Introduction to the EGRET package

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1 Introduction to Exploration and Graphics for RivEr Trends (EGRET)

EGRET includes statistics and graphics for streamflow history, water quality trends, and the modeling algorithm Weighted Regressions on Time, Discharge, and Season (WRTDS). **Please see the official EGRET manual:** (*http://dx.doi.org/10.3133/tm4A10*) **for more information on the EGRET package.** For information on getting started in R, downloading and installing the package, see section 11.

The best way to learn about the WRTDS approach and to see examples of its application to multiple large data sets is to read two journal articles. They are available, for free, from the journals in which they were published. The first relates to nitrate and total phosphorus data for 9 rivers draining to Chesapeake Bay. The URL is (1): *http://onlinelibrary.wiley.com/doi/10.1111/j.1752-1688.2010.00482.x/full*. The second is an application to nitrate data for 8 monitoring sites on the Mississippi River or its major tributaries (2). The URL is: *http://pubs.acs.org/doi/abs/10.1021/es201221s*

This vignette assumes that you understand the concepts underlying WRTDS, and reading at least the first of these papers is necessary for that understanding. The method has been enhanced beyond what was previously published, and it now properly handles censored data by using survival regression rather than ordinary regression. The details of this change are in a report on Chesapeake Bay river input trends (3):*http://pubs.usgs.gov/sir/2012/5244/*. The specific enhancements for handling censored data are on pages 9-11 of the report.

This vignette guides you through the major functions provided by the EGRET package. The package dataRetrieval is required for importing data in an EGRET-friendly format. The dataRetrieval package and installation instructions are at: *https://github.com/USGS-R/dataRetrieval*. Installing dataRetrieval will provide a vignette similar to this document, with complete working examples of the main dataRetrieval functions. This document assumes you are familiar with the dataRetrieval package. Further details are in the user guide available on gitHub: *https://github.com/USGS-R/EGRET/raw/master/inst/doc/EGRET.pdf*

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2 EGRET Workflow

Subsequent sections of this vignette discuss the EGRET workflow steps in greater detail. This section provides a handy cheat sheet for diving into an EGRET analysis. The first example is for a flow history analysis:

```
library(dataRetrieval)
library(EGRET)

# Flow history analysis

############################
# Gather discharge data:
siteNumber <- "01491000" #Choptank River at Greensboro, MD
startDate <- "" # Get earliest date
endDate <- "" # Get latest date
Daily <- readNWISDaily(siteNumber,"00060",startDate,endDate)
```

```
# Gather site and parameter information:
# Here user must input some values for
# the default (interactive=TRUE)
INFO<- readNWISInfo(siteNumber,"00060")
INFO$shortName <- "Choptank River at Greensboro, MD"
############################

############################
# Check flow history data:
eList <- as.egret(INFO, Daily, NA, NA)
plotFlowSingle(eList, istat=7,qUnit="thousandCfs")
plotSDLogQ(eList)
plotQTimeDaily(eList, qLower=1,qUnit=3)
plotFour(eList, qUnit=3)
plotFourStats(eList, qUnit=3)
############################

# modify this for your own computer file structure:
savePath<-"/Users/rhirsch/Desktop/"
saveResults(savePath, INFO)
```

The second workflow example is for a water quality analysis. It includes data retrieval, merging of water quality and streamflow data, running the WRTDS estimation, and various plotting functions available in the EGRET package.

```
library(dataRetrieval)
library(EGRET)

############################
# Gather discharge data:
siteNumber <- "01491000" #Choptank River at Greensboro, MD
startDate <- "" #Gets earliest date
endDate <- "2011-09-30"
# Gather sample data:
parameter_cd<-"00631" #5 digit USGS code
Sample <- readNWISSample(siteNumber,parameter_cd,startDate,endDate)
#Gets earliest date from Sample record:
#This is just one of many ways to assure the Daily record
#spans the Sample record
startDate <- min(as.character(Sample$Date))
# Gather discharge data:
Daily <- readNWISDaily(siteNumber,"00060",startDate,endDate)
# Gather site and parameter information:

# Here user must input some values for
# the default (interactive=TRUE)
INFO<- readNWISInfo(siteNumber,parameter_cd, interactive=FALSE)
INFO$shortName <- "Choptank River at Greensboro, MD"
```

```
# Merge discharge with sample data:
eList <- mergeReport(INFO, Daily, Sample)
############################

############################
# Check sample data:
boxConcMonth(eList)
boxQTwice(eList)
plotConcTime(eList)
plotConcQ(eList)
multiPlotDataOverview(eList)
############################

############################
# Run WRTDS model:
eList <- modelEstimation(eList)
############################

############################
#Check model results:

#Require Sample + INFO:
plotConcTimeDaily(eList)
plotFluxTimeDaily(eList)
plotConcPred(eList)
plotFluxPred(eList)
plotResidPred(eList)
plotResidQ(eList)
plotResidTime(eList)
boxResidMonth(eList)
boxConcThree(eList)

#Require Daily + INFO:
plotConcHist(eList)
plotFluxHist(eList)

# Multi-line plots:
date1 <- "2000-09-01"
date2 <- "2005-09-01"
date3 <- "2009-09-01"
qBottom<-100
qTop<-5000
plotConcQSmooth(date1, date2, date3, qBottom, qTop,
                    concMax=2,qUnit=1)
q1 <- 10
q2 <- 25
q3 <- 75
centerDate <- "07-01"
```

```
yearEnd <- 2009
yearStart <- 2000
plotConcTimeSmooth(eList, q1, q2, q3, centerDate, yearStart, yearEnd)

# Multi-plots:
fluxBiasMulti(eList)

#Contour plots:
clevel<-seq(0,2,0.5)
maxDiff<-0.8
yearStart <- 2000
yearEnd <- 2010

plotContours(eList, yearStart,yearEnd,qBottom,qTop,
             contourLevels = clevel,qUnit=1)
plotDiffContours(eList, yearStart,yearEnd,
                 qBottom,qTop,maxDiff,qUnit=1)

# modify this for your own computer file structure:
savePath<-"/Users/rhirsch/Desktop/"
saveResults(savePath, INFO)
```

3 EGRET Dataframes and Units

The EGRET package uses 3 default dataframes throughout the calculations, analysis, and graphing. These dataframes are Daily (3.1), Sample (3.2), and INFO (3.3). EGRET uses entirely SI units to store the data, but for purposes of output, it can report results in a wide variety of units, which will be discussed in (5.1). To start our exploration, you must install the packages (check Section 11 for detailed instructions), and then open EGRET with the following command:

```
library(EGRET)
```

3.1 Daily

The Daily dataframe initially is populated with columns generated by the dataRetrieval package (Table 1). After you run the WRTDS calculations by using the function `modelEstimation` (as will be described in section 8), additional columns are inserted (Table 2).

Table 1. Daily dataframe

ColumnName	Type	Description	Units
Date	Date	Date	date
Q	number	Discharge in m^3/s	m^3/s
Julian	number	Number of days since January 1, 1850	days
Month	integer	Month of the year [1-12]	months
Day	integer	Day of the year [1-366]	days
DecYear	number	Decimal year	years
MonthSeq	integer	Number of months since January 1, 1850	months
Qualifier	string	Qualifying code	character
i	integer	Index of days, starting with 1	days
LogQ	number	Natural logarithm of Q	numeric
Q7	number	7 day running average of Q	m^3/s
Q30	number	30 day running average of Q	m^3/s

Table 2. Columns added to Daily dataframe after running `modelEstimation`

ColumnName	Type	Description	Units
yHat	number	The WRTDS estimate of the log of concentration	numeric
SE	number	The WRTDS estimate of the standard error of yHat	numeric
ConcDay	number	The WRTDS estimate of concentration	mg/L
FluxDay	number	The WRTDS estimate of flux	kg/day
FNConc	number	Flow-normalized estimate of concentration	mg/L
FNFlux	number	Flow-normalized estimate of flux	kg/day

Notice that the "Day of the year" column can span from 1 to 366. The 366 accounts for leap years. Every day has a consistent day of the year. This means, February 28^{th} is always the 59^{th} day of the year, Feb. 29^{th} is always the 60^{th} day of the year, and March 1^{st} is always the 61^{st} day of the year whether or not it is a leap year.

3.2 Sample

The Sample dataframe initially is populated with columns generated by the dataRetrieval package (Table 3). After you run the WRTDS calculations using the `modelEstimation` function (as described in section 8), additional columns are inserted (Table 4):

Table 3. Sample dataframe

ColumnName	Type	Description	Units
Date	Date	Date	date
ConcLow	number	Lower limit of concentration	mg/L
ConcHigh	number	Upper limit of concentration	mg/L
Uncen	integer	Uncensored data (1=true, 0=false)	integer
ConcAve	number	Average concentration	mg/L
Julian	number	Number of days since January 1, 1850	days
Month	integer	Month of the year [1-12]	months
Day	integer	Day of the year [1-366]	days
DecYear	number	Decimal year	years
MonthSeq	integer	Number of months since January 1, 1850	months
SinDY	number	Sine of DecYear	numeric
CosDY	number	Cosine of DecYear	numeric
Q [1]	number	Discharge	cms
LogQ [1]	number	Natural logarithm of discharge	numeric

[1] Populated after calling `mergeReport`.

Table 4. Columns added to Sample dataframe after running `modelEstimation`

ColumnName	Type	Description	Units
yHat[1]	number	estimate of the log of concentration	numeric
SE[1]	number	estimate of the standard error of yHat	numeric
ConcHat[1]	number	unbiased estimate of concentration	mg/L

[1] These estimates are "leave-one-out cross validation" estimates. See the EGRET Manual for more details.

3.3 INFO

The INFO dataframe stores information about the measurements, such as station name, parameter name, drainage area, and so forth. There can be many additional, optional columns, but the columns in Table 5 are required to initiate the EGRET analysis. After you run the WRTDS calculations (as described in section 8), additional columns (Table 6) are automatically inserted into the INFO dataframe (see the EGRET Manual for complete description of each term):

Table 5. INFO dataframe

ColumnName	Type	Description
shortName	string	Name of site, suitable for use in graphical headings
staAbbrev	string	Abbreviation for station name, used in saveResults
paramShortName	string	Name of constituent, suitable for use in graphical headings
constitAbbrev	string	Abbreviation for constituent name, used in saveResults
drainSqKm	numeric	Drainage area in km^2
paStart [1]	integer (1-12)	Starting month of period of analysis
paLong [1]	integer (1-12)	Length of period of analysis in months

[1] Inserted with the `setPA` function.

