# STREAM FLOW


Hydrosphere (EOS 656)
April 06, 2010

Guest Lecture
By: M. Tugrul Yilmaz
*tugrul@iges.org*

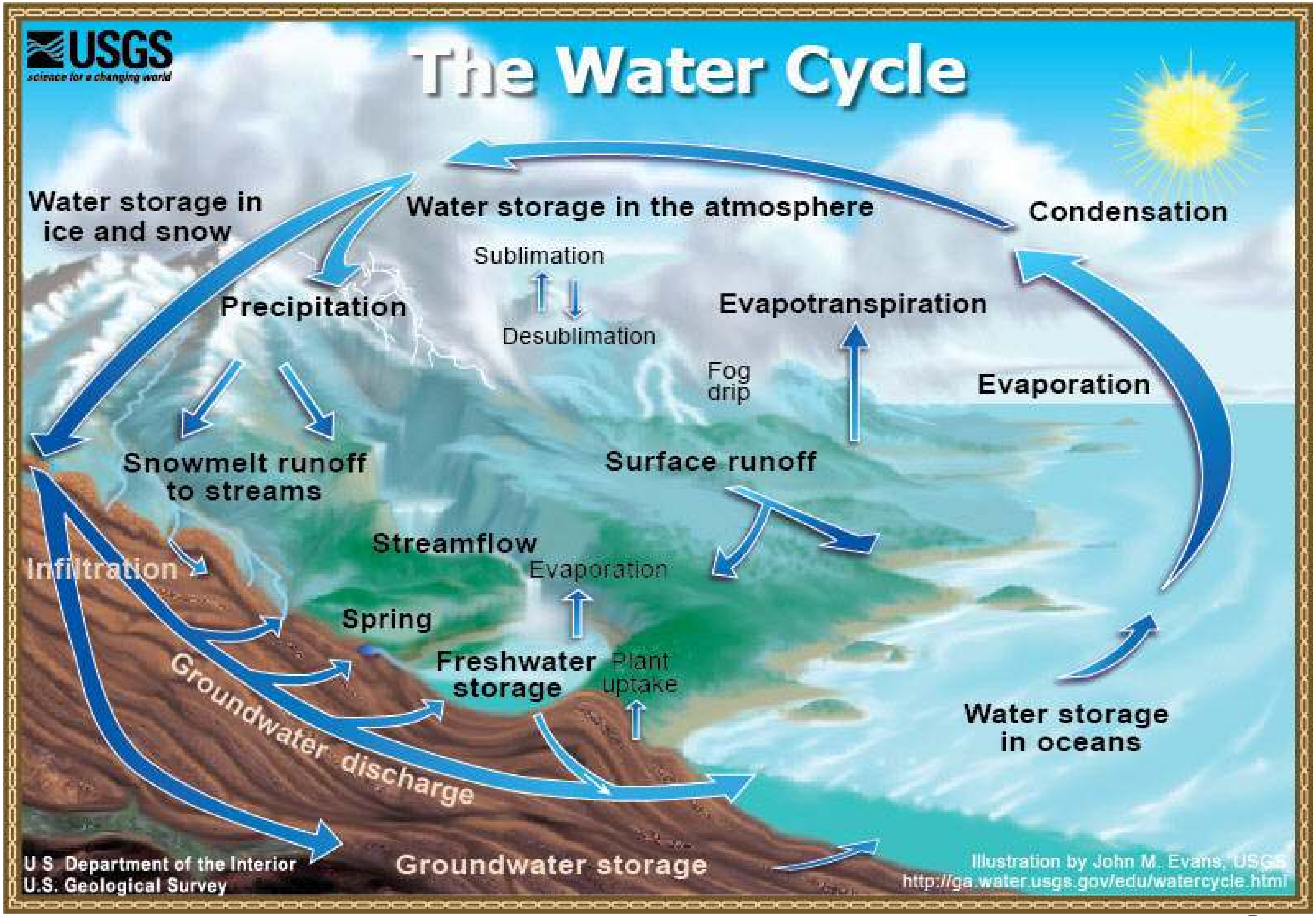



Image courtesy of USGS, http://ga.water.usgs.gov/edu/watercycle.html

Stream flow is a body of water that is flowing on Earth’s surface.

It is, arguably, the most important component of hydrological cycle that effects us directly (socially, economically, politically).

It is a major source for our drinking water and agricultural needs, a habitat for living organisms, a source for electricity production, and sometimes the disaster itself.

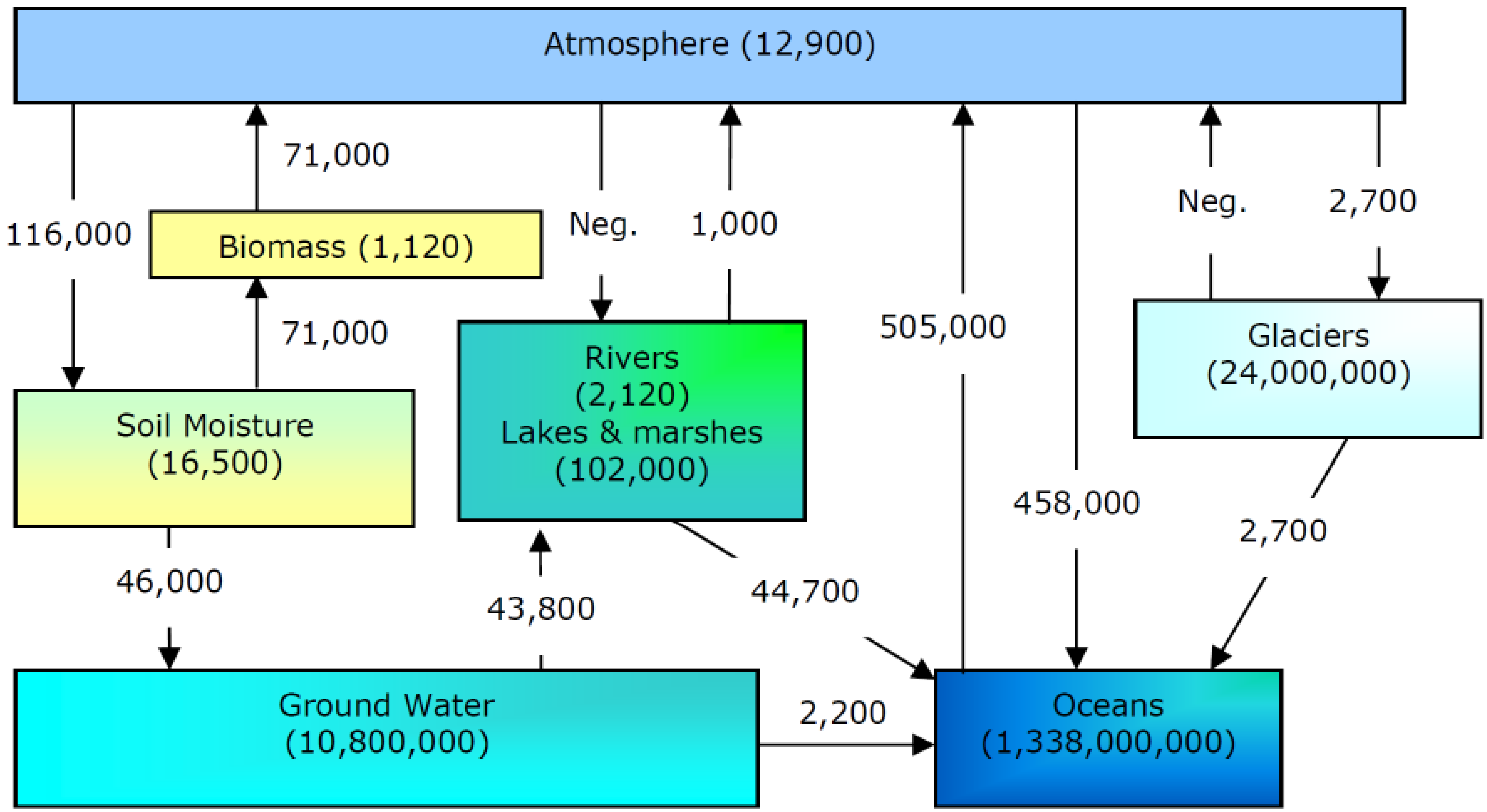



Image courtesy of MIT, ocw.mit.edu/OcwWeb/Civil-and-Environmental-Engineering/1-72Fall-2005/LectureNotes/

Streamflow is a residual of the other water cycle elements; hence its accurate indirect estimation (through other parameters) is still a challenge.

# 1- Basic Terms

**Riparian Zones** are the ecosystems at the interface between land and rivers.

**Watershed** is a piece of land that all the water that falls on the ground drains into a river.

**Tributaries** are small streams or rivers that flow into larger rivers.

Image courtesy of http://techalive.mtu.edu/meec/module01/Watershed.html

Image courtesy of www.anra.gov.au/topics/vegetation/pubs/biodiversity/bio_assess_conservation.html

**Infiltration Rate:** The capacity of soil to suck the available water at the surface (or at lower layers). It is inversely related with the saturation of soil.

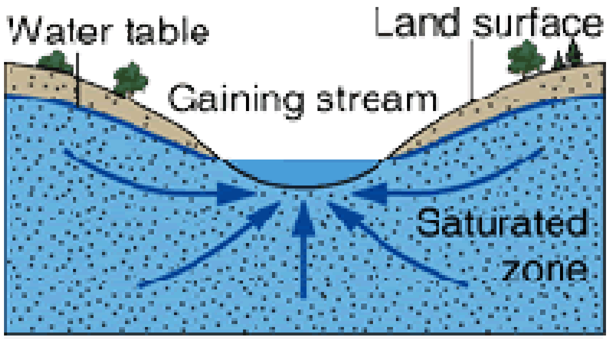
**Overland Flow:** Can happen in two ways:

1) When the rainfall intensity exceed the infiltration rate of soil (also called **Hortonian Overland Flow**).

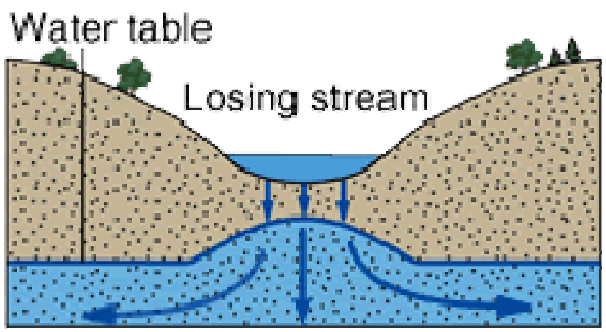
2) When the groundwater table rises up to the surface (also called **Saturation Overland Flow**).

Hortonian Overland Flow

Image courtesy of http://www.flickr.com/photos/15157983@N00/211869881




## Gaining Stream




## Loosing Stream

## Dry Stream Bed

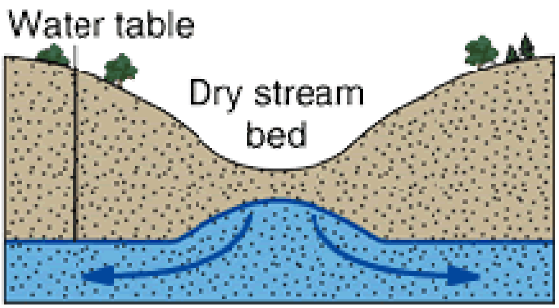



Image courtesy of http://www.salemstate.edu/~lhanson/gls100/gls100_hydro.htm

# How is Streamflow born?

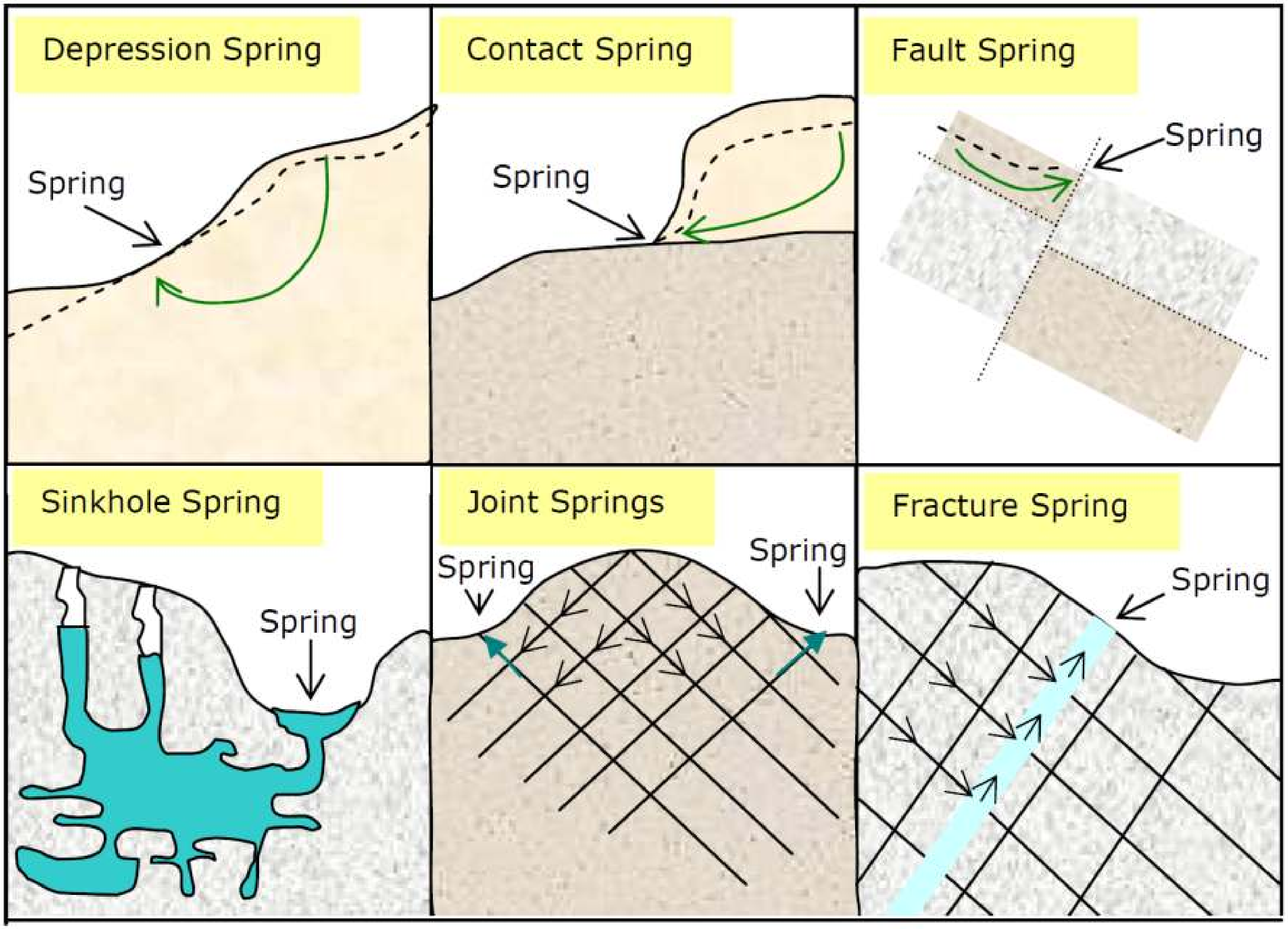



Image courtesy of MIT, ocw.mit.edu/OcwWeb/Civil-and-Environmental-Engineering/1-72Fall-2005/LectureNotes/

# 2- Measuring/estimating Stream flow

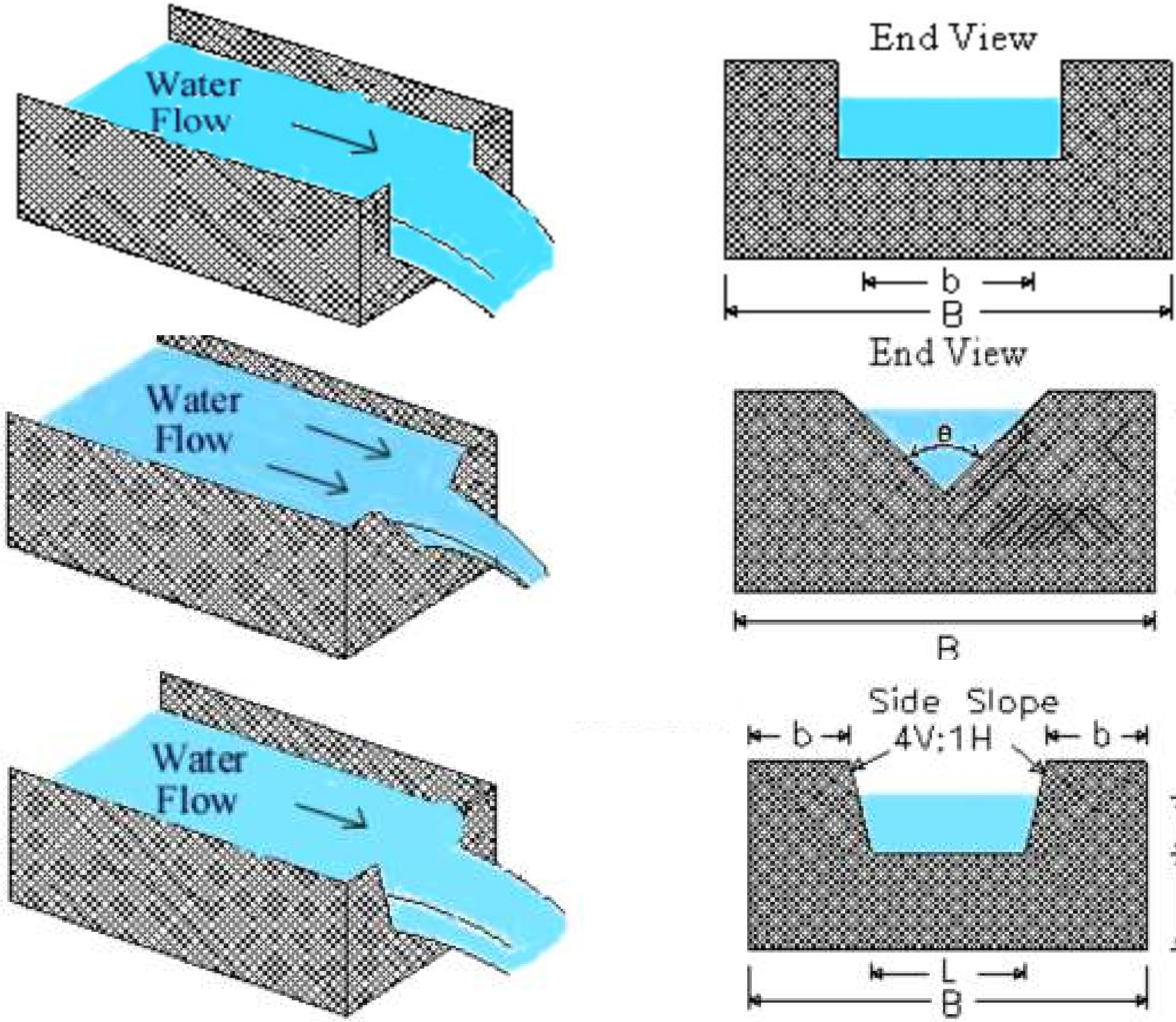
# Measuring Discharge

Weirs are structures that have known area – discharge relationship (depending on some other empirical parameters).

