# Recurrence Intervals for the June 2006 Flood in Delaware and Otsego counties, New York

Earth Sciences Brown Bag Seminar
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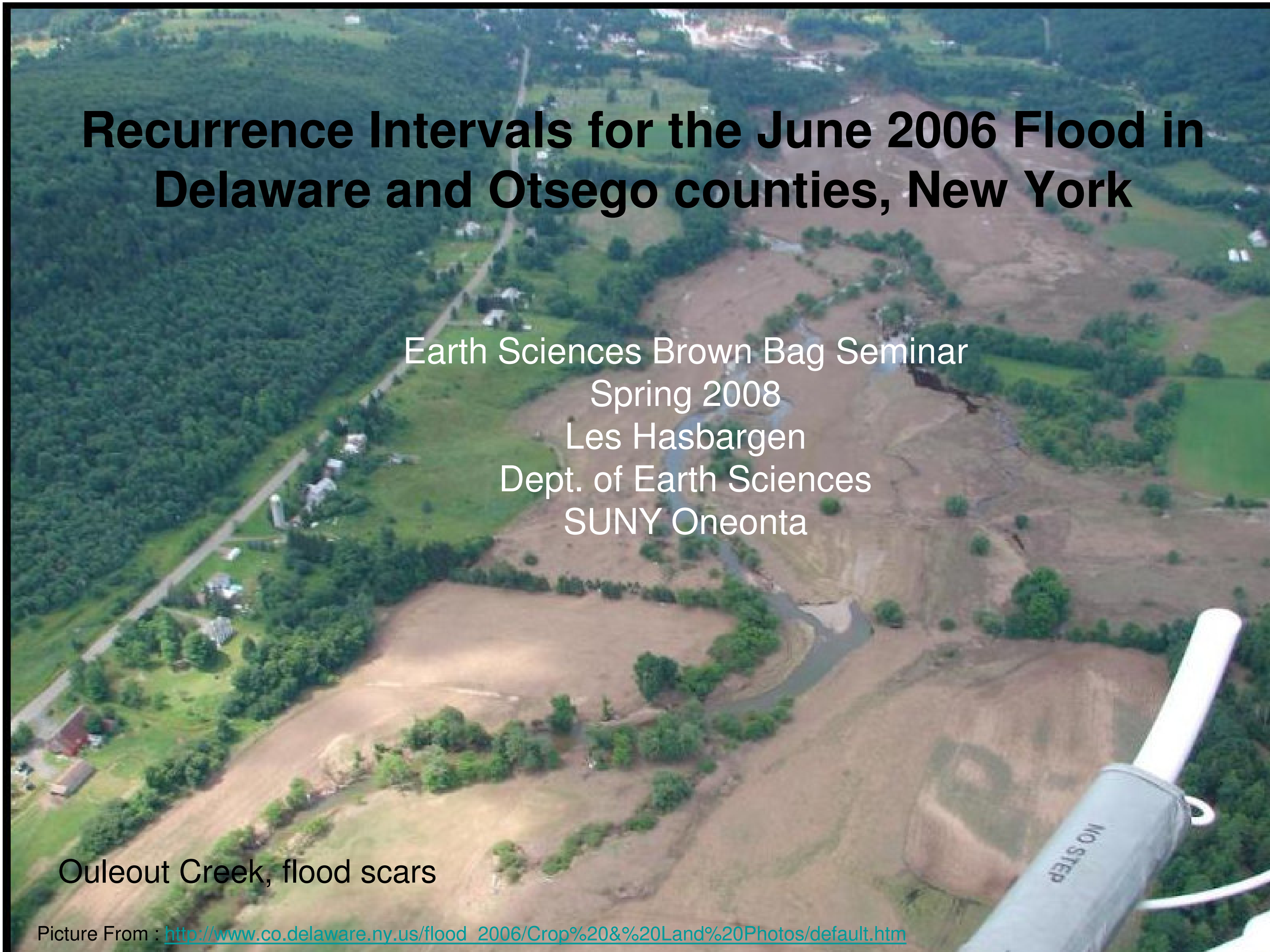
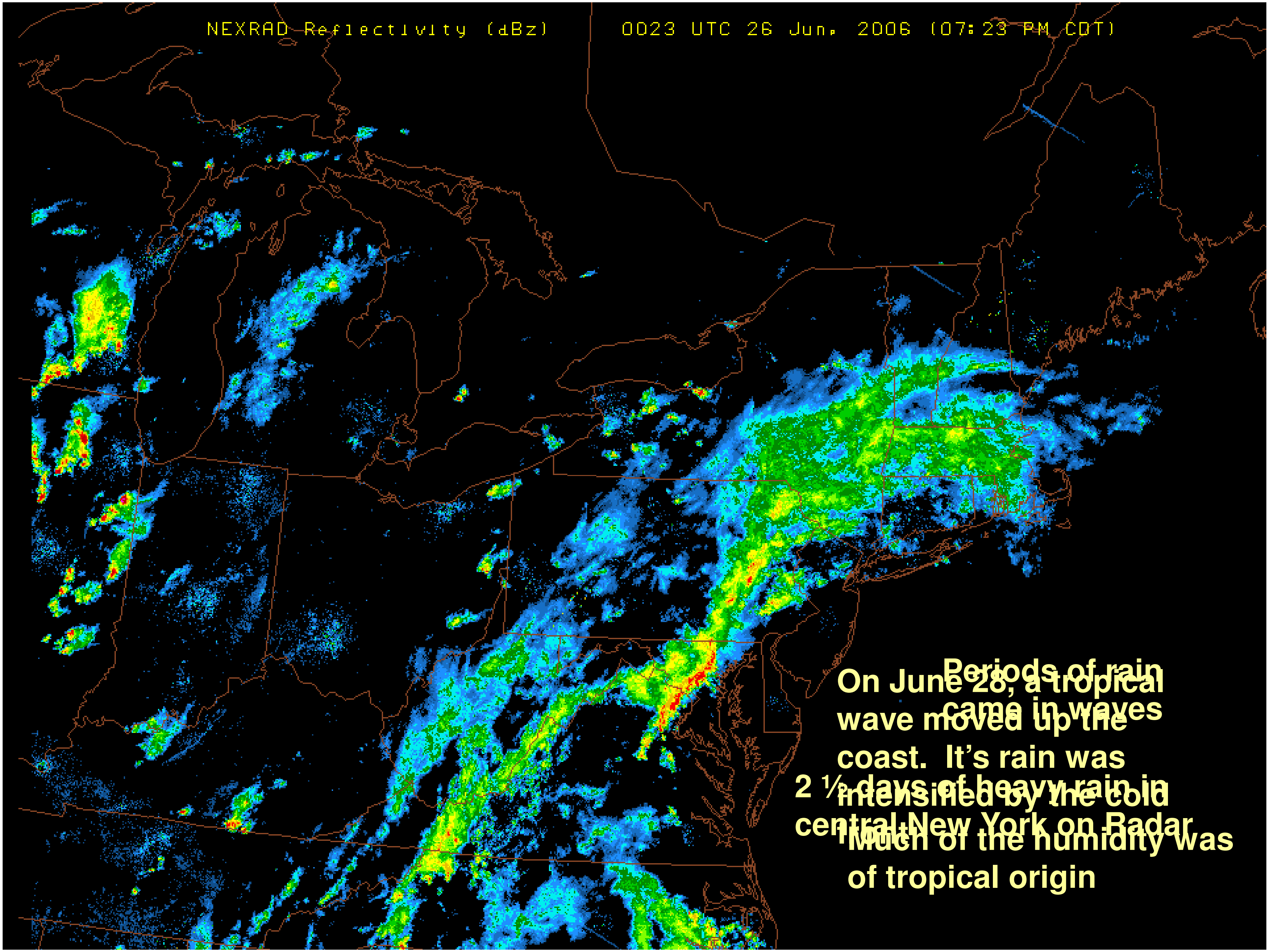