Table 6. INFO dataframe after running `modelEstimation`

ColumnName	Description	Units
bottomLogQ	Lowest discharge in prediction surfaces	numeric
stepLogQ	Step size in log discharge in prediction surfaces	numeric
nVectorLogQ	Number of steps in discharge, prediction surfaces	numeric
bottomYear	Starting year in prediction surfaces	numeric
stepYear	Step size in years in prediction surfaces	numeric
nVectorYear	Number of steps in years in prediction surfaces	numeric
windowY	Half-window width in the time dimension	years
windowQ	Half-window width in the log discharge dimension	numeric
windowS	Half-window width in the seasonal dimension	years
minNumObs	Minimum number of observations for regression	integer
minNumUncen	Minimum number of uncensored observations	integer

4 Data Retrievals Structured For Use In The EGRET Package

EGRET includes data retrieval functions that return the data in a structure that has been designed to work with the EGRET R package (*https://github.com/USGS-R/EGRET/wiki*). In general, these dataframes may be much more "R-friendly" than the raw data, and will contain additional date information that allows for efficient data analysis.

In this section, we use 3 dataRetrieval functions to get sufficient data to perform an EGRET analysis. We will continue analyzing the Choptank River. The data are structured into three EGRET-specific dataframes. The daily discharge data are placed in a dataframe called Daily. The nitrate sample data are placed in a dataframe called Sample. The data about the site and the parameter are placed in a dataframe called INFO. Although these dataframes were designed to work with the EGRET R package, they can be very useful for a wide range of hydrology studies that don't use EGRET.

4.1 INFO Data

The `readNWISInfo`, `readWQPInfo`, and `readUserInfo` functions obtain metadata, or data about the streamgage and measured parameters. Any number of columns can be included in this dataframe. Table 7

describes fields are required for EGRET functions.

Table 7. INFO columns required in EGRET functions

Column Name	Type	Description
constitAbbrev	string	Constituent abbreviation, used for saving the workspace in EGRET
drainSqKm	numeric	Drainage area in square kilometers
paramShortName	string	Parameter name to use on graphs
param.units	string	Parameter units
shortName	string	Station name to use on graphs
staAbbrev	string	Station Abbreviation

The function `readNWISInfo` combines `getNWISSiteInfo` and `getNWISPcodeInfo`, producing one dataframe called INFO.

```
parameterCd <- "00618"
siteNumber <- "01491000"
INFO <- readNWISInfo(siteNumber,parameterCd, interactive=FALSE)
```

It is also possible to create the INFO dataframe using information from the Water Quality Portal:

```
parameterCd <- "00618"
INFO_WQP <- readWQPInfo("USGS-01491000",parameterCd)
```

Finally, the function `readUserInfo` can be used to convert comma separated files into an INFO dataframe.

Any supplemental column that would be useful can be added to the INFO dataframe.

```
INFO$riverInfo <- "Major tributary of the Chesapeake Bay"
INFO$GreensboroPopulation <- 1931
```

4.2 Daily Data

The `readNWISDaily` function retrieves the daily values (discharge in this case). It requires the inputs siteNumber, parameterCd, startDate, endDate, interactive, and convert. These arguments are described in detail in the `dataRetrieval` vignette, however `"convert"` is a new argument (that defaults to TRUE). The convert argument tells the program to convert the values from cubic feet per second (ft^3/s) to cubic meters per second (m^3/s) as shown in the example Daily data frame in Table 8. For EGRET applications with NWIS Web retrieval, do not use this argument (the default is TRUE), EGRET assumes that discharge is always stored in units of cubic meters per second. If you don't want this conversion and are not using EGRET, set convert=FALSE in the function call.

```
siteNumber <- "01491000"
startDate <- "2000-01-01"
endDate <- "2013-01-01"
# This call will get NWIS (ft3/s) data , and convert it to m3/s:
Daily <- readNWISDaily(siteNumber, "00060", startDate, endDate)

There are 4750 data points, and 4750 days.
```

If discharge values are negative or zero, the code will set all of these values to zero and then add a small

Table 8. Daily dataframe

ColumnName	Type	Description	Units
Date	Date	Date	date
Q	number	Discharge in m^3/s	m^3/s
Julian	number	Number of days since January 1, 1850	days
Month	integer	Month of the year [1-12]	months
Day	integer	Day of the year [1-366]	days
DecYear	number	Decimal year	years
MonthSeq	integer	Number of months since January 1, 1850	months
Qualifier	string	Qualifying code	character
i	integer	Index of days, starting with 1	days
LogQ	number	Natural logarithm of Q	numeric
Q7	number	7 day running average of Q	m^3/s
Q30	number	30 day running average of Q	m^3/s

constant to all of the daily discharge values. This constant is 0.001 times the mean discharge. The code will also report on the number of zero and negative values and the size of the constant. Use EGRET analysis only if the number of zero values is a very small fraction of the total days in the record (say less than 0.1% of the days), and there are no negative discharge values. Columns Q7 and Q30 are the 7 and 30 day running averages for the 7 or 30 days ending on this specific date. Table 8 lists details of the Daily data frame.

Notice that the "Day of the year" column can span from 1 to 366. The 366 accounts for leap years. Every day has a consistent day of the year. This means, February 28^{th} is always the 59^{th} day of the year, Feb. 29^{th} is always the 60^{th} day of the year, and March 1^{st} is always the 61^{st} day of the year whether or not it is a leap year.

User-generated Sample dataframes can also be created using the `readUserDaily` function. This is discused in detail in section 4.5.1.

4.3 Sample Data

The `readNWISSample` function retrieves USGS sample data from NWIS. The arguments for this function are also siteNumber, parameterCd, startDate, endDate, interactive. These are the same inputs as `getWQPqwData` or `getWQPData` as described in the previous section.

```
parameterCd <- "00618"
Sample <-readNWISSample(siteNumber,parameterCd,
      startDate, endDate)
```

The `readWQPSample` function retrieves Water Quality Portal sample data (STORET, NWIS, STEWARDS). The arguments for this function are siteNumber, characteristicName, startDate, endDate, interactive. Table 9 lists details of the Sample data frame.

```
site <- 'WIDNR_WQX-10032762'
characteristicName <- 'Specific conductance'
Sample <-readWQPSample(site,characteristicName,
```

```
      startDate, endDate)
```

User-generated Sample dataframes can also be created using the `readUserSample` function. This is discused in detail in section 4.5.2.

Table 9. Sample dataframe

ColumnName	Type	Description	Units
Date	Date	Date	date
ConcLow	number	Lower limit of concentration	mg/L
ConcHigh	number	Upper limit of concentration	mg/L
Uncen	integer	Uncensored data (1=true, 0=false)	integer
ConcAve	number	Average of ConcLow and ConcHigh	mg/L
Julian	number	Number of days since January 1, 1850	days
Month	integer	Month of the year [1-12]	months
Day	integer	Day of the year [1-366]	days
DecYear	number	Decimal year	years
MonthSeq	integer	Number of months since January 1, 1850	months
SinDY	number	Sine of DecYear	numeric
CosDY	number	Cosine of DecYear	numeric
Q [1]	number	Discharge	m^3/s
LogQ [1]	number	Natural logarithm of discharge	numeric

[1] Discharge columns are populated from data in the Daily dataframe after calling the `mergeReport` function.

Notice that the "Day of the year" column can span from 1 to 366. The 366 accounts for leap years. Every day has a consistent day of the year. This means, February 28th is always the 59th day of the year, Feb. 29th is always the 60th day of the year, and March 1st is always the 61st day of the year whether or not it is a leap year.

Section 4.4 is about summing multiple constituents, including how interval censoring is used. Since the Sample data frame is structured to only contain one constituent, when more than one parameter codes are requested, the `readNWISSample` function will sum the values of each constituent as described below.

4.4 Censored Values: Summation Explanation

In the typical case where none of the data are censored (that is, no values are reported as "less-than" values), the ConcLow = ConcHigh = ConcAve and Uncen = 1 are equal to the reported value. For the most common type of censoring, where a value is reported as less than the reporting limit, then ConcLow = NA, ConcHigh = reporting limit, ConcAve = 0.5 * reporting limit, and Uncen = 0.

To illustrate how the dataRetrieval package handles a more complex censoring problem, let us say that in 2004 and earlier, we computed total phosphorus (tp) as the sum of dissolved phosphorus (dp) and particulate phosphorus (pp). From 2005 and onward, we have direct measurements of total phosphorus (tp). A small subset of this fictional data looks like Table 10.

The dataRetrieval package will "add up" all the values in a given row to form the total for that sample when using the Sample dataframe. Thus, you only want to enter data that should be added together. If you want a dataframe with multiple constituents that are not summed, do not use readNWISSample, readWQPSample, or readUserSample. The raw data functions: `getWQPData`, `getNWISqwData`, `getWQPqwData`, `getWQPData` will not sum constituents, but leave them in their individual columns.

Table 10. Example data

cdate	rdp	dp	rpp	pp	rtp	tp
2003-02-15		0.020		0.500		
2003-06-30	<	0.010		0.300		
2004-09-15	<	0.005	<	0.200		
2005-01-30						0.430
2005-05-30					<	0.050
2005-10-30					<	0.020

For example, we might know the value for dp on 5/30/2005, but we don't want to put it in the table because under the rules of this data set, we are not supposed to add it in to the values in 2005.

For every sample, the EGRET package requires a pair of numbers to define an interval in which the true value lies (ConcLow and ConcHigh). In a simple uncensored case (the reported value is above the detection limit), ConcLow equals ConcHigh and the interval collapses down to a single point. In a simple censored case, the value might be reported as <0.2, then ConcLow=NA and ConcHigh=0.2. We use NA instead of 0 as a way to elegantly handle future logarithm calculations.