***Advantage***: Water head is the only necessary measurement needed to estimate the discharge.

**Q = C*L*H**

Q is the discharge (flow rate over the weir)
C is the effective coefficient of discharge
L is the length of the weir crest
H is the head measured above the weir crest




**Rectangular weir**

**V-notch weir**

**Cipoletti weir**

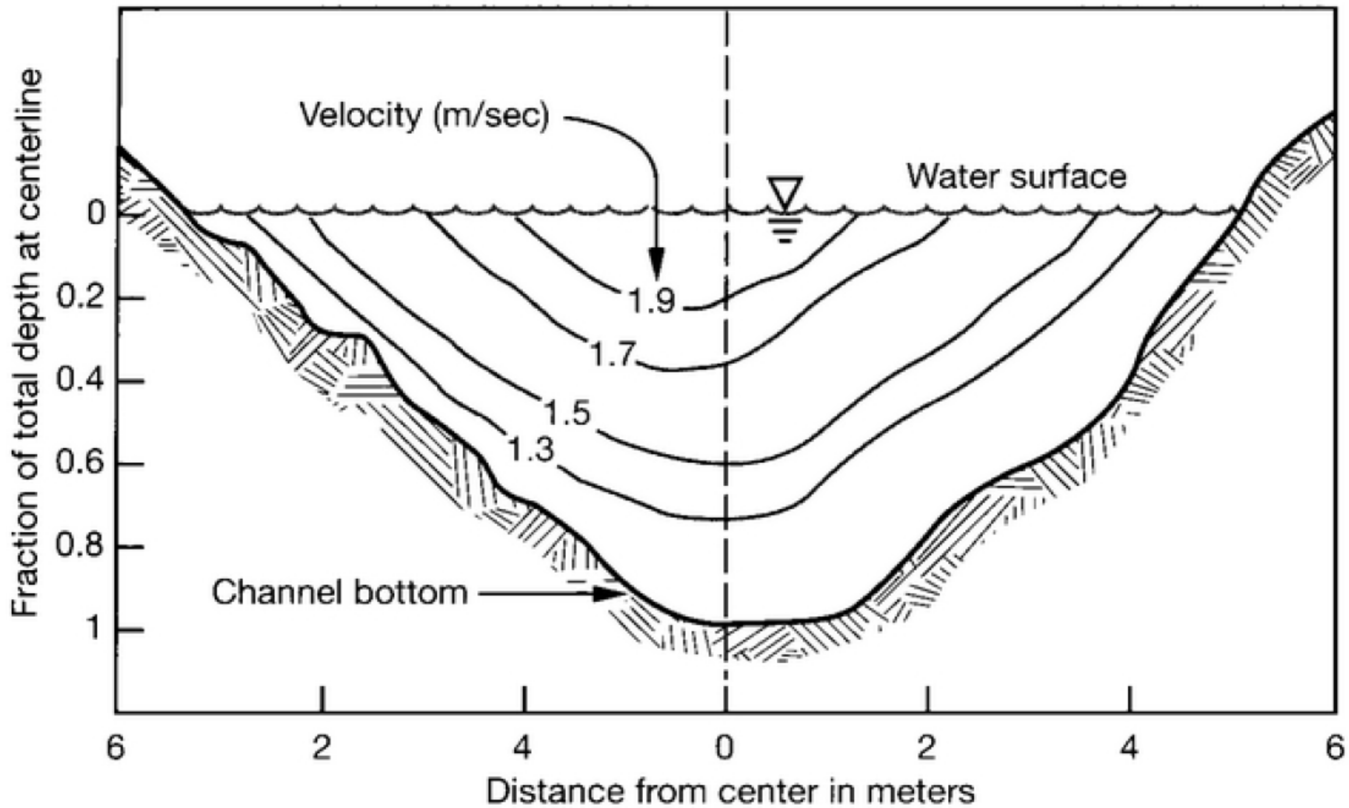
Image courtesy of http://www.lmnoeng.com/Weirs/RectangularWeir.htm

**Other types include triangular and circular. Among them rectangular weir is the most common type whereas V-notch type gives more sensitivity to the discharge.**

Image courtesy of http://tiee.ecoed.net/vol/v1/data_sets/hubbard/fig1stream.jpg




# Estimating Discharge, Q = V *A




Q = V * A
Q=discharge (m$^3$/sec)
V=Velocity(m/sec)
A=Area(m$^2$)

# Measuring Water Depth

## Ultrasonic water depth measurements

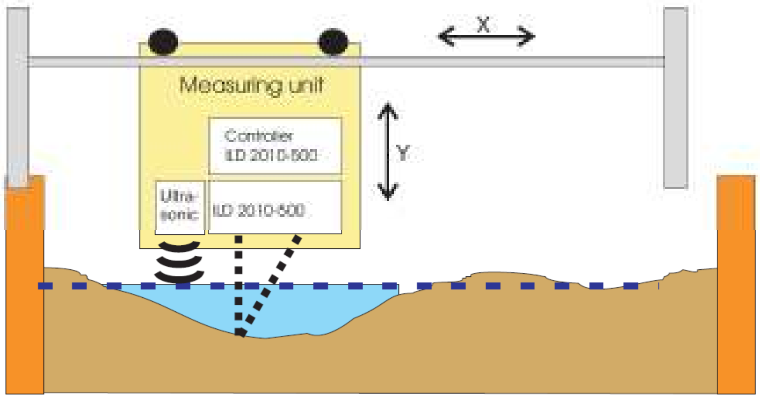



Image courtesy of www.micro-epsilon.com

## Pressure Tensiometers

Image courtesy of www.decagon.com

## Water Level Recorder

Image courtesy of www.geneq.com

# Rating curves

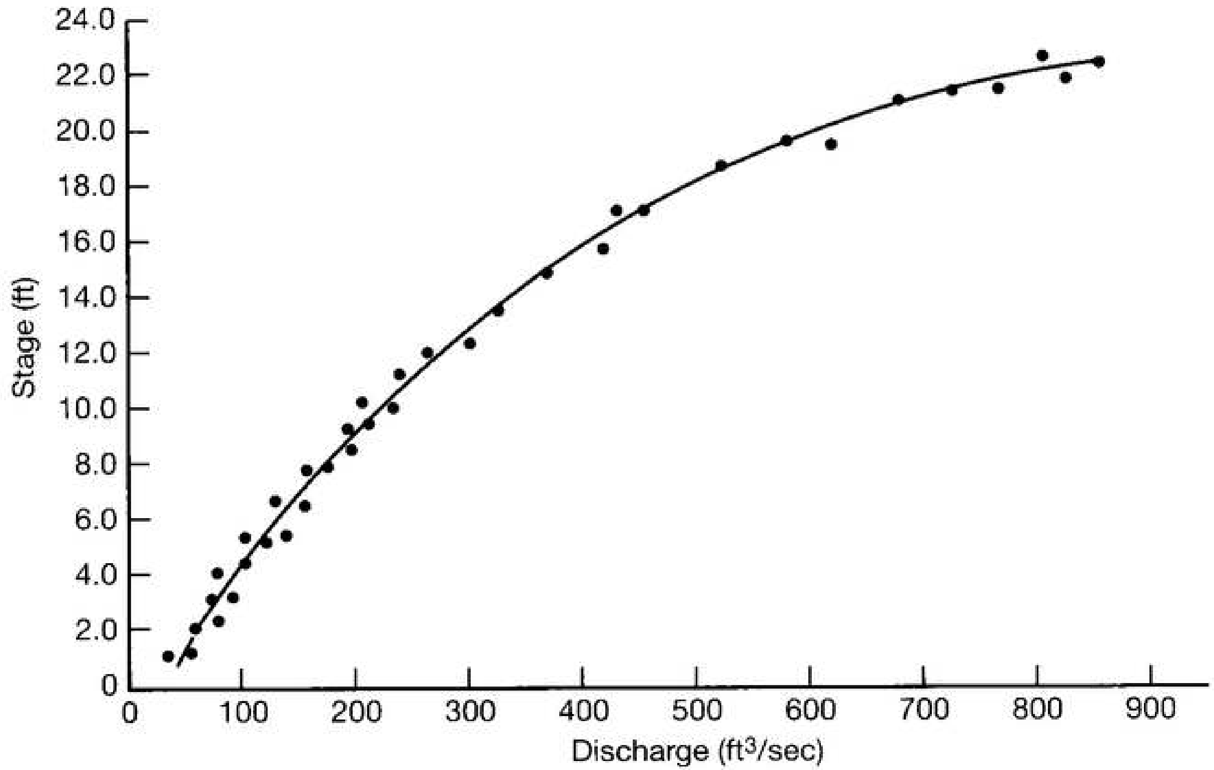



Image courtesy of http://www.utdallas.edu/~brikowi/Teaching/Field_Methods/sanders-1998_fig3-22.jpg

# Measuring Velocity

**$Q = V * A$**

Velocity profile along the river (both horizontally and vertically) is not uniform!!!

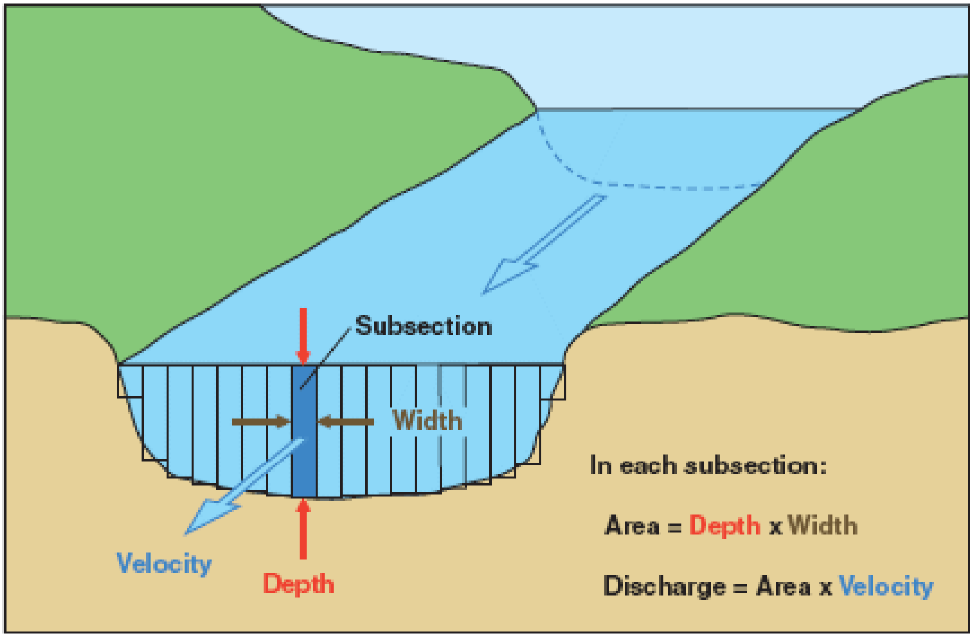
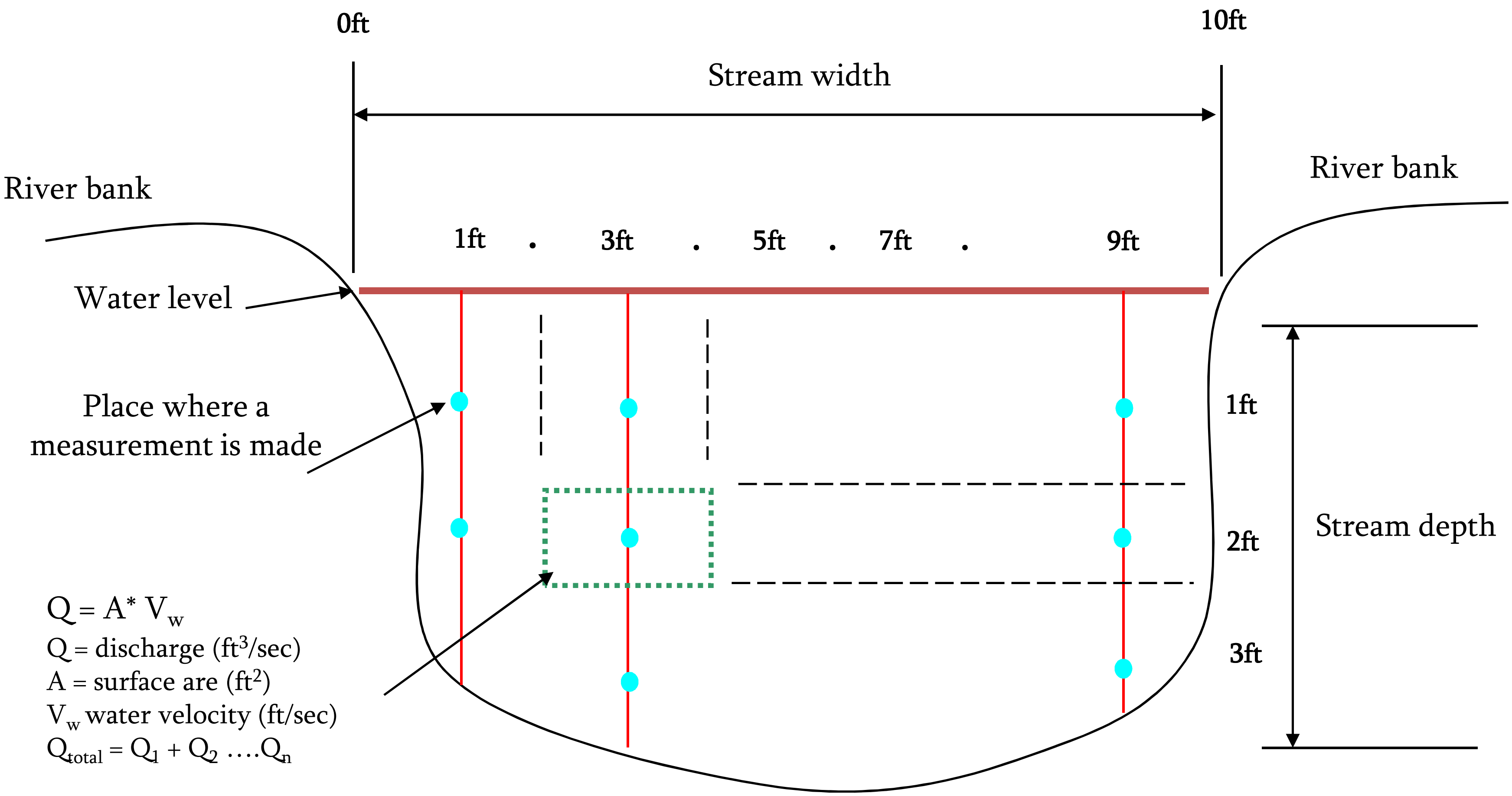



Image courtesy of USGS, http://ga.water.usgs.gov/edu/streamflow2.html

An average value is needed. Two options:

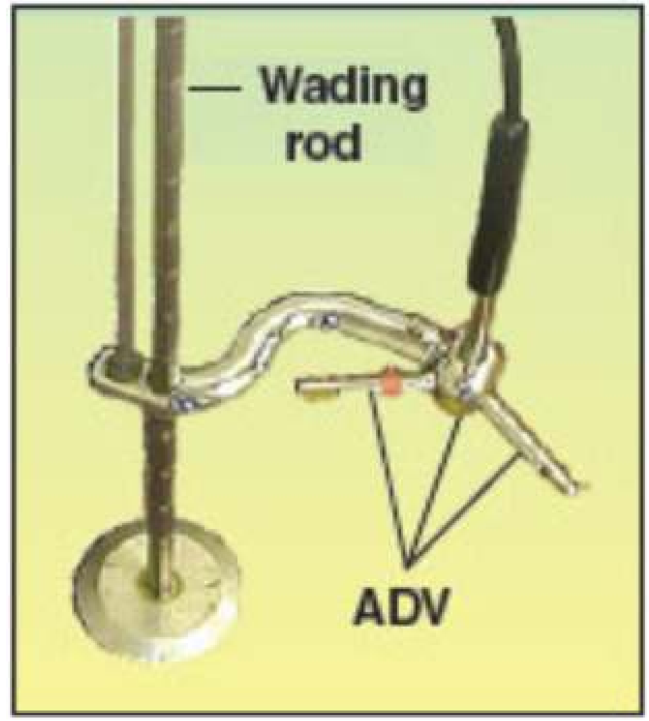
1) Measure the velocity of the river both horizontally and vertically for predetermined locations (and take an average value).
2) Using open channel (Manning Equations)



0ft
10ft
Stream width
River bank
River bank
1ft
3ft
5ft
7ft
9ft
Water level
Place where a measurement is made
1ft
2ft
3ft
Stream depth
Q = A* V_w
Q = discharge (ft^3/sec)
A = surface are (ft^2)
V_w water velocity (ft/sec)
Q_total = Q_1 + Q_2 ….Q_n

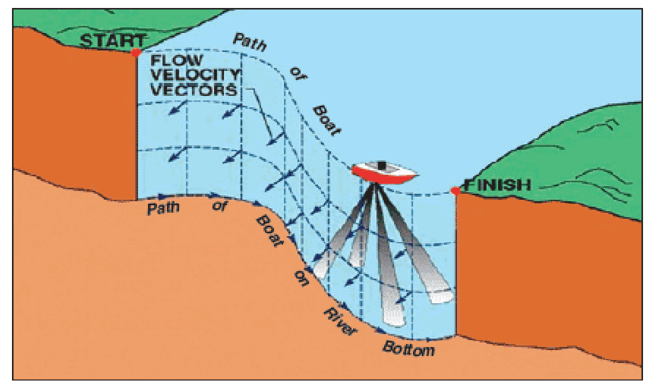

**Current Meter**

**Mechanical Current Meter**




**Acoustic Doppler Velocimeter**

Image courtesy of http://ga.water.usgs.gov/edu/streamflow2.html




Current meter has a wheel of six metal cups that revolve around a vertical axis, where timed-revolutions are used to estimate the water velocity.