Ouleout Creek, flood scars

Picture From : http://www.co.delaware.ny.us/flood_2006/Crop%20&%20Land%20Photos/default.htm


NEXRAD Reflectivity (dBz)
0023 UTC 26 Jun. 2006 (07:23 PM CDT)
Periods of rain came in waves
On June 28, a tropical wave moved up the coast. It's rain was intensified by the cold front
2 ½ days of heavy rain in central New York on Radar
Much of the humidity was of tropical origin

Otego Creek in  Laurens, NY

Floods caused erosion of cropland
Significant transport of cobbles and boulders


Picture From : http://www.co.delaware.ny.us/flood_2006/Crop%20&%20Land%20Photos/default.htm

From: http://www.co.delaware.ny.us/flood_2006/During%20the%20Flood/default.htm

From: http://www.co.delaware.ny.us/flood_2006/During%20the%20Flood/default.htm

# What can we learn from these floods?

- How often will a flood like this come along?
- What areas were most damaged?
- What areas were least affected?
- This was a “geomorphic” event. Can we learn something about erosion, transport, and deposition from this event?

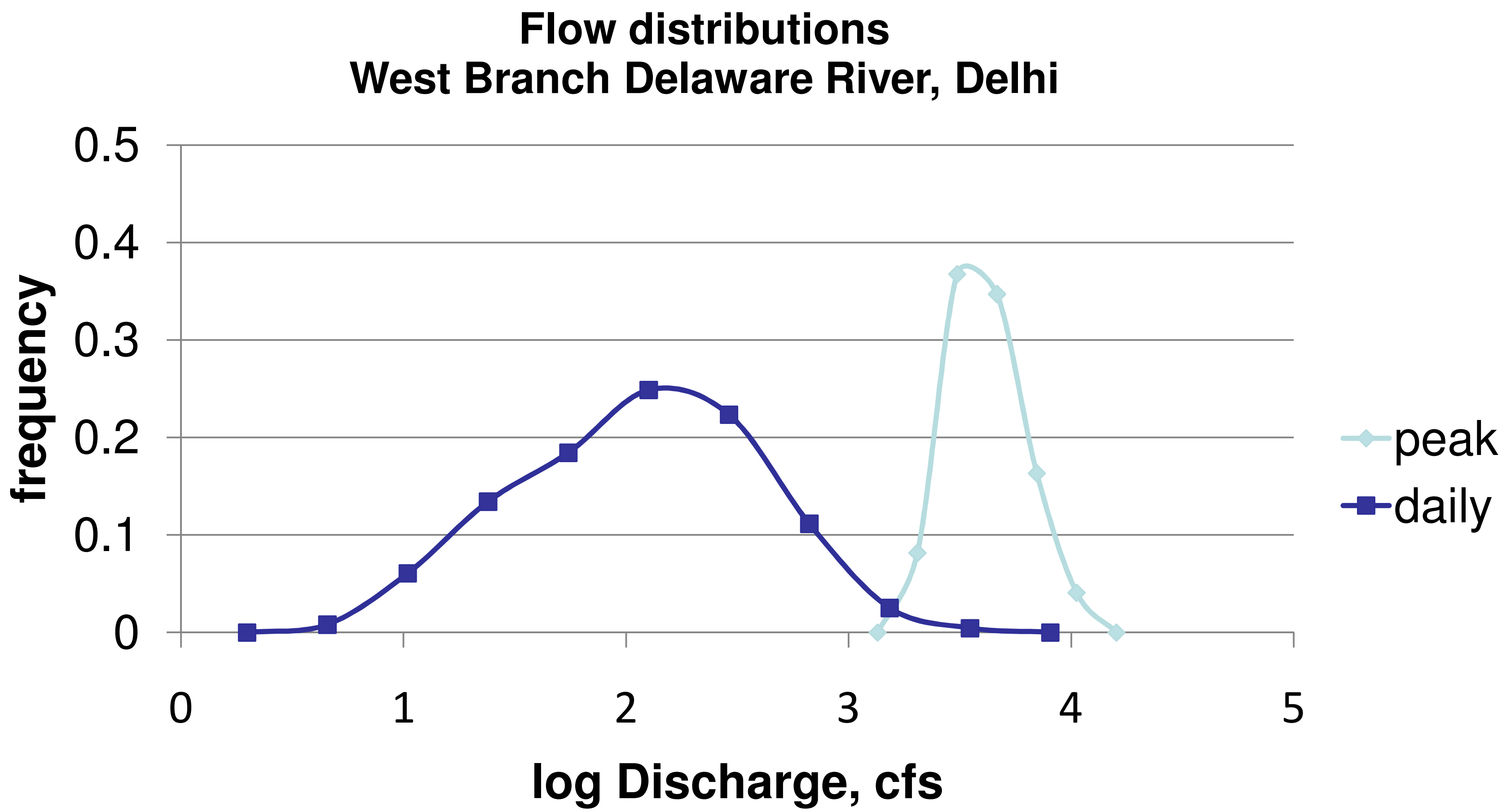
# There is a lot of basic research to do here!

- Recent research by USGS provides estimates of ***flood recurrence***—but there's more to be done…
- Quantify relationships between ***rainfall and runoff*** for local basins
- Characterize relation between ***flood heights*** and ***channel characteristics*** (how rough is the bed?)
- Document ***erosion, transport, and deposition*** in a range of settings and **grain sizes**
- Today, I'll start with flood recurrence

# Flood Recurrence

- The frequency-size distribution for all of the flows a river experiences would be very helpful to know
- Once a mathematical model is fit to the data, we can determine the size of flow for a given recurrence interval (e.g., the *100-yr flood*)

# Log-normal flow distributions




*A note on flood frequency distributions*: Real flow distributions do not fit any known mathematical distributions perfectly well; the USGS recommends the Log Pearson Type III distribution, but they do so with a nod to future changes (USGS Circular 17b, 1982)

# The standard model for flood frequency distributions from the USGS

- Treat the flood records as Log-normal distributions (Log Pearson Type III)
  - Compute average, standard deviation, and skew of **log transformed data**
- With these values, we can reconstruct the distribution with the LPTIII model