For the more complex example case, let us say dp is reported as <0.01 and pp is reported as 0.3. We know that the total must be at least 0.3 and could be as much as 0.31. Therefore, ConcLow=0.3 and ConcHigh=0.31. Another case would be if dp is reported as <0.005 and pp is reported <0.2. We know in this case that the true value could be as low as zero, but could be as high as 0.205. Therefore, in this case, ConcLow=NA and ConcHigh=0.205. The Sample dataframe for the example data would be:

```
  Sample

         Date ConcLow ConcHigh Uncen ConcAve Julian Month
1 2003-02-15    0.52    0.520     1  0.5200  55927     2
2 2003-06-30    0.30    0.310     0  0.3050  56062     6
3 2004-09-15      NA    0.205     0  0.1025  56505     9
4 2005-01-30    0.43    0.430     1  0.4300  56642     1
5 2005-05-30      NA    0.050     0  0.0250  56762     5
6 2005-10-30      NA    0.020     0  0.0100  56915    10
  Day  DecYear MonthSeq       SinDY      CosDY
1  46 2003.125     1838  0.70558361  0.7086267
2 182 2003.495     1842  0.03442161 -0.9994074
3 259 2004.706     1857 -0.96251346 -0.2712339
4  30 2005.081     1861  0.48627271  0.8738071
5 151 2005.410     1865  0.53800517 -0.8429415
6 304 2005.829     1870 -0.88001220  0.4749511
```

Section 4.5 discusses inputting user-generated files. The functions `readUserSample` and `readNWISSample` assume summation with interval censoring inputs, and are discussed in sections 4.5.1 and 4.5.2.

4.5 User-Generated Data Files

In addition to retrieving data from the USGS Web services, the dataRetrieval package also includes functions to generate the Daily and Sample data frame from local files.

4.5.1 readUserDaily

The `readUserDaily` function will load a user-supplied text file and convert it to the Daily dataframe. The file should have two columns, the first dates, the second values. The dates are formatted either mm/dd/yyyy or yyyy-mm-dd. Using a 4-digit year is required. This function has the following inputs: filePath, fileName,hasHeader (TRUE/FALSE), separator, qUnit, and interactive (TRUE/FALSE). filePath is a string that defines the path to your file, and the string can either be a full path, or path relative to your R working directory. The input fileName is a string that defines the file name (including the extension).

Text files that contain this sort of data require some sort of a separator, for example, a "csv" file (comma-separated value) file uses a comma to separate the date and value column. A tab delimited file would use a tab (`"\t"`) rather than the comma (`","`). Define the type of separator you choose to use in the function call in the `"separator"` argument, the default is `","`. Another function input is a logical variable: hasHeader. The default is TRUE. If your data does not have column names, set this variable to FALSE.

Finally, qUnit is a numeric argument that defines the discharge units used in the input file. The default is qUnit = 1 which assumes discharge is in cubic feet per second. If the discharge in the file is already in cubic meters per second then set qUnit = 2. If it is in some other units (like liters per second or acre-feet per day), the user must pre-process the data with a unit conversion that changes it to either cubic feet per second or cubic meters per second.

So, if you have a file called "ChoptankRiverFlow.txt" located in a folder called "RData" on the C drive (this example is for the Windows® operating systems), and the file is structured as follows (tab-separated):

```
date  Qdaily
10/1/1999  107
10/2/1999  85
10/3/1999  76
10/4/1999 76
10/5/1999 113
10/6/1999 98
...
```

The call to open this file, convert the discharge to cubic meters per second, and populate the Daily data frame would be:

```
fileName <- "ChoptankRiverFlow.txt"
filePath <-  "C:/RData/"
Daily <-readDataFromFile(filePath,fileName,
                    separator="\t")
```

Microsoft® Excel files can be a bit tricky to import into R directly. The simplest way to get Excel data into R is to open the Excel file in Excel, then save it as a .csv file (comma-separated values).

4.5.2 readUserSample

The `readUserSample` function will import a user-generated file and populate the Sample dataframe. The difference between sample data and discharge data is that the code requires a third column that contains a remark code, either blank or `"<"`, which will tell the program that the data were "left-censored" (or, below the detection limit of the sensor). Therefore, the data must be in the form: date, remark, value. An example

of a comma-delimited file is:

```
cdate;remarkCode;Nitrate
10/7/1999,,1.4
11/4/1999,<,0.99
12/3/1999,,1.42
1/4/2000,,1.59
2/3/2000,,1.54
...
```

The call to open this file, and populate the Sample dataframe is:

```
fileName <- "ChoptankRiverNitrate.csv"
filePath <-  "C:/RData/"
Sample <-readUserSample(filePath,fileName,
                                  separator=",")
```

When multiple constituents are to be summed, the format can be date, remark_A, value_A, remark_b, value_b, etc... A tab-separated example might look like the file below, where the columns are date, remark dissolved phosphate (rdp), dissolved phosphate (dp), remark particulate phosphorus (rpp), particulate phosphorus (pp), remark total phosphate (rtp), and total phosphate (tp):

```
date  rdp dp rpp pp rtp tp
2003-02-15 0.020 0.500
2003-06-30 <0.010 0.300
2004-09-15 <0.005 <0.200
2005-01-30 0.430
2005-05-30 <0.050
2005-10-30 <0.020
...
```

```
fileName <- "ChoptankPhosphorus.txt"
filePath <-  "C:/RData/"
Sample <-readUserSample(filePath,fileName,
                                  separator="\t")
```

4.6 Merge Report

Finally, there is a function called `mergeReport` that will look at both the Daily and Sample dataframe, and populate Q and LogQ columns into the Sample dataframe. The default arguments are Daily and Sample, however if you want to use other similarly structured dataframes, you can specify localDaily or localSample. Once `mergeReport` has been run, the Sample dataframe will be augmented with the daily discharges for all the days with samples. None of the water quality functions in EGRET will work without first having run the `mergeReport` function.

```
siteNumber <- "01491000"
parameterCd <- "00631"  # Nitrate
startDate <- "2000-01-01"
endDate <- "2013-01-01"
```

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

There are 4750 data points, and 4750 days.

Sample <- readNWISSample(siteNumber,parameterCd, startDate, endDate)
INFO <- readNWISInfo(siteNumber, parameterCd, interactive=FALSE)
eList <- mergeReport(INFO, Daily,Sample)
# eList
```

5 Summary

Tables 11,12, and 13 summarize the data retrieval functions:

Table 11. dataRetrieval functions

Data Type	Function Name	Description
Daily	`getNWISdvData`	Raw USGS daily data
Daily	`getNWISData`	Raw USGS data in generalized query
Daily[1]	`readNWISDaily`	USGS daily values
Daily[1]	`readUserDaily`	User-generated daily data
Sample	`getNWISqwData`	Raw USGS water quality data
Sample	`getWQPqwData`	Raw Water Quality Data Portal data
Sample	`getWQPData`	Raw Water Quality Portal data in generalized query
Sample[1]	`readNWISSample`	USGS water quality data
Sample[1]	`readWQPSample`	Water Quality Data Portal data
Sample[1]	`readUserSample`	User-generated sample data
Unit	`getNWISunitData`	Raw USGS instantaneous data
Information[1]	`readNWISInfo`	Station and parameter code information extracted from USGS
Information[1]	`readWQPInfo`	Station and parameter information extracted from Water Quality Portal
Information[1]	`readUserInfo`	Station and parameter information extracted from user-generated file
Information	`getNWISPcodeInfo`	USGS parameter code information
Information	`getNWISSiteInfo`	USGS station information
Information	`getNWISDataAvailability`	Data available at USGS stations
Information	`getNWISSites`	USGS station information in generalized query

[1] Indicates that the function creates a data frame suitable for use in EGRET software, otherwise data is returned in the exact form that it was received.

Table 12. dataRetrieval functions organization

	Site Query	Meta Data	Data Retrieval

NWIS:
Daily
Unit/Instantaneous
Groundwater
Water Quality
	`getNWISSites`
	`getNWISDataAvailability`
		`readNWISInfo`[1]
		`getNWISSiteInfo`
		`getNWISPcodeInfo`
			`getNWISData`
			`readNWISDaily`[1]
			`readNWISSample`[1]
			`getNWISdvData`
			`getNWISunitData`
			`getNWISqwData`

Water Quality Portal:
USGS
EPA
USDA
	`getWQPSites`	`readWQPInfo`[1]	`readWQPSample`[1]
			`getWQPqwData`
			`getWQPData`

User-supplied files: *Daily* *Sample* *Site Information*		`readUserInfo`[1]	`readUserDaily`[1] `readUserSample`[1]

[1] Indicates that the function creates a data frame suitable for use in EGRET software, otherwise data is returned in the exact form that it was received.

Table 13. Supplemental dataRetrieval functions

Function Name	Description
`compressData`	Converts value/qualifier into ConcLow, ConcHigh, Uncen
`importRDB1`	Retrieves and converts RDB data to dataframe
`importWaterML1`	Retrieves and converts WaterML1 data to dataframe
`importWaterML2`	Retrieves and converts WaterML2 data to dataframe
`mergeReport`	Merges flow data from the daily record into the sample record
`populateDateColumns`	Generates Julian, Month, Day, DecYear, and MonthSeq columns
`removeDuplicates`	Removes duplicated rows
`renameColumns`	Renames columns from raw data retrievals

5.1 Units

EGRET uses entirely SI units to store the data, but for purposes of output, it can report results in a wide variety of units. The defaults are mg/L for concentration, cubic meters per second (m^3/s) for discharge, kg/day for flux, and km^2 for drainage area. When discharge values are imported from USGS Web services (using the dataRetrieval package), they are automatically converted from cubic feet per second (cfs) to cms unless the argument `"convert"` in function `readNWISDaily` is set to FALSE. This can cause confusion if you are not careful.

For all functions that provide output, you can define two arguments to set the output units: qUnit and fluxUnit. qUnit and fluxUnit are defined by either a numeric code or name. You can call two functions that can be called to see the options: `printqUnitCheatSheet` and `printFluxUnitCheatSheet`.

```
printqUnitCheatSheet()

The following codes apply to the qUnit list:
1 =  cfs  ( Cubic Feet per Second )
2 =  cms  ( Cubic Meters per Second )
3 =  thousandCfs  ( Thousand Cubic Feet per Second )
4 =  thousandCms  ( Thousand Cubic Meters per Second )
```

When a function has an input argument qUnit, you can define the discharge units that will be used in the figure or table that is generated by the function with the index (1-4) as shown above. Base your choice on the units that are customary for your intended audience, but also so that the discharge values don't have too many digits to the right or left of the decimal point.

