# New Tools for Water Quality Data Access, Trend and Load Analysis

## An overview of the USGS R Packages:

## dataRetrieval and EGRET

**Robert M. Hirsch**
**USGS**
**2014-11-20**

# dataRetrieval

Retrieves water data for use in R

Includes: sample data, daily data, sensor data, meta-data

Retrieves from USGS NWIS and Water Quality Portal

# EGRET: Exploration & Graphics for RivEr Trends

Retrieve sample data, discharge data, & meta data from web-services or spreadsheet

Flow history analysis

**WRTDS:** Weighted Regressions on Time Discharge & Season: for water quality trends and fluxes

Graphics & exploration

USGS

# These packages have been a joint effort for 3 years

- Laura De Cicco of the USGS CIDA group in Wisconsin  is the primary author of dataRetrieval and has made huge contributions to all aspects, including trying to retrain a “Paleo Code Writer”
- Thanks to our colleague reviewers: Jeff Chanat, USGS VA WSC &Jessica Thompson, USGS WI WSC
- Thanks to many beta-test users who have asked great questions and suggested enhancements of functionality of the system

USGS

# Outline

- Motivations for the packages
- The WRTDS concept and examples of results
- Overview of EGRET data retrievals
- How EGRET works, doing WRTDS analysis and producing graphs and tables

# 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.**

Keeling, 2008, Recording Earth's vital signs, Science, p1771-1772

## Models without data are fantasy, but data without models are chaos

How do we come to understand what is happening to water quality in large watersheds.

Is it getting better or worse?

Can we develop ideas of causative factors and changes in processes?

Can these be used to guide management choices?

# Motivations for the method

- Describe the evolving behavior of the watershed.  No mathematical straight-jacket!!
- Estimate both concentration & flux (averages as well as trends).
- Estimate the actual history but also a flow-normalized history.
- Resolve a serious bias in flux estimates.
- Be quantitative but also exploratory.

# Data requirements

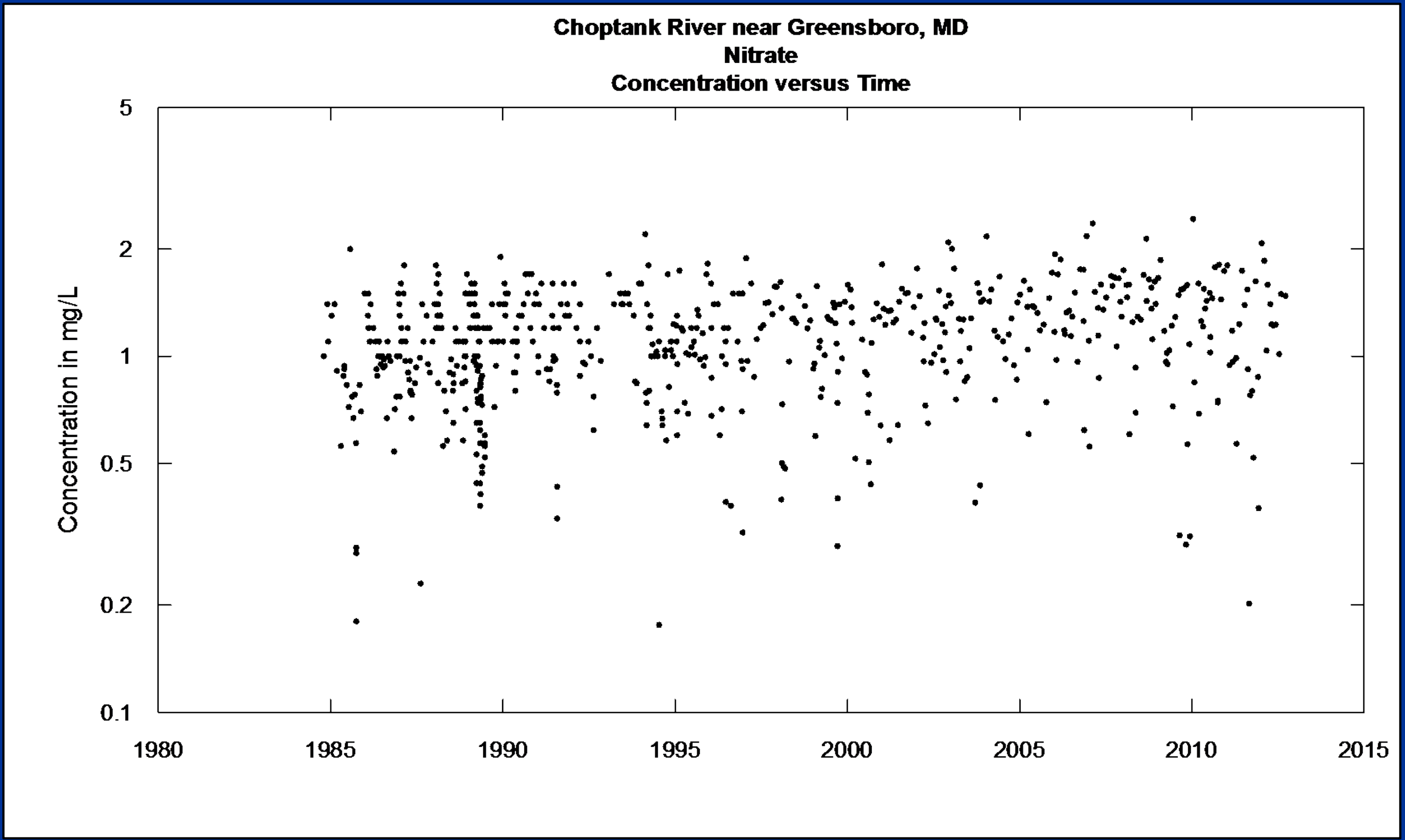
- Low intra-day variability (not flashy)
- Requires a complete daily discharge record
- Intended for >200 samples, but has been used for some purposes with as few as 60 samples
- Water quality samples cover most of the discharge range
- For trend studies: 20+ years, but can do less
- For average flux computations: 5 – 10 years.

USGS


Choptank,
293 km²
watershed

# “Data without models are chaos, but models without data are fantasy”

**Nesbit, Dlugokencky and Bousquet, Science, 31 January 2014, pp. 493-495**




USGS

Use the data and a simple, highly-flexible smoothing model to decompose the data into 4 components.

1) Discharge related component

2) Seasonal component

3) Time trend

4)Random component

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

USGS

# Locally Weighted Regression

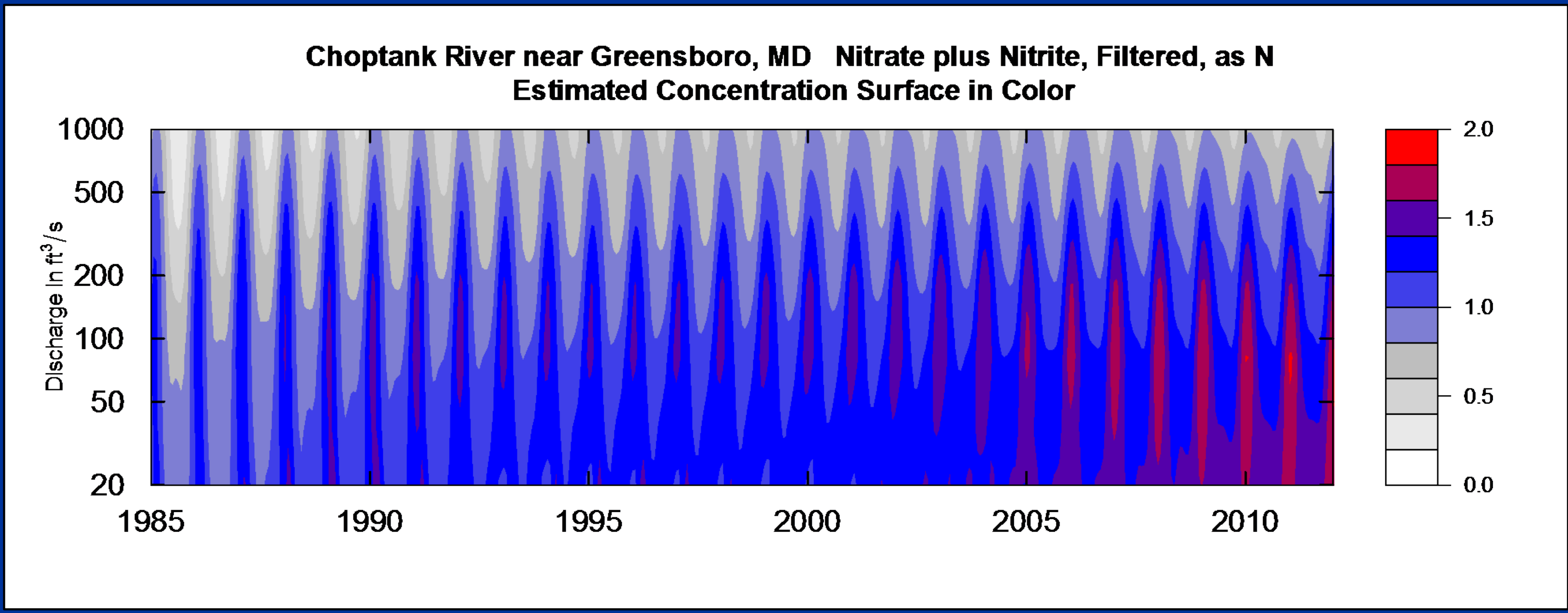
**For any location in time - discharge space (*t* and *Q*) we assume that concentration (*c*) follows this model**

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

**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.**

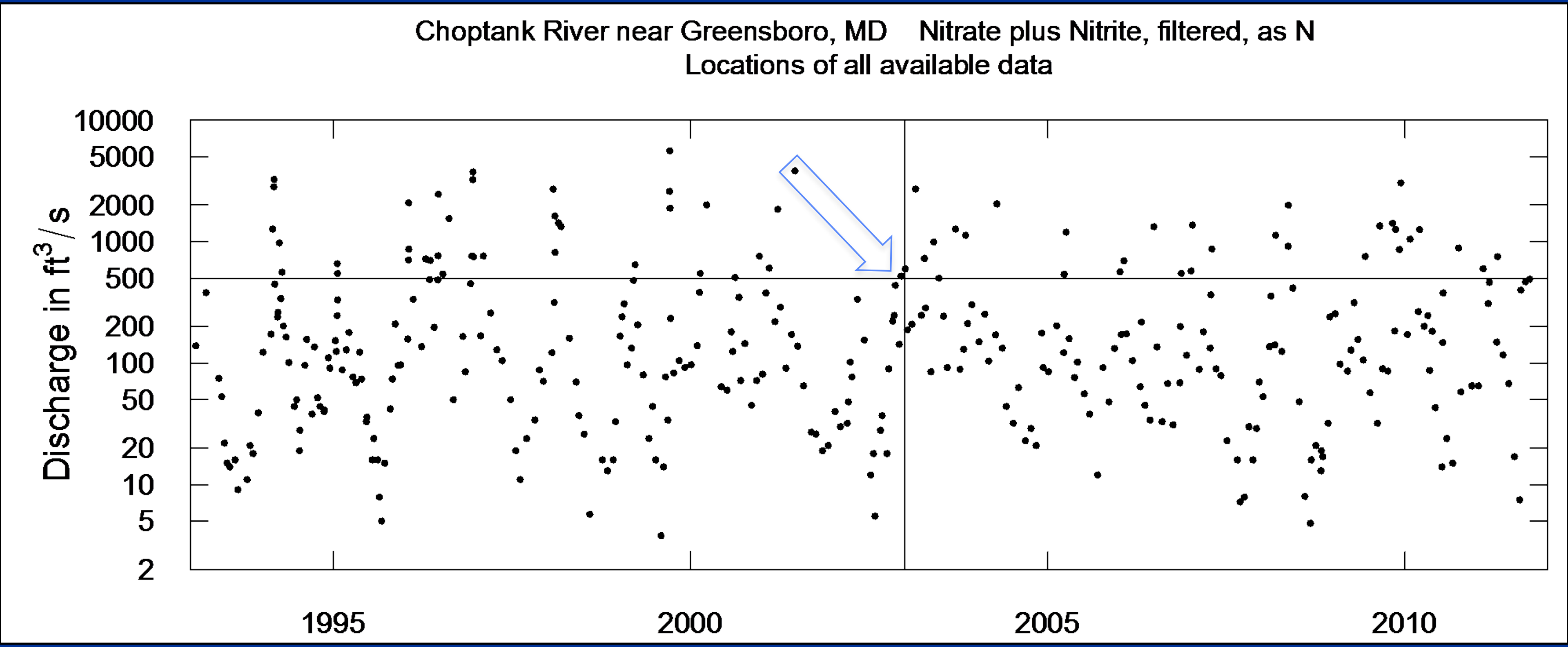
# WRTDS view of the evolving behavior of nitrate




## How is this surface created?

USGS

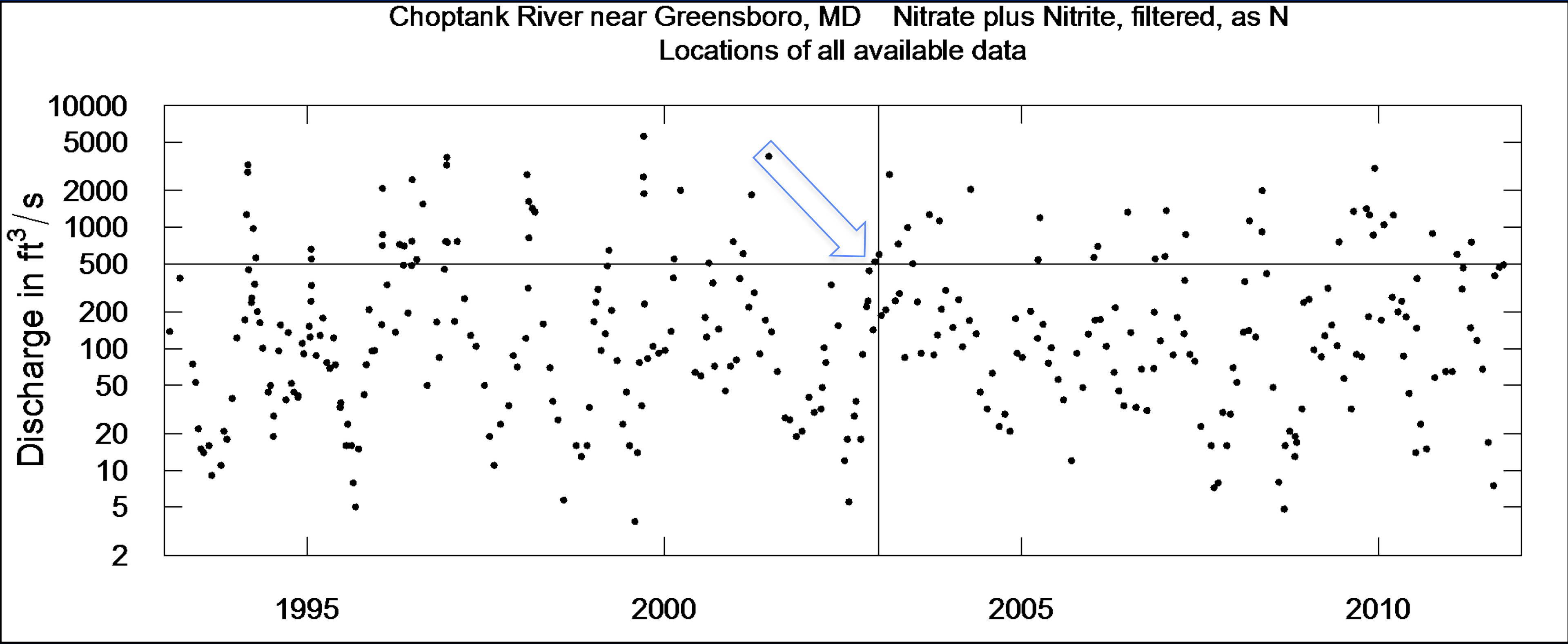
- Every dot is a data point from 1993 to 2012
- Let's say we want to use the data to estimate the expected value of concentration for January 1, 2003 at Q=500 cfs




