science for a changing world

River Management:
Coming to terms with a changing environment

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U.S. Geological Survey

Thinking about change

- Flow (low flow, average flow, floods): Understanding changes to help us plan for the future.

- Water quality: can we describe the progress (or deterioration), relate it to causes, to help improve strategies for the future.

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Ways we can go about connecting the past to the future

1. Classical stationary statistics
2. Stationary statistics with long-term persistence
3. Focus on change and assume we know how to model it
4. Focus on change: Explore the nature of the change but only model it if we can demonstrate that we can hindcast it.

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Our tools are mostly for a stationary world, but the world we work in has some big change drivers

- Urbanization
- Agricultural land use practices
- Quasi-periodic climate variation
- Climate change
- Land drainage
- Groundwater depletion

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1. Let’s look at some daily streamflow data

1-day max
+ 177%

Mean
+ 243%

Median
+ 627%

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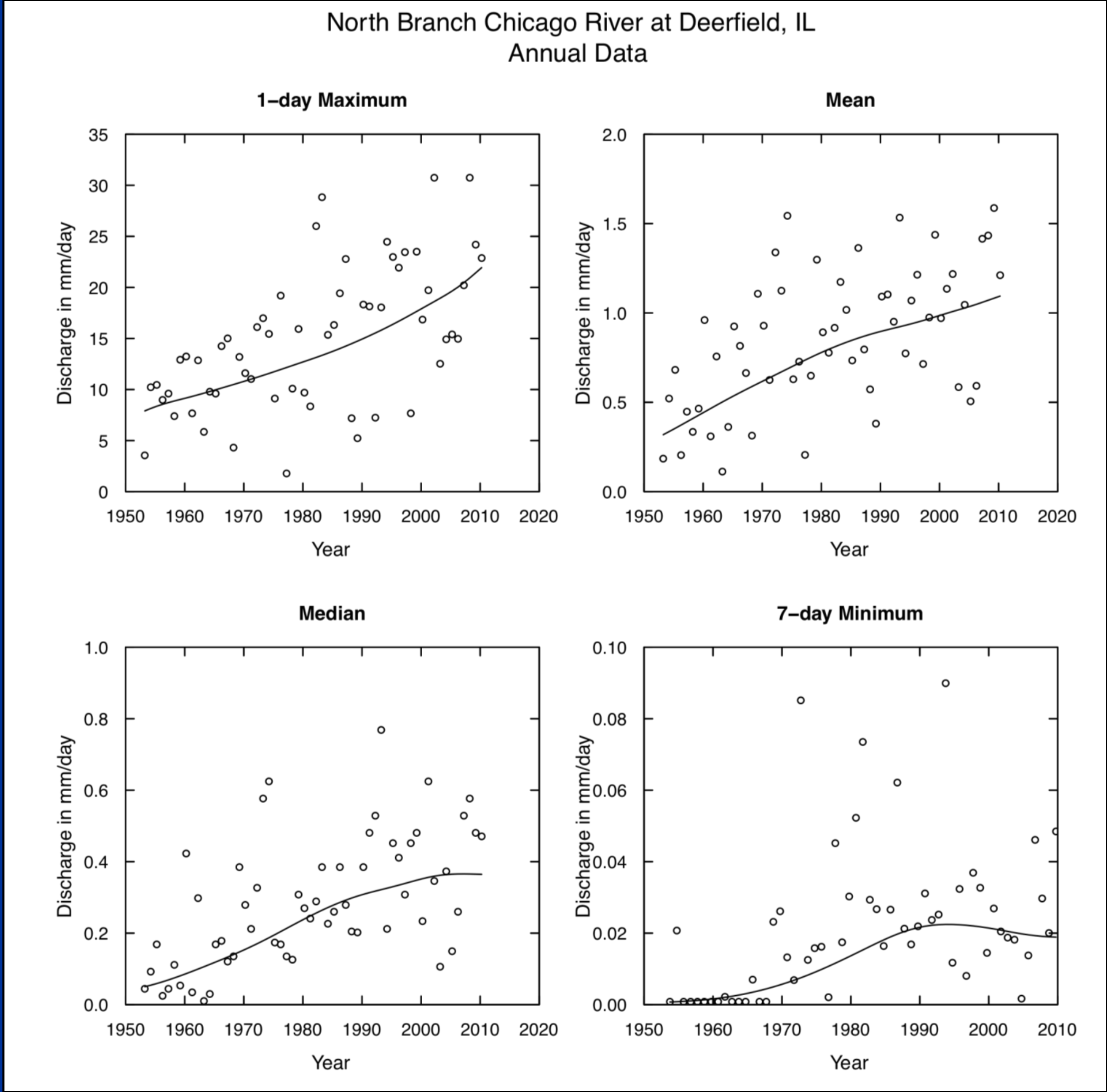

1-day max
+ 93%

Mean
- 34% then
+ 17%

7-day
min
-72 %

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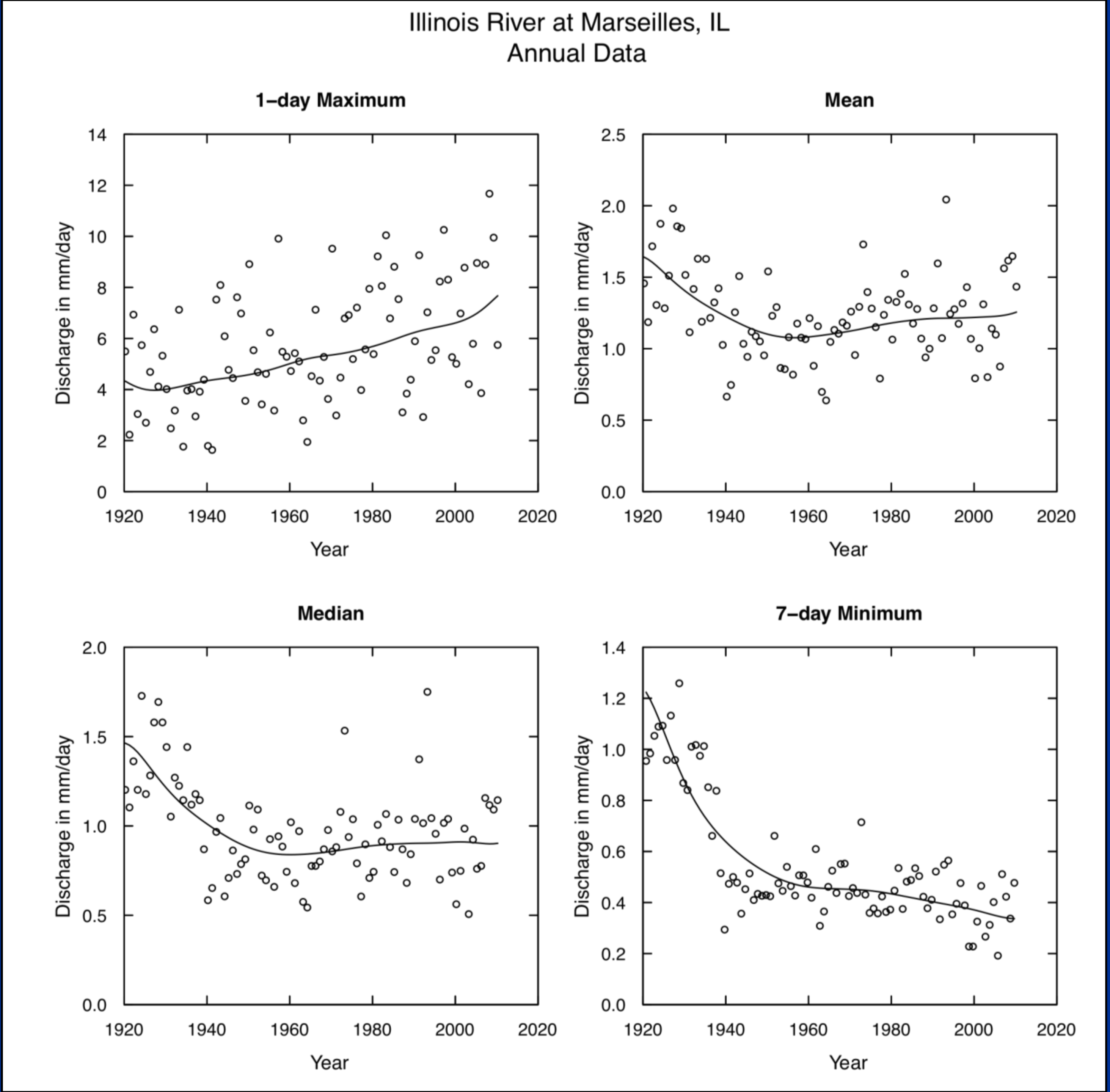
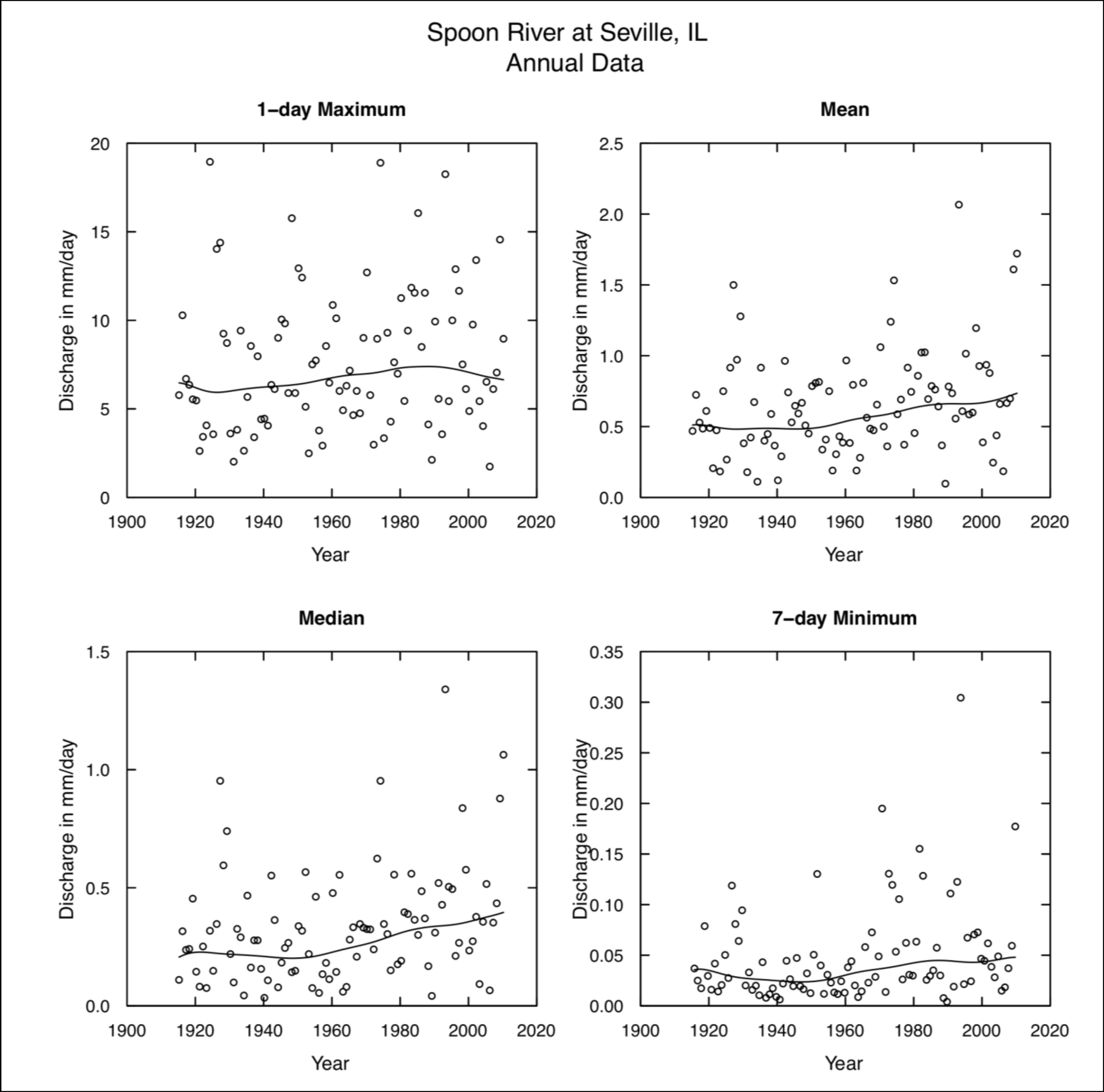


1-day max
Little change

Mean
+ 53%
since1950

7-day min
+ 103%
since 1950



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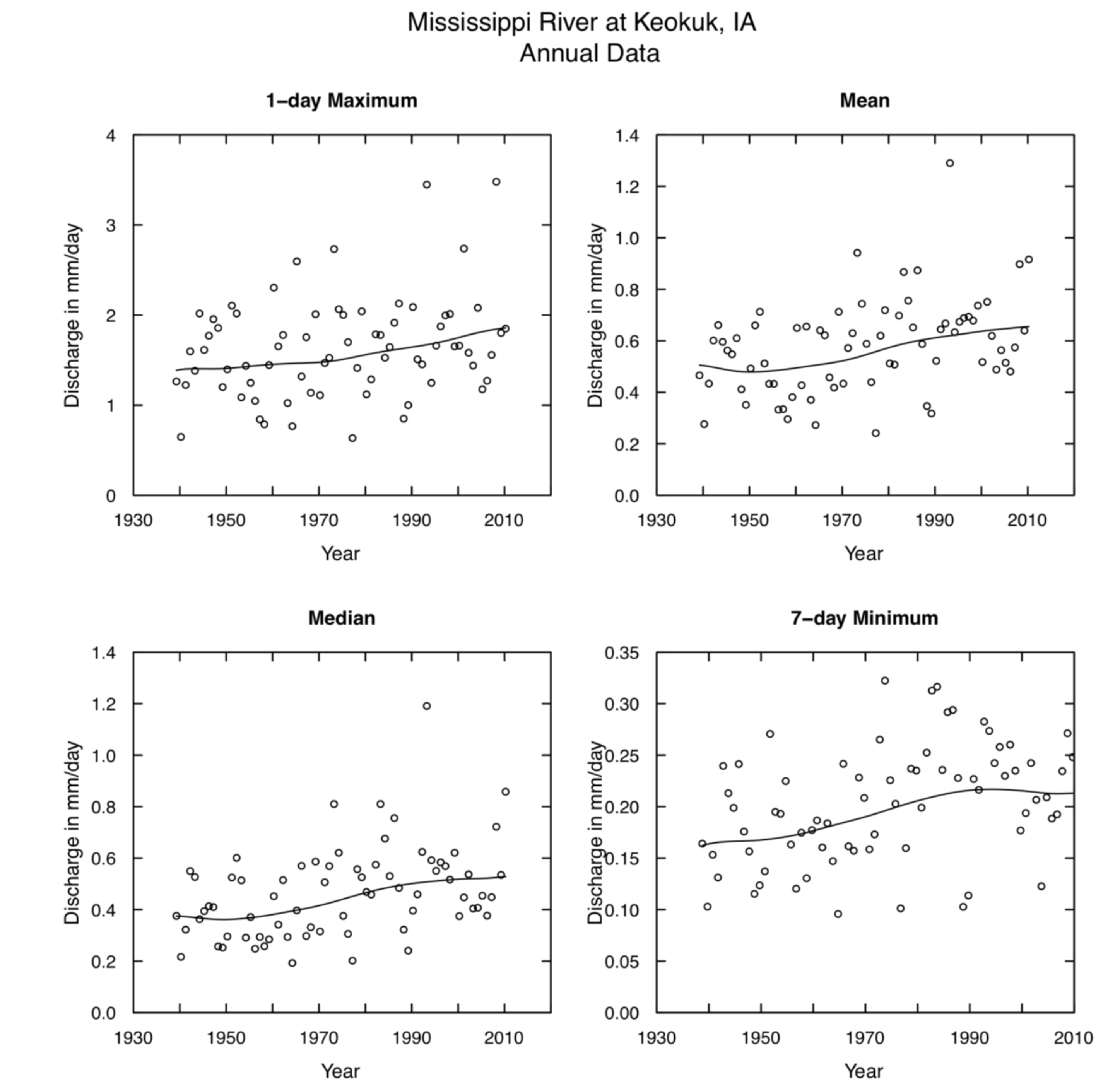
Short record