```
printFluxUnitCheatSheet()
```

```
The following codes apply to the fluxUnit list:
1 =  poundsDay  ( pounds/day )
2 =  tonsDay  ( tons/day )
3 =  kgDay  ( kg/day )
4 =  thousandKgDay  ( thousands of kg/day )
5 =  tonsYear  ( tons/year )
6 =  thousandTonsYear  ( thousands of tons/year )
7 =  millionTonsYear  ( millions of tons/year )
8 =  thousandKgYear  ( thousands of kg/year )
9 =  millionKgYear  ( millions of kg/year )
10 =  billionKgYear  ( billions of kg/year )
11 =  thousandTonsDay  ( thousands of tons/day )
12 =  millionKgDay  ( millions of kg/day )
```

When a function has an input argument fluxUnit, you can define the flux units with the index (1-12) as shown above. Base the choice on the units that are customary for your intended audience, but also so that the flux values don't have too many digits to the right or left of the decimal point. Tons are always "short tons" and not "metric tons".

6 Flow History

This section describes functions included in the EGRET package that provide a variety of table and graphical outputs for examining discharge statistics based on time-series smoothing. These functions are designed for studies of long-term change and work best for daily discharge data sets of 50 years or longer. This type of analysis might be useful for studying issues such as the influence of land use change, water management change, or climate change on discharge conditions. This includes potential impacts on average discharges, high discharges, and low discharges, at annual time scales as well as seasonal or monthly time scales.

At this point it is assumed that you can load the daily discharge record into R, create the Daily dataframe, and enter the required metadata into the INFO dataframe. If not, see the dataRetrieval vignette:

```
vignette("dataRetrieval")
```

Consider this example from Columbia River at The Dalles, OR.

```
siteNumber <- "14105700"
startDate <- ""
endDate <- ""

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

```
There are 49819 data points, and 49821 days.
```

```
 discharge data jumps from 2014-10-15 to 2014-10-18

INFO <- readNWISInfo(siteNumber,"",interactive=FALSE)
INFO$shortName <- "Columbia River at The Dalles, OR"

eList <- as.egret(INFO, Daily, NA, NA)
```

You first must determine the period of analysis to use (PA). What is the period of analysis? If you want to examine your data set as a time series of water years, then the period of analysis is October through September. If you want to examine the data set as calendar years then the period of analysis is January through December. You might want to examine the winter season, which you could define as December through February, then those 3 months become the period of analysis. The only constraints on the definition of a period of analysis are these: it must be defined in terms of whole months; it must be a set of contiguous months (like March-April-May), and have a length that is no less than 1 month and no more than 12 months. Define the PA by using two arguments: paLong and paStart. paLong is the length of the PA, and paStart is the first month of the PA. Table 14 summarizes paLong and paStart.

Table 14. Period of Analysis Information

Period of Analysis	paStart	paLong
Calendar Year	1	12
Water Year	10	12
Winter	12	3
September	9	1

To set a period running from December through February:

```
eList <- setPA(eList,paStart=12,paLong=3)
```

To set the default value (water year):

```
eList <- setPA(eList)
```

The next step is to create the annual series of discharge statistics. These will be stored in a matrix called annualSeries that contain the statistics described in table 15. The statistics are based on the period of analysis set with the `setPA` function.

Table 15. Index of discharge statistics information

istat	Name
1	minimum 1-day daily mean discharg
2	minimum 7-day mean of the daily mean discharges
3	minimum 30-day mean of the daily mean discharges
4	median of the daily mean discharges
5	mean of the daily mean discharges
6	maximum 30-day mean of the daily mean discharges
7	maximum 7-day mean of the daily mean discharges
8	maximum 1-day daily mean discharge

To create the annualSeries matrix, using the function `makeAnnualSeries`:

```
annualSeries <- makeAnnualSeries(eList)
```

After you create the annualSeries matrix, you can generate the plots of any of the stored statistics by using the `plotFlowSingle` function.

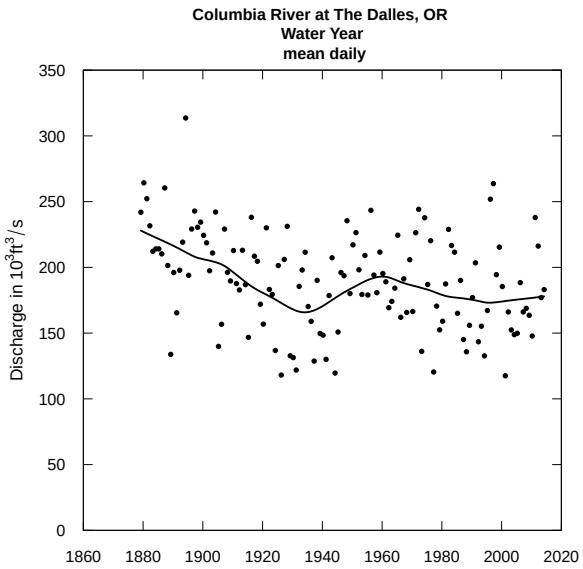
6.1 Plotting Options

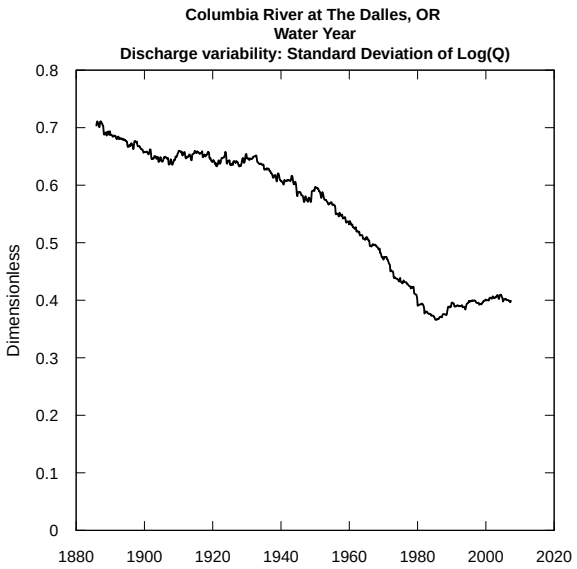
This section shows examples of the available plots appropriate for studying discharge history once the annualSeries has been created. The plots here use the default variable input options. For any function, you can get a complete list of input variables (as described in section 12.1) in a help file by typing a ? before the function name in the R console. The EGRET manual has more detailed information for each plot type (link to download). Finally, see section 14 for information on saving plots.

The simplest way to look at these time series is with the function `plotFlowSingle`. The statistic index (istat) must be defined by the user, but for all other arguments there are default values so the user isn't required to specify anything else. To see a list of these optional arguments and other information about the function, type ?plotFlowSingle in the R console. All of the graphs in `plotFlowSingle`, `plotFourStats`, and all but one of the graphs in plotFour, show both the individual annual values of the selected discharge statistic (e.g. the annual mean or 7-day minimum), but they also show a curve that is a smooth fit to those data. The curve is a LOWESS (locally weighted scatterplot smooth). The algorithm for computing it is provided in (4):*http://pubs.usgs.gov/sir/2012/5151/* (pages 6 and 7). The default is that the annual values of the selected discharge statistics are smoothed with a "half-window width" of 30 years. The smoothing window is an optional user-defined option.

`plotSDLogQ` produces a graphic of the running standard deviation of the log of daily discharge over time to visualize how variability of daily discharge is changing over time. By using the standard deviation of the log discharge the statistic becomes dimensionless. The standard deviation plot is a way of looking at variability quite aside from average values, so, in the case of a system where discharge might be increasing over a period of years, this graphic provides a way of looking at the variability relative to that changing mean value. The standard deviation is much like a coefficient of variation, but it has sample properties that make it a smoother measure of variability. People often comment about how things like urbanization or enhanced greenhouse gases in the atmosphere are bringing about an increase in variability, and this analysis is one way to explore that idea. `plotFour`, plotFourStats, and `plot15` are all designed to plot several graphs from the other functions in a single figure.

```
plotFlowSingle(eList, istat=5,qUnit="thousandCfs")
plotSDLogQ(eList)
```



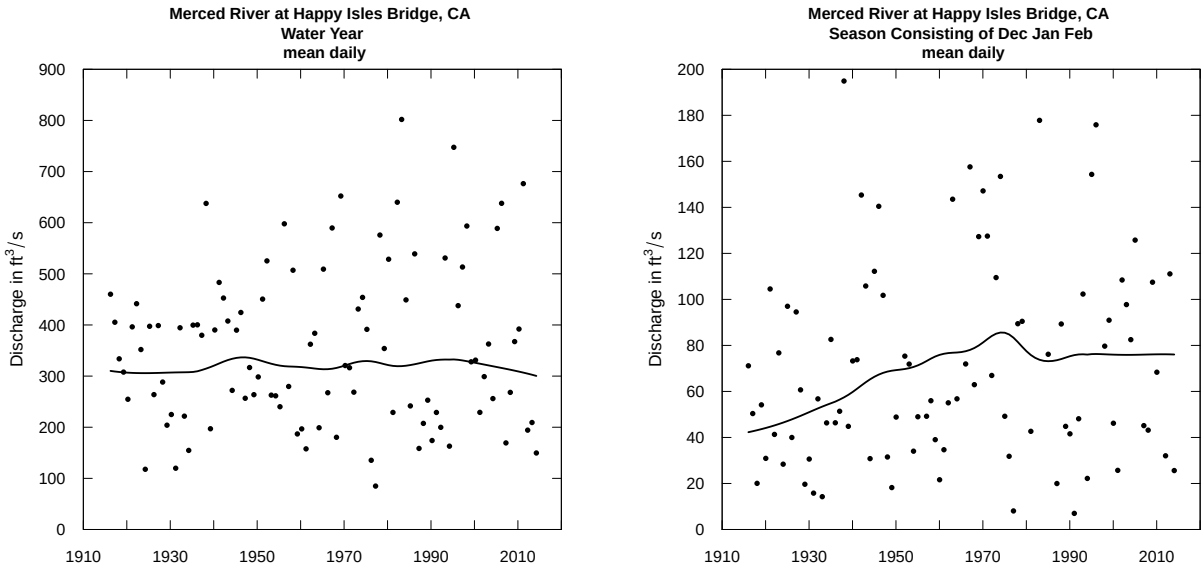


(a) plotFlowSingle(istat=5,qUnit='thousandCfs') **(b)** plotSDLogQ(eList)

