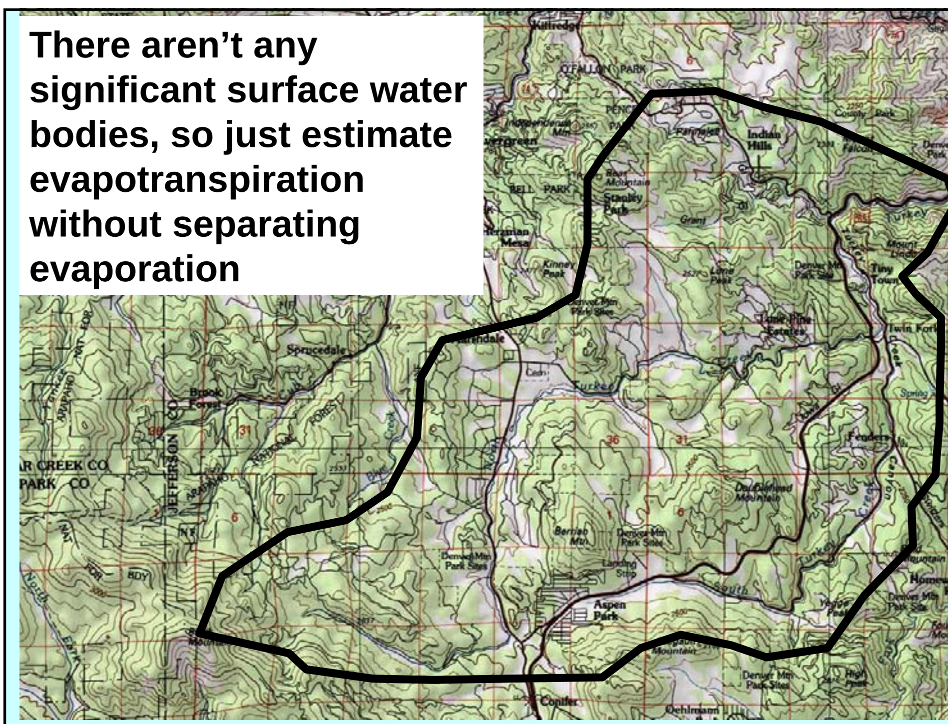
Pre-outflow depth = 1.8cm

Collected "evaporation water"



Measured volume = ~160ml

There aren't any significant surface water bodies, so just estimate evapotranspiration without separating evaporation



Volume of Evapotranspiration in Turkey Creek Basin in a year?
Hopefully when you researched the ET rate in TCB you would find the Jefferson County – Mountain Ground Water Resource Study Report
http://inside.mines.edu/~epoeter/_GW/02Budget1/wri03-4034.pdf This is a big file & only FYI not required because:
Use 18 inches/yr for the average to facilitate moving along in class

Area of Turkey Creek Basin? = 47.2 mi^2

Take a few minutes to
estimate the volume output to evapotranspiration

Are there other inputs?

COMPONENTS OF A BASIN WATER BUDGET

INFLOW = OUTFLOW + CHANGE IN STORAGE

IN'S
PRECIPITATION + SW INFLOW + GW INFLOW + IMPORTED WATER =
TCB 50000 AF
PAN 500 ml

OUT'S
ET + EVAPORATION + SW OUT + GW OUT + EXPORT + CONSUMPTION
TCB 45000 AF + 0
PAN 0 + 160 ml

STORAGE
+ INCREASE IN SW STORAGE + INCREASE IN GW STORAGE