# EGRET: Exploration and Graphics for RivEr Trends

**An R-package for the analysis of long-term changes in river-water quality and streamflow, including the water quality method "Weighted Regressions on Time, Discharge, and Season" (WRTDS)**

**Developed by Bob Hirsch & Laura De Cicco:**

**In Beta testing**

USGS
science for a changing world

# The WRTDS analysis is a method that has been described in peer reviewed publications

**Links to these papers, plus the R-packages, draft manual and this presentation are on the EGRET web site**

**https://github.com/USGS-CIDA/WRTDS/blob/master/README.md**

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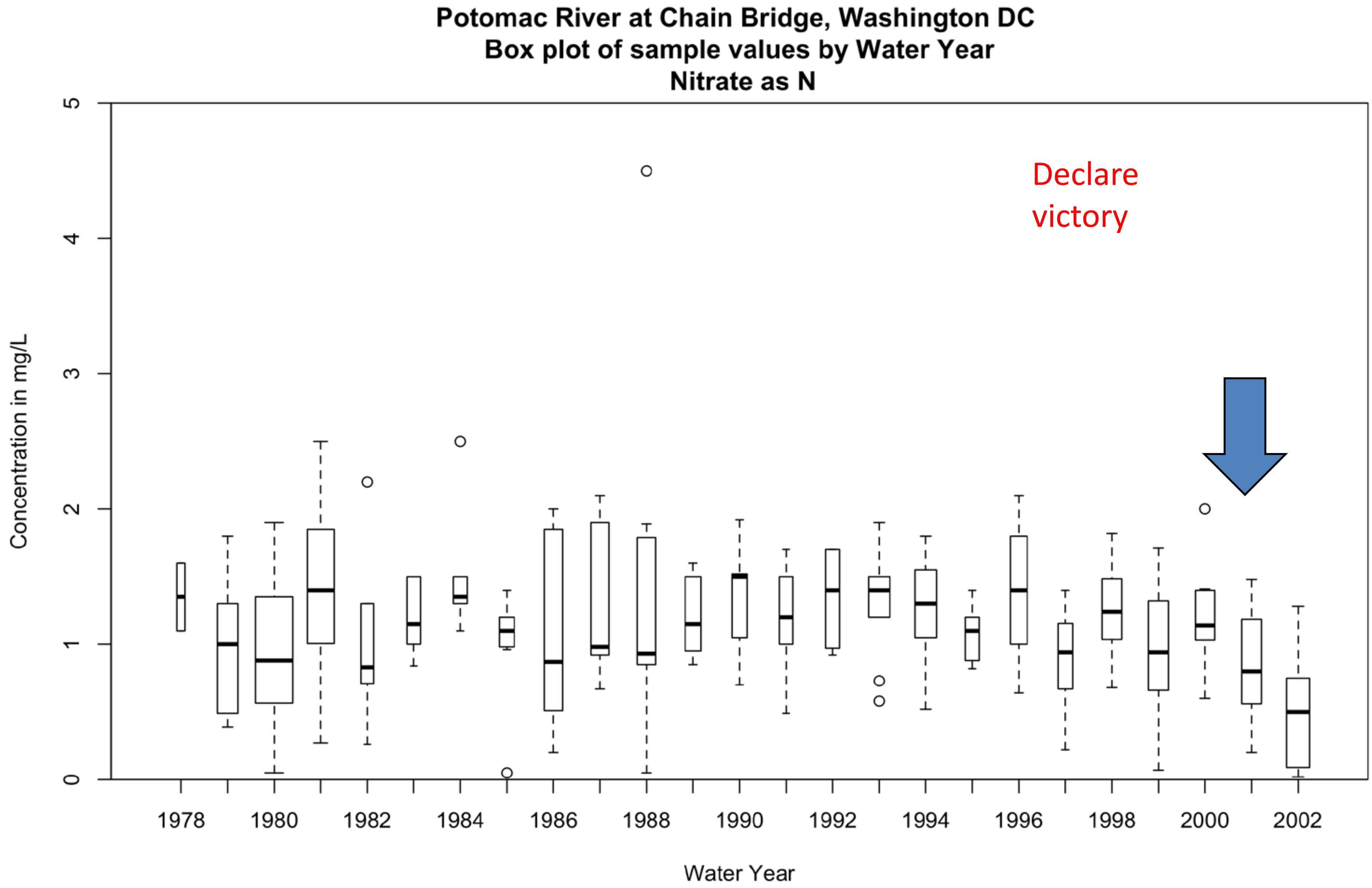
# The driving philosophy for WRTDS and EGRET:

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

**and this means tracking changes decade after decade**

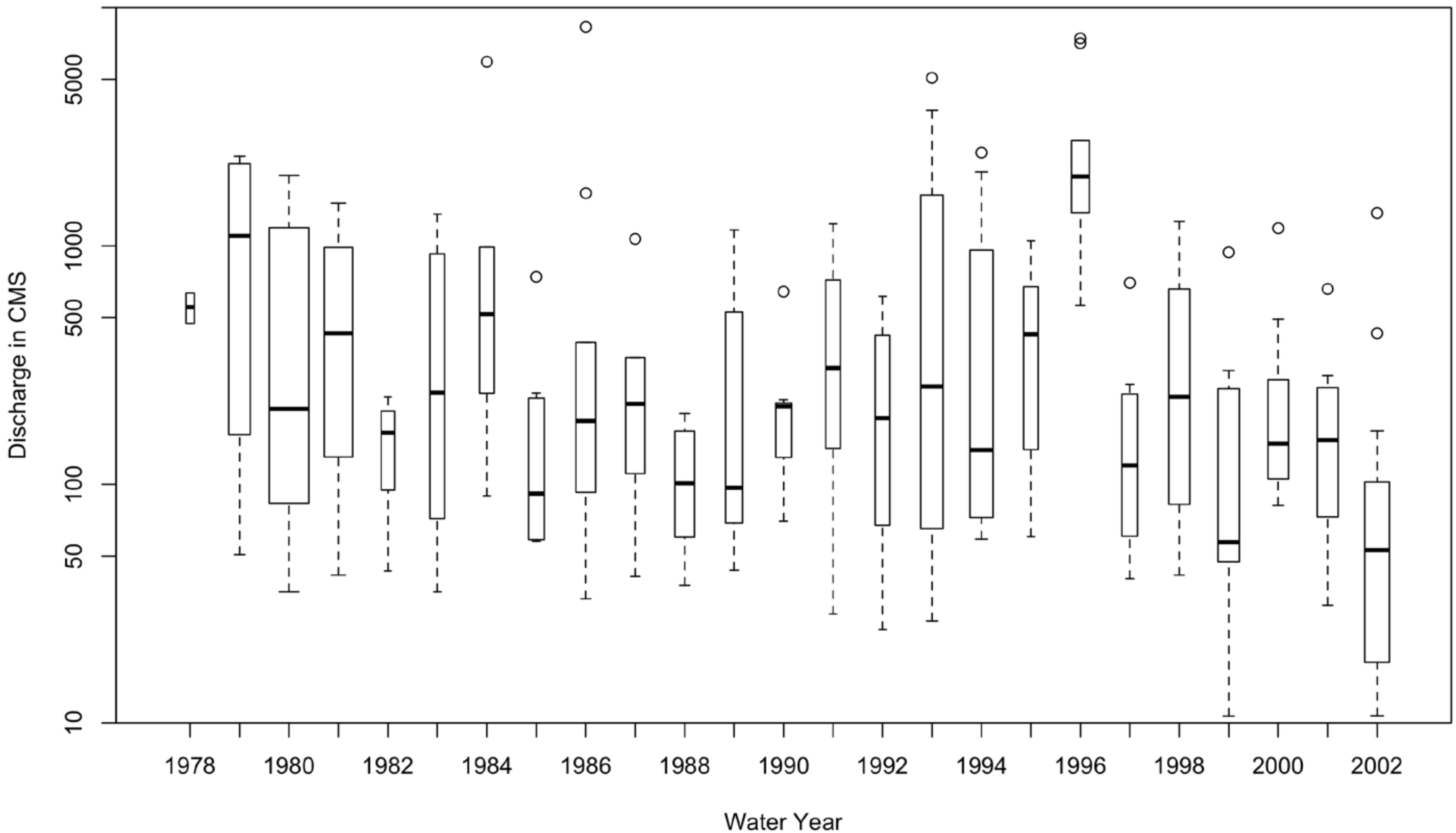
**and poring over the records."**

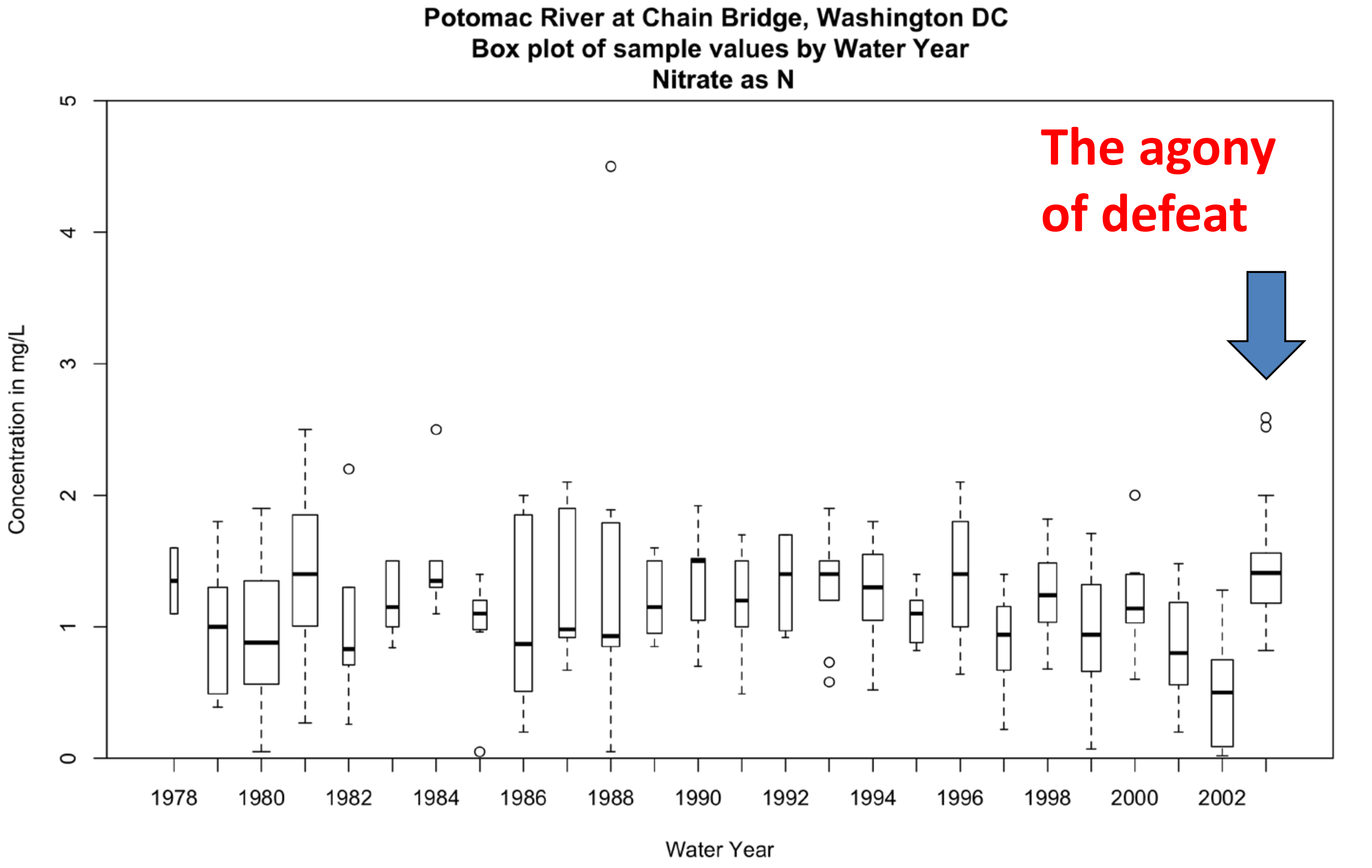
*(Ralph Keeling, Science Magazine, 2008)*



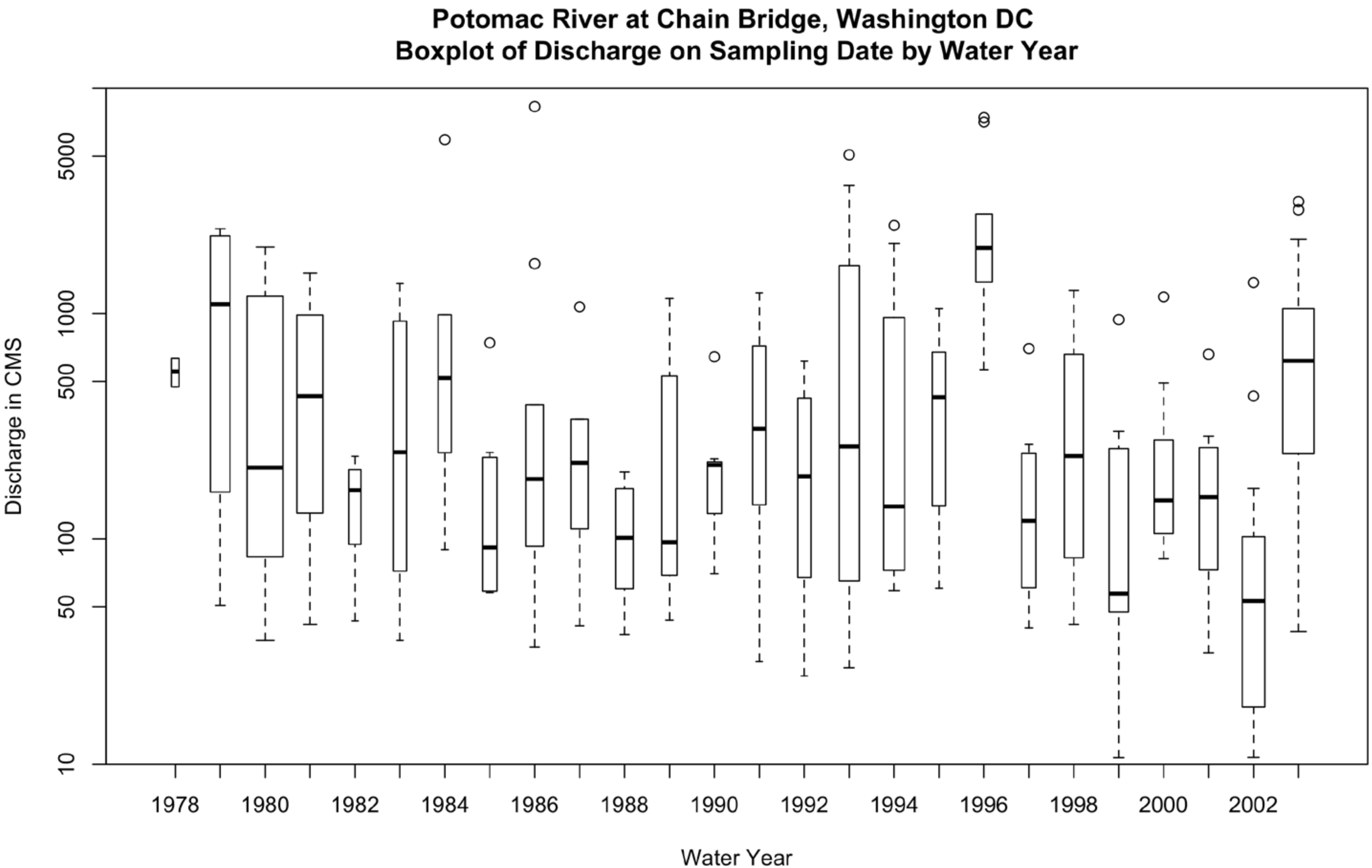

# Data through September 2002

**Potomac River at Chain Bridge, Washington DC**
**Boxplot of Discharge on Sampling Date by Water Year**

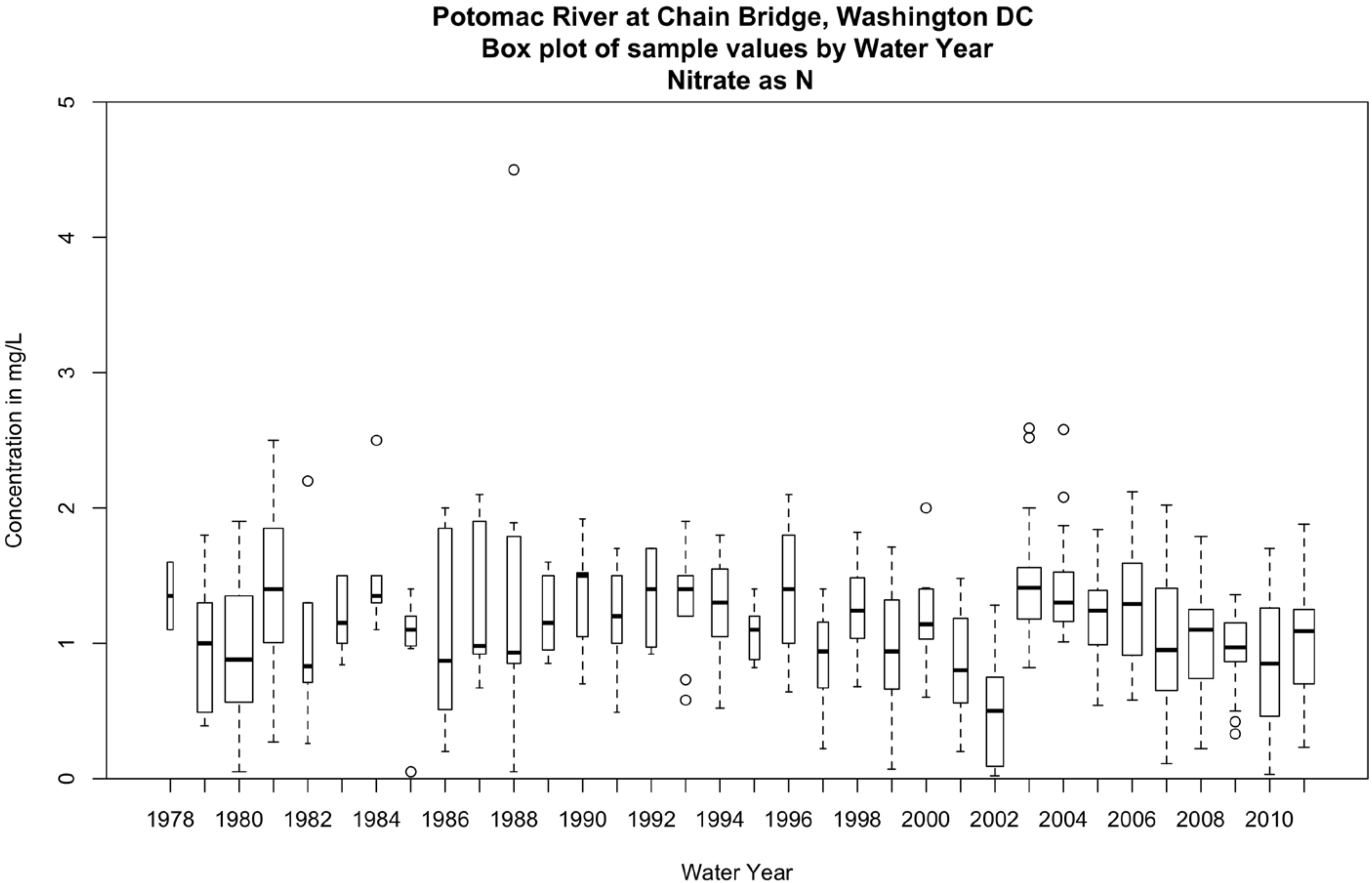




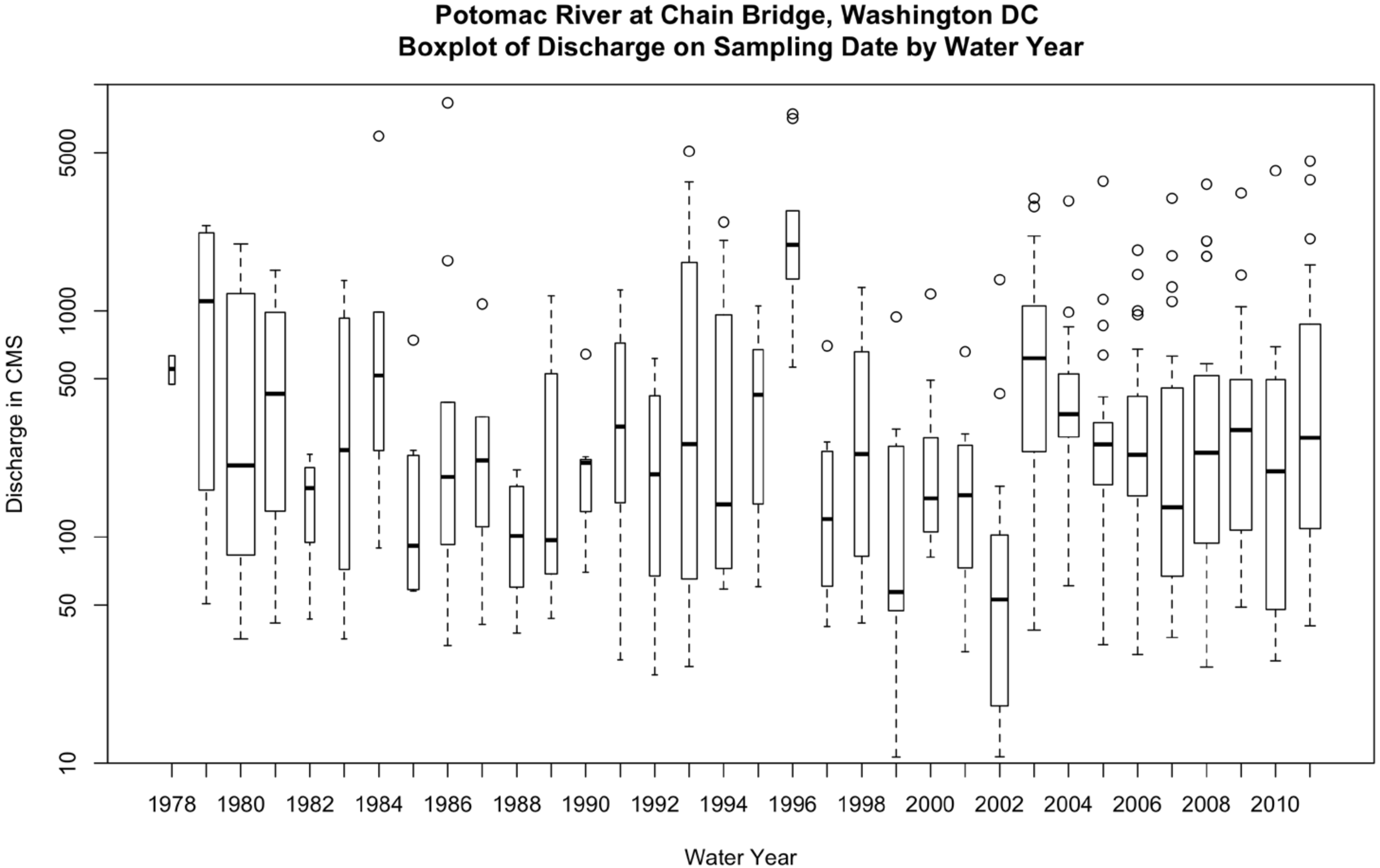

Data through September 2003



Potomac River at Chain Bridge, Washington DC
Boxplot of Discharge on Sampling Date by Water Year
Discharge in CMS
5000
1000
500
100
50
10
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
Water Year




Data through September 2011


Potomac River at Chain Bridge, Washington DC
Boxplot of Discharge on Sampling Date by Water Year
Discharge in CMS
10
50
100
500
1000
5000
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
Water Year

# What needs motivated WRTDS?

- Let the data inform the statistical model.  No mathematical straight-jacket!!
- Estimate both concentration & flux.
- Estimate the actual history but also a flow-normalized history.
- Try to resolve a serious flux-bias problem.
- Be quantitative but also exploratory.
- Focus on description and understanding not on statistical significance.  Like economic and social time series.

# EGRET overview

- Ingest water quality sample data, daily streamflow data, and meta data from **USGS Web services** or from **user-supplied files**

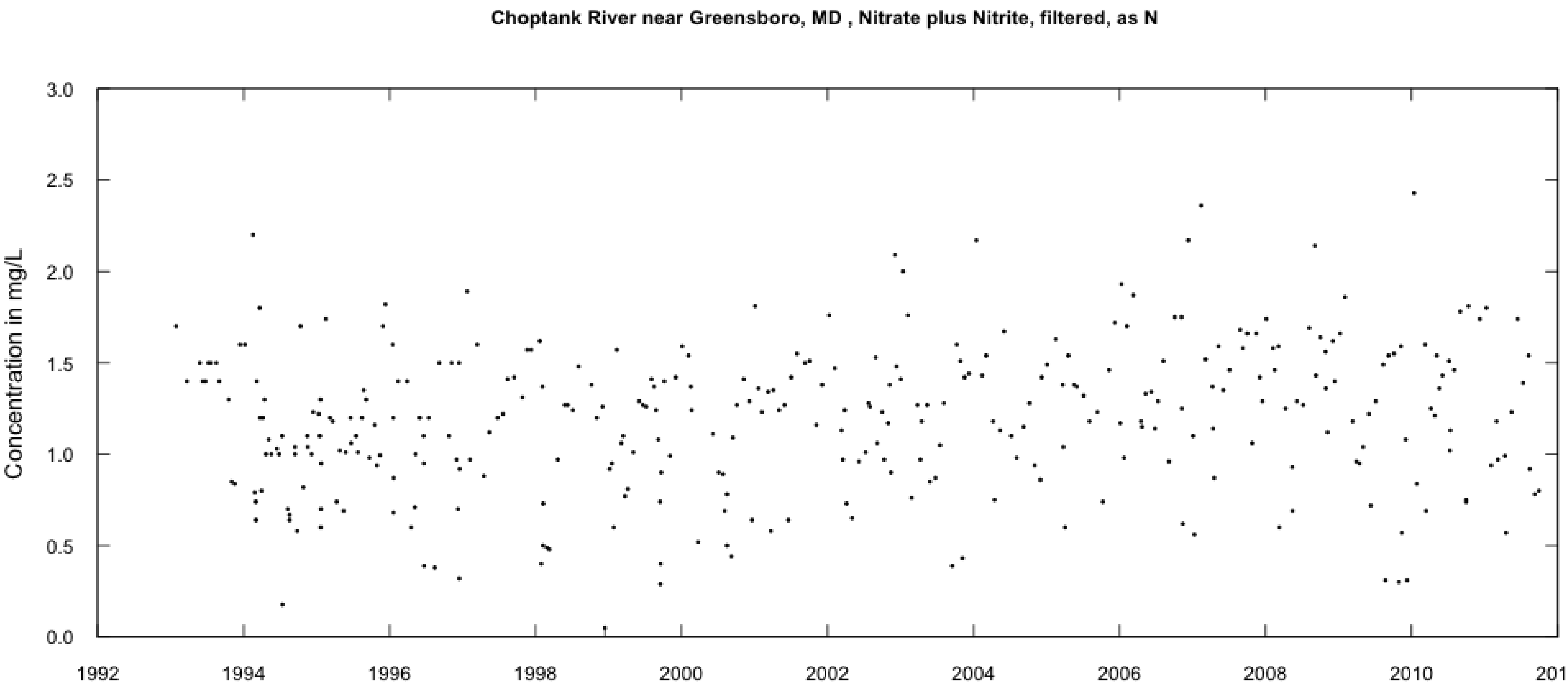
- Sub-systems: **WRTDS** for river water quality data analysis and **flowHistory** for analysis of streamflow alone

- Goal: Exploration of the data to describe the evolving hydrologic system.  Produce: graphs, summary statistics, understanding, and hypotheses.

# What's the underlying idea of WRTDS?

Water quality is influenced by many factors, we need tools to sort out the factors

What's going on here?



# What’s the underlying idea of WRTDS?

Use the data and a simple, **highly-flexible** smoothing model, to compute **for every day** in the study period, an estimate of **concentration** and an estimate of **flux.**

The smoothing model expresses the behavior as a combination of influences:

1) **Time trend**
2) **Discharge**
3) **Seasonal cycle**
4) **Random component**

# Locally Weighted Regression

For any location in time - discharge space ($t$ and $Q$) we assume that concentration ($c$) follows this model

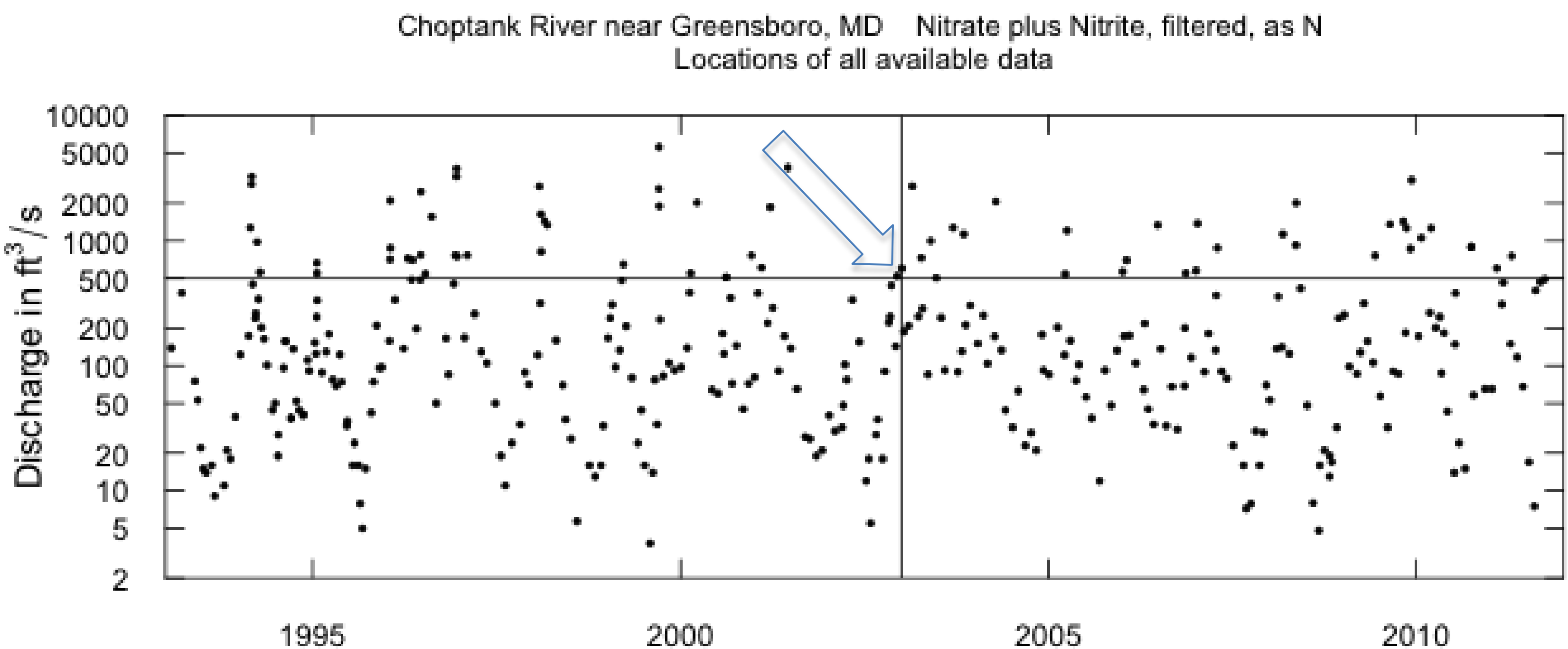
$$\ln(c) = \beta_0 + \beta_1 \bullet t + \beta_2 \bullet \ln(Q) + \beta_3 \bullet \sin(2\pi t) + \beta_4 \cos(2\pi t) + \varepsilon$$

But the coefficients should be smoothly changing as we move through the space

Use weighted regression at many points in that space. The weight on each sample is determined by its "relevance" to that particular point in the space.