Measures the velocity of the water flowing beneath the ice.

Can also measure the width and the depth of the river as well as the velocity.

## More primitive ways:

**Branch Method**: Throw a branch of tree at the up stream and measure the travel time it takes for a particular distance.

**Salt Method**: Prepare a bucket of salty water (very dense). Then, dump the bucket in the river and continually measure the conductivity (EC) of the river. From the EC change in time, the speed of the river can be estimated.

But these methods only give the speed of the water at the points where the measurements are done; but wouldn't provide a profile info.

# Estimating Velocity using Manning Equations

$$V_{avg} = \frac{1.49}{n} R^{2/3} S^{1/2}$$

R, ratio of cross-sectional area to wetted perimeter of channel
S, is slope of water surface
N, is the Manning channel roughness coefficient

# USGS – monthly average streamflow

March 2007

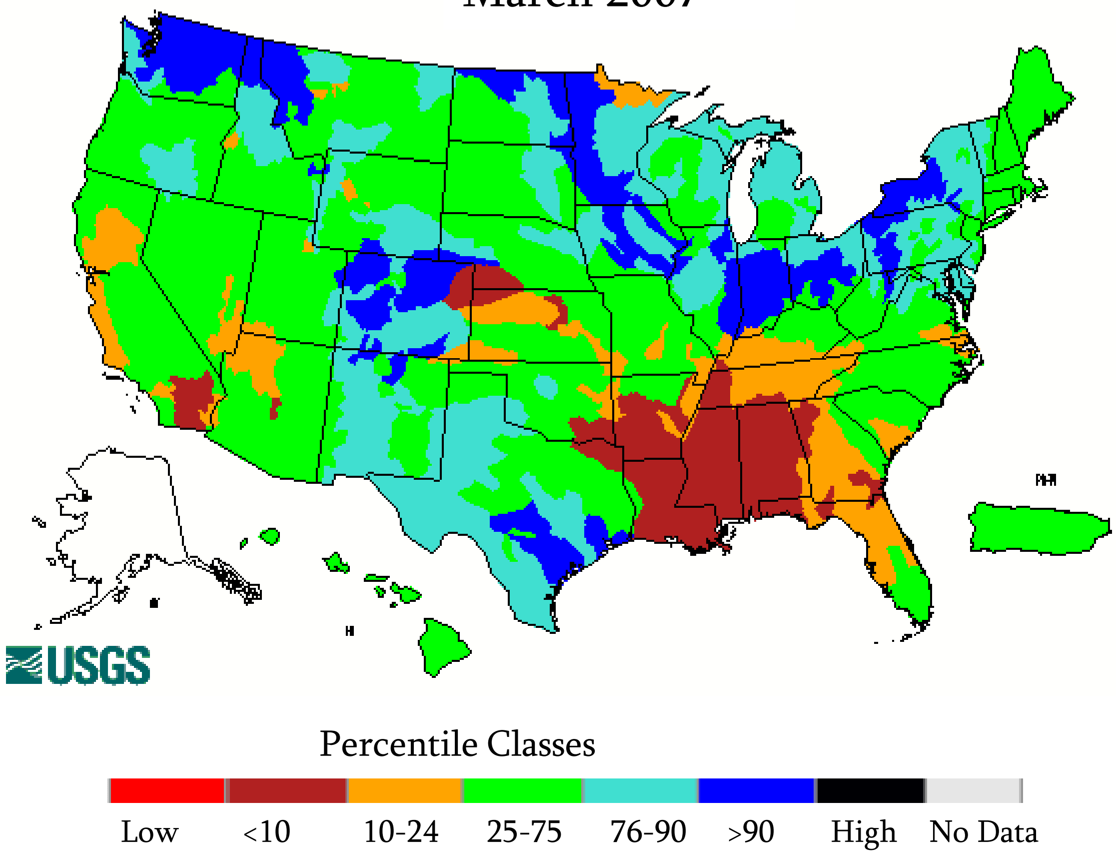



Image courtesy of USGS, http://water.usgs.gov/waterwatch/

March 2007 streamflow value compared to 30 years of average streamflow conditions.

A percentile > 75 *above normal*

A percentile 25 – 75 *normal*

A percentile < 25 *below normal*

## How about recovery of historical Streamflow??

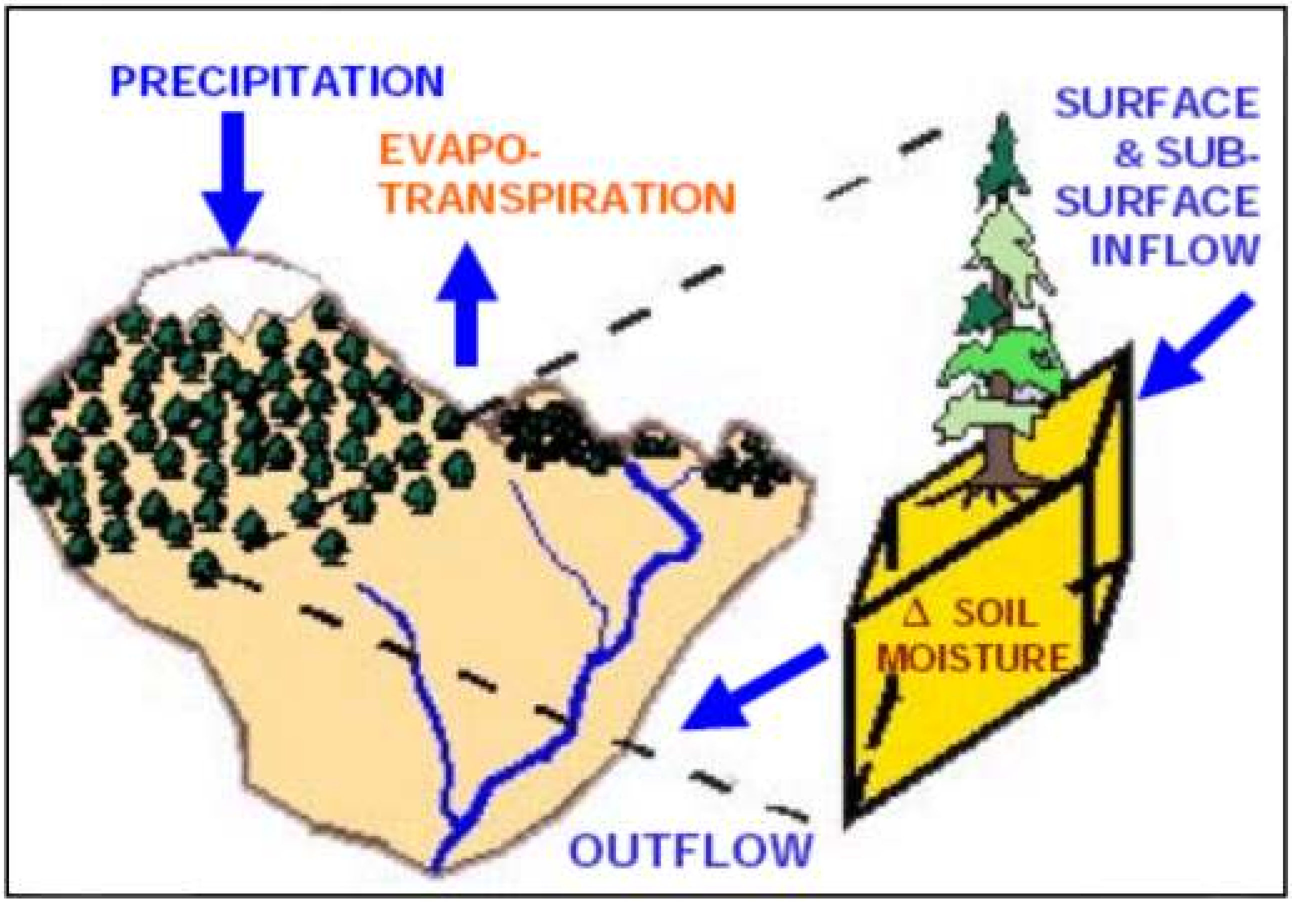



Image Courtesy of http://wwa.colorado.edu/treeflow/lees/treering.html

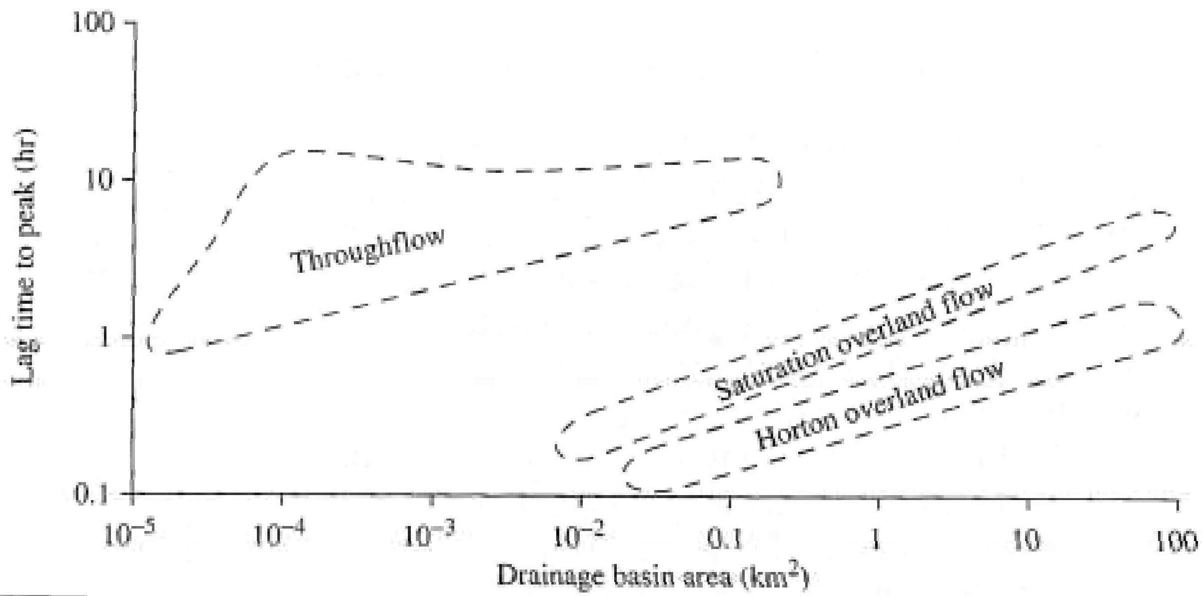
In this study, trees (at slopes located at higher altitudes than rivers) were assumed to have strong relation between its growth and the overall water balance (related to streamflow) of its watershed. Hence, the tree rings were used to extract historical streamflow info.

# 3- Precipitation - Discharge relation

Depending on soil characteristics, soil moisture, and the nature of the storm, each watershed have a different precipitation – discharge response.

**Hyetographs** (Precipitation change in time)
**(Unit) Hydrographs** (Discharge change in time under a constant precipitation rate)

**Initial Abstraction** Initial soil absorption of precipitation (no discharge)
**Rising Limb** Increase in discharge due to intensified storm
**Falling Limb** Decrease in discharge due to recessing storm
**Peak Discharge** Maximum amount of discharge that the storm produces
**Lag Time** The time delay between the time of peak discharge and the precipitation
**Runoff** Overland flow that feeds the stream
**Through flow** Horizontal sub-surface movement of water. It first appears at the surface before it merges to stream, lake, etc.
**Inter flow (Sub-Surface flow)** Same as through flow; but it does not appear at surface before merging.
**Baseflow** Groundwater flow that discharges to stream.




# Drainage Area effect

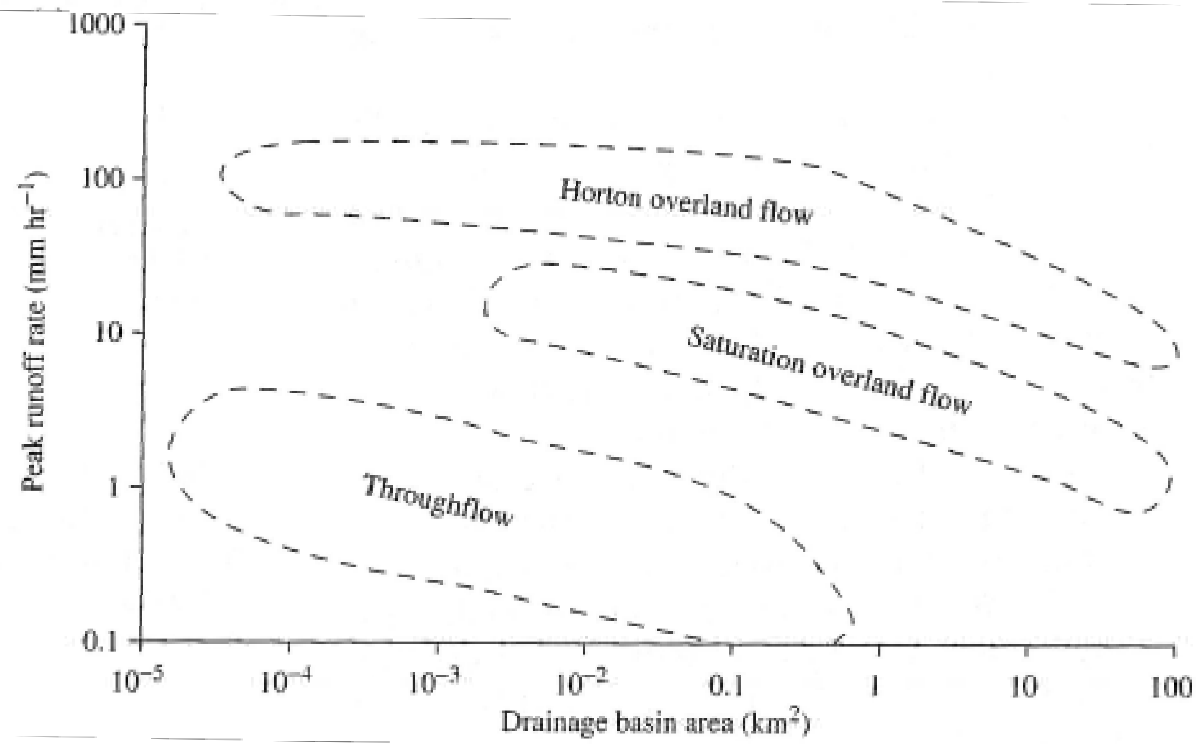
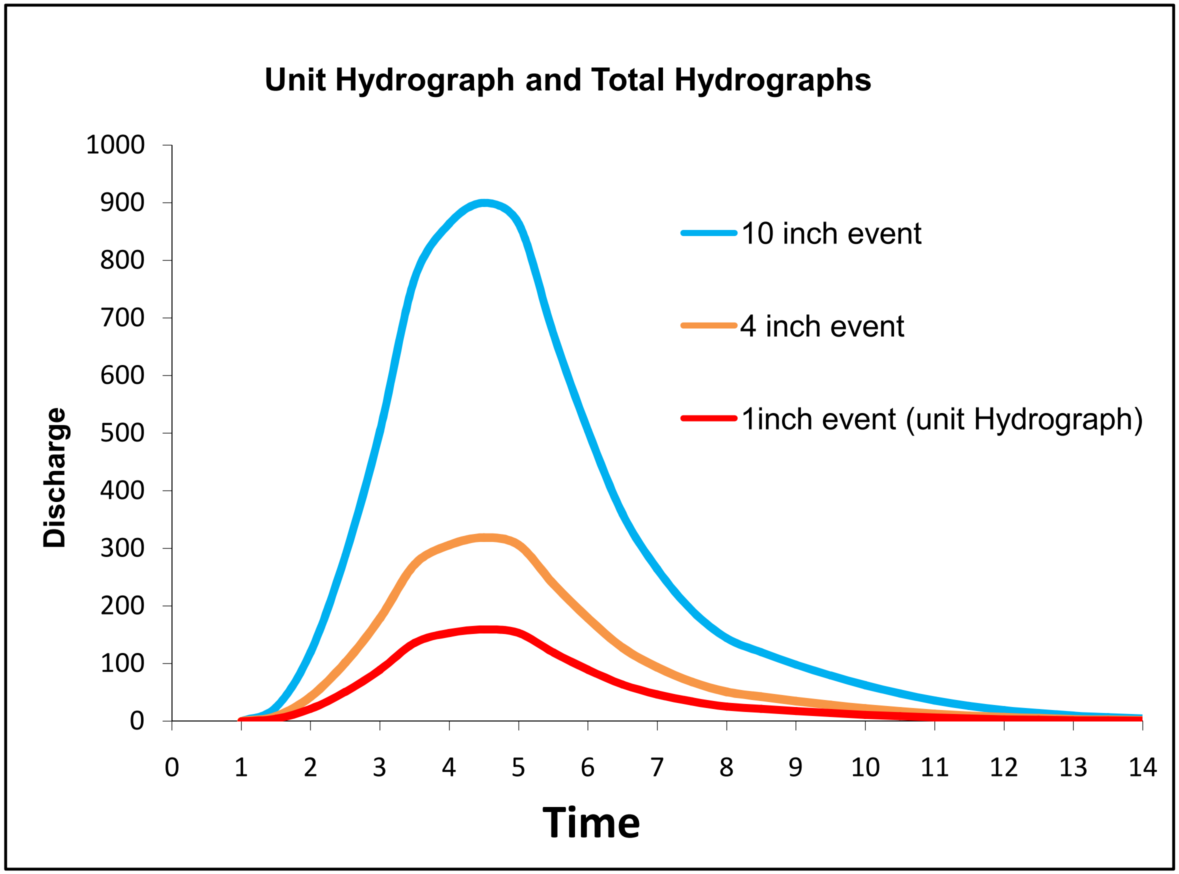



Image courtesy of S. L. Dingman, Physical Hydrology,

# Total Hydrograph vs Unit Hydrograph




Unit hydrograph is the response of the drainage area to a unit (1 inch/ 1mm) volume of runoff.