1-day max
+ 39%

Mean
+ 45%

7-day min
+ 22%



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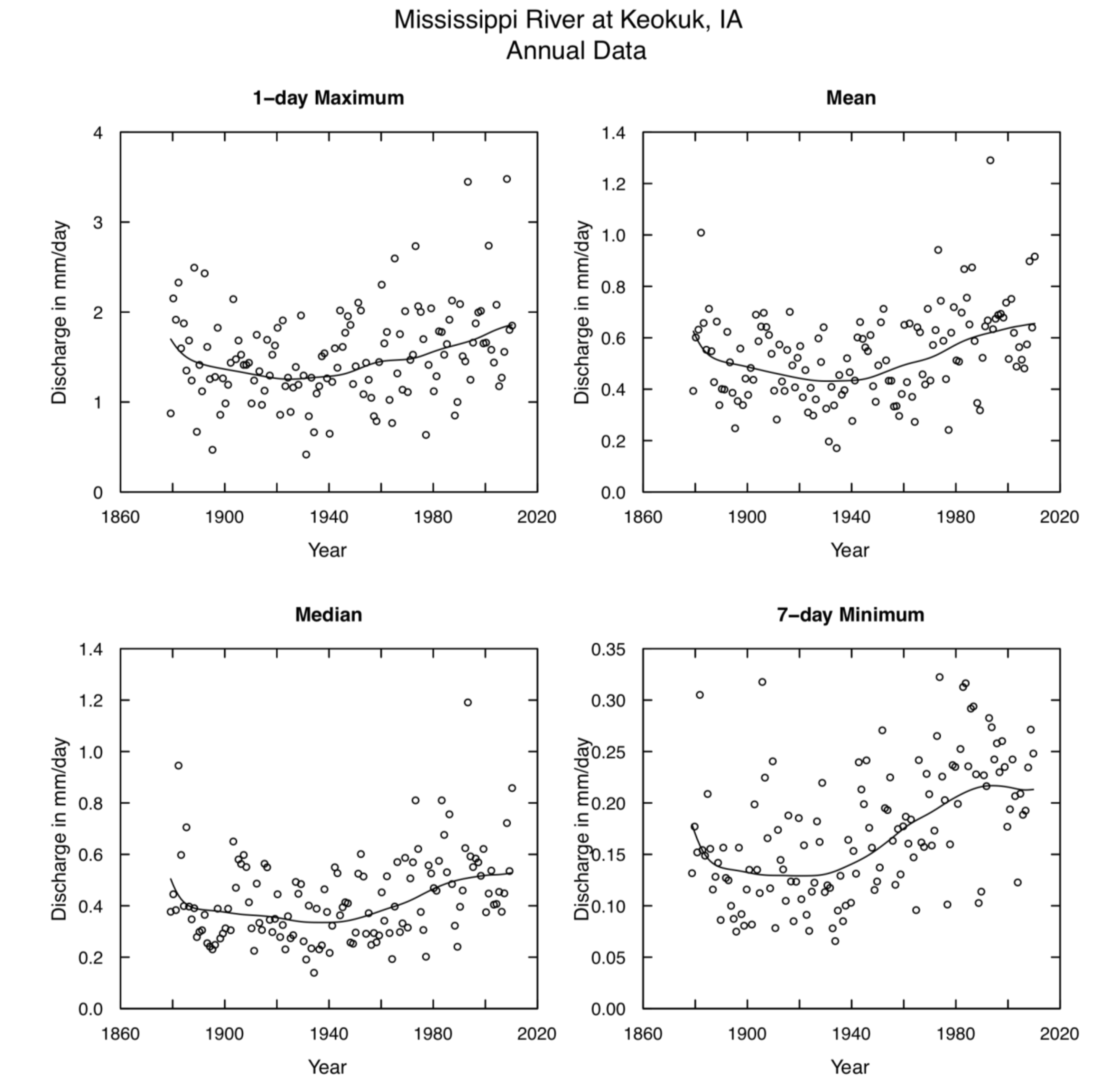
Full Record

1-day max
- 21% then
+ 39%

Mean
- 28% then
+ 45%

7-day min
- 28% then
+ 65%



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Take away messages

- We see trends at various time scales.
- Some we can explain with known causes, some we can't.
- Very easy to confuse trends and long-term oscillations.
- Easy to "blame" the "greenhouse" when we only look at a few decades. Much harder when we look longer term.


Part 2:Global CO_2 and floods
Can we consider the past century to be an unplanned global experiment.
What can we learn from that?

Learning from the unplanned global greenhouse gas experiment

- CO_2 has increased 32% since 1885
- Expected increase: 40% more by 2050
- Use watersheds as experimental subjects
- Use very long records to partially overcome the “trend-like” effect of quasi-periodic oscillations
- Simple question: what’s the relationship between log(annual flood) and global CO_2?
- Records used are 85 – 127 years in length

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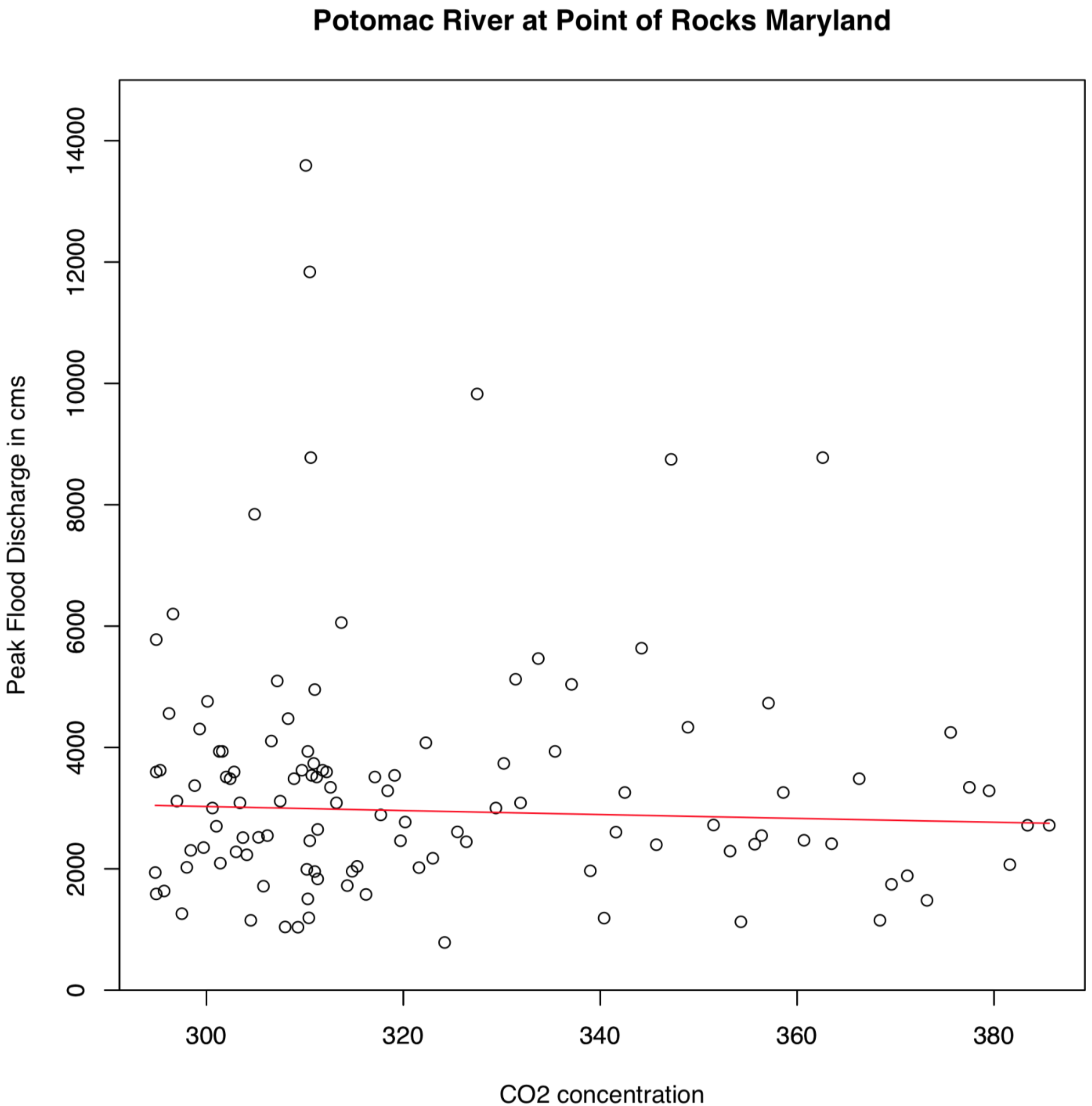
Slope= -1.4 % per 10 ppm CO_2

p=0.5



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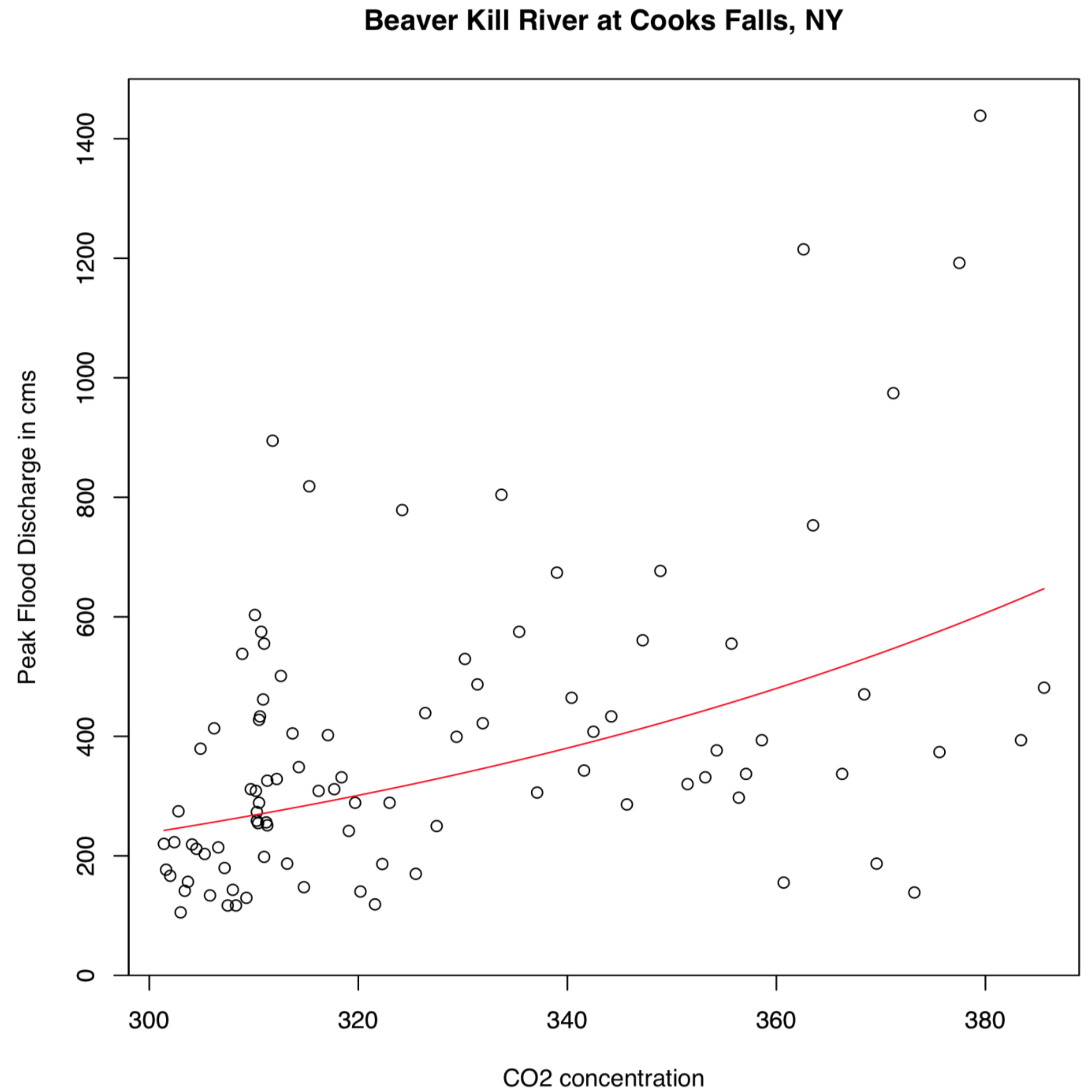
Slope= +12.4 % per 10 ppm CO_2