USGS

**The principle is this:**

**Do a weighted regression at this point.  The weights on each observation are related to their "distance"**

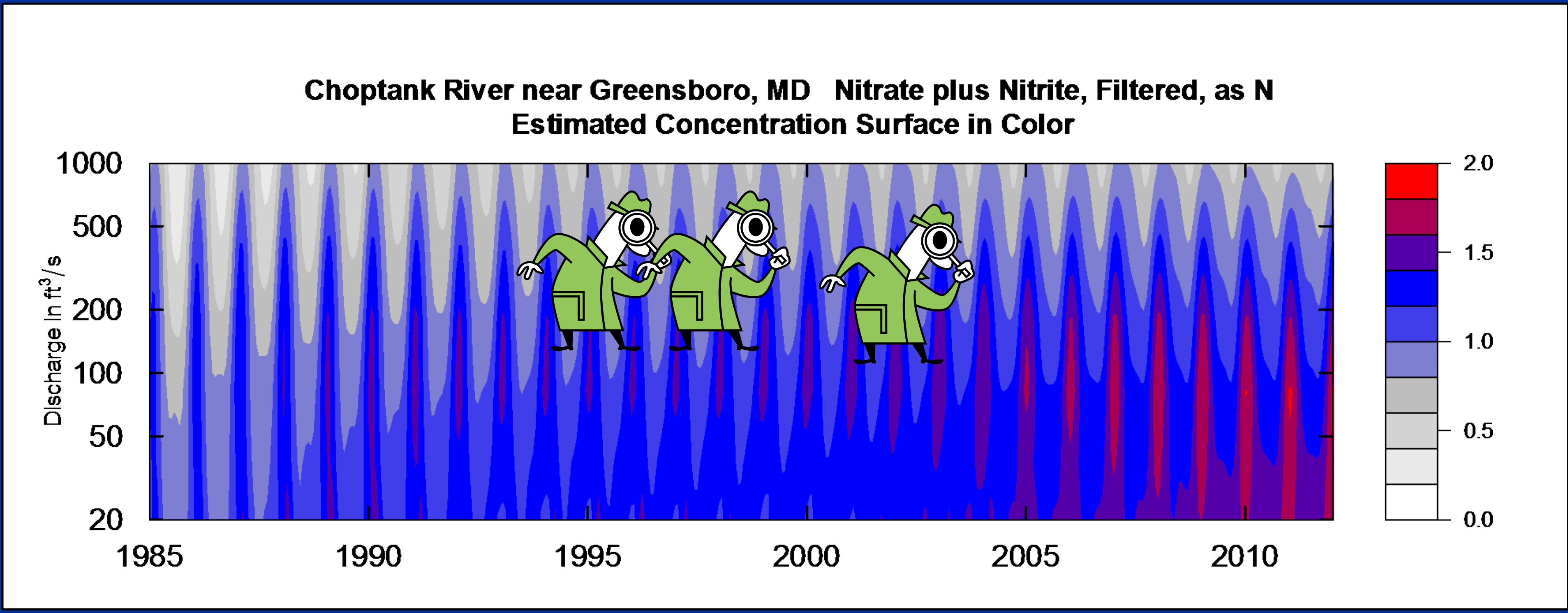



**Distance in time, in log(Q), and season.**

**Now move to the next point and do it all over again.**

USGS

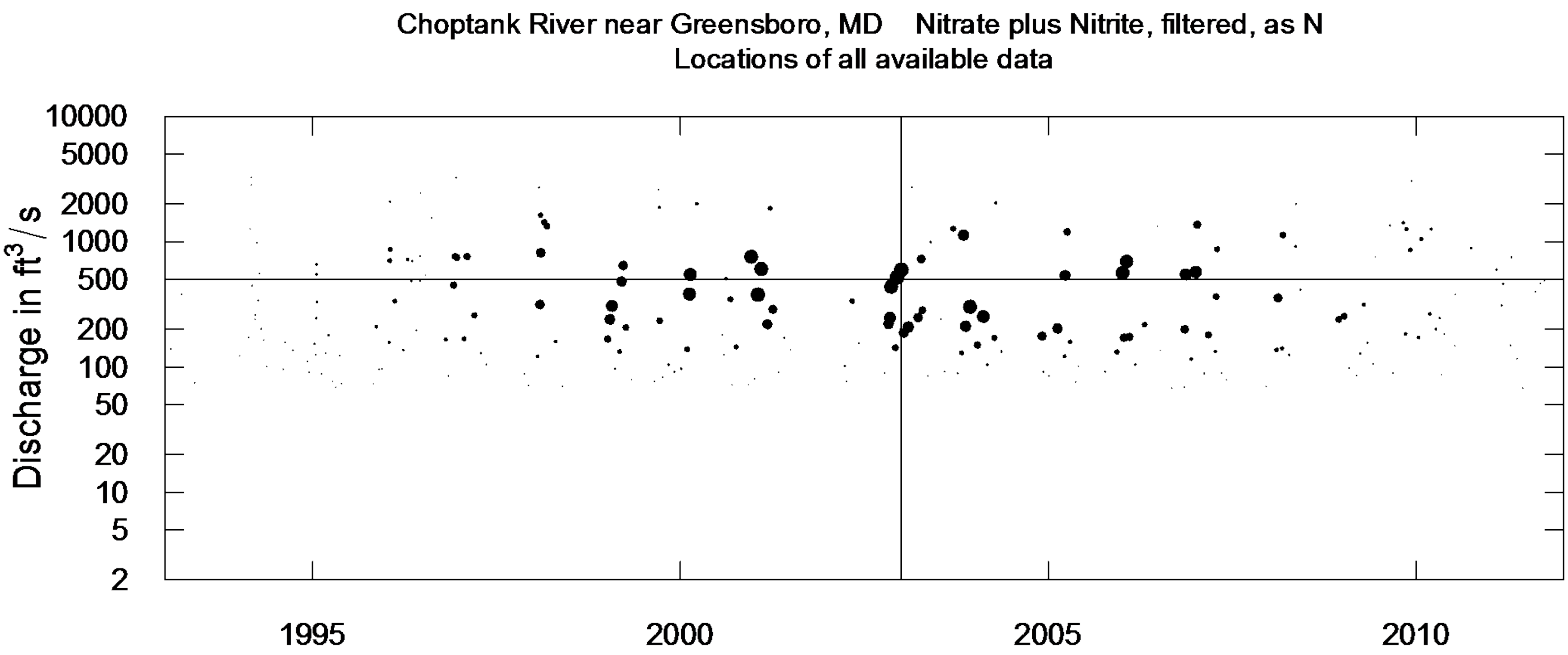
# This kind of weighted regression gets done about 6000 times to form this whole surface!!




**You must be kidding. This is a ton of computations!!**
**That's right! But it's what we need to make order out of chaos.**

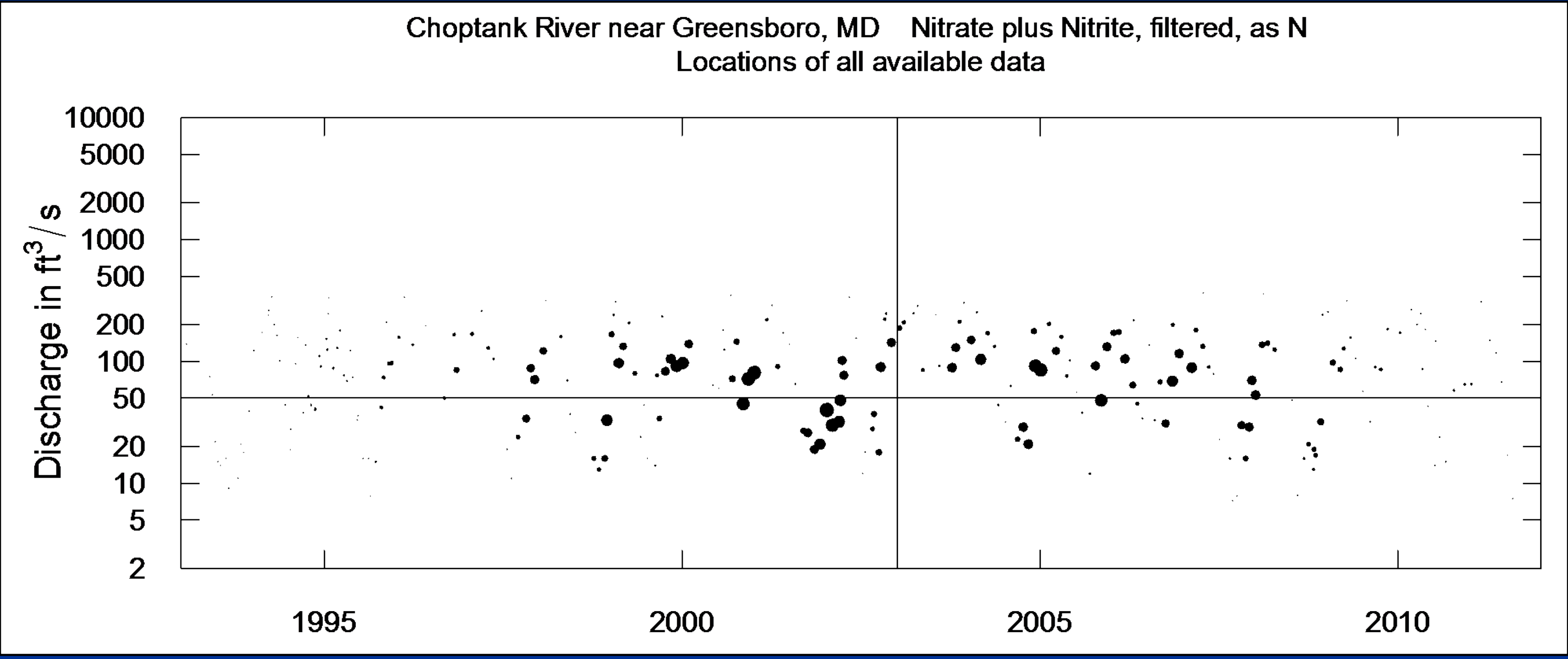
USGS

- 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



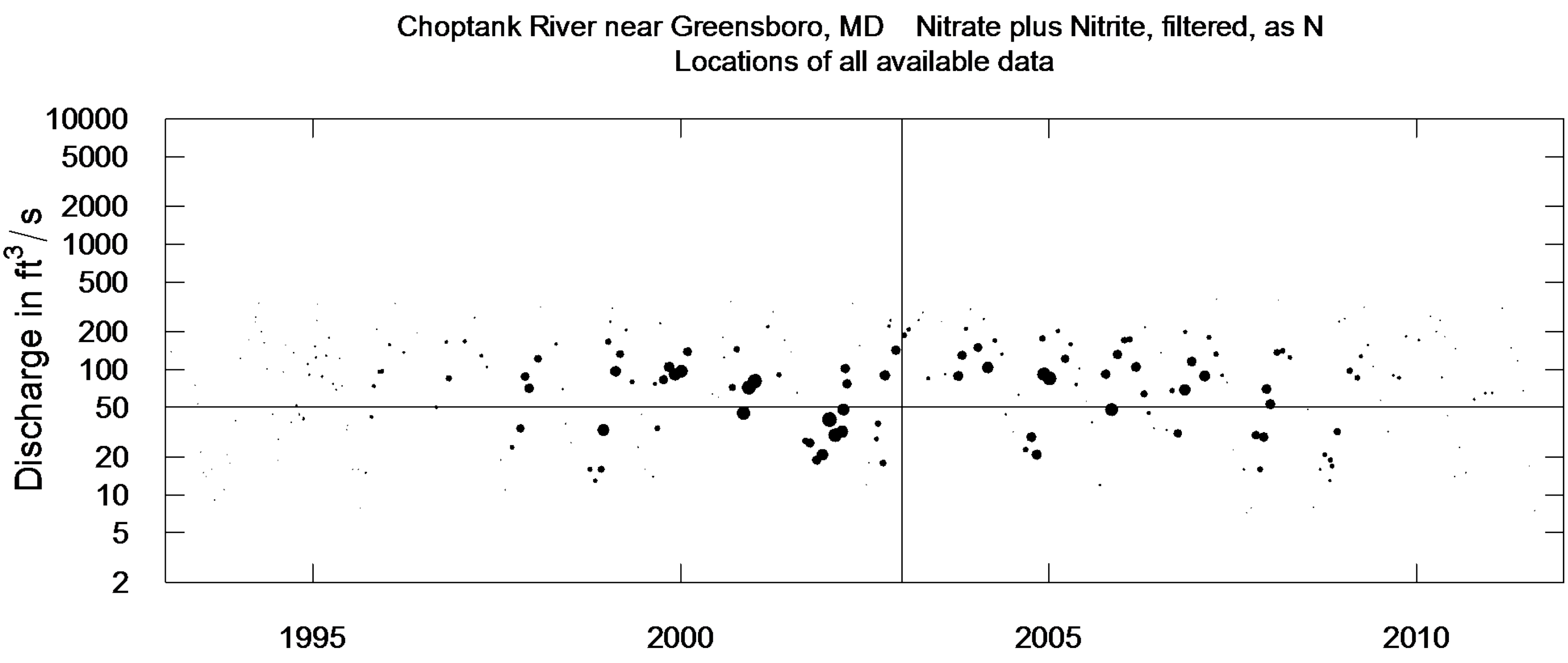
# What if we wanted to make an estimate for January 1, 2003 but for Q = 50 cfs

# Redo the weights for distance from that point

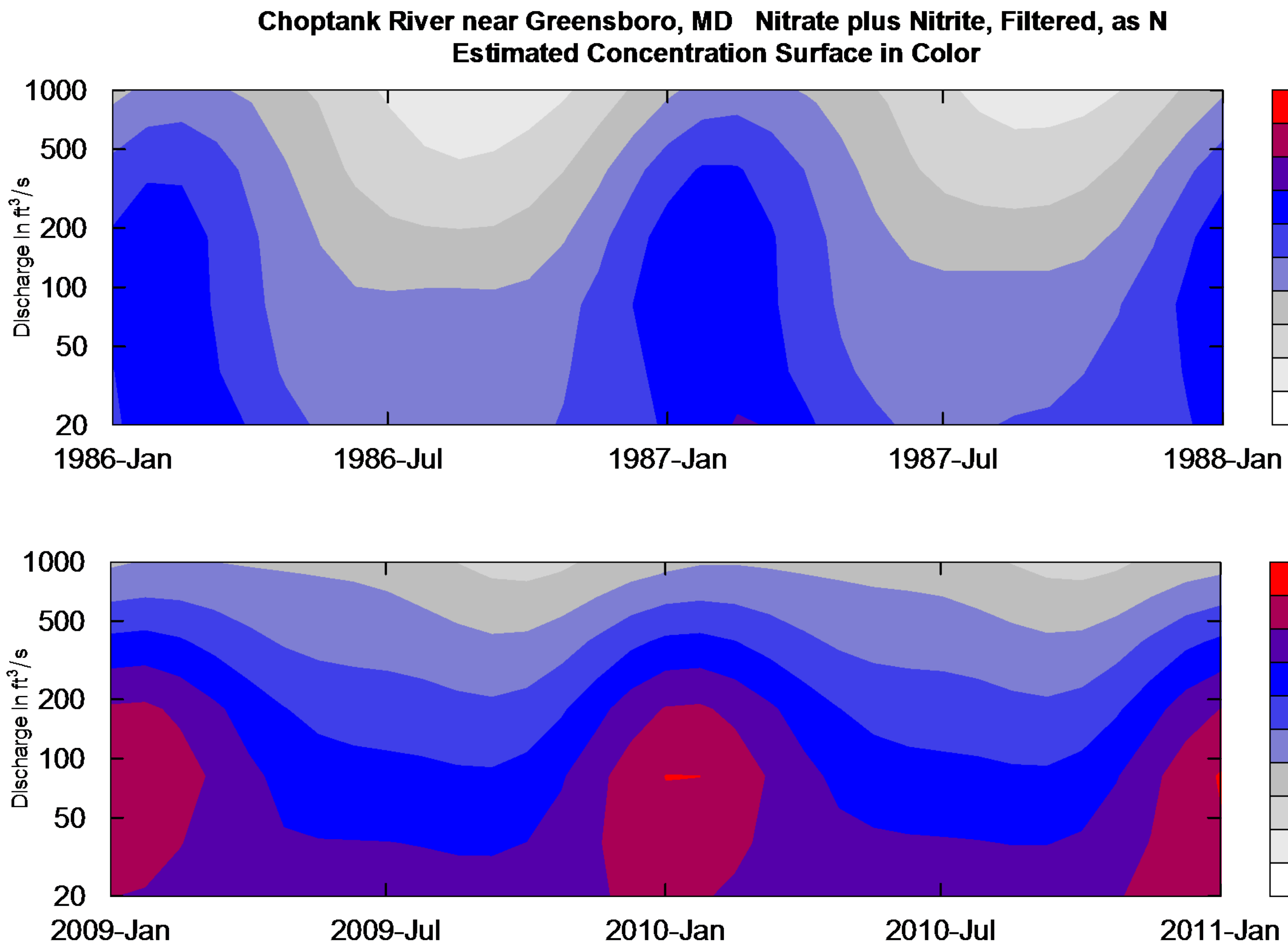


To organize the work, lets make estimates for a fine mesh of points in this space.

We will do it at 14 Q values and 177 time values, for a grid of 2,478 points.



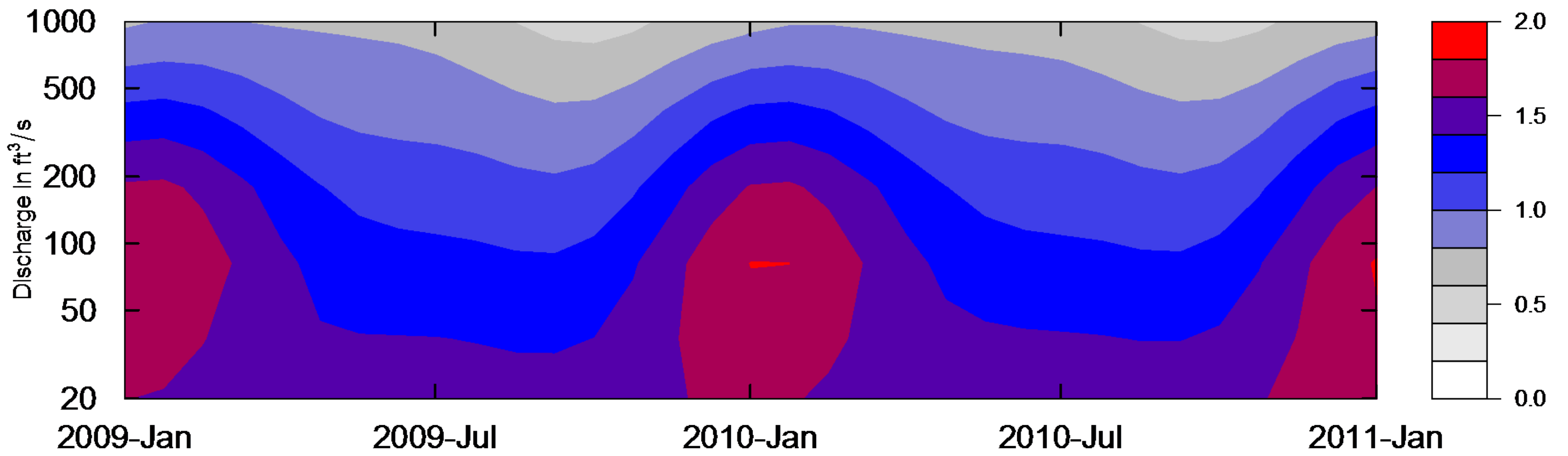
# Here are two, more detailed looks at this surface



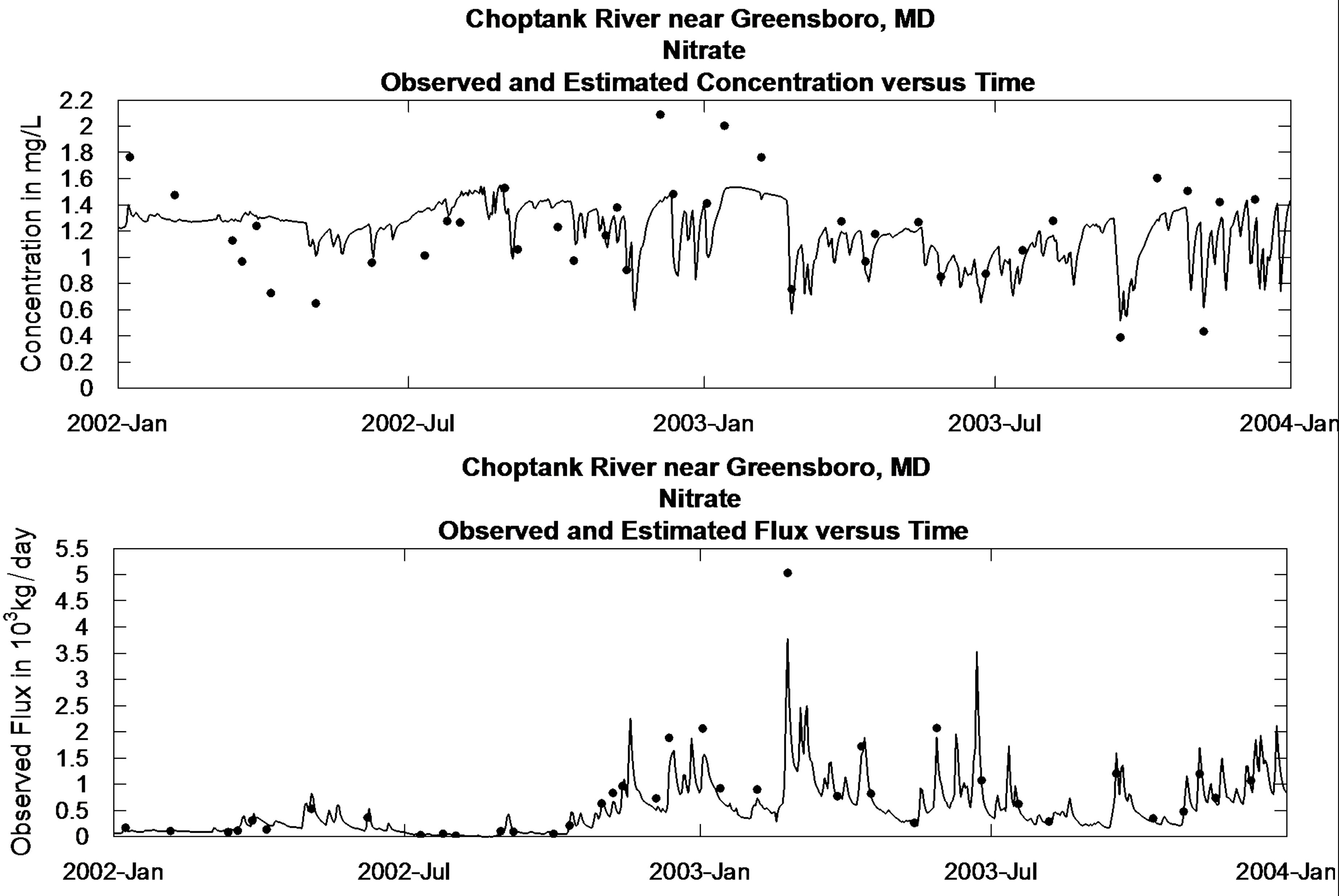
Now, for every one of 10,227 days in the record from 1985 through 2012:

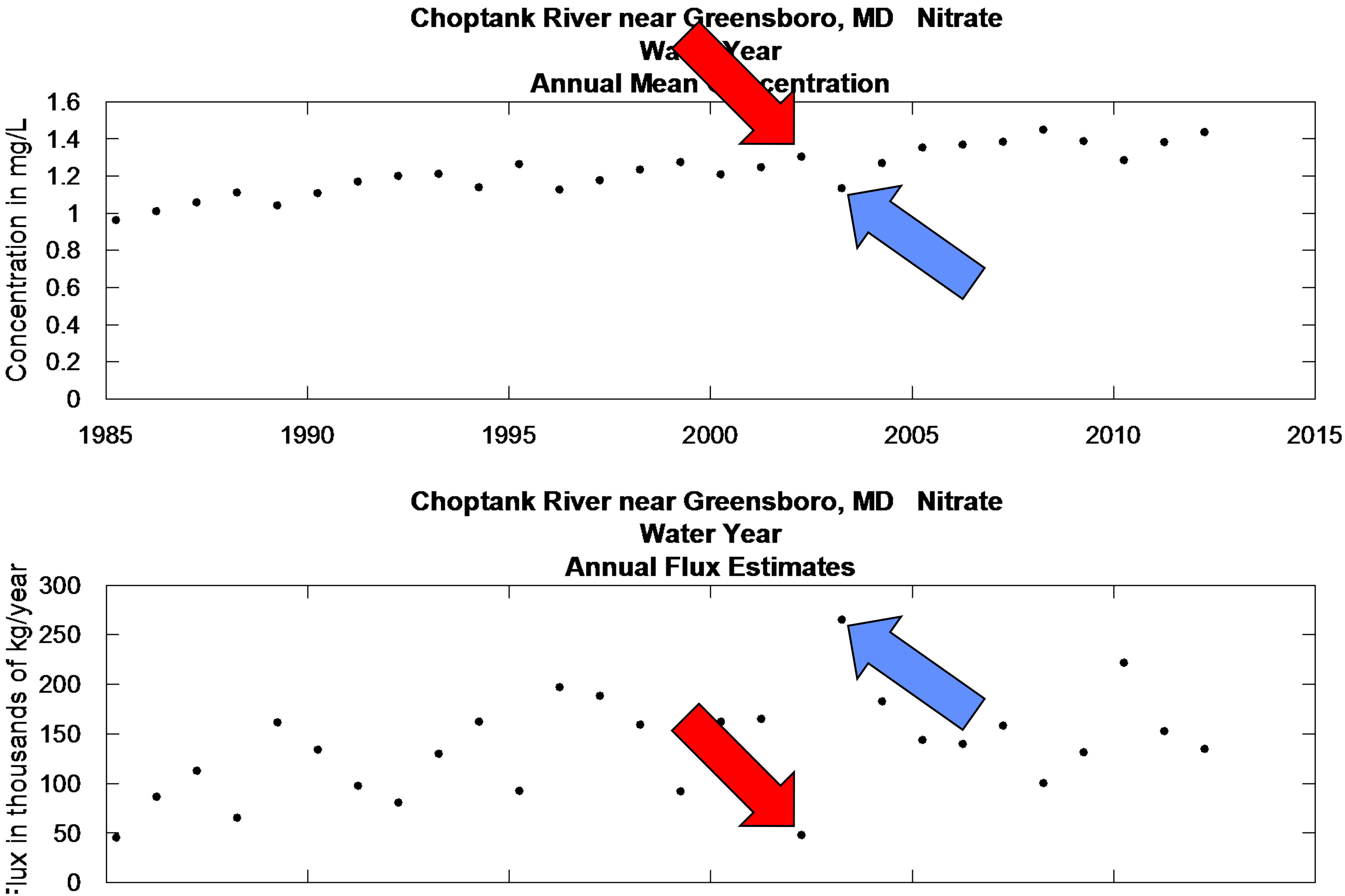
We can use the date and the observed discharge to compute the expected value of concentration.

From that value we can compute the expected value of flux.

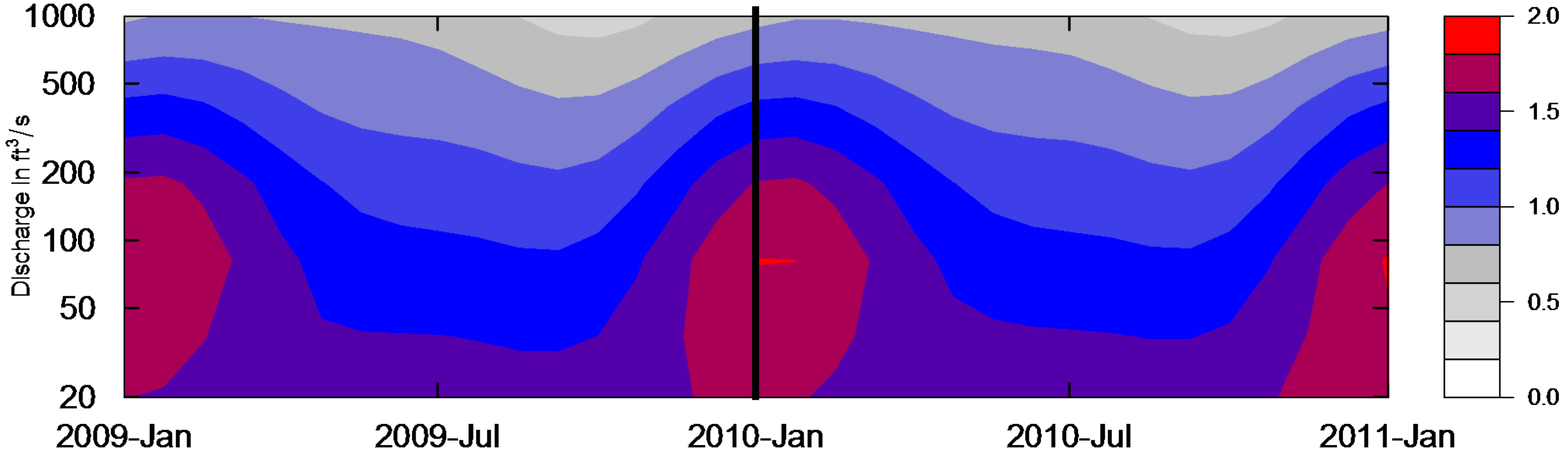


# Then we can sum these estimates by year to compute estimates of annual mean concentration & annual mean flux





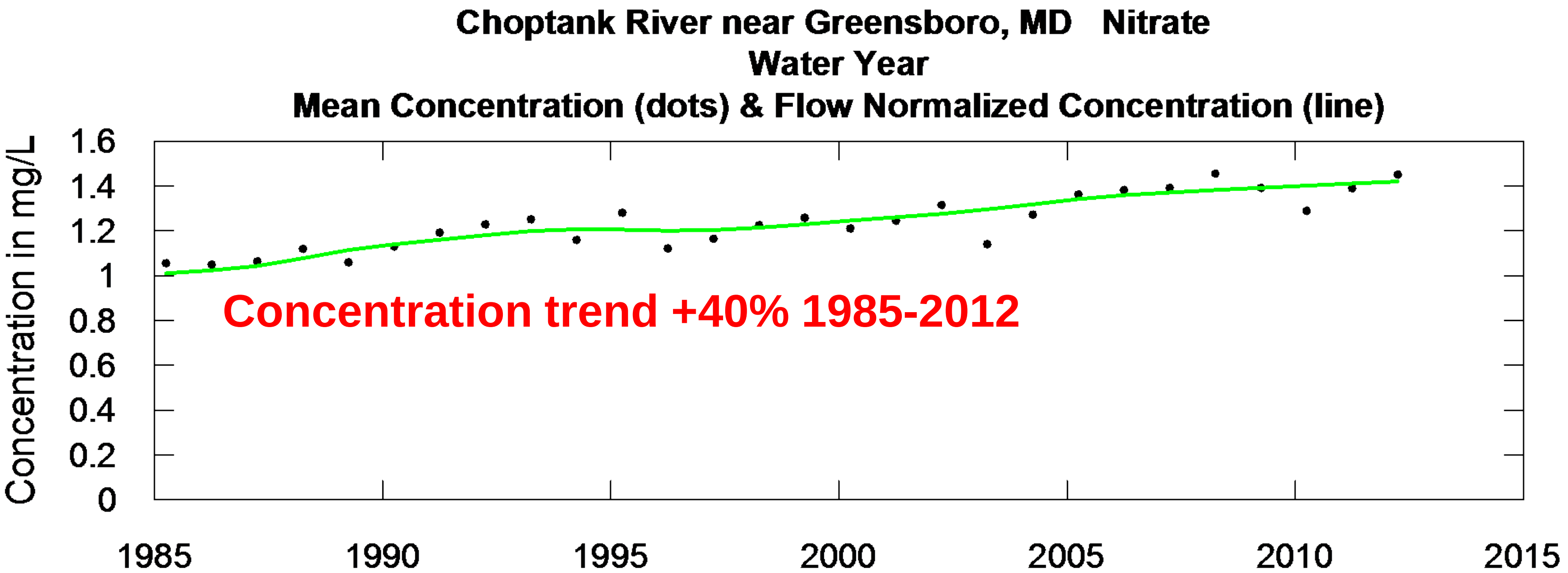

**Can we filter out this flow-driven variation to see the underlying change?**

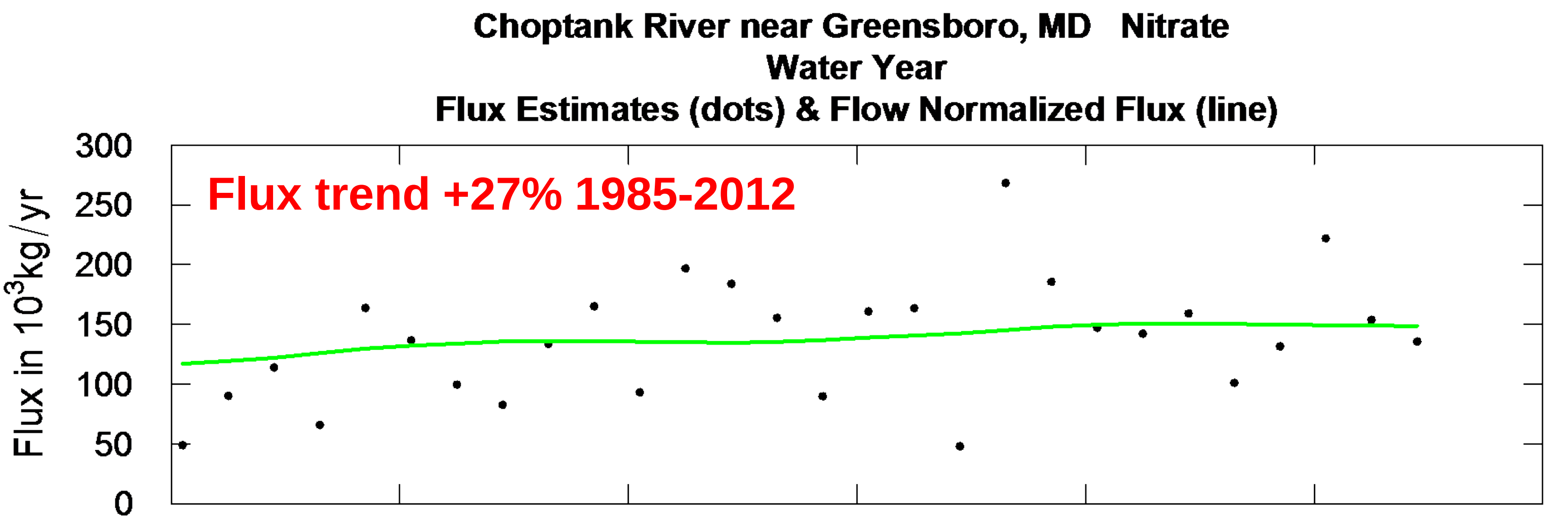



**The "flow normalized concentration" on any given day is: c=f(Q,T) integrated over the probability distribution of Q for that day of the year.**

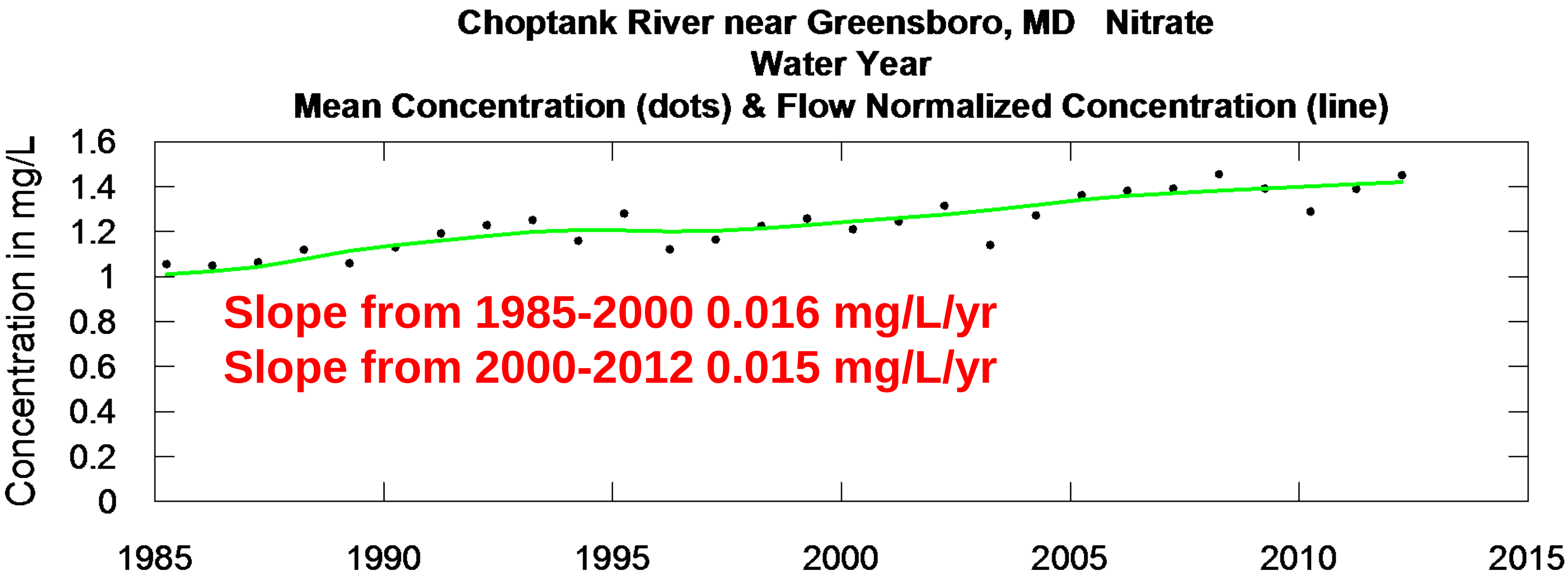
**Flow normalized flux is just c x Q integrated over discharge.**

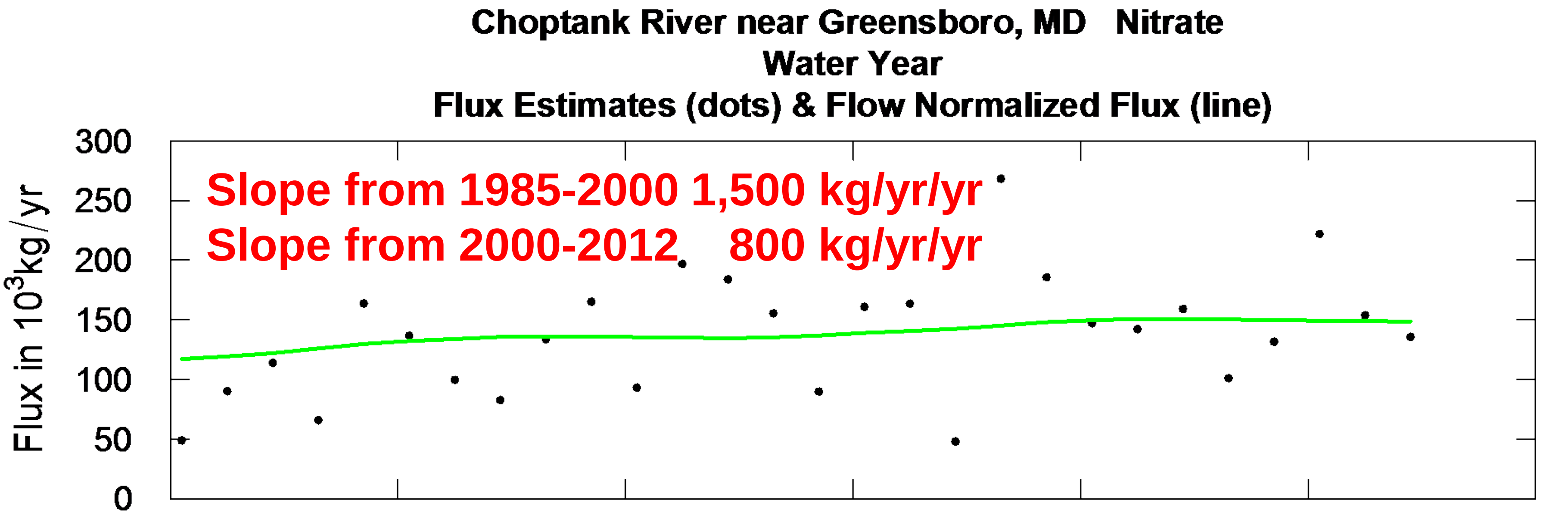
**Sum those over the year to get annual flow-normalized mean concentration and flux.**