Unit hydrographs are estimated from historical data. Any amount of excess runoff can be calculated from unit hydrographs

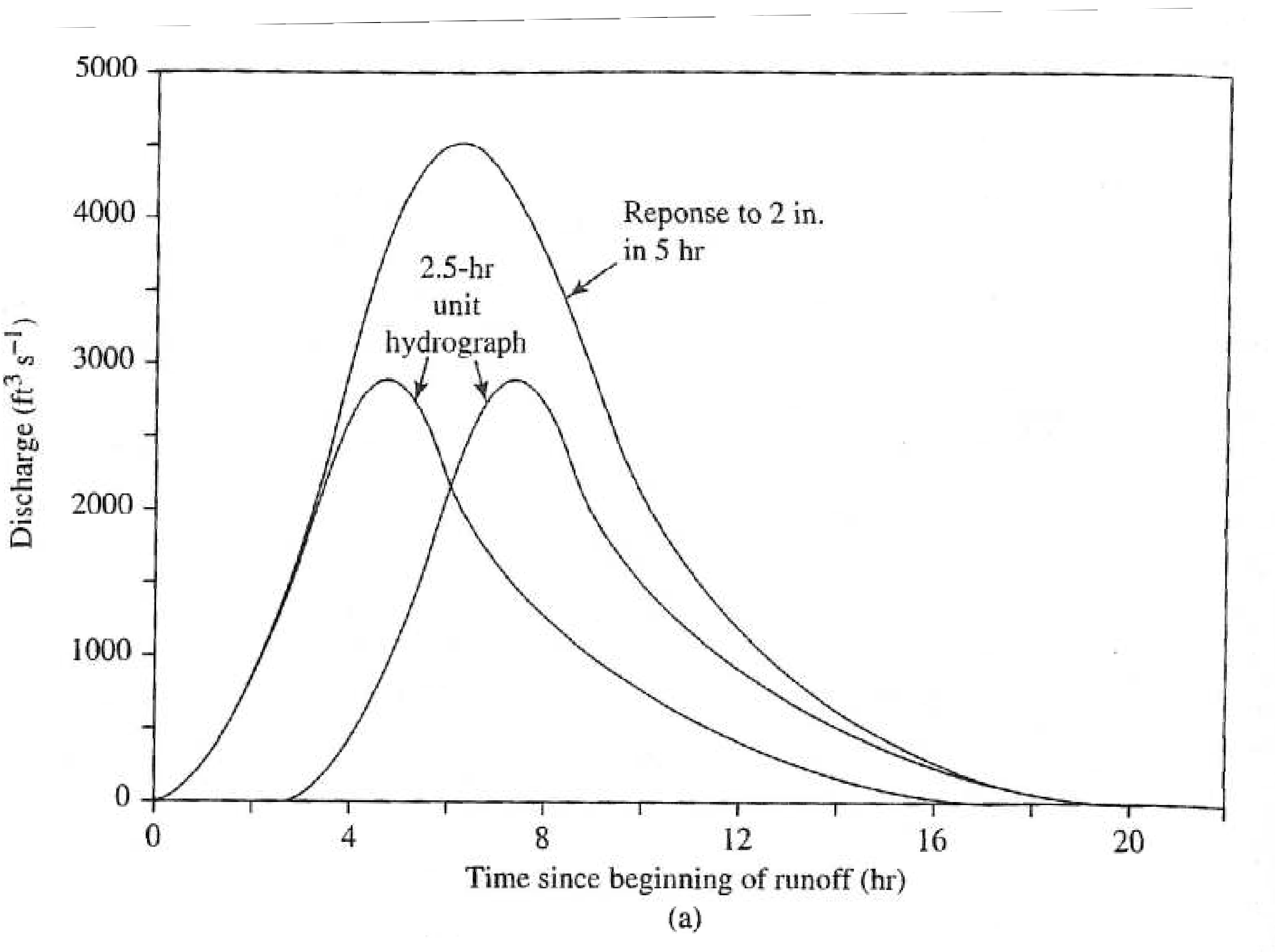
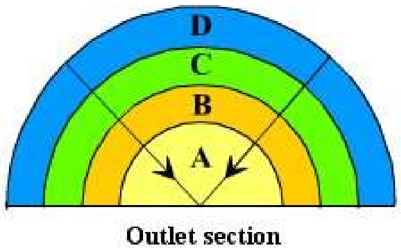


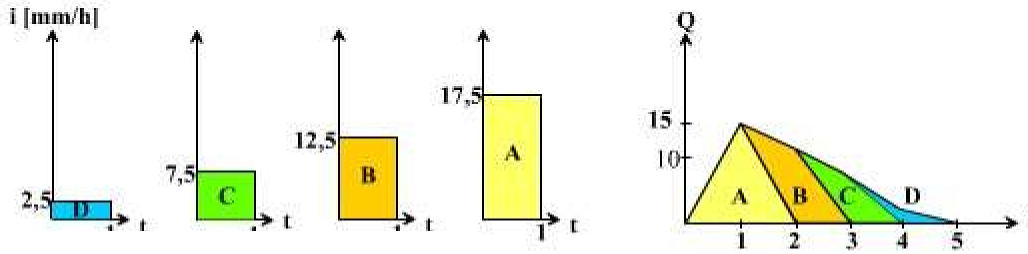

Image courtesy of S. L. Dingman, Physical Hydrology, second edition

## Consecutive Storms

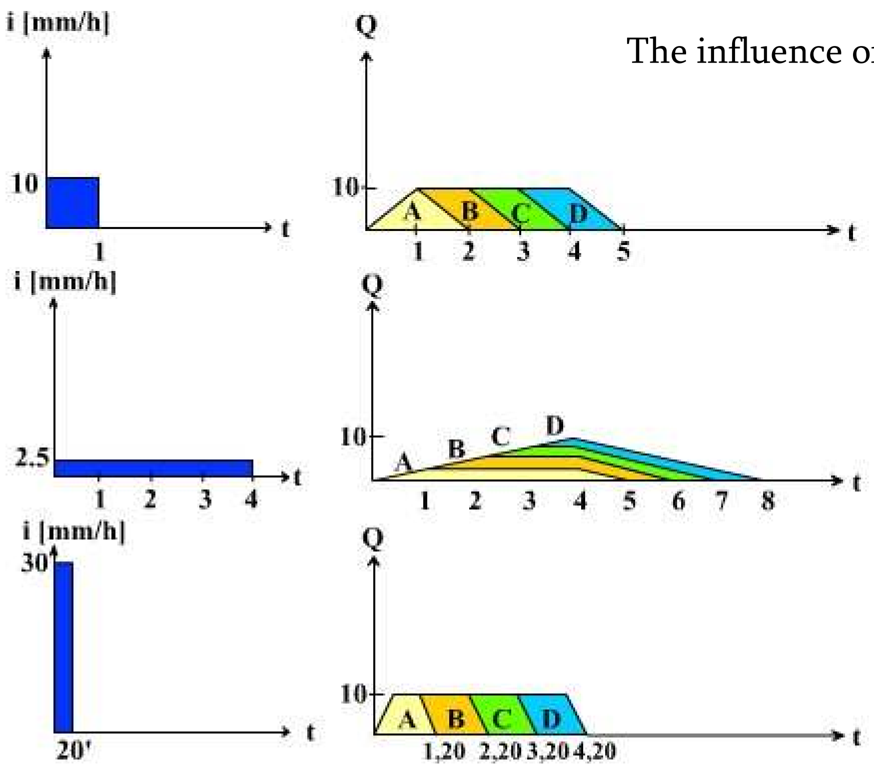
# Rainfall-Discharge relation in space and time



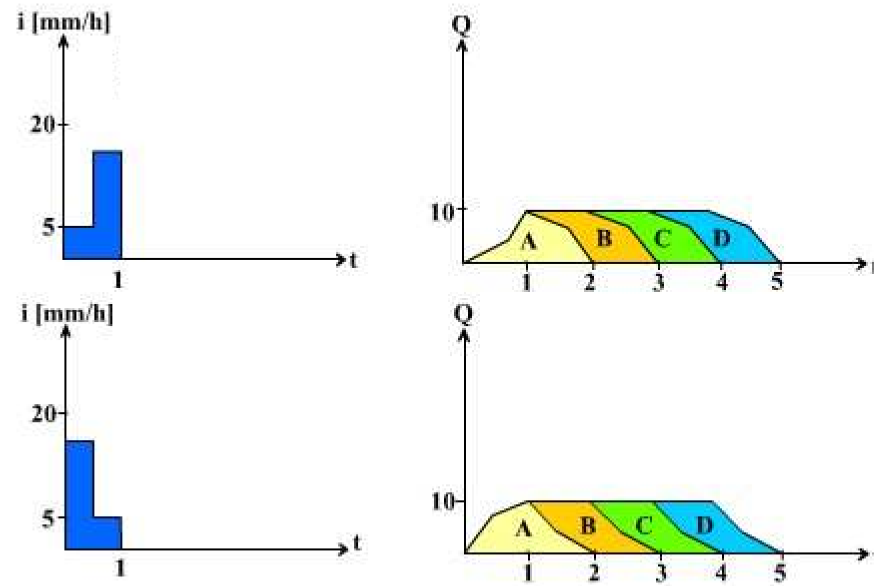

Catchment representation




The influence of rainfall spatial distribution




The influence of rainfall duration




The influence of rainfall intensity

Image courtesy of http://hydram.epfl.ch/VICAIRE/

# Drainage Area size affect

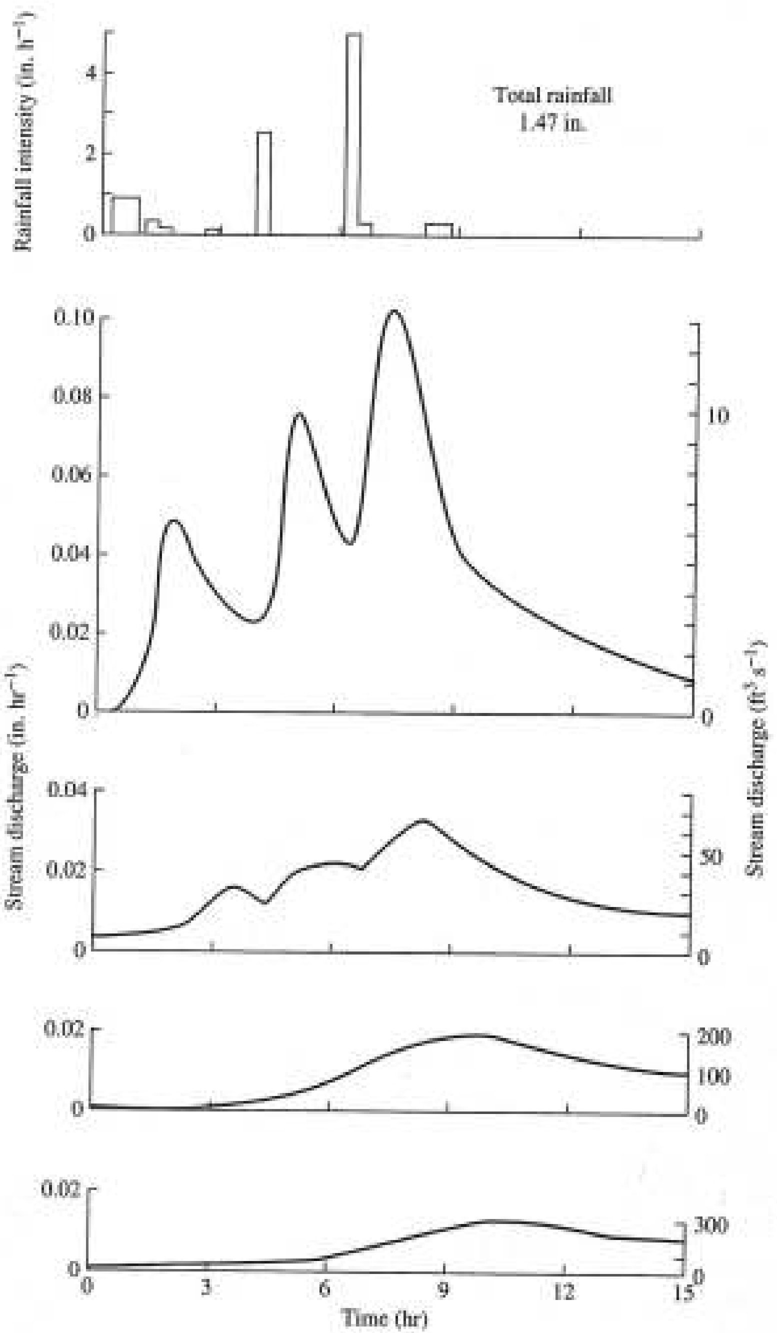



Image courtesy of S. L. Dingman, Physical Hydrology, second edition

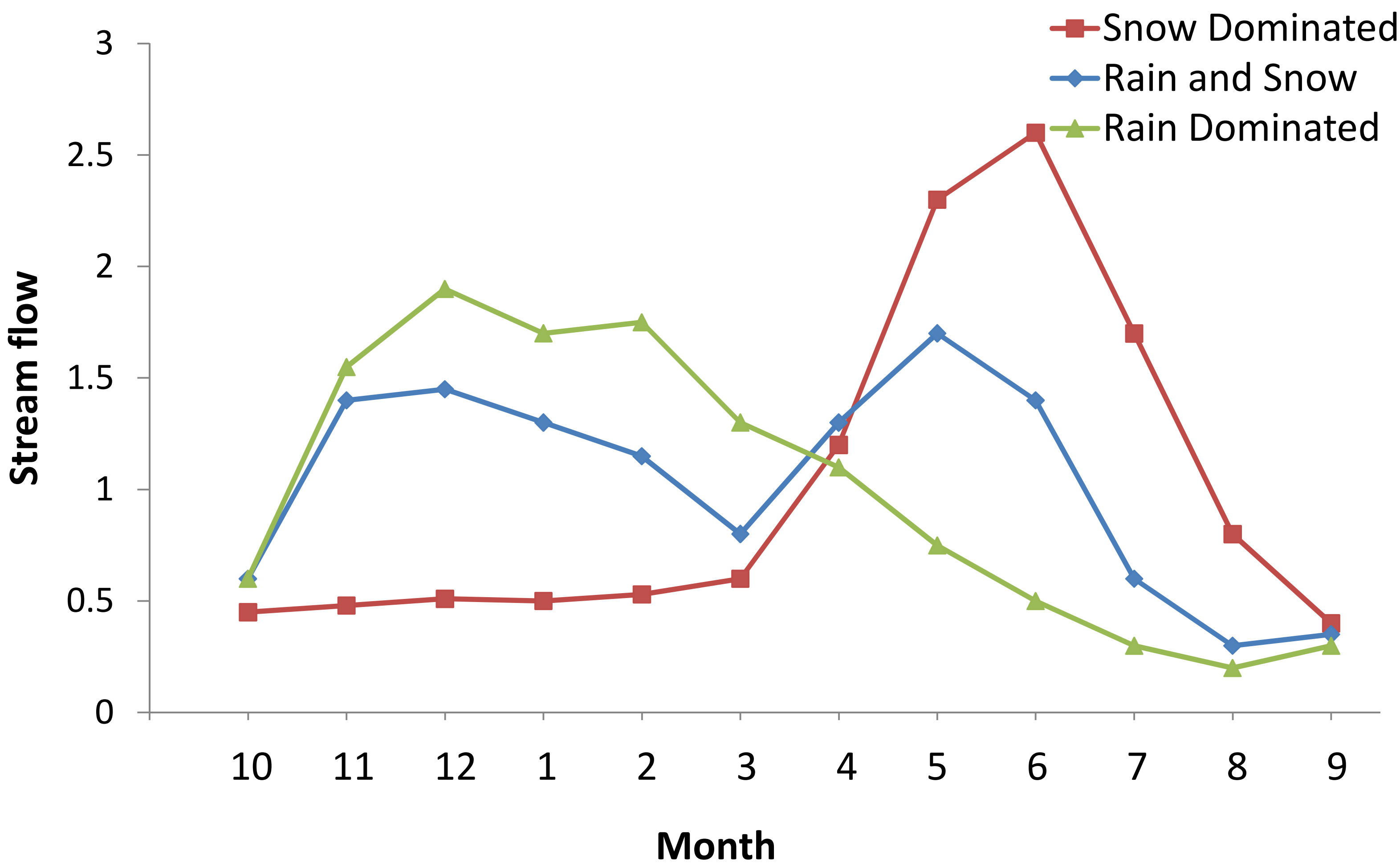
Drainage area 0.20 mi$^2$

Drainage area 3.2 mi$^2$

Drainage area 16.6 mi$^2$

Drainage area 43 mi$^2$

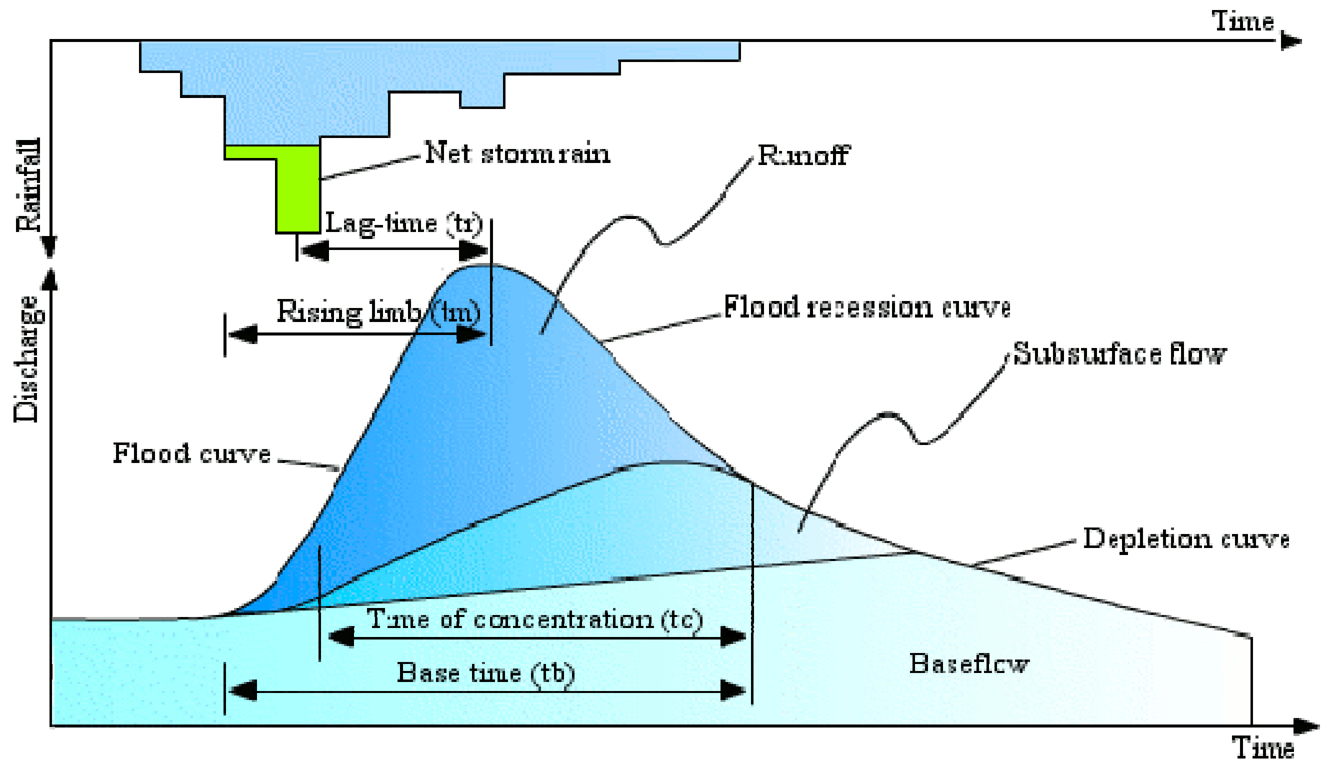
# Hydrological response to precipitation type