Figure 1. Plots of discharge statistics

Here is an example of looking at daily mean discharge for the full water year and then looking at mean daily discharge for the winter season only for the Merced River at Happy Isles Bridge in Yosemite National Park in California. First, we look at the mean daily discharge for the full year (after having read in the data and metadata):

```
siteNumber<-"11264500"
Daily <-readNWISDaily(siteNumber,"00060",startDate="",endDate="")

There are 36225 data points, and 36225 days.

INFO <- readNWISInfo(siteNumber,"",interactive=FALSE)
INFO$shortName <- "Merced River at Happy Isles Bridge, CA"
eListMerced <- as.egret(INFO, Daily, NA, NA)
eListMerced <- setPA(eListMerced)
plotFlowSingle(eListMerced, istat=5)

# Then, we can run the same function, but first set
# the pa to start in December and only run for 3 months.

eListMerced <- setPA(eListMerced,paStart=12,paLong=3)
plotFlowSingle(eListMerced,istat=5,qMax=200)
```



(a) Water Year

(b) December - February

Figure 2. Merced River Winter Trend

What these figures show us is that on an annual basis there is very little indication of a long-term trend in mean discharge, but for the winter months there is a pretty strong indication of an upward trend. This could well be related to the climate warming in the Sierra Nevada, resulting in a general increase in the ratio of rain to snow in the winter and more thawing events.

```
plotFour(eListMerced, qUnit=3)
```

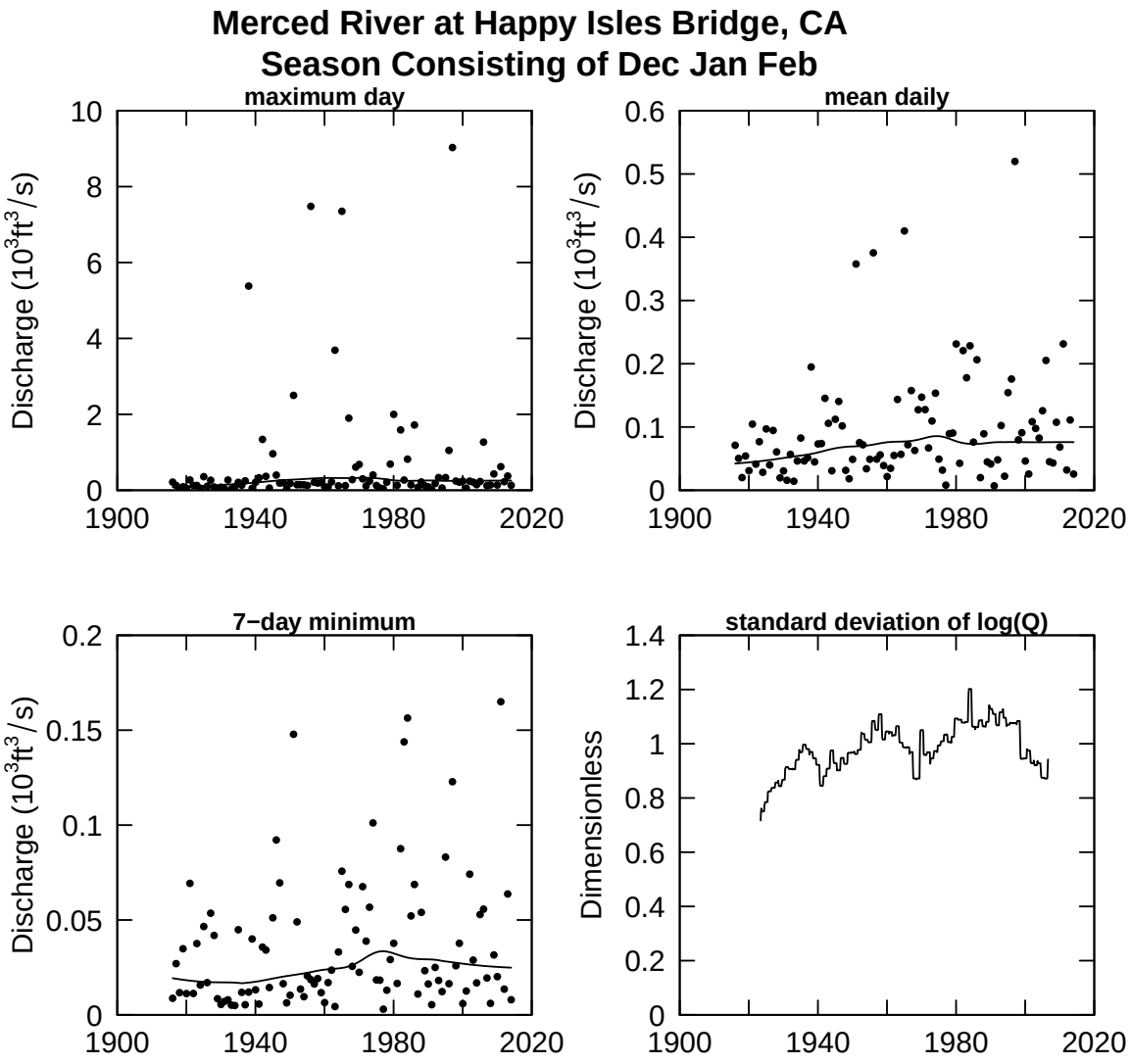


Figure 3. `plotFour(qUnit=3)`

```
plotFourStats(eListMerced, qUnit=3)
```

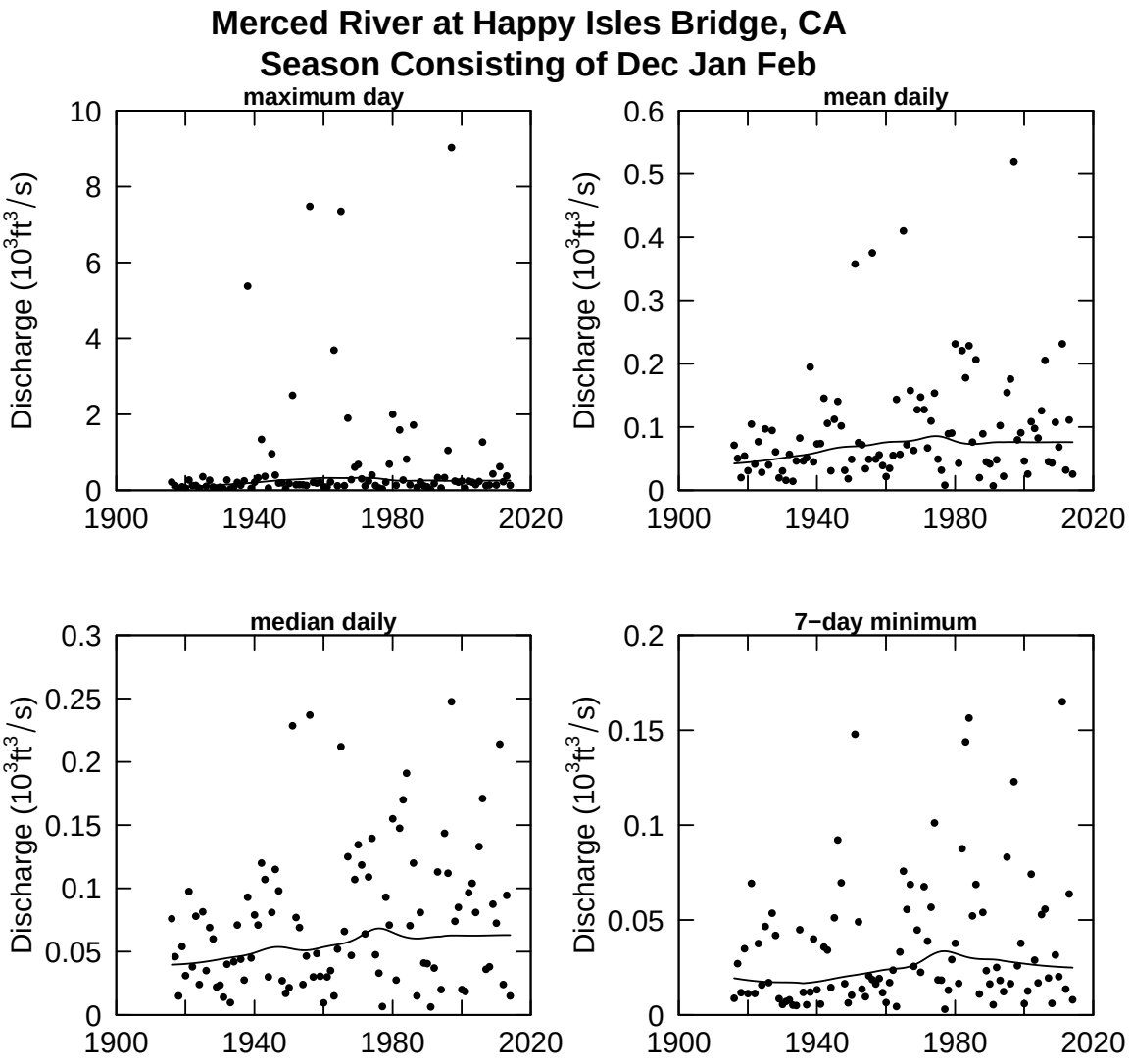


Figure 4. `plotFourStats(qUnit=3)`

```
siteNumber<-"05474500"
Daily <-readNWISDaily(siteNumber,"00060",startDate="",endDate="")

There are 49946 data points, and 49946 days.

INFO <- readNWISInfo(siteNumber,"",interactive=FALSE)
INFO$shortName <- "Mississippi River at Keokuk Iowa"
eListMiss <- as.egret(INFO, Daily, NA, NA)

plotQTimeDaily(eListMiss, qUnit=3,qLower=300)
```