Choptank River near Greensboro, MD Nitrate
Water Year
Mean Concentration (dots) & Flow Normalized Concentration (line)
Concentration in mg/L
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1985
1990
1995
2000
2005
2010
2015
Concentration trend +40% 1985-2012


Choptank River near Greensboro, MD Nitrate
Water Year
Flux Estimates (dots) & Flow Normalized Flux (line)
Flux in 10³kg/yr
300
250
200
150
100
50
0
Flux trend +27% 1985-2012

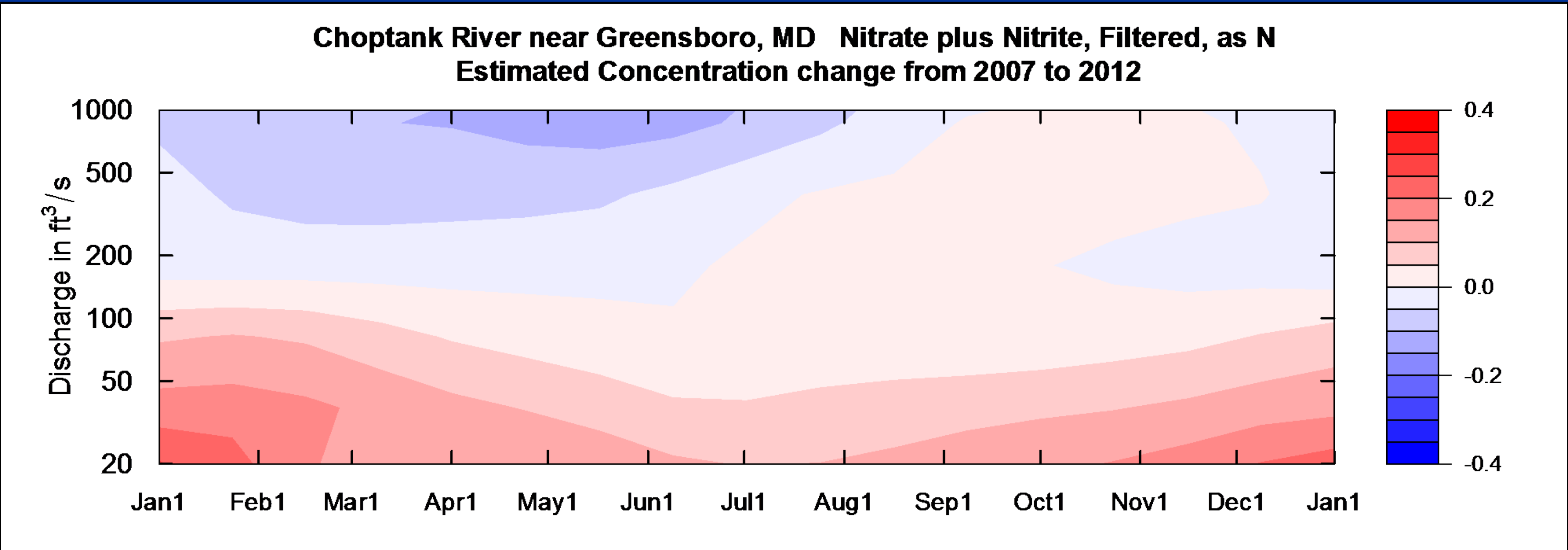
Hints that rates of increase have slowed?



Look at changes in just the last few years.

This is a graphic of differences 2007 to 2012




Hypothesis, cover crops are helping at higher flows particularly in the winter. Low flows are still responding to legacy of nitrate enriched groundwater.

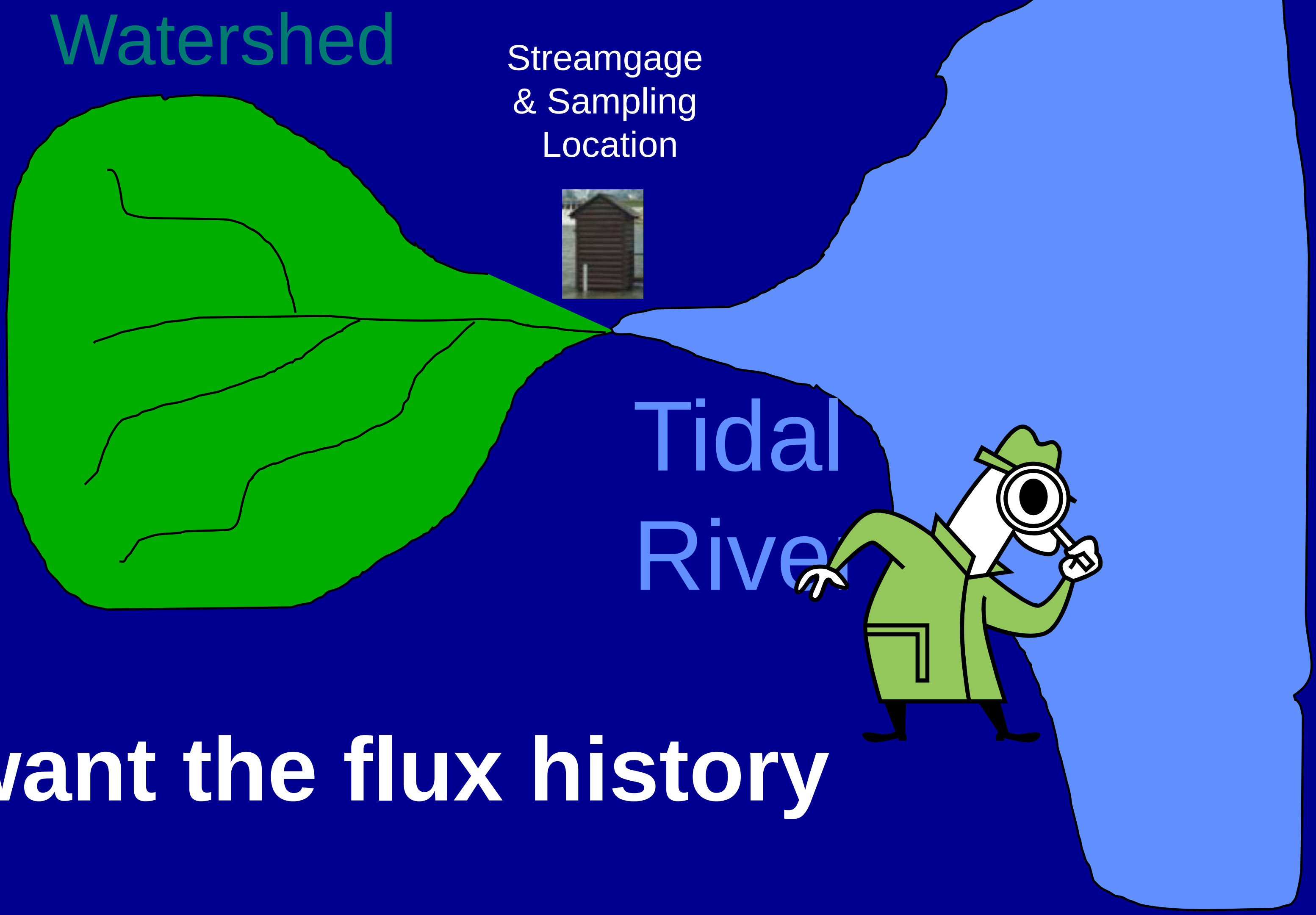
USGS

# Why all this complexity?

Different products for different purposes

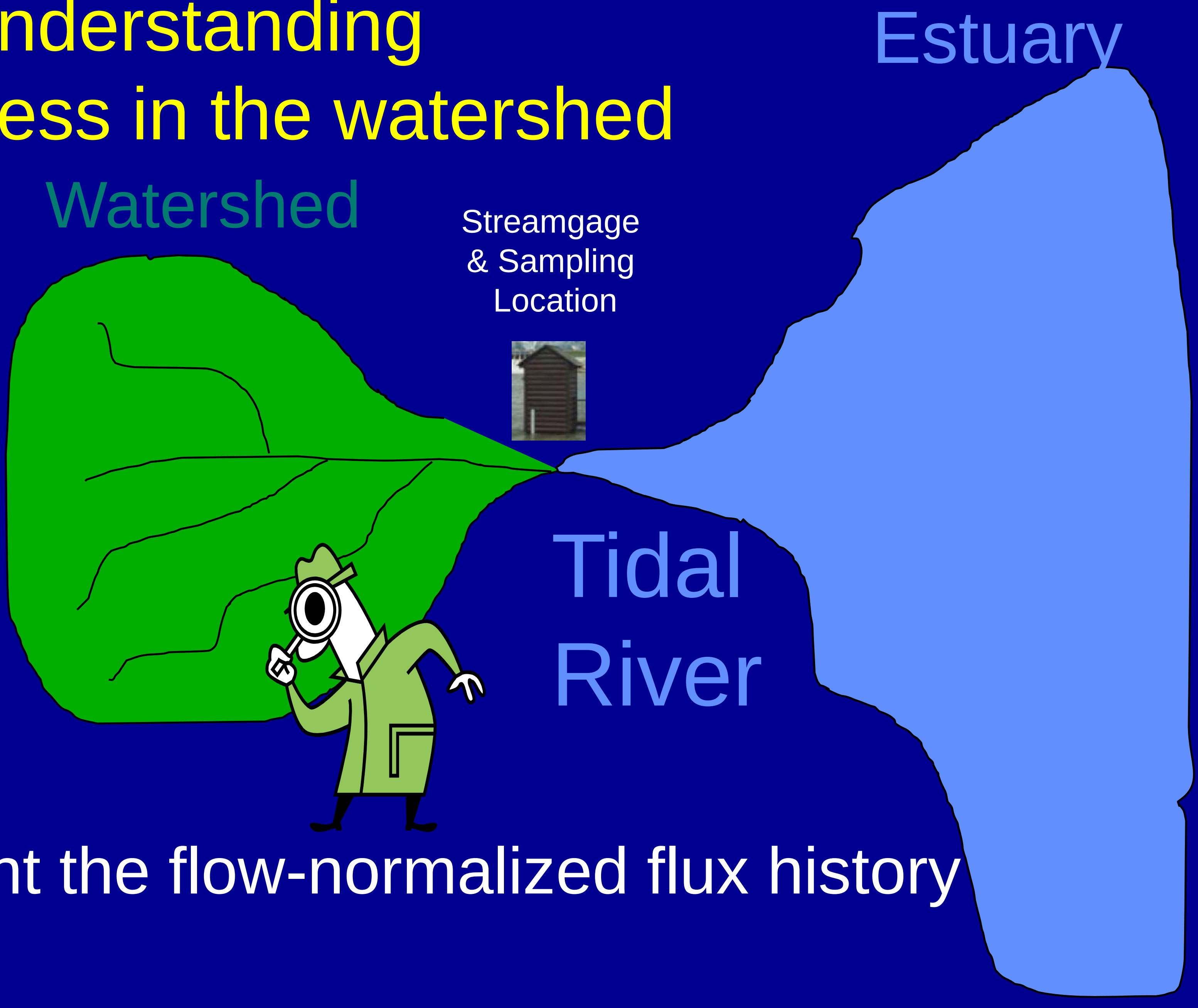
- Concentration versus flux
- Actual history versus flow-normalized history