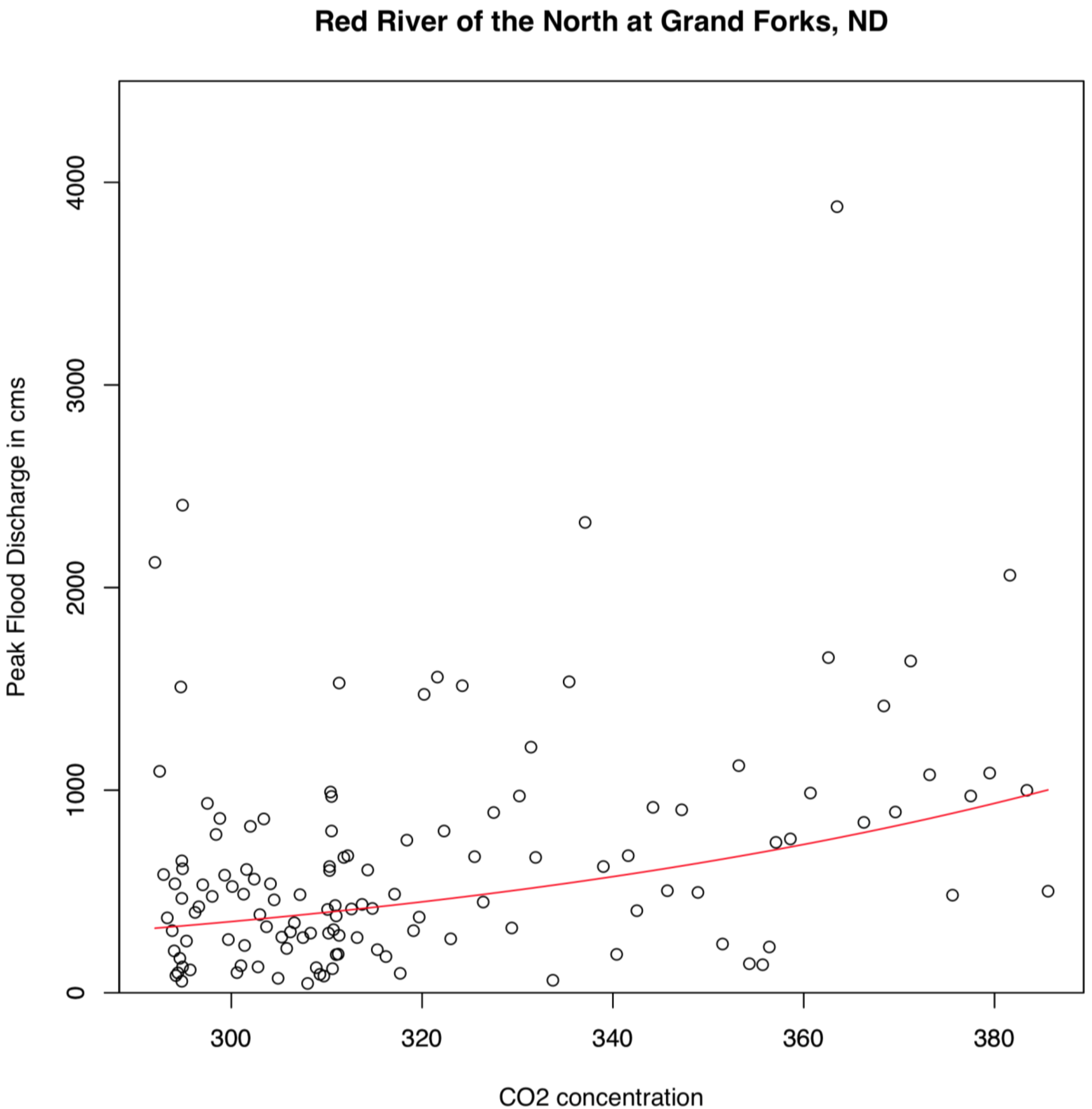
p<0.001



USGS

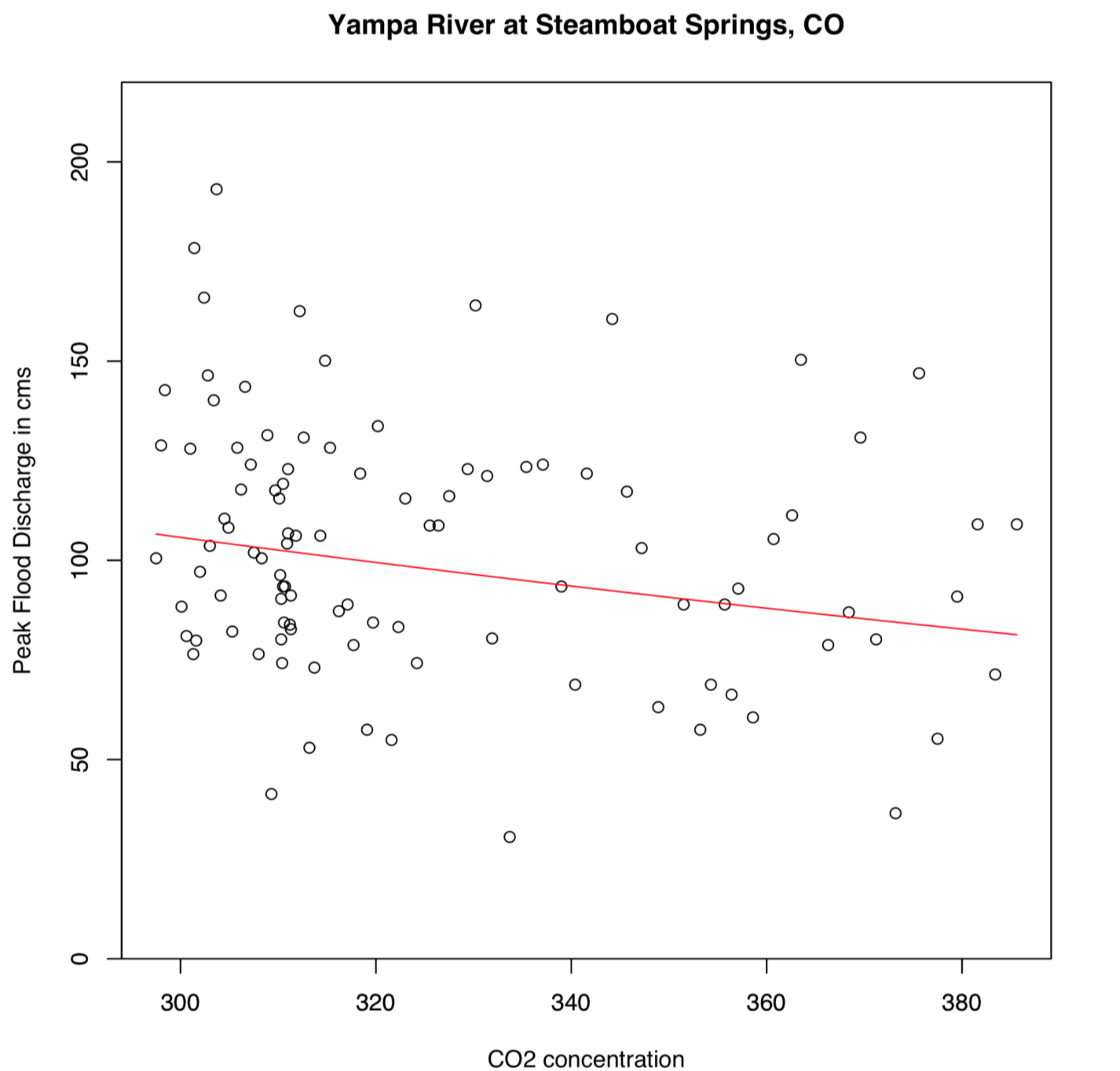
Slope= +14%
per 10 ppm CO_2

p<0.001



Slope= -3 % per 10 ppm CO_2

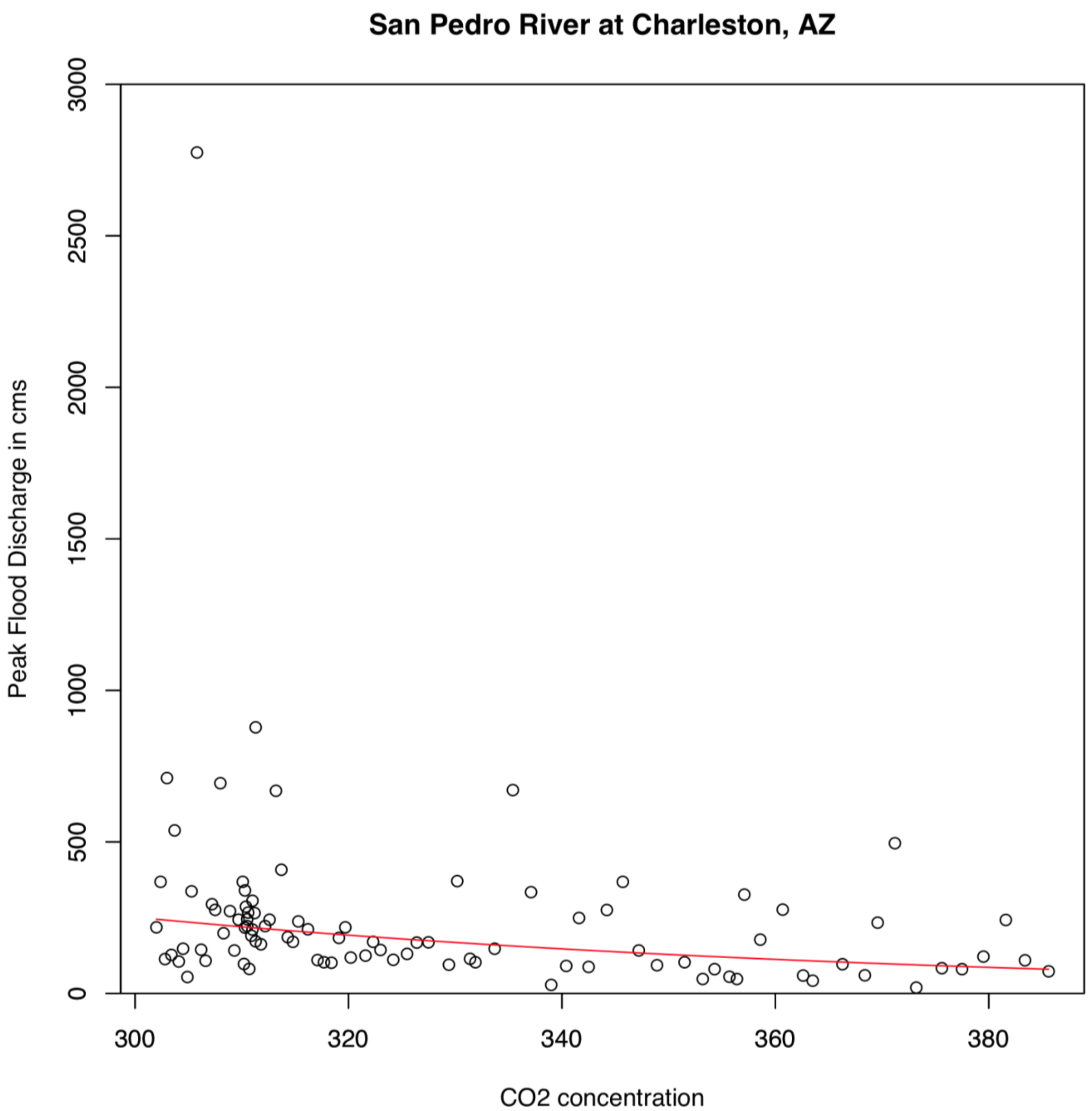
p=0.022



USGS

Slope= -12 % per 10 ppm CO_2

p<0.001



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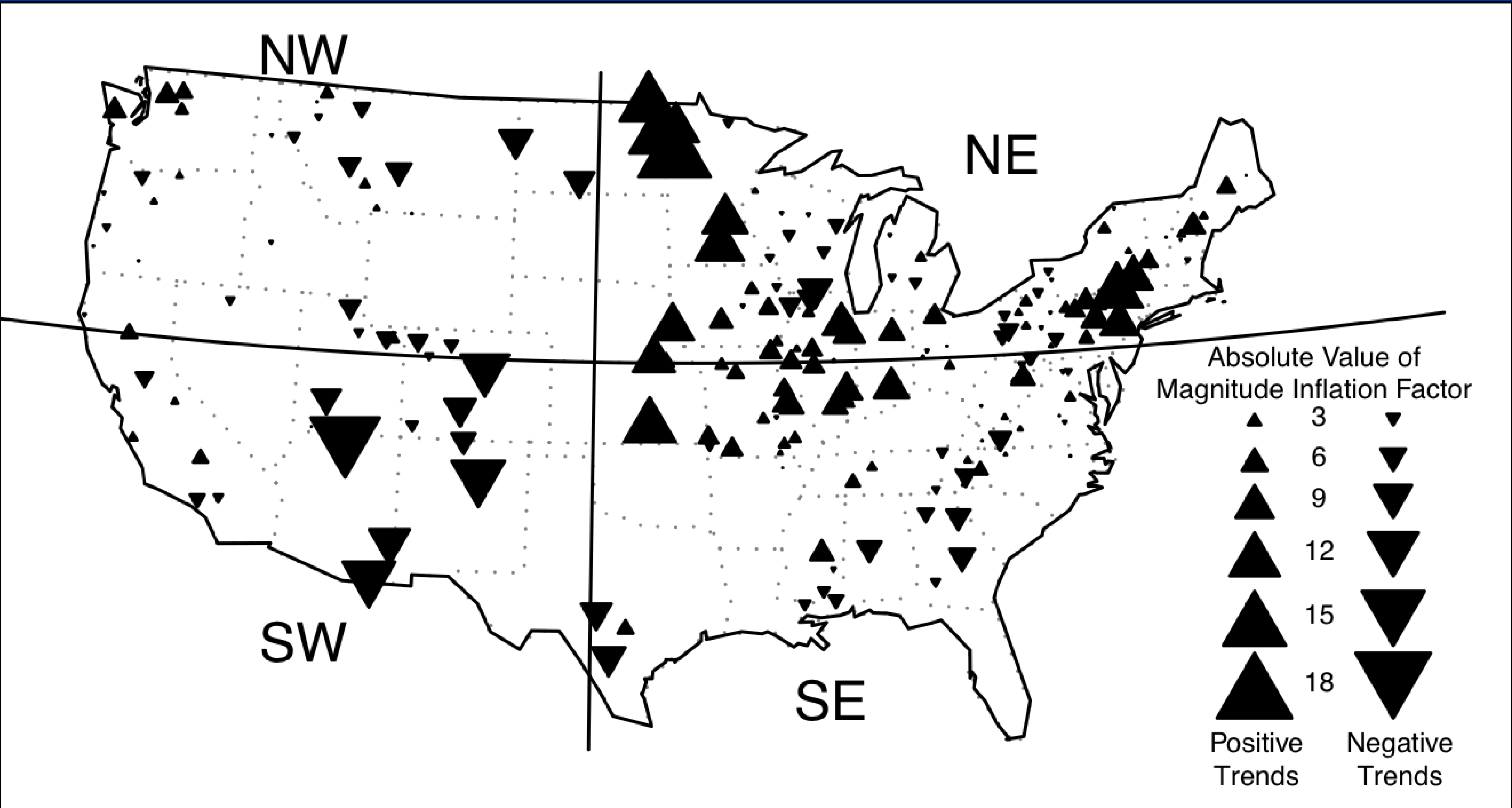
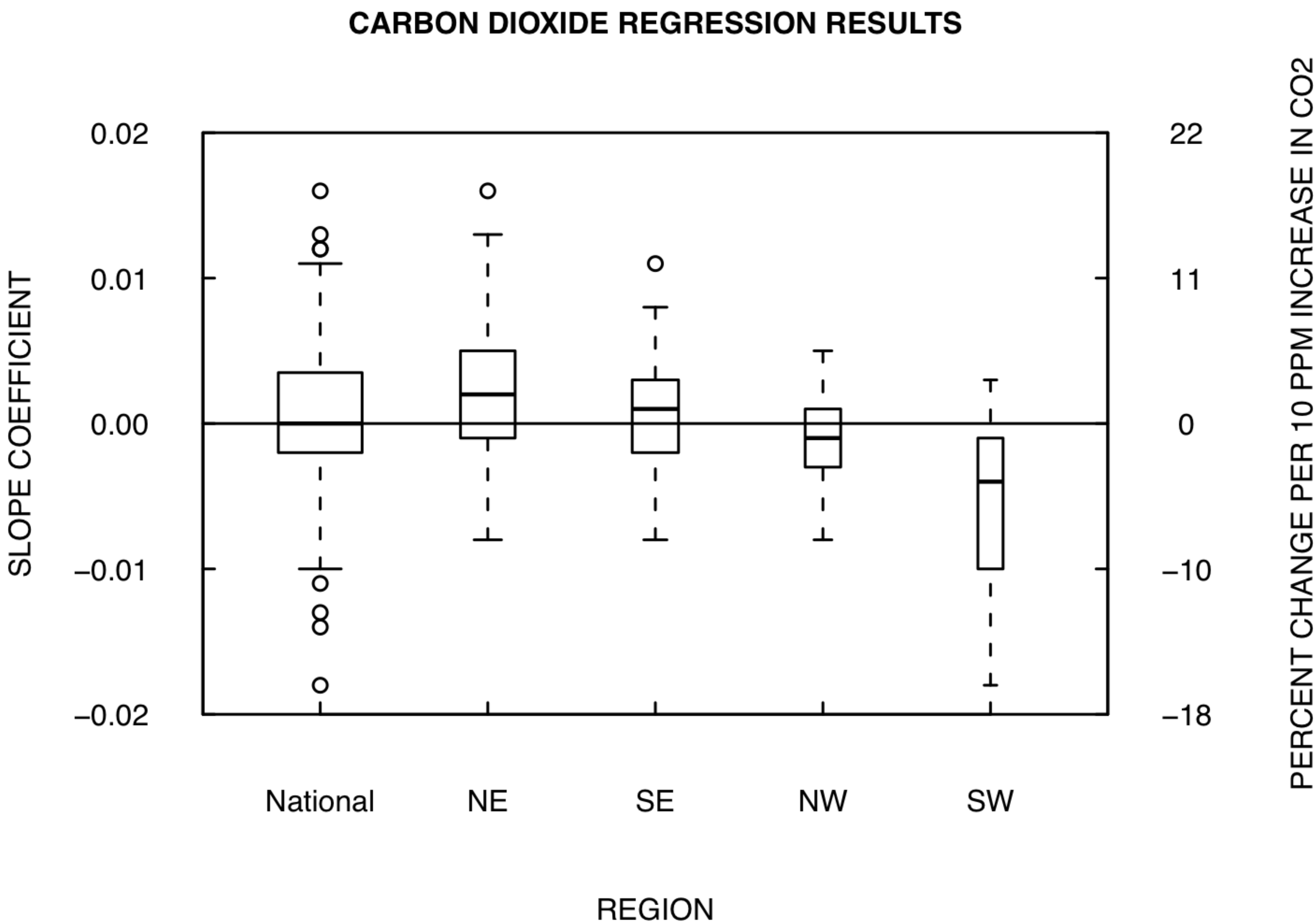
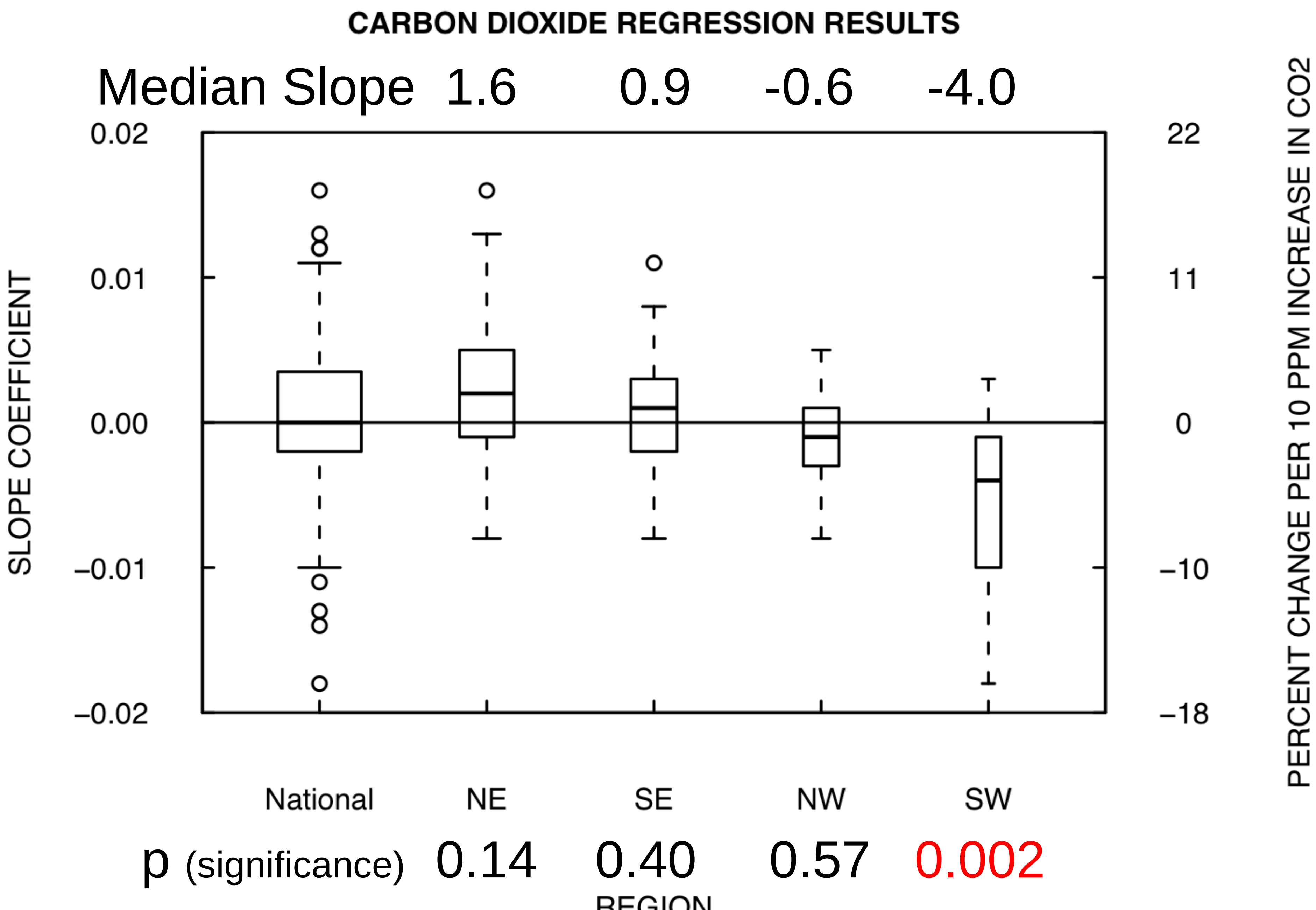
National results: 200 streamgage records




CARBON DIOXIDE REGRESSION RESULTS
SLOPE COEFFICIENT
0.02
0.01
0.00
−0.01
−0.02
PERCENT CHANGE PER 10 PPM INCREASE IN CO2
22
11
0
−10
−18
National
NE
SE
NW
SW
REGION


CARBON DIOXIDE REGRESSION RESULTS
Median Slope 1.6 0.9 -0.6 -4.0
SLOPE COEFFICIENT
0.02
0.01
0.00
−0.01
−0.02
PERCENT CHANGE PER 10 PPM INCREASE IN CO2
22
11
0
−10
−18
National
NE
SE
NW
SW
p (significance) 0.14 0.40 0.57 0.002
REGION

Take away messages:

- The only region in which there is strong statistical evidence of an association between floods and global CO_2 is in the southwest, and the relationship there is negative.

- All approaches to understanding the flooding/greenhouse gas question have flaws. But we need to **look at the data regularly** and **with diverse approaches** to see what might be emerging.

Part 3: Nutrients

Nitrate in rivers:

- Mississippi River average nitrate concentrations near the mouth of the river have increased by about 200% over the 20th Century, from about 0.5 to 1.5 mg/L.