Every dot is a data point from 1993 to 2012

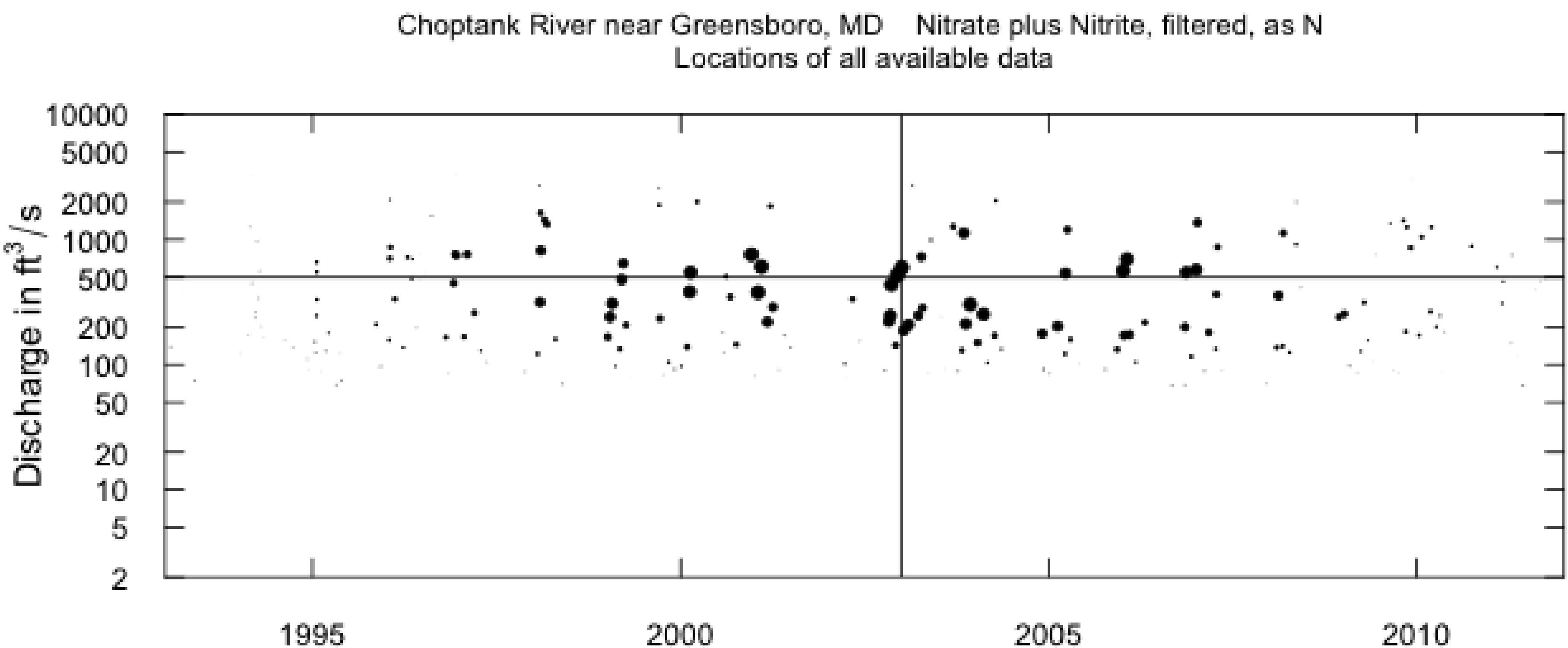
Let's say we want to use the data to estimate the expected value of concentration for January 1, 2003 at Q=500 cfs



# How do we set the weights for the regression?

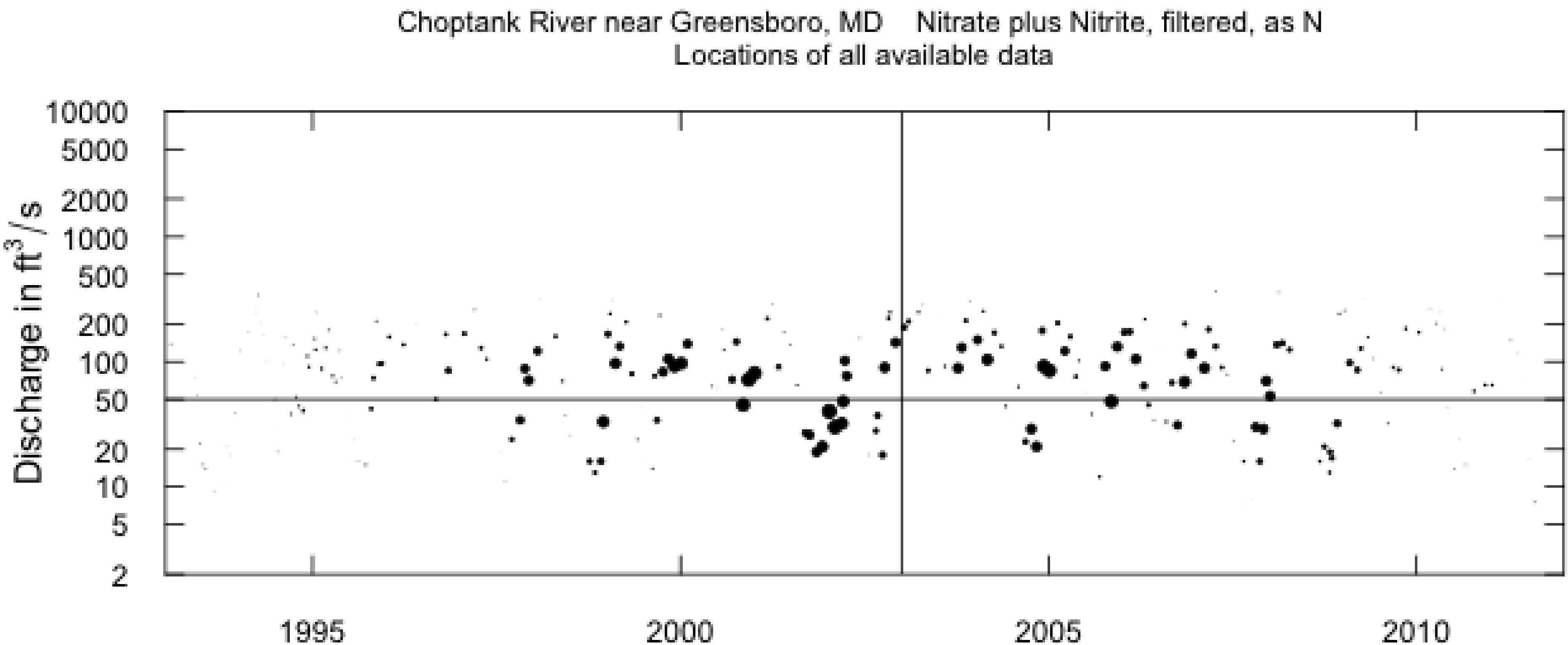
These are the same points we just saw, but the radius of the dot is proportional to weight assigned to that point for purposes of estimating concentration for January 1, 2003 at Q=500 cfs

The weight depends on distance in: time, log discharge, and season from January 1, 2003 at Q = 500 cfs



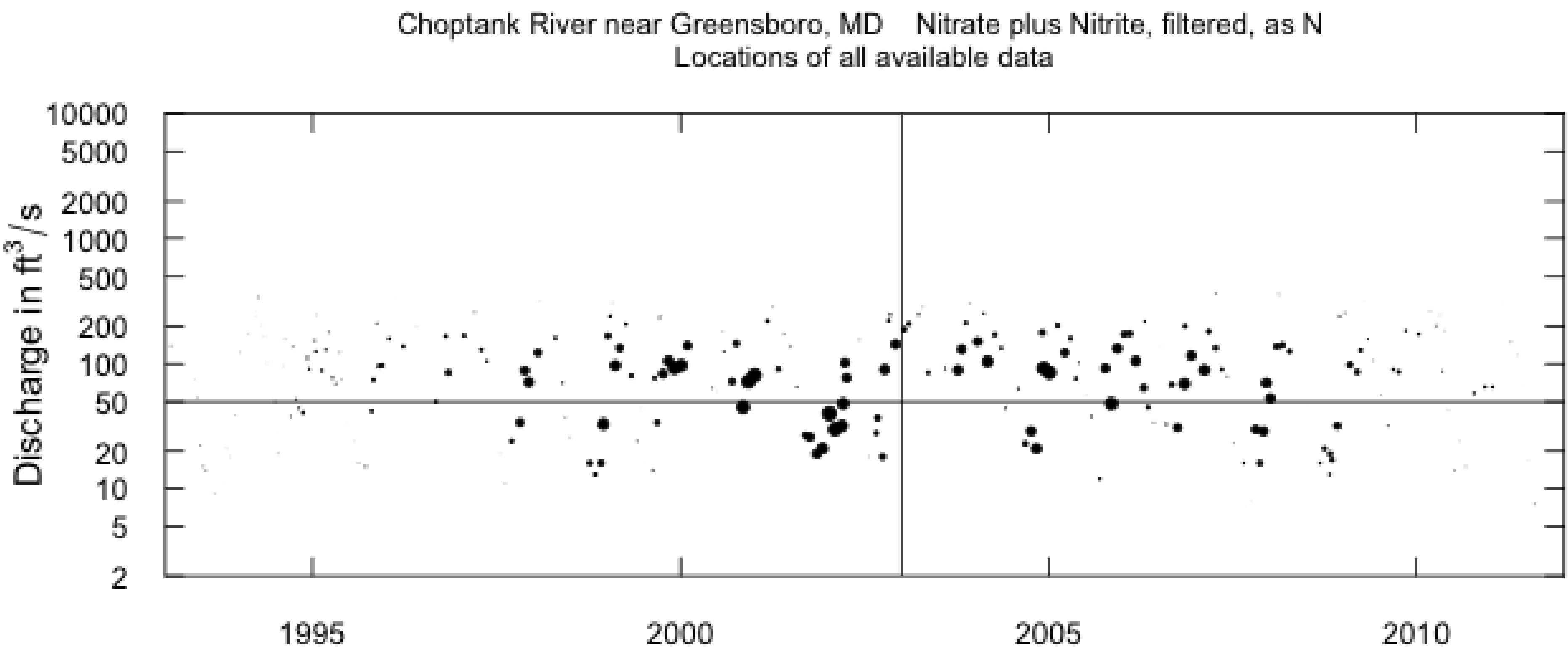
What if we wanted to make an estimate for January 1, 2003 but for Q = 50 cfs

Redo the weights for distance from that point



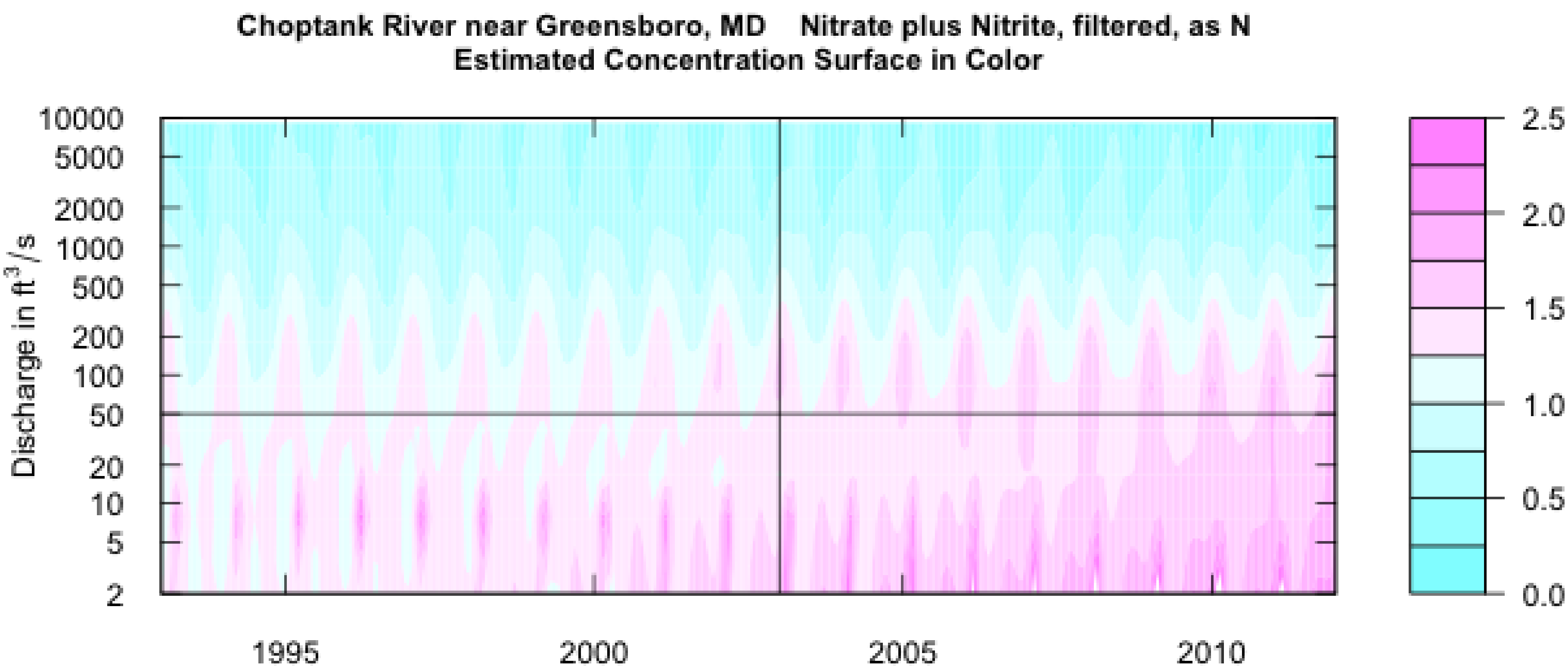
To organize the work, lets make estimates for a fine mesh of points in this space.

Over this space we will do it at 14 Q values and 177 time values, for a grid of 2,478 points.

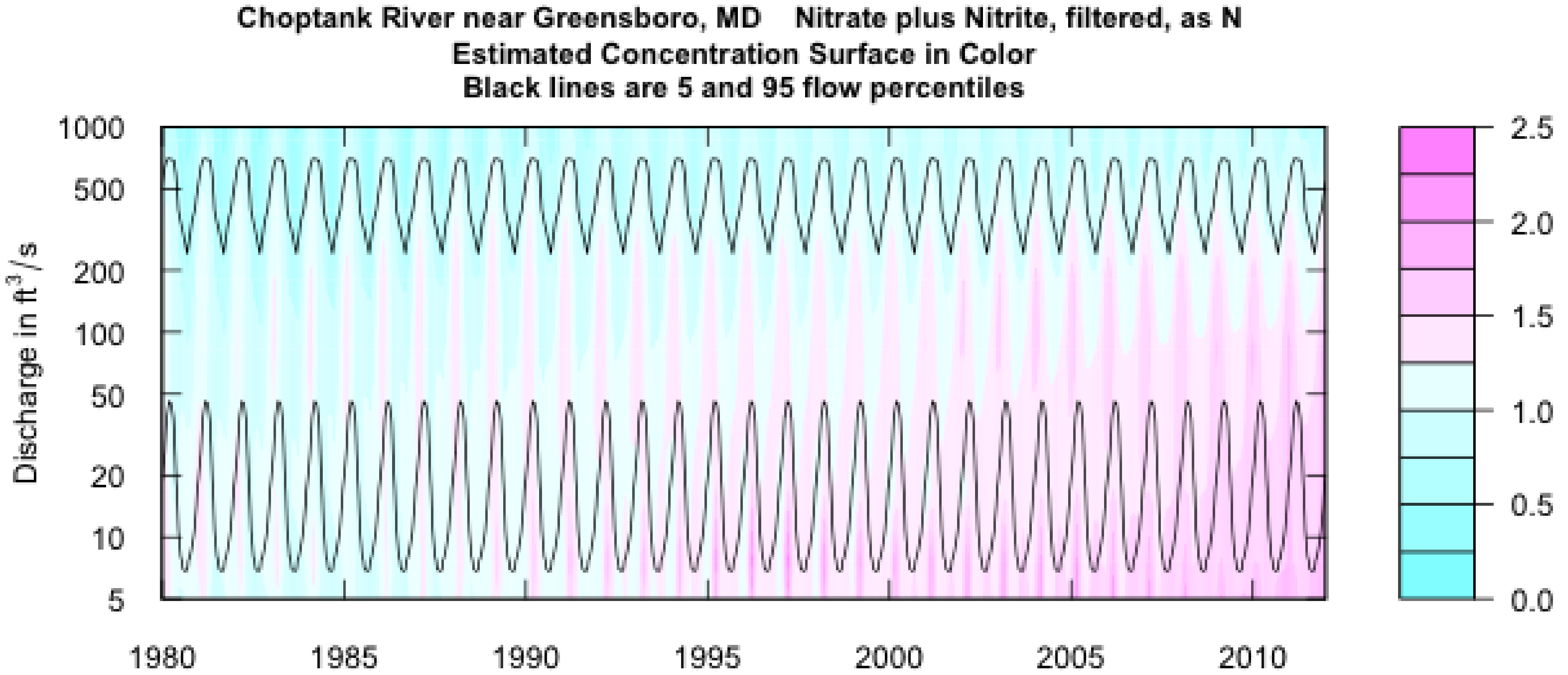


Here is the "surface" computed:

It is the estimates of the Expected value of Concentration as a function of time and discharge



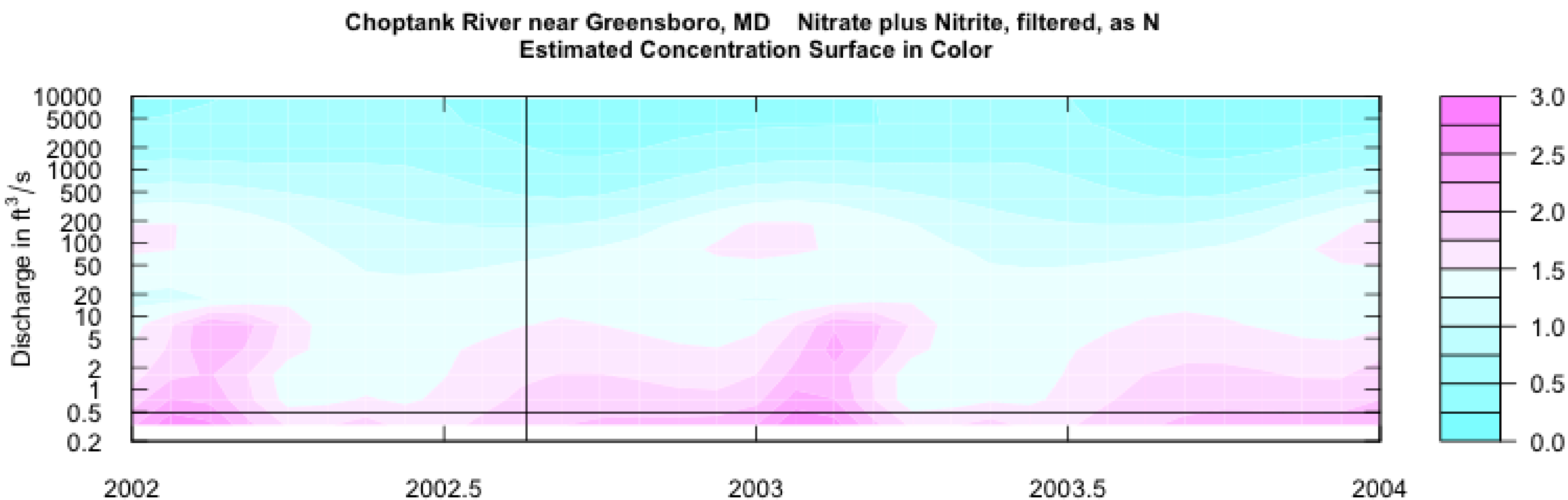
# Here is the whole surface: 513 time values by 14 discharge values, for a total of 7,168 points




**Added the black lines to illustrate the 5th and 95th percentiles on the seasonal flow duration curve**

# Look at a small part of this contour plot

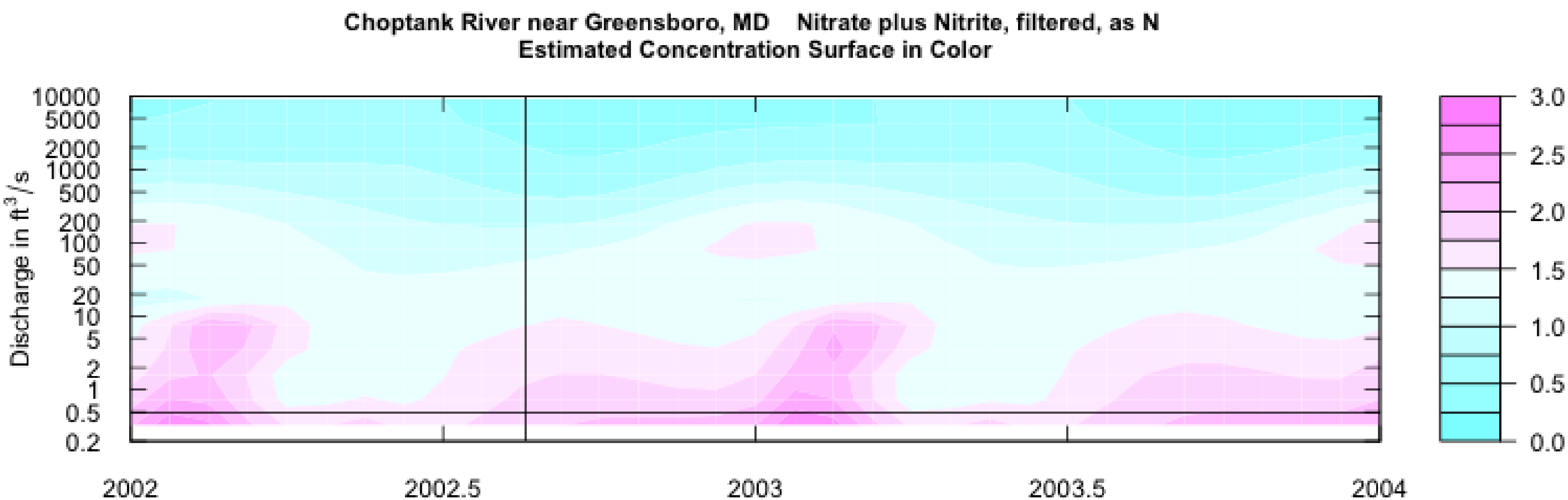
# Let’s look at August 20, 2002 (a serious drought), discharge was 0.49 cfs




Interpolation off this surface gives me an estimate of **concentration** for that day: 1.86 mg/L

For **flux** we compute: E(C) * Q to get 2.24 kg/day

# EGRET does this process for each of the 11,718 days in the period of record.

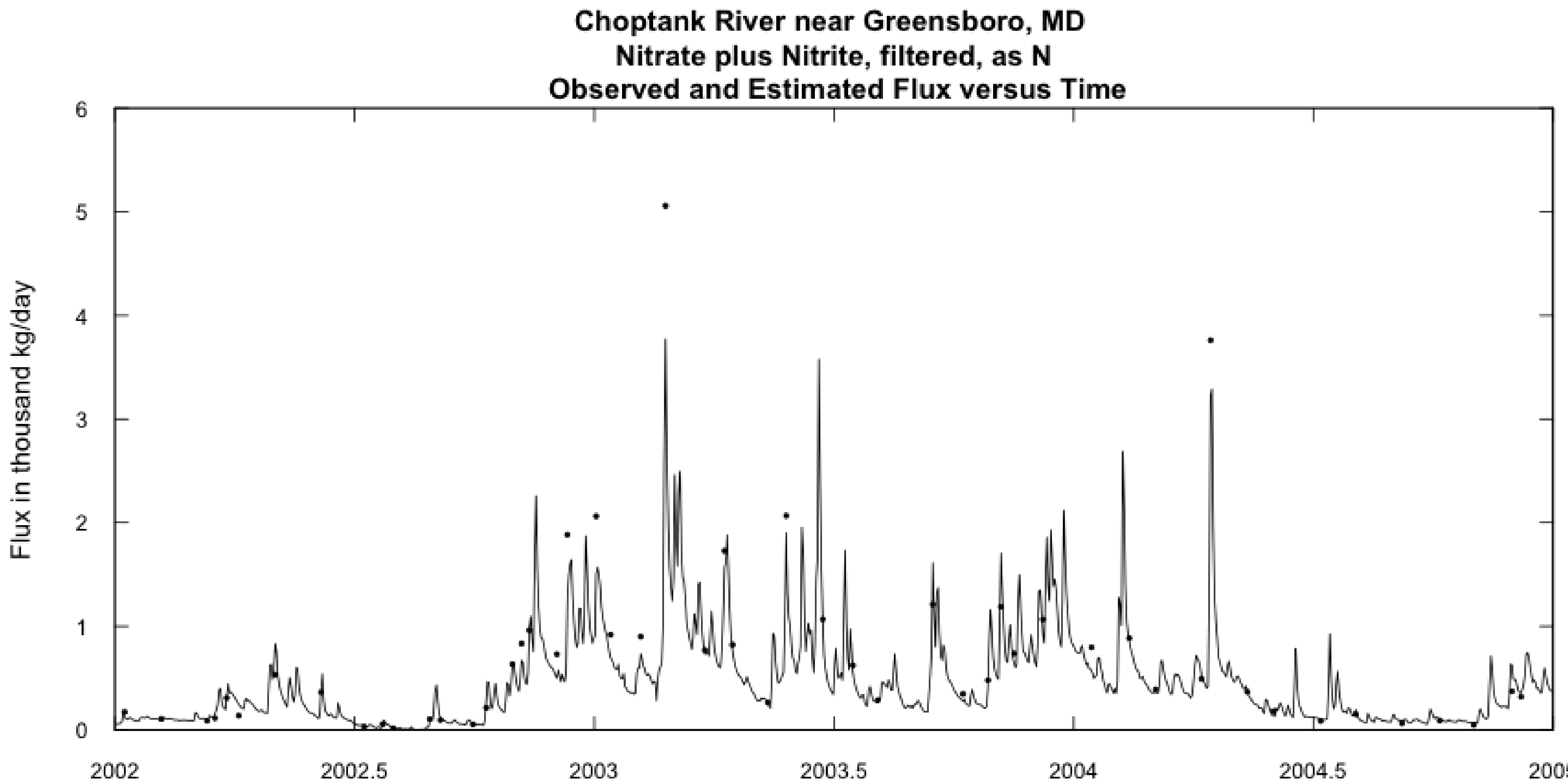



It computes and stores:

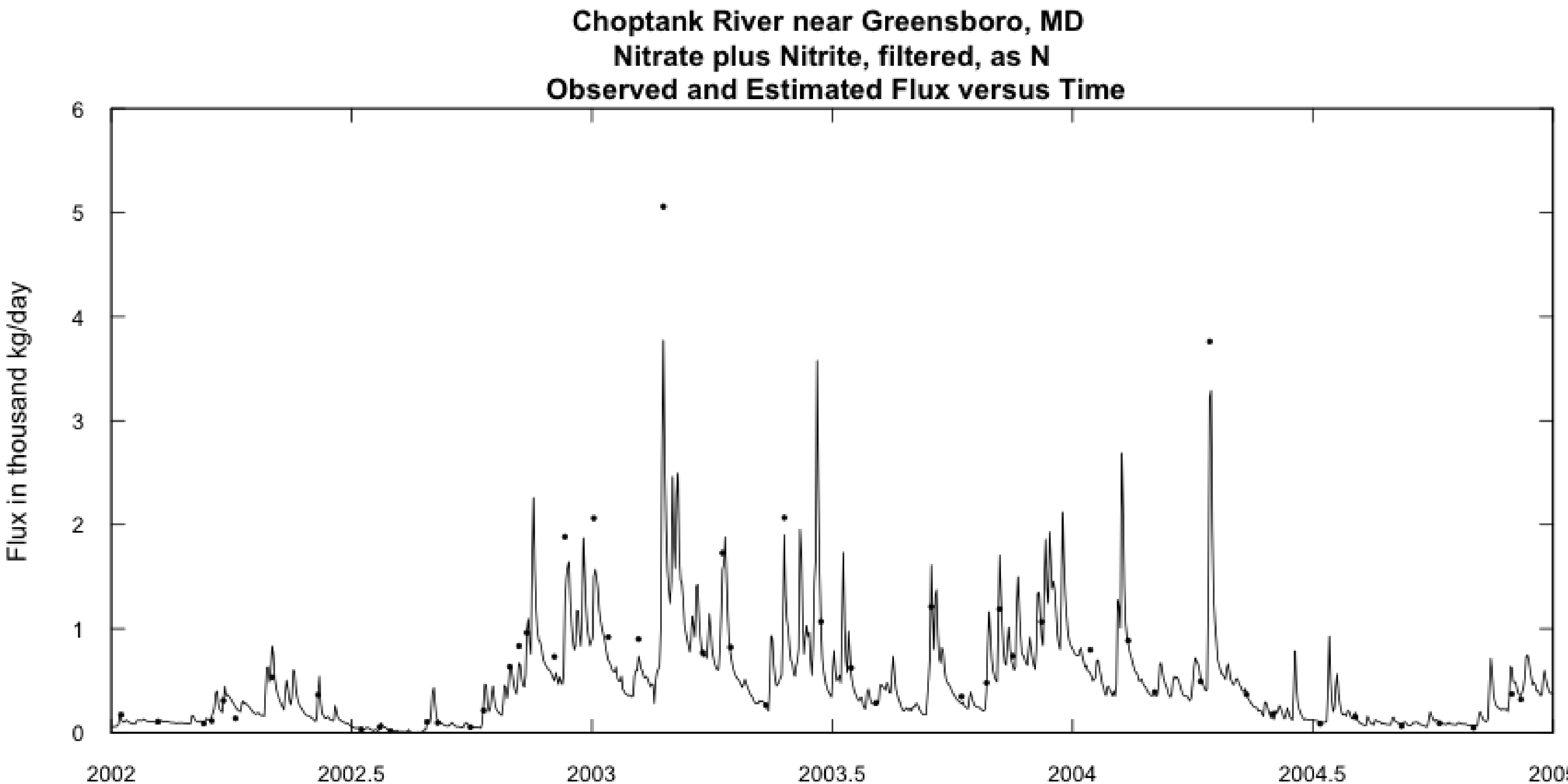
11,718 estimated daily concentrations

11,718 estimated daily fluxes

# We can look at these flux estimates and compare them to the actual fluxes for the sampled days



# Most of the difference between years is driven by the natural random variation in streamflow. Water years 2003 and 2004 were very wet.