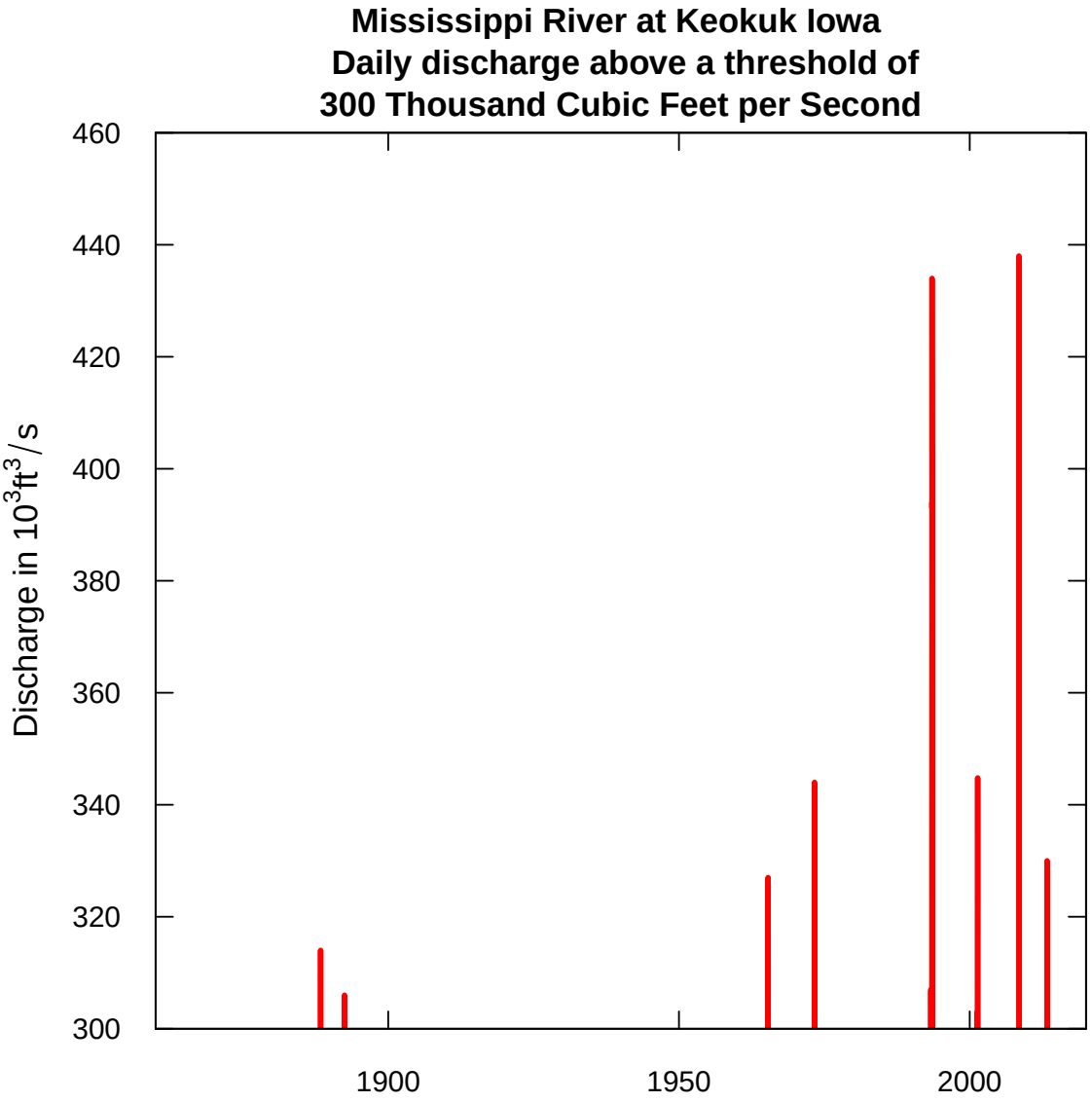


Figure 5. Mississippi River at Keokuk Iowa

`plotQTimeDaily` is simply a time series plot of discharge. But, it is most suited for showing events

above some discharge threshold. In the simplest case, it can plot the entire record, but given the line weight and use of an arithmetic scale it primarily provides a visual focus on the higher values.

The example shown in Figure 5 illustrates a very long record with a long gap of more than 60 years with no discharges above 300,000 cfs, followed by the last 50 years with at least 5 events above that threshold. `plotQTimeDaily` requires startYear and endYear, along with some other optional arguements (see `?plotQTimeDaily` for more details).

6.2 Table Options

Sometimes it is easier to consider results in table formats rather than graphically. Similar to the function `plotFlowSingle`, the `printSeries` will print the requested discharge statistics (Table 15), as well as return the results in a dataframe. A small sample of the output is printed below.

```
seriesResult <- printSeries(eListMiss, istat=3, qUnit=3)
```

```
Mississippi River at Keokuk Iowa
 Water Year
    30-day minimum
    Thousand Cubic Feet per Second
   year   annual   smoothed
           value    value
   1879     22.6     30.1
   1880     31.7     28.7
   1881     23.0     27.5
...
   2011     51.0     32.4
   2012     34.3     32.1
   2013     16.2     31.8
```

Another way to look at the results is to consider how much the smoothed values change between various pairs of years. These changes can be represented in four different ways.

- As a change between the first and last year of the pair, expressed in the discharge units selected.
- As a change between the first and last year of the pair, expressed as a percentage of the value in the first year
- As a slope between the first and last year of the pair, expressed in terms of the discharge units per year.
- As a slope between the first and last year of the pair, expressed as a percentage change per year (a percentage based on the value in the first year).

Another argument can be very useful in this function: yearPoints. In the default case, the set of years that are compared are at 5 year intervals along the whole data set. If the data set was quite long this can be a daunting number of comparisons. For example, in an 80 year record, there would be 136 such pairs. Instead, we could look at changes between only 3 year points: 1890, 1950, and 2010:

```
tableFlowChange(eListMiss, istat=3, qUnit=3,yearPoints=c(1890,1950,2010))
```

```
  Mississippi River at Keokuk Iowa
  Water Year
   30-day minimum

            Streamflow Trends
  time span          change        slope       change        slope
                   10^3 cfs   10^3cfs/yr        %            %/yr
1890  to  1950          1.3        0.022          5.7        0.095
1890  to  2010          9.6         0.08           42         0.35
1950  to  2010          8.3         0.14           34         0.57
```

See section 13 for instructions on converting an R dataframe to a table in Microsoft® software. Excel, Microsoft, PowerPoint, Windows, and Word are registered trademarks of Microsoft Corporation in the United States and other countries.

7 Summary of Water Quality Data (without using WRTDS)

Before you run the WRTDS model, it is helpful to examine the measured water quality data graphically to better understand its behavior, identify possible data errors, and visualize the temporal distribution of the data (identify gaps). It is always best to clear up these issues before moving forward.

The examples below use the Choptank River at Greensboro, MD. The Choptank River is a small tributary of the Chesapeake Bay. Inorganic nitrogen (nitrate and nitrite) has been measured from 1979 onward. First, we need to load the discharge and nitrate data into R. Before we can graph or use it for WRTDS analysis, we must bring the discharge data into the Sample dataframe. We do this by using the `mergeReport` function which merges the discharge information and also provides a compact report about some major features of the data set.

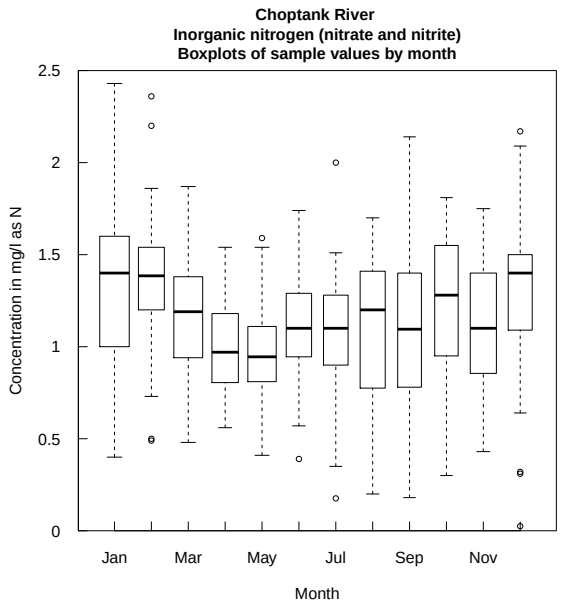
```
siteNumber <- "01491000" #Choptank River at Greensboro, MD
startDate <- "1979-10-01"
endDate <- "2011-09-30"
param<-"00631"
Daily <- readNWISDaily(siteNumber,"00060",startDate,endDate)
INFO<- readNWISInfo(siteNumber,param,interactive=FALSE)
INFO$shortName <- "Choptank River"

Sample <- readNWISSample(siteNumber,param,startDate,endDate)
eList <- mergeReport(INFO, Daily, Sample)
```

7.1 Plotting Options

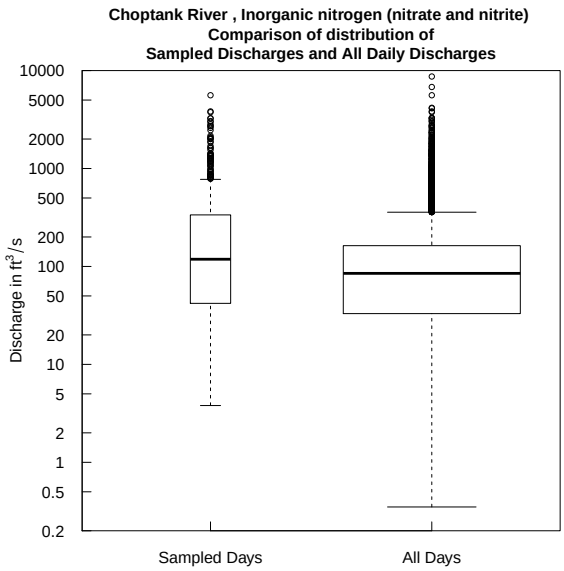
This section shows examples of the available plots appropriate for analyzing data prior to performing a WRTDS analysis. The plots here use the default variable input options. For any function, you can get a complete list of input variables in a help file by typing a ? before the function name in the R console. See section 12.2 for information on the available input variables for these plotting functions.