- Some tributaries of the Mississippi such as the Cedar River in Iowa or Minnesota River have increased as much as 800%.

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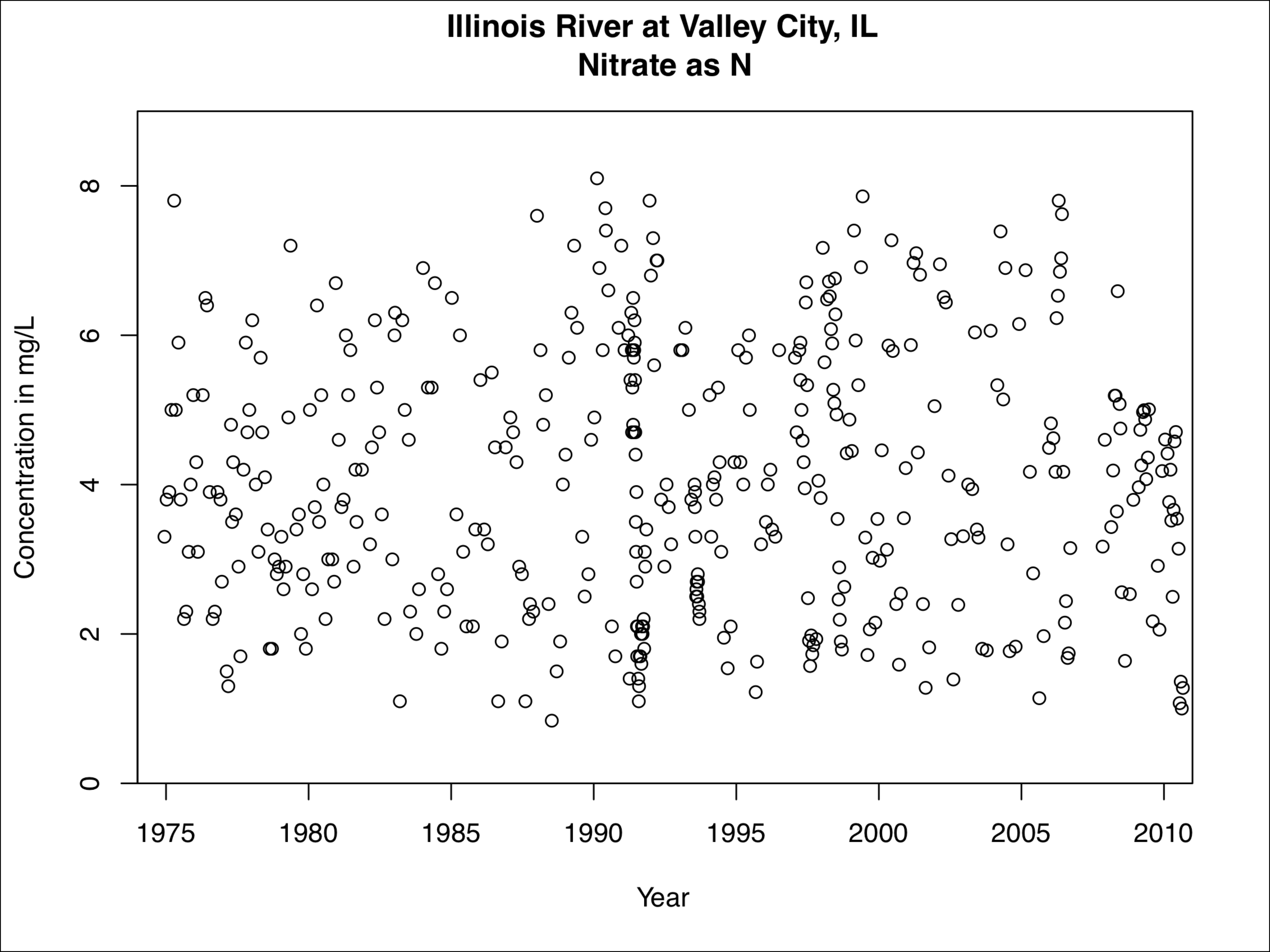
Illinois River at Valley City, IL
Nitrate as N
Concentration in mg/L
0
2
4
6
8
Year
1975
1980
1985
1990
1995
2000
2005
2010

Why a new method?

Weighted Regressions on Time, Discharge, and Season (WRTDS)

- Extract more information from long data sets
- Single approach for reporting fluxes and concentrations and their long-term trends
- Provide insights about the nature of the changes taking place
- Resolve some methodological problems

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Methodological issues

- Flow – Concentration relationship is flexible – avoids potential flux bias problems
- Flow – Concentration relationship evolves over time: Thus % changes in flux can be different than % changes in concentration
- Trend pattern flexible, not constrained to linear or quadratic
- Different seasons can have different trend patterns

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WRTDS uses smoothing methods to decompose the variations in the sampled data into four components:

Seasonal variation

Streamflow-driven variation

Long-term trend

Random (unexplained) variation

How does WWRTDS work?