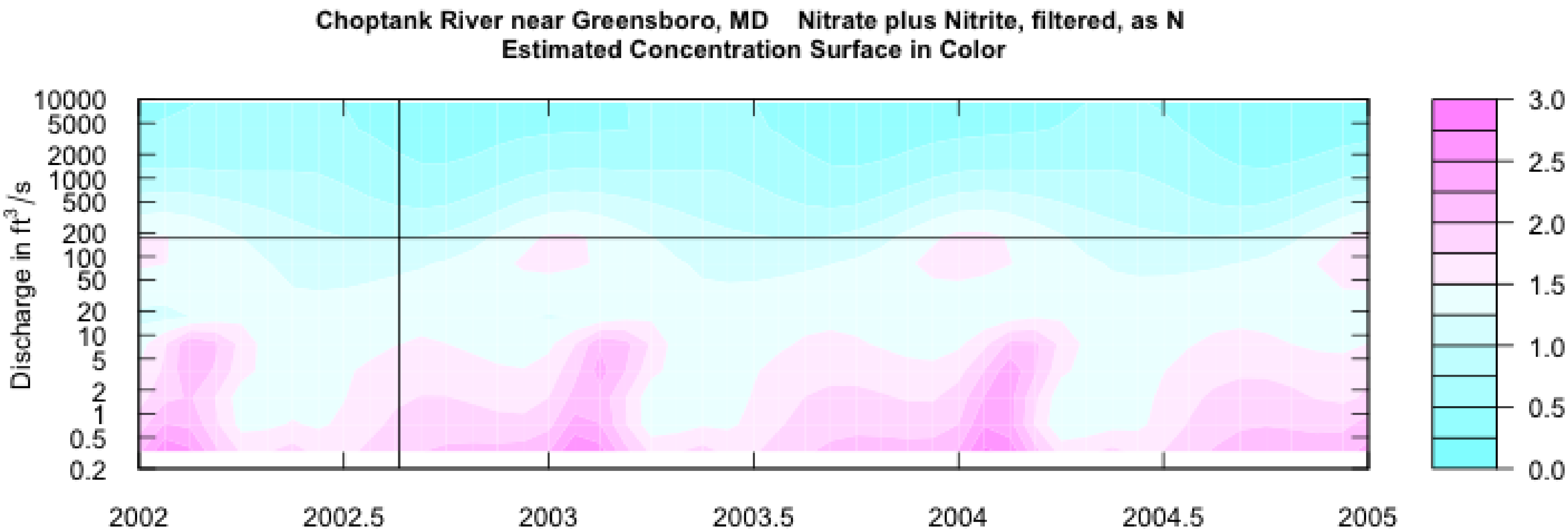
**The estimated concentrations and fluxes are important, particularly if one wants to understand the estuary's response to inputs.**

**But, if we really want to understand "progress" or "lack of progress" in improving water quality in this watershed, we need to remove the effect of these random year-to-year variations driven by streamflow.**

**We do this through "flow-normalization"**

**How does that work?**

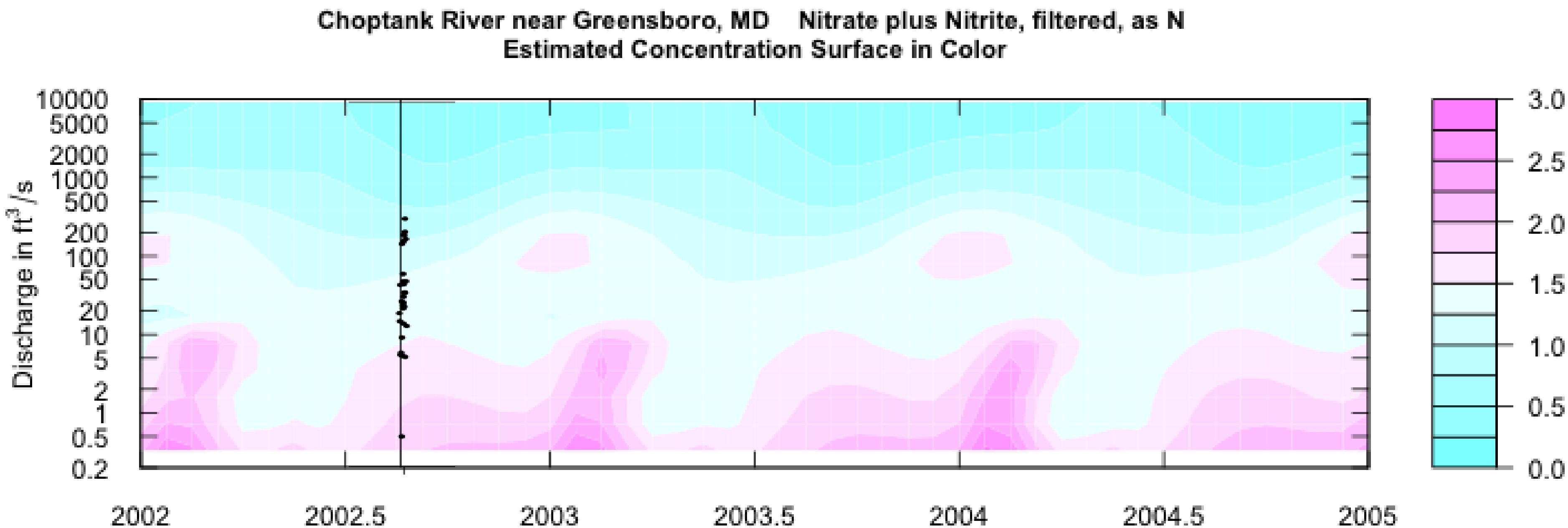
We can say that it is just as likely that Q could have been 172 cfs that day (it happens to be the Q from August 20, 2003) as the 0.49 cfs that happened August 20, 2002




The WRTDS estimate of concentration for that discharge, but based on the “behavior of the system” on August 20, 2002, is 1.0 mg/L

The flux for that discharge and that concentration comes to 431 kg/day

Let’s think of every Aug. 20 Q value we have seen as equally likely to have happened on Aug. 20, 2002 and estimate the concentration and flux we would have had on Aug. 20, 2002 with that Q




**The mean of those concentrations is 1.31 mg/L, we call this the “flow-normalized concentration” for Aug. 20, 2002**

**The mean of the flux values is 164.4 kg/day, we call this the “flow-normalized flux” for Aug. 20, 2002**

**Flow-normalization allows us to remove the influence of the year to year variation in discharge (but not the natural seasonal variation in discharge)**

**The program computes, for every day:**

- **The estimated concentration**
- **The flow-normalized concentration**
- **The estimated flux (flow * concentration)**
- **The flow-normalized flux (by integrating flux over the frequency distribution of flow)**

Now we have, for August 20, 2002

Estimated Concentration = 1.86 mg/L

Flow Normalized Concentration = 1.31 mg/L

Estimated Flux = 2.24 kg/day

Flow Normalized Flux = 164.4 kg/day

Now: do that process again and again for all 11,718 days in the record and store each of those four numbers for each day

It is assumed here that streamflow is stationary over the period of interest.

If I had a strong reason to believe that the past 34 years of August 20 streamflows is not a reasonable sample of the probability distribution of streamflows I can expect to see on this year's August 20, then I should not use flow normalization.

Major new water controls (dams built or removed), or major changes in flow due to changes in water withdrawals, changes in impervious surface area, or groundwater drawdown, would require a modified approach.

I do not see climate change as sufficiently large at this time to invalidate this approach.

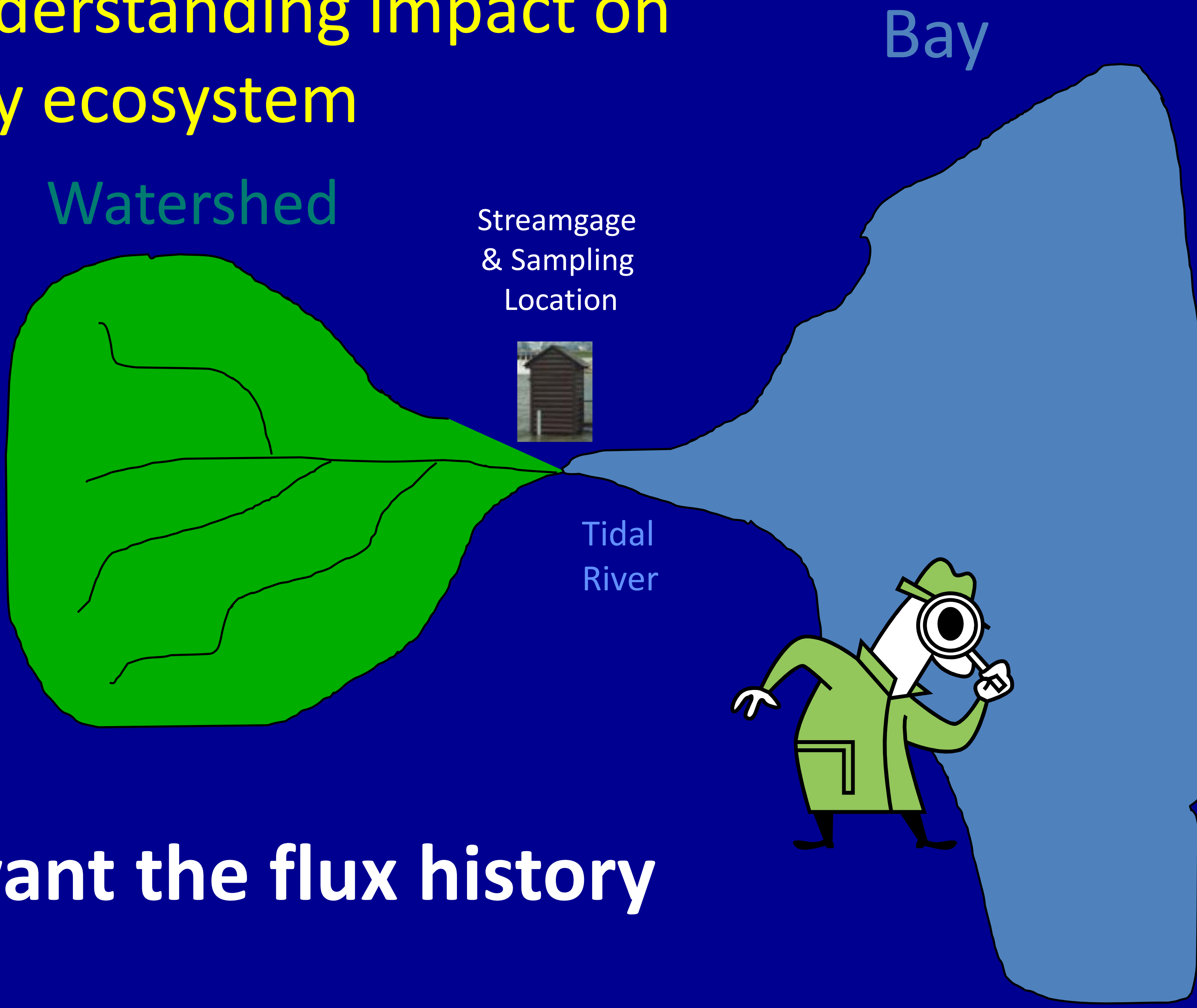
# Why all this complexity?

## Different products for different purposes

Concentration vs Flux

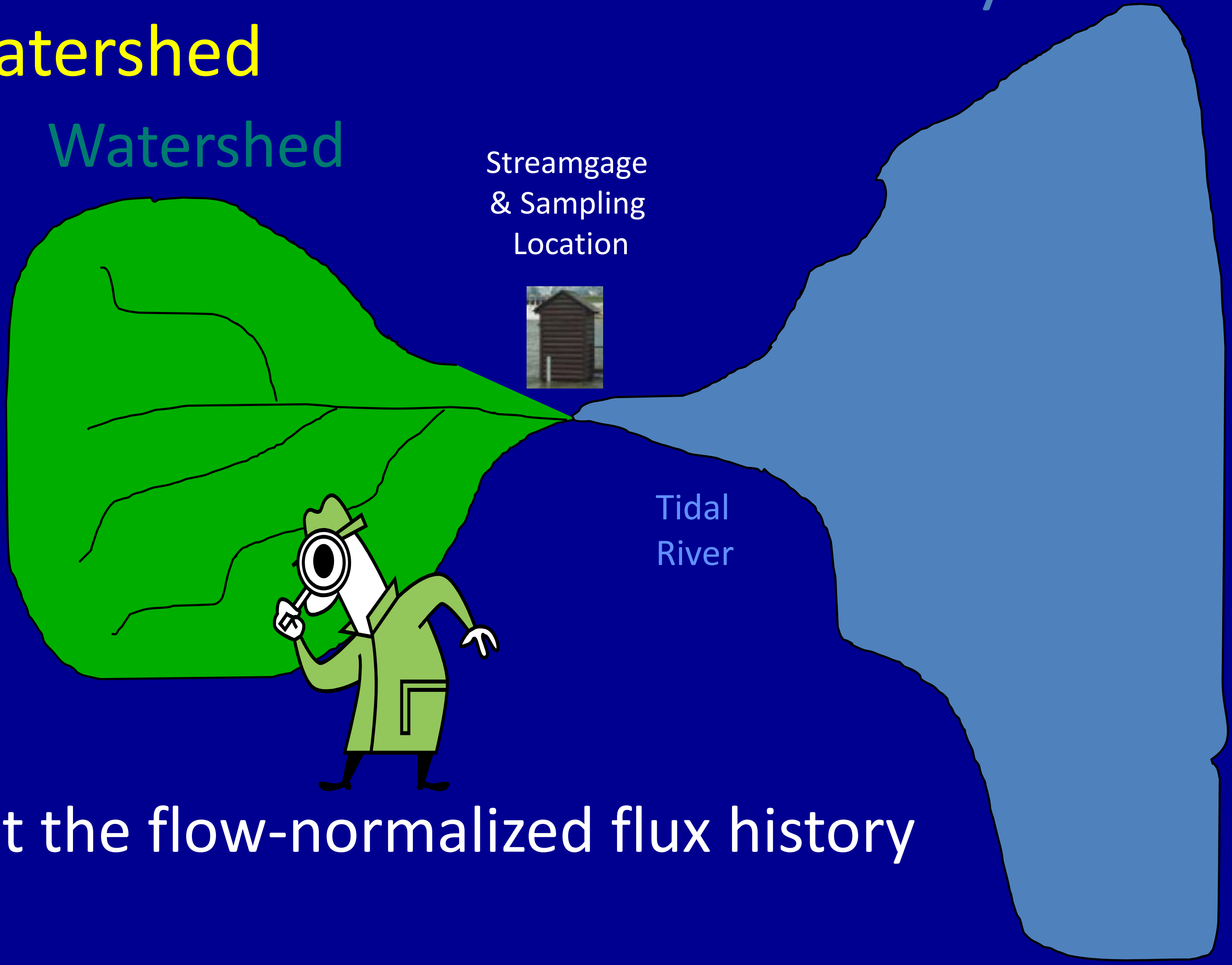
History vs Flow-normalized history

# For understanding impact on the Bay ecosystem



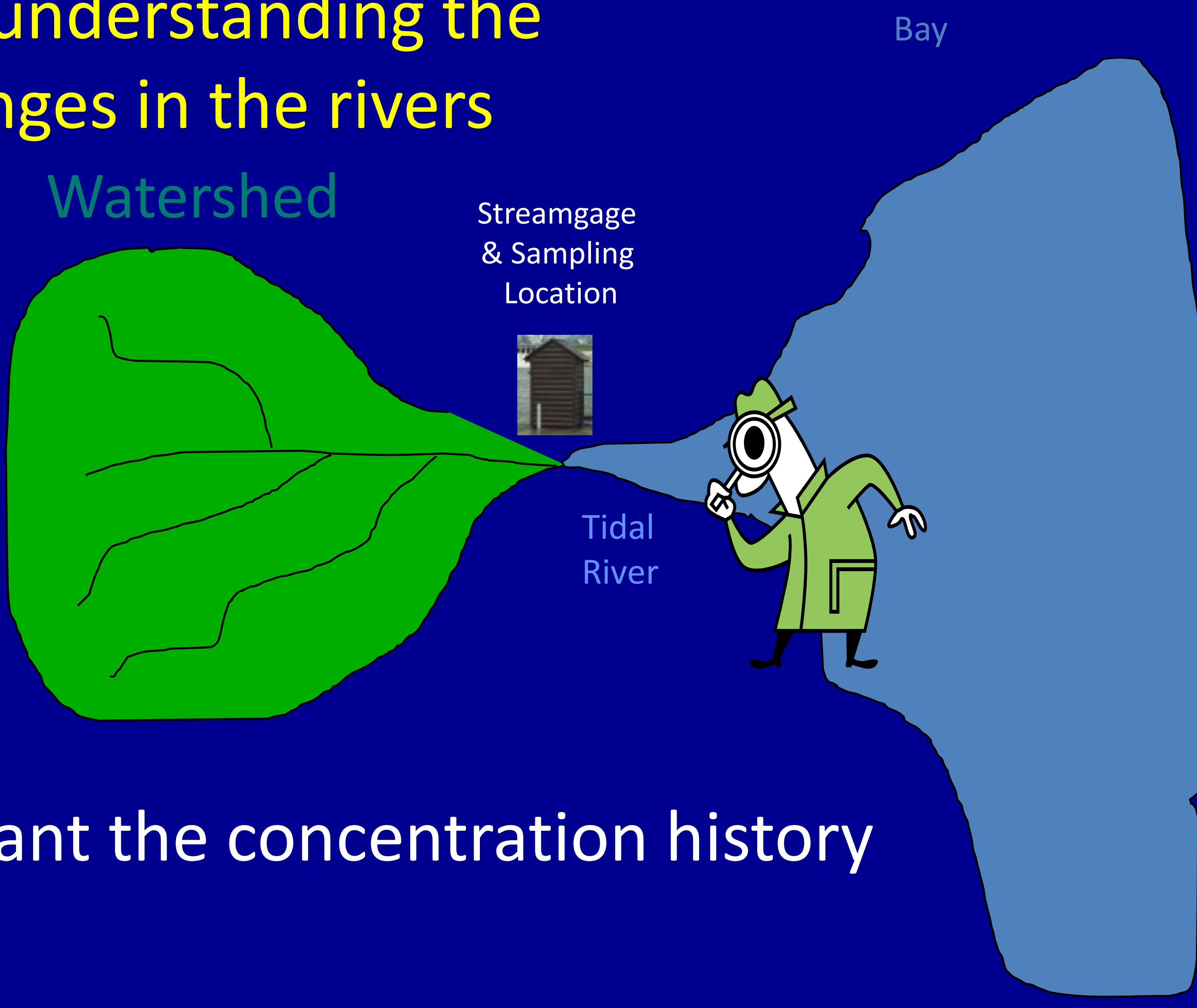

**We want the flux history**

# For understanding progress in the watershed




We want the flow-normalized flux history

# For understanding the changes in the rivers



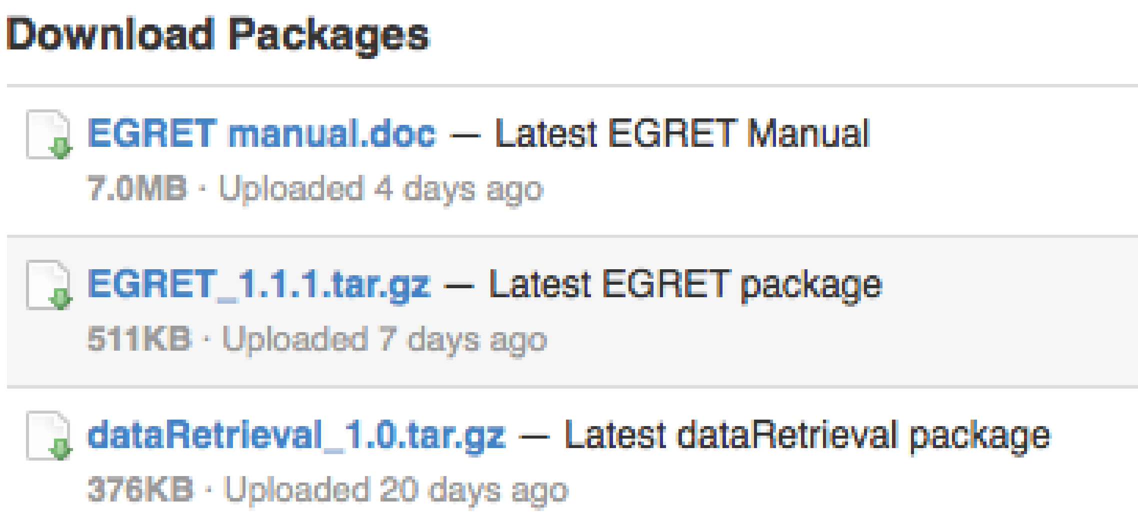

We want the concentration history

# Let’s run an analysis

- Read in data
- Look at the data
- Run the model in cross-validation mode and check quality of the fit
- Compute the “surface” of the expected value of concentration as a function of time, discharge and season
- Use that surface to produce the 4 daily time series:
- Reports those results as graphs, tables, and change measures
- Explore the data and the model

# https://github.com/USGS-CIDA/WRTDS/blob/master/README.md

- At the downloads page you will see something like this: this:




Download the tar.gz files them and then open R

```
> library(dataRetrieval)
> library(EGRET)
> sta<-"01491000"
> param<-"00631"
> StartDate<-"1979-09-01"
> EndDate<-"2011-09-30"
> Sample<-getSampleData(sta,param,StartDate,EndDate)
> summary(Sample)
```

```
      Date              ConcLow          ConcHigh          Uncen             ConcAve           Julian
 Min.   :1979-09-25   Min.   :0.176   Min.   :0.050   Min.   :0.0000   Min.   :0.025   Min.   :47383
 1st Qu.:1988-12-30   1st Qu.:0.880   1st Qu.:0.880   1st Qu.:1.0000   1st Qu.:0.880   1st Qu.:50768
 Median :1994-03-06   Median :1.100   Median :1.100   Median :1.0000   Median :1.100   Median :52659
 Mean   :1995-05-05   Mean   :1.125   Mean   :1.123   Mean   :0.9985   Mean   :1.123   Mean   :53085
 3rd Qu.:2002-04-12   3rd Qu.:1.400   3rd Qu.:1.400   3rd Qu.:1.0000   3rd Qu.:1.400   3rd Qu.:55618
 Max.   :2011-09-29   Max.   :2.430   Max.   :2.430   Max.   :1.0000   Max.   :2.430   Max.   :59075
                      NA's   :1.000
     Month             Day              DecYear         MonthSeq          SinDY              CosDY
 Min.   : 1.00   Min.   :  2.00   Min.   :1980   Min.   :1557   Min.   :-1.0000   Min.   :-0.999963
 1st Qu.: 3.00   1st Qu.: 81.75   1st Qu.:1989   1st Qu.:1669   1st Qu.:-0.6306   1st Qu.:-0.672949
 Median : 6.00   Median :155.50   Median :1994   Median :1731   Median : 0.1961   Median :-0.017166
 Mean   : 6.06   Mean   :168.06   Mean   :1995   Mean   :1745   Mean   : 0.0875   Mean   : 0.004315
 3rd Qu.: 9.00   3rd Qu.:255.25   3rd Qu.:2002   3rd Qu.:1828   3rd Qu.: 0.7841   3rd Qu.: 0.710135
 Max.   :12.00   Max.   :363.00   Max.   :2012   Max.   :1941   Max.   : 0.9999   Max.   : 0.999668
```

```
> length(Sample$Date)
[1] 652
>
```

# Treatment of “less than values”

In the uncensored case, let’s say concentration is 1.0

Then ConcLow = 1.0 and ConcHigh = 1.0

In the usual type of censored case, say concentration is reported as <1.0

Then ConcLow = NA and ConcHigh = 1.0

Because of censoring we use weighted “survival regression” (the function survreg in R) in place of ordinary weighted regression.

It views every data point as an interval:

In the first case the interval is (1.0 to 1.0)
In the second case the interval is (0.0 to 1.0)

# Treatment of "less than values"

**There is one more kind of case. The analyte of interest is the sum of two or more measured analytes.**

**Here is a real example for Total Nitrogen in the Susquehanna River, Maryland, April 27, 1988.**

**The rule is: Compute Total N as Ammonia plus organic N, unfiltered + Nitrate plus nitrite, filtered**

**They were reported as <0.2 and 0.9 mg/L respectively.**

**Then ConcLow = 0.9 and ConcHigh = 1.1**

**Conventional left-censored approach calls this (0, 1.1)**

**WRTDS calls this (0.9 to 1.1)**

```
> Daily<-getDVData(sta,"00060",StartDate,EndDate)
```

```
There are  11718 data points, and  11718 days.
There are  0 zero flow days
If there are any zero discharge days, all days had
0 cfs added to the discharge value.
```

```
> summary(Daily)
      Date                  Q                 Julian          Month             Day            DecYear
 Min.   :1979-09-01   Min.   :9.911e-03   Min.   :47359   Min.   : 1.000   Min.   :  1.0   Min.   :1980
 1st Qu.:1987-09-08   1st Qu.:9.345e-01   1st Qu.:50288   1st Qu.: 4.000   1st Qu.: 92.0   1st Qu.:1988
 Median :1995-09-15   Median :2.407e+00   Median :53218   Median : 7.000   Median :184.0   Median :1996
 Mean   :1995-09-15   Mean   :4.082e+00   Mean   :53218   Mean   : 6.529   Mean   :183.3   Mean   :1996
 3rd Qu.:2003-09-22   3rd Qu.:4.616e+00   3rd Qu.:56147   3rd Qu.:10.000   3rd Qu.:274.0   3rd Qu.:2004
 Max.   :2011-09-30   Max.   :2.464e+02   Max.   :59076   Max.   :12.000   Max.   :366.0   Max.   :2012
    MonthSeq       Qualifier               i                LogQ                Q7                 Q30
 Min.   :1557   Length:11718       Min.   :    1   Min.   :-4.61412   Min.   : 0.01808   Min.   : 0.09606
 1st Qu.:1653   Class :character   1st Qu.: 2930   1st Qu.:-0.06779   1st Qu.: 0.99109   1st Qu.: 1.17609
 Median :1749   Mode  :character   Median : 5860   Median : 0.87835   Median : 2.55661   Median : 2.87133
 Mean   :1749                      Mean   : 5860   Mean   : 0.76602   Mean   : 4.08154   Mean   : 4.08059
 3rd Qu.:1845                      3rd Qu.: 8789   3rd Qu.: 1.52945   3rd Qu.: 4.91095   3rd Qu.: 5.68036
 Max.   :1941                      Max.   :11718   Max.   : 5.50678   Max.   :84.00395   Max.   :25.47478
                                                                      NA's   : 6.00000   NA's   :29.00000
```

```
> length(Daily$Q)
[1] 11718
```

# Reasons for the meta-data:

- Knowing what data you have and where they came from

- Putting labels on figures and tables

- Putting a name on your saved workspaces, using abbreviations

# > INFO<-getMetaData(sta,param)

```
Your site for streamflow data is 01491000 .

Your site name is CHOPTANK RIVER NEAR GREENSBORO, MD ,but
you can modify this to a short name in a style you prefer.

This name will be used to label graphs and tables.

If you want the program to use the name given above, just
do a carriage return, otherwise enter the preferred short
name(no quotes):
```

**Choptank River near Greensboro, MD**

**The latitude and longitude of the site are:  38.99719 ,  -75.78581 (degrees north and west).**

**The drainage area at this site is  113 square miles which is being stored as 292.6687 square kilometers.**

**It is helpful to set up a station abbreviation when doing multi-site studies, enter a unique id (three or four characters should work).**

**It is case sensitive.  Even if you don't feel you need an abbreviation for your site you need to enter something (no quotes):**

**Chop**

**Your water quality data are for parameter number 00631 which has the name:' Nitrate plus nitrite, water, filtered, milligrams per liter as nitrogen '.**

**Typically you will want a shorter name to be used in graphs and tables. The suggested short name is:' Nitrate-nitrite '.**

**If you would like to change the short name, enter it here, otherwise just hit enter (no quotes):**

**Nitrate, filtered, as N**

**The units for the water quality data are: mg/l as N .**

**It is helpful to set up a constiuent abbreviation when doing multi-constituent studies, enter a unique id (three or four characters should work something like tn or tp or NO3).**

**It is case sensitive. Even if you don't feel you need an abbreviation you need to enter something (no quotes):**

# no3

# This command works even if all of your data came from your own spreadsheet

**Nothing in the system will work if you don’t have, at least:**

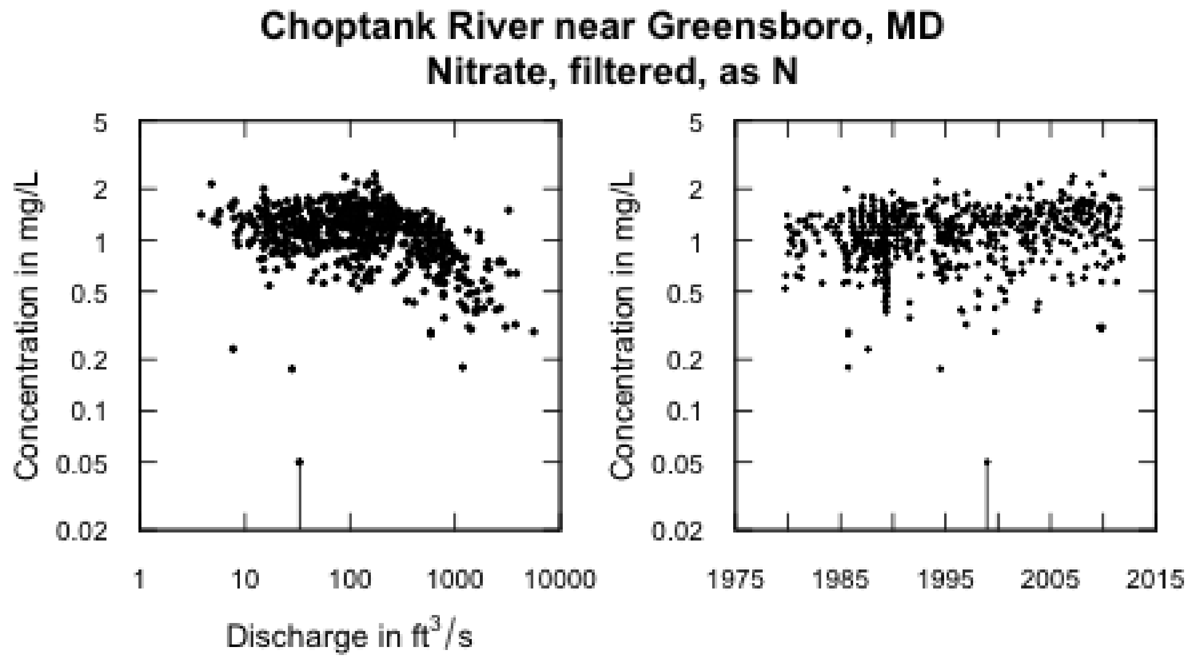
- **A site name**
- **A parameter name**
- **A site abbreviation**
- **A parameter abbreviation**

# Two more commands before we can start our analysis of the data

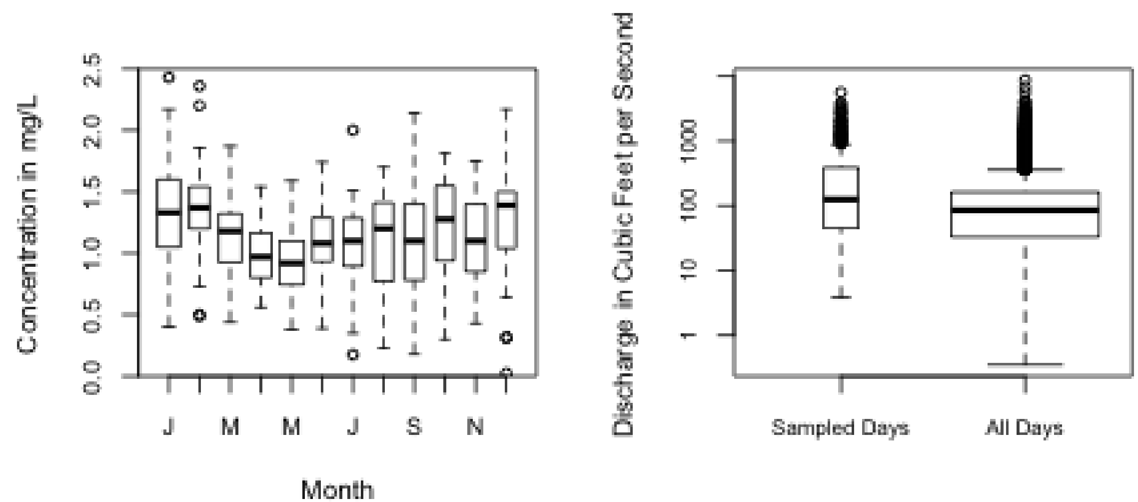
**> Sample<-mergeReport()**

```
Discharge Record is 11718 days long, which is 32 years
First day of the discharge record is 1979-09-01 and last day is 2011-09-30
The water quality record has 652 samples
The first sample is from 1979-09-25 and the last sample is from 2011-09-29
Discharge: Minimum, mean and maximum 0.00991 4.08 246
Concentration: Minimum, mean and maximum 0.05 1.1 2.4
Percentage of the sample values that are censored is 0.15 %
```

# Let’s look at the data before we proceed, the function is:

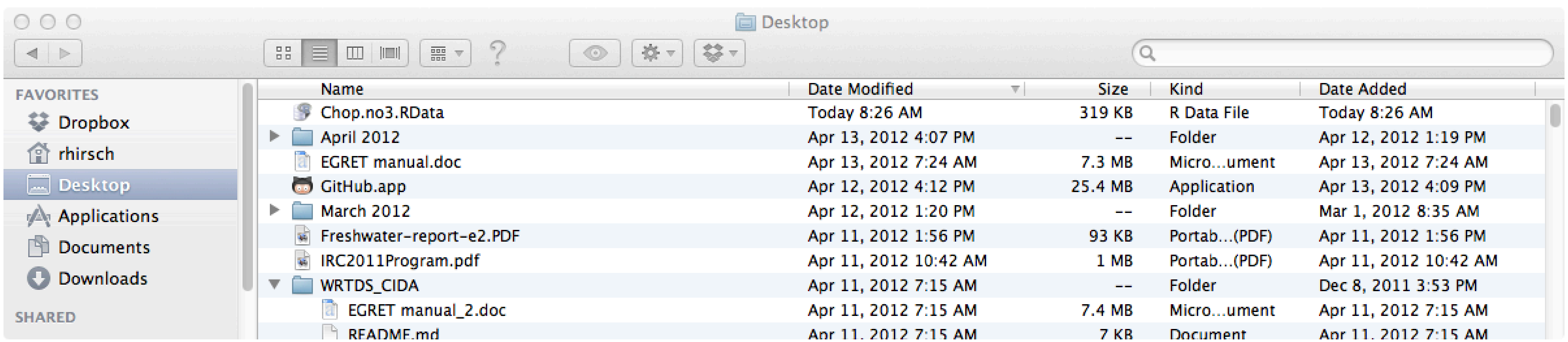



```
> multiPlotDataOverview(qUnit=1)
```



# We've gone to all this effort, let's save our work

> savePath<-"/Users/rhirsch/Desktop/"
> saveResults(savePath)




Chop.no3.RData

**Save it over and over as you proceed and add results**

# We now have 3 data frames

- Sample (652 rows, 14 columns)
- Daily (11,718 rows, 12 columns)
- INFO (1 row, 42 columns)

# > modelEstimation()

- **Jack-knife cross-validation of model**
- **Sets up the grid in ln(Q) and time**
- **Estimates surfaces for log(C), standard error and Concentration**
- **Estimates the daily values from these surfaces (Conc, Flux, FNConc, FNFlux)**
- **Creates a summary of monthly results**

Various options are possible here, for window widths and minimum data requirements

# Setting up the "Period of Analysis"

- Could be water year
- Could be calendar year
- Could be April-May-June
- Could be Dec-Jan-Feb-Mar
- Could be only May