# For understanding impact on the estuary ecosystem



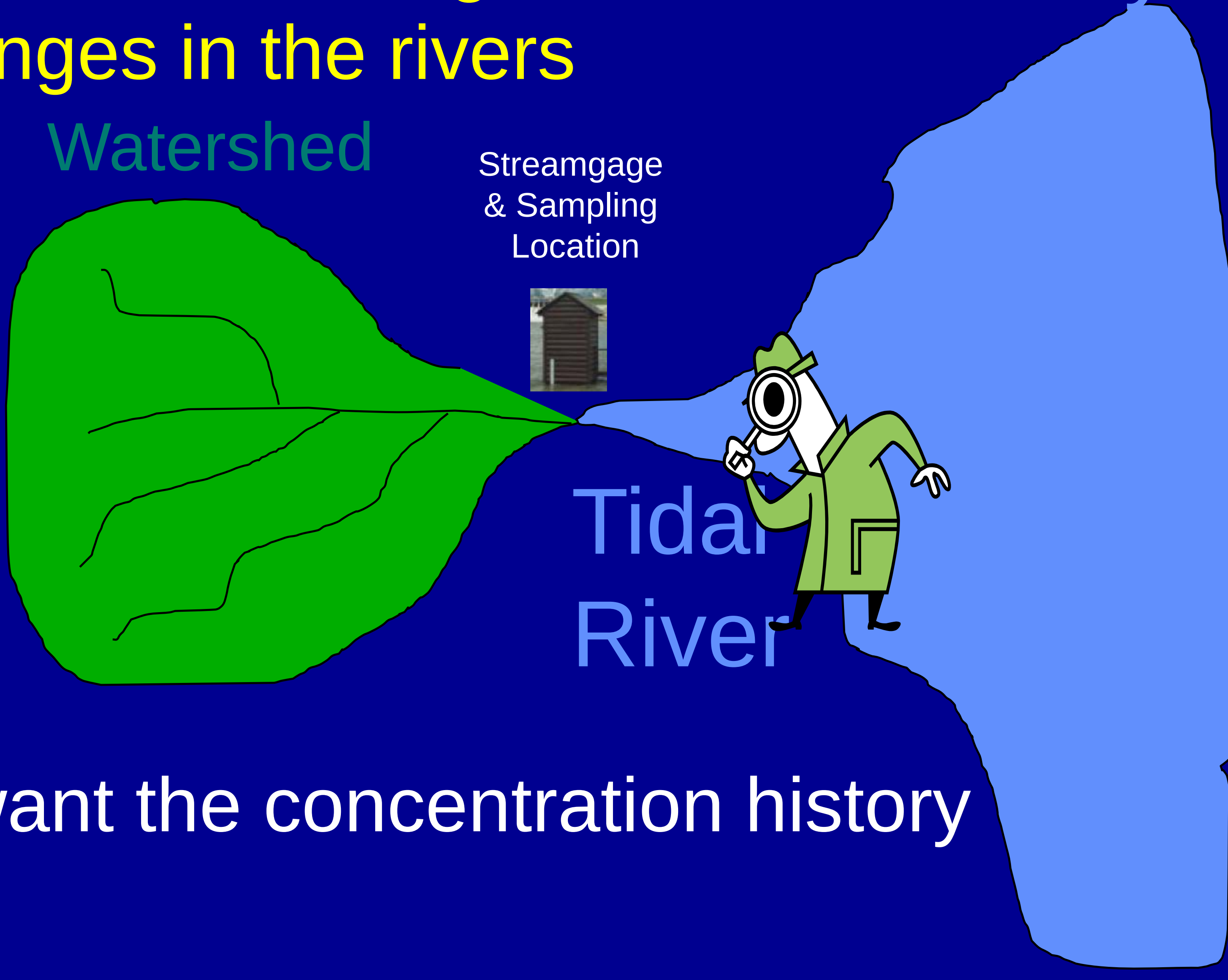

**We want the flux history**

# For understanding progress in the watershed



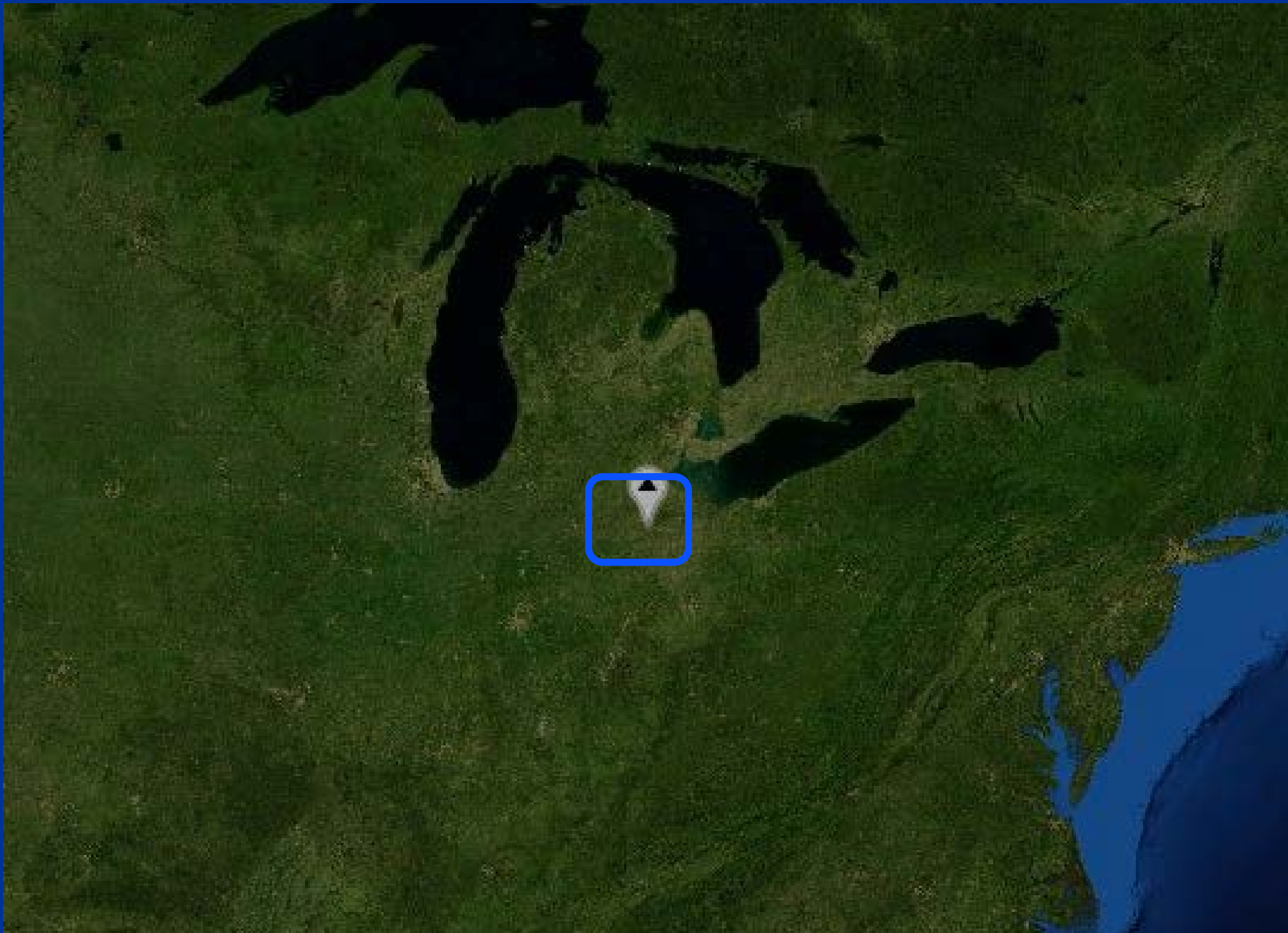

We want the flow-normalized flux history

# For understanding the changes in the rivers




We want the concentration history

# Maumee River – 16,000 km$^2$ Tributary to Lake Erie



USGS

# Cyanobacter – Lake Erie

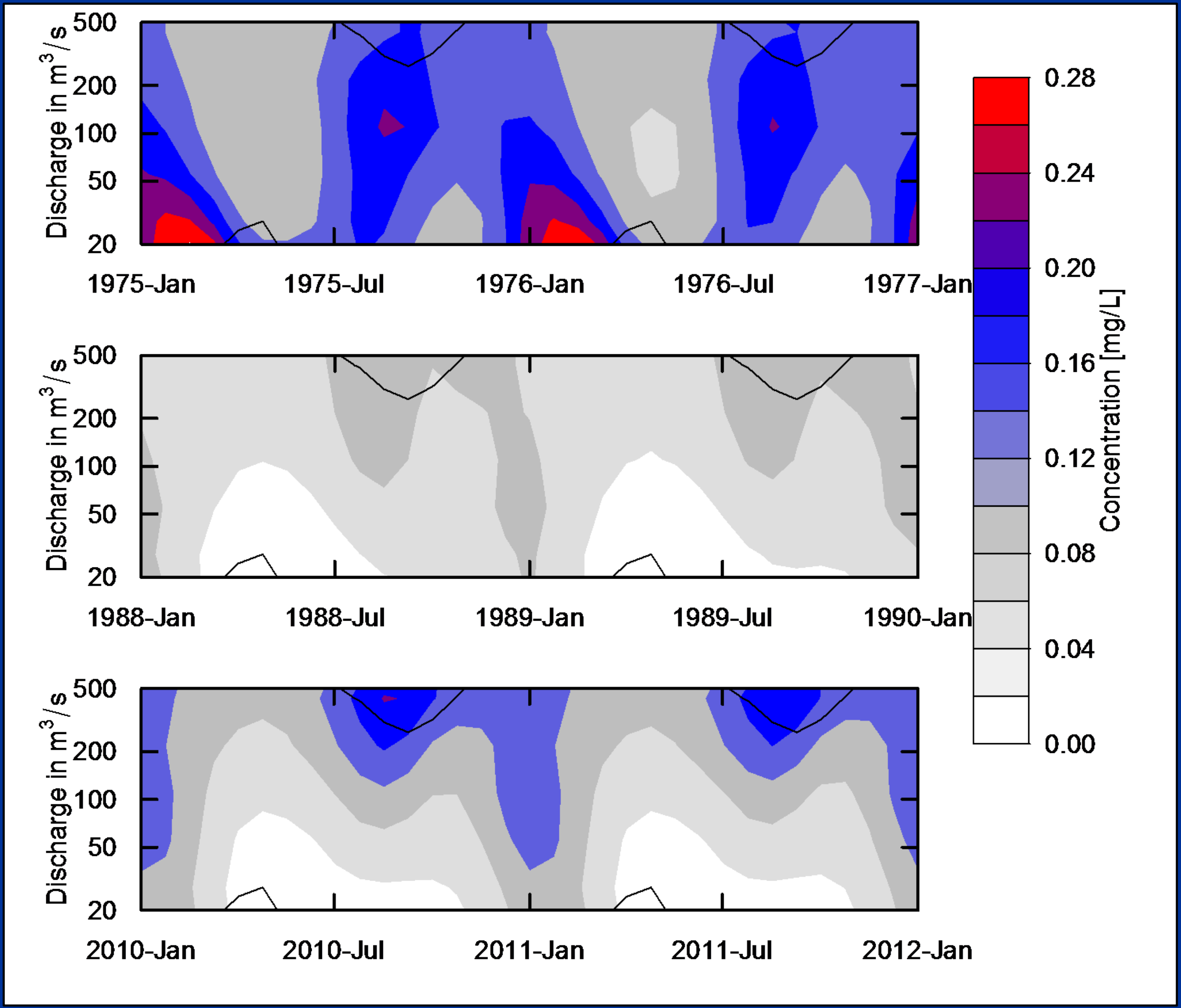
USGS

# Dissolved Reactive Phosphorus, Maumee River, at Waterville, OH

Mid 1970's

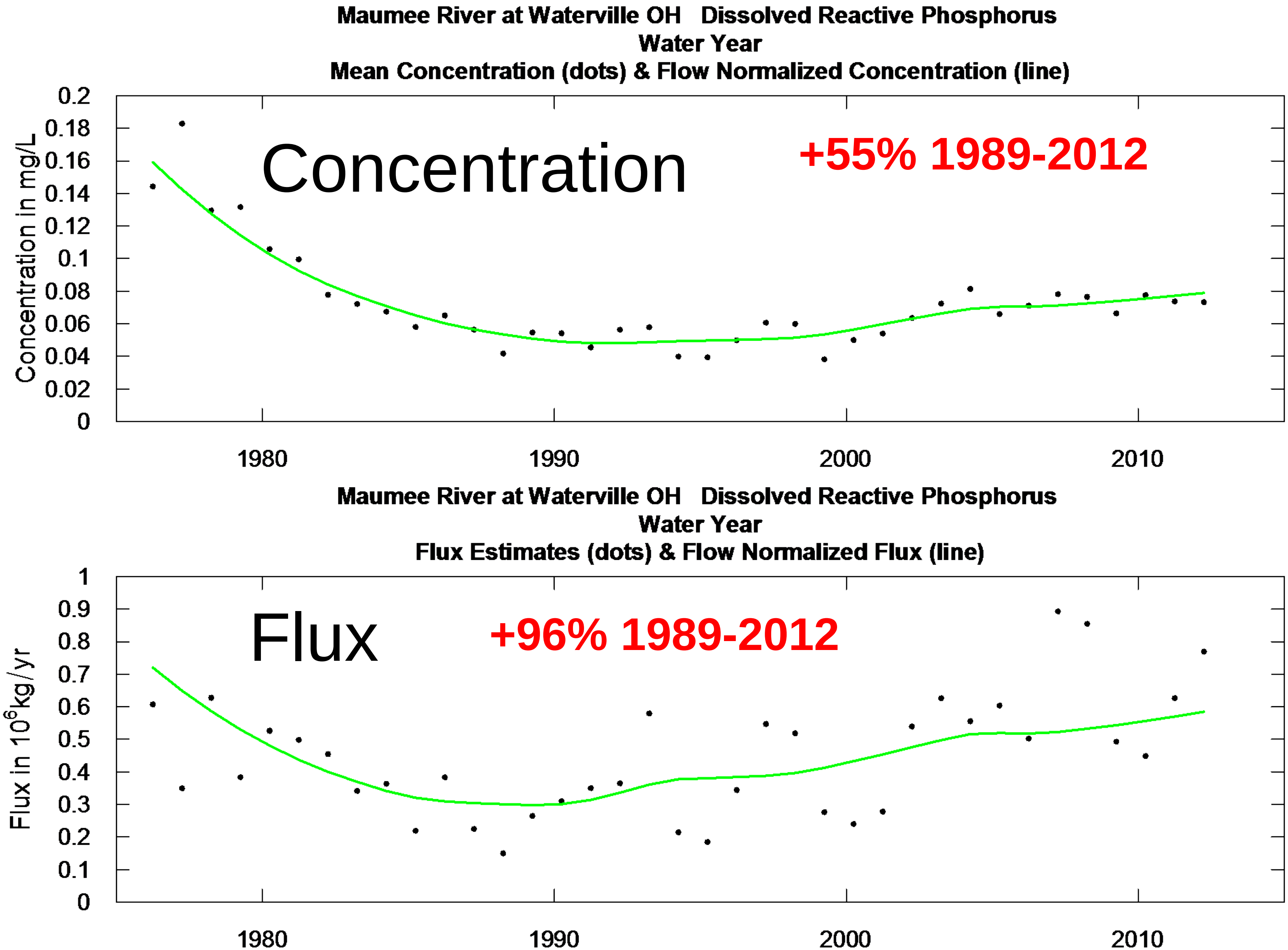
Late 1980's

Early 2010's




USGS

# Dissolved Reactive Phosphorus, Maumee River, at Waterville, OH



# dataRetrieval

- Brings data from various sources into R
- Organizes it
- Some of the functions organize for EGRET uses

# dataRetrieval functions: By information source and purpose

| Information Source | Site Query | Meta Data | Data |
| --- | --- | --- | --- |
| NWIS | | | |
| Water Quality Portal | | | |
| User-supplied files | | | |

# Functions: by information source and purpose

## EGRET functions, dataRetrieval functions

| Information Source | Site Query | Meta Data | Data |
|---|---|---|---|
| NWIS | whatNWISsites<br>whatNWISdata | readNWISInfo<br>readNWISsite<br>readNWISpCode | readNWISdata<br>readNWISDaily<br>readNWISSample<br>readNWISdv<br>readNWISuv<br>readNWISqw<br>readNWISrating<br>readNWISmeas<br>readNWISpeak<br>readNWISgwl |
| Water Quality Portal | whatWQPsites | readWQPInfo | readWQPSample<br>readWQPqw<br>readWQPdata |
| User-supplied files | | readUserInfo | readUserDaily<br>readUserSample |

# EGRET data input functions

- Can acquire data from web services (USGS or the Water Quality Portal) as well as from user-supplied files
- Includes capability for sample data, daily discharge, and meta data about site and parameter
- Structures the data to be conveniently used by the EGRET software

# Getting Started

- Need to install R (freely downloaded from http://cran.us.r-project.org/
- Next install the EGRET & dataRetrieval packages per the instructions on our wiki page.  A source for general information about the packages

**https://github.com/USGS-R/EGRET/wiki**

**As of 2014-11-20 both packages are on CRAN**

USGS

# Getting Started 2

- Then each time packages are used, they need to be loaded, using the commands

  library(dataRetrieval)

  library(EGRET)

- Once this is done you will have access to help and to the package vignettes.
- To get help with a function (such as the function readNWISSample) just type ?readNWISSample

# How can we enter data

- For the water quality sample data
  - From USGS web services
  - From Water Quality Portal (for STORET)
  - From a user supplied file
- For the daily discharge data
  - From USGS web services
  - From a user supplied file
- For the meta-data
  - From USGS or Water Quality Portal
  - From user entries

USGS

```
> library(dataRetrieval)
> library(EGRET)
> siteNumber <- "01491000"
> parameterCd <- "00631"
> startDate <- "1979-10-01"
> endDate <- "2014-09-28"
> Sample<- readNWISSample(siteNumber,parameterCD,startDate,endDate)
> summary(Sample)
```

```
> Sample<-readNWISSample("01491000","00631","1979-10-01","2014-09-28")
> summary(Sample)
      Date                ConcLow         ConcHigh          Uncen            ConcAve           Julian
 Min.   :1979-10-24   Min.   :0.176   Min.   :0.050   Min.   :0.0000   Min.   :0.025   Min.   :47412
 1st Qu.:1989-03-18   1st Qu.:0.900   1st Qu.:0.900   1st Qu.:1.0000   1st Qu.:0.900   1st Qu.:50845
 Median :1995-01-21   Median :1.130   Median :1.130   Median :1.0000   Median :1.130   Median :52980
 Mean   :1996-10-21   Mean   :1.138   Mean   :1.137   Mean   :0.9986   Mean   :1.137   Mean   :53620
 3rd Qu.:2004-10-12   3rd Qu.:1.400   3rd Qu.:1.400   3rd Qu.:1.0000   3rd Qu.:1.400   3rd Qu.:56532
 Max.   :2014-08-13   Max.   :2.430   Max.   :2.430   Max.   :1.0000   Max.   :2.430   Max.   :60124
                      NA's   :1
     Month            Day              DecYear        MonthSeq         SinDY              CosDY
 Min.   : 1.000   Min.   :  2.00   Min.   :1980   Min.   :1558   Min.   :-1.00000   Min.   :-1.000000
 1st Qu.: 3.000   1st Qu.: 83.75   1st Qu.:1989   1st Qu.:1671   1st Qu.:-0.62876   1st Qu.:-0.686704
 Median : 6.000   Median :157.00   Median :1995   Median :1741   Median : 0.19667   Median :-0.021513
 Mean   : 6.082   Mean   :169.23   Mean   :1997   Mean   :1762   Mean   : 0.09121   Mean   :-0.001613
 3rd Qu.: 9.000   3rd Qu.:256.25   3rd Qu.:2005   3rd Qu.:1858   3rd Qu.: 0.79226   3rd Qu.: 0.700615
 Max.   :12.000   Max.   :364.00   Max.   :2015   Max.   :1976   Max.   : 0.99992   Max.   : 0.999667

> length(Sample$Date)
[1] 708
```

# Censored values

All concentration data are treated as intervals.

•Let’s say reported concentration is 1 mg/L
•We code this as: ConcLow = 1.0 and ConcHigh = 1.0
•The interval for this data point is then 1.0 to 1.0

•For a value reporte as “less than 1.0 mg/L”
•We code this as: ConcLow = NA and ConcHigh = 1.0
•The interval for this data point is then 0.0 to 1.0

All of the “weighted regressions” in WRTDS are really “survival regression” (the function survreg in R) which is design for data reported as an interval.

USGS

# Censored values and compound analytes

**Sometimes an 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**

**The two analyte values were reported as <0.2 and 0.9 mg/L respectively. Therefore, this data point has ConcLow = 0.9 and ConcHigh = 1.1.**

- **The conventional left-censored approach calls this (0,1.1)**
- **WRTDS calls this (0.9 to 1.1)**

USGS

# EPA Storet Data from the Water Quality Portal

```
> siteNumber<-"IL_EPA_WQX-BPK-07"
> characteristicName<-"Inorganic nitrogen (nitrate and nitrite)"
> startDate<-"2005-01-01"
> endDate<-"2013-12-31"
> Sample<-readWQPSample(siteNumber,characteristicName,startDate,endDate)
> summary(Sample)
      Date                ConcLow           ConcHigh            Uncen        ConcAve              Julian
 Min.   :2005-01-24   Min.   : 0.041   Min.   : 0.0180   Min.   :0.0   Min.   : 0.0090   Min.   :56636
 1st Qu.:2009-02-08   1st Qu.: 3.658   1st Qu.: 0.1905   1st Qu.:1.0   1st Qu.: 0.1905   1st Qu.:58112
 Median :2010-01-07   Median : 5.205   Median : 4.5950   Median :1.0   Median : 4.5950   Median :58446
 Mean   :2009-05-21   Mean   : 4.834   Mean   : 3.8710   Mean   :0.8   Mean   : 3.8692   Mean   :58215
 3rd Qu.:2011-03-03   3rd Qu.: 6.560   3rd Qu.: 6.2250   3rd Qu.:1.0   3rd Qu.: 6.2250   3rd Qu.:58866
 Max.   :2011-11-28   Max.   :11.400   Max.   :11.4000   Max.   :1.0   Max.   :11.4000   Max.   :59135
                      NA's   :8
     Month              Day            DecYear         MonthSeq         SinDY                CosDY
 Min.   : 1.000   Min.   : 10.0   Min.   :2005   Min.   :1861   Min.   :-0.997917   Min.   :-0.99867
 1st Qu.: 4.000   1st Qu.: 96.5   1st Qu.:2009   1st Qu.:1910   1st Qu.:-0.739146   1st Qu.:-0.69630
 Median : 6.500   Median :184.0   Median :2010   Median :1921   Median : 0.000000   Median :-0.14961
 Mean   : 6.425   Mean   :179.5   Mean   :2009   Mean   :1913   Mean   :-0.009202   Mean   :-0.07491
 3rd Qu.: 9.000   3rd Qu.:256.2   3rd Qu.:2011   3rd Qu.:1934   3rd Qu.: 0.740889   3rd Qu.: 0.62203
 Max.   :12.000   Max.   :349.0   Max.   :2012   Max.   :1943   Max.   : 0.999250   Max.   : 0.98666

> length(Sample$Date)
[1] 40
```

USGS

# Daily <- readNWISDaily(siteNumber,"00060",startDate,endDate)

```
> Daily<-readNWISDaily("01491000","00060","1979-10-01","2014-09-28")
There are 12782 data points, and 12782 days.
> summary(Daily)
      Date                  Q                  Julian          Month             Day            DecYear    
 Min.   :1979-10-01   Min.   :  0.00991   Min.   :47389   Min.   : 1.000   Min.   :  1.0   Min.   :1980  
 1st Qu.:1988-06-30   1st Qu.:  0.96277   1st Qu.:50584   1st Qu.: 4.000   1st Qu.: 93.0   1st Qu.:1988  
 Median :1997-03-30   Median :  2.46357   Median :53780   Median : 7.000   Median :184.0   Median :1997  
 Mean   :1997-03-30   Mean   :  4.17317   Mean   :53780   Mean   : 6.522   Mean   :183.7   Mean   :1997  
 3rd Qu.:2005-12-28   3rd Qu.:  4.72891   3rd Qu.:56975   3rd Qu.:10.000   3rd Qu.:275.0   3rd Qu.:2006  
 Max.   :2014-09-28   Max.   :246.35656   Max.   :60170   Max.   :12.000   Max.   :366.0   Max.   :2015  

    MonthSeq     Qualifier               i                LogQ                Q7                 Q30          
 Min.   :1558   Length:12782       Min.   :    1   Min.   :-4.61412   Min.   : 0.01808   Min.   : 0.09606  
 1st Qu.:1662   Class :character   1st Qu.: 3196   1st Qu.:-0.03794   1st Qu.: 1.00727   1st Qu.: 1.21102  
 Median :1767   Mode  :character   Median : 6392   Median : 0.90161   Median : 2.63549   Median : 2.97421  
 Mean   :1767                      Mean   : 6392   Mean   : 0.78216   Mean   : 4.17433   Mean   : 4.17615  
 3rd Qu.:1872                      3rd Qu.: 9587   3rd Qu.: 1.55370   3rd Qu.: 5.09804   3rd Qu.: 5.88802  
 Max.   :1977                      Max.   :12782   Max.   : 5.50678   Max.   :84.00395   Max.   :25.47478  
                                                                      NA's   :6          NA's   :29        
> length(Daily$Date)
[1] 12782
```

# Storing the metadata

- For NWIS data  INFO<-readNWISInfo(siteNumber,parameterCD)

- Similar function for the Water Quality Portal

- The contents of INFO are used to label tables and figures as well as document the site and constituent information

- Creates a system of abbreviations to keep track of workspace files

USGS

```
> INFO<-readNWISInfo(siteNumber,parameterCd)
```

```
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):

<cr>
```