- Uses weighted regressions to develop a flexible representation of the evolving behavior of the system.
- From this representation, computes best estimates of concentration and flux for every day of the record
- Accumulates these into monthly, seasonal and annual averages

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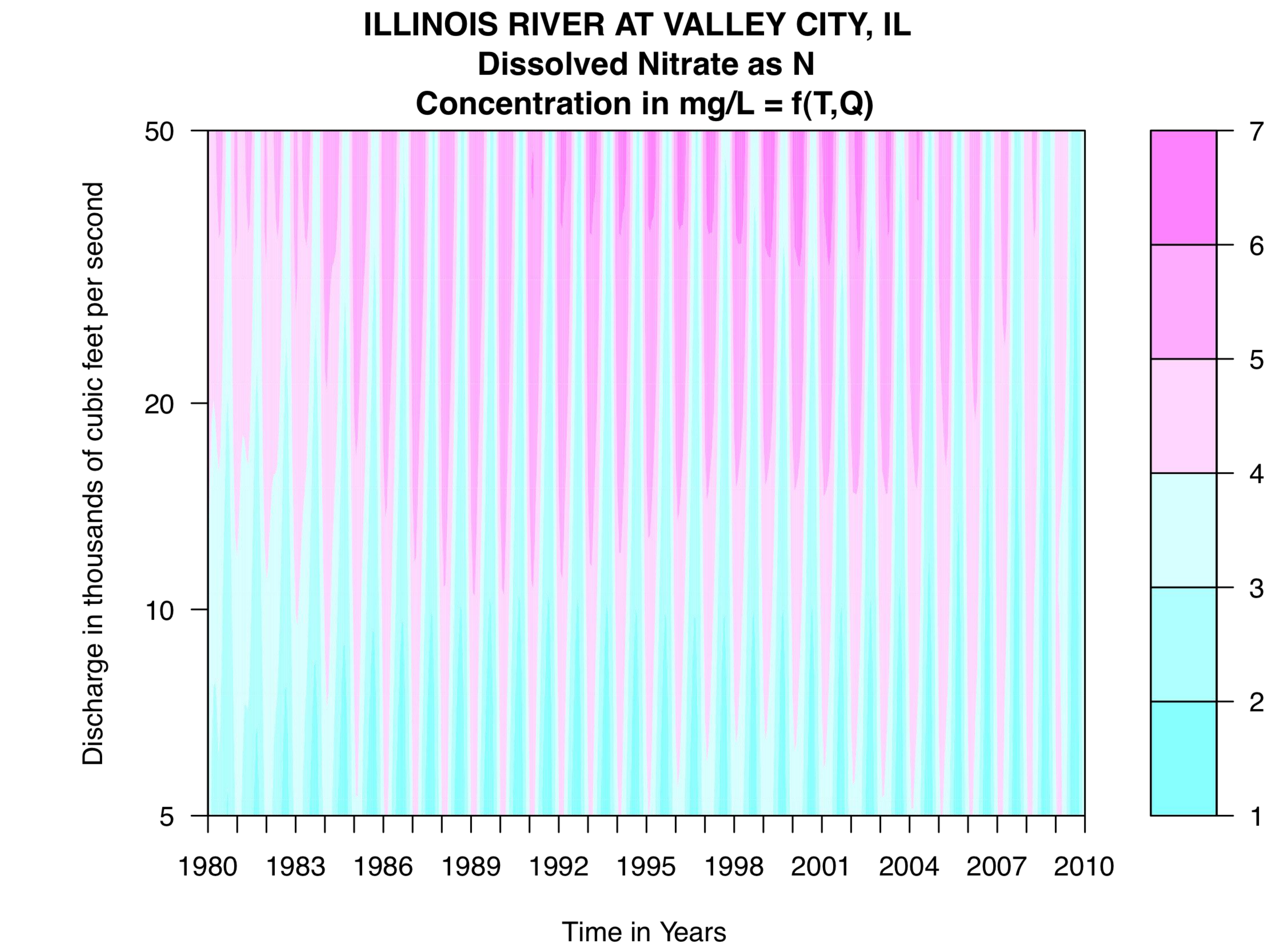
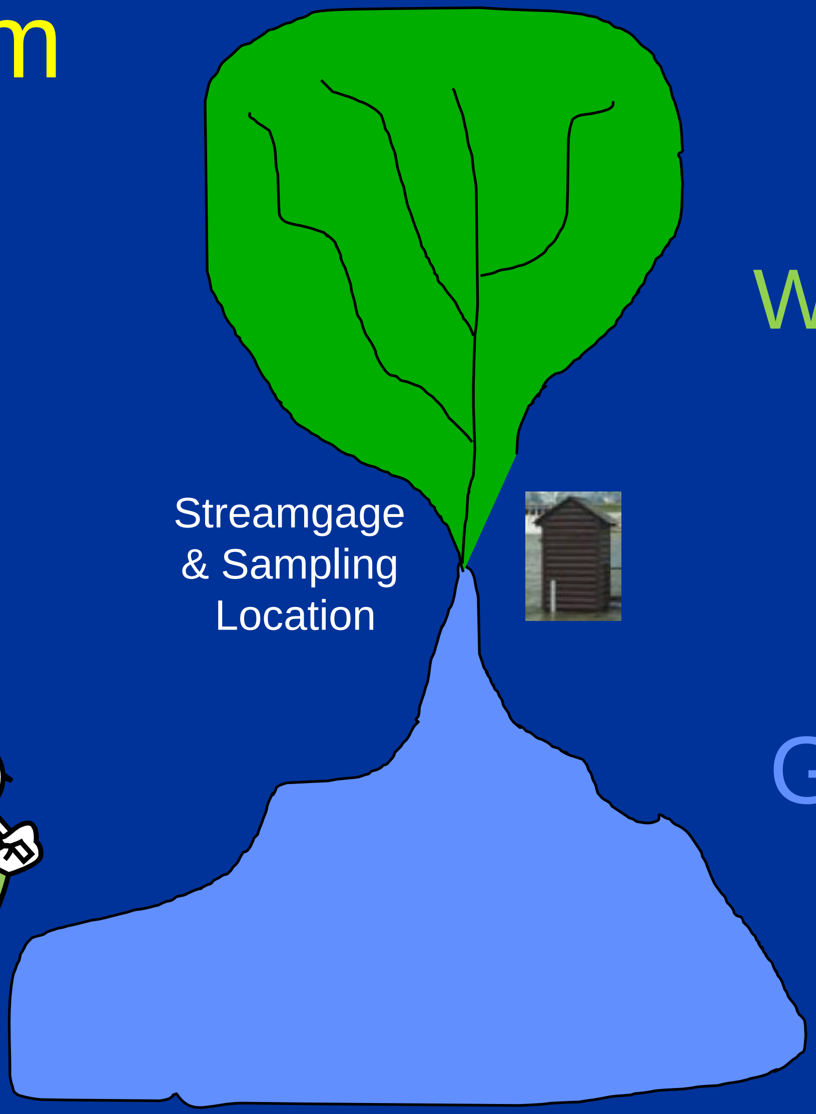

ILLINOIS RIVER AT VALLEY CITY, IL
Dissolved Nitrate as N
Concentration in mg/L = f(T,Q)
Discharge in thousands of cubic feet per second
50
20
10
5
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
Time in Years
7
6
5
4
3
2
1

Different products for different purposes

Concentration vs Flux

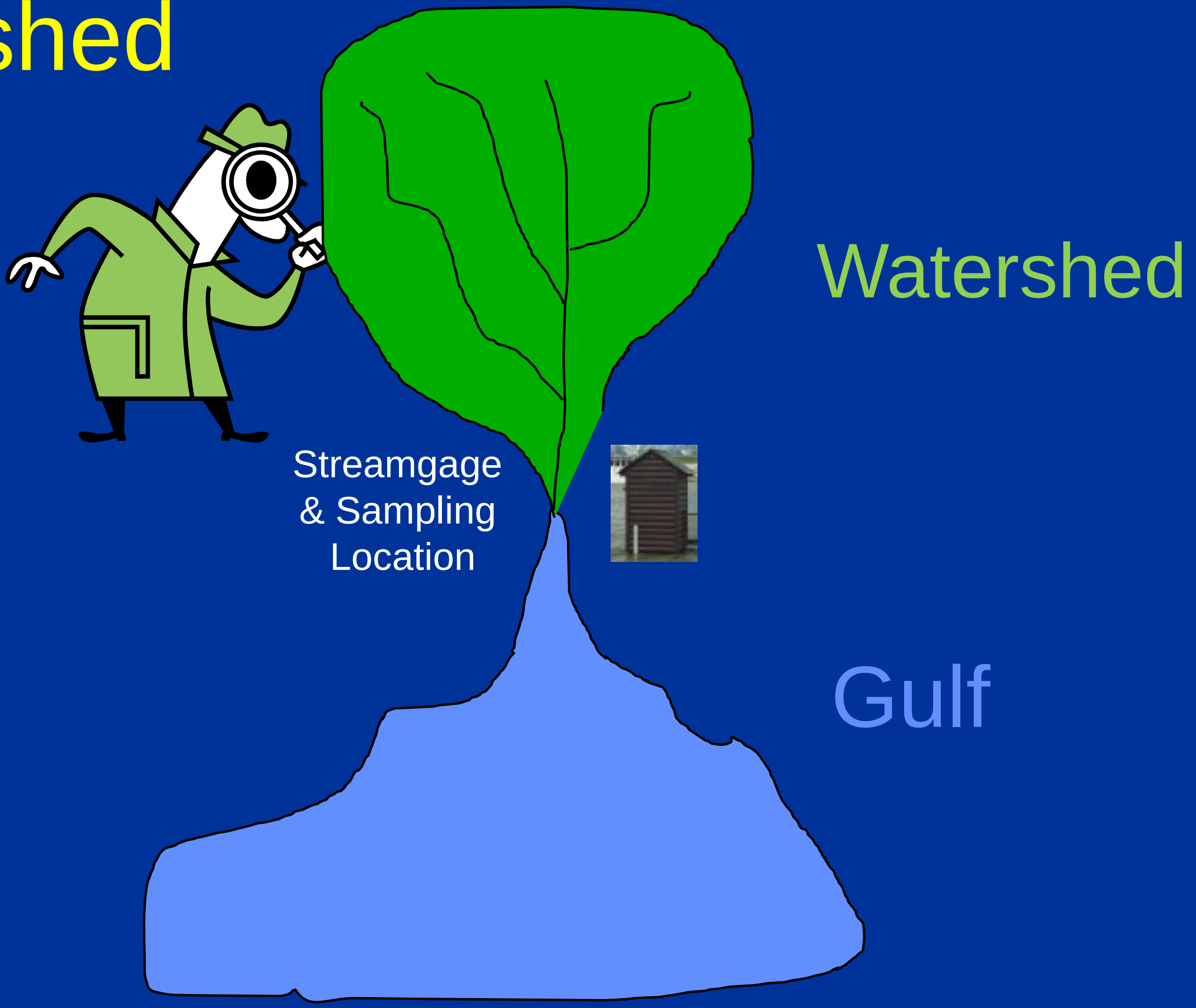
History vs Flow-normalized history

To understand impact on Gulf ecosystem

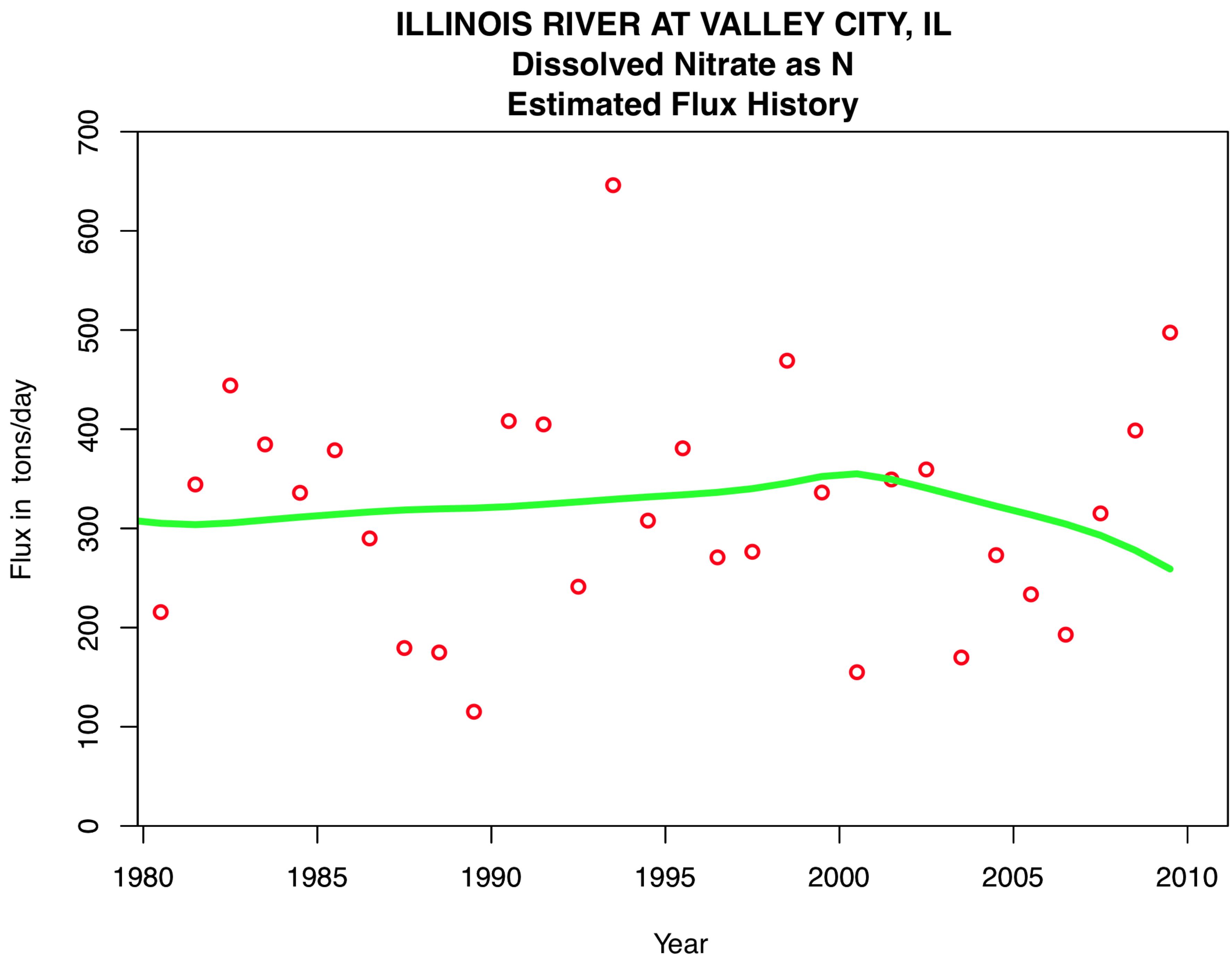


We want the flux history

To understand progress in the watershed



We want the flow-normalized flux history


ILLINOIS RIVER AT VALLEY CITY, IL
Dissolved Nitrate as N
Estimated Flux History
Flux in tons/day
0
100
200
300
400
500
600
700
1980
1985
1990
1995
2000
2005
2010
Year