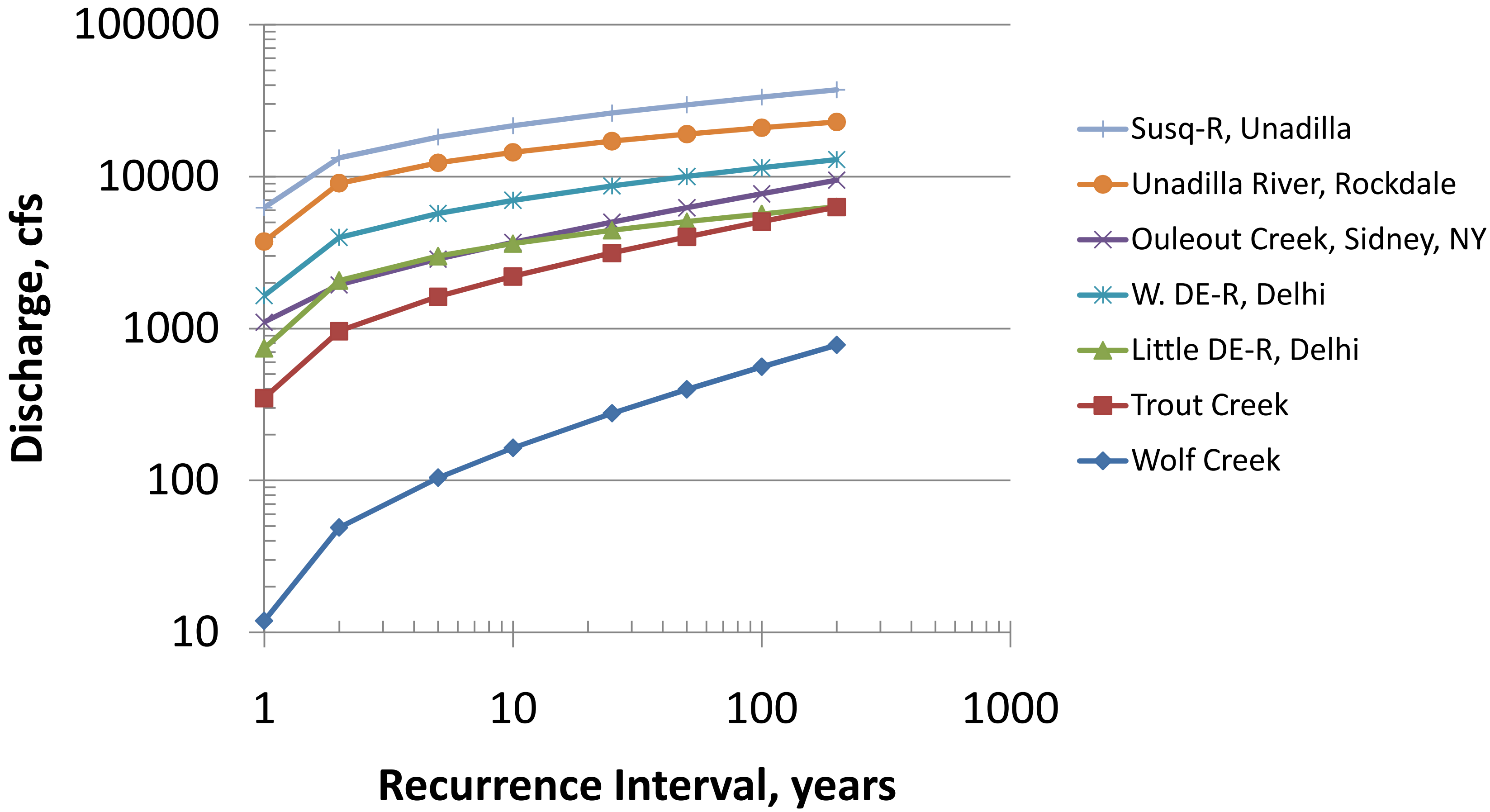
$$\log(Q) = \mu + K\sigma$$

where $\mu$ is the average of log ($Q$), $K$ is a frequency factor that depends on recurrence interval (and you need to use look-up tables to get this!!) and skew of log ($Q$) and $\sigma$ is the standard deviation of log ($Q$)

- From this equation, we can estimate the probability that a flow of a given size will be equaled or exceeded

# Recurrence Intervals Using Log Pearson Type III

Note Recurrence Interval is the reciprocal of probability



# Flow frequency: Weibull method

- Flow events are ranked (m) from largest to smallest (the $n^{th}$ event)
- This is essentially the number of events in the record that are larger than some value [*exceedance probability, P*]

- *P* is the probability
- *m* is the rank
- *n* is the # data values
- *RI* is recurrence interval

$$P = \frac{m}{n+1}$$

$$RI = \frac{1}{P} = \frac{n+1}{m}$$

# Basic steps to get the frequency

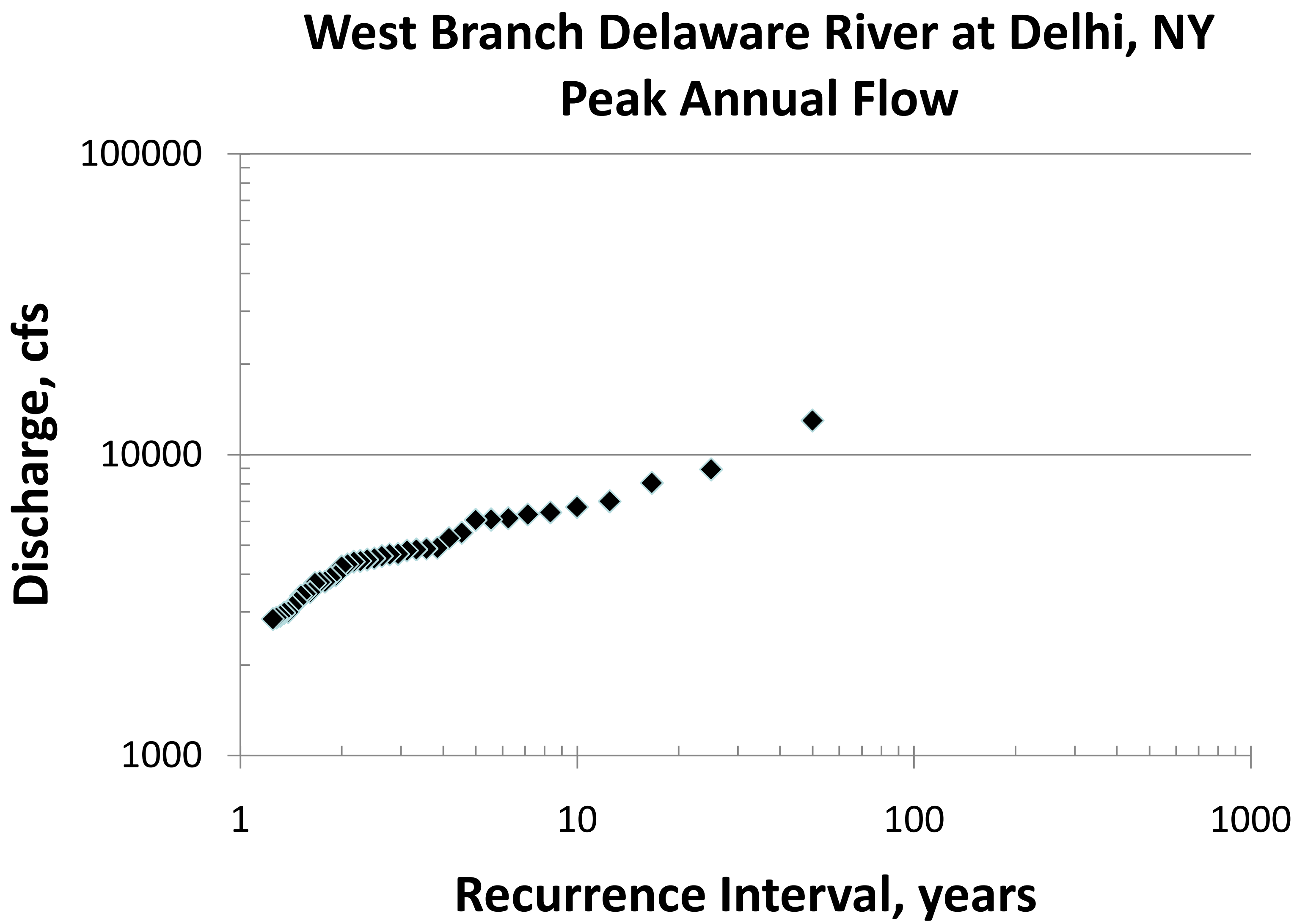
- Sort the data by size, largest to smallest
- Rank each event (*m*), from 1 (the largest) to *n* (the smallest)
- Calculate the probability *P* that a flow of a given size will be equaled or exceeded:

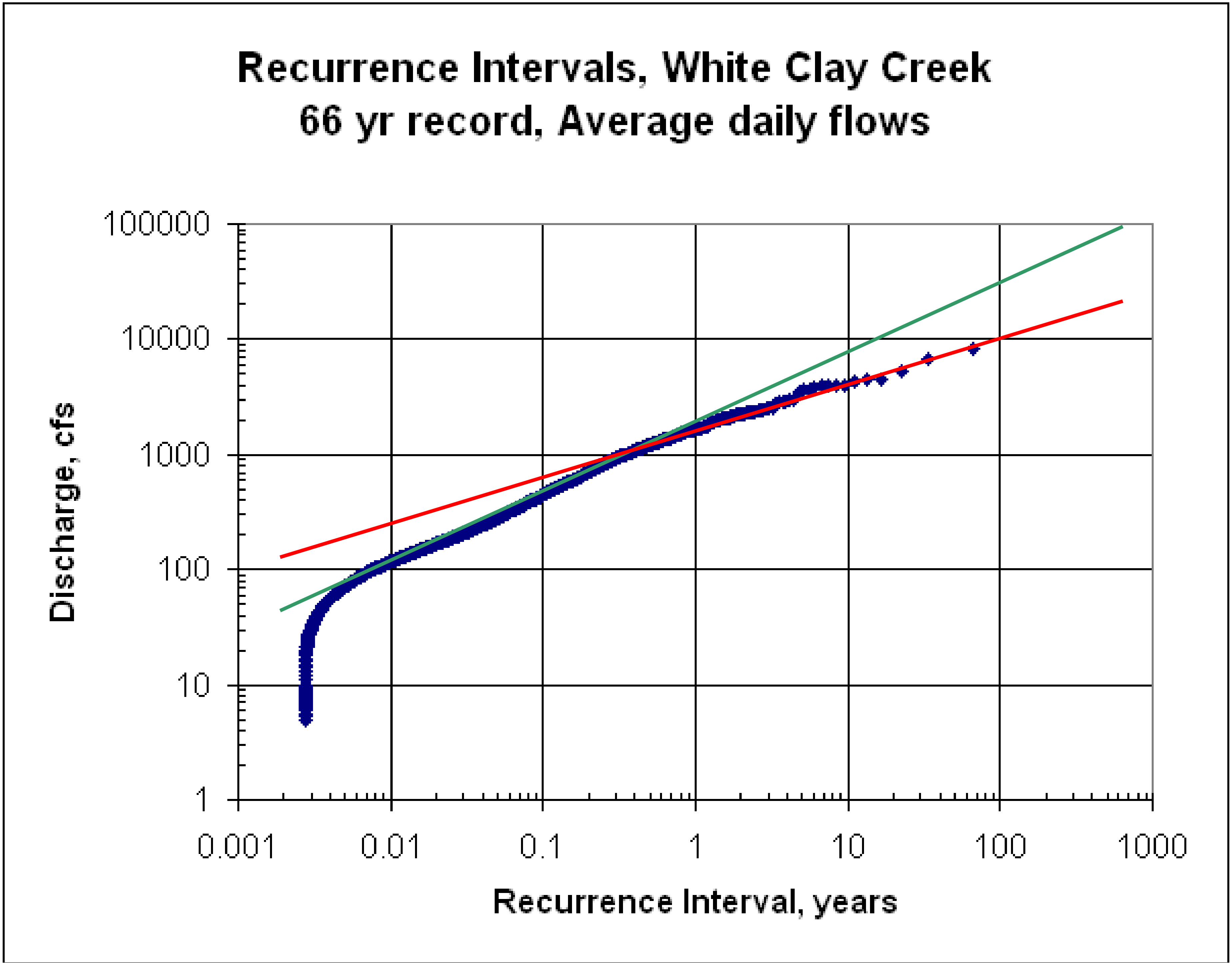
$$P = \frac{m}{n+1}$$

- The reciprocal of *P* is the **recurrence interval** *RI*, the size of flow that comes along once in the time interval (years, in our situation)

$$RI = \frac{n+1}{m}$$

- Plot the discharge vs RI
- Fit a trend line to the data


West Branch Delaware River at Delhi, NY
Peak Annual Flow
100000
10000
1000
Discharge, cfs
1
10
100
1000
Recurrence Interval, years



Recurrence Intervals, White Clay Creek
66 yr record, Average daily flows
Discharge, cfs
100000
10000
1000
100
10
1
0.001
0.01
0.1
1
10
100
1000
Recurrence Interval, years

# Power law distribution (fractal)

- Many events in nature have lots of small events and few large ones (earthquakes, fault sizes, floods)
- These distributions are self-similar—we can use one part of the distribution to describe any other part
  - They look the same at any level of magnification
  - They can span several orders of magnitude [thresholds]
- A power law mathematical model describes such events
  - Order the flows and compute recurrence intervals
  - Fit a power law equation to the data
    - Bruce Malamud and Donald Turcotte, The applicability of power-law frequency statistics to floods, Journal of Hydrology Volume 322, Issues 1-4, 15 May 2006, Pages 168-180.
    - R. Kidson*, K. S. Richards, & P. A. Carling, **Power-law extreme flood frequency,** *Geological Society, London, Special Publications*; 2006; v. 261; p. 141-153; DOI: 10.1144/GSL.SP.2006.261.01.11.

# General form of a power law

$$y(x) = ax^b$$

where $y$ is the dependent variable

$a$ is a constant coefficient; think of this as a unit scale (at $\text{x} = 1$)