Note that for any of the plotting functions that show the sample data, if a value in the data set is a non-detect (censored), it is displayed on the graph as a vertical line. The top of the line is the reporting limit and the bottom is either zero, or if the graph is plotting log concentration values, or the minimum value on the y-axis. This line is an "honest" representation of what we know about that observation and thus we need not become involved in using a statistical model to fill in what we don't know.

```
boxConcMonth(eList)
boxQTwice(eList,qUnit=1)
```



(a) `boxConcMonth(eList)`

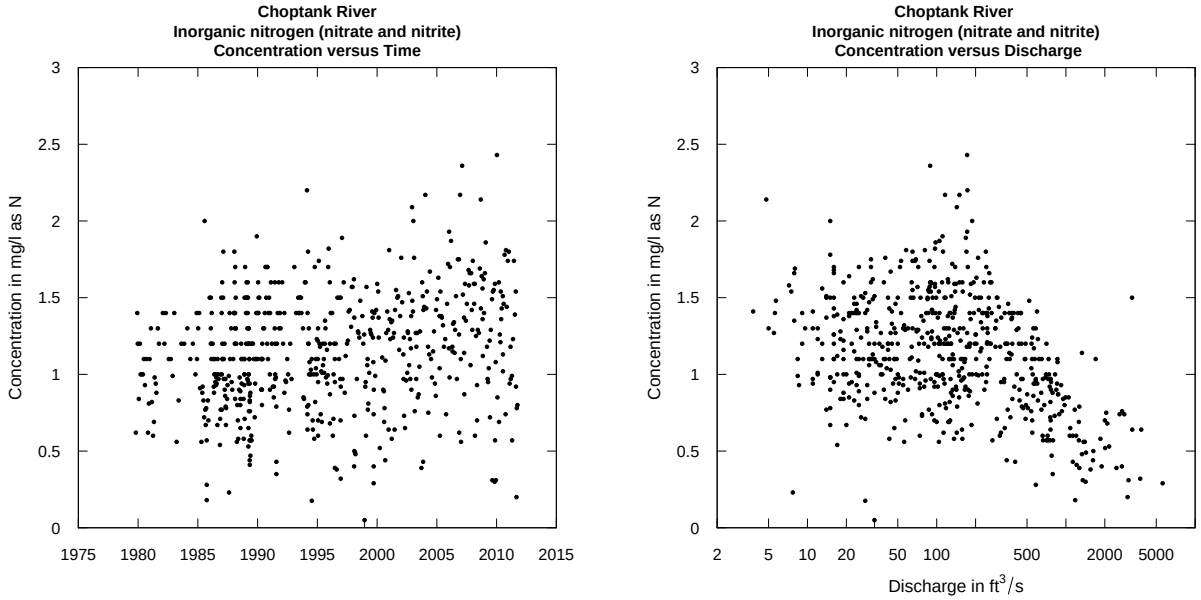


(b) `boxQTwice(eList, qUnit=1)`

Figure 6. Concentration box plots

Note that the statistics to create the boxplot in `boxQTwice` are performed after the data are log-transformed.

```
plotConcTime(eList)
plotConcQ(eList, qUnit=1)
```



(a) `plotConcTime(eList)` **(b)** `plotConcQ(eList)`

Figure 7. The relation of concentration vs time or discharge

It is interesting to note in Figure 7 the change in the convention for rounding of data values that occurred around 1995.

```
plotFluxQ(eList, fluxUnit=4)
```

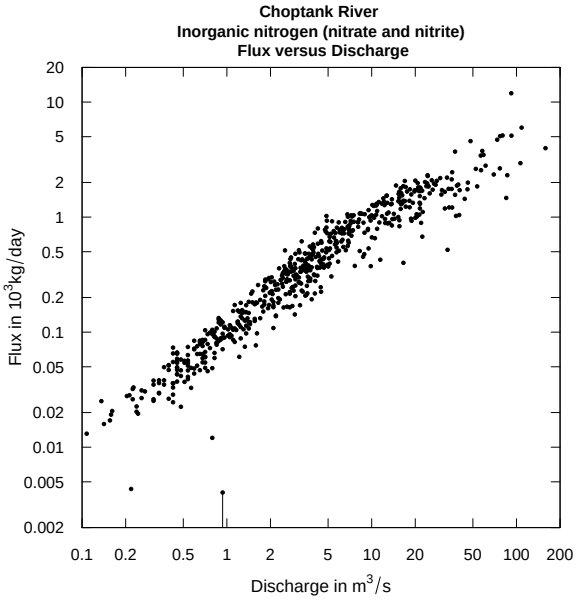


Figure 8. The relation of flux vs discharge

The `plotFluxQ` (Figure 8) function only plots in a log-log scale.

```
multiPlotDataOverview(eList, qUnit=1)
```

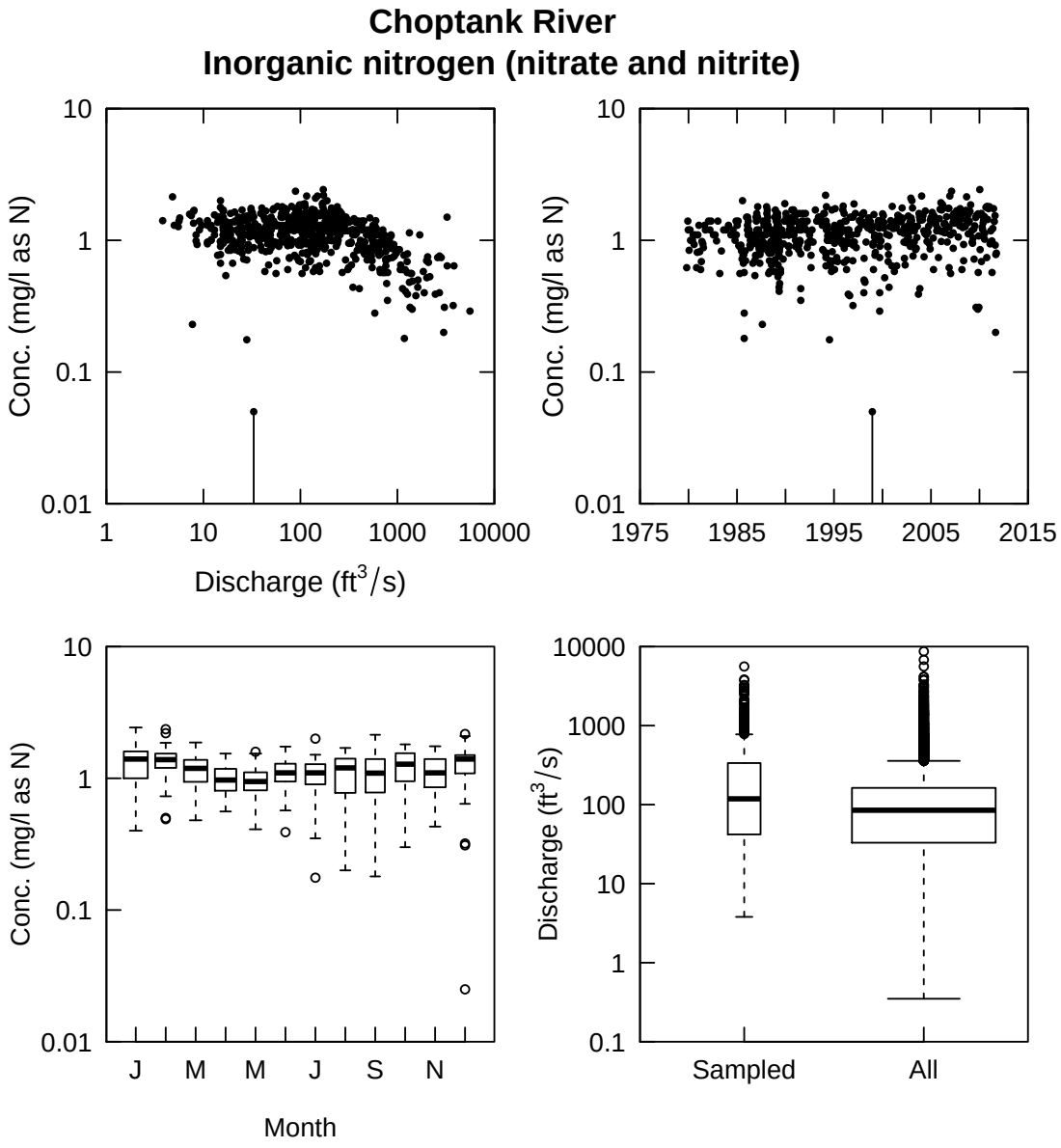


Figure 9. `multiPlotDataOverview(qUnit=1)`

The `multiPlotDataOverview` (Figure 9) function uses a log scale as default. To change the concentration axes to an arithmetic scale, use logScaleConc=FALSE in the `multiPlotDataOverview` function call.

7.2 Table Options

Another useful tool for checking the data before running the WRTDS estimations is `flowDuration`. This is a utility function that can help you define the discharge ranges that we want to explore. It prints out

key points on the discharge duration curve. Define the points for a particular part of the year using the "centerDate" and "span" arguments, although the points can be defined for the entire year (default).

```
flowDuration(eList, qUnit=1)


Flow Duration for Choptank River

Flow duration is based on full year

Discharge units are Cubic Feet per Second
    min      5%     10%     25%     50%     75%     90%
   0.35   12.00   16.00   33.00   85.00  163.00  290.00
    95%     max
 462.00 8700.00

flowDuration(eList, qUnit=1, centerDate="09-30", span=30)


Flow Duration for Choptank River

Flow duration period is centered on September 30
And spans the period from August 31  To October 30

Discharge units are Cubic Feet per Second
   min     5%    10%    25%    50%    75%    90%    95%
   2.5    8.8   11.0   15.0   27.0   67.0  138.0  223.0
   max
5600.0
```

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

WRTDS creates a model of the behavior of concentration as a function of three components: time trend, discharge, and season. You can use WRTDS to estimate annual or seasonal mean concentrations and fluxes as well as describe long-term trends in the behavior of the system. In this section, we will step though the process required for a WRTDS analysis. Section (9) provides details about the available methods for viewing and evaluating the model results.

Once you have looked at your data using the tools described in section 7, and have determined there are sufficient representative data, it is time to run the WRTDS model. Assuming you are using the defaults, with dataframes called Daily, Sample, and INFO, the `modelEstimation` function runs the WRTDS modeling algorithm:

```
eList <- modelEstimation(eList)
```

Details of the options available when running `modelEstimation` can be found in Section 12.3. This function is slow, and shows the progress in percent complete. See the references and manual for more information. It's important to understand that this is the one function that will globally change your Daily, Sample, and INFO dataframes. It also creates a new matrix "surfaces", and a new dataframe "AnnualResults".

It is unusual R programming behavior to create global variables, but global variables were chosen to make it easy for you.