Let’s compare to some other sites in the Mississippi River Basin

Missouri River
at Hermann, MO

Mississippi River
at Clinton, IA

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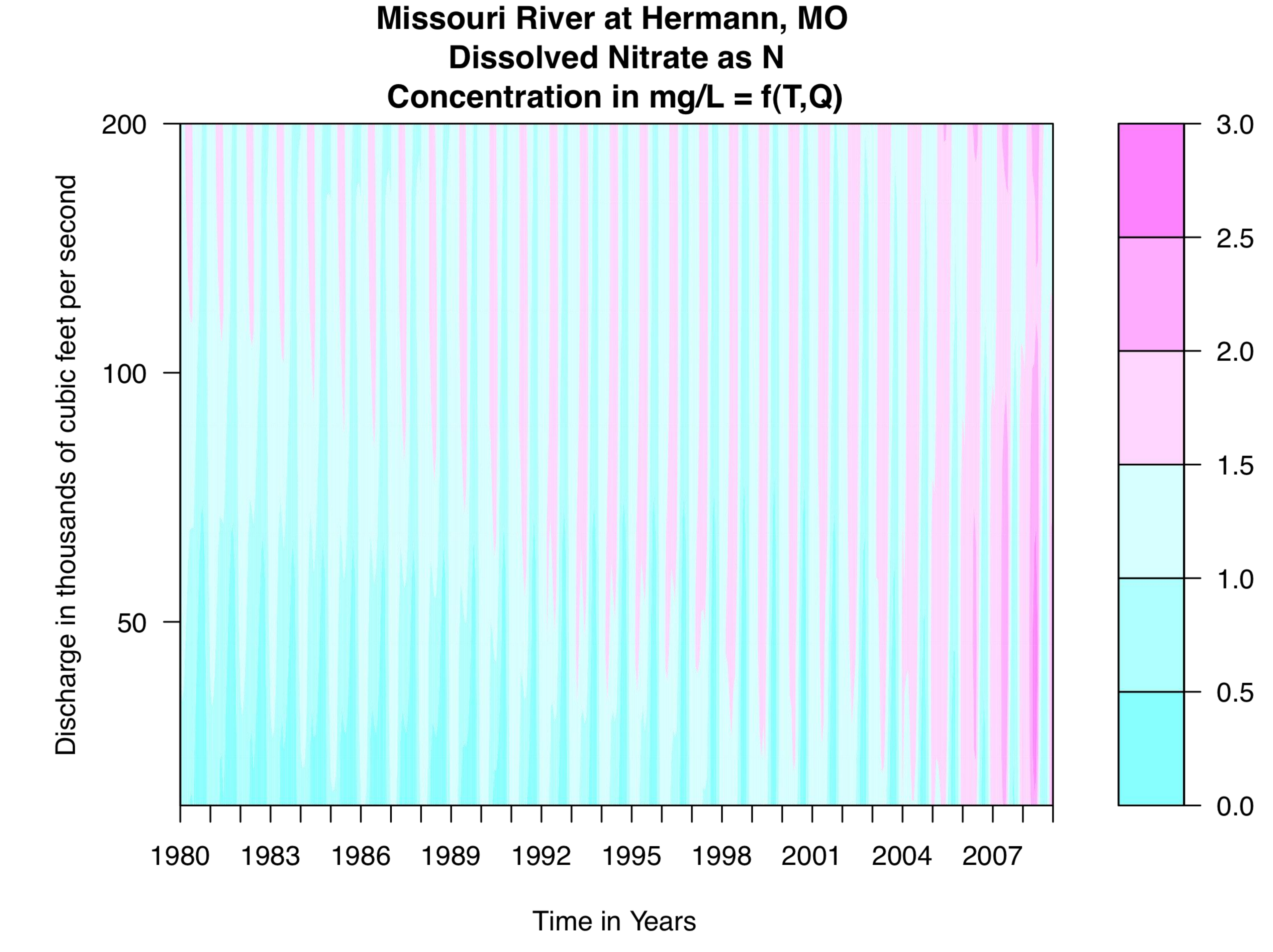
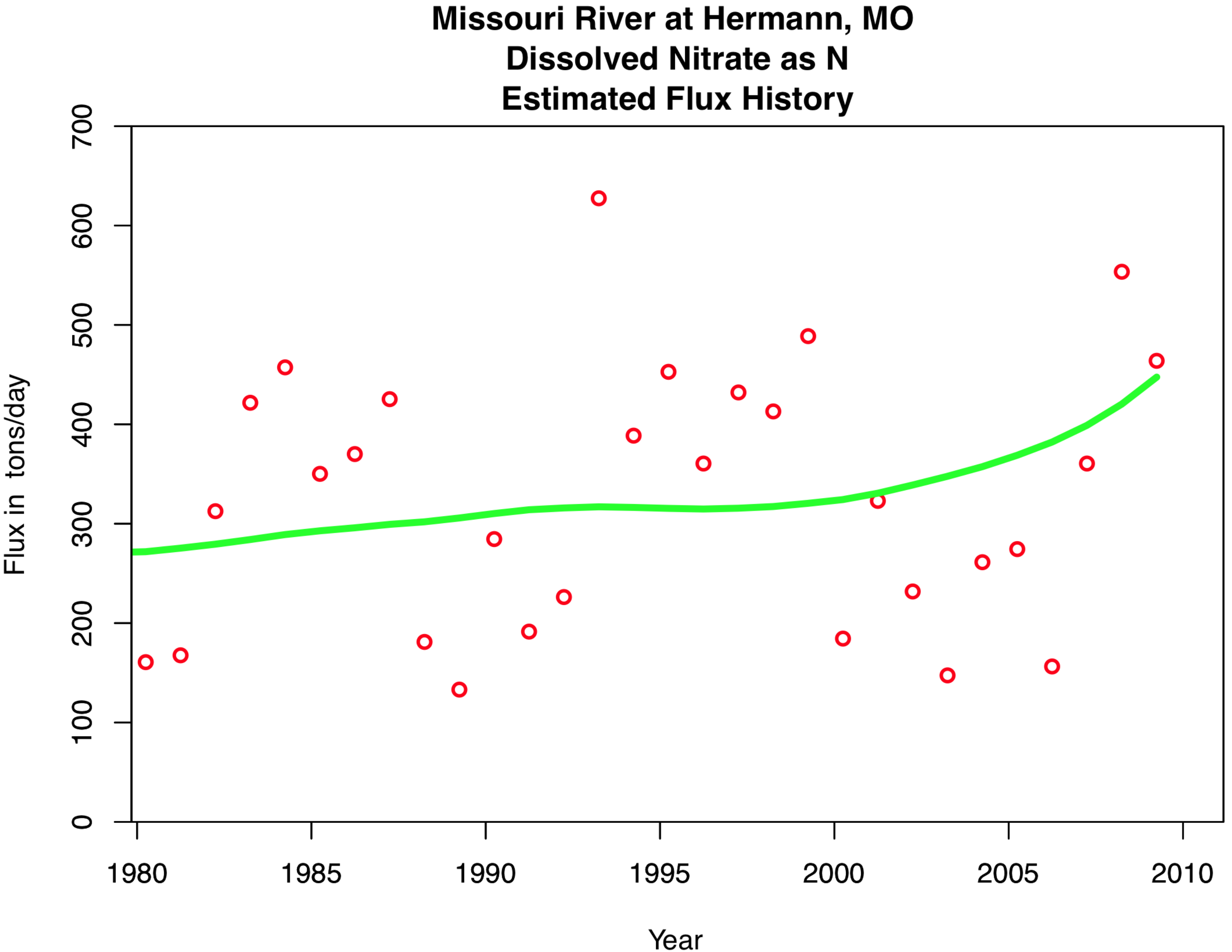
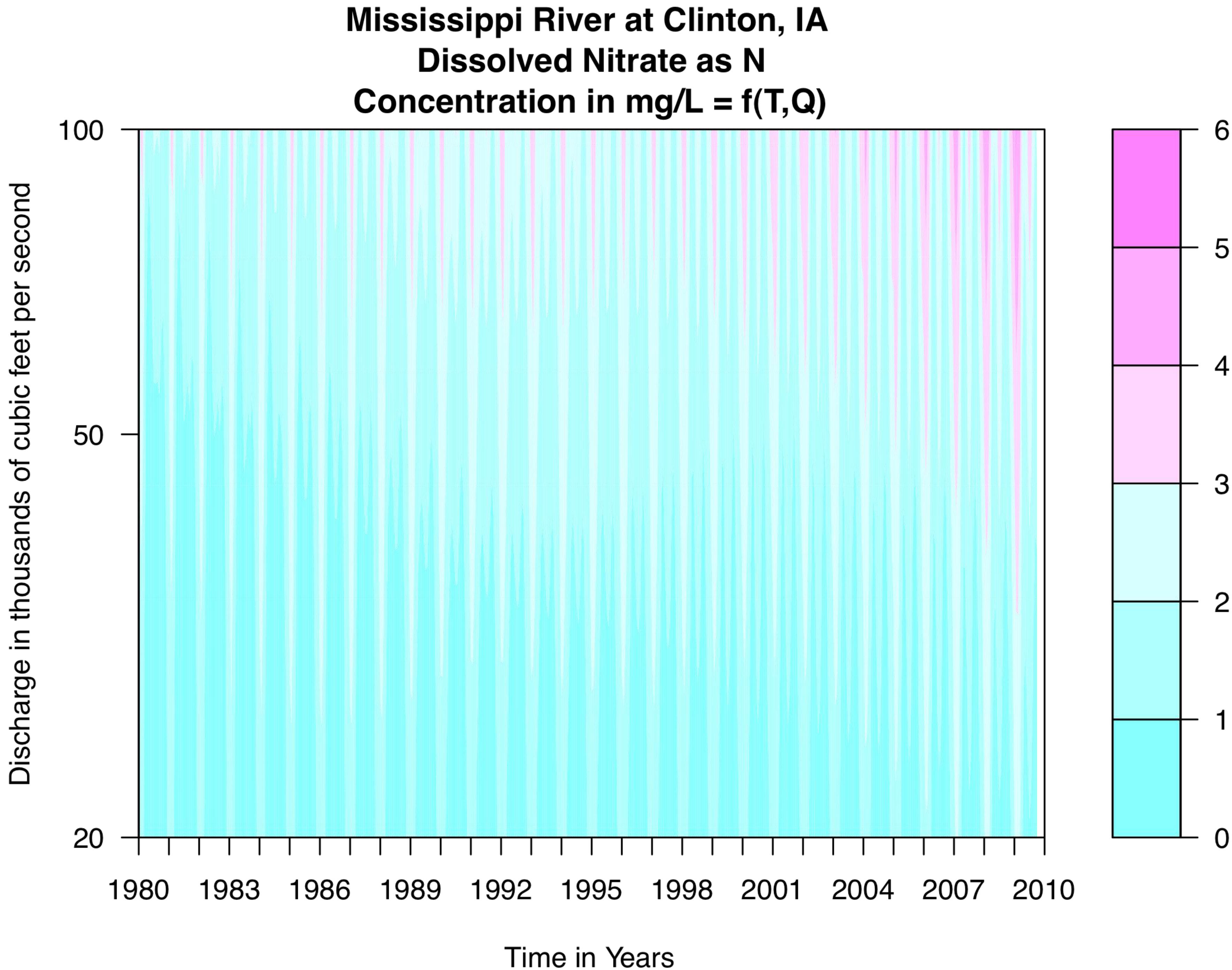
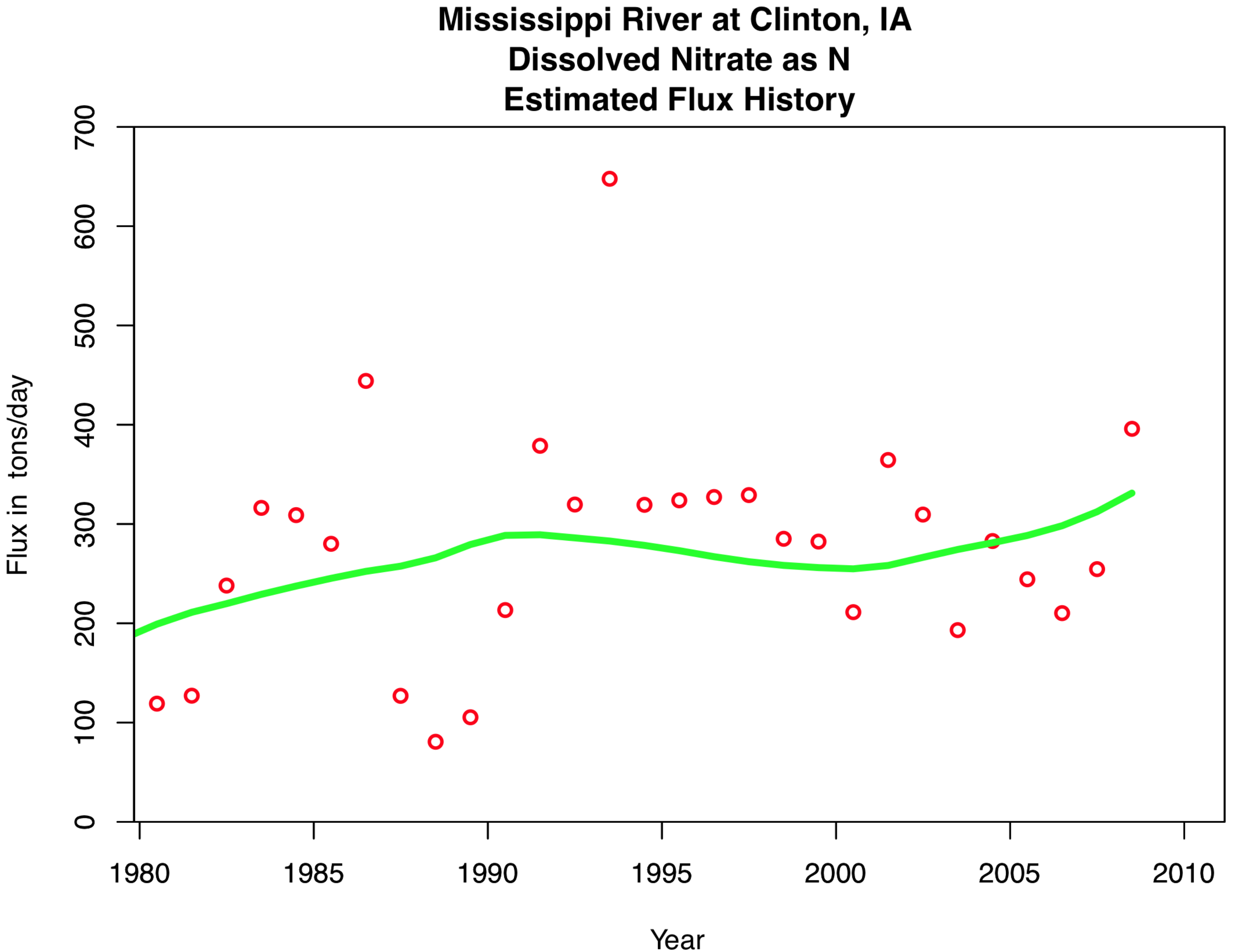


Missouri River at Hermann, MO
Dissolved Nitrate as N
Concentration in mg/L = f(T,Q)
Discharge in thousands of cubic feet per second
200
100
50
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
Time in Years
3.0
2.5
2.0
1.5
1.0
0.5
0.0