**paStart = calendar month that starts the Period**
**paLong = length of Period, in months**

# Setting up the "Period of Analysis"

| | paStart | paLong |
|---|---|---|
| • Could be water year | 10 | 12 |
| • Could be calendar year | 1 | 12 |
| • Could be April-May-June | 4 | 3 |
| • Could be Dec-Jan-Feb-Mar | 12 | 4 |
| • Could be only May | 5 | 1 |

paStart = calendar month that starts the Period
paLong = length of Period, in months

# Now what is in Daily?

```
> summary(Daily)
      Date                  Q                  Julian          Month             Day            DecYear       MonthSeq
 Min.   :1979-09-01   Min.   :9.911e-03   Min.   :47359   Min.   : 1.000   Min.   :  1.0   Min.   :1980   Min.   :1557
 1st Qu.:1987-09-08   1st Qu.:9.345e-01   1st Qu.:50288   1st Qu.: 4.000   1st Qu.: 92.0   1st Qu.:1988   1st Qu.:1653
 Median :1995-09-15   Median :2.407e+00   Median :53218   Median : 7.000   Median :184.0   Median :1996   Median :1749
 Mean   :1995-09-15   Mean   :4.082e+00   Mean   :53218   Mean   : 6.529   Mean   :183.3   Mean   :1996   Mean   :1749
 3rd Qu.:2003-09-22   3rd Qu.:4.616e+00   3rd Qu.:56147   3rd Qu.:10.000   3rd Qu.:274.0   3rd Qu.:2004   3rd Qu.:1845
 Max.   :2011-09-30   Max.   :2.464e+02   Max.   :59076   Max.   :12.000   Max.   :366.0   Max.   :2012   Max.   :1941

  Qualifier               i              LogQ                Q7                 Q30                Leap
 Length:11718       Min.   :    1   Min.   :-4.61412   Min.   : 0.01808   Min.   : 0.09606   Min.   :  1.0
 Class :character   1st Qu.: 2930   1st Qu.:-0.06779   1st Qu.: 0.99109   1st Qu.: 1.17609   1st Qu.: 92.0
 Mode  :character   Median : 5860   Median : 0.87835   Median : 2.55661   Median : 2.87133   Median :184.0
                    Mean   : 5860   Mean   : 0.76602   Mean   : 4.08154   Mean   : 4.08059   Mean   :183.3
                    3rd Qu.: 8789   3rd Qu.: 1.52945   3rd Qu.: 4.91095   3rd Qu.: 5.68036   3rd Qu.:274.0
                    Max.   :11718   Max.   : 5.50678   Max.   :84.00395   Max.   :25.47478   Max.   :365.0
                                                       NA's   : 6.00000   NA's   :29.00000
      yHat                SE              ConcDay           FluxDay              FNConc             FNFlux
 Min.   :-1.534999   Min.   :0.1347   Min.   :0.230   Min.   :   1.633   Min.   :0.8208   Min.   : 77.3
 1st Qu.:-0.006091   1st Qu.:0.2186   1st Qu.:1.033   1st Qu.:  98.053   1st Qu.:1.0524   1st Qu.:168.3
 Median : 0.130494   Median :0.2504   Median :1.195   Median : 248.578   Median :1.2042   Median :317.3
 Mean   : 0.117362   Mean   :0.2678   Mean   :1.194   Mean   : 365.030   Mean   :1.1975   Mean   :361.5
 3rd Qu.: 0.258278   3rd Qu.:0.3002   3rd Qu.:1.353   3rd Qu.: 482.075   3rd Qu.:1.3286   3rd Qu.:536.0
 Max.   : 0.659426   Max.   :0.6129   Max.   :1.962   Max.   :5705.826   Max.   :1.7017   Max.   :928.3
```

# Compute AnnualResults

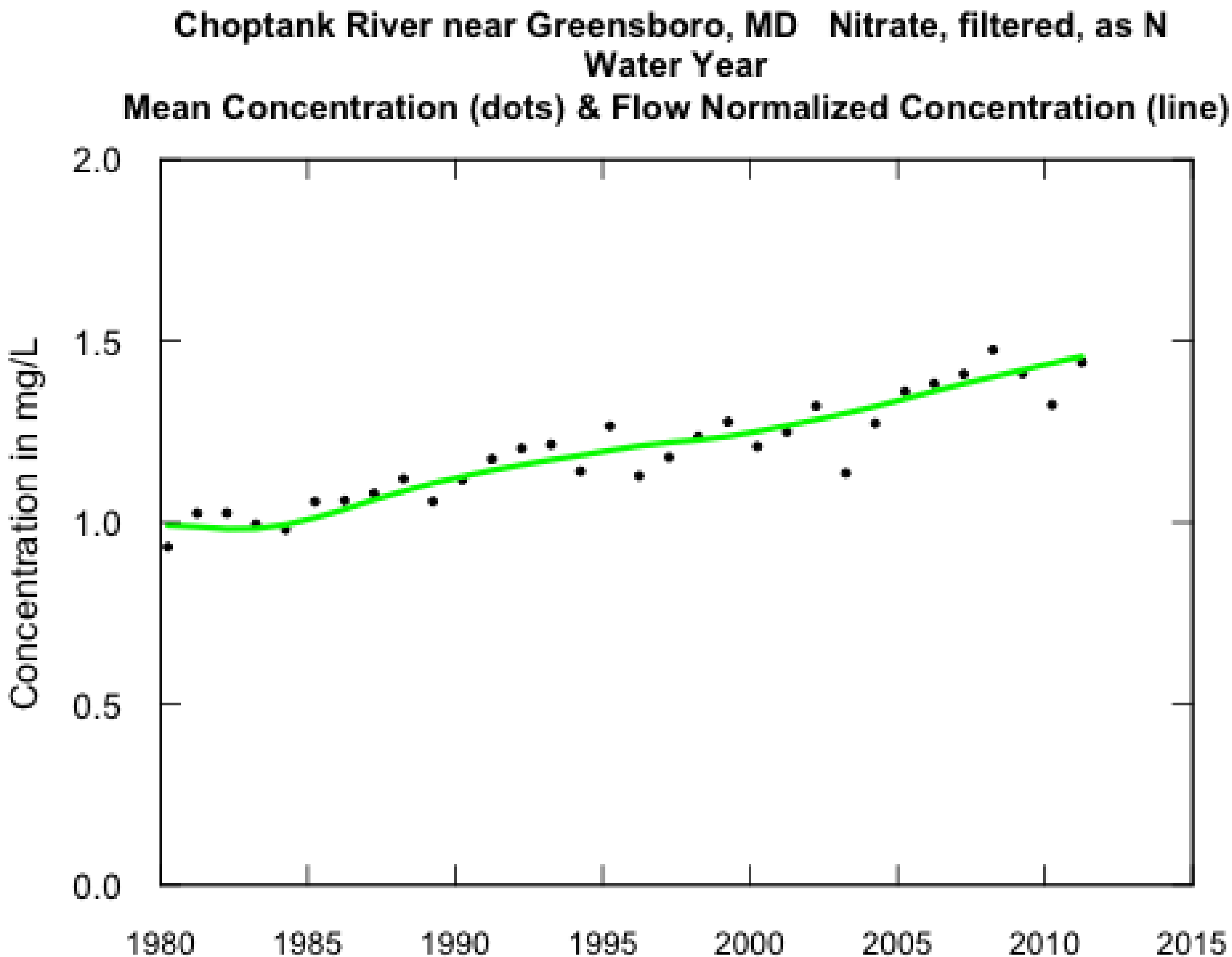
```
> AnnualResults<-setupYears(paLong=12,paStart=1)

> AnnualResults<-setupYears()
```

# We now have 5 data frames

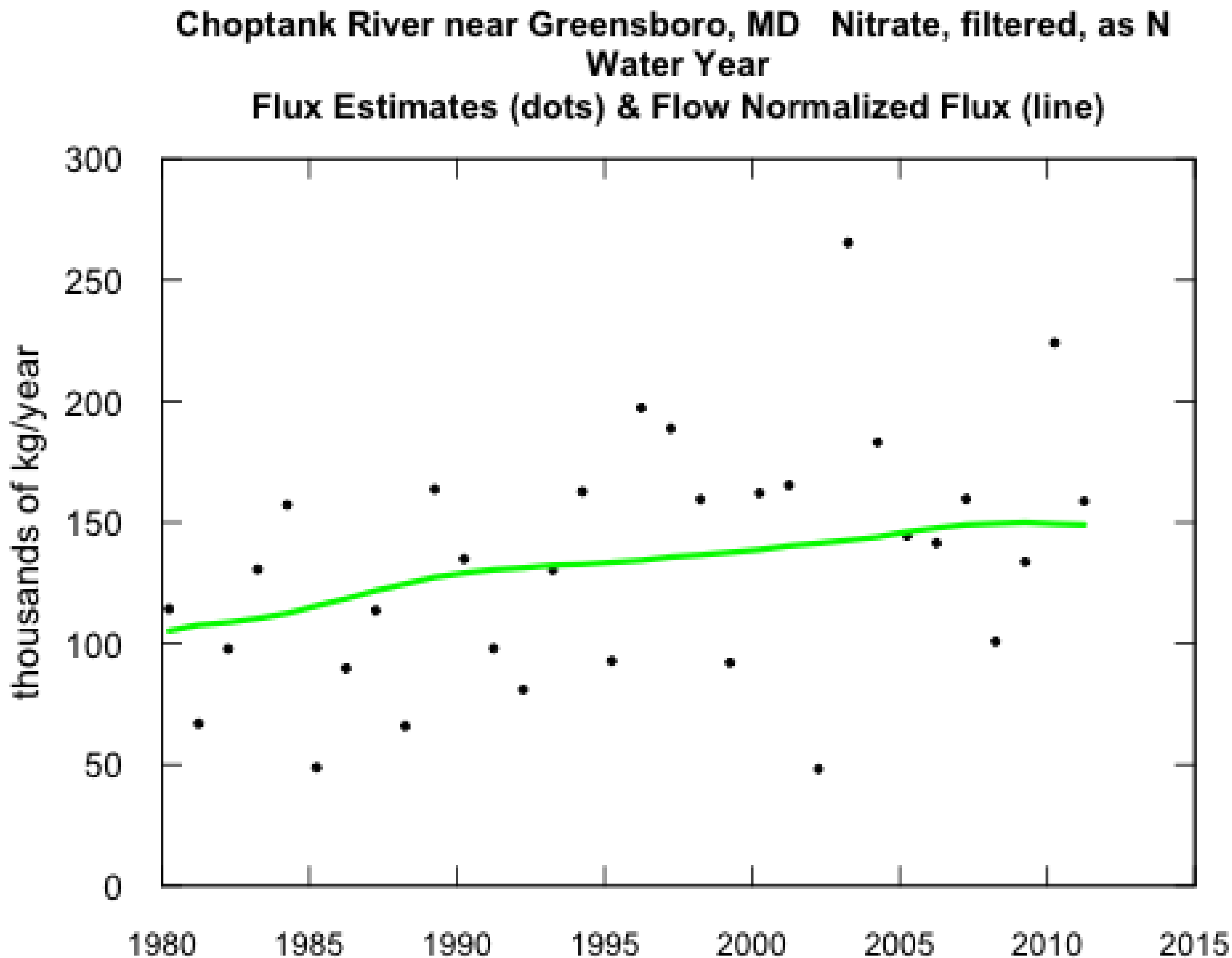
- Sample (652 rows, 17 columns)
- Daily (11,718 rows, 19 columns)
- INFO (1 row, 53 columns)
- MonthlyResults (385 rows, 7 colmuns)
- AnnualResults (32 rows, 8 columns)

**And a matrix *surfaces* 14*529*3**

# > plotConcHist(1980,2012)



# > plotFluxHist(1980,2012,fluxUnit=8)



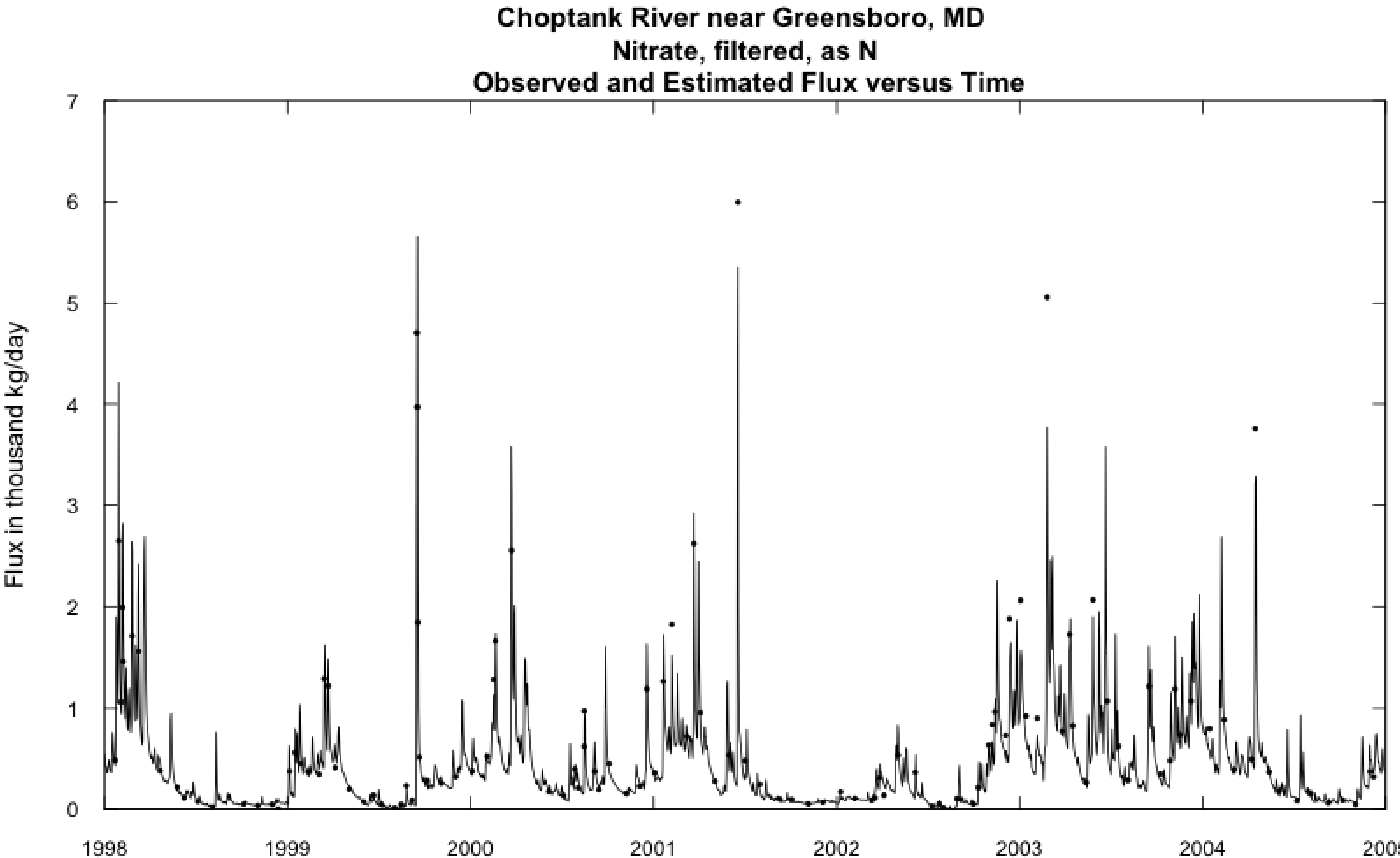
```
> tableResults(qUnit=1,fluxUnit=5)

   Choptank River near Greensboro, MD
   Nitrate, filtered, as N
   Water Year

   Year   Discharge    Conc    FN_Conc     Flux    FN_Flux
             cfs            mg/L              tons/yr

   1980      150.2    0.932      0.992    126.0        116
   1981       78.3    1.025      0.988     73.7        119
   1982      107.6    1.025      0.982    107.9        120
   1983      176.1    0.995      0.983    143.9        122
   1984      201.9    0.981      0.994    173.3        124
   1985       53.6    1.056      1.012     53.8        127
   1986       92.8    1.060      1.036     99.0        131
   1987      119.1    1.079      1.062    125.2        134
   1988       66.0    1.120      1.086     72.6        137
   1989      198.2    1.057      1.108    180.4        140
   1990      141.5    1.118      1.126    148.7        142
   1991       97.0    1.174      1.144    108.1        144
   1992       77.2    1.204      1.158     89.2        145
    .
    .
    .
    .
   2007      151.2    1.408      1.382    176.0        164
   2008       90.5    1.476      1.401    111.1        165
   2009      130.0    1.410      1.420    147.4        165
   2010      254.0    1.324      1.438    247.1        165
   2011      185.2    1.441      1.458    175.0        164
```

```
> tableChange(fluxUnit=5,yearPoints=c(1980,1995,2011))
```

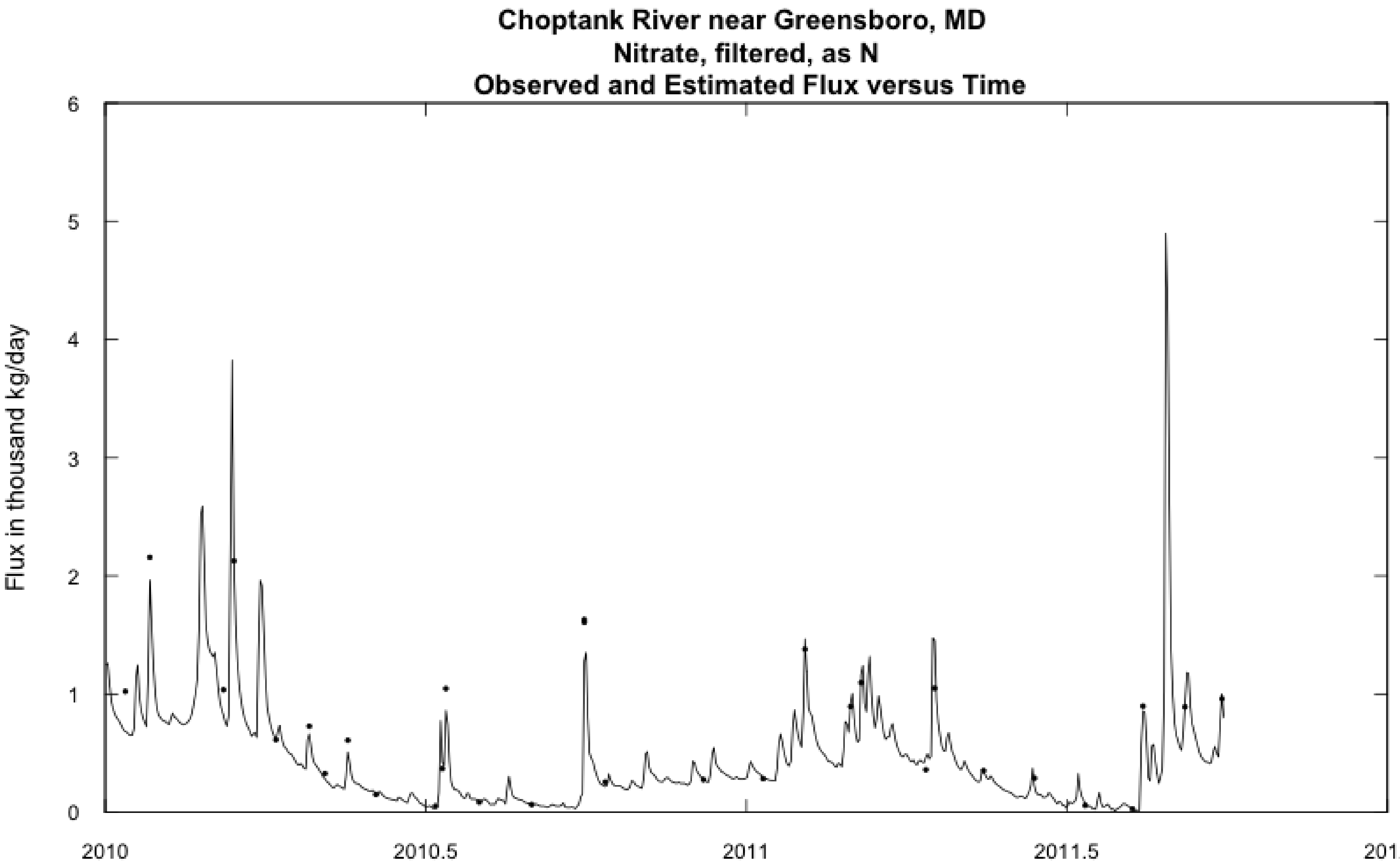
```
> tableChange(fluxUnit=5,yearPoints=c(1980,1995,2011))

   Choptank River near Greensboro, MD
   Nitrate, filtered, as N
   Water Year

           Concentration trends
   time span          change    slope    change     slope
                        mg/L  mg/L/yr         %      %/yr

 1980  to  1995         0.21    0.014        21       1.4
 1980  to  2011         0.47    0.015        47       1.5
 1995  to  2011         0.26    0.016        22       1.4


                 Flux Trends
   time span              change         slope     change         slope
                         tons/yr    tons/yr/yr          %          %/yr
 1980  to  1995               31           2.1         27           1.8
 1980  to  2011               48           1.6         42           1.3
 1995  to  2011               17           1.1         12          0.73
```

# Looking at the WRTDS model - Diagnostics

## > plotFluxTimeDaily(1998,2005)



# > plotFluxTimeDaily(2010,2011.75)



# More Diagnostics – Looking at quality of fit and flux bias

**EGRET computes a flux bias statistic which is computed from the Sample data frame, using the Jack-Knife estimates of concentration. The statistic is:**

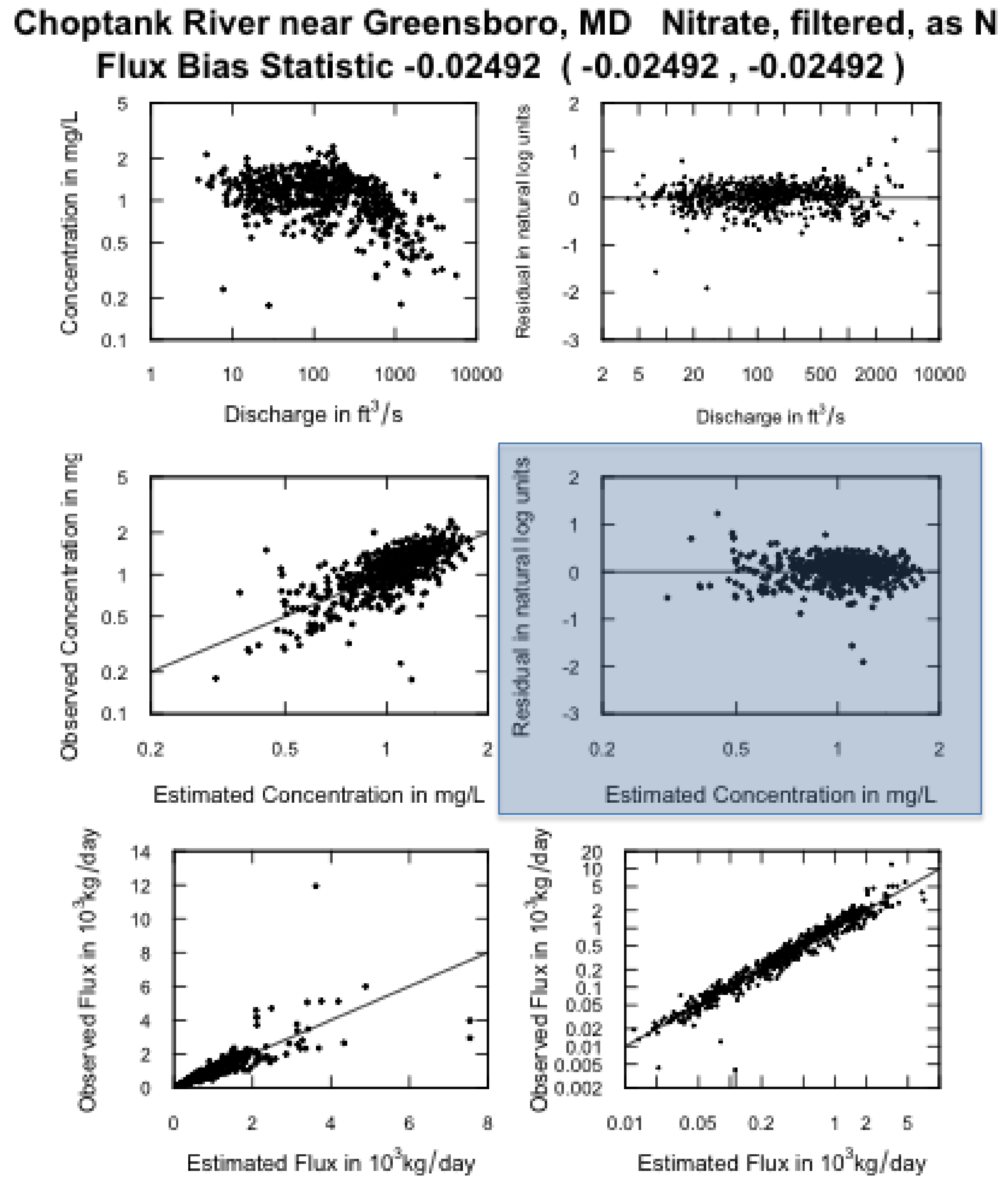
$$\frac{\text{Mean(Sampled day flux estimates)} - \text{Mean(Sampled day flux values)}}{\text{Mean(Sampled day flux values)}}$$

For example a value of 0.25 would mean that the estimates are, on average, 25% too high.

**Because of censoring we don't know the Sampled day flux values exactly, but we can put bounds on them.**

**It is rare that the censoring matters to this statistic.**

\> fluxBiasMulti(qUnit=1,fluxUnit=4)



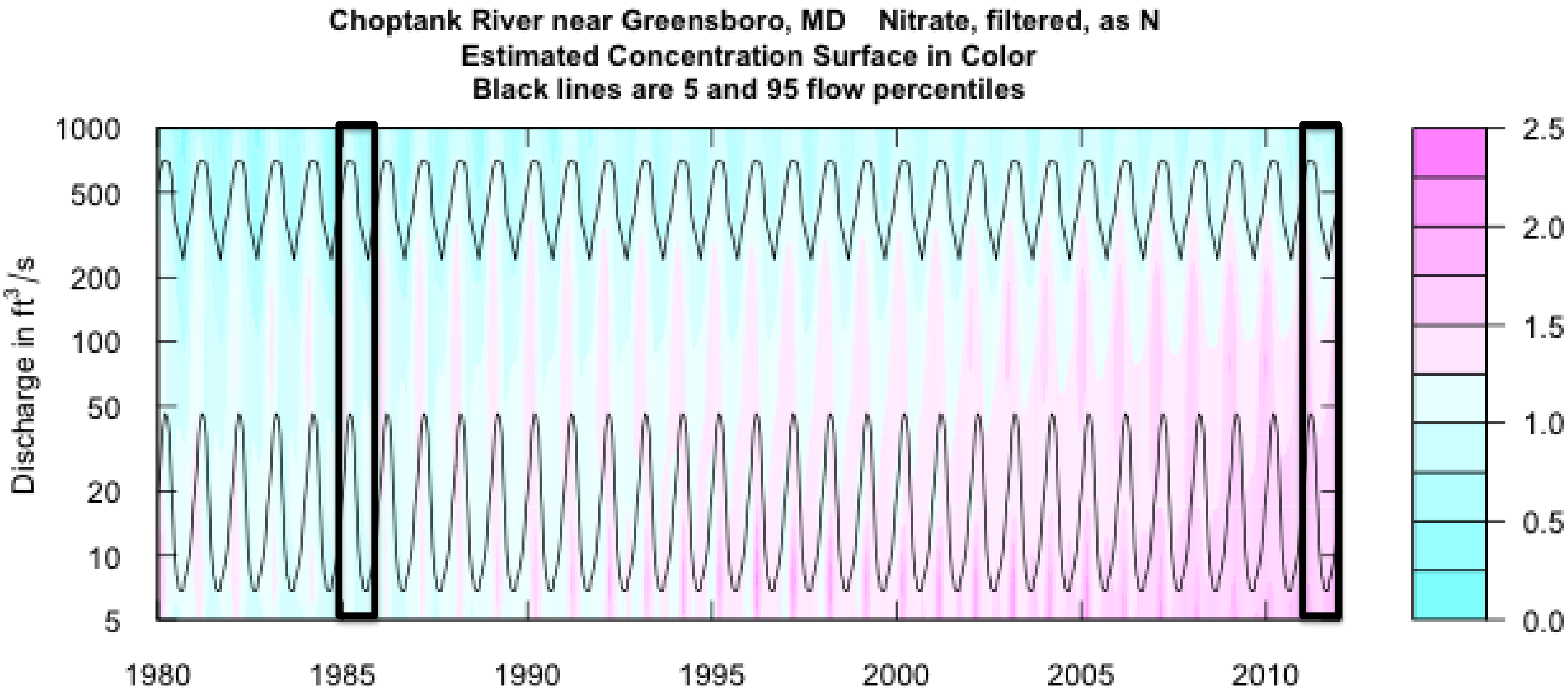

**For this data set flux bias statistic looks fine.**

**Average estimates are about 2.5% below average observed.**

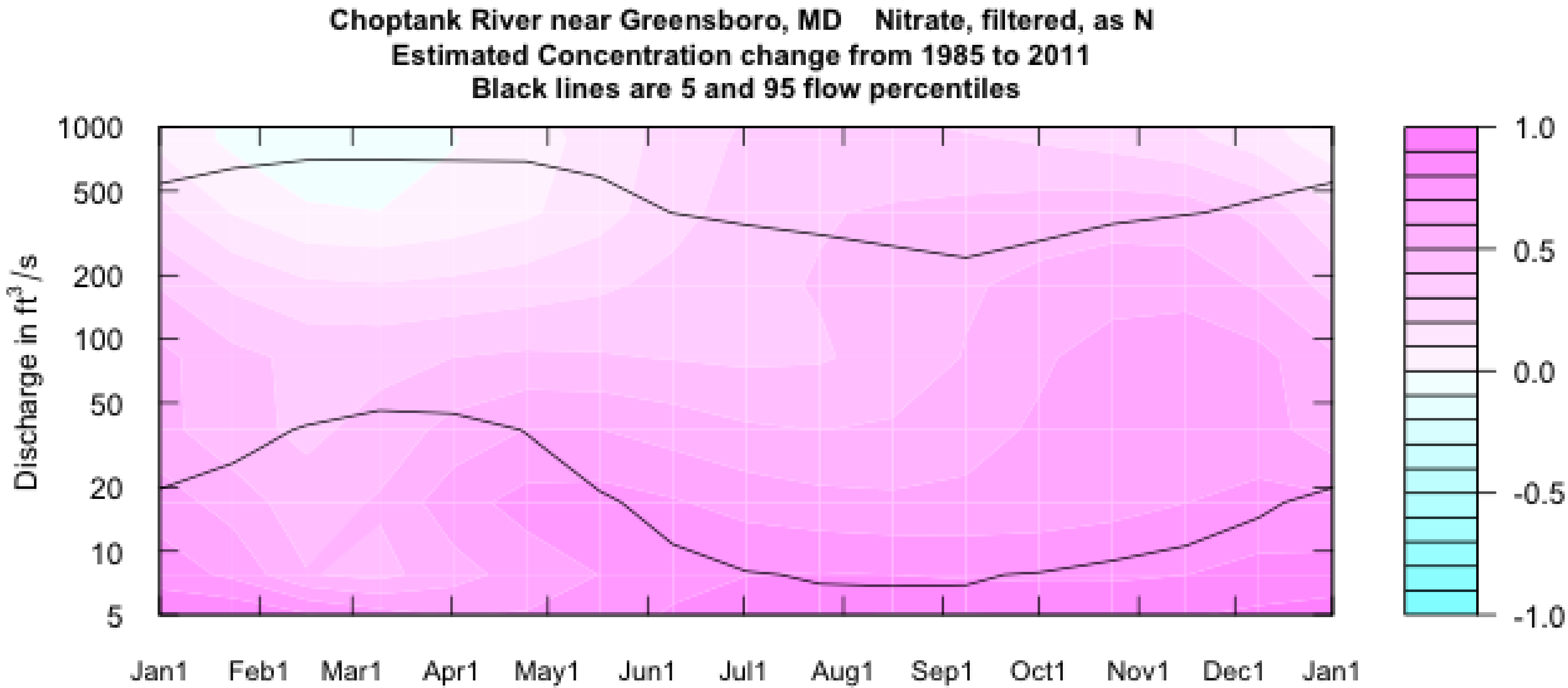
**This is very acceptable.**

**So, what does the model "look like"?**
**How has the system's behavior changed over time?**

```
> plotContours(1980,2012,5,1000,qUnit=1,contourLevels=seq(0,2.5,0.25))
```