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

**If you are using supplied data, you can run the command:**

```
> INFO <- readNWISInfo(“”,””)
```

**or to import a file:**

```
> INFO <- readUserInfo(filePath, filename)
```

**The program will then prompt you to enter metadata about your site and study.**

**All metadata is voluntary except the following required fields:**

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

USGS

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

> eList<-mergeReport(INFO,Daily,Sample)

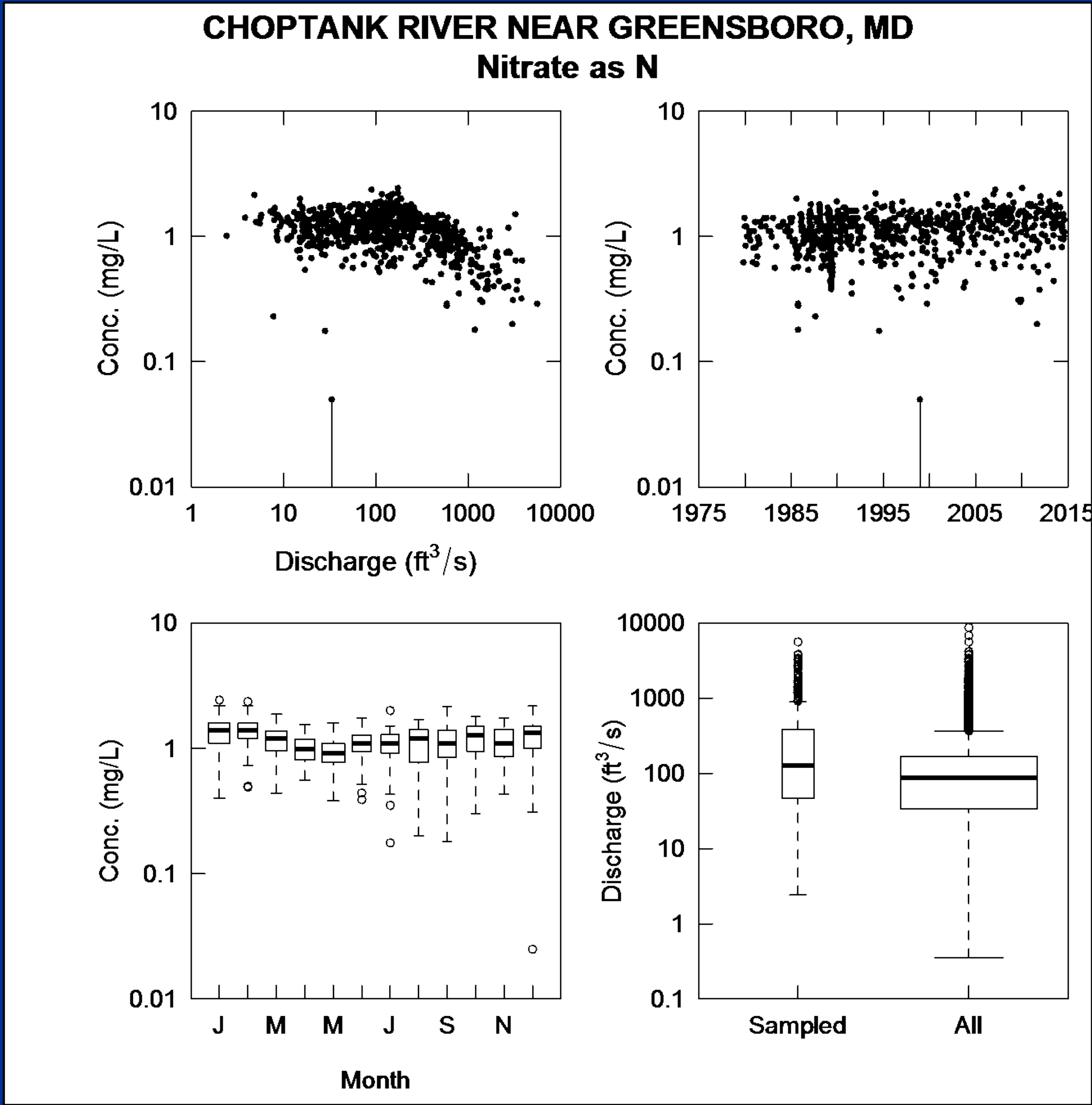
```
> eList<-mergeReport(INFO,Daily,Sample)

 Discharge Record is 12782 days long, which is 35 years
 First day of the discharge record is 1979-10-01 and last day is 2014-09-28
 The water quality record has 708 samples
 The first sample is from 1979-10-24 and the last sample is from 2014-08-13
 Discharge: Minimum, mean and maximum 0.00991 4.17 246
 Concentration: Minimum, mean and maximum 0.05 1.1 2.4
 Percentage of the sample values that are censored is 0.14 %
```

**eList is a named list that contains the 4 objects that contain all the data and results:**

**INFO, Daily, Sample, and surfaces**

# > multiPlotDataOverview(eList,qUnit=1)

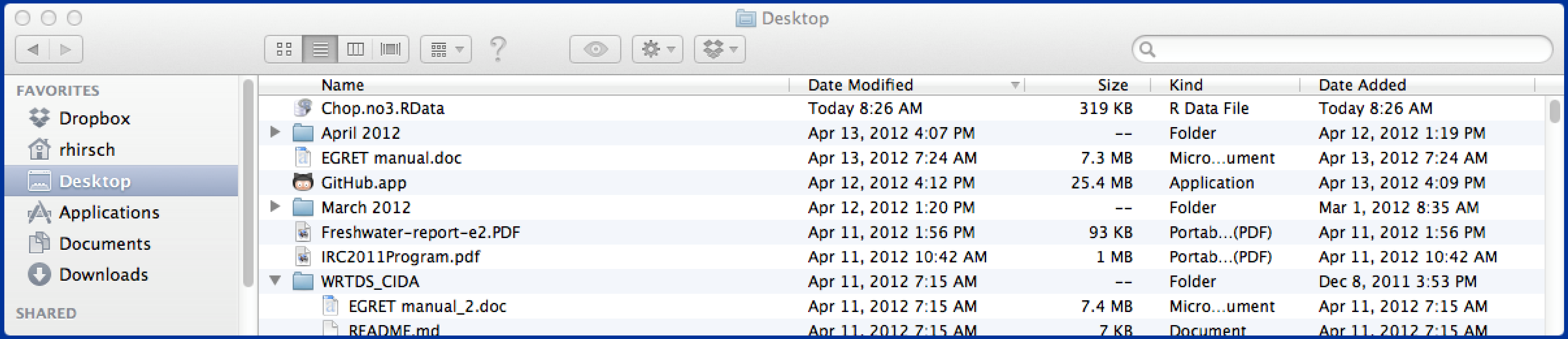
**Let's look at the data before we proceed, the function is:**




USGS

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

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





Save it over and over as you proceed and add results

# We now have 3 data frames

- Sample (708 rows, 14 columns)
- Daily (12,782 rows, 12 columns)
- INFO (1 row, 53 columns)

**They are all stored in the named list called eList**

USGS

# A short digression into other things you can do with dataRetrieval, not related to EGRET

# Unit values retrieval (not used by EGRET)

- Raccoon River at Van Metre, IA
- Nitrate sensor data
- March – Sept 2013

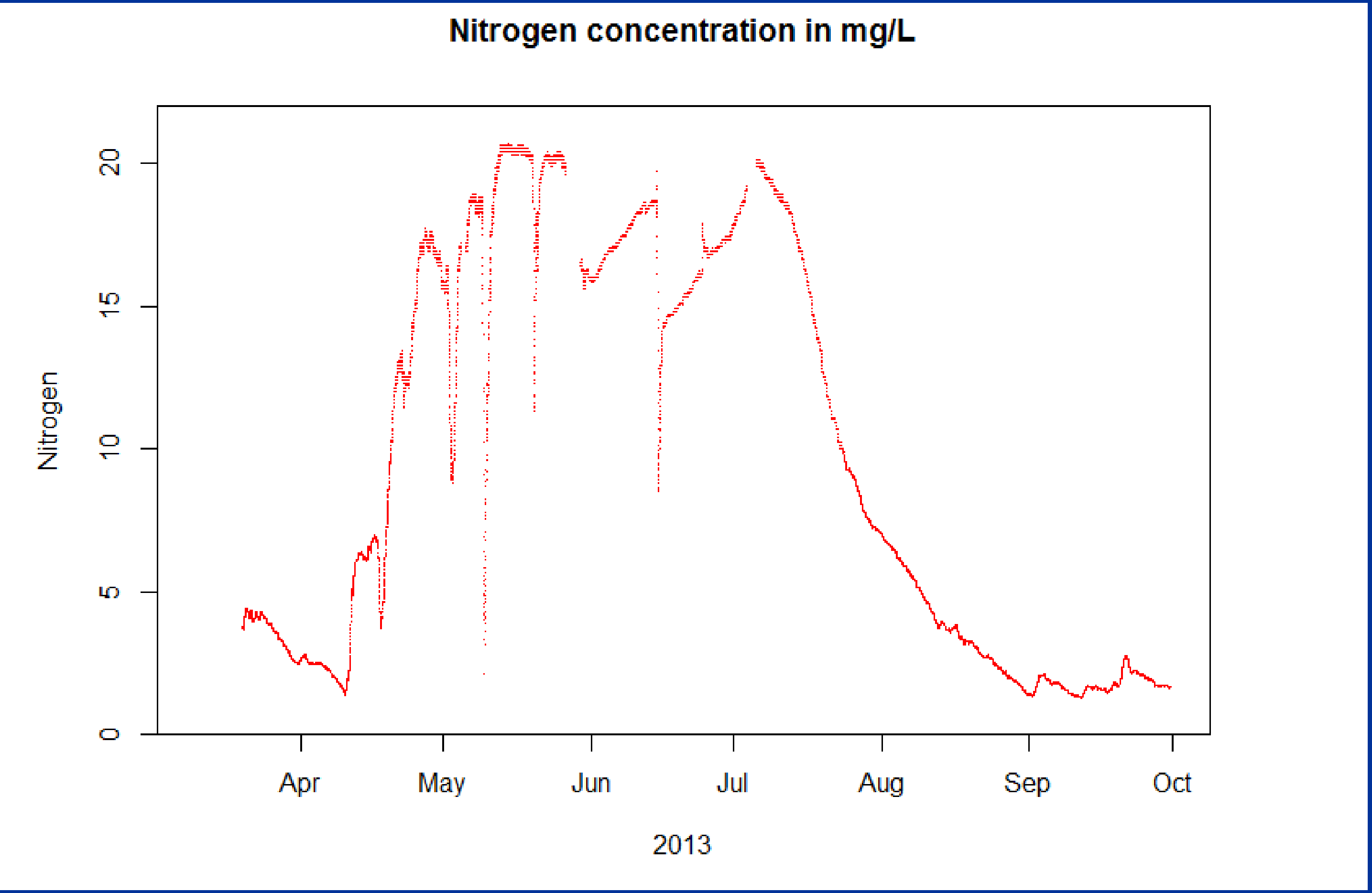
```
> Unit<-readNWISuv("05484500",parameterCd=c("99133","00060"),"2013-03-01","2013-09-30")
> summary(Unit)
  agency_cd           site_no             datetime                       tz_cd           X01_00060_00011
 Length:19568       Length:19568       Min.   :2013-03-10 00:00:00   Length:19568       Min.   :  108
 Class :character   Class :character   1st Qu.:2013-04-30 00:26:15   Class :character   1st Qu.:  331
 Mode  :character   Mode  :character   Median :2013-06-21 00:22:30   Mode  :character   Median : 1320
                                       Mean   :2013-06-20 14:54:09                      Mean   : 3370
                                       3rd Qu.:2013-08-10 23:18:45                      3rd Qu.: 4180
                                       Max.   :2013-09-30 23:45:00                      Max.   :24600
                                                                                        NA's   :86
 X01_00060_00011_cd X18_99133_00011  X18_99133_00011_cd
 Length:19568       Min.   : 1.260   Length:19568
 Class :character   1st Qu.: 2.540   Class :character
 Mode  :character   Median : 7.250   Mode  :character
                    Mean   : 9.651
                    3rd Qu.:16.900
                    Max.   :20.700
                    NA's   :1848
> Unit<-na.omit(Unit)
```

We have 19,568 time steps

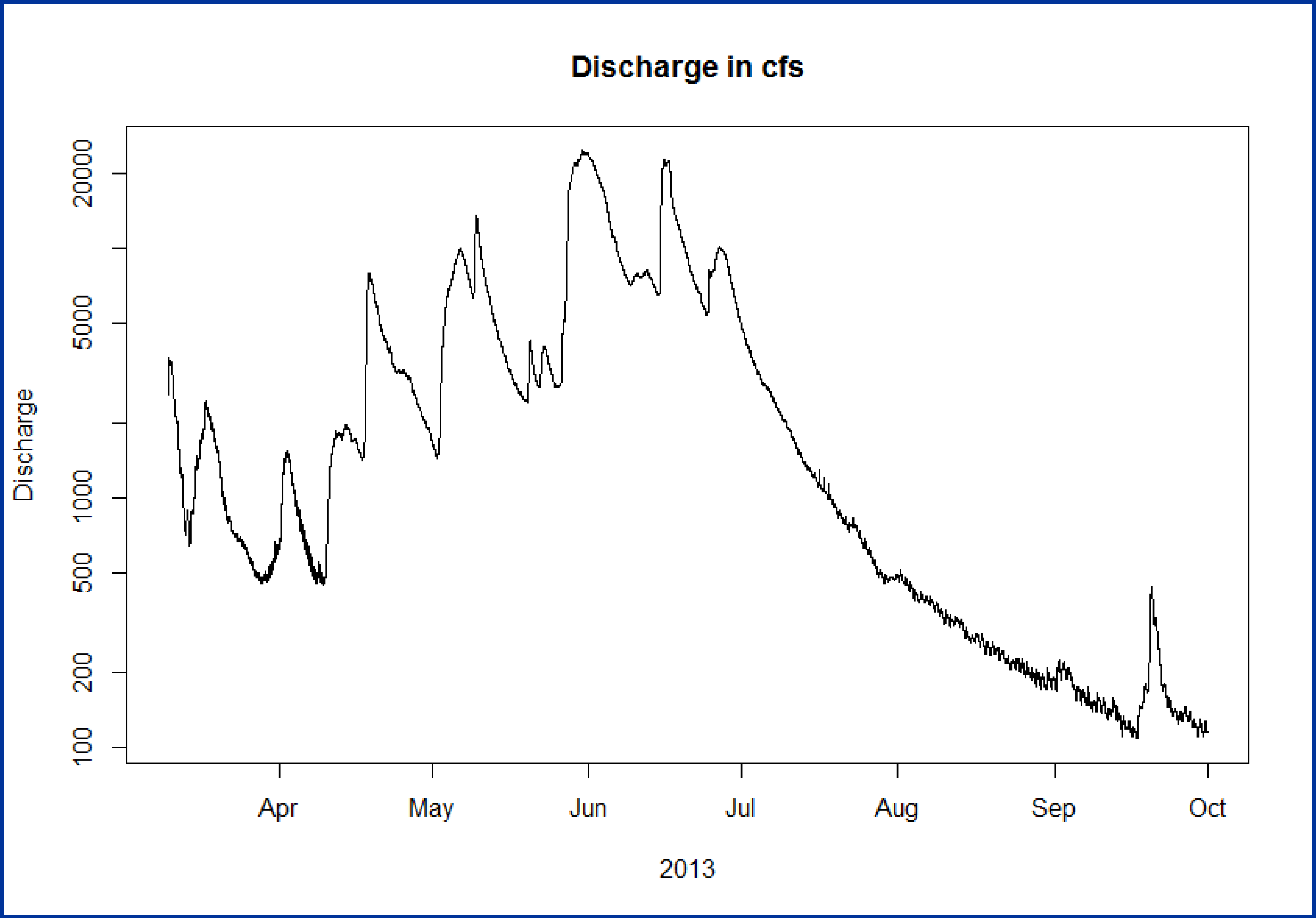
Discharge missing at 86 of them

Nitrate missing at 1848 of them

```
> with(Unit, plot(datetime,X18_99133_00011,
            col="red",pch=".",ylim=c(0,22),yaxs="i",
            xlab="2013",ylab="Nitrogen",
            main="Nitrogen concentration in mg/L"))
```

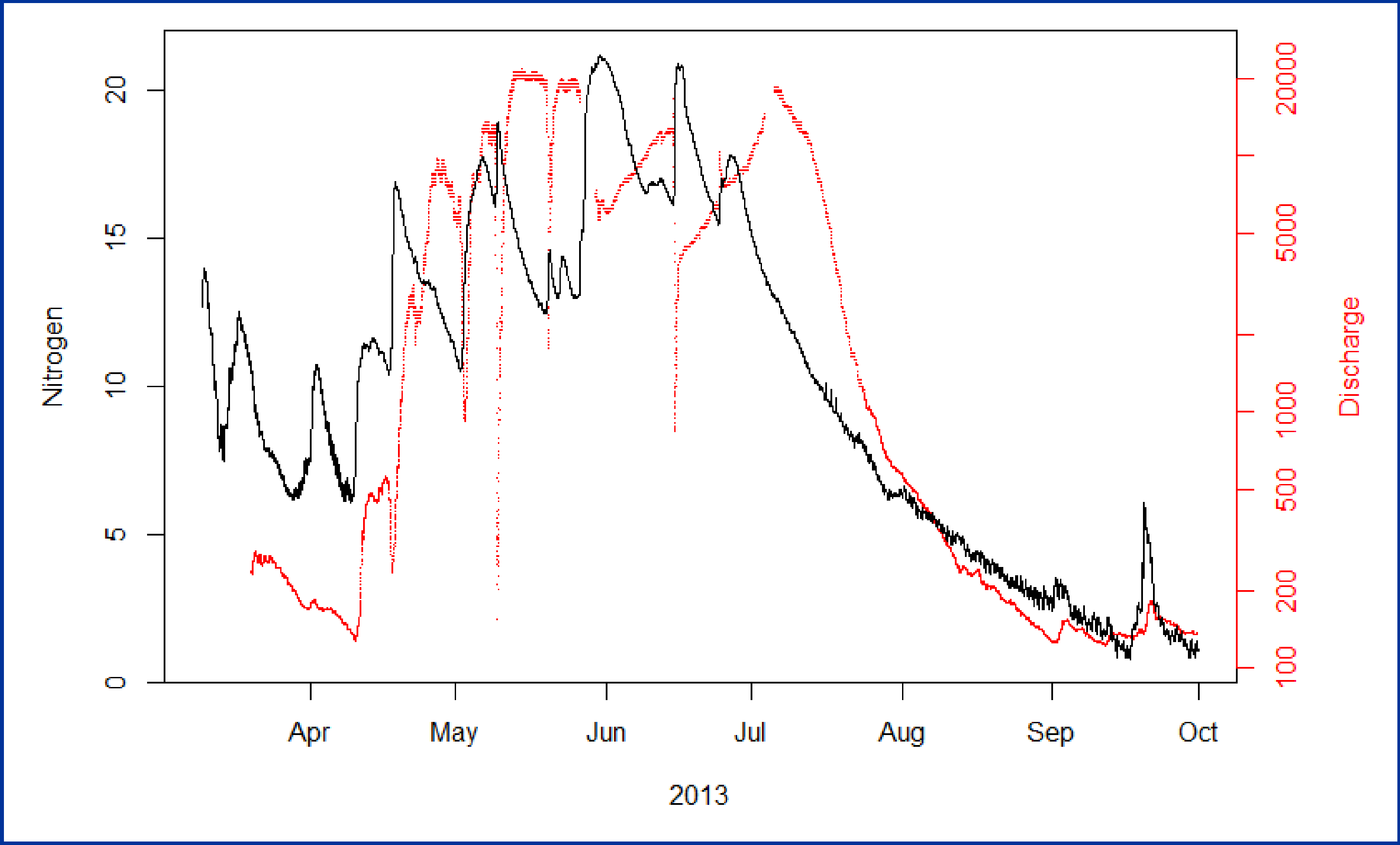


```
> with(Unit, plot(datetime, X01_00060_00011,
            col="black", log="y", type="l",
            xlab="2013", ylab="Discharge",
            main="Discharge in cfs"))
```



```
> par(mar=c(5,5,5,5))
with(Unit, plot(datetime,X18_99133_00011,
        col="red",pch=".",ylim=c(0,22),yaxs="i",
        xlab="2013",ylab="Nitrogen"))
> par(new=TRUE)
> with(Unit, plot(datetime,X01_00060_00011,
        col="black",log="y",type="l",
        xaxt="n",yaxt="n",axes=FALSE,ylab="",xlab=""))
> axis(4,col="red",col.axis="red")
> mtext("Discharge",side=4,line=3,col="red")
```