Missouri River at Hermann, MO
Dissolved Nitrate as N
Estimated Flux History
Flux in tons/day
0
100
200
300
400
500
600
700
1980
1985
1990
1995
2000
2005
2010
Year


Mississippi River at Clinton, IA
Dissolved Nitrate as N
Concentration in mg/L = f(T,Q)
Discharge in thousands of cubic feet per second
100
50
20
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
Time in Years
0
1
2
3
4
5
6



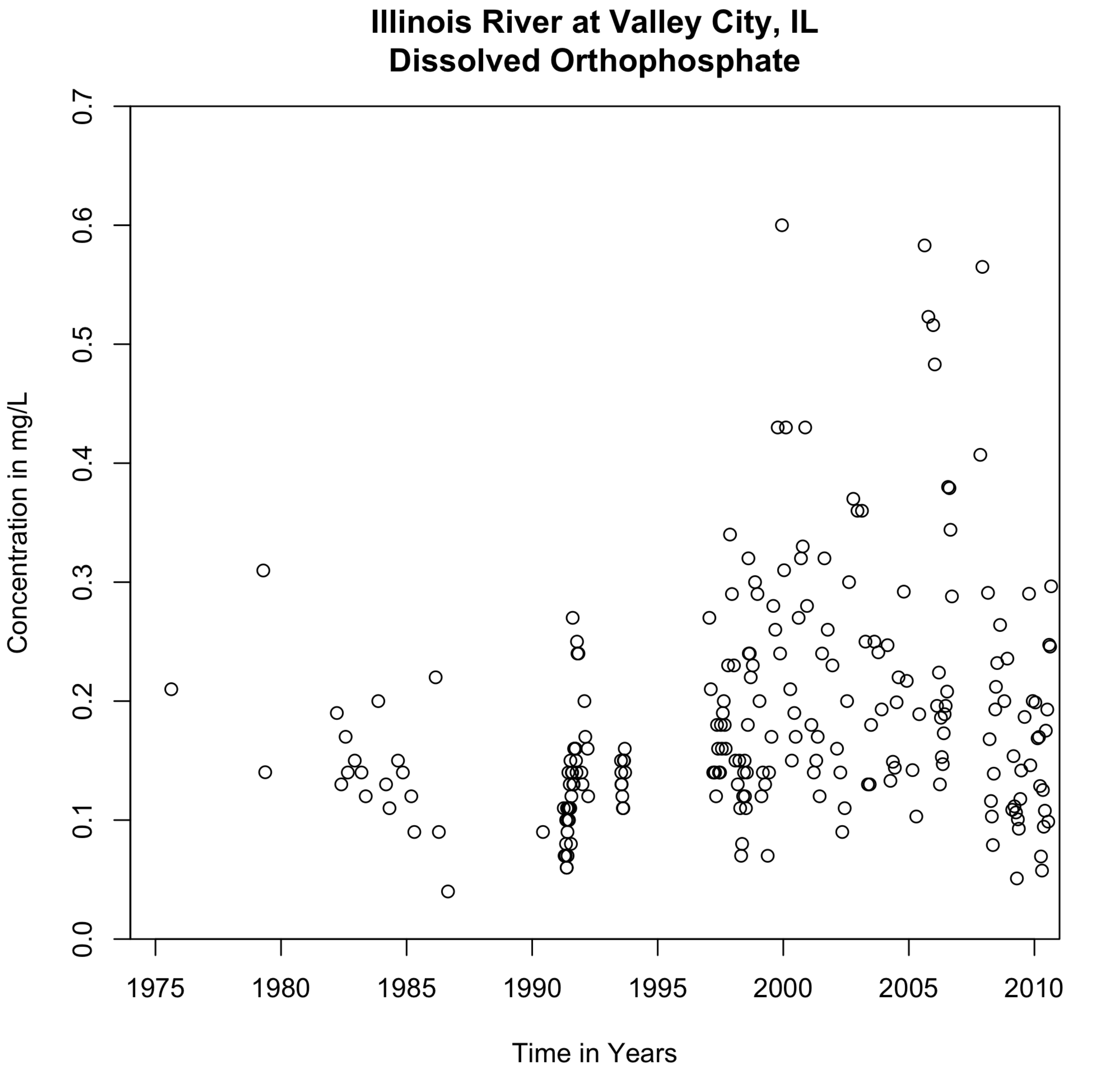
Mississippi River at Clinton, IA
Dissolved Nitrate as N
Estimated Flux History
Flux in tons/day
0
100
200
300
400
500
600
700
1980
1985
1990
1995
2000
2005
2010
Year

Let's look at other nutrients on the Illinois River at Valley City

Dissolved Orthophosphate is interesting

Need to decompose this into components:

flow related
seasonal
time trend
random



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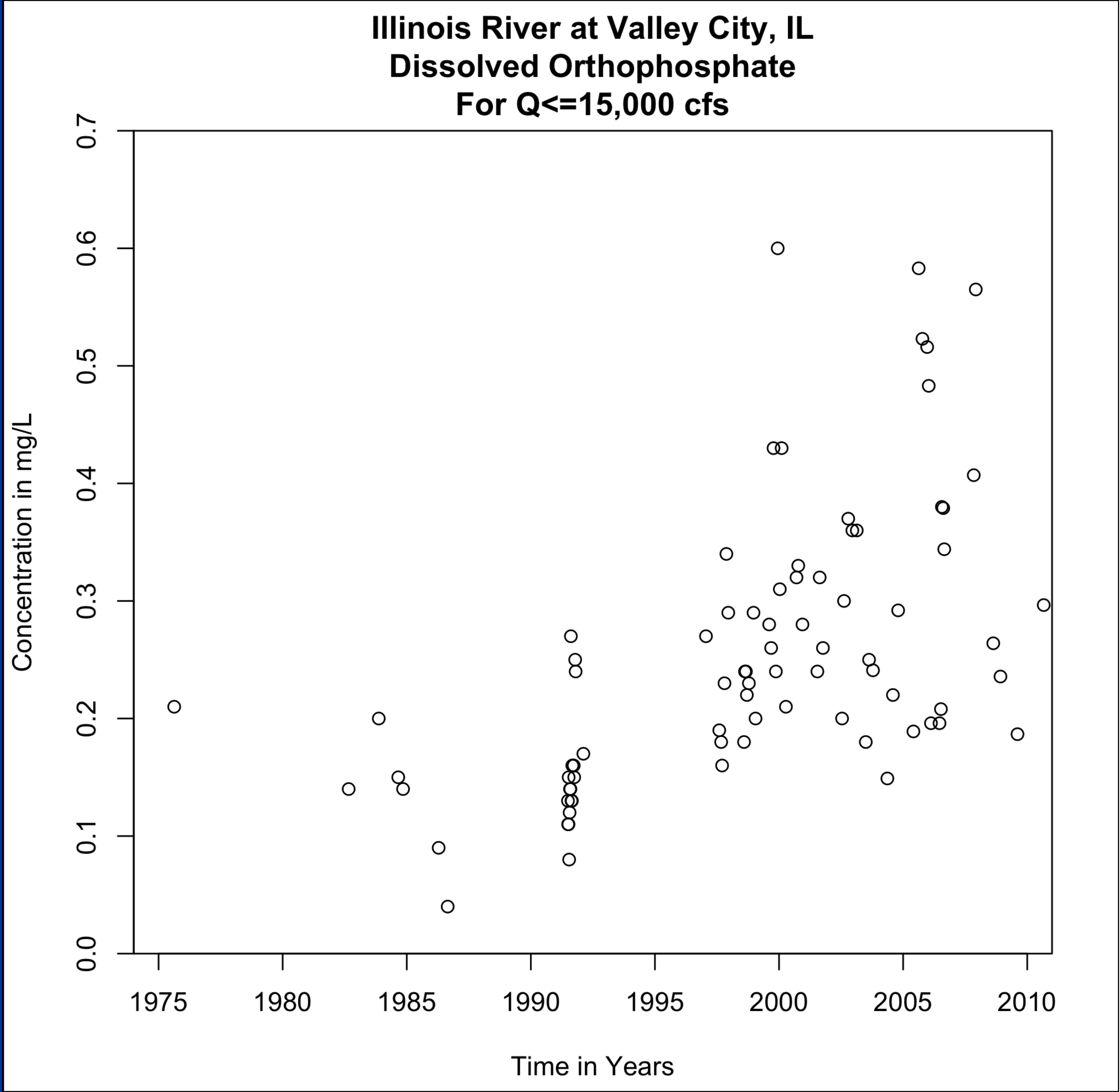
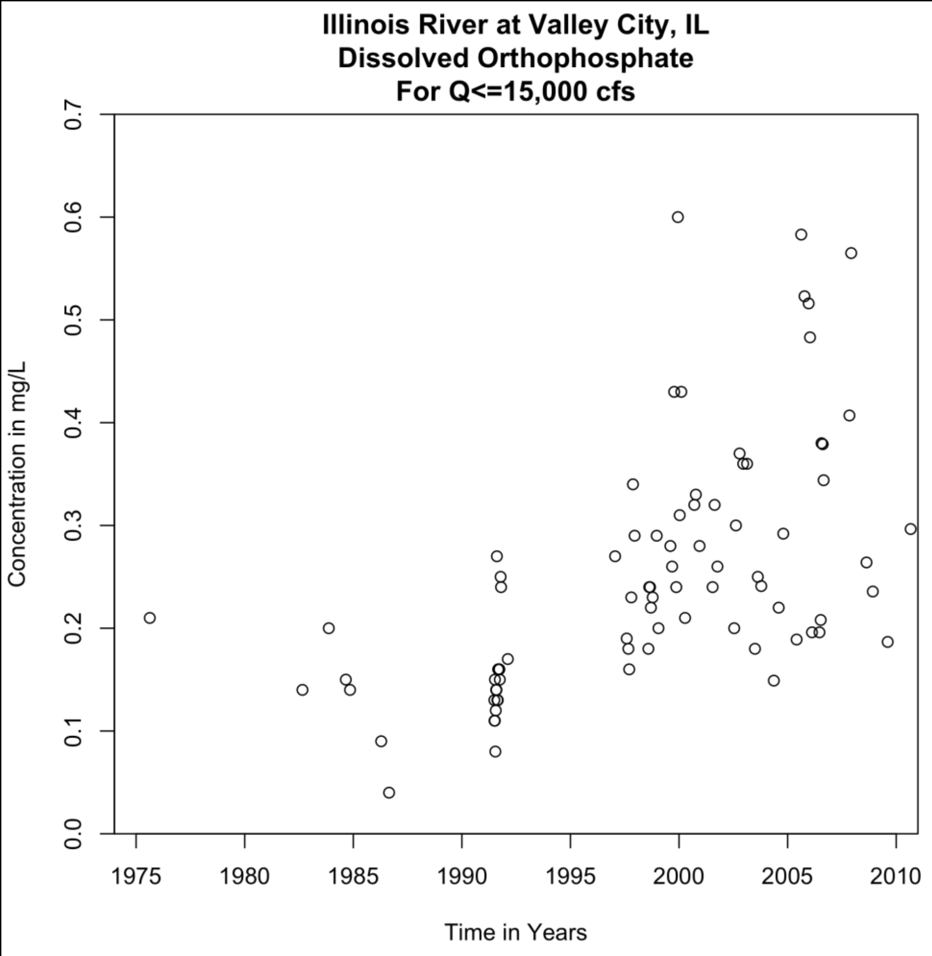
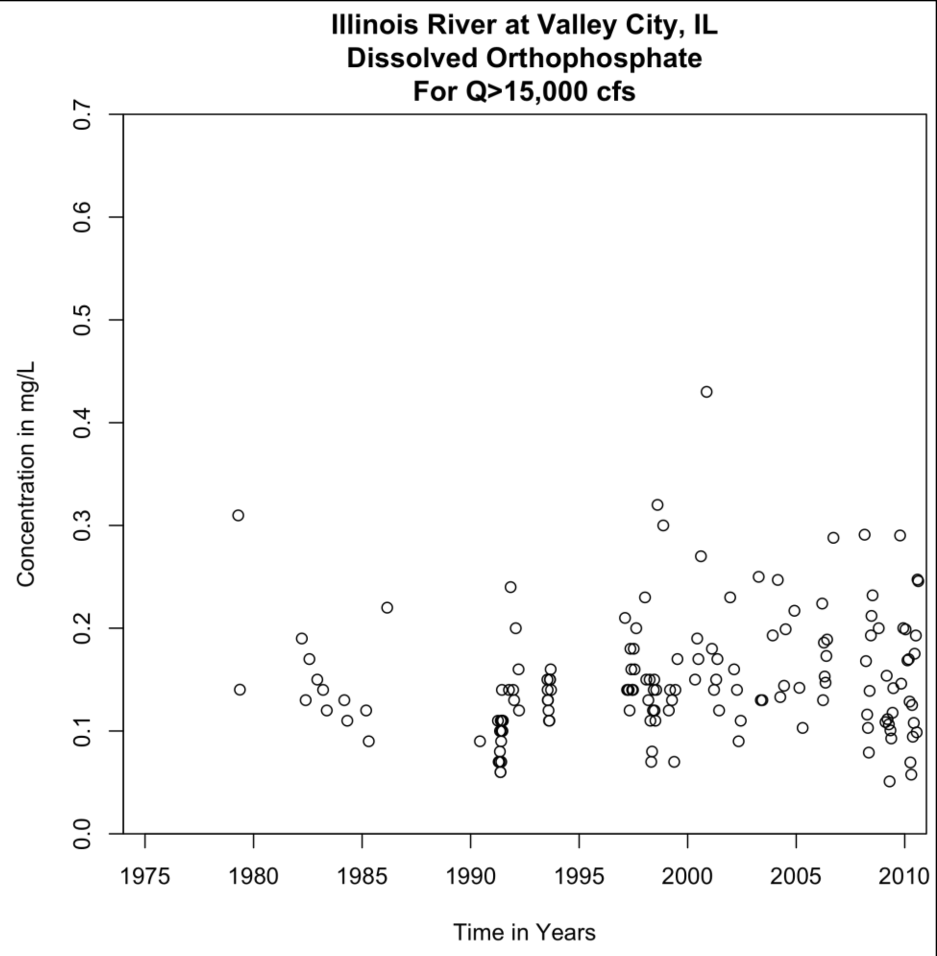
For example: what if we subdivide the flows into “low” and “high” groups