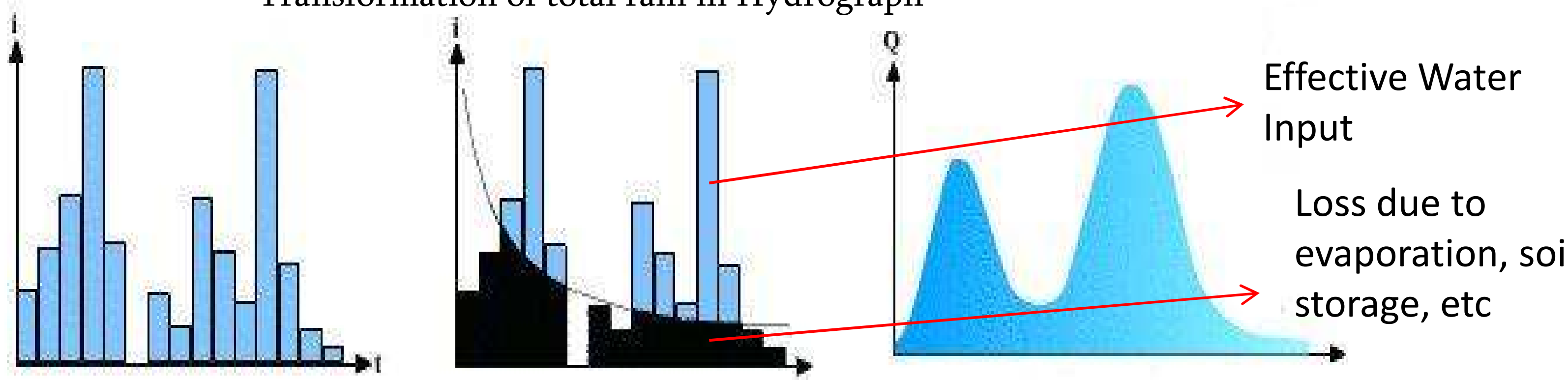
# Rainfall – Runoff relation of a storm event

Hyetograph

Hydrograph




Transformation of total rain in Hydrograph




Total rainfall

Net rain

Hydrograph

Image courtesy of http://hydram.epfl.ch/VICAIRE/

# Hydrograph (Baseflow) Separation

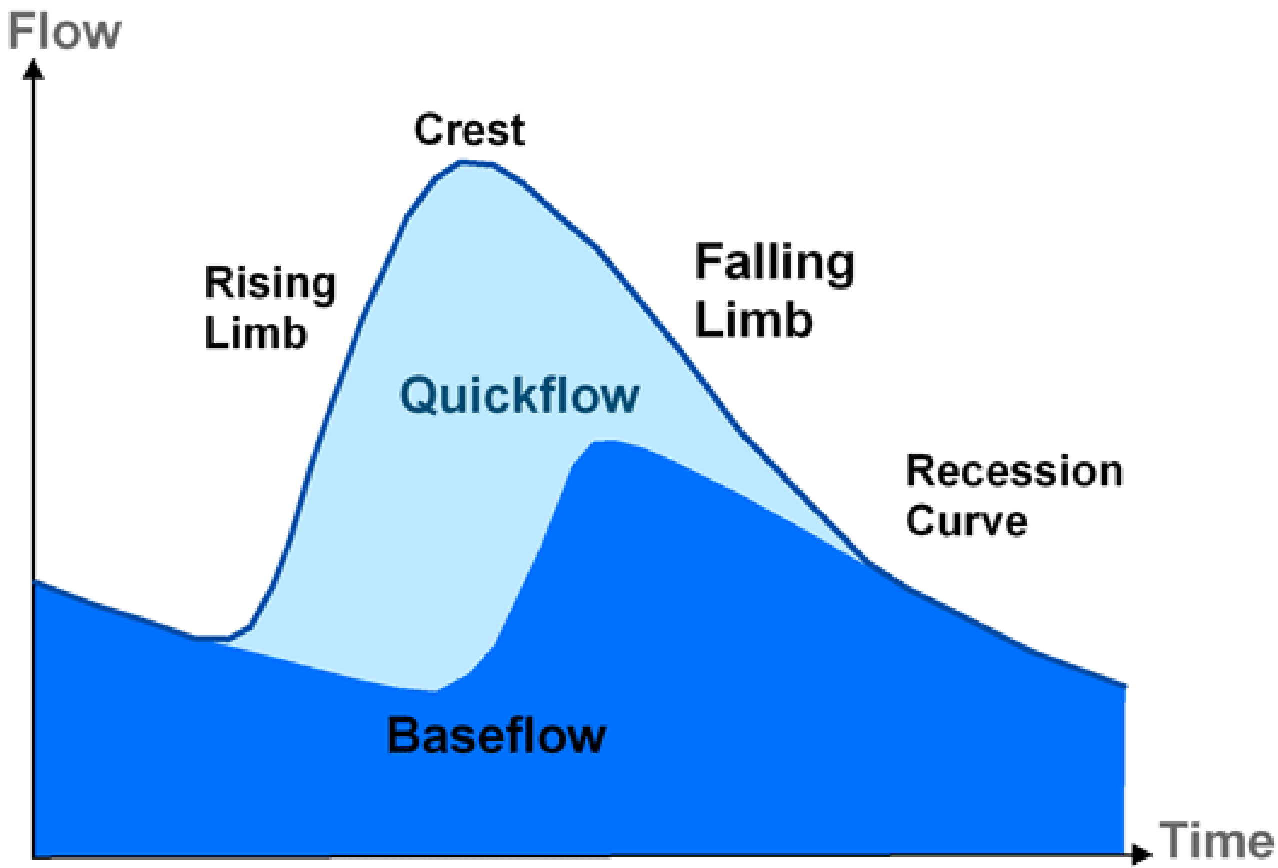



Image courtesy of http://www.connectedwater.gov.au/processes/baseflow.html

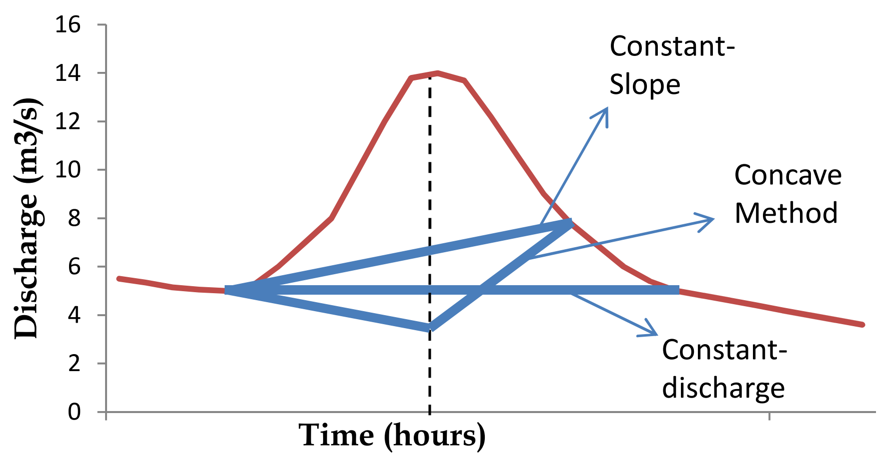
## a) Graphical Separation Methods

**Constant-discharge method**: Baseflow is assumed constant at the (minimum) discharge level before rising limb starts.

**Constant-slope method**: Falling Limb inflection point is connected to the beginning of rising limb. For large watersheds, the inflection point is estimated by empirical formulas.

**Concave method**: Extend the hydrograph right before the rising limb until the time of peak discharge. Then connect that point to the inflection point of the falling limb. This method assumes the baseflow decreases during the rising limb and increases during falling limb.

**Master Depletion Curve method**: Several depletion curves are used to obtain an average slope of the falling limb.



# Master Depletion Curve

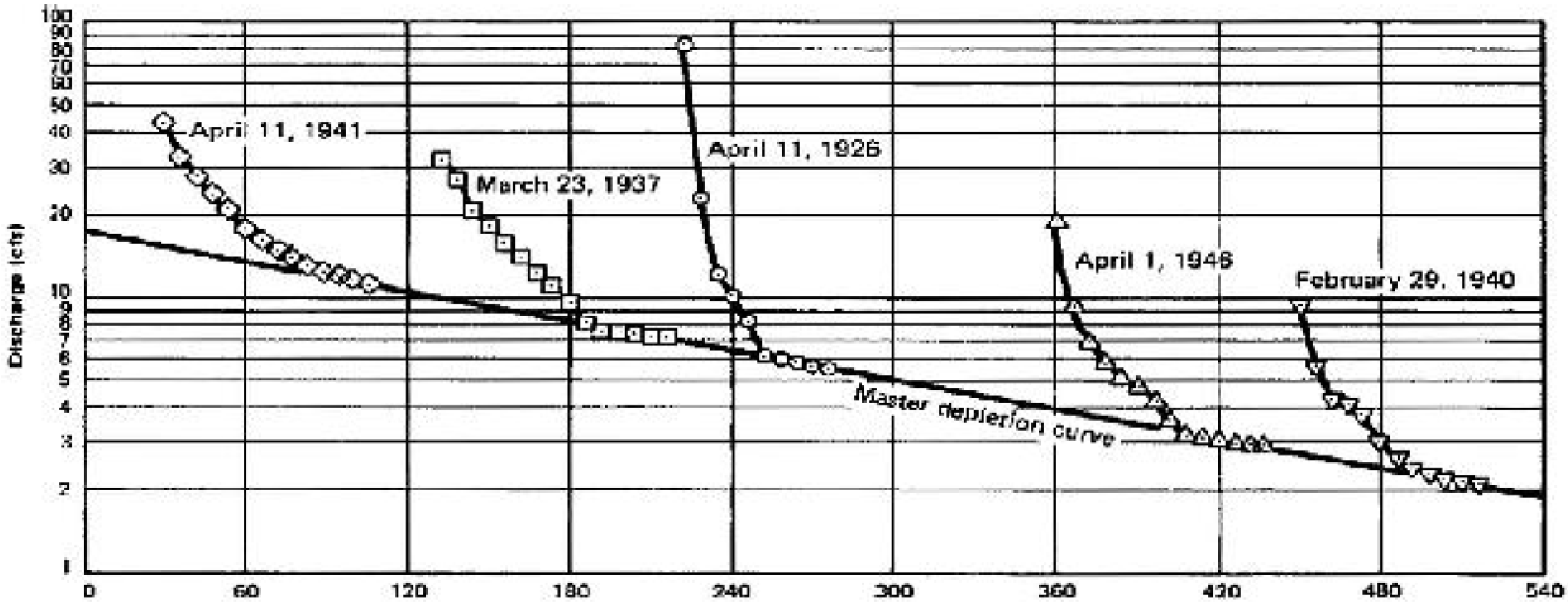



Figure Courtesy of T. Brikowski www.utdallas.edu/~brikowi/Teaching/Applied_Modeling

## b) Time Series Processing Methods

These methods may not have hydrological basis. They use the time series of discharge data to obtain useful baseflow information.

**The baseflow index (BFI)**: Long-term ratio of baseflow to total streamflow

**Mean annual baseflow volume**

**Long-term average daily baseflow**

**Filtering the discharge time series:** (i.e. filtering the high frequency runoff to obtain baseflow)

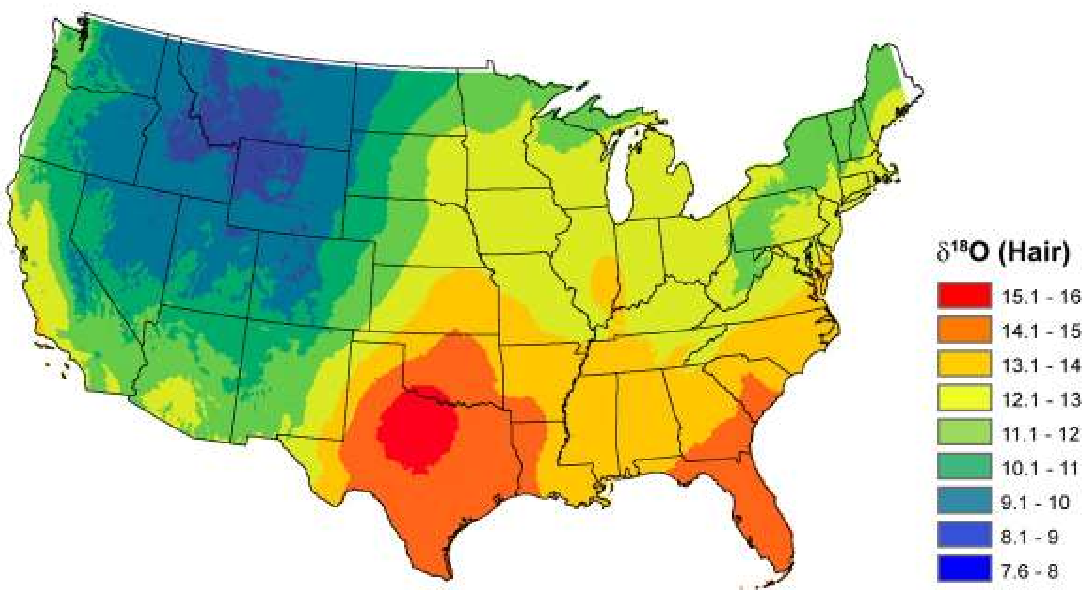
## c) Isotope Separation Methods

**Using Isotope dating methods to estimate the origin and the age of the water to separate the baseflow and the overland flow.**

Water molecule is formed by $O^{-2}$ and $H^{+}$ elements. $^{16}O$ is the most common oxygen isotope

•Heaviest isotopes of the perceptible water fall first. Then lighter isotopes.

•Lightest isotopes evaporates first. Then heavier isotopes.

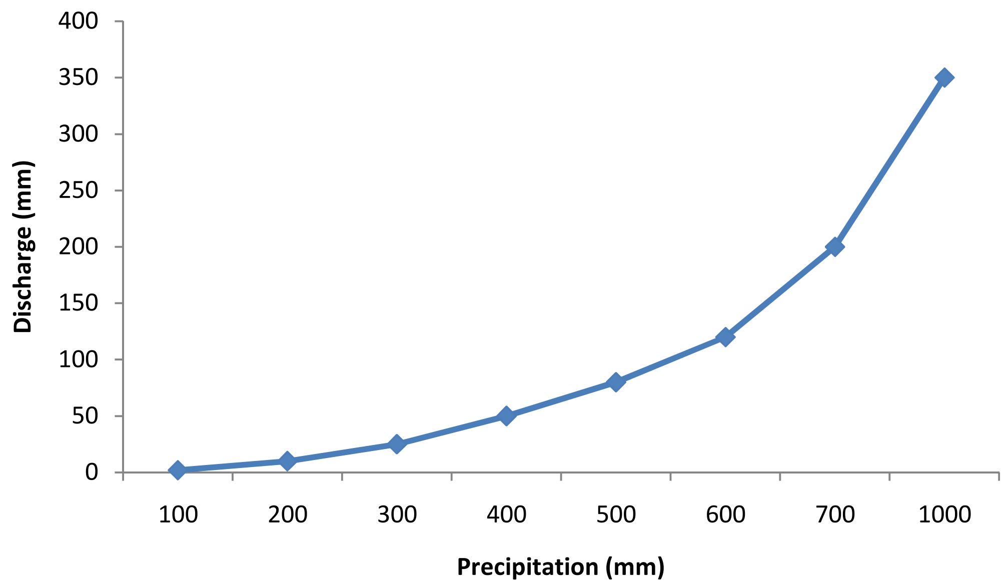



$^{18}O$ / $^{16}O$ ratio of human scalp hair.

Image courtesy of Ehleringer J R et al. PNAS 2008;105:2788-2793

# 4- Rainfall Runoff Models

For long term averages, rainfall and the basin area information can be used to **model** the amount of runoff that a particular storm would produce.




Models are needed to estimate the peak of the discharge and prediction of floods.
Two examples of these models are Rational method and the SCS method.

## The Rational Method

$$Q_{max} = C * I * A$$

$Q_{max}$ : Is the peak discharge ($m^3$/day)
C : Constant (dependent on soil/cover)
I : Intensity of the rain (mm/day)
A : Area of the watershed ($m^2$)

More accurate for smaller watersheds!!
(~ <50 acres=400m*500m)

| | |
|---|---|
| **Downtown** | **C= 0.70 – 0.95** |
| **Crop/Agriculture** | **C= 0.05 – 0.25** |

# SCS Curve number Method

Based on the antecedent soil wetness conditions and the soil type, this method relates the effective water input ($W_{eff}$) to the amount of rainfall.