$x$ is the variate

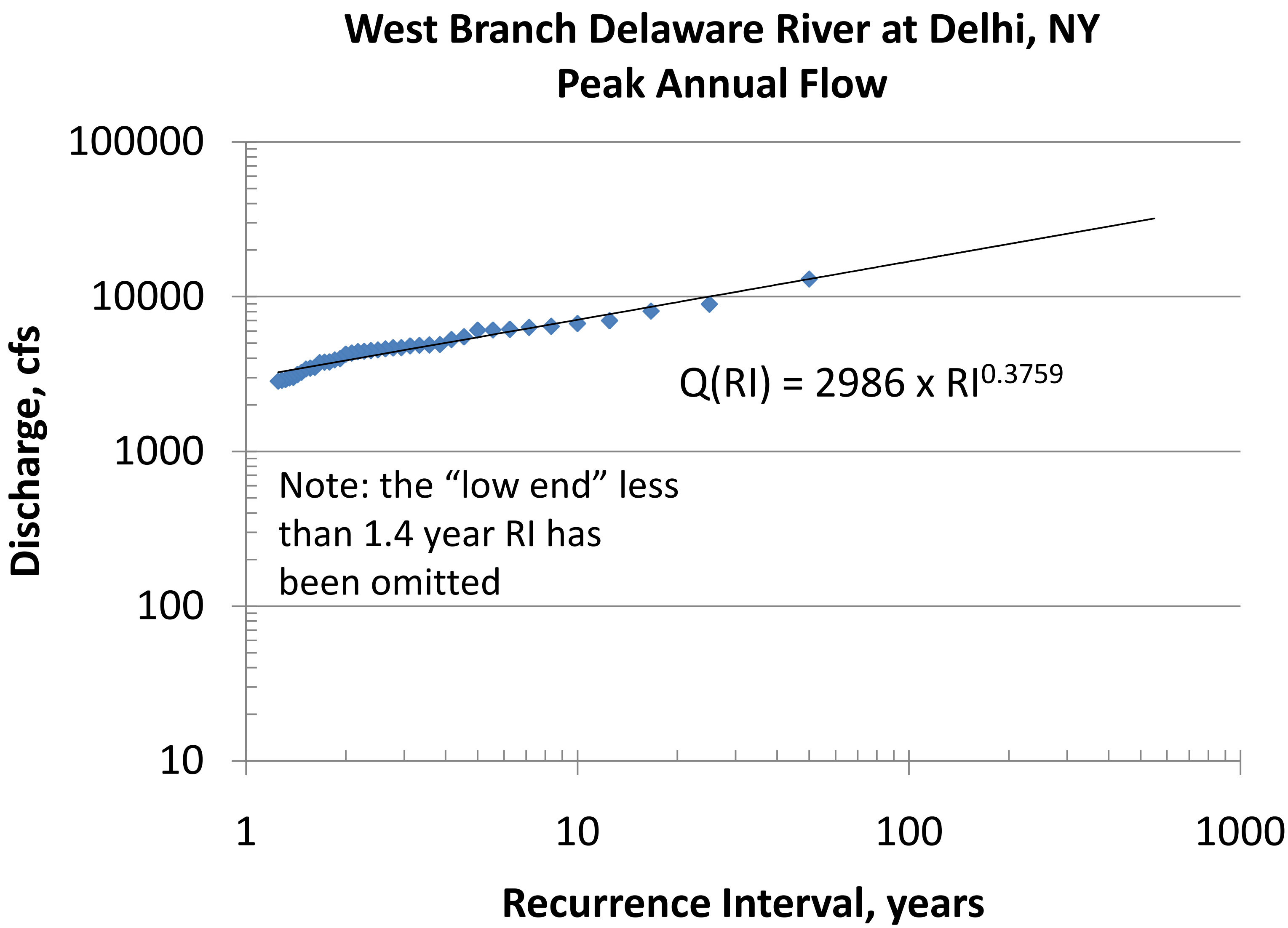
and $b$ is the exponent which characterizes the rate of change of $y$ vs $x$