**Many options for graphics and modeling of concentration and discharge together. Not a part of EGRET – but it must be in a next generation of EGRET!**




USGS

# Now back to what is in EGRET

- This is where EGRET estimates the WRTDS model and applies it

# > eList <- modelEstimation(eList)

- Runs the model in cross-validation mode
- Estimates the “surface” for concentration as a function of time and discharge
- Uses the surface to compute daily values of
  - Concentration
  - Flux
  - Flow-normalized concentration
  - Flow-normalized flux
- Adds those to the Daily data frame

**User has choices about some of the parameters of the WRTDS model**

USGS

# Now eList contains 4 objects

- INFO
- Daily
- Sample
- surfaces

  surfaces contains three surfaces in (T,Q) space

  - the expected value of log(c),
  - the standard error of log(c)
  - the expected value of c

USGS

# Now what is in Daily?
# It is a data frame that has dimension (12782, 19)

```
> summary(Daily)
      Date                  Q                  Julian          Month             Day            DecYear    
 Min.   :1979-10-01   Min.   :  0.00991   Min.   :47389   Min.   : 1.000   Min.   :  1.0   Min.   :1980  
 1st Qu.:1988-06-30   1st Qu.:  0.96277   1st Qu.:50584   1st Qu.: 4.000   1st Qu.: 93.0   1st Qu.:1988  
 Median :1997-03-30   Median :  2.46357   Median :53780   Median : 7.000   Median :184.0   Median :1997  
 Mean   :1997-03-30   Mean   :  4.17317   Mean   :53780   Mean   : 6.522   Mean   :183.7   Mean   :1997  
 3rd Qu.:2005-12-28   3rd Qu.:  4.72891   3rd Qu.:56975   3rd Qu.:10.000   3rd Qu.:275.0   3rd Qu.:2006  
 Max.   :2014-09-28   Max.   :246.35656   Max.   :60170   Max.   :12.000   Max.   :366.0   Max.   :2015  

    MonthSeq     Qualifier               i              LogQ                Q7                Q30        
 Min.   :1558   Length:12782       Min.   :    1   Min.   :-4.61412   Min.   : 0.01808   Min.   : 0.09606  
 1st Qu.:1662   Class :character   1st Qu.: 3196   1st Qu.:-0.03794   1st Qu.: 1.00727   1st Qu.: 1.21102  
 Median :1767   Mode  :character   Median : 6392   Median : 0.90161   Median : 2.63549   Median : 2.97421  
 Mean   :1767                      Mean   : 6392   Mean   : 0.78216   Mean   : 4.17433   Mean   : 4.17615  
 3rd Qu.:1872                      3rd Qu.: 9587   3rd Qu.: 1.55370   3rd Qu.: 5.09804   3rd Qu.: 5.88802  
 Max.   :1977                      Max.   :12782   Max.   : 5.50678   Max.   :84.00395   Max.   :25.47478  
                                                                      NA's   :6          NA's   :29        
      yHat                 SE            ConcDay           FluxDay             FNConc           FNFlux       
 Min.   :-1.470422   Min.   :0.1303   Min.   :0.2485   Min.   :   1.245   Min.   :0.8072   Min.   :  74.77  
 1st Qu.:-0.004537   1st Qu.:0.2066   1st Qu.:1.0370   1st Qu.: 100.207   1st Qu.:1.0756   1st Qu.: 176.68  
 Median : 0.147315   Median :0.2348   Median :1.2147   Median : 258.263   Median :1.2287   Median : 328.73  
 Mean   : 0.133796   Mean   :0.2583   Mean   :1.2131   Mean   : 380.318   Mean   :1.2151   Mean   : 375.83  
 3rd Qu.: 0.277517   3rd Qu.:0.2888   3rd Qu.:1.3785   3rd Qu.: 508.028   3rd Qu.:1.3363   3rd Qu.: 559.70  
 Max.   : 0.595483   Max.   :0.7169   Max.   :1.8551   Max.   :5741.182   Max.   :1.7822   Max.   :1013.80  
```

USGS

# “Period of Analysis” concept in EGRET.

- 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 Period**
**paLong = length of Period, in months**

USGS

# Period of analysis set up

Say we want calendar year

eList <- setPA(eList, paStart = 1, paLong=12)

Say we want April, May, June

eList <- setPA(eList, paStart = 4, paLong = 3)

Default is water year

USGS

# Units in EGRET

Everything stored as:

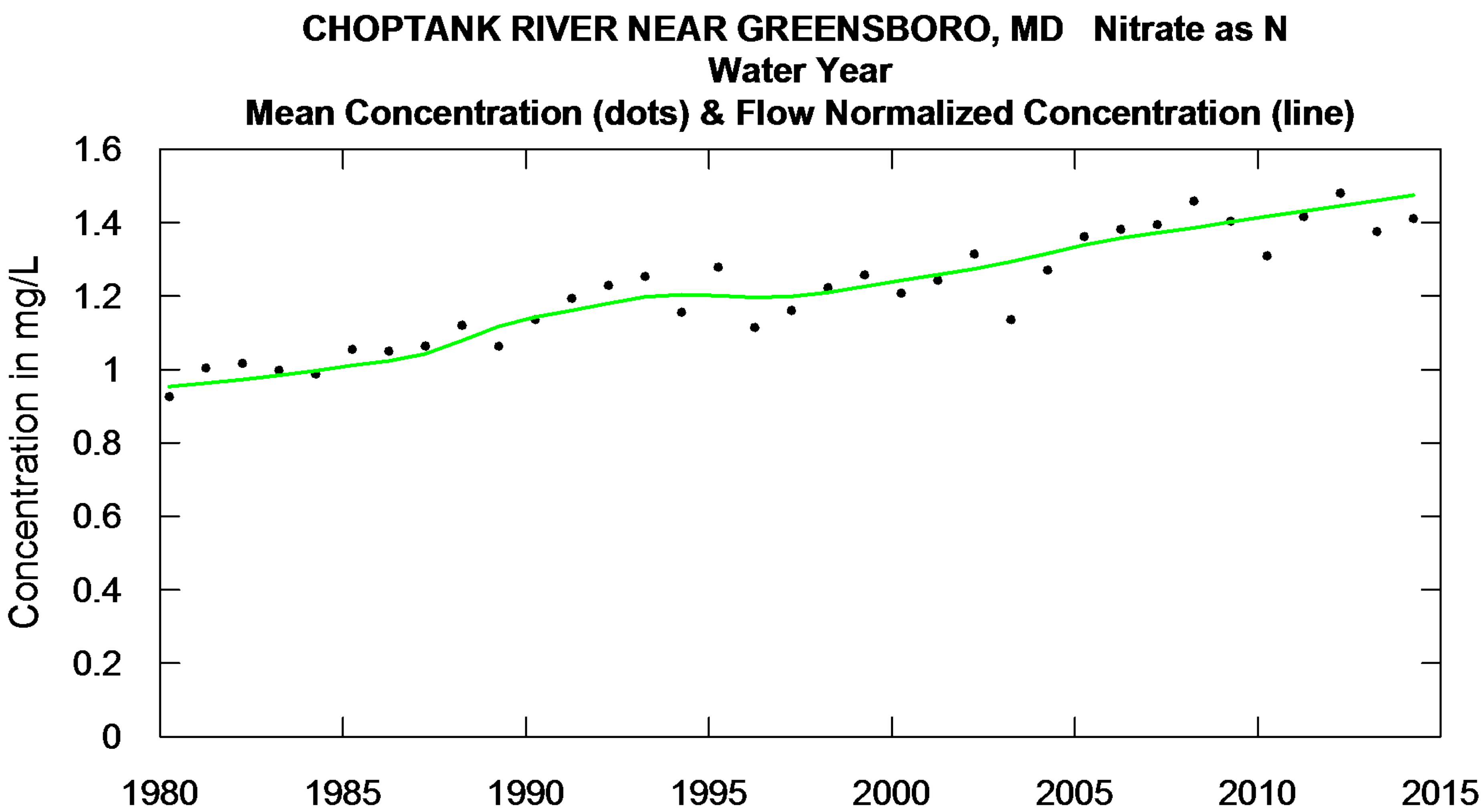
$m^3$/s, kg/day, or mg/L

But each graphic or table has a wide choice of units (English and SI) that the user can select

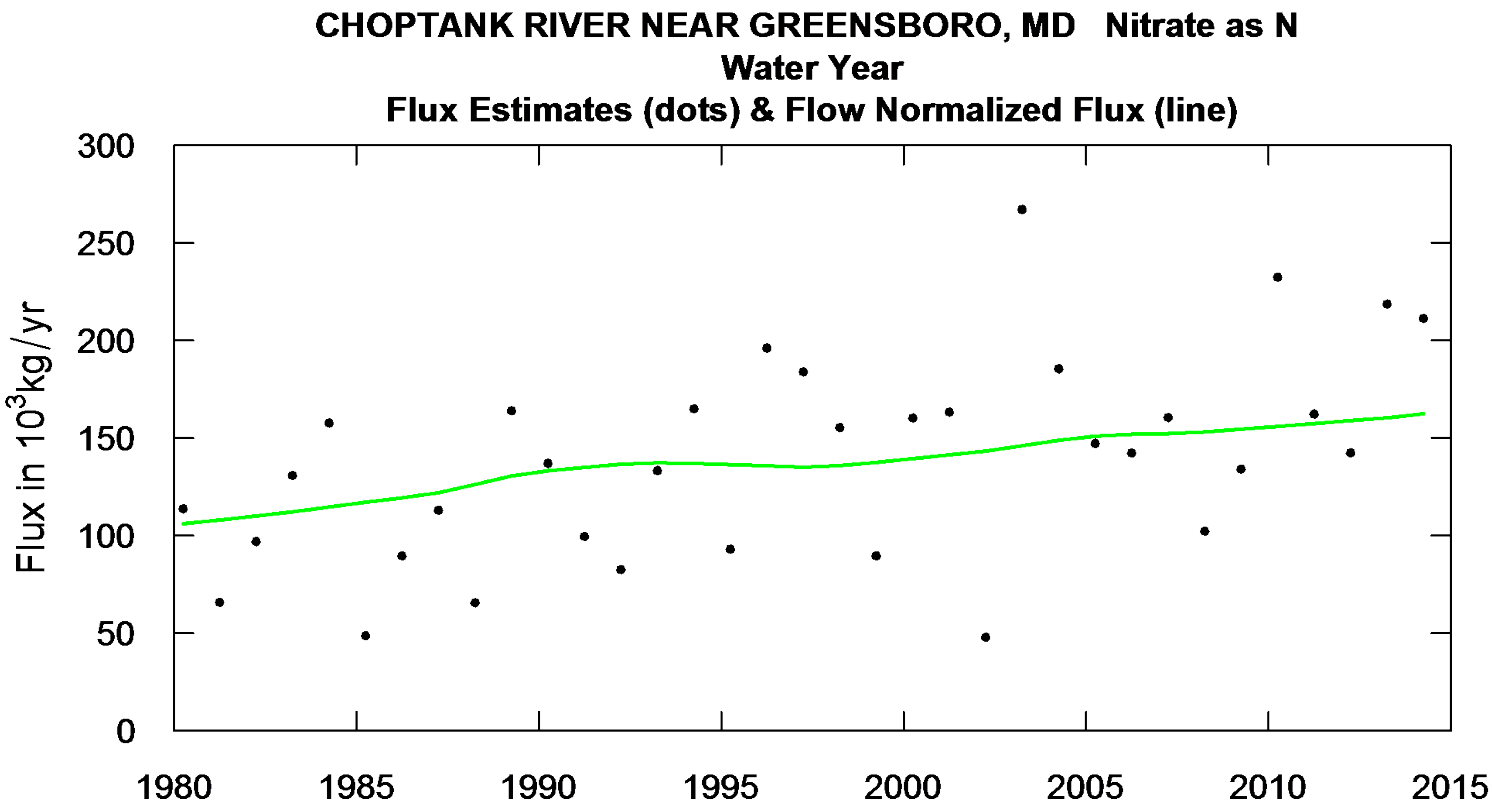
Now lets see some trend results

USGS

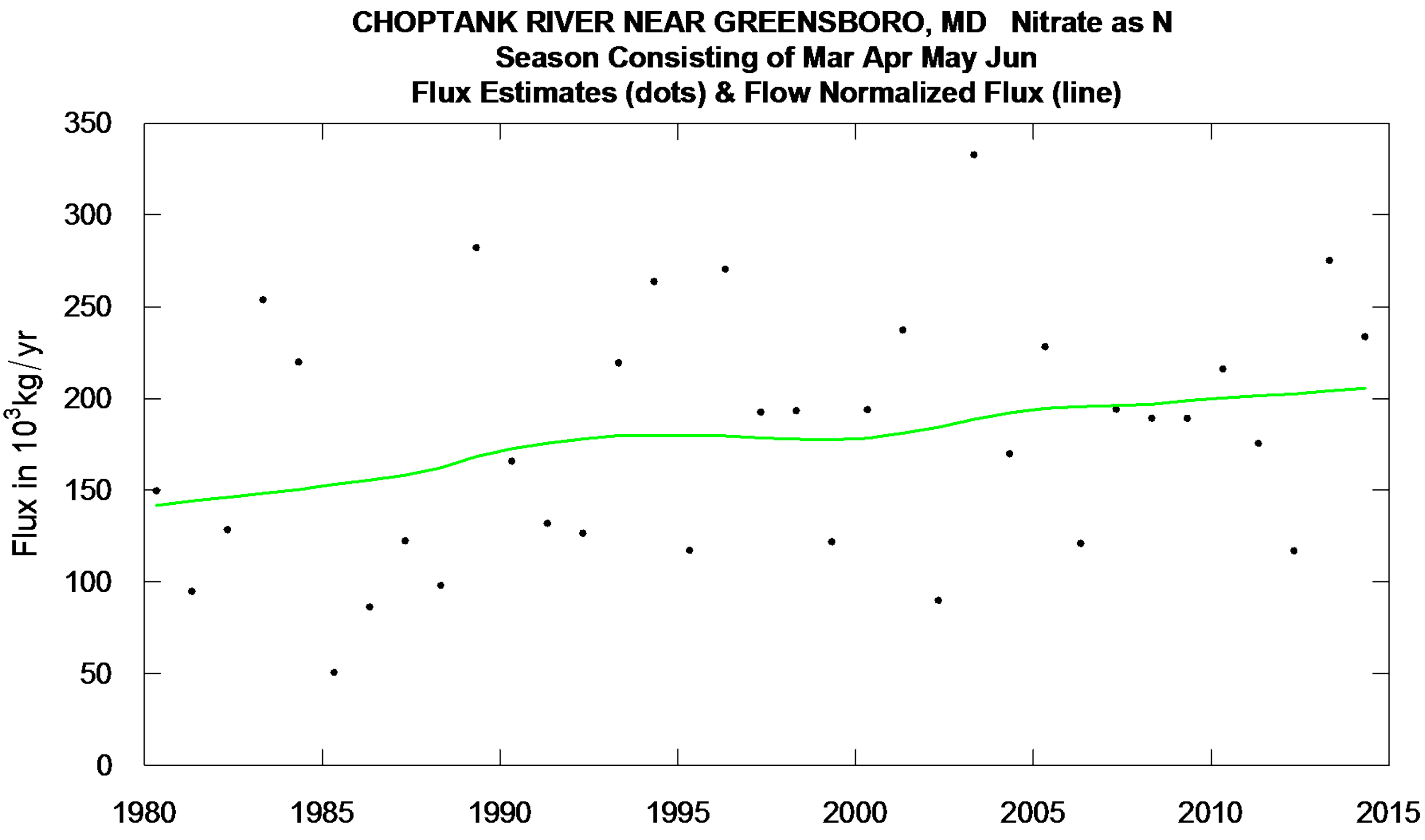
# > plotConcHist(eList)



# > plotFluxHist(eList, fluxUnit=8)



```
> eList <- setPA(eList, paStart=3, paLong=4)
> plotFluxHist(eLIst, fluxUnit=8)
```



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

   CHOPTANK RIVER NEAR GREENSBORO, MD
   Nitrate as N
   Water Year

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

   1980     150.2     0.926     0.953     125.5        117
   1981      78.3     1.004     0.963      72.6        119
   1982     107.6     1.017     0.972     107.0        121
   1983     176.1     0.998     0.984     144.4        124
   1984     201.9     0.988     0.997     173.9        126
   1985      53.6     1.055     1.011      53.8        129
   1986      92.8     1.050     1.023      98.9        132
   1987     119.1     1.064     1.043     124.7        135
   1988      66.0     1.121     1.079      72.4        139
     .
     .
     .
   2007     151.2     1.395     1.373     177.1        168
   2008      90.5     1.459     1.386     112.8        169
   2009     130.0     1.404     1.402     147.9        170
   2010     254.0     1.310     1.417     256.4        172
   2011     185.2     1.417     1.431     179.0        174
   2012     122.6     1.480     1.445     157.1        175
   2013     226.0     1.376     1.460     241.1        177
   2014     191.8     1.411     1.475     233.0        179
```