1) Obtain Curve number for the watershed based on the land cover and conditions.
2) Adjust CN for watershed wetness
3) Calculate $V_{max}$
4) Calculate $W_{eff}$

$$V_{max} = 1000/CN - 10$$

$$W_{eff} = (W - 0.2^* V_{max})^2 / (W + 0.8^* V_{max})$$

$$V_i = 0.2 * V_{max} \quad \text{(for normal wetness)}$$

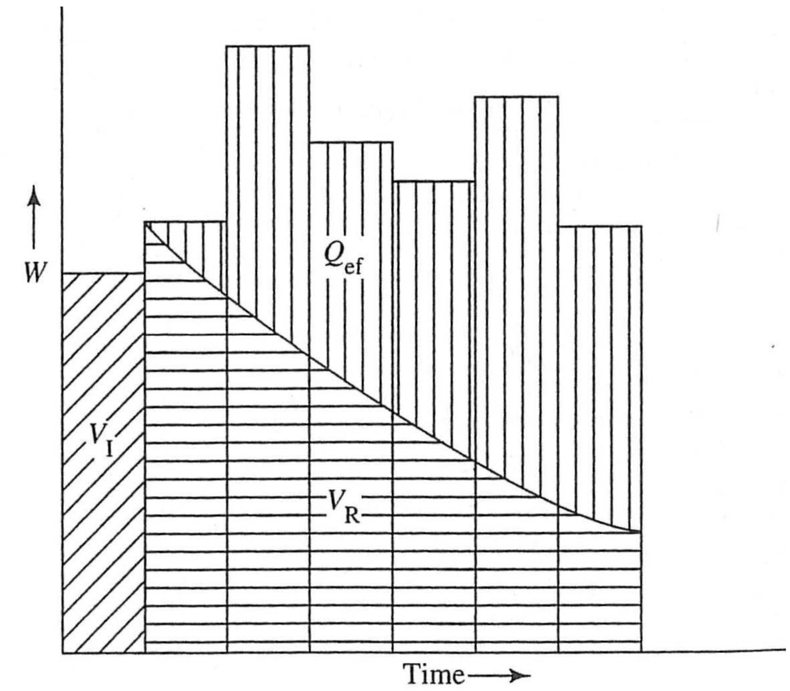



**FIGURE 9-42**
Definitions of initial abstraction, $V_I$, retention, $V_R$, and event flow, $Q_{ef}$, in the SCS method.

Image courtesy of S. L. Dingman, Physical Hydrology, second edition

$V_i$ : Initial Abstraction
$V_r$ : Retention
$Q_{eff}$ : Event Flow
W : Hyetograph of water input
$V_{max}$: Maximum Retention capacity

## How about topography?

TOPMODEL bases its distributions on the topography of the drainage basin.

The model estimates the saturation excess and infiltration excess (Hortonian) surface runoff and subsurface flow.

# 5- Floods

## Flood Types:

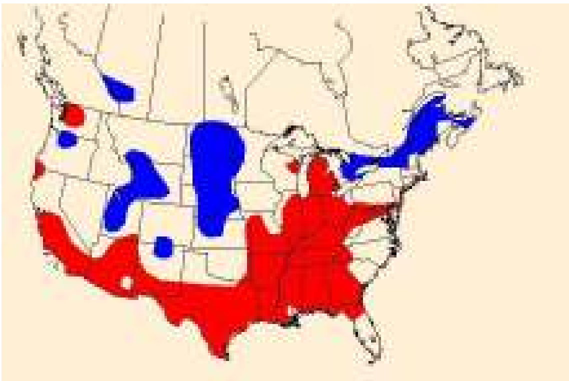
**Flash Flooding** occurs minutes or hours of a heavy rainfall event which causes water levels to rise rapidly.

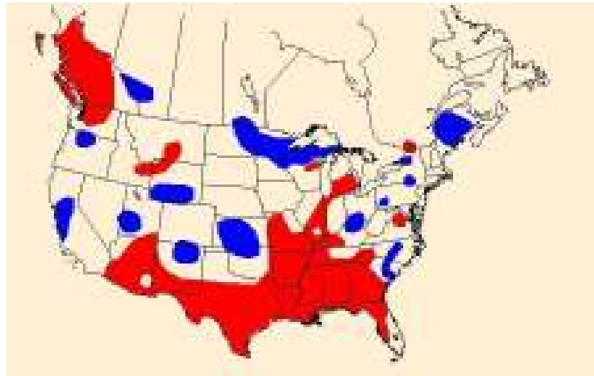
**River Flooding** happens as a result of the heavy rains related with decaying storms.

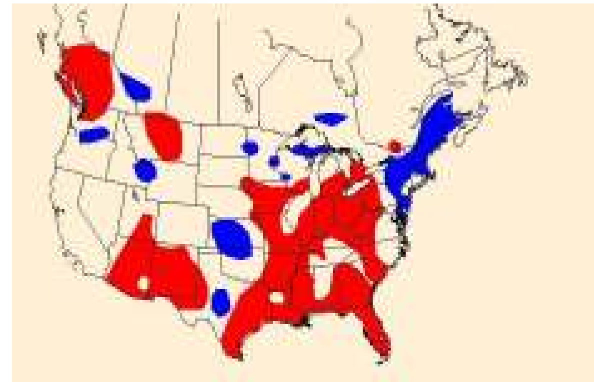
Seasonal watershed characteristics:

Spring: Snow melt, moist soil ➔ Higher level streamflow
Summer: High evaporation, drier soil ➔ Lower level flows.

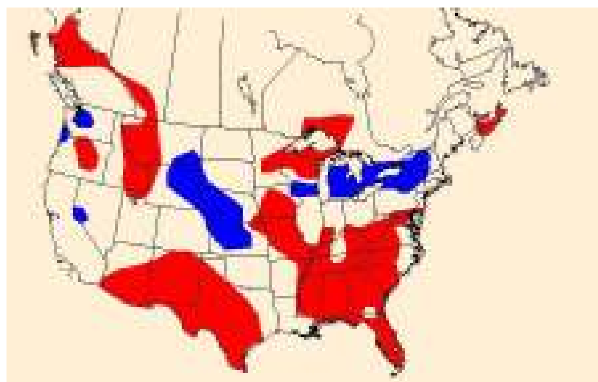
# USGS Historic Maps of Monthly and Annual Streamflow

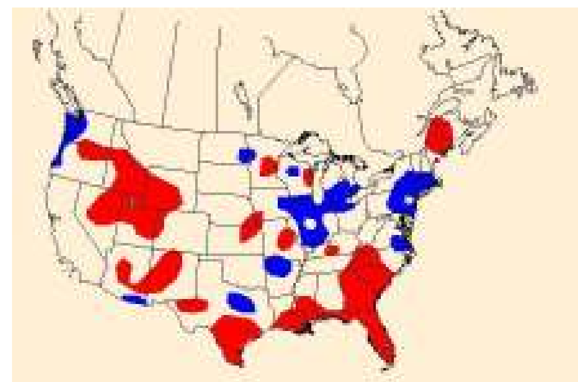

January 2000


February 2000


March 2000


April 2000


May 2000


June 2000

Above normal   Normal   Below normal

Image courtesy of USGS http://water.usgs.gov/nwc/

# Example of heavy snow melt

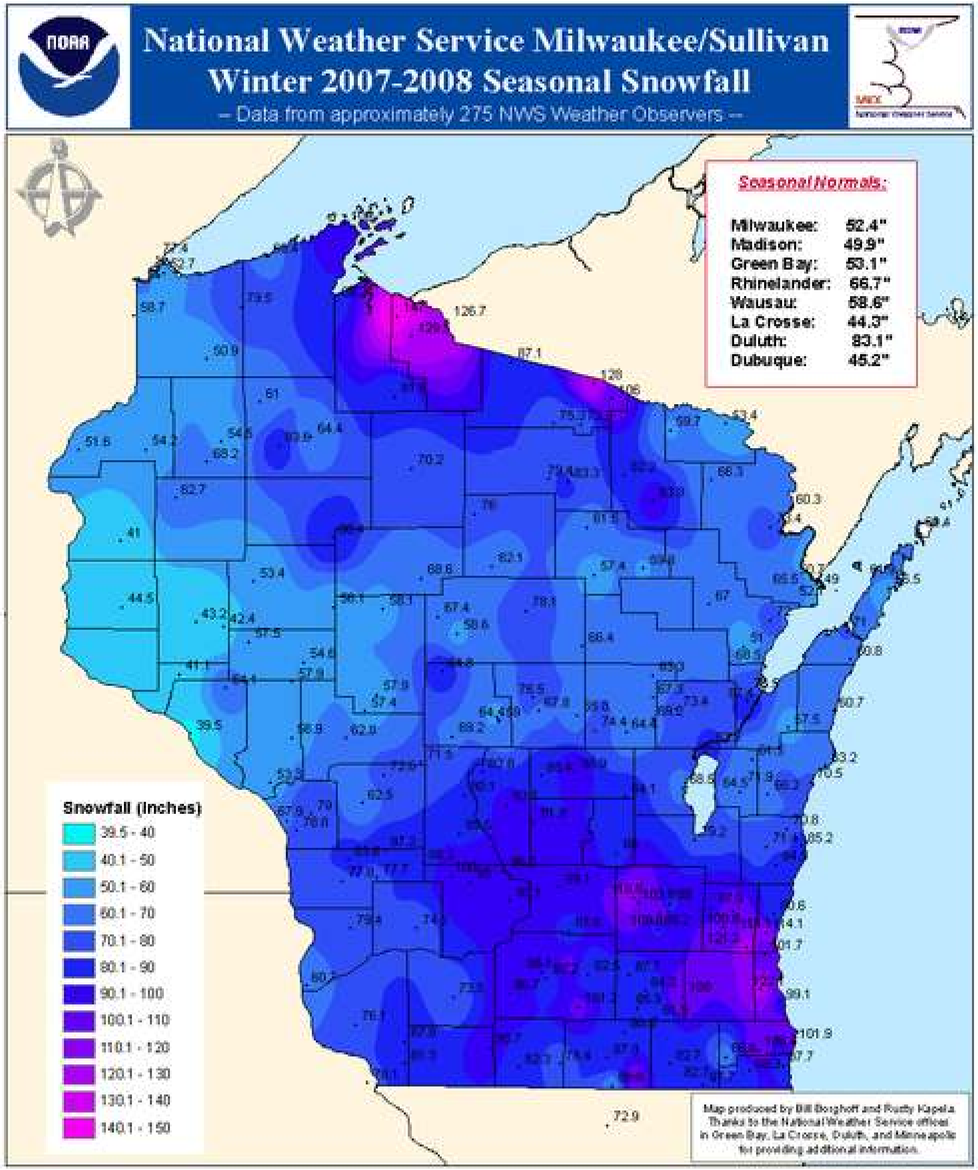



Image courtesy of http://commons.wikimedia.org/wiki/File:2007-08_Winter_Snowfall_in_Wisconsin.png

The final 2007-2008 seasonal snowfall map of Wisconsin, record setting for parts of Southern Wisconsin. For example, Madison WI received 101.4 inches surpassing the previous record of 76.1 inches.

Dodge County, WI, June 14, 2008 -- Farms and homes are under water flooding in the rural areas of Wisconsin continues. Barry Bahler/FEMA
Image courtesy of http://commons.wikimedia.org/wiki/Category:Wisconsin_flood_of_2008

# Damage prevention and mitigation efforts requires information about the magnitude and frequency of floods.

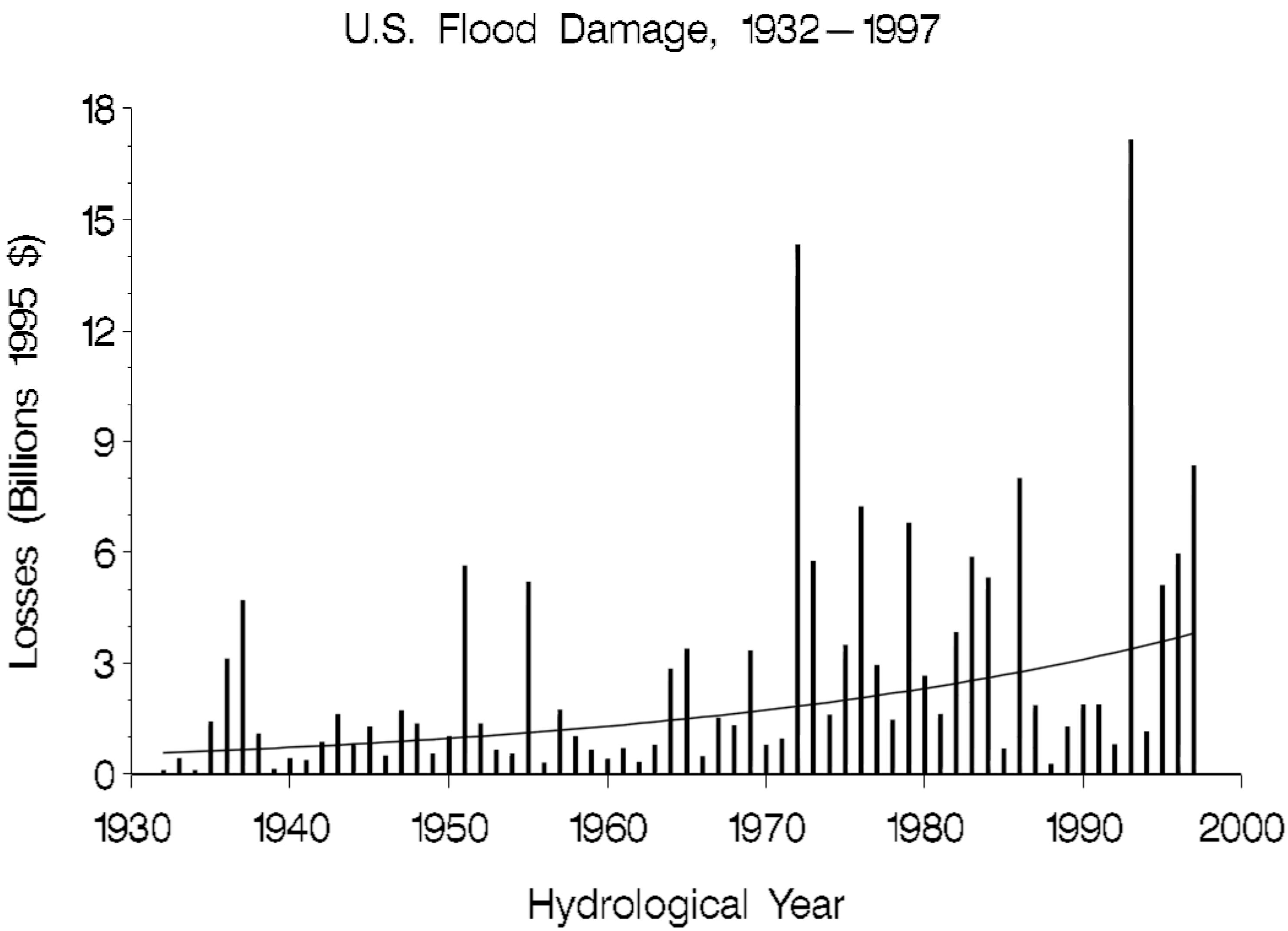



Image courtesy of Pielke and Downton. Journal of Climate, 2000

## Probability of Floods

In general **peak (max) discharge** in a given year is the parameter of interest for flood design studies.

**Probability** : Likelihood of a discharge to happen in any given year

**Return Period** : On average, how many years is any given event would repeat.

**EXAMPLE-1:** Given we have 100 years of streamflow data. To calculate the probability of a given discharge:

- Rank the available discharge data
- Find the corresponding rank of the discharge to be investigated
- P = rank / #observations
- T= 1 / P

**WARNING!!!** Do NOT attempt to calculate any probability exceeding the historically available maximum discharge.

**EXAMPLE-2:**

What is the probability that an event with a discharge of Q will happen at least once in the next 15 years?