for instance, as $b \to 0$, $y$ doesn't vary with $x$

if $b > 0$, then $y$ increases with $x$

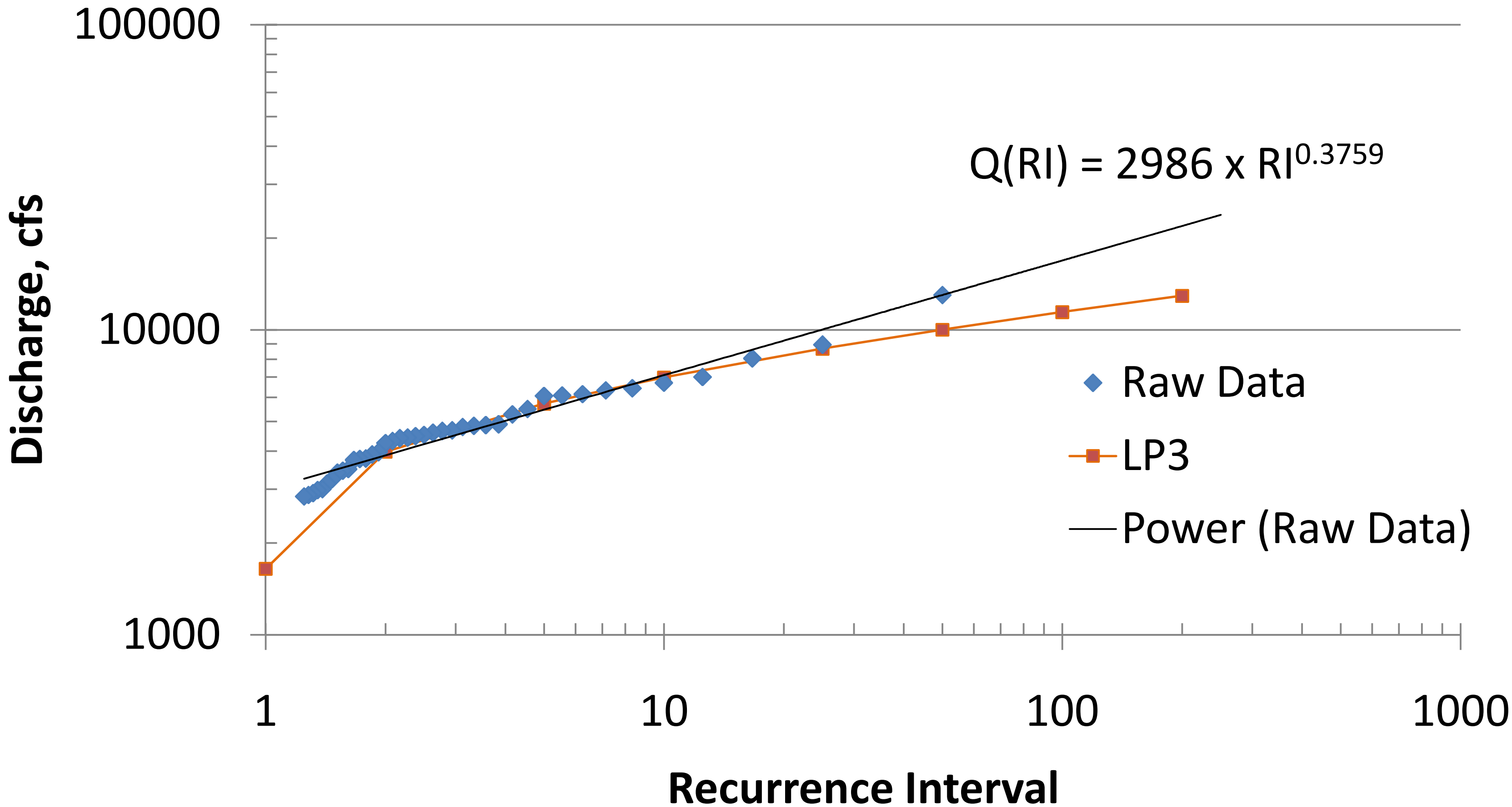
if $b < 0$, then $y$ decreases with $x$

# Power law flow distribution



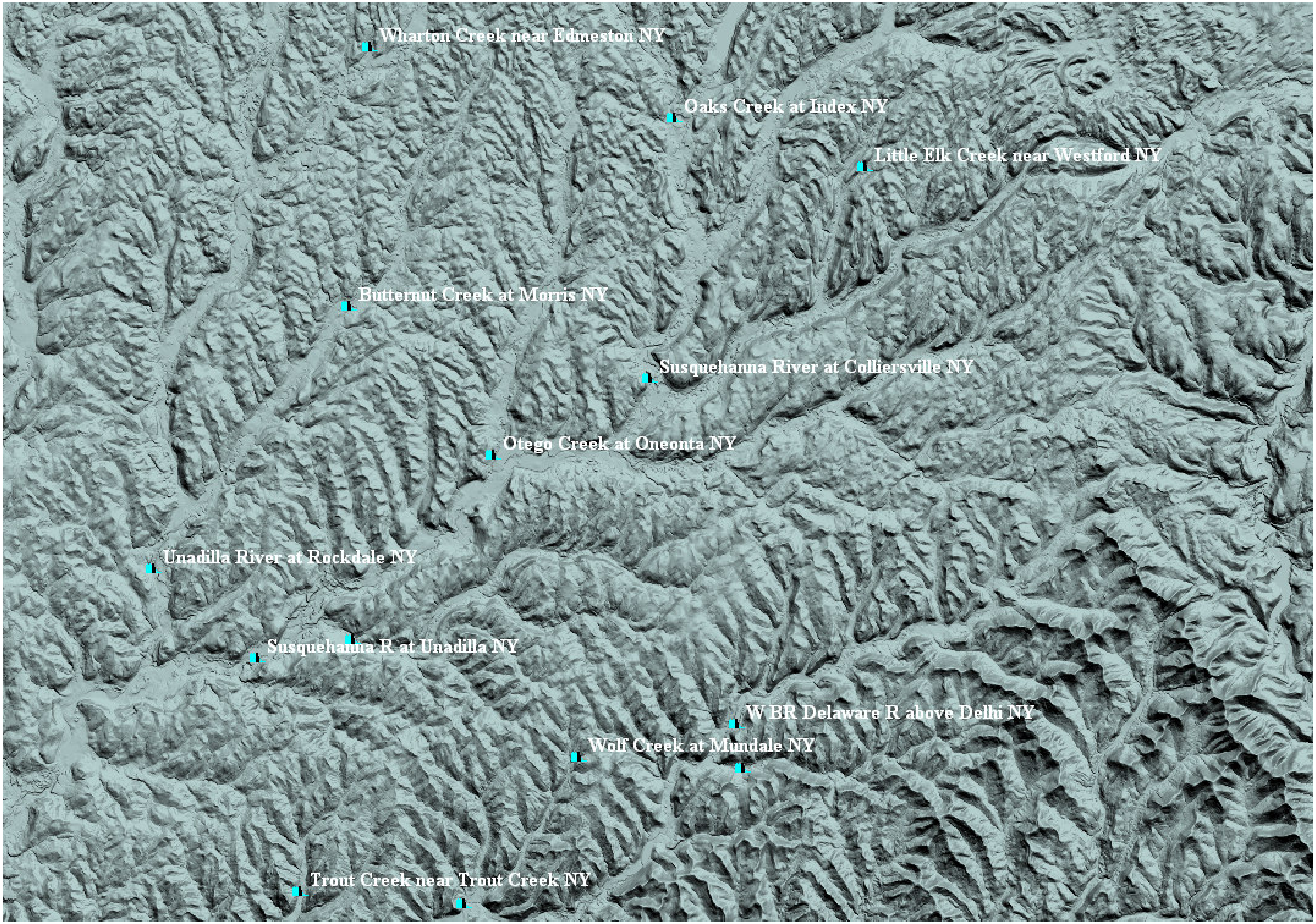

Note: Each gage record exhibits the same form as above, but with different exponents and coefficients in the power law relation

# Comparing LPT3 and Power Law fits to the data




Peak Annual Flow at the West Branch Delaware River at Delhi, NY

# Shaded Relief Map of USGS Gage Stations



# Recurrence Intervals for the 2006 Flood Event

| River | Peak Discharge (cfs) | Recurrence Interval, LPT3 | Recurrence Interval, Power Law |
|---|---|---|---|
| Susquehanna River, Unadilla | 34,900 | 121 years | 48 years |
| West Branch Delaware River, Walton | 28,600 | 67 years | 32 years |
| Unadilla River, Rockdale | 23,100 | 167 years | 70 years |
| West Branch Delaware River, Delhi | 13000 | 208 years | 51 years |
| Ouleout Creek | 7250 | 76 years | 43 years |
| Little Delaware River at Delhi | 6100 | 141 years | 50 years |
| Trout Creek | 4350 | 54 years | 25 years |
| Wolf Creek | 350 | 23 years | 12 years |

Note: these are all model dependent approximations, and should NOT be considered an official estimate for planning purposes

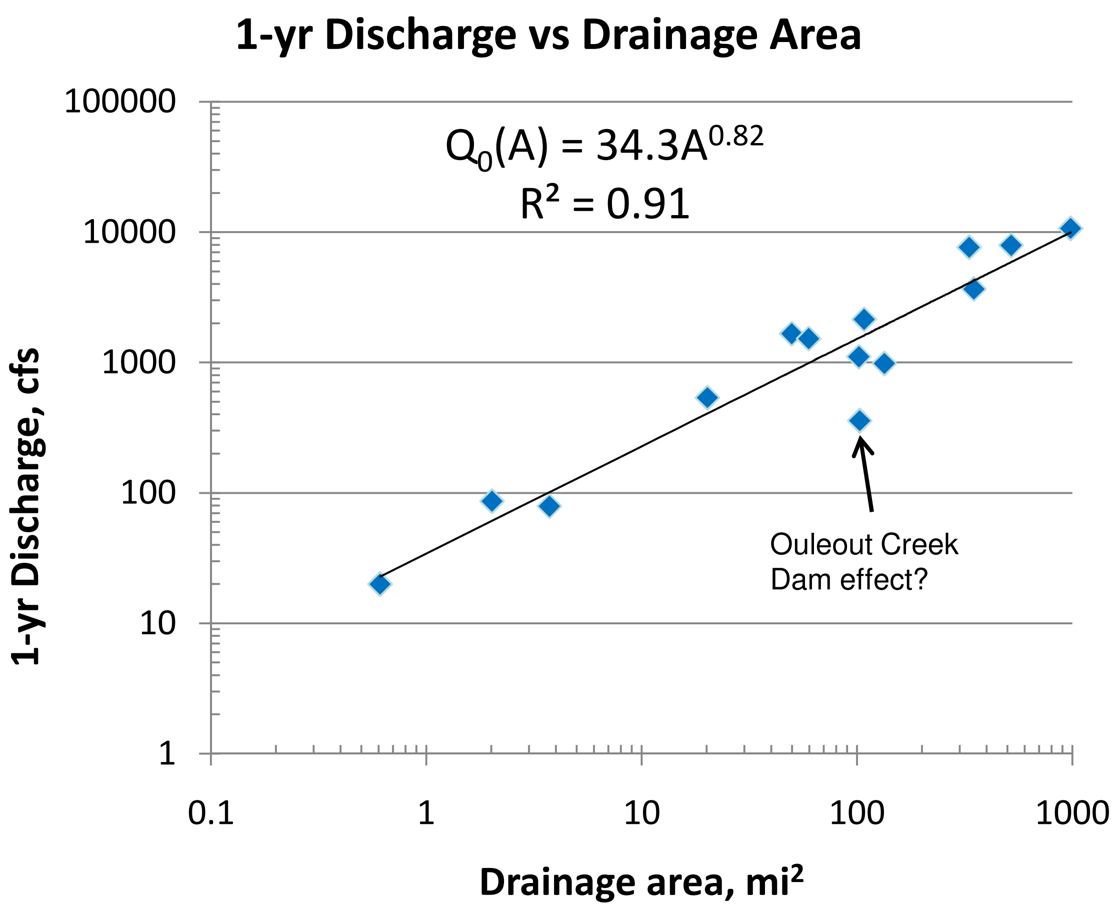
# Bottom line on the 2006 Flood event

- The 2006 Flood is probably a once-(or twice)-in-a-lifetime experience, but this depends on **where you live**!!
- Recurrence intervals vary with drainage basin size (smaller basins exhibit larger ranges)
- The Log Pearson Type III distribution gives longer return periods than the power law
- The relationship of RI with basin size is worth following…