# > plotDiffContours(1985,2011,5,1000,qUnit=1,maxDiff=1.0)

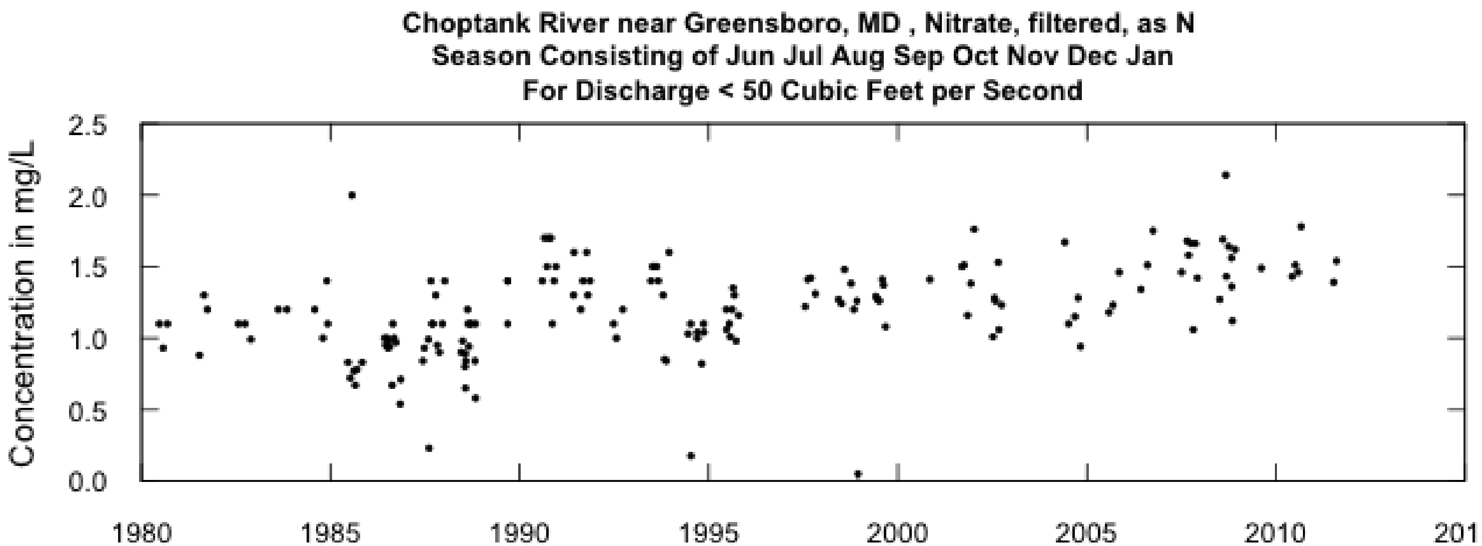



**Increases at almost all seasons and flows, greatest increases are at lower flows in the months June through January**

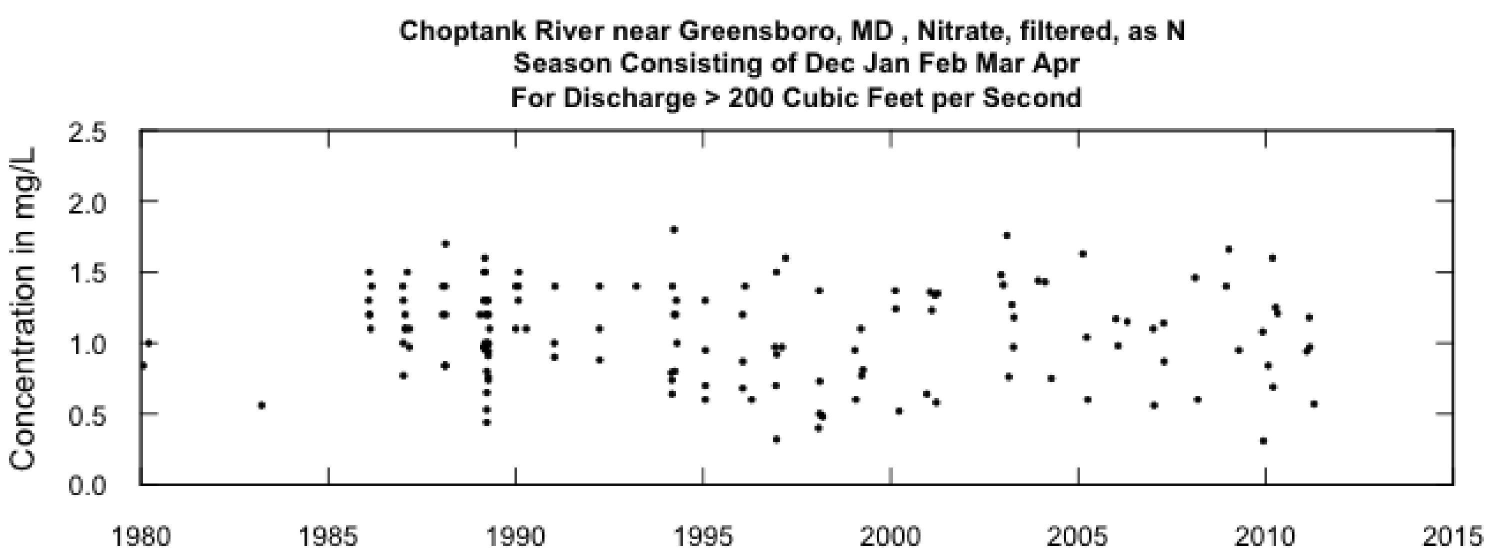
**Very small improvement at very high flows in January through April**

**Now, can we look at *the data* without all the "statistical tricks?"**

```
> plotConcTime(qUnit=1,qUpper=50,paLong=8,paStart=6,concMax=2.5)
```



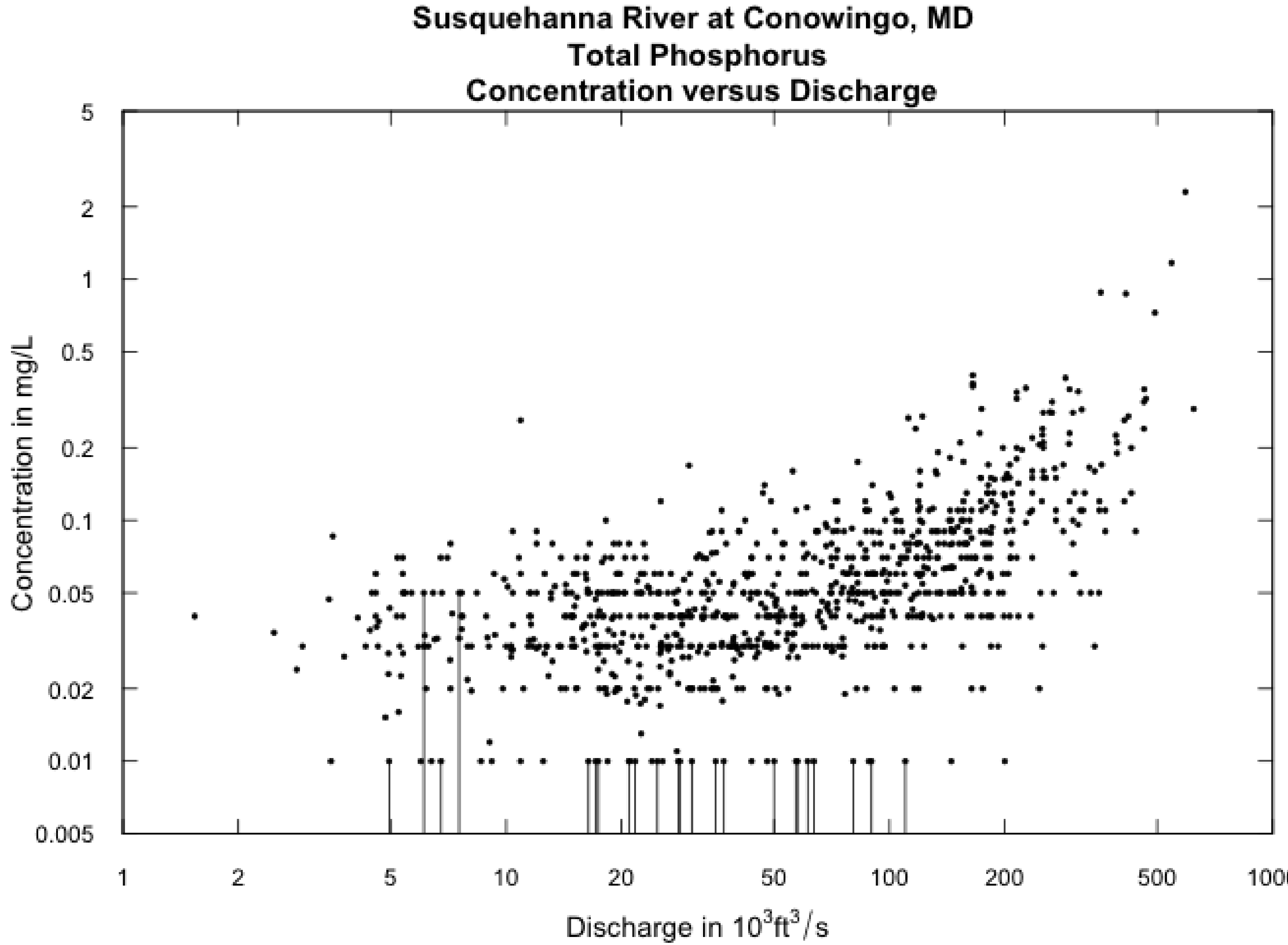

```
> plotConcTime(qUnit=1,qLower=200,paLong=5,paStart=12,concMax=2.5)
```



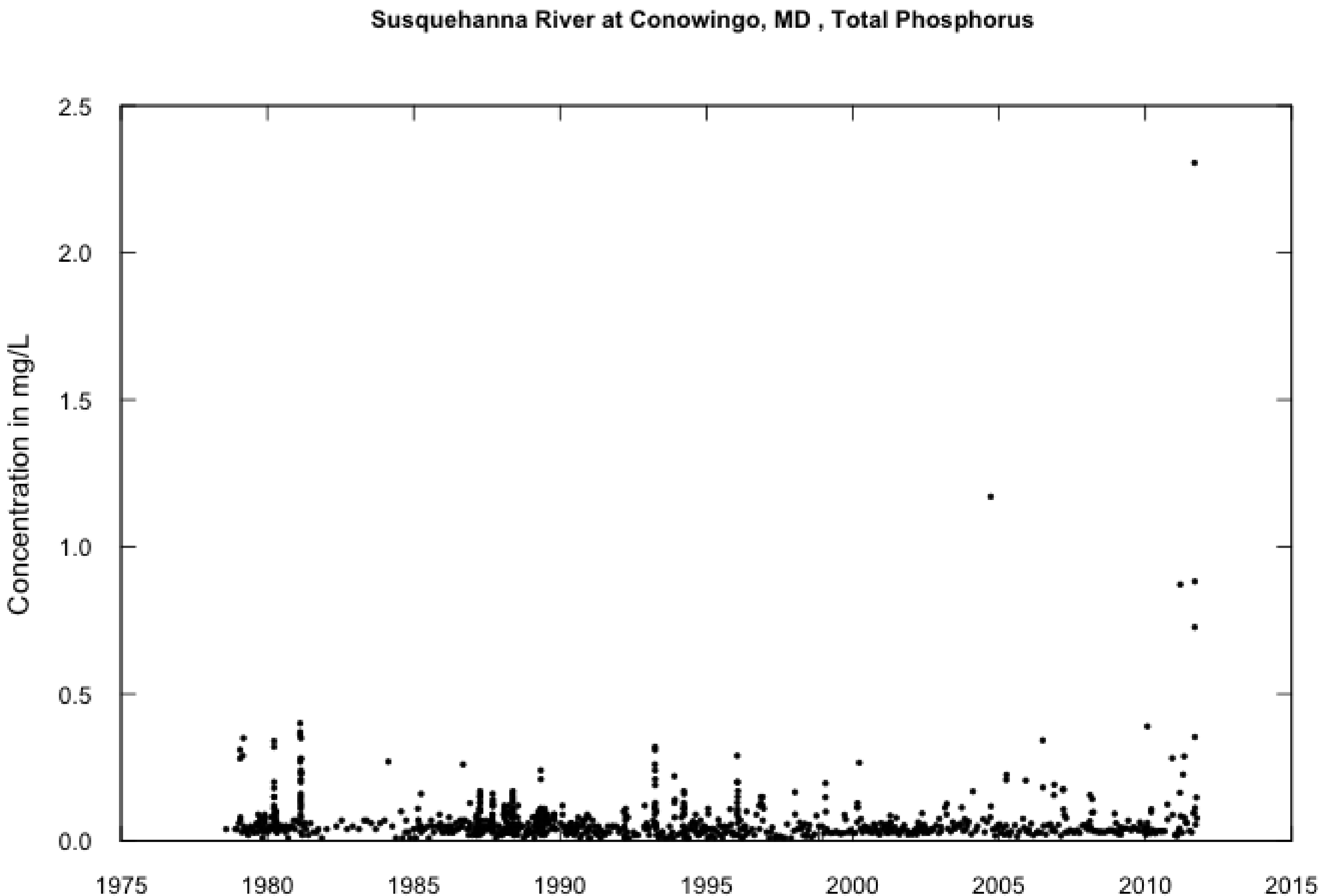
# Look at a different data set: Total Phosphorous Susquehanna River at Conowingo, MD

- Single largest river input to Chesapeake Bay
- Sampling at Conowingo Dam, reservoir capacity getting nearly full of sediment

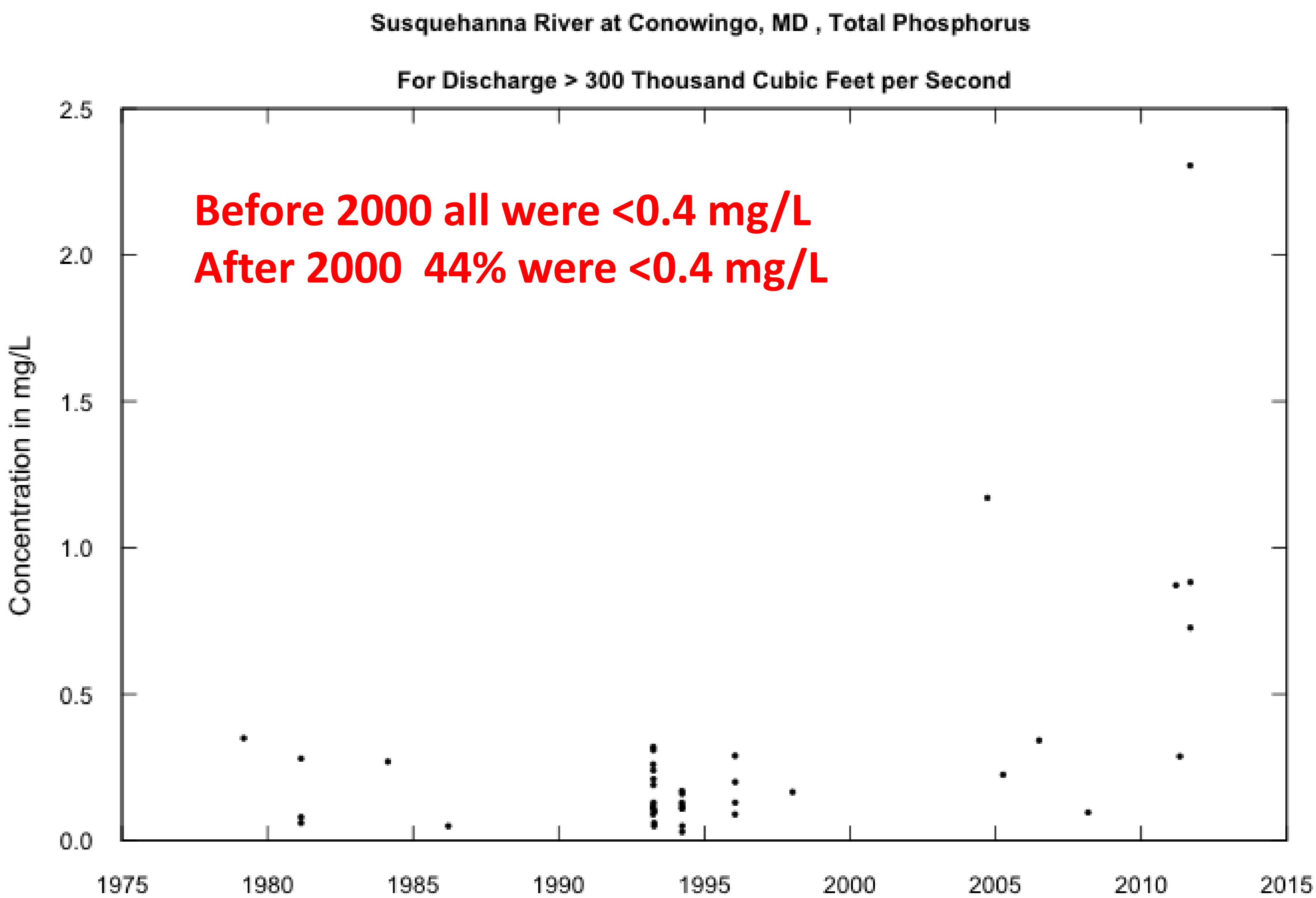
> plotLogConcQ(concMin=0.005,qUnit=3)



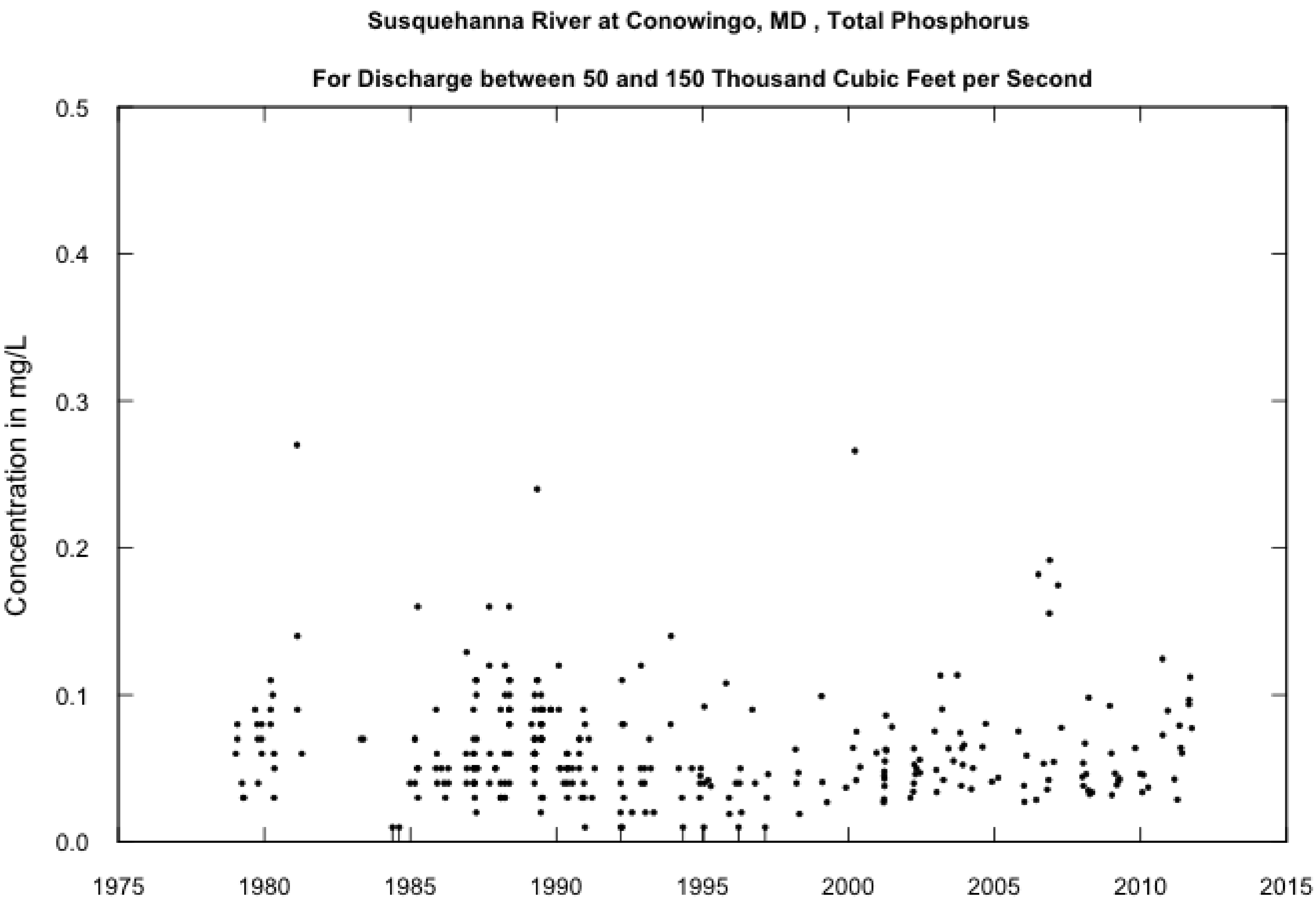
> plotConcTime()



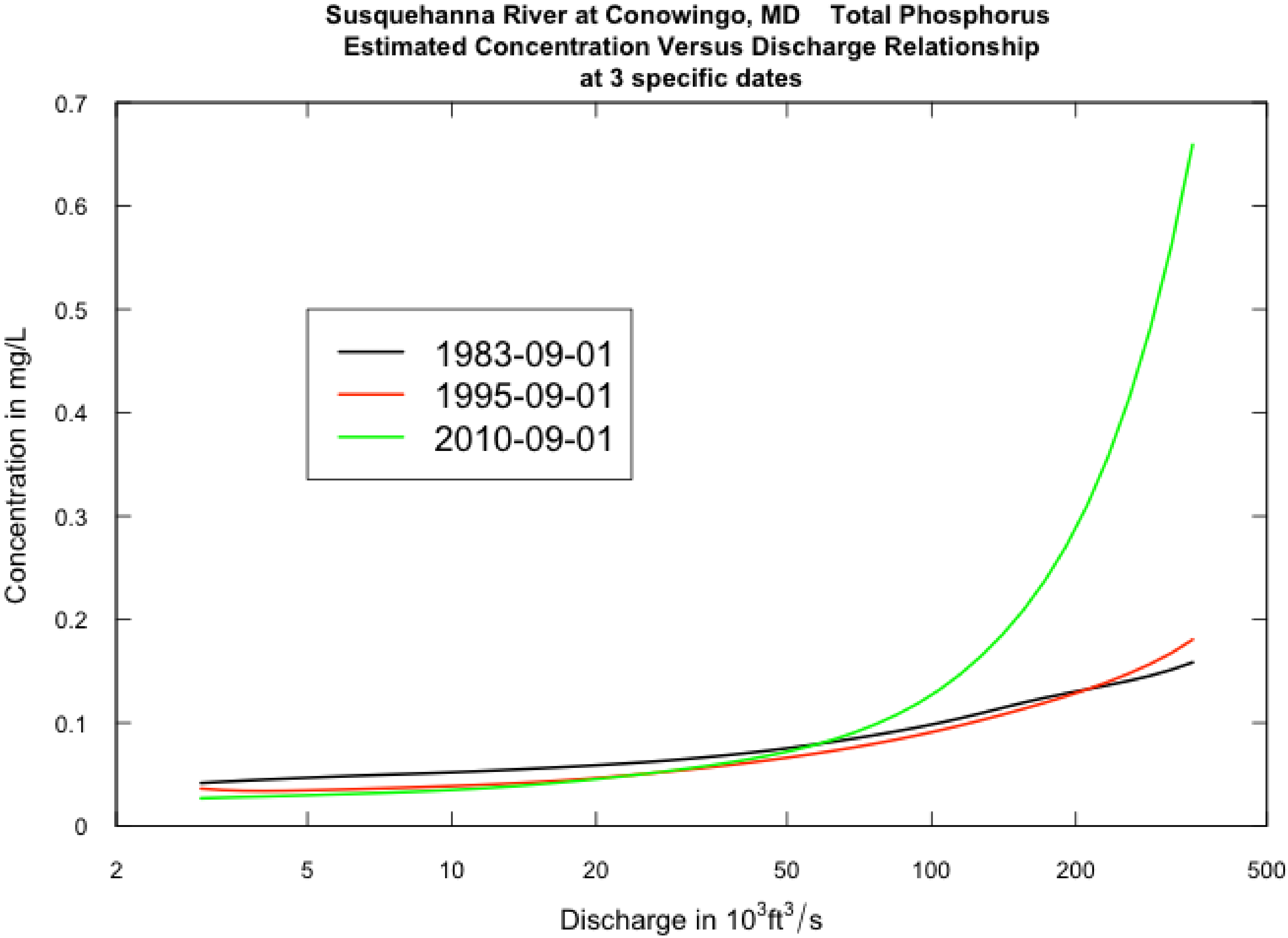
> plotConcTime(concMax=2.5,qLower=300,qUnit=3)



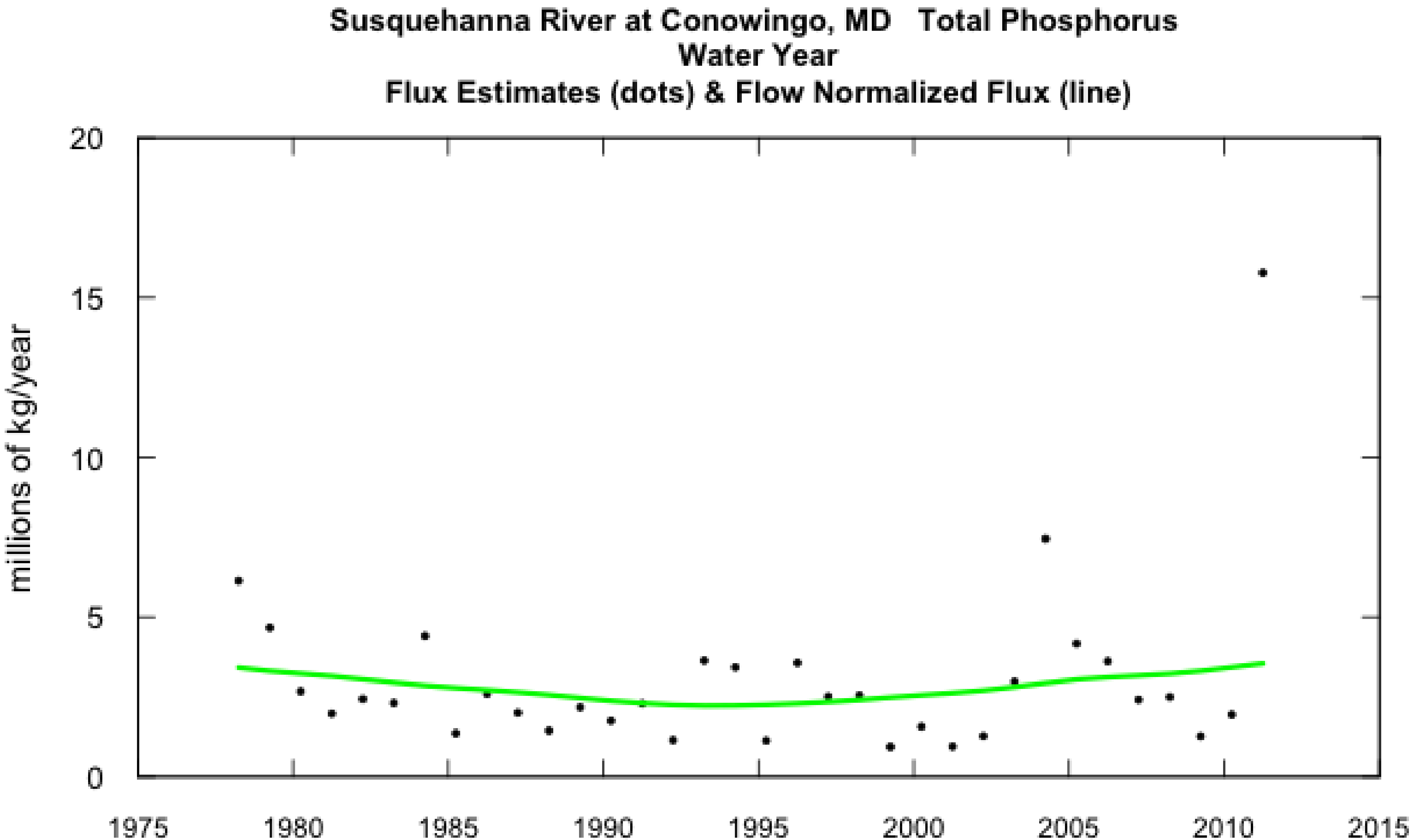
> plotConcTime(concMax=0.5,qLower=50,qUpper=150,qUnit=3)



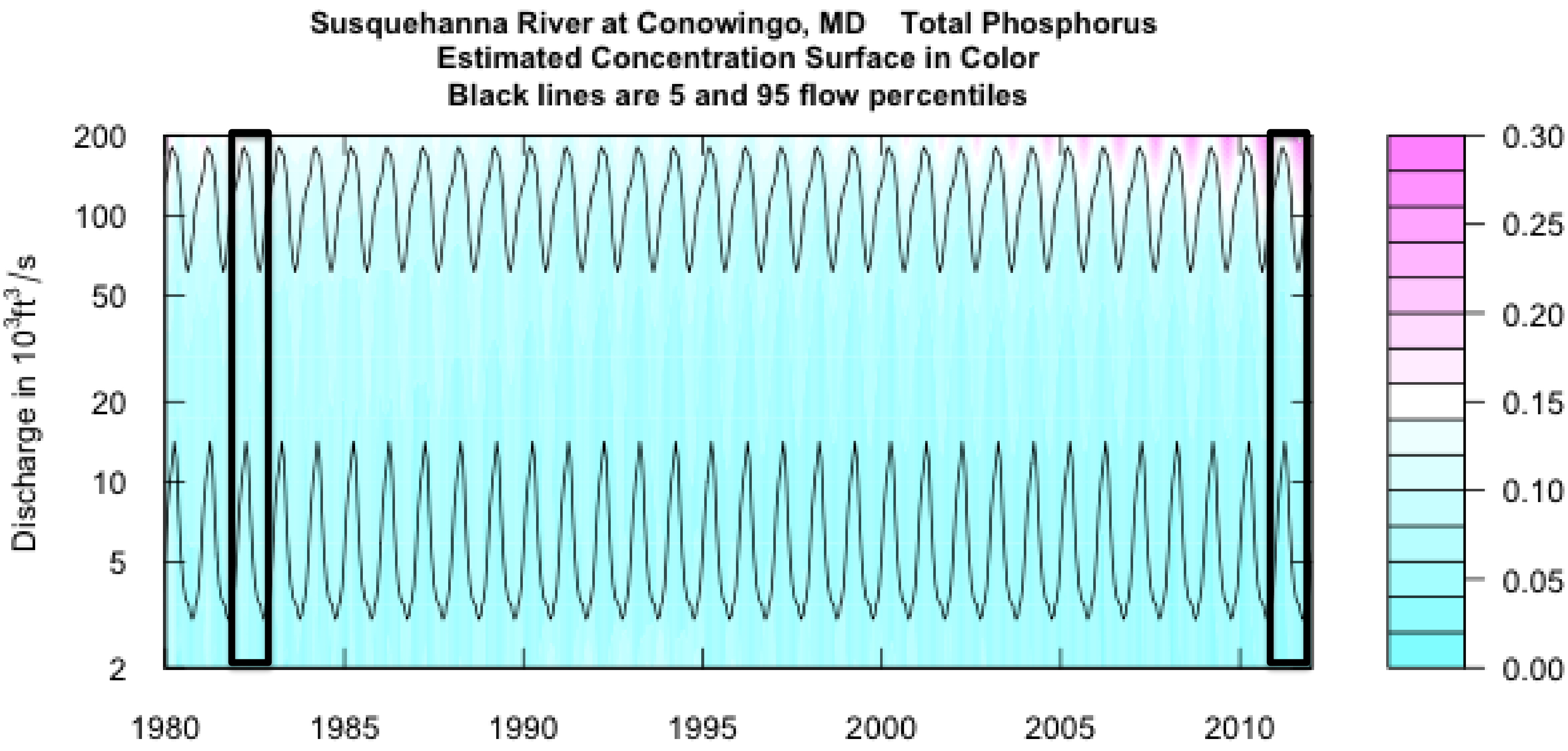
```
> plotConcQSmooth("1983-09-01","1995-09-01","2010-09-01",qLow=3,qHigh=350,
qUnit=3,legendLeft=5,legendTop=0.5)
```