-Find the probability that corresponds to Q (assume p1)

-$P_{\text{at least once}} = 1 – P_{\text{none}} = 1 – (1 - p1)^{15}$

**Occurrence of a storm does not affect the chances that the storm would happen next (or in the same) year again!!**

**EXAMPLE-3:**

The return year (T) of a storm with 200 years return period

P=1/200=0.005

Chances that two storms with the same magnitude would happen (same year)

P=0.005*0.005 = 0.000025

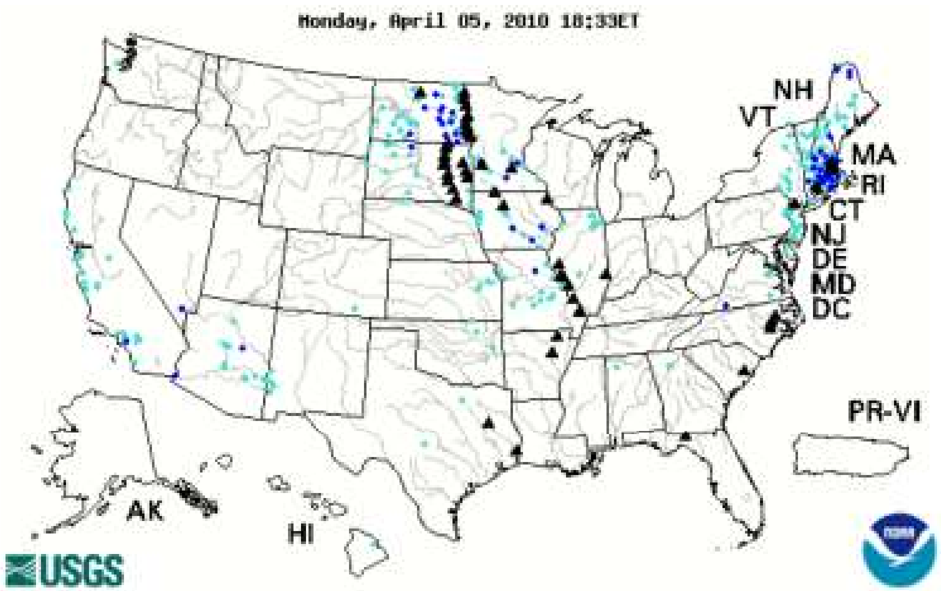
**Katrina:** Based on the 100 years of historical data (includes Hurricane Ethel in 1960, 71 m $s^{-1}$; Hurricane Carla in 1961, 77 m $s^{-1}$; Hurricane Camille in 1969, 85 m $s^{-1}$), Elsner et al. *(2006, G.R.L., 33, L08704)* build a model. Model has

5-year return level of 54 m $s^{-1}$
50-year return level of 77 m $s^{-1}$
500-year return level of 88 m $s^{-1}$

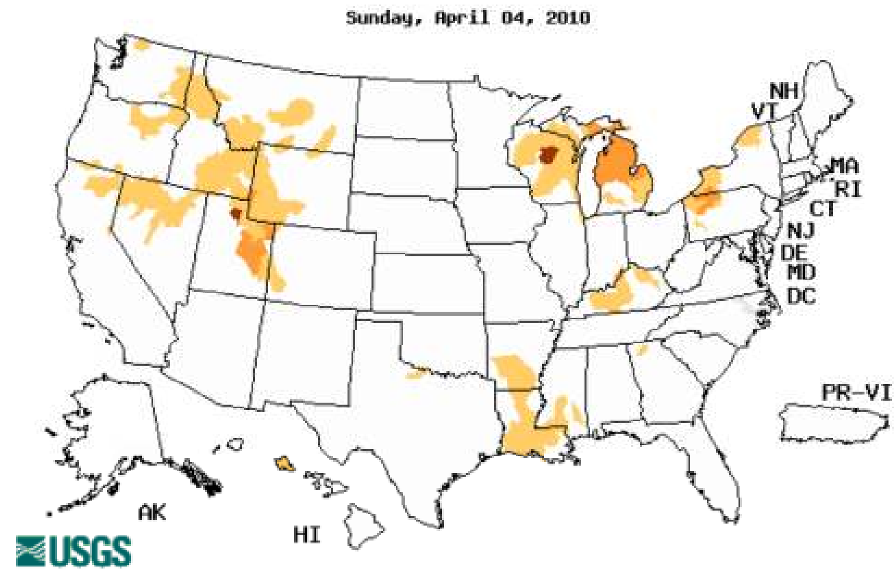
According to this model, Hurricane **Katrina** (with maximum wind speed of 71 m $s^{-1}$) has **return period of 21 years** with 95% confidence levels at 10-50 years.

When model was extended to include the entire U.S. coast from Texas to Maine, a return period of 14 years was found for hurricanes with wind speed equal to Katrina with a 95% interval range from **9 to 30 years**.

# High and Low streamflow conditions




Map of flood and high flow conditions for April 5, 2010




Map of below normal 7-day average streamflow compared to historic streamflow for April 4, 2010

Percentile classes

| 95-98 | >=99 | above flood average |
|---|---|---|

Percentile classes

| Low | <=5 | 6-9 | 10-24 | insufficient data |
|---|---|---|---|---|

Image courtesy of http://waterwatch.usgs.gov/?m=flood,map&r=us&w=real,map

# Remote Sensing and GIS provides the excellent sources and tools to assess, manage, and identify the impact of floods.

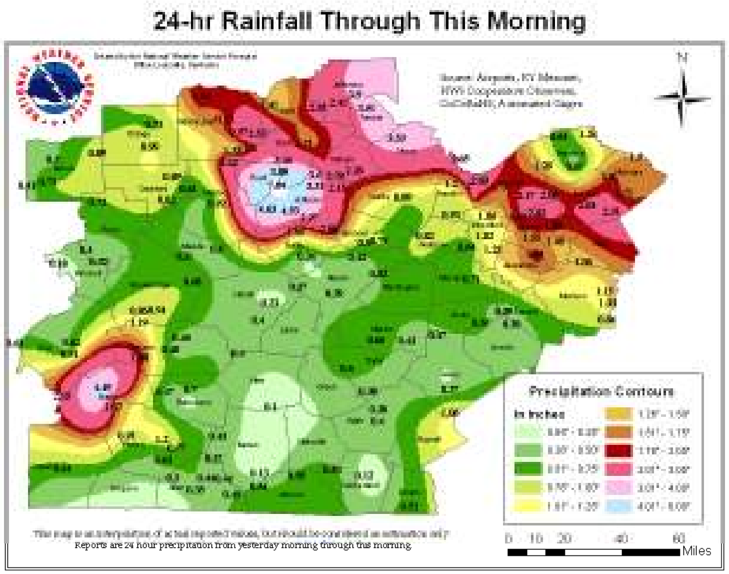



Image courtesy of http://www.crh.noaa.gov/images/

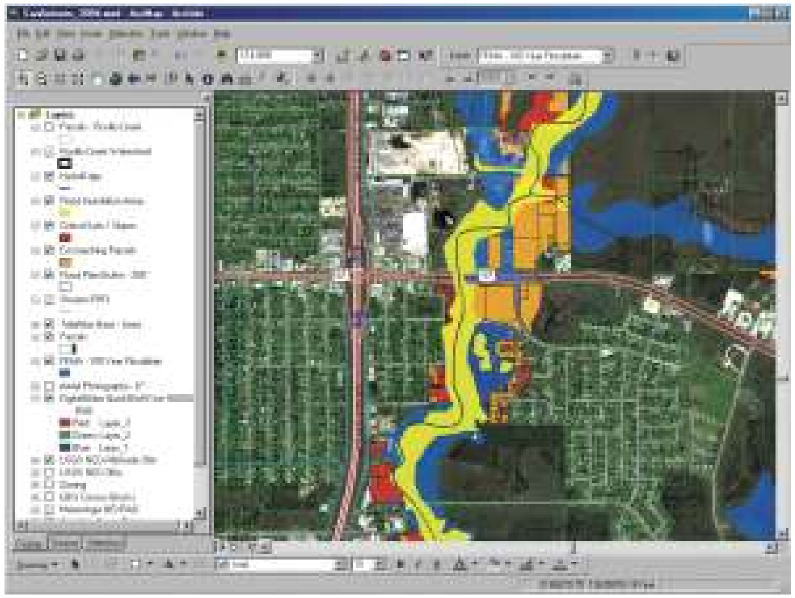
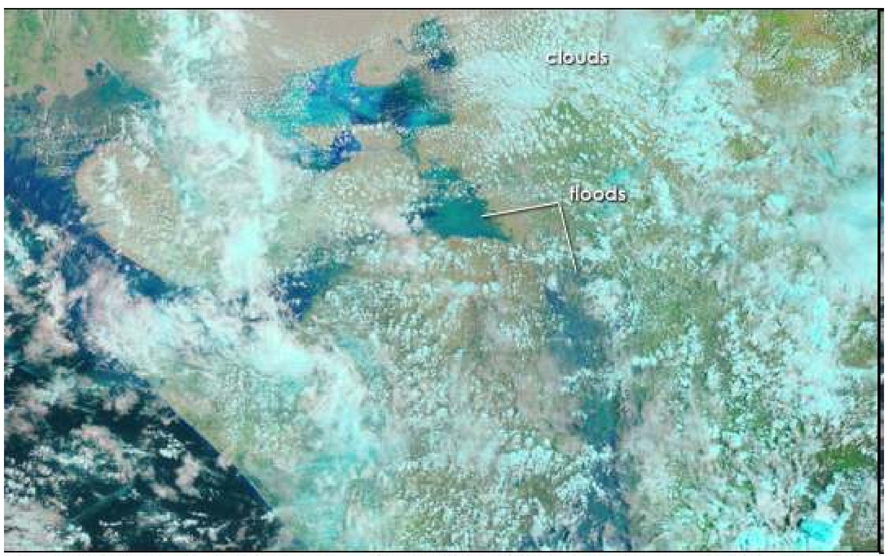


Image courtesy of www.esri.com/industries/water_resources/




July 7, 2005


June 18, 2005

MODIS images of Monsoon Flooding in India, Image courtesy of http://visibleearth.nasa.gov/view_rec.php?id=20072

# 6-) Effect of climate change

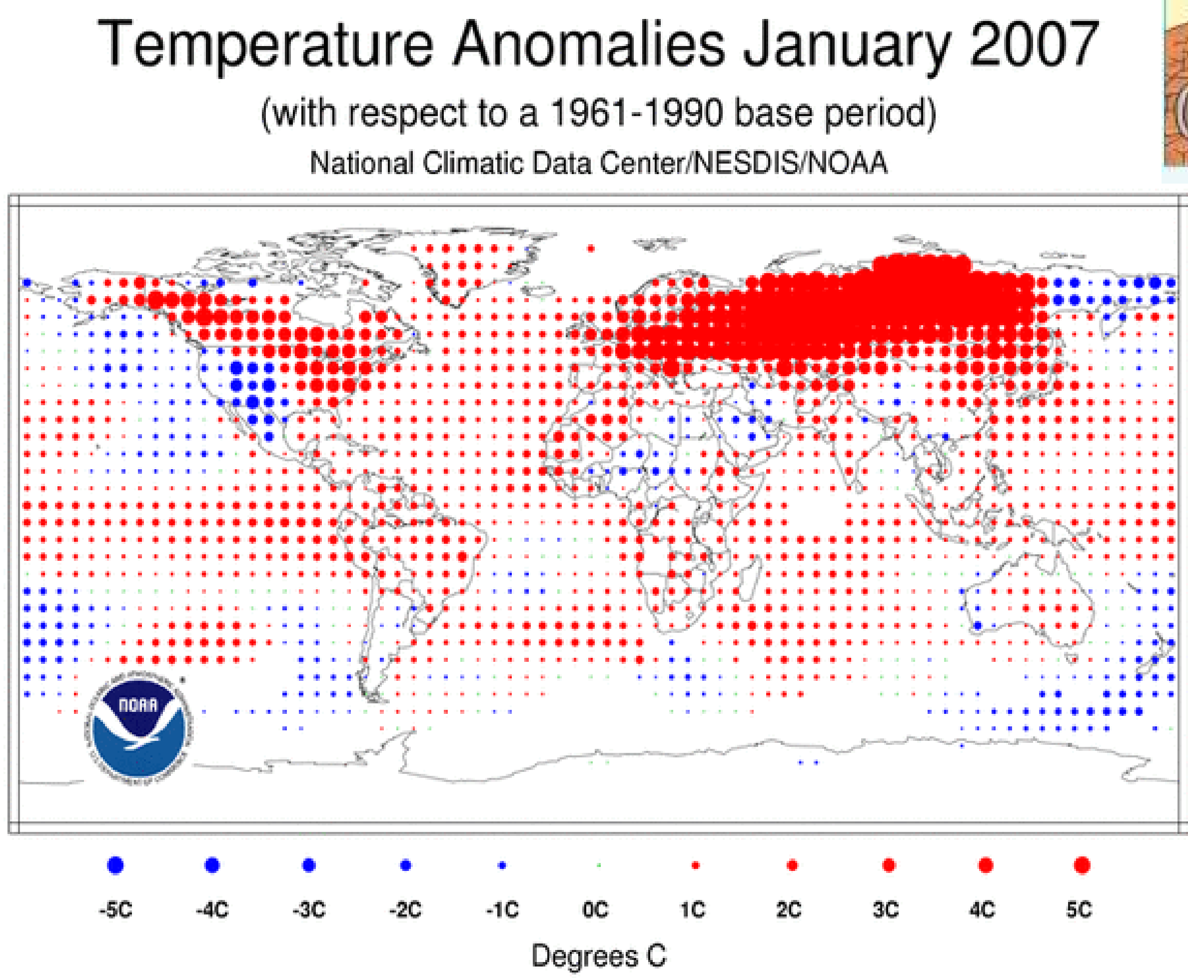
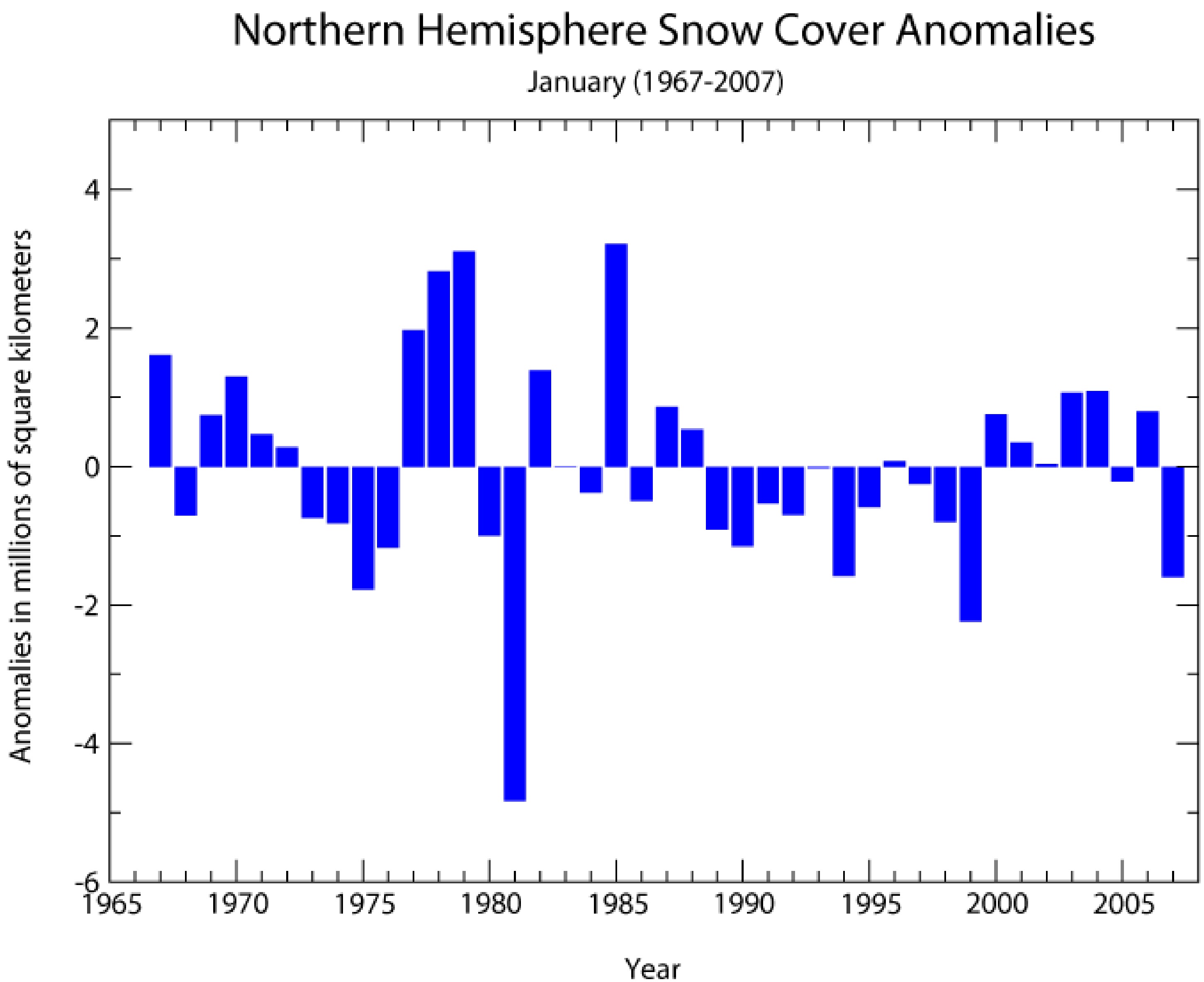


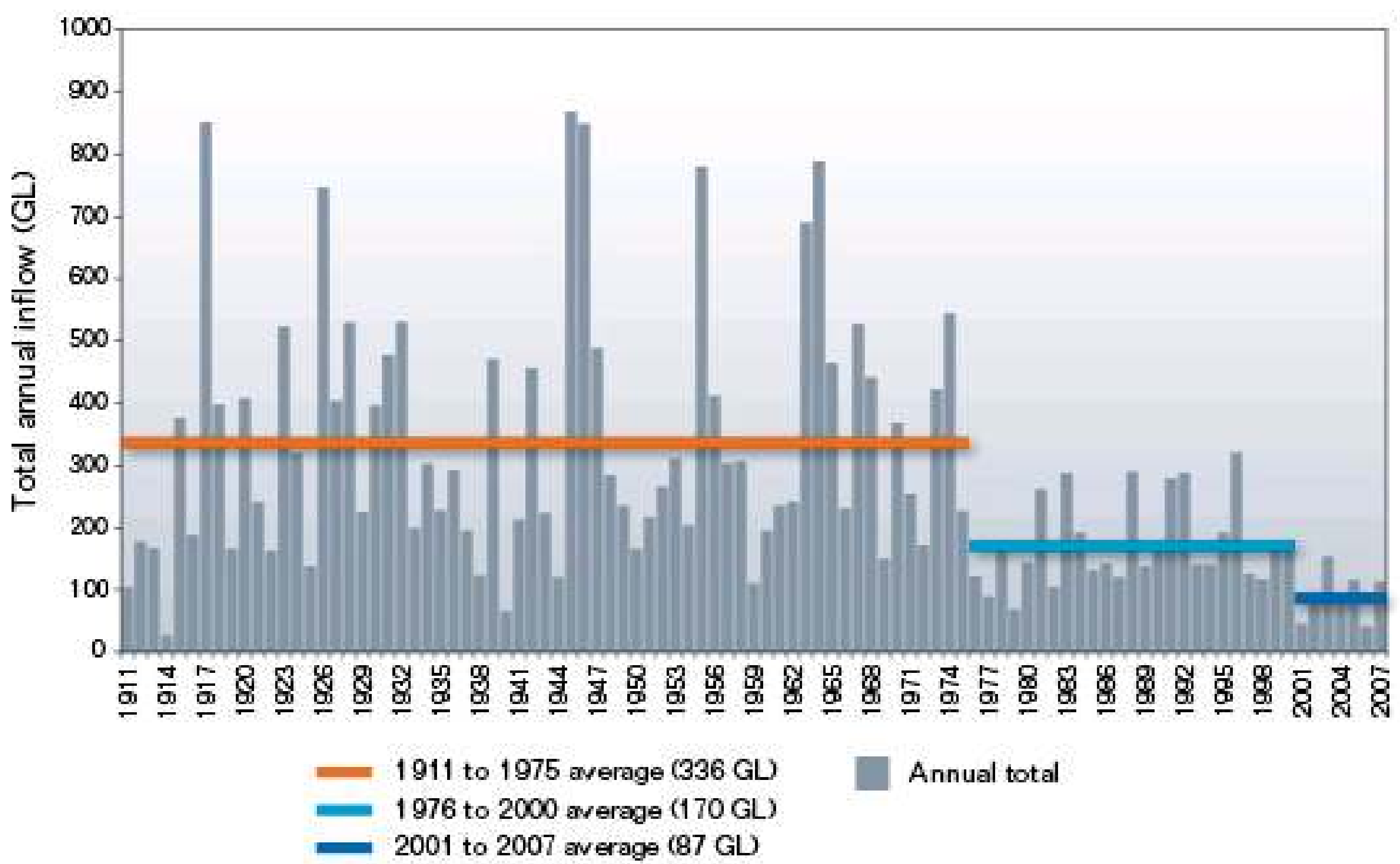

Image courtesy of http://global-warming.accuweather.com/blogpics/map_blended_mntp_02_2007_pg.gif




http://global-warming.accuweather.com/blogpics/map_blended_mntp_02_2007_pg.gif

LOW FLOW: The Colorado River is one of several around the world losing water.