# Flood Recurrence-Discharge power law parameters for Delaware and Otsego County

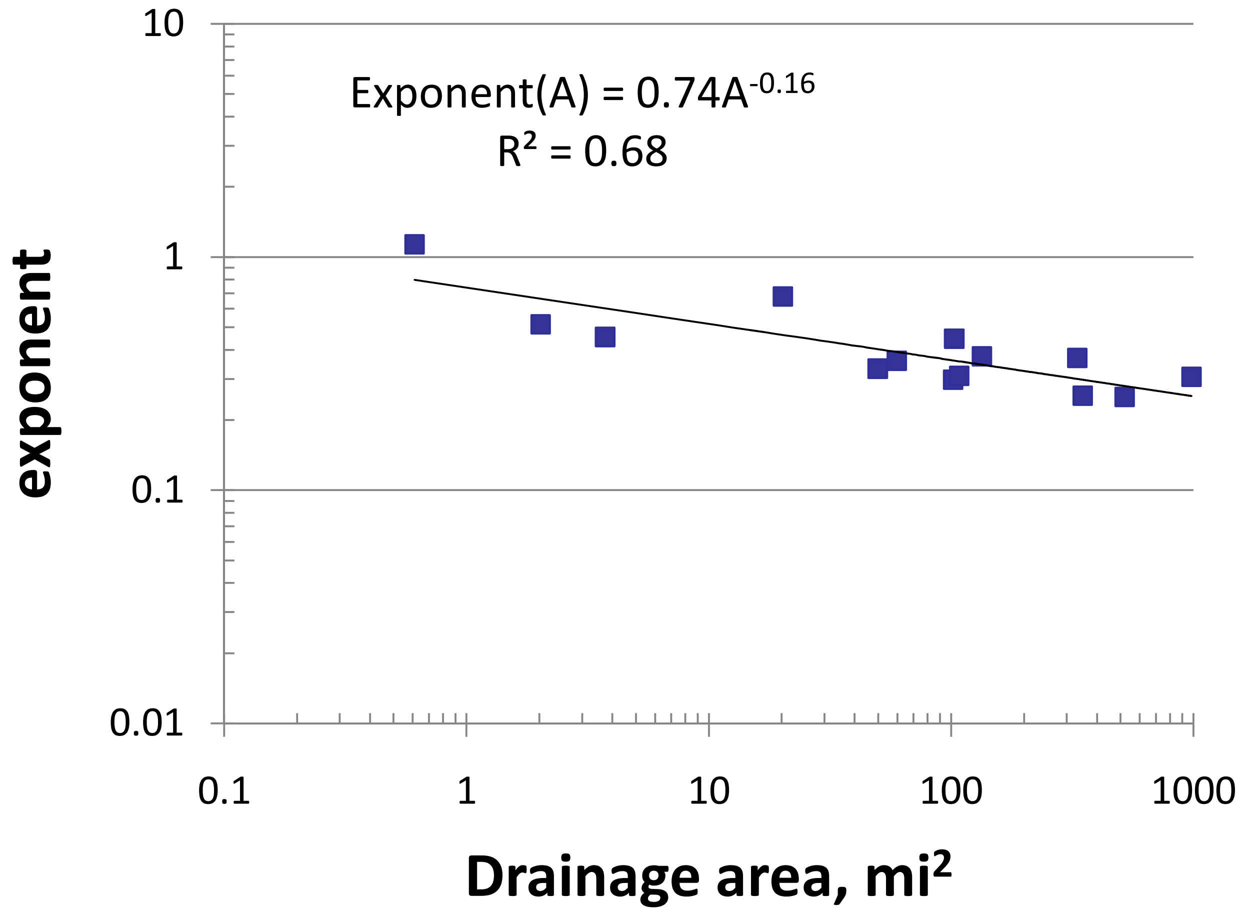
| Drainage Basin | Area ($mi^2$) | 1-yr Discharge (cfs) | Scaling exponent |
|---|---|---|---|
| Wolf Creek | 0.61 | 20 | 1.13 |
| Wharton Creek, Edmeston NY | 2.02 | 86.6 | 0.51 |
| Little Elk Creek, Westford NY | 3.73 | 79.2 | 0.45 |
| Trout Creek | 20.2 | 539 | 0.68 |
| Little DE-R, Delhi | 49.8 | 1669 | 0.33 |
| Butternut Creek, Morris NY | 59.7 | 1528 | 0.36 |
| Oaks Creek, Index NY | 102 | 1111 | 0.30 |
| Ouleout Creek, Sidney, NY | 103 | 359 | 0.45 |
| Otego Creek, Oneonta NY | 108 | 2149 | 0.31 |
| W. DE-R, Delhi | 134 | 986 | 0.38 |
| W. Br. Del-R, Walton | 332 | 7678 | 0.37 |
| Susquehanna River, Colliersville | 349 | 3677 | 0.25 |
| Unadilla River, Rockdale | 520 | 7956 | 0.25 |
| Susq-R, Unadilla | 982 | 10719 | 0.31 |

# Plot of the power law coefficients vs drainage basin area for Delaware and Otsego Counties




The coefficient can be thought of as the 1-yr peak discharge for the given drainage basin

# Plot of power law exponents vs drainage basin area for Delaware and Otsego Counties




The small value (-0.16) indicates a weak relation between drainage area and exponent; in general, smaller basins exhibit a larger exponent, which means that small basins exhibit larger increase in flood size with RI than large basins do

# Predicting flow in ungauged basins

- We can use the empirical relations between power law parameters and basin size to develop a model for an ungauged basin
- First, compute the parameters given basin area
- Then these parameters go into the power law for discharge as a function of recurrence

# Example: Ungaged basin model for Delaware and Otsego Counties

Given the two relations for power law parameters

$Q_0(A) = 34.3A^{0.82}$

$Exponent(A) = 0.74A^{-0.16}$

where A is an drainage basin area in $mi^2$

If an ungaged basin is $A = 5$ $mi^2$, then

$Q_0(A) = 34.3 \times 5^{0.82} = 128$

$Exponent(A) = 0.74 \times 5^{-0.16} = 0.57$

So $Q(RI) = 128\ RI^{0.57}$

# Recent stream flow estimation from the USGS

- Multivariate analysis of stream flow, basin area, land cover and use, rainfall results in a set of predictive equations for ungaged basins

Lumia, Richard, Freehafer, D.A., and Smith, M.J., 2006, Magnitude and frequency of floods in New York: U.S. Geological Survey Scientific Investigations Report 2006–5112, 152 p.

$$Q = kA^{b} S_{st}{}^{c} R^{d} S_{sl}{}^{e}$$

where $k$ is a dimensional coefficient

$A$ is drainage area, in $\mathrm{mi}^2$

$S_{st}$ is % storage in the drainage (lakes, wetlands, etc)