**> plotFluxHist(1975,2012)**

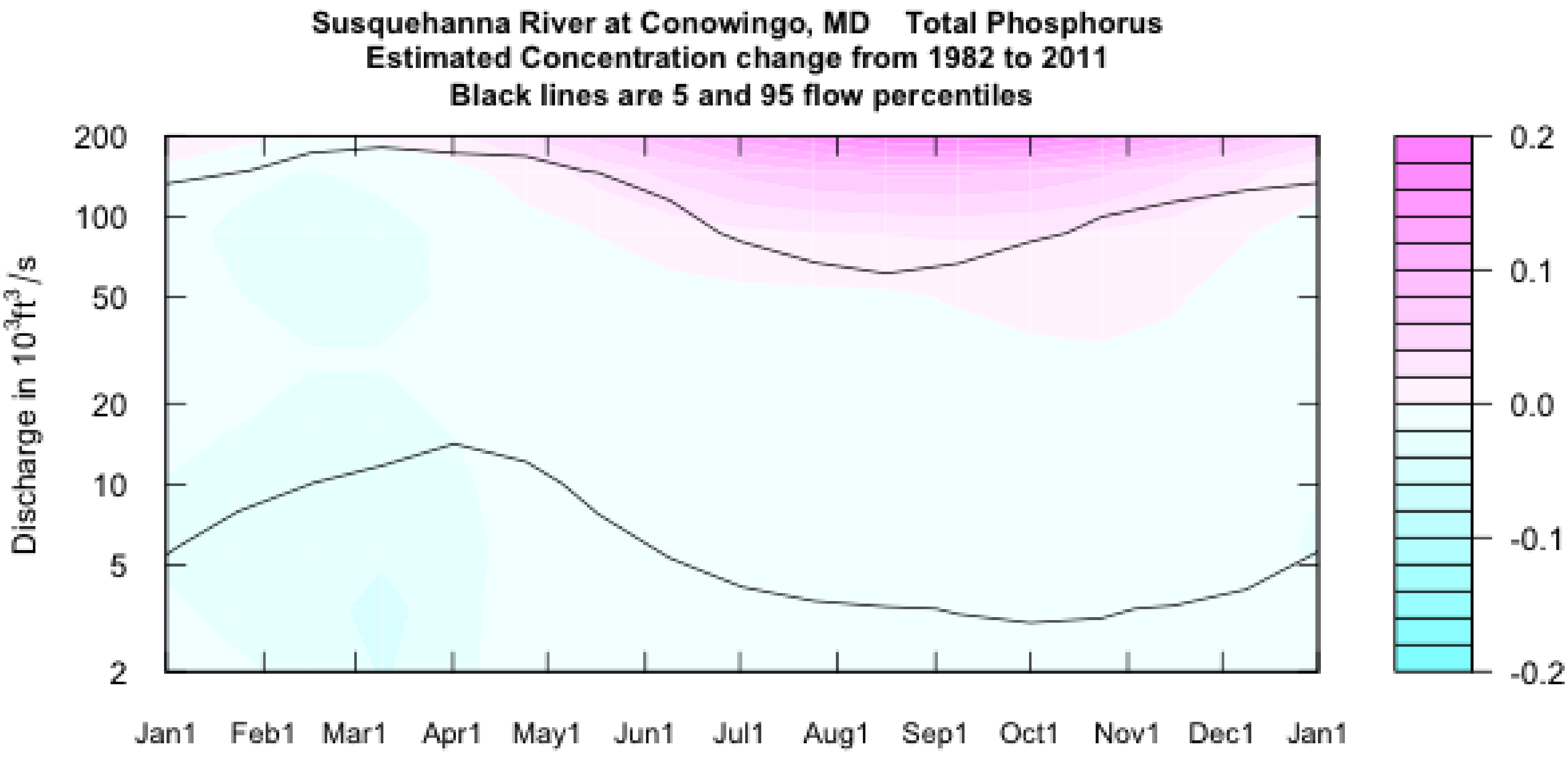


**> plotContours(1980,2012,2,200,qUnit=3,contourLevels=seq(0,0.3,0.02))**

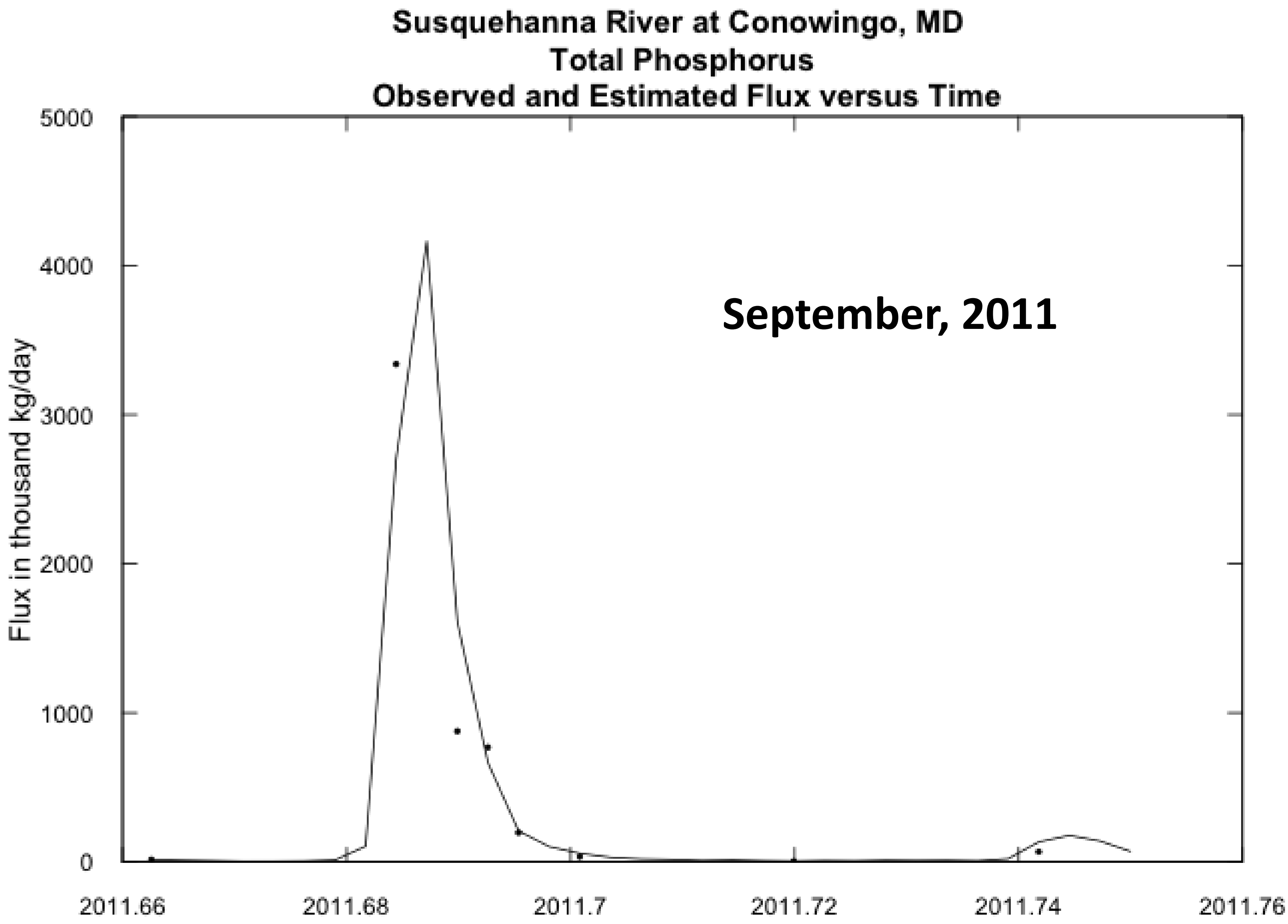


# > plotDiffContours(1982,2011,2,200,qUnit=3,maxDiff=0.2)

- **Over most flows and most seasons there has been little change between 1982 and 2011**
- **But, for discharge above about 100,000 cfs there are substantial increases, especially in the tropical storm season.**
- **Slight improvement indicated in winter at most flows.**



**> plotFluxTimeDaily(2011.66,2011.75)**



**Because we have the Daily data frame, with an estimated flux for every day of the record, we can look at it to calculate things like:**

- **Tropical Storm Lee flux, about 10,600 tons**
- **Water Year 2011 flux, about 17,400 tons**
- **Average flux over past decade about 4,800 tons/year**
- **Average flux over entire 34 year record about 3,300 tons/year**

**Tropical Storm Lee carried**

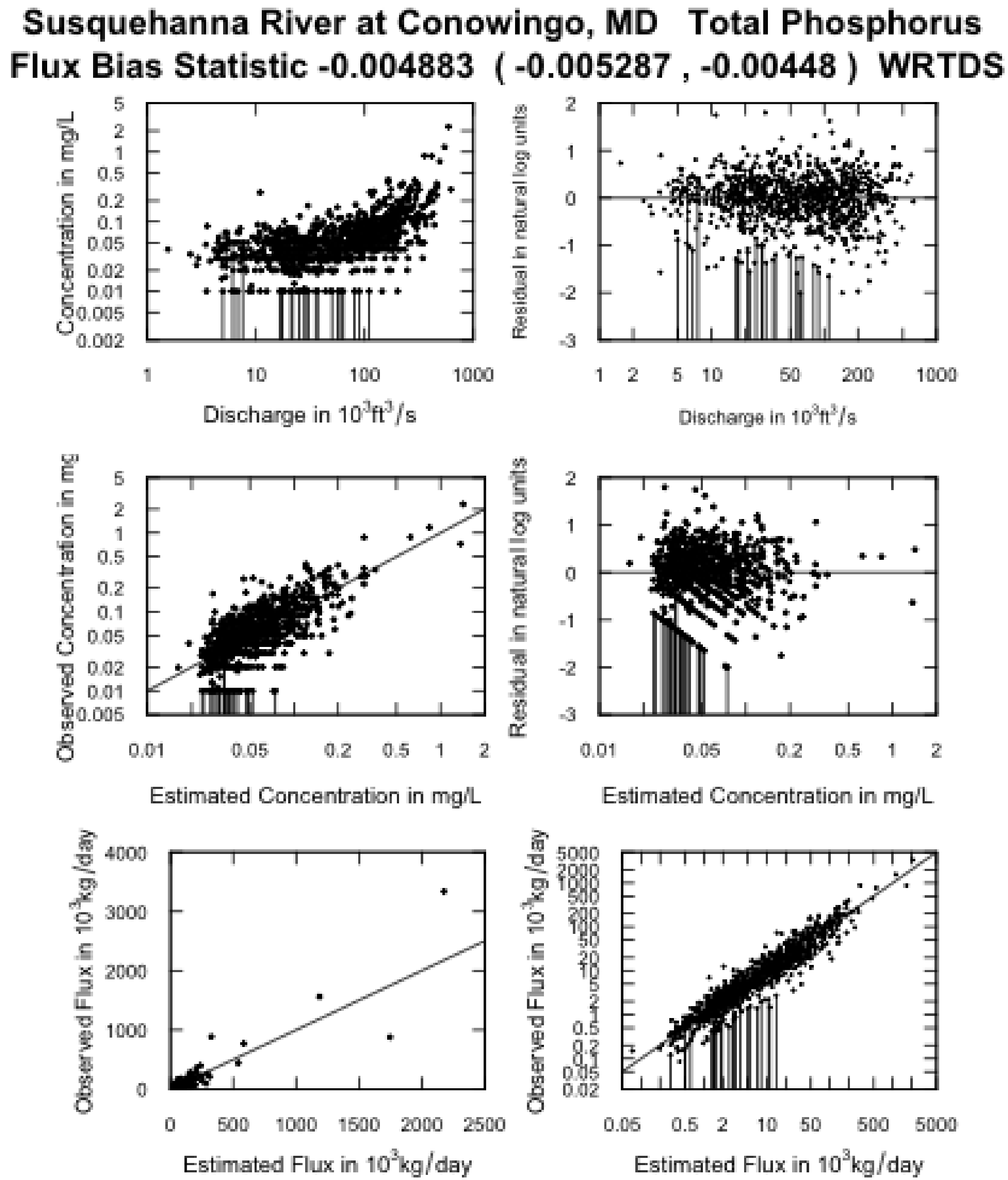
- **12% of 2011 streamflow and 61% of 2011 Total Phosphorus**
- **1.8% of the past decade's streamflow and 22% of the Total Phosphorus**
- **0.6% of the streamflow of the 34 years and 9% of the Total Phosphorus**

```
> tableChange(fluxUnit=8,yearPoints=c(1980,1995,2011))

   Susquehanna River at Conowingo, MD
   Total Phosphorus
   Water Year

           Concentration trends
   time span          change     slope      change      slope
                        mg/L   mg/L/yr          %        %/yr

 1980  to  1995      -0.014  -0.00095         -24        -1.6
 1980  to  2011     -0.0098  -0.00031         -17       -0.54
 1995  to  2011      0.0046   0.00028          10        0.64


                 Flux Trends
   time span             change          slope          change          slope
                     10^3 kg/yr    10^3 kg/yr /yr          %           %/yr
 1980  to  1995            -977            -65           -30             -2
 1980  to  2011             314             10           9.7           0.31
 1995  to  2011            1291             81            57            3.6
```

```
> AnnualResults<-setupYears(paLong=3,paStart=4)
> tableChange(fluxUnit=8,yearPoints=c(1980,1995,2011))
```

```
Susquehanna River at Conowingo, MD
Total Phosphorus
Season Consisting of Apr May Jun

       Concentration trends
time span           change      slope      change      slope
                      mg/L    mg/L/yr         %         %/yr

1980  to  1995      -0.016     -0.001        -27        -1.8
1980  to  2011     -0.0045   -0.00015       -7.9       -0.26
1995  to  2011       0.011    0.00069         26         1.7


                 Flux Trends
time span                change          slope          change         slope
                      10^3 kg/yr    10^3 kg/yr /yr         %            %/yr
1980  to  1995              -972            -65          -27            -1.8
1980  to  2011               529             17           15            0.47
1995  to  2011              1501             94           57             3.6
```

```
> fluxBiasMulti(qUnit=3, fluxUnit=4, moreTitle="WRTDS")
```




**A short aside about the "flux bias" problem**

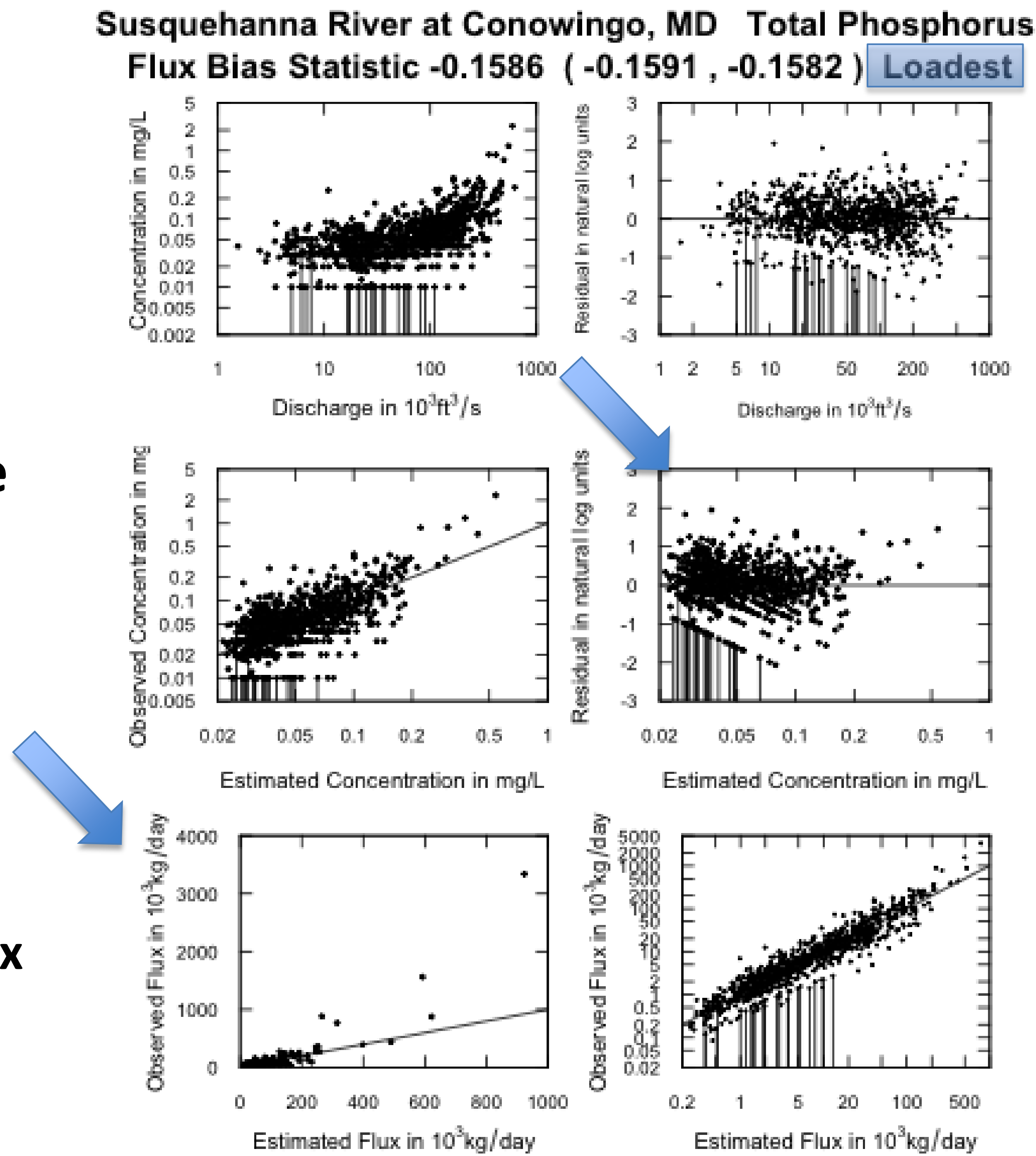
**Models such as WRTDS or LOADEST are fit in log space but used in "real" space.**

**None of them should be used without checking that the model behavior is reasonably close to actual behavior.**

# Average flux bias for Loadest on sampled days is about -16%

## Notice the U shape of residuals versus predicted

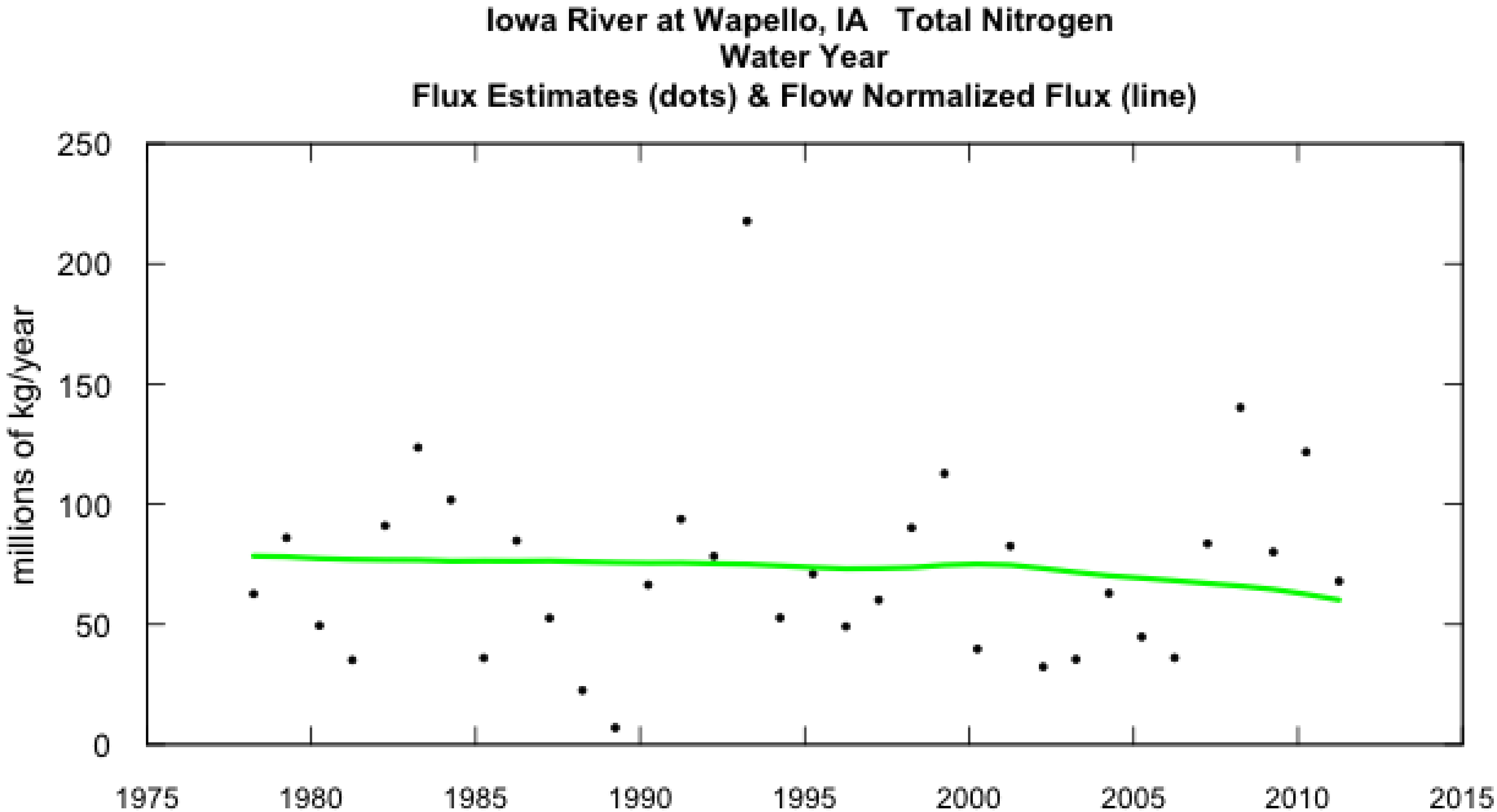
## Notice the severe under-prediction of flux on the highest flux days



# Let’s move to the corn belt:

# Iowa River at Wapello, IA

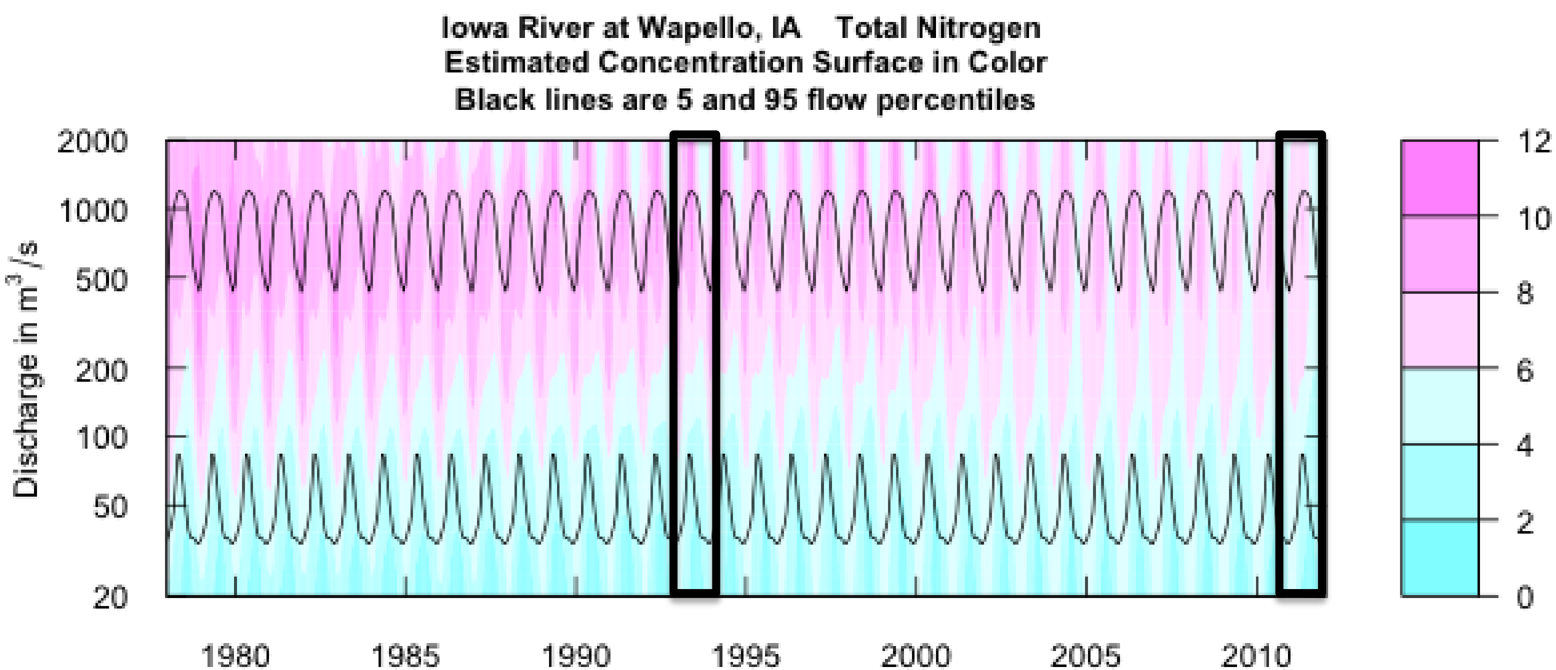
# Total Nitrogen



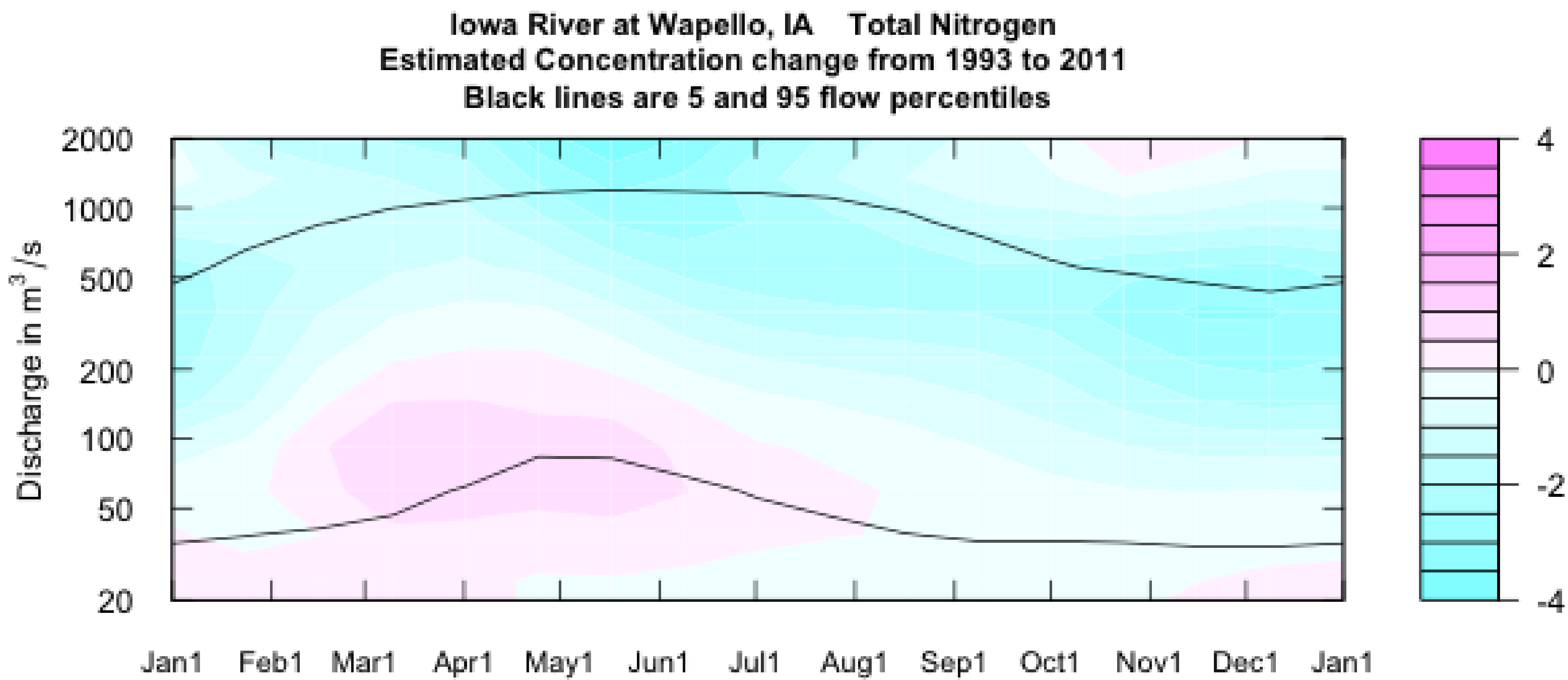

**Pretty good news, Flow Normalized Flux**
**1980 – 1993 decreasing about 0.2%/year**
**1993 – 2011 decreasing about 1.1%/year**

```
> flowDuration()

Flow Duration for Iowa River at Wapello, IA

Flow duration is based on full year

Discharge units are Cubic Meters per Second

  min    5%   10%   25%   50%   75%   90%   95%    max
 16.4  44.5  68.0 104.5 194.0 390.8 690.9 900.5 4870.5
```

**> plotContours(1978,2012,20,2000,contourLevels=seq(0,12,2))**

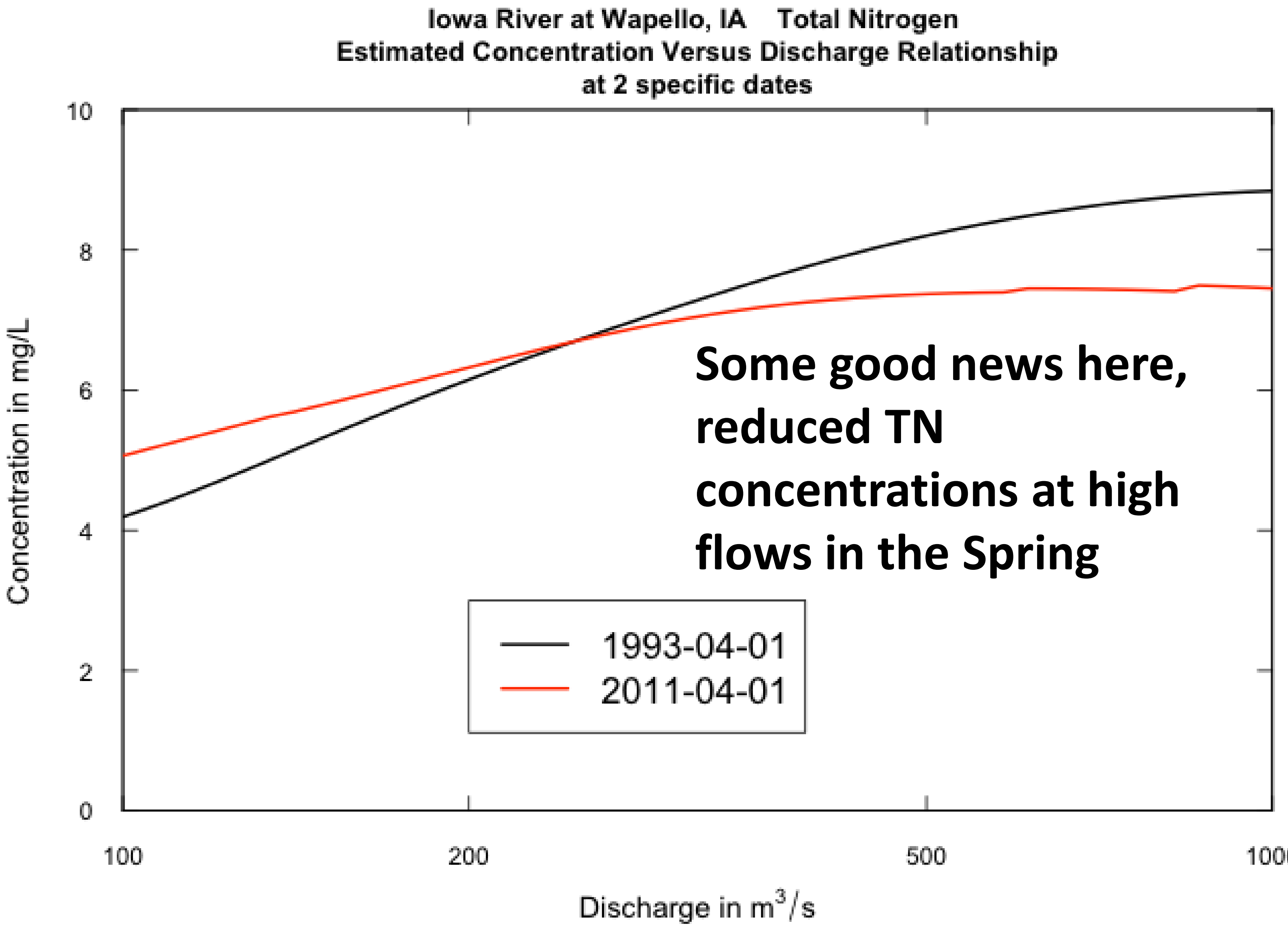


# > plotDiffContours(1993,2011,20,2000,maxDiff=4)

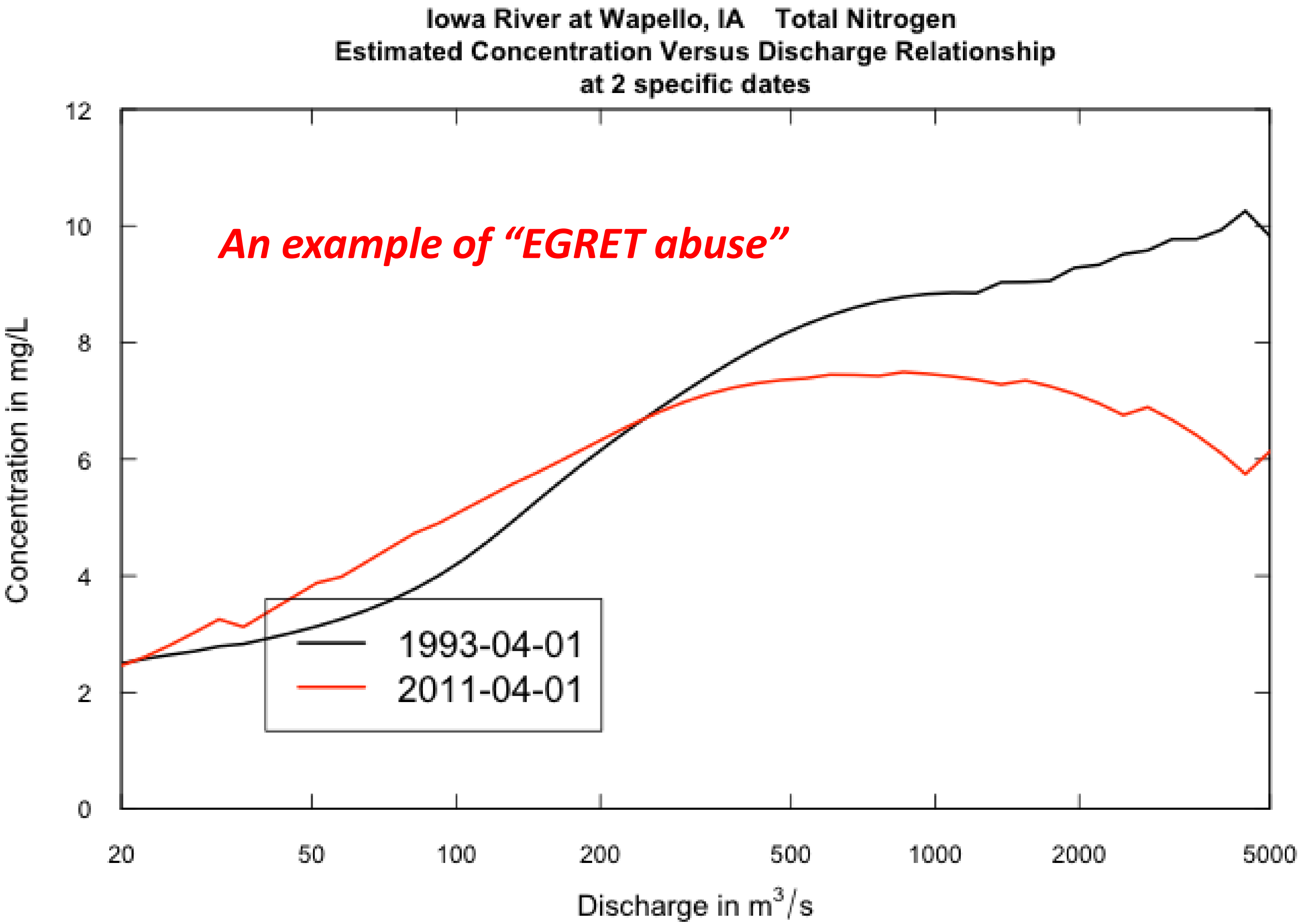



**Concentrations decreasing at high discharge throughout the year**
**Biggest declines around May and June**
**Some increase at low flows from February through June**