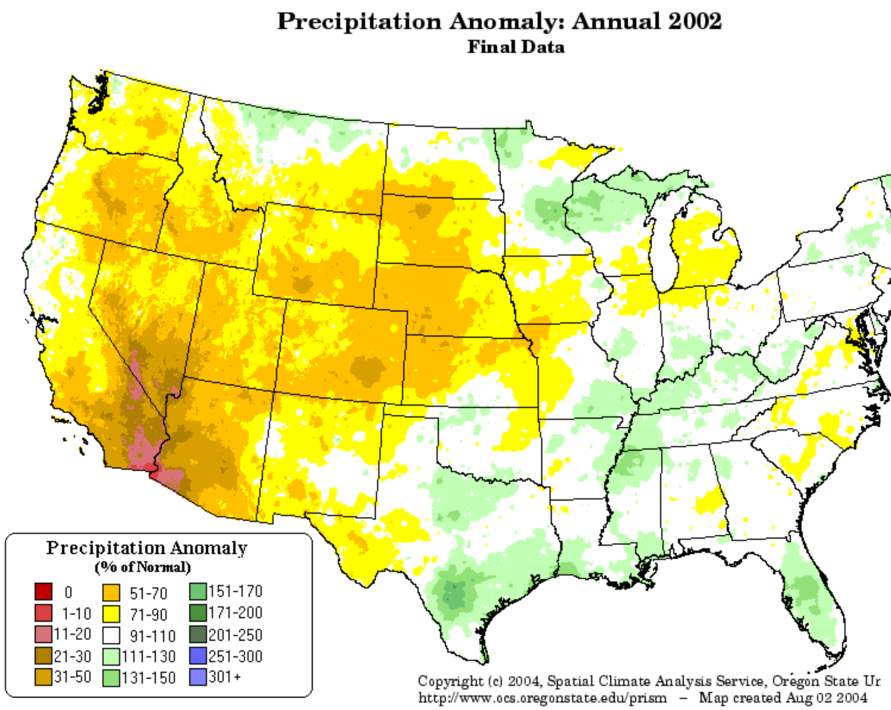
Image courtesy of ZUMA Press http://www.mnn.com/earth-matters/climate-change




Annual streamflows into Perth's dams

Figure courtesy of http://www.garnautreview.org.au/chp5.htm

# Precipitation Anomalies



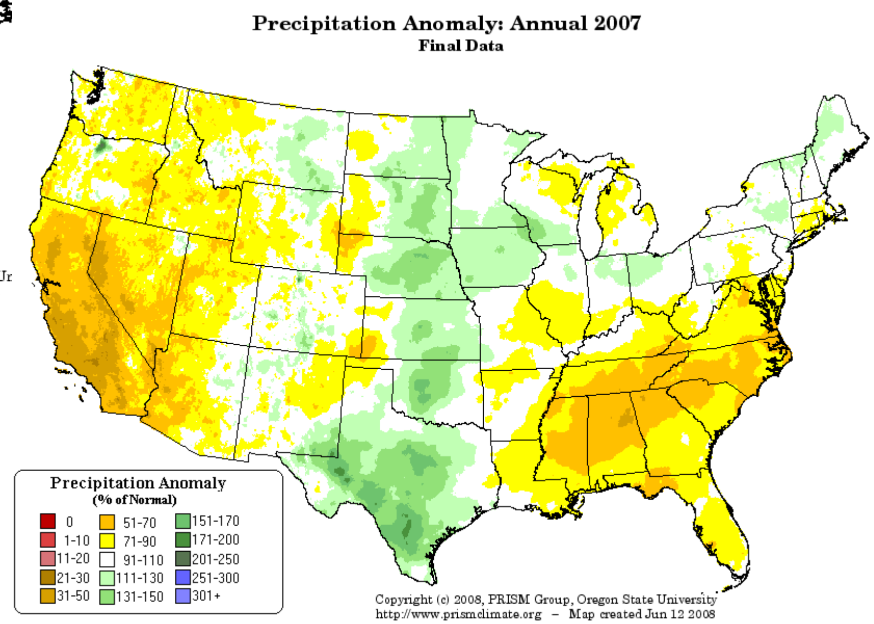



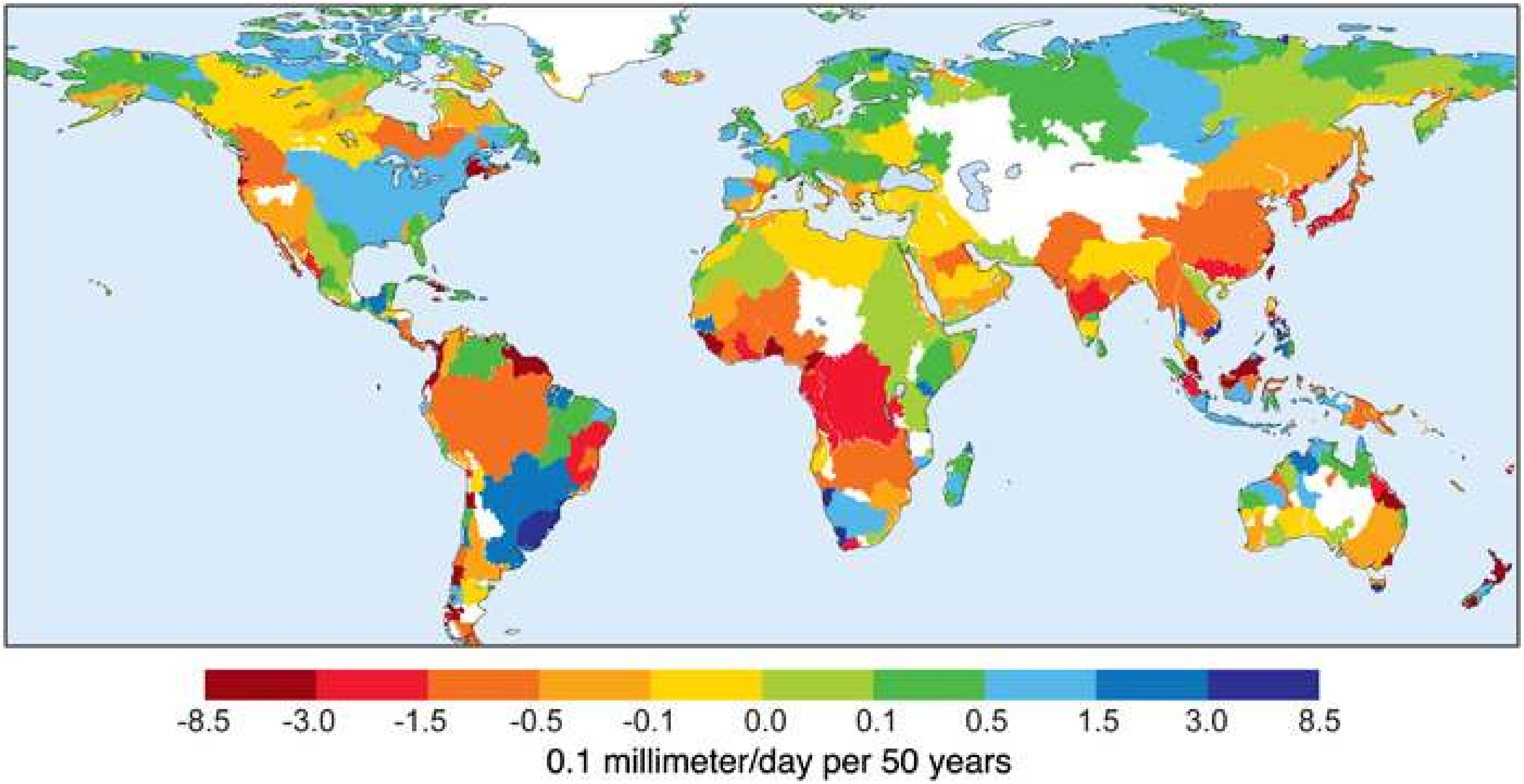

Image courtesy of http://www.prism.oregonstate.edu/index.phtml

## Projected U.S. Regional Climate Impacts

| Impacts | Region |
|---|---|
| Coastal flooding/erosion | South, Southeast, Mid-Atlantic, Northeast, Northwest, Alaska |
| Hurricanes | Atlantic and Gulf of Mexico coastal areas |
| Decreased snow cover and ice, more intense winter storms | Alaska, West, Great Lakes, Northeast |
| Flooding/intense precipitation | All regions, increasing with higher northern latitude |
| Sea-level rise | Atlantic and Gulf of Mexico coastal areas, San Francisco Bay/Sacramento Delta region, Puget Sound, Alaska, Guam, Puerto Rico |
| Decreased precipitation and stream-flow | Southwest |
| Drought | Portions of the Southeast and Southwest |
| Wildfires | West, Alaska |
| Intense heat waves | All regions |

Courtesy of http://www.pewclimate.org/docUploads/

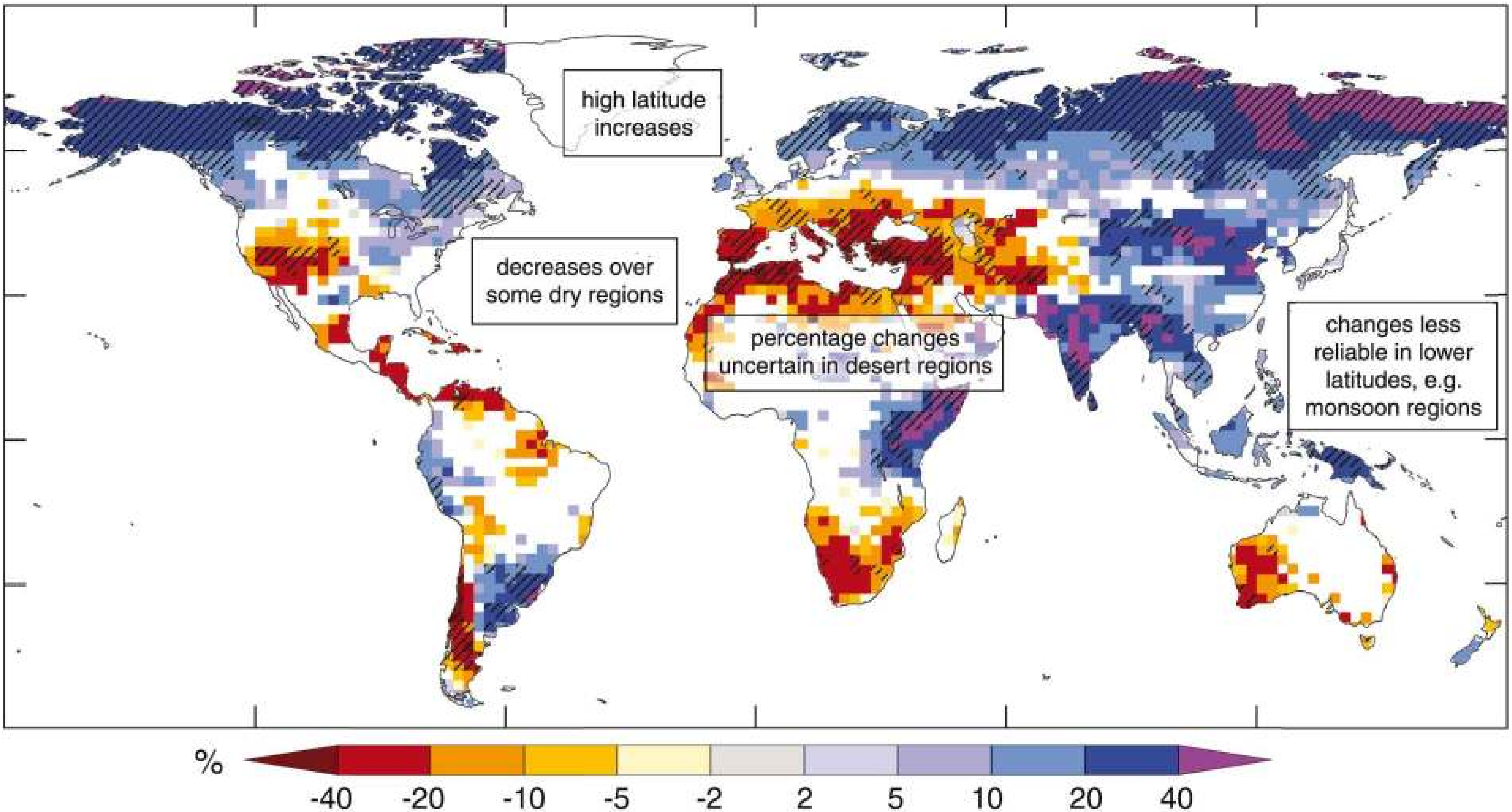
# Change in runoff  based on streamflow data




Time period: 1948-2004

Image courtesy of http://www.laboratoryequipment.com/news-climate-change-river-level-drops-042209.aspx

# Annual runoff projection by four climate models




Percentage changes in average annual runoff projected by four climate models for the period 2090-2099, relative to 1980-1999 Source: IPCC. 2007. Climate Change 2007: Synthesis Report. Intergovernmental Panel on Climate Change. Figure 3.5, p. 49.

Image courtesy of http://www.theclimatechangeclearinghouse.org/HydrologicEffects/ChangesAnnualAvgRunoff/default.aspx

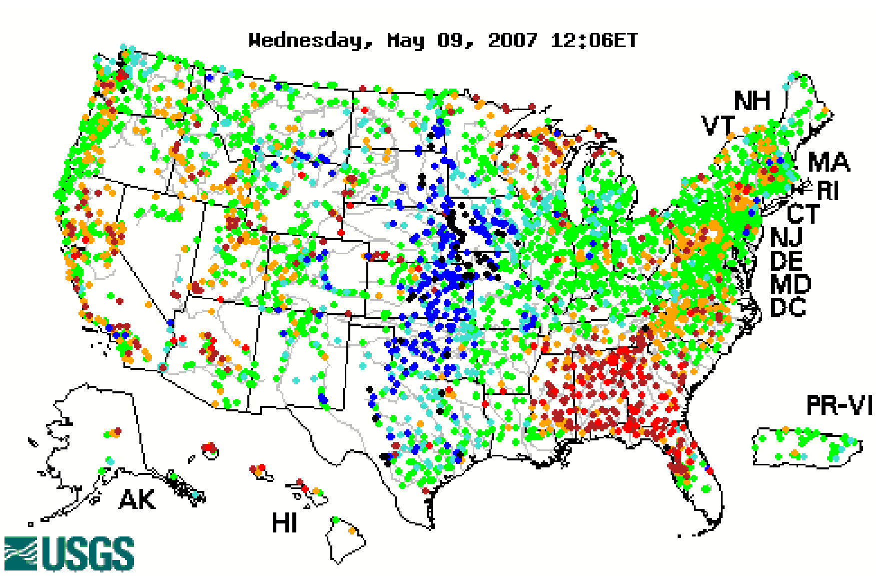
# More room for climate change studies than ever!

Climate change impact on:
- Freshwater systems (availability, sustainability)
- Human Health
- Ecosystems
- Existing Infrastructure
- Financial cost
- …

For future:
- Adaptation & Mitigation studies
- Risk/Vulnerability analysis

# Appendix-1 - Where to get the data?

## USGS Daily Streamflow Conditions
## Real-Time Water Data for the Nation




- High
- >90th percentile
- 75th – 89th percentile
- 25th – 74th percentile
- 10th – 24th percentile
- < 10th percentile
- Low
- Not rated

Note: Percentile is computed from the period of record for the current day of year. Only stations with at least 30 years of record are included.

USGS observation station
Site name: San Lorenzo Creek
Location: near King city, CA
Drainage area: 233 miles$^2$
Period of recorded data: Oct 1958 to current
Gage datum: 431.8 feet ASL NGVD29

# USGS DAILY STREAMFLOW DATA DOWNLOAD

-http://nwis.waterdata.usgs.gov/nwis

Surface Water

Daily Data

Site Name/Location/etc.

**SUBMIT**

# Appendix-2 – Related Links

USGS

http://waterwatch.usgs.gov/

http://water.usgs.gov/osw/

http://nwis.waterdata.usgs.gov/nwis

EPA

http://www.epa.gov/watertrain/

NOAA

http://www.katrina.noaa.gov/helicopter/helicopter-2.html

http://www.nhc.noaa.gov/HAW2/english/storm_surge.shtml

IPCC

http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm

FEMA

http://www.fema.gov/hazard/flood/index.shtm

UCAR

http://www.ucar.edu/communications/factsheets/Flooding.html

# Homework!!!

1) Download from USGS web site the Annual Discharge (m/sec) Statistic for site "FOURMILE RUN AT ALEXANDRIA, VA " (site # 01652500). Calculate the return period of a storm that has above 26$m^3$/sec annual mean discharge. Also calculate the probability of having two consecutive storms with discharge values above 20.1 $m^3$/sec.

2) How will the global warming (rising temperatures) effect the spatial or temporal distribution of runoff? Answers may include the aspects of streamflows that are snow/precipitation driven. How would the feedback mechanisms contribute to this affect? How about the hydrographs, any shape change expected? If so why and how? How floods and extreme event probabilities would be affected? (Remember, there is no correct answer to any of the questions).