$R$ is mean annual rainfall, in inches

$S_{sl}$ is the ratio of stream slope to basin slope

and $b$, $c$, $d$ and $e$ are scaling exponents derived empirically

# USGS Recurrence Model for New York

For ungauged basins, and based on Area (A), %storage (ST), annual rainfall (R), and channel to basin slope ratio (SR), and coefficients and exponents are functions of the recurrence interval for Log Pearson Type III distribution

**Region 4**

$$Q_{1.25} = 0.037\,(A)^{1.029}\,(ST+0.5)^{-0.104}\,(RUNF)^{2.308}\,(SR)^{0.317}$$

$$Q_{1.5} = 0.064\,(A)^{1.022}\,(ST+0.5)^{-0.120}\,(RUNF)^{2.205}\,(SR)^{0.320}$$

$$Q_{2} = 0.115\,(A)^{1.012}\,(ST+0.5)^{-0.139}\,(RUNF)^{2.092}\,(SR)^{0.319}$$

$$Q_{5} = 0.424\,(A)^{0.992}\,(ST+0.5)^{-0.189}\,(RUNF)^{1.822}\,(SR)^{0.316}$$

$$Q_{10} = 0.829\,(A)^{0.981}\,(ST+0.5)^{-0.219}\,(RUNF)^{1.685}\,(SR)^{0.314}$$

$$Q_{25} = 1.585\,(A)^{0.970}\,(ST+0.5)^{-0.250}\,(RUNF)^{1.559}\,(SR)^{0.312}$$

$$Q_{50} = 2.330\,(A)^{0.963}\,(ST+0.5)^{-0.269}\,(RUNF)^{1.489}\,(SR)^{0.312}$$

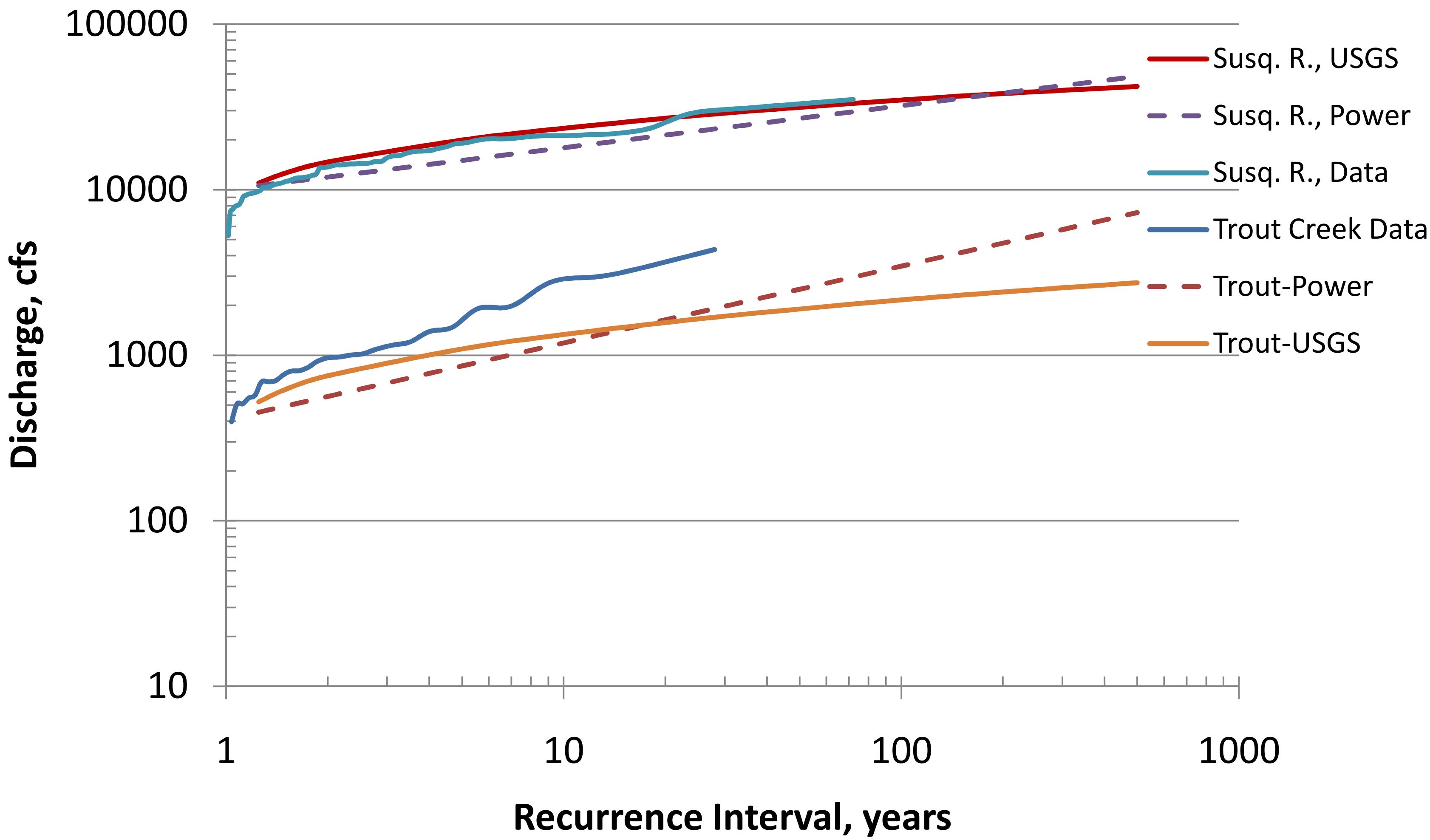
$$Q_{100} = 3.243\,(A)^{0.957}\,(ST+0.5)^{-0.285}\,(RUNF)^{1.431}\,(SR)^{0.312}$$

$$Q_{200} = 4.350\,(A)^{0.952}\,(ST+0.5)^{-0.300}\,(RUNF)^{1.380}\,(SR)^{0.313}$$

$$Q_{500} = 6.163\,(A)^{0.946}\,(ST+0.5)^{-0.317}\,(RUNF)^{1.320}\,(SR)^{0.315}$$

$$Q(RI) = f(RI) \times A^{f(RI)} (S_T + 0.5)^{f(RI)} R^{f(RI)} S_R^{f(RI)}$$

# Unguaged Model Comparison
# USGS and Power Law



# *Conclusions*

- Recurrence intervals for the 2006 flood event vary from 23 to 208 years
- Small basins exhibit shorter recurrence intervals
- Peak annual flow and average daily flow are different distributions (choice of distribution matters!)
- Models can be tweaked to fit local gage records quite well
- A power law model for flow distributions is simpler than the current USGS method
- We can estimate flows for ungaged basins, but crudely…

# More work to do…

- Discrepancies between models need to be explored
- Establish relations for rainfall-runoff for local basins
- Survey 2006 flood heights, channel geometry, and channel changes in targeted settings
- Estimate flows in targeted field sites
- Get a better handle on flow depth and channel characteristics

Bedrock vs Alluvial cover in Morris Brook, about 100 m between locations

Flood heights varied dramatically between sites

Thanks for your Attention!

# References

- Link to OSU's tutorial site for computing river flow statistics http://water.oregonstate.edu/streamflow/
- Link to USGS's site for the method to determine flood recurrence (LPT3)

  http://water.usgs.gov/osw/bulletin17b/bulletin_17B.html


- Lumia, Richard, Freehafer, D.A., and Smith, M.J., 2006, *Magnitude and frequency of floods in New York*: U.S. Geological Survey Scientific Investigations Report 2006–5112, 152 p.