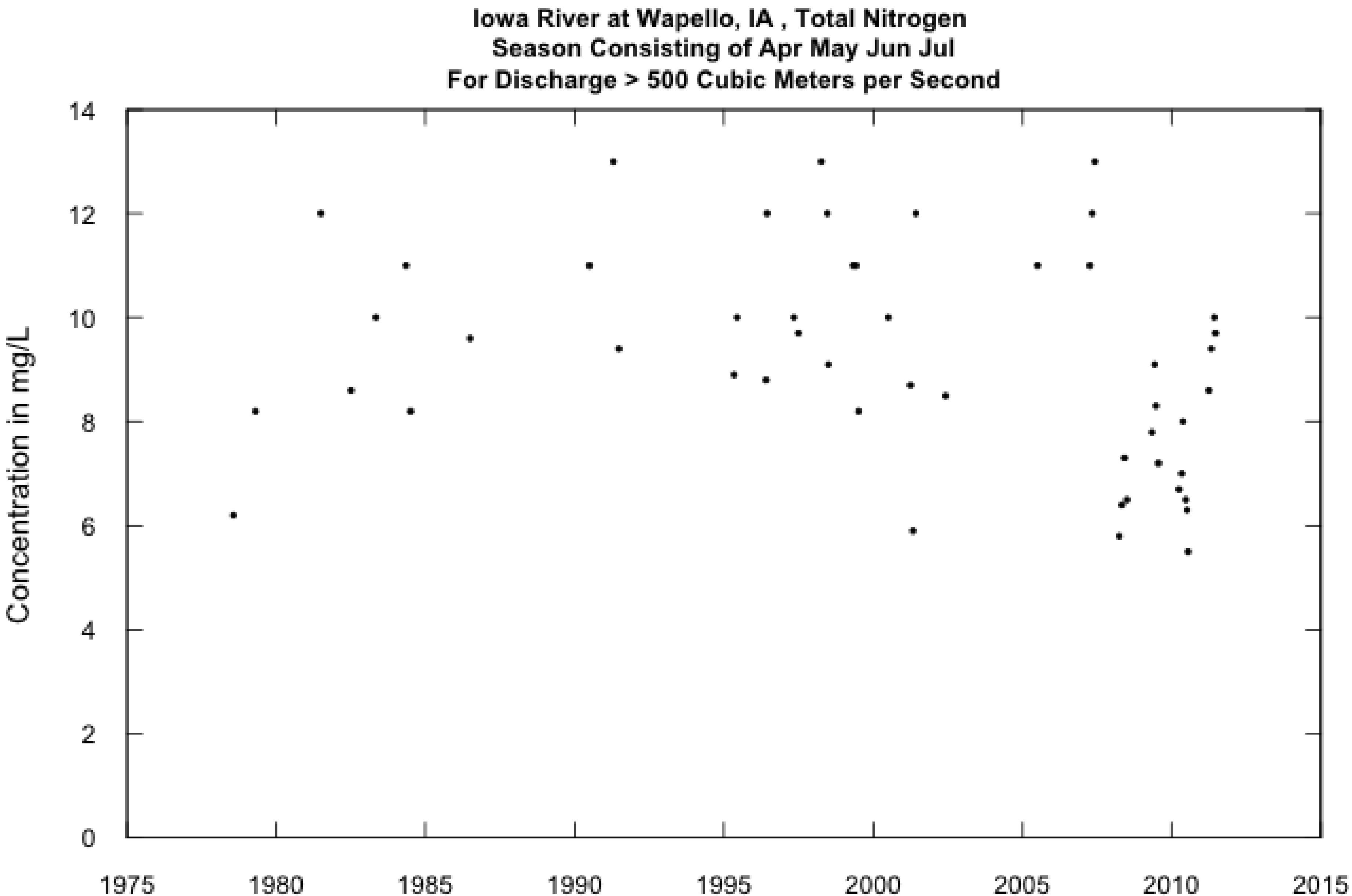
> plotConcQSmooth("1993-04-01","2011-04-01",NA,qLow=100,qHigh=1000)



```
> plotConcQSmooth("1993-04-01","2011-04-01",NA,qLow=20,qHigh=5000)
```



```
> plotConcTime(qLower=500,paLong=4,paStart=4)
```



# Moving to the western edge of the corn belt – the Missouri River at Hermann, MO

```
Missouri River at Hermann, MO
   Nitrate as N
   Water Year
```

Concentration trends

| time span | change mg/L | slope mg/L/yr | change % | slope %/yr |
|---|---|---|---|---|
| 1980 to 2000 | 0.24 | 0.012 | 24 | 1.2 |
| 1980 to 2011 | 0.74 | 0.024 | 75 | 2.4 |
| 2000 to 2011 | 0.5 | 0.045 | 40 | 3.7 |

Flux Trends

| time span | change 10^6 kg/yr | slope 10^6 kg/yr /yr | change % | slope %/yr |
|---|---|---|---|---|
| 1980 to 2000 | 31 | 1.5 | 36 | 1.8 |
| 1980 to 2011 | 48 | 1.6 | 56 | 1.8 |
| 2000 to 2011 | 17 | 1.6 | 15 | 1.3 |

```
> tableChange(fluxUnit=9,yearPoints=c(1980,2000,2011))
```

# Moving to the western edge of the corn belt – the Missouri River at Hermann, MO

```
Missouri River at Hermann, MO
   Nitrate as N
   Water Year
```

Concentration trends

| time span | change mg/L | slope mg/L/yr | change % | slope %/yr |
|---|---|---|---|---|
| 1980 to 2000 | 0.24 | 0.012 | 24 | 1.2 |
| 1980 to 2011 | 0.74 | 0.024 | 75 | 2.4 |
| 2000 to 2011 | 0.5 | 0.045 | 40 | 3.7 |

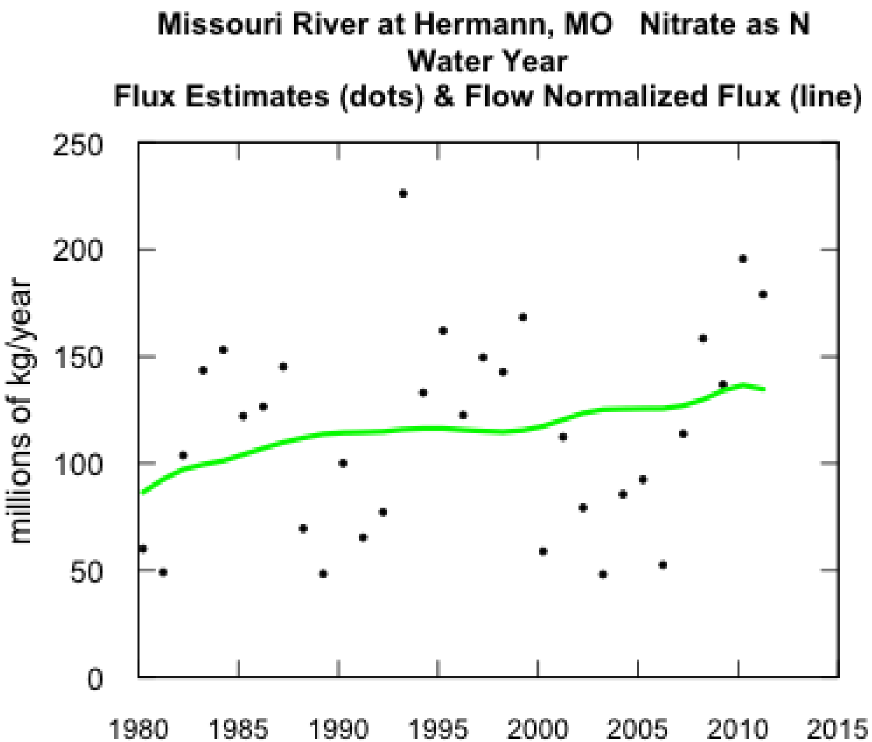
Flux Trends

| time span | change 10^6 kg/yr | slope 10^6 kg/yr /yr | change % | slope %/yr |
|---|---|---|---|---|
| 1980 to 2000 | 31 | 1.5 | 36 | 1.8 |
| 1980 to 2011 | 48 | 1.6 | 56 | 1.8 |
| 2000 to 2011 | 17 | 1.6 | 15 | 1.3 |

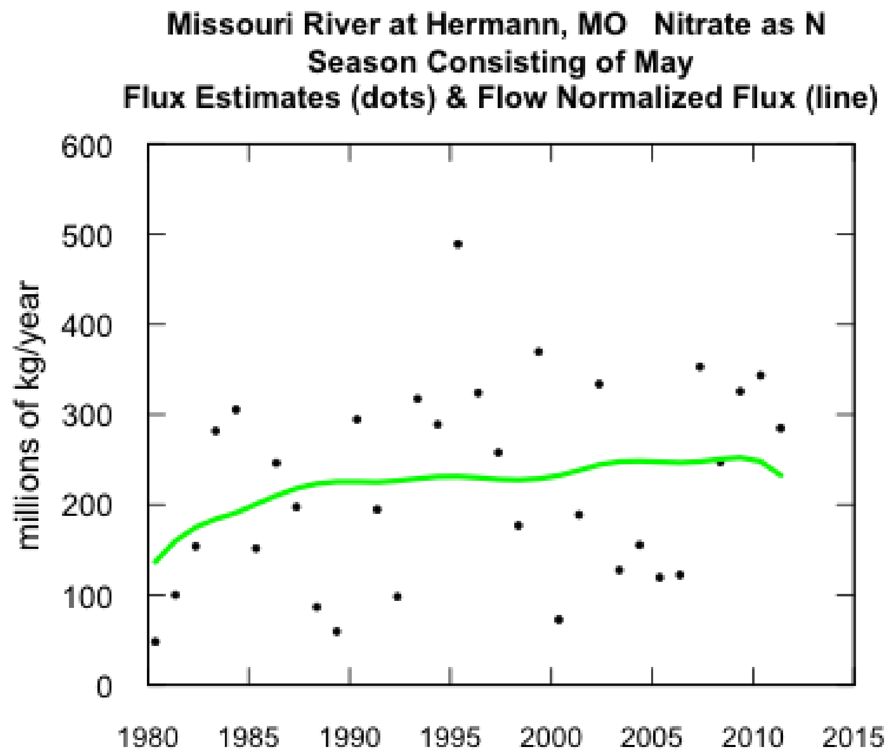
```
> tableChange(fluxUnit=9,yearPoints=c(1980,2000,2011))
```

# Gulf Hypoxia concerns are focused on May flux (rather than annual). What's been the trend in May flux.

```
> AnnualResults<-setupYears(paLong=12,paStart=10)
> plotFluxHist(1980,2012)
```

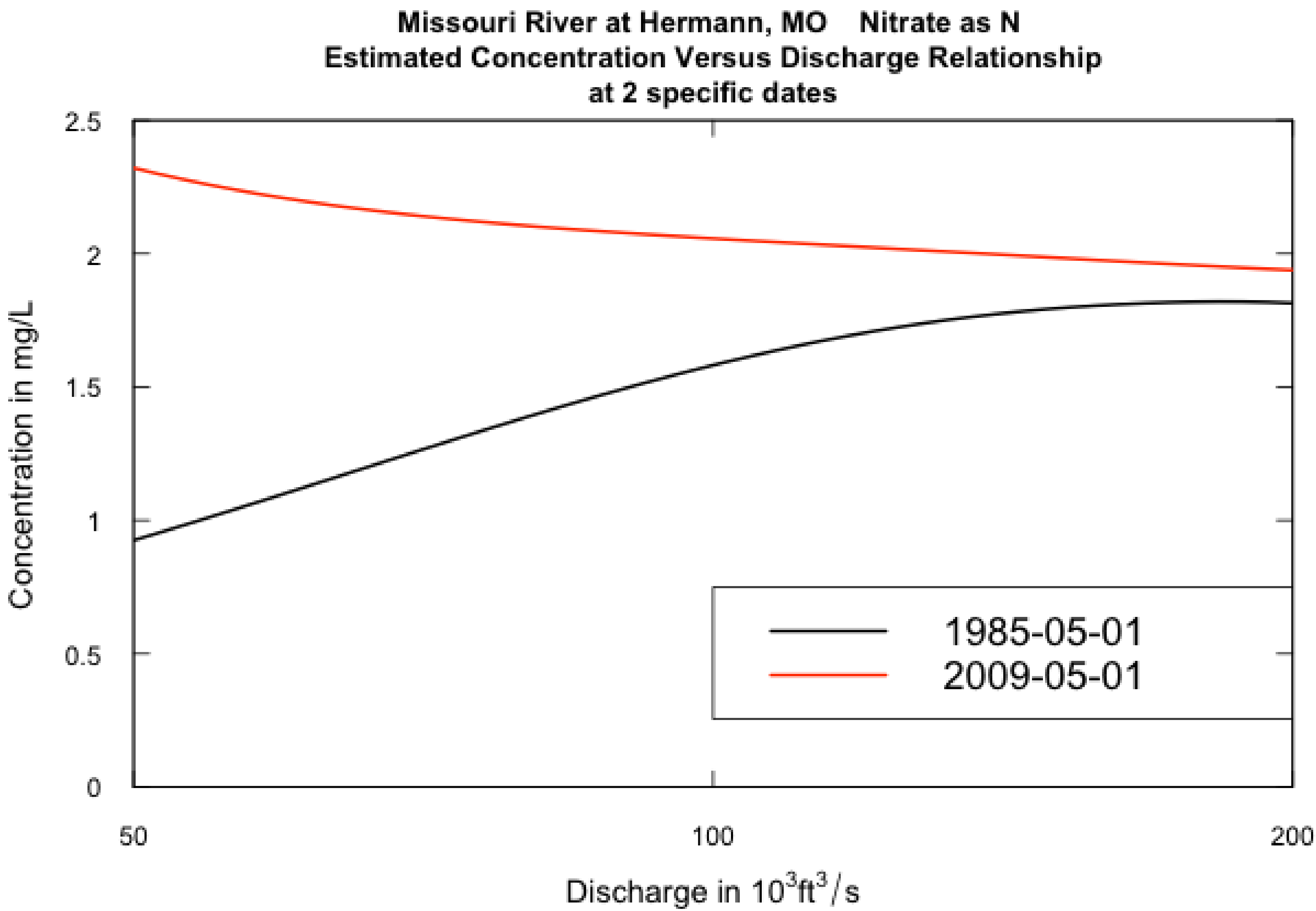



```
> AnnualResults<-setupYears(paLong=1,paStart=5)
> plotFluxHist(1980,2012)
```

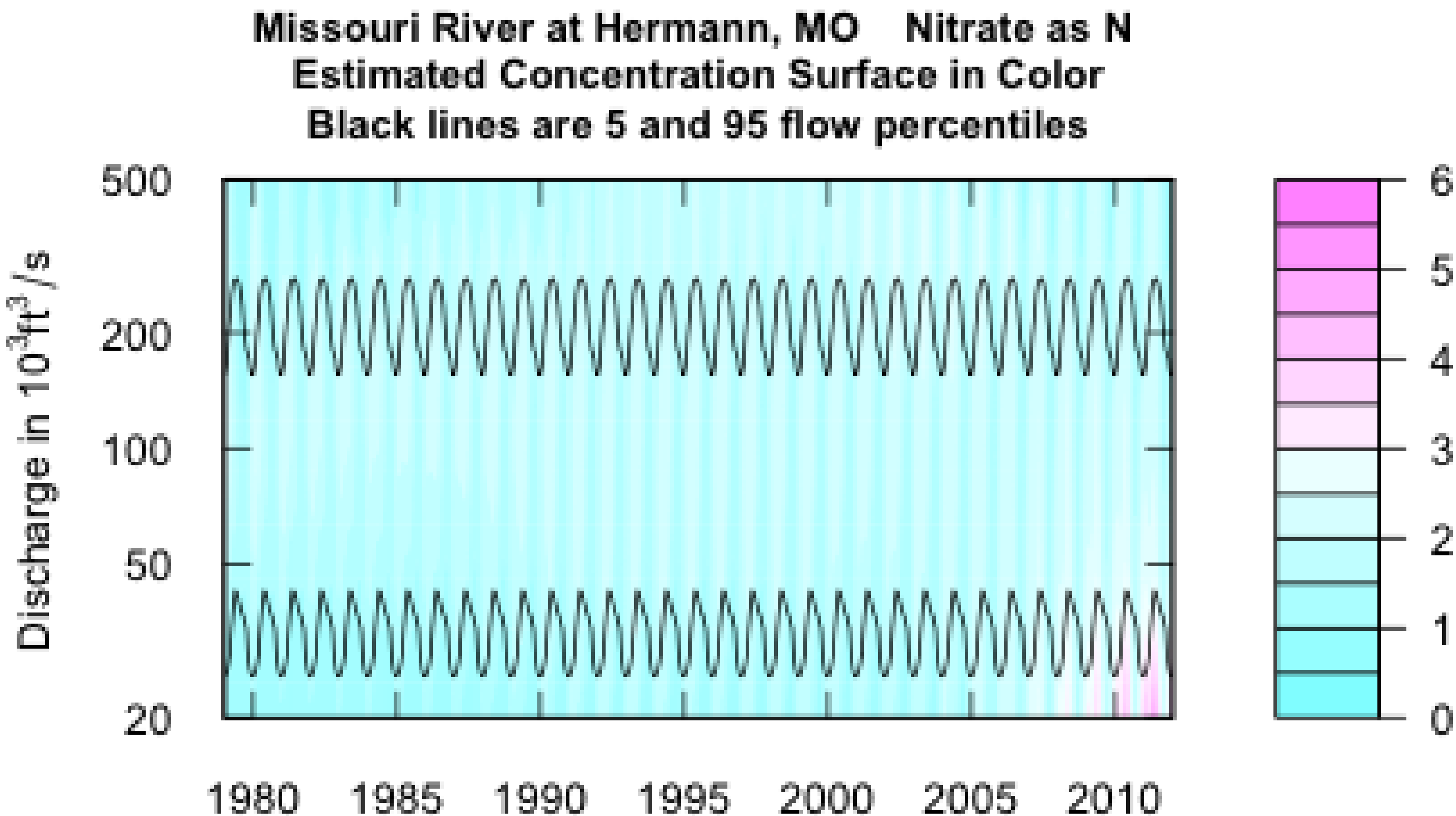



**Annual flux keeps rising, but May flux seems flat, suggesting that the flux is getting more "spread out" over the course of the year.** ***The role of groundwater?***

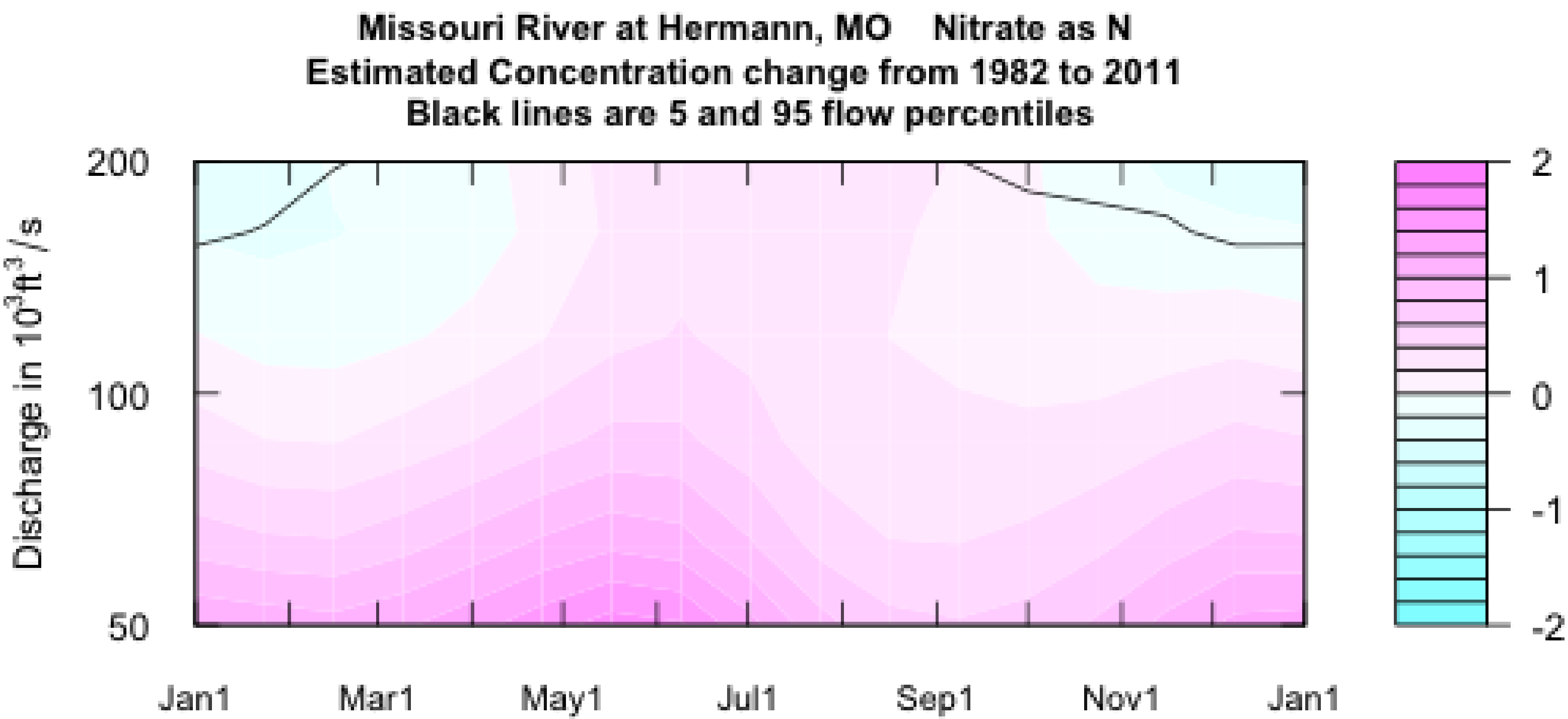
```
> plotConcQSmooth("1985-05-01","2009-05-01",NA,qLow=50,qHigh=200,qUnit=3)
```

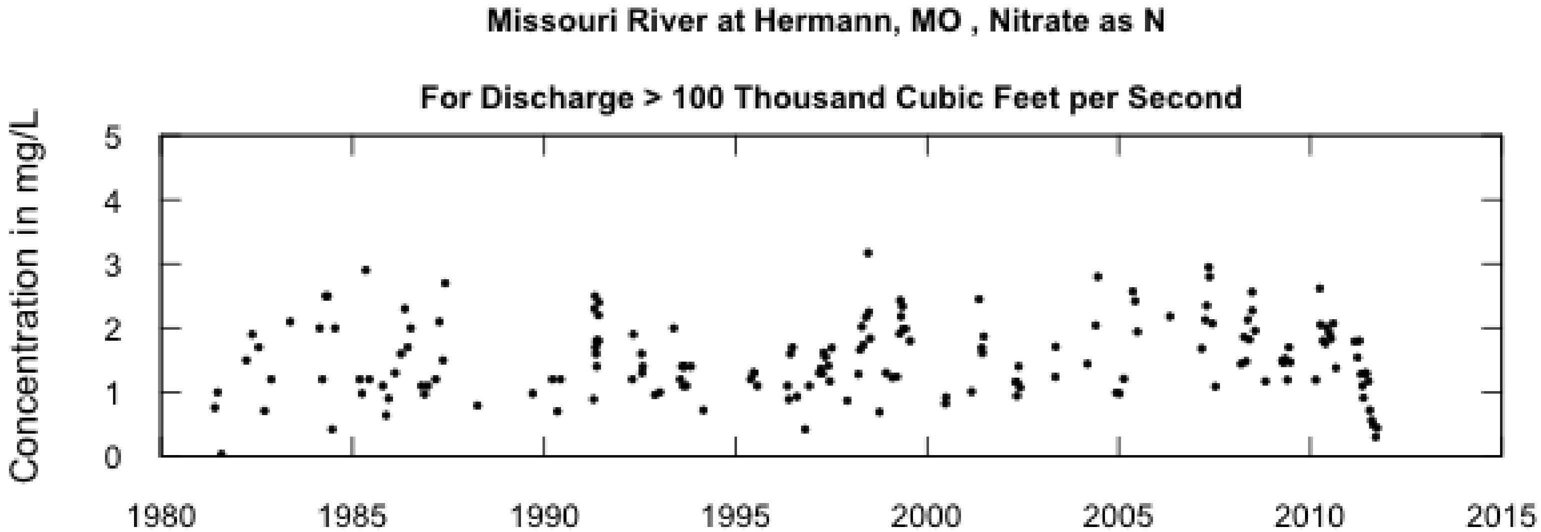


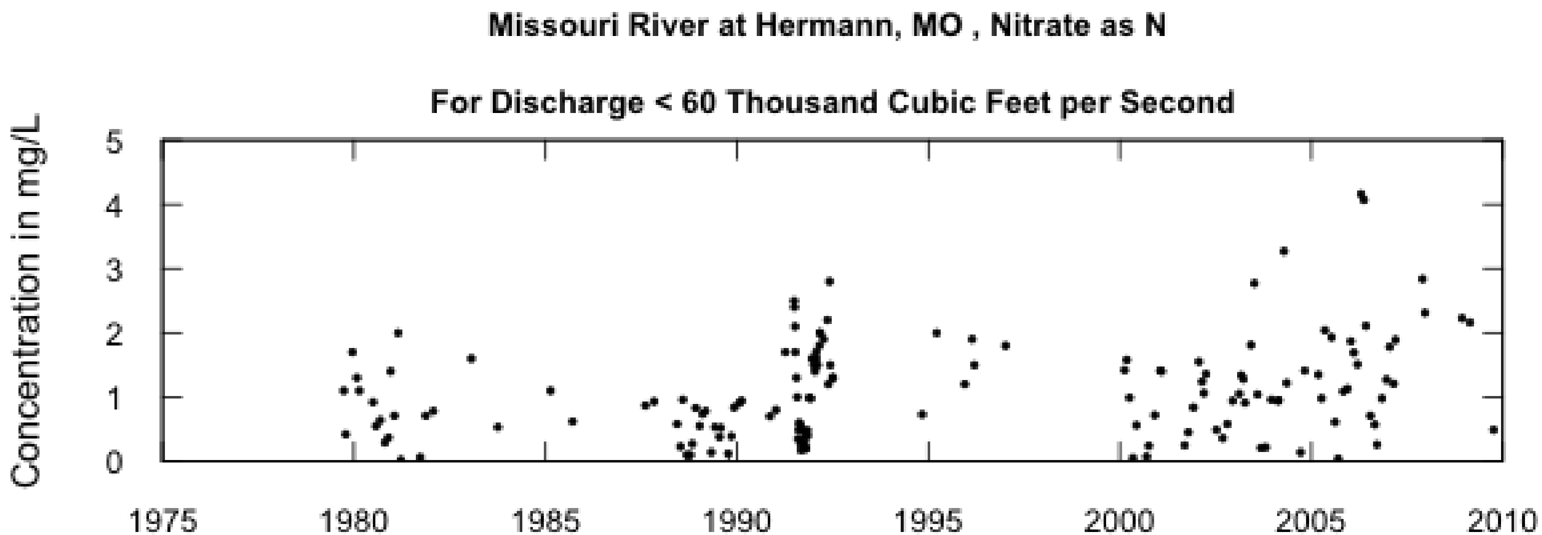
```
> plotContours(1979,2012,20,500,qUnit=3,contourLevels=seq(0,6,0.5))
```



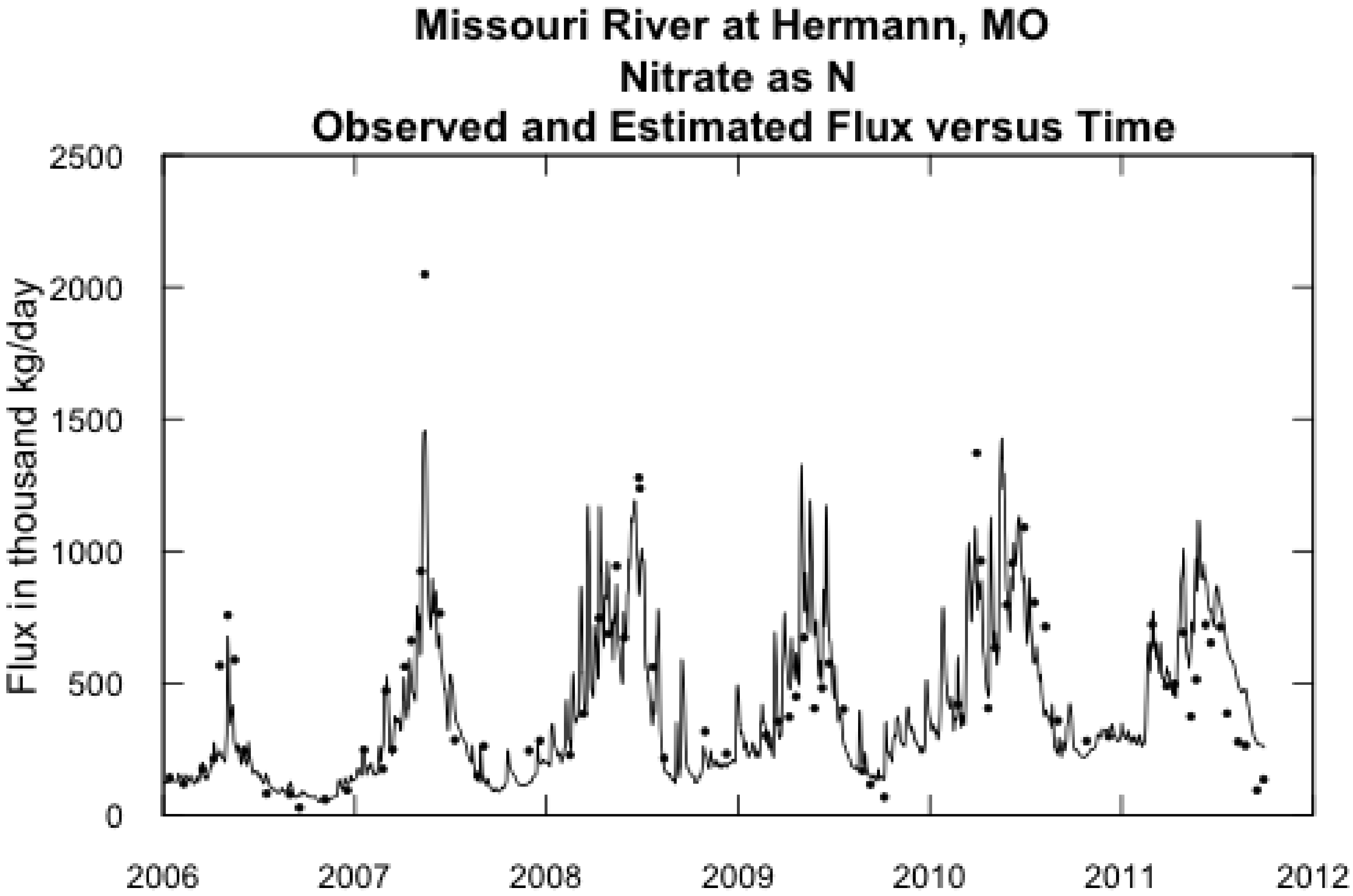
> plotDiffContours(1982,2011,50,200,qUnit=3,maxDiff=2)