This is the low flow group







Low Flow Samples **High Flow Samples**

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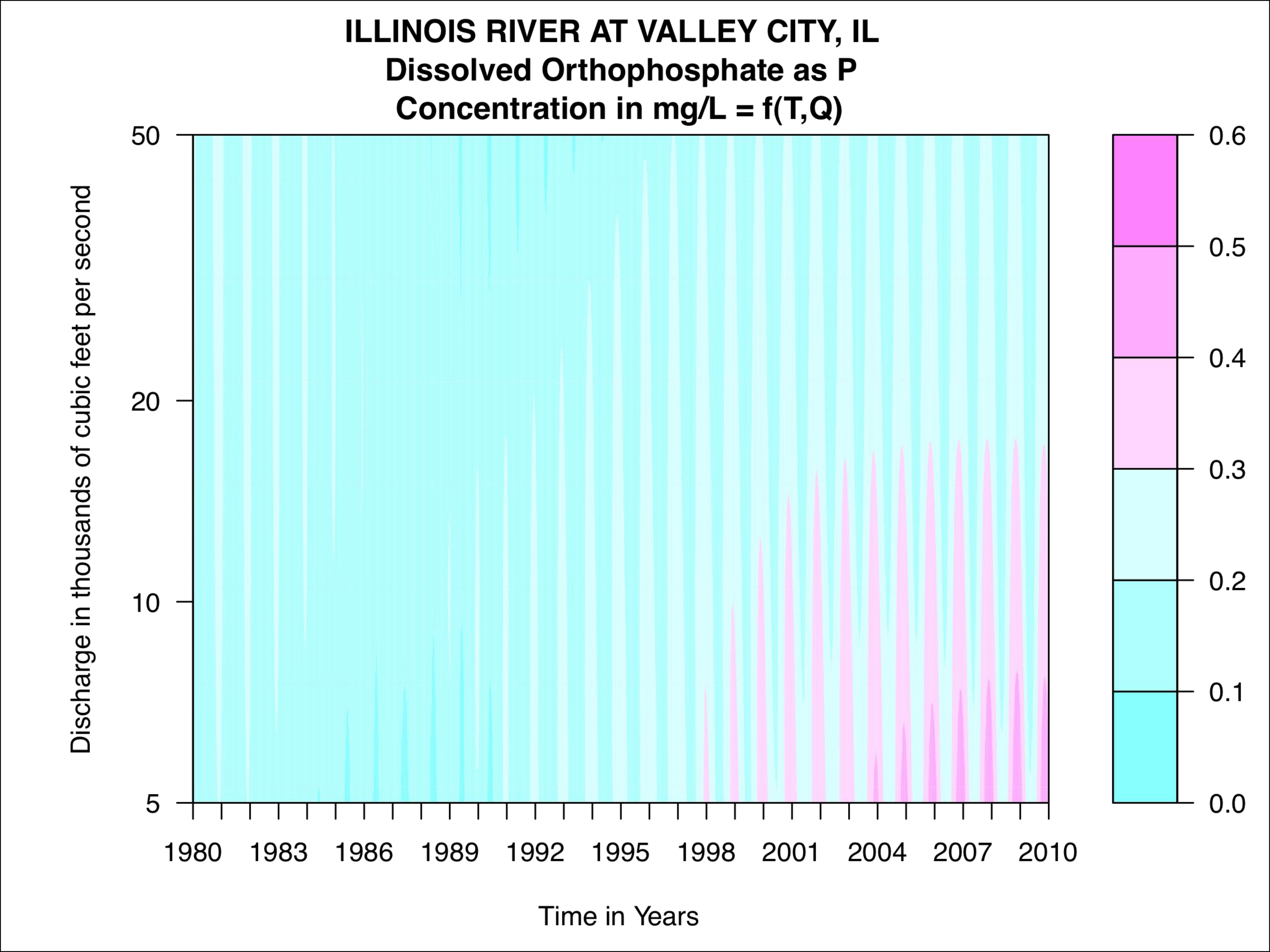
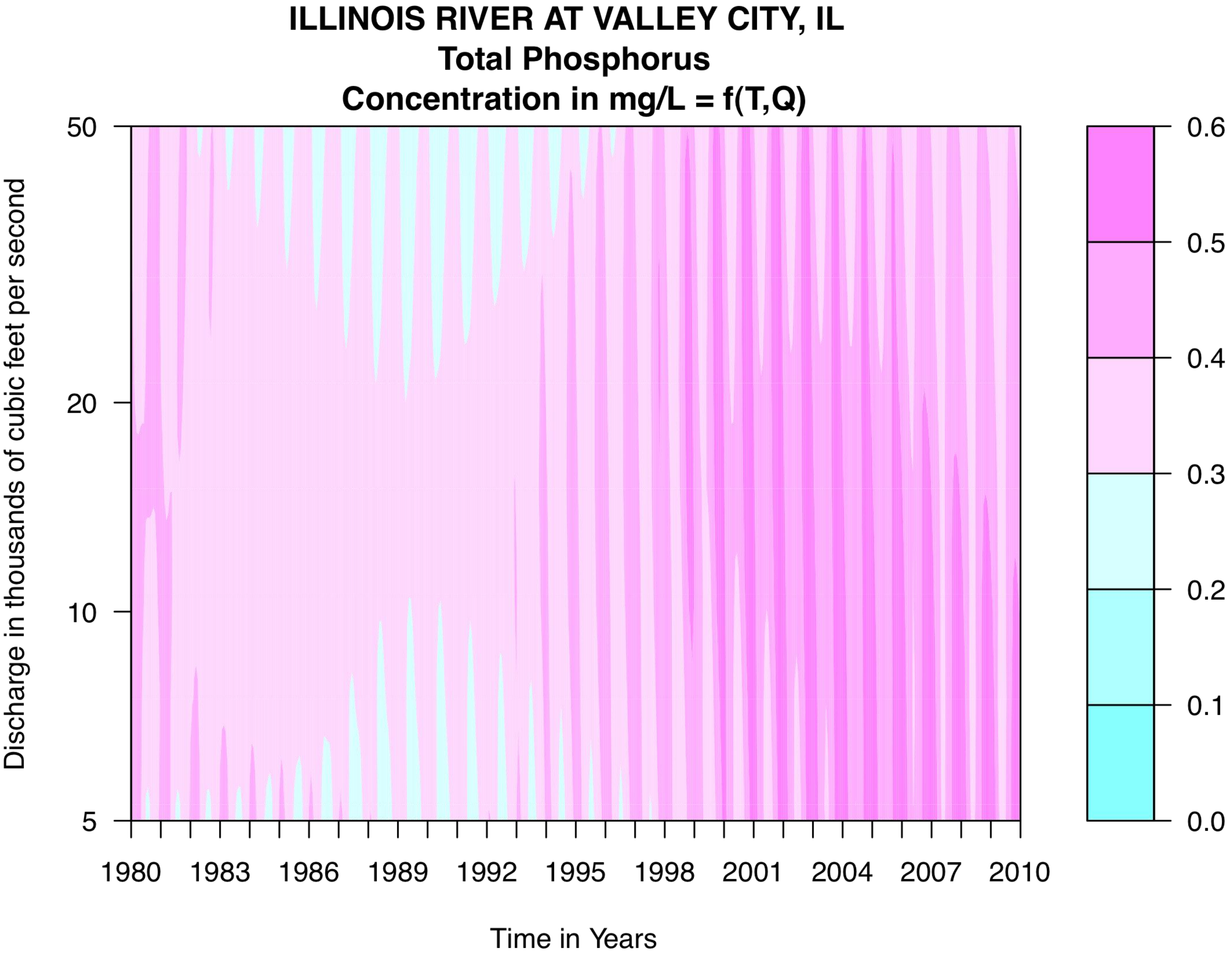
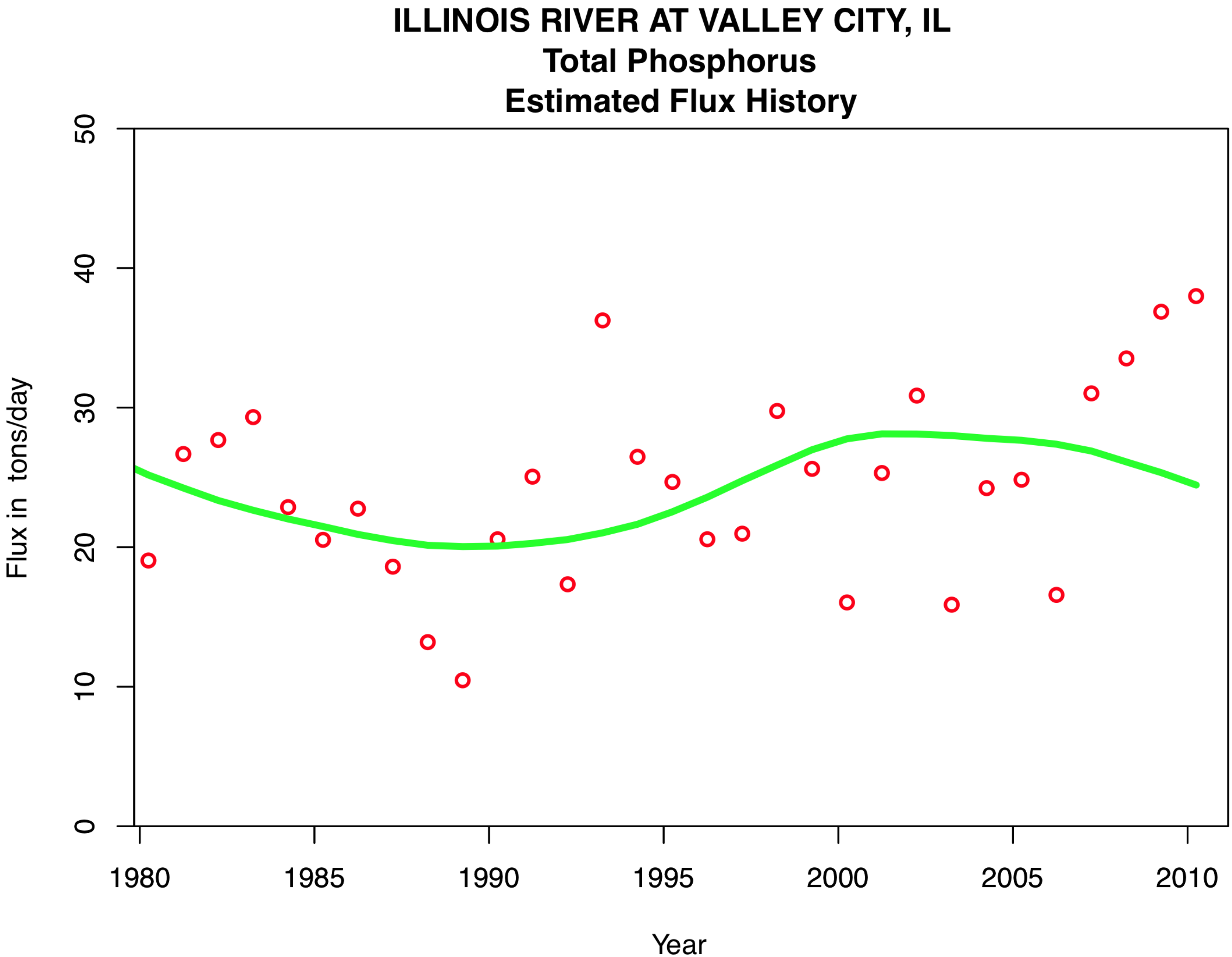

ILLINOIS RIVER AT VALLEY CITY, IL
Dissolved Orthophosphate as P
Concentration in mg/L = f(T,Q)
Discharge in thousands of cubic feet per second
50
20
10
5
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
Time in Years
0.6
0.5
0.4
0.3
0.2
0.1
0.0


ILLINOIS RIVER AT VALLEY CITY, IL
Total Phosphorus
Concentration in mg/L = f(T,Q)
Discharge in thousands of cubic feet per second
50
20
10
5
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
Time in Years
0.6
0.5
0.4
0.3
0.2
0.1
0.0


ILLINOIS RIVER AT VALLEY CITY, IL
Total Phosphorus
Estimated Flux History
Flux in tons/day
0
10
20
30
40
50
1980
1985
1990
1995
2000
2005
2010
Year

Take away messages

- The question isn’t “Is there a significant trend?”
- The question is, “What’s the pattern of change and what can we learn from it?”
- We need to look at the actual concentrations and fluxes, but also look at them with the influence of flow removed.

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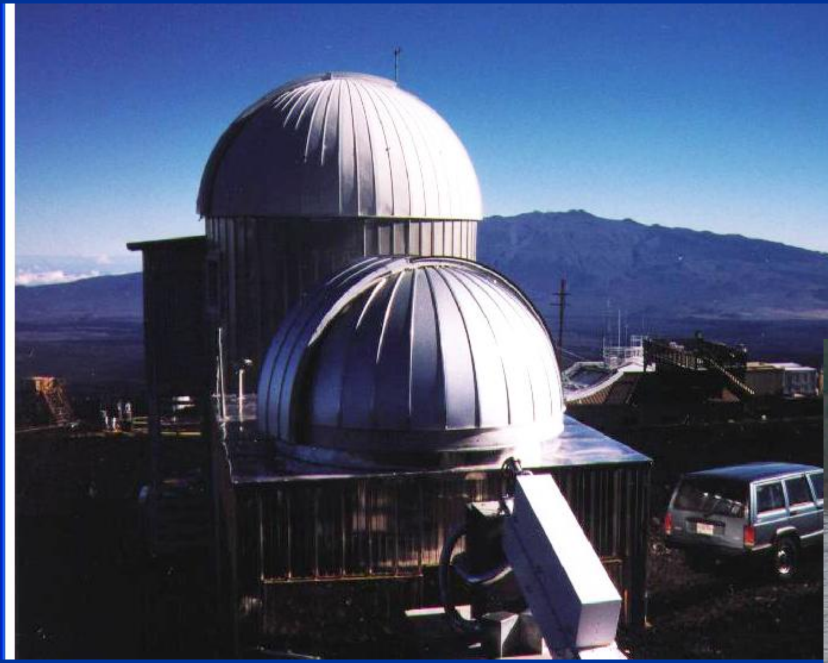
Overall Summary: Avoid

- Thinking we can learn much from short records
- Failing to fully exploit the data
- Confusing model results with findings based on actual data
- Assuming GCMs get the water “right”
- The “greenhouse cop-out”

So what should we do?



A quote from Ralph Keeling: “Recording Earth’s Vital Signs”

Science, 2008, 1771-1772

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From Ralph Keeling

A continuing challenge to long-term Earth observations is the prejudice against science that is not directly aimed at hypothesis testing.

At a time when the planet is being propelled by human action …. We cannot afford such a rigid view of the scientific enterprise.

USGS

From Ralph Keeling

The only way to figure out what is happening to our planet is to measure it,

and this means tracking changes decade after decade

and poring over the records.

USGS

Parting Thoughts

- **We must avoid the trap of relying only on past experience or only on model-based projections.**
- **The future will not be the same as the past, but the past is not irrelevant to understanding the future.**