```
> tableChange(eList,fluxUnit=5,yearPoints=c(1980,1995,2014))
```

CHOPTANK RIVER NEAR GREENSBORO, MD
Nitrate as N
Water Year

Concentration trends

| time span | change mg/L | slope mg/L/yr | change % | slope %/yr |
|---|---|---|---|---|
| 1980 to 1995 | 0.25 | 0.017 | 26 | 1.7 |
| 1980 to 2014 | 0.52 | 0.015 | 55 | 1.6 |
| 1995 to 2014 | 0.27 | 0.014 | 23 | 1.2 |

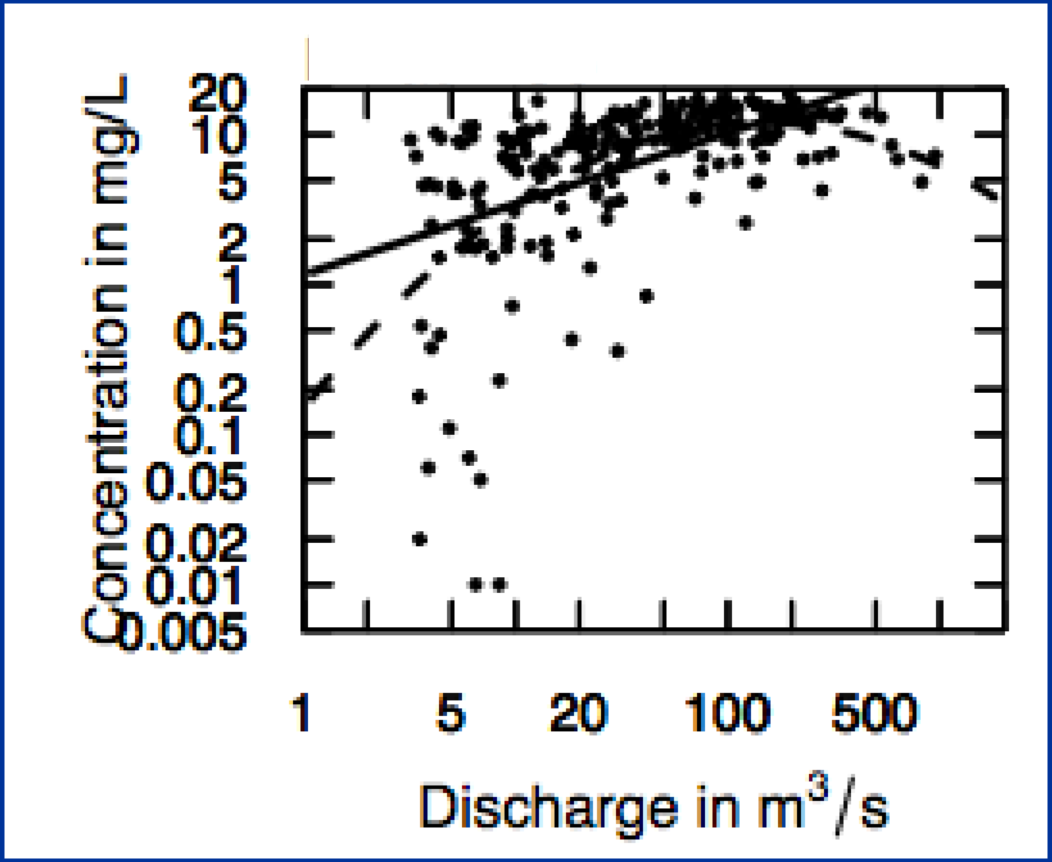
Flux Trends

| time span | change tons/yr | slope tons/yr /yr | change % | slope %/yr |
|---|---|---|---|---|
| 1980 to 1995 | 33 | 2.2 | 29 | 1.9 |
| 1980 to 2014 | 62 | 1.8 | 53 | 1.6 |
| 1995 to 2014 | 29 | 1.5 | 19 | 1 |

**Running tableChange for the March-June Period of Analysis shows a flux change from 1995-2014 of only 14%**

USGS

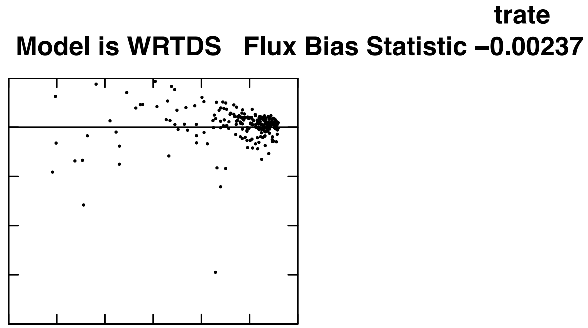
# I'm going to switch data sets to Nitrate for the Raccoon River at Des Moines Iowa



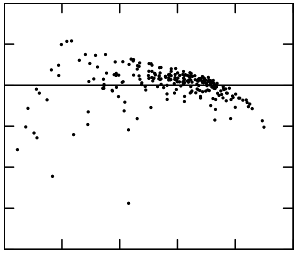

USGS

# EGRET produces a diagnostic plot to help spot serious problems with the model

fluxBiasMulti(eList, fluxUnit=4)



# This same type of plot can be used to look at other models, here the LOADEST7



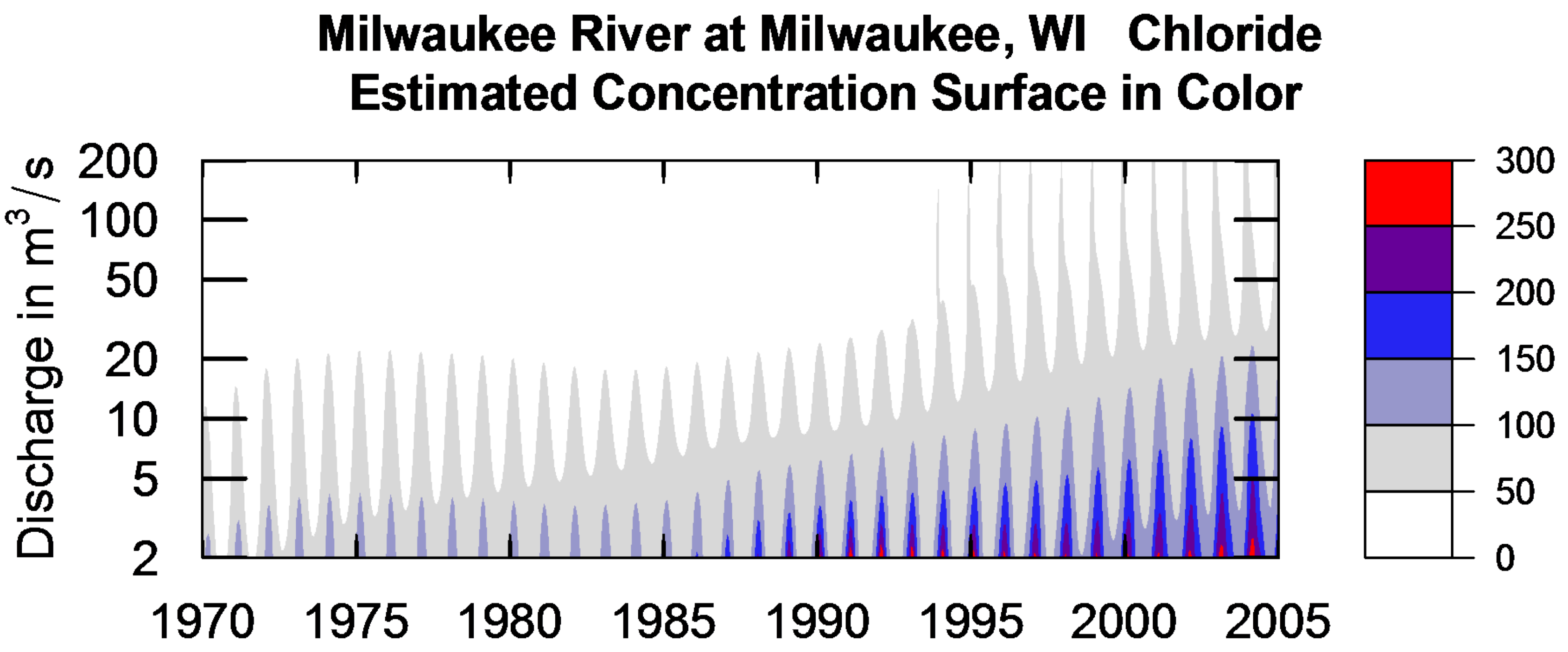
# Diagnostics and potential problems with estimating mean flux, see:

**Hirsch, R.M., 2014, Large biases in regression-based constituent flux estimates: causes and diagnostics. Journal of the American Water Resources Association.**

**Bottom line, look at the fit before you use a statistical model!!!**

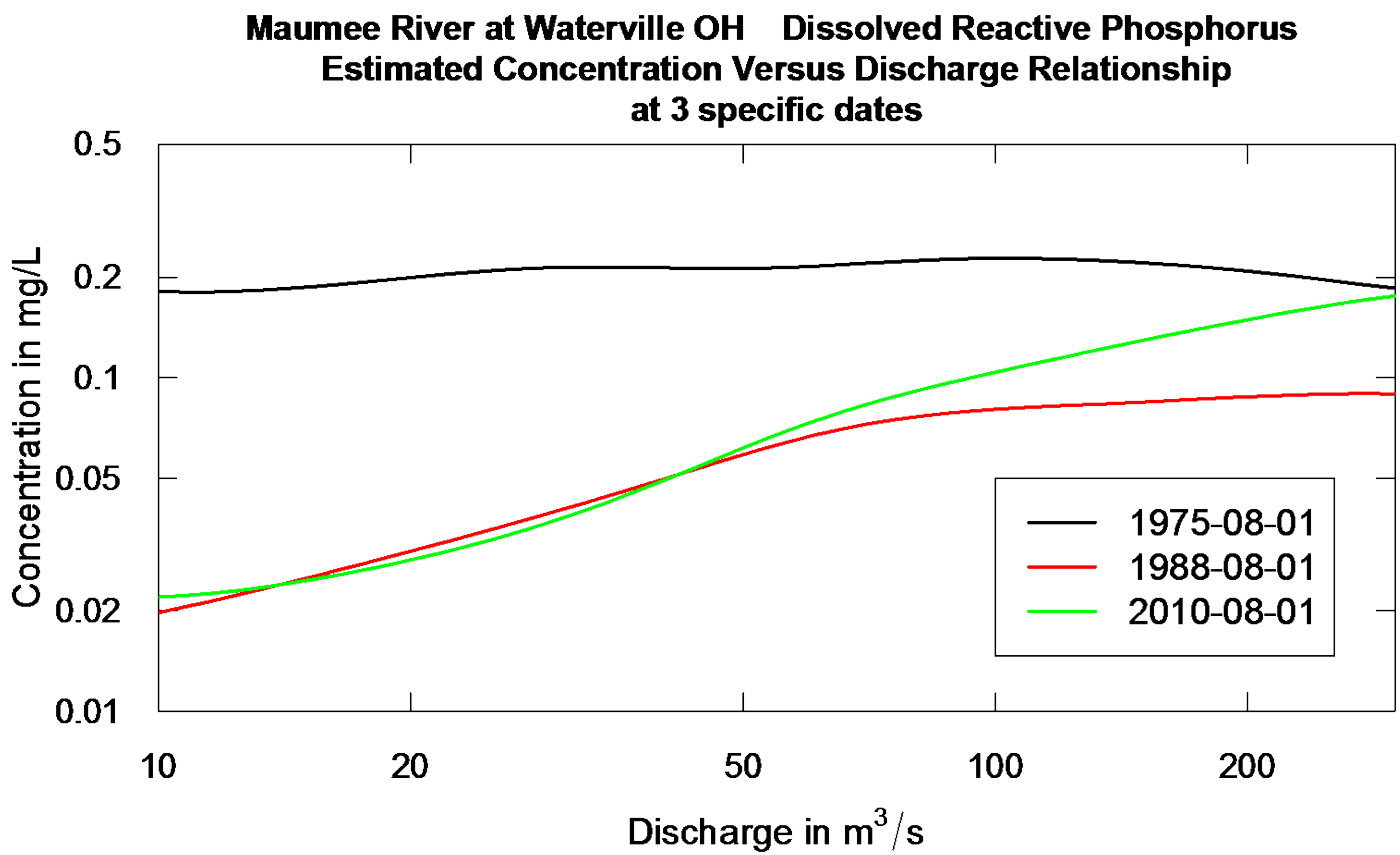
# How difficult is it to make those contour plots?

>plotContours(eList,yearStart=1970, yearEnd=2005, qBottom=2, qTop=200, qUnit=2, contourLevels=seq(0,300,50))

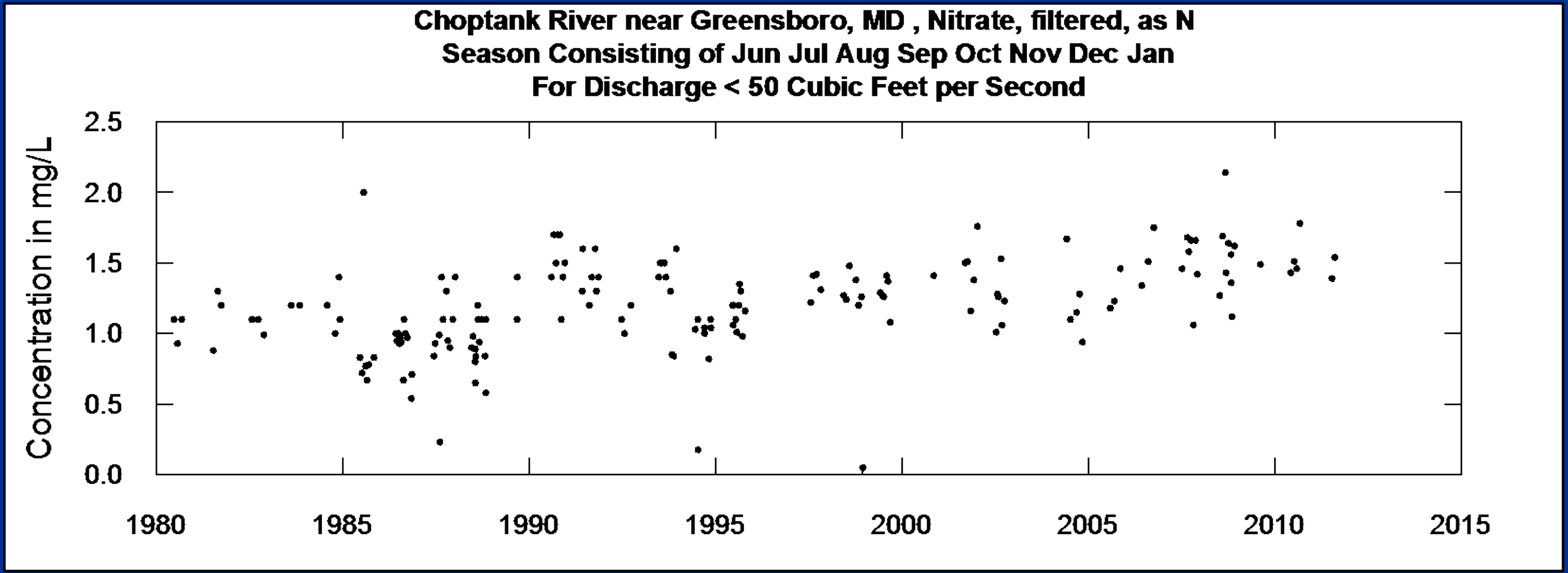


# There are many more graphics, for example

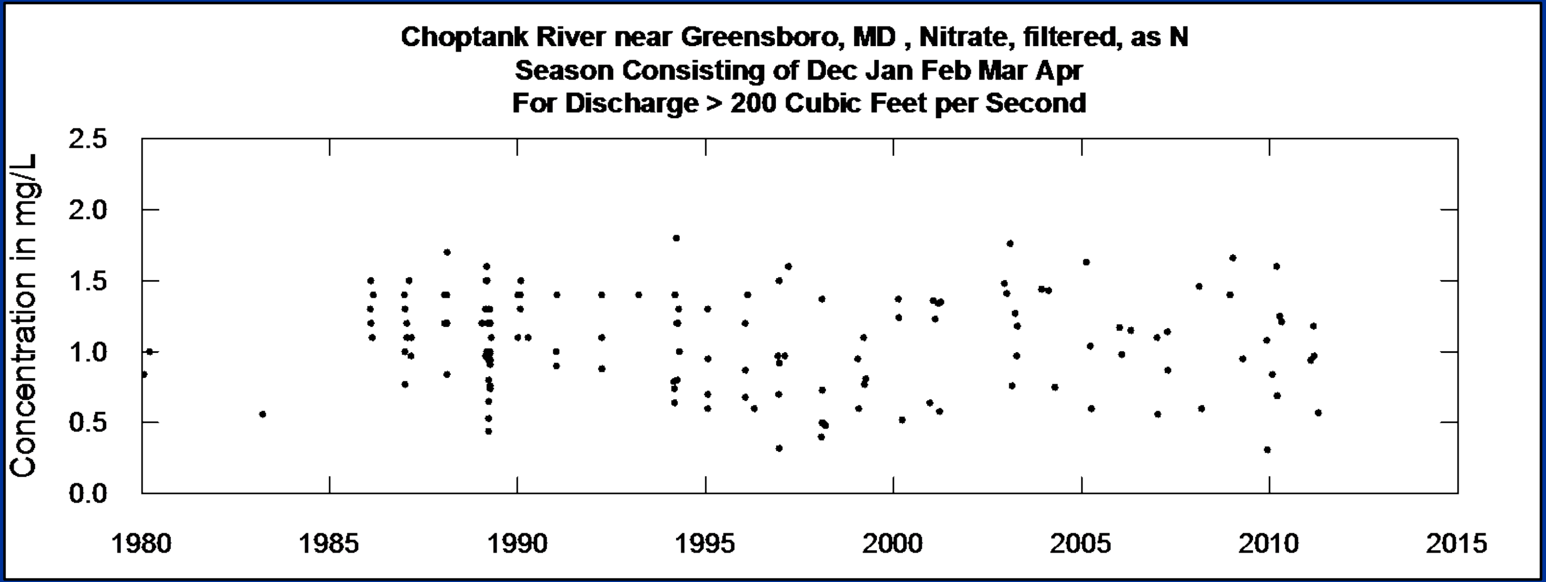
```
> plotConcQSmooth(eList, "1975-08-01”, "1988-08-01", "2010-08-01",
qLow=10, qHigh=300, qUnit=2, logScale=TRUE, legendLeft=100,
legendTop=0.05)
```



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




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




USGS

When all is said and done:

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.

# Anticipated enhancements

- **Significance levels and confidence intervals for trends**
- **Dealing with ephemeral streams**
- **Estimation of trends in frequency of exceedances of threshold values**
- **Dealing with nonstationarity in Q**
- **Improved estimates of yearly fluxes**
- ***Users ideas?***

# dataRetrieval and EGRET

- Information and software available at: https://github.com/USGS-R/EGRET/wiki

A huge thanks to Laura De Cicco for making this dream a reality

USGS