Missouri River at Hermann, MO , Nitrate as N
For Discharge > 100 Thousand Cubic Feet per Second
Concentration in mg/L
0
1
2
3
4
5
1980
1985
1990
1995
2000
2005
2010
2015


Missouri River at Hermann, MO , Nitrate as N
For Discharge < 60 Thousand Cubic Feet per Second
Concentration in mg/L
0
1
2
3
4
5
1975
1980
1985
1990
1995
2000
2005
2010

Sometimes what doesn't work well is highly informative and suggests the need for a more complex model. *> plotFluxTimeDaily(2006,2012)*

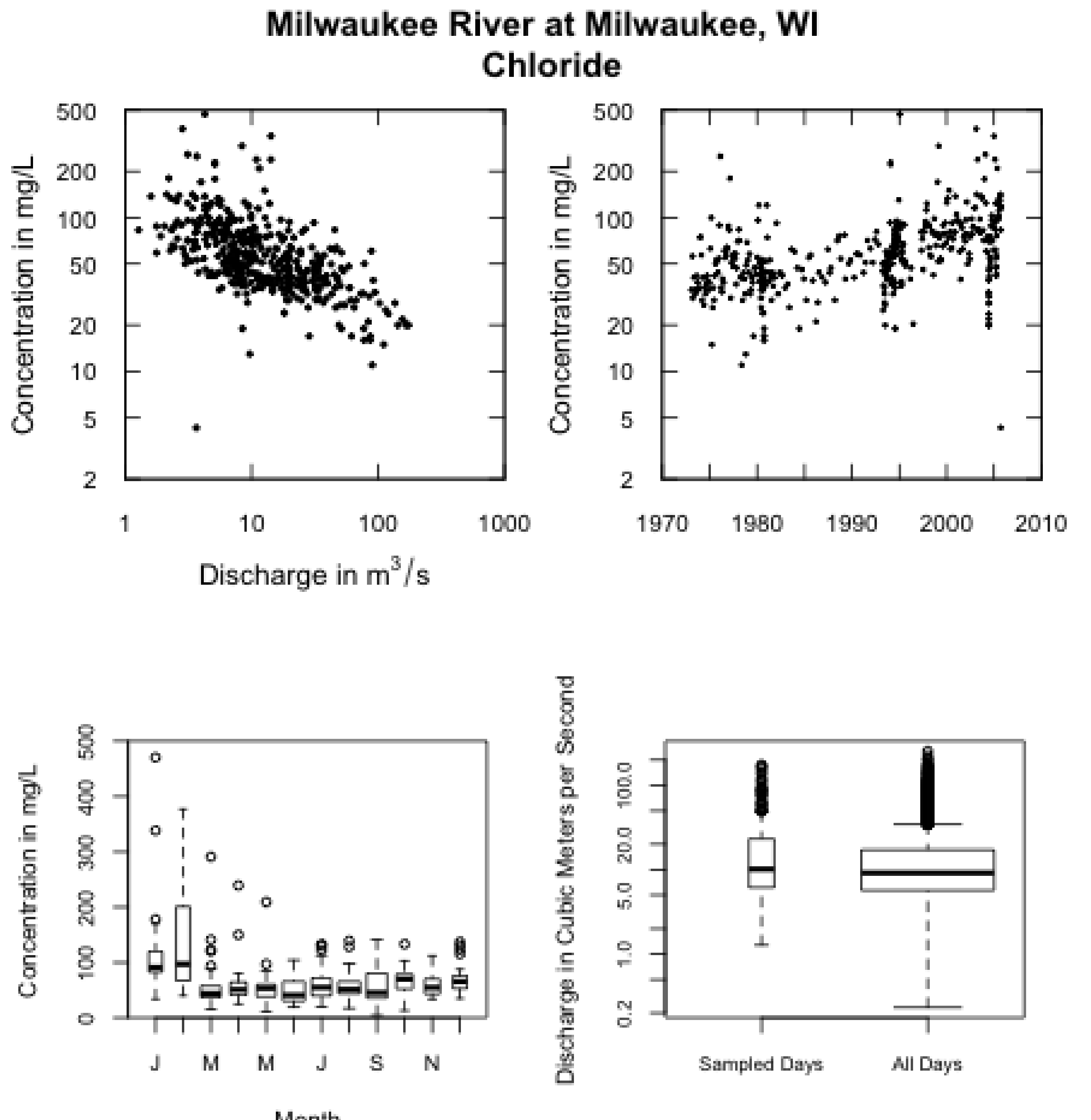


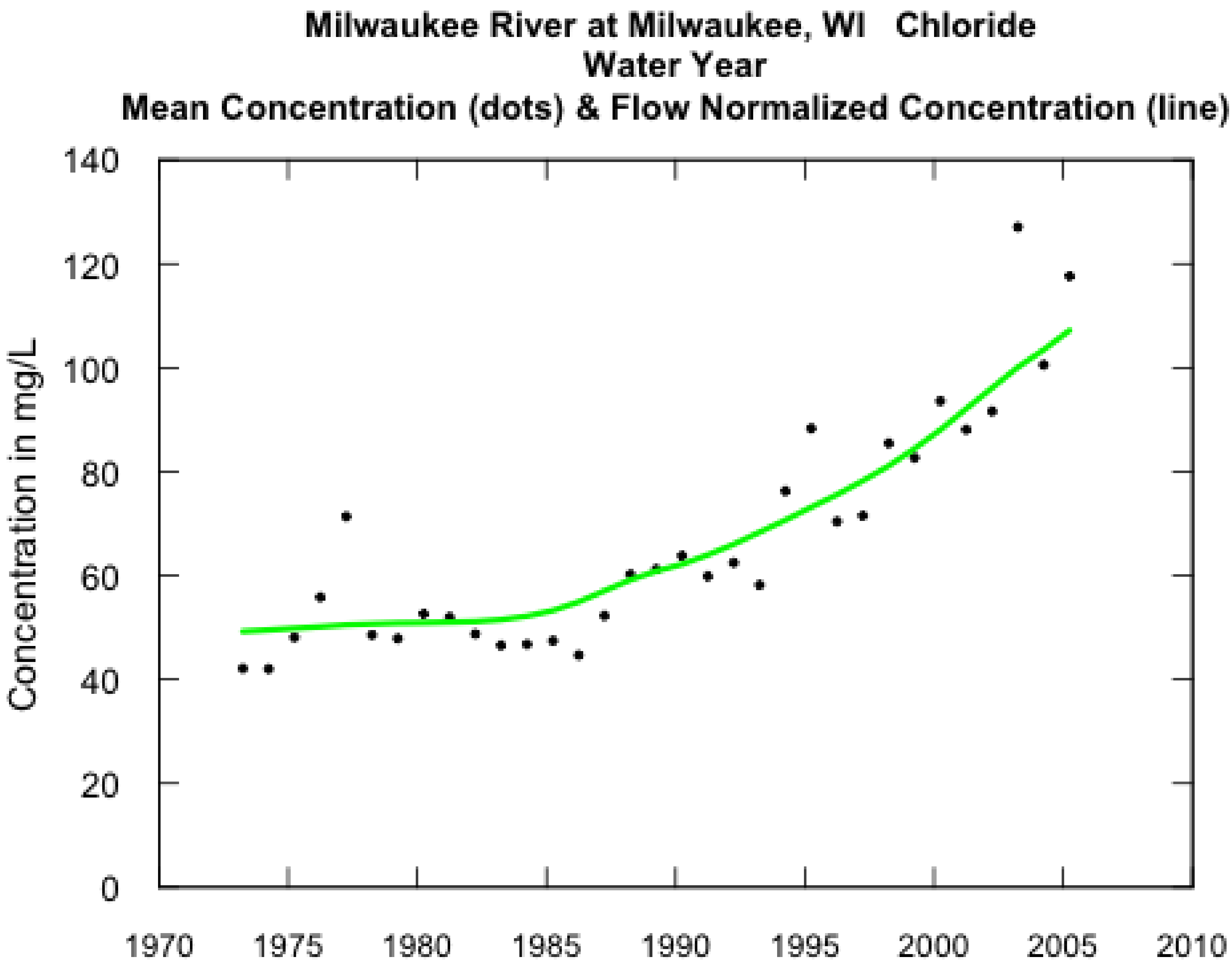

**What was special about 2011 for the Missouri River?**

# One last example

**It doesn’t take a rocket scientist to see that chloride decreases with flow, has increased with time, and is highest in the winter**

**But is there more to the story?**



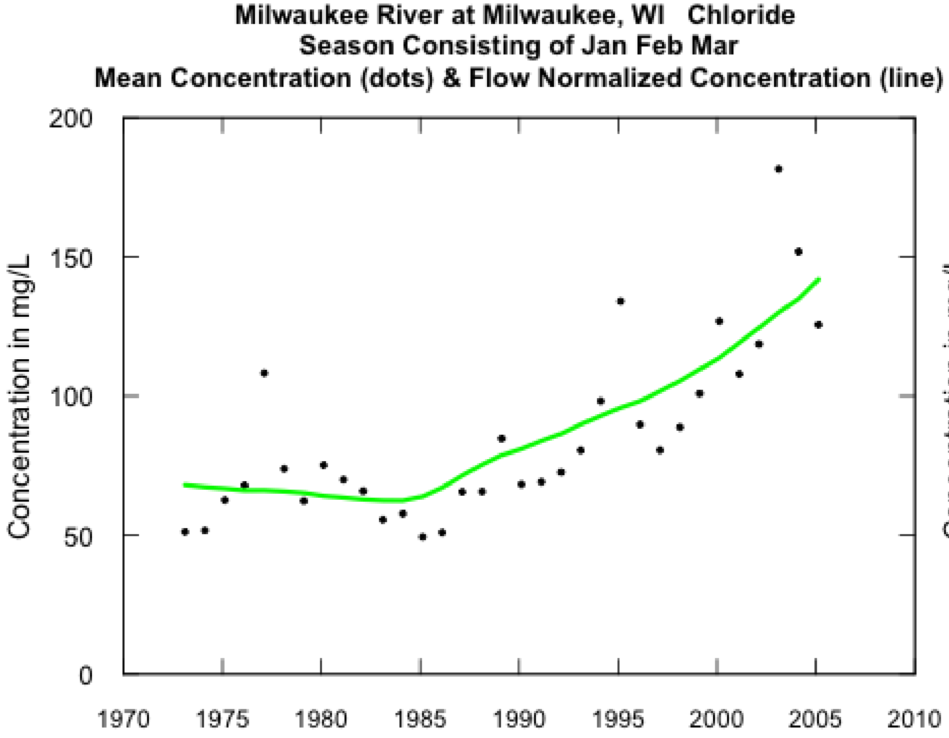


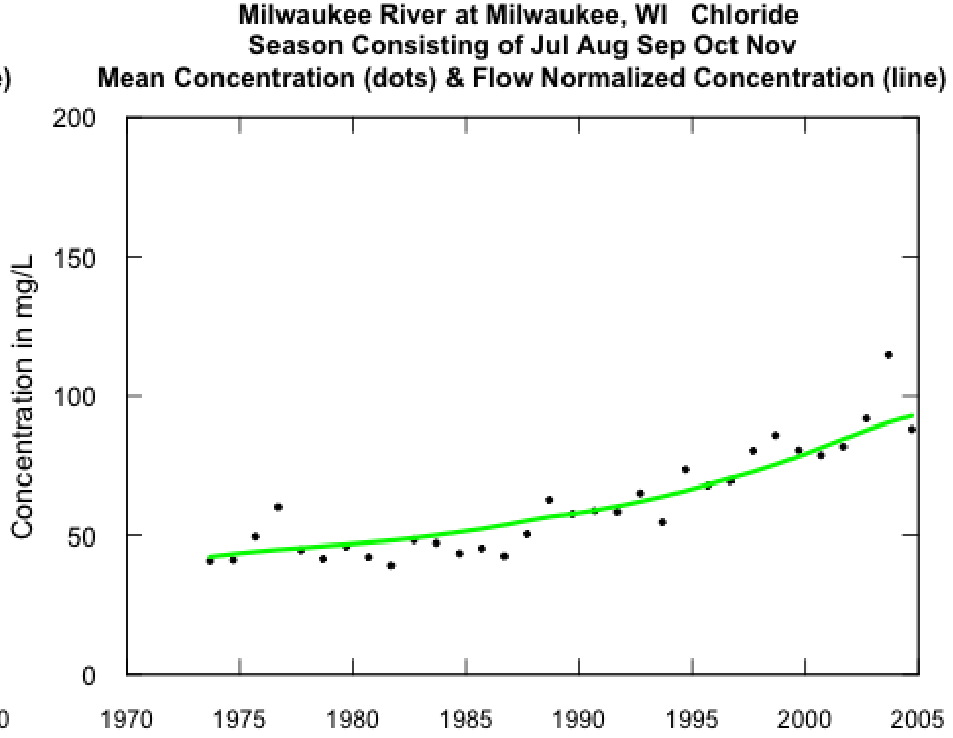
Milwaukee River at Milwaukee, WI Chloride
Water Year
Mean Concentration (dots) & Flow Normalized Concentration (line)
Concentration in mg/L
0
20
40
60
80
100
120
140
1970
1975
1980
1985
1990
1995
2000
2005
2010

# The changes are not confined to the winter months

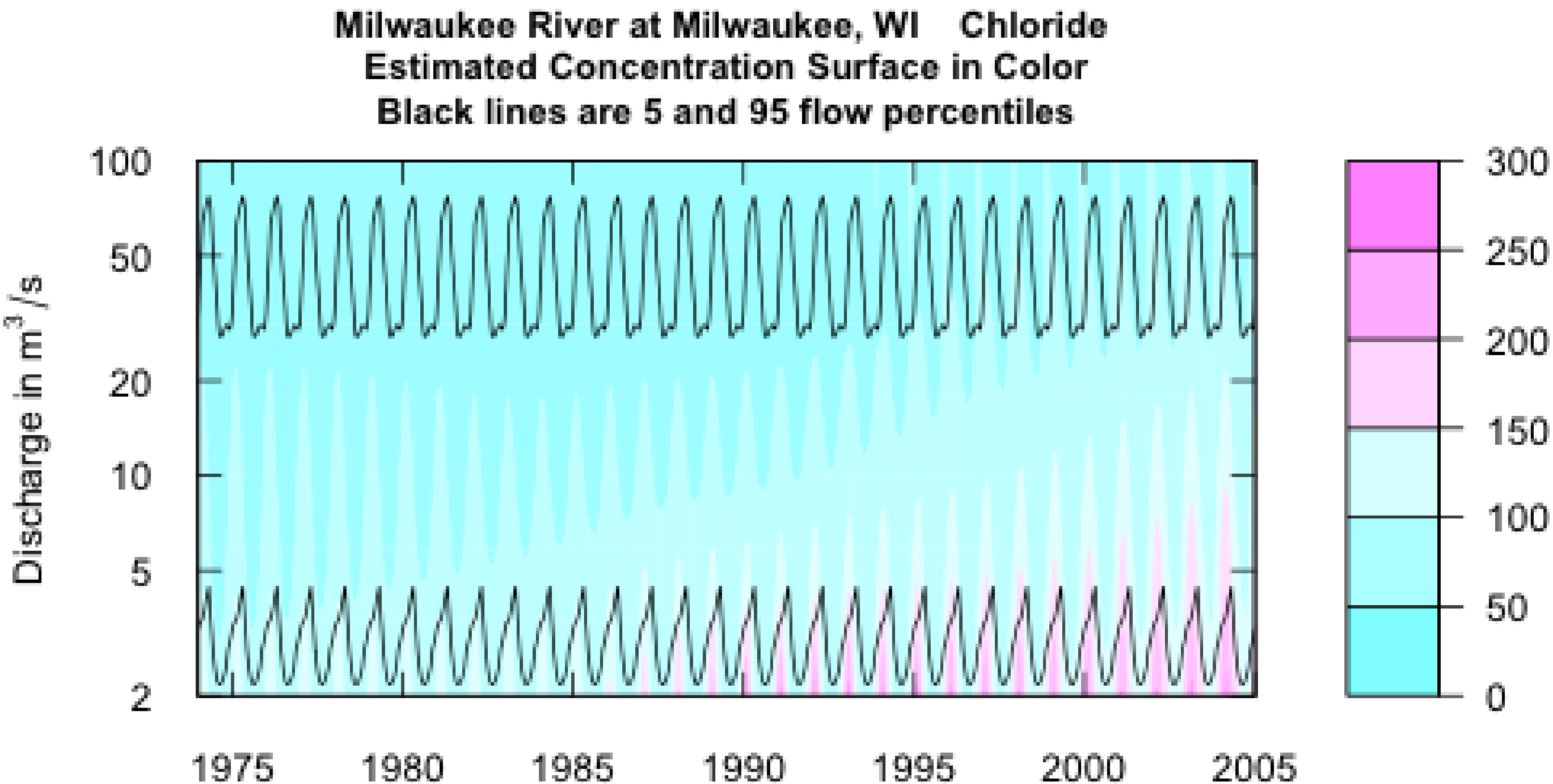
```
> AnnualResults<-setupYears(paLong=3,paStart=1)
> plotConcHist(1970,2010)
```

```
> AnnualResults<-setupYears(paLong=5,paStart=7)
> plotConcHist(1970,2010,concMax=200)
```

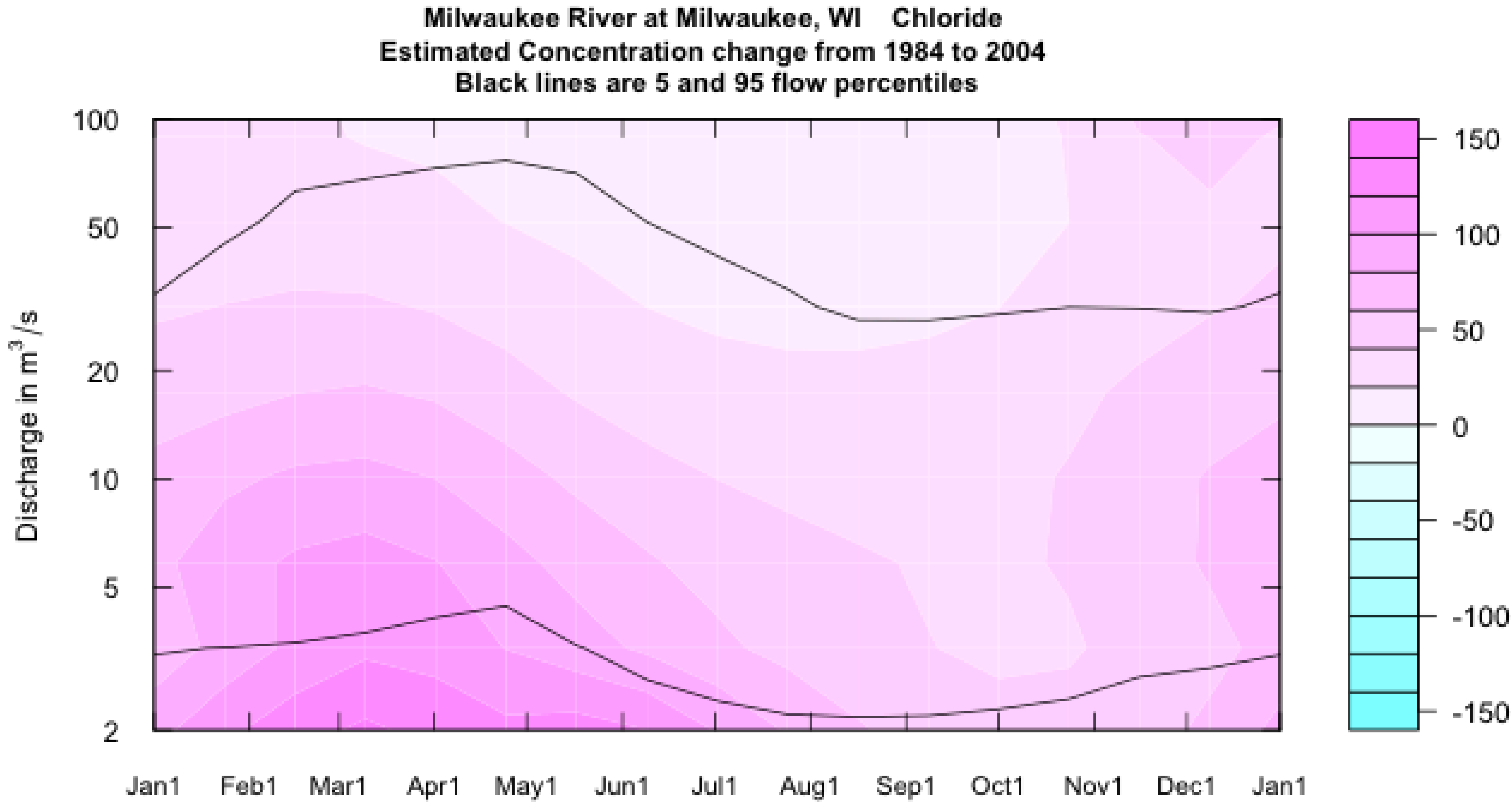


```
> flowDuration()
Flow Duration for Milwaukee River at Milwaukee, WI
Flow duration is based on full year
Discharge units are Cubic Meters per Second

     min       5%      10%      25%      50%      75%      90%      95%      max
   0.232    2.860    3.681    5.663    9.175   17.188   32.564   47.572  254.002
> plotContours(1974,2005,2,100,contourLevels=seq(0,300,50))
```



> plotDiffContours(1984,2004,2,100,maxDiff=150)

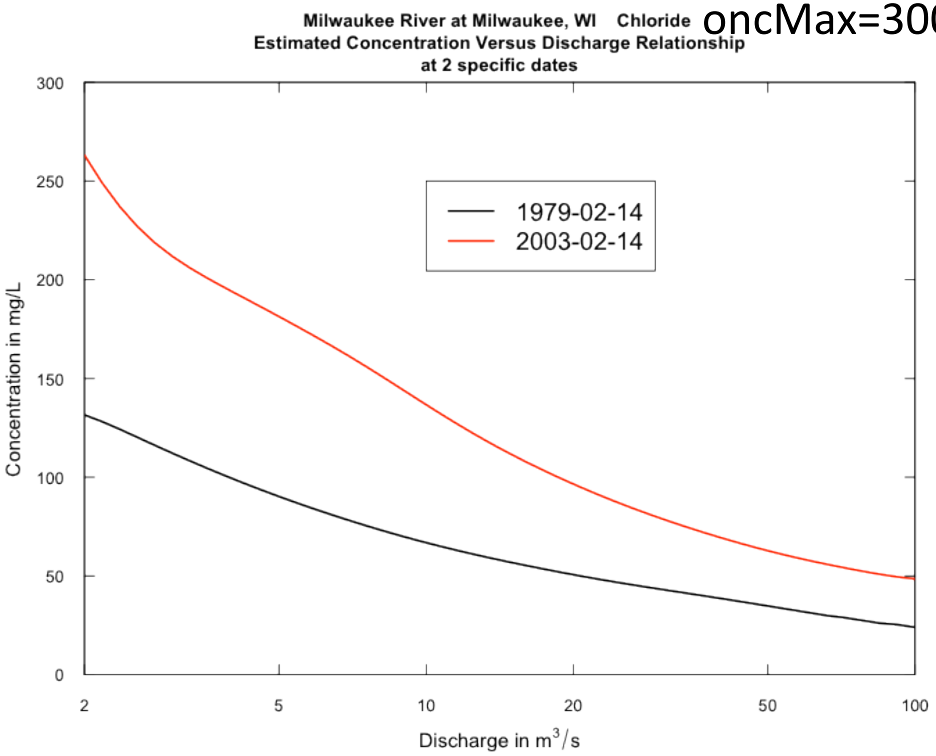


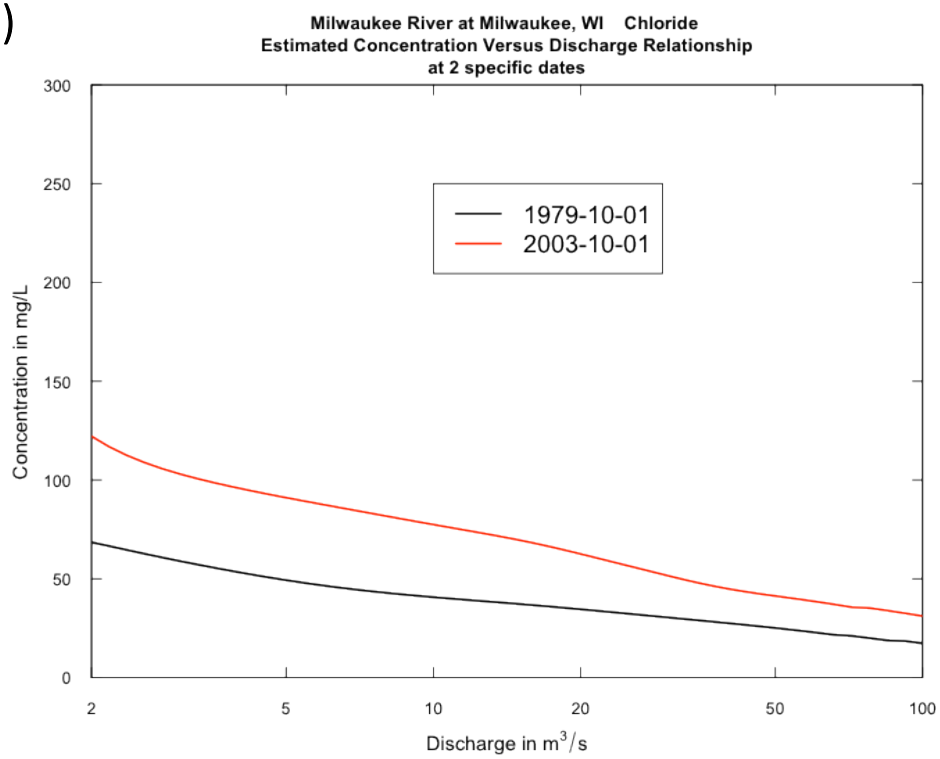

**Increases at all flows and all seasons**

**The largest changes are at winter low to moderate flow conditions**

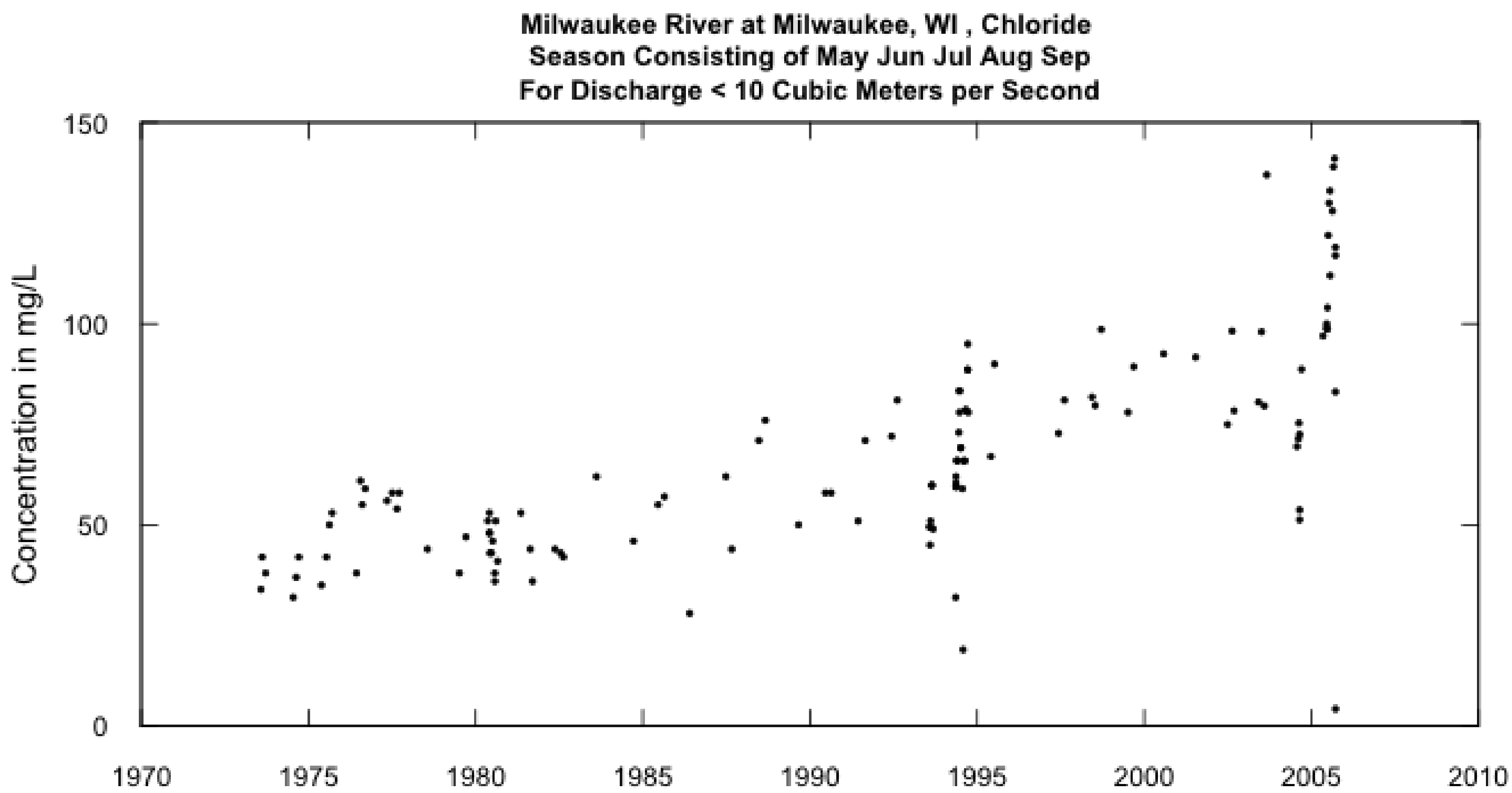
plotConcQSmooth("1979-02-14","2003-02-14",NA,qLow=2,qHigh=100,legendLeft=10,legendTop=250)

plotConcQSmooth("1979-10-01","2003-10-01",NA,qLow=2,qHigh=100,legendLeft=10,legendTop=250,concMax=300)



> plotConcTime(qUpper=10,paLong=5,paStart=5)



# EGRET functionality

- Graphs and tables are self-labeling and suitable for presentation or publication.
- Reporting units selected by user.
- Works interactively or in batch.
- Structures the data and results so it is easy to go back and ask further questions.
- Data structure opens up options for many other kinds of analysis using a wide-range of functions that are part of R.
- Data frames can be easily shared among users.

# EGRET philosophy

- Get the data easily and organize it for analysis.
- Don't only drive to get numbers or significance levels.
- Drive to understanding, hypotheses, & descriptions of our changing world.

USGS
science for a changing world

# EGRET philosophy

There are changes all around us, now describe them to help guide how we manage our water resources!

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**We welcome your questions and feedback on:** ***the methods, the outputs, the manual***

**The R-packages, draft manual and this presentation are on the EGRET web site:**

**https://github.com/USGS-CIDA/WRTDS/blob/master/README.md**

**Send your questions and feedback to: egret_comments@usgs.gov**

science for a changing world