Finally, it is a good idea to save your results because of the computational time that has been invested in producing these results. The workspace is saved to a directory that you designate savePath and the file name is determined by the abbreviations for station and constituent that were required entries when the `readNWISInfo` function was used. The command for saving the workspace is:

```
savePath <- "C:/Users/egretUser/WRTDS_Output/" #An example directory name
saveResults(savePath, INFO)
```

This saves all of the objects in your workspace. If you have saved workspaces from R versions earlier than 3.0, a warning will appear when you open them in R 3.0 (or later). Re-saving the workspace using R 3.0 (or later) should get rid of the warning.

Using `saveResults`, the workspace is saved with INFO$staAbbrev and INFO$constitAbbrev as the file-name (separated by a period), and the extension .RData. So, if staAbbrev was "Chop" and the constitAbbrev was "NO3" the file name would be "Chop.NO3.RData". To load the data in some future session the commands could be:

```
loadPath <- "C:/Users/egretUser/WRTDS_Output/"
staAbbrev <- "Chop"
constitAbbrev <- "NO3"
pathToFile <- paste(loadPath,staAbbrev,".",
                    constitAbbrev,".RData",sep="")
load(pathToFile)
```

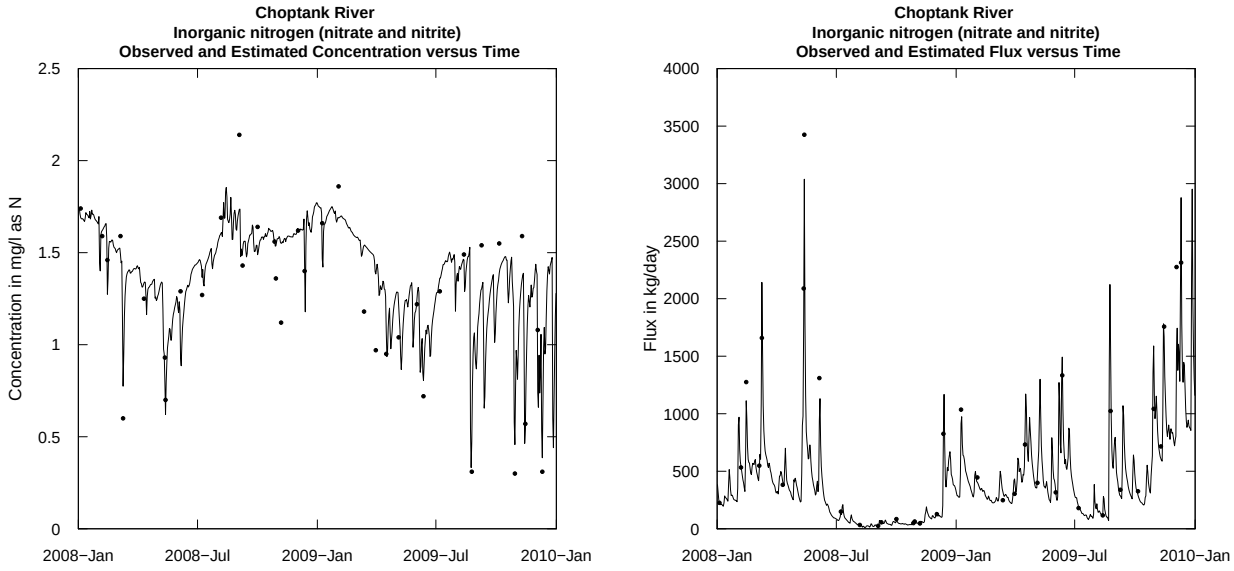
9 WRTDS Results

At this point (after having run `modelEstimation`) we can start considering how to view the annual averages for the variables that have been calculated. See section 12.4 for common input variables for these functions. Additionally, check the help files (in the R console, type ? followed by the function name).

9.1 Plotting Options

Check the help files or manual for more details on the following functions. See section 14 for information on saving plots. In these examples, we will return to looking at the data in the water year by using the `setPA` function. Most plotting functions will use the period of analysis information in the INFO dataframe to determine what data are plotted. There are only four graph or table functions that don't allow the user to specify a Period of Analysis (PA). These are: `plotContour`, `plotDiffContour`, `plotConcTimeSmooth`, `plotConcQSmooth`.

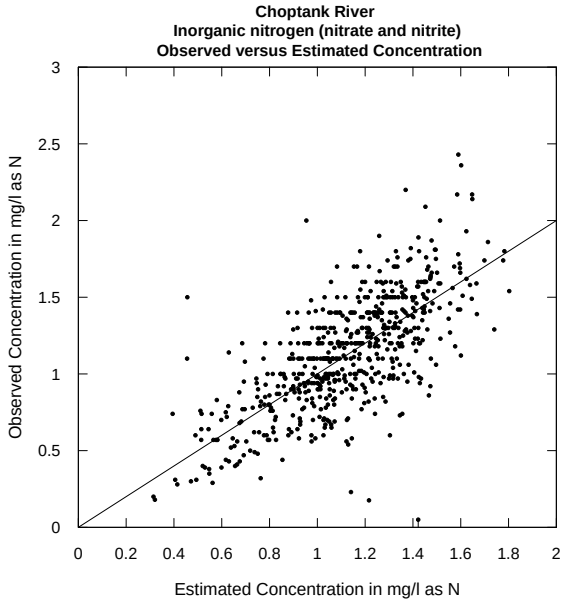
```
# Return to water year:
eList <- setPA(eList)

yearStart <- 2008
yearEnd <- 2010

plotConcTimeDaily(eList, yearStart, yearEnd)
plotFluxTimeDaily(eList, yearStart, yearEnd)
```



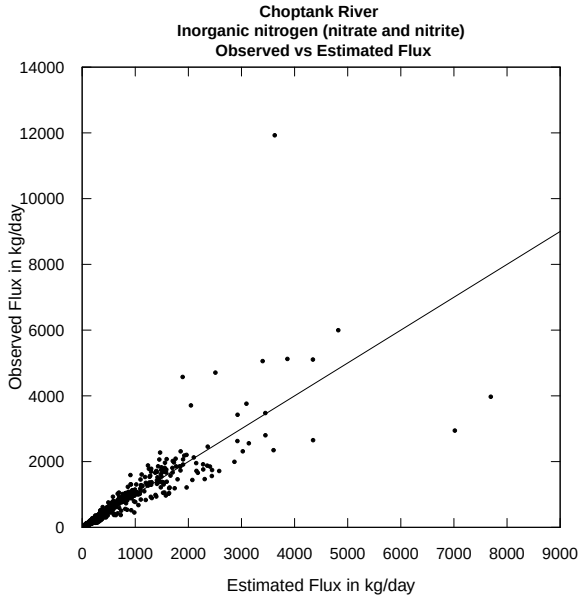
(a) `plotConcTimeDaily(2008, 2010)` **(b)** `plotFluxTimeDaily(2008, 2010)`

Figure 10. Concentration and flux vs time

```
plotConcPred(eList)
plotFluxPred(eList)
```



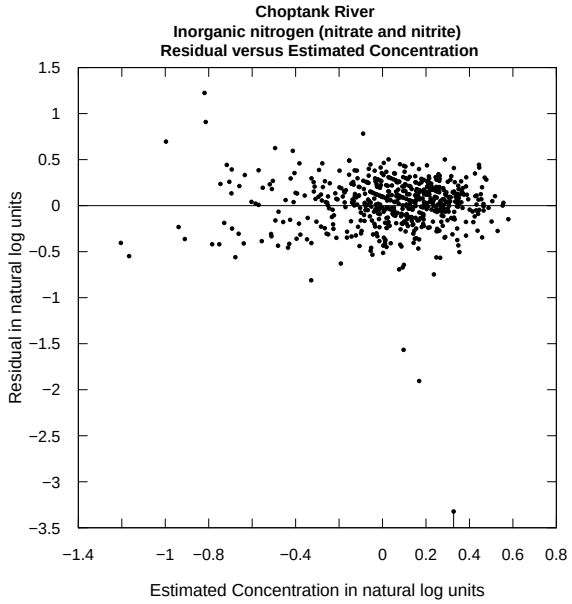
(a) `plotConcPred(eList)`



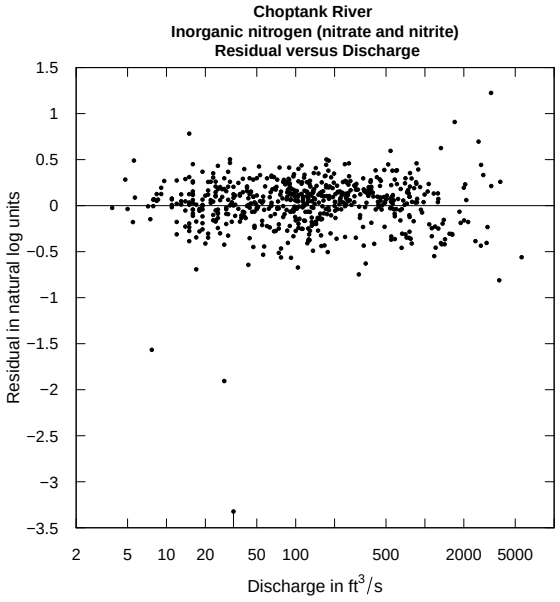
(b) `plotFluxPred(eList)`

Figure 11. Concentration and flux predictions

```
plotResidPred(eList)
plotResidQ(eList, qUnit=1)
```



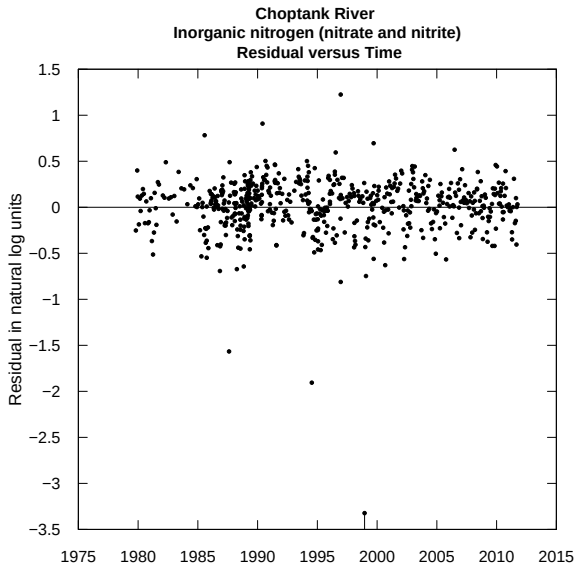
(a) `plotResidPred(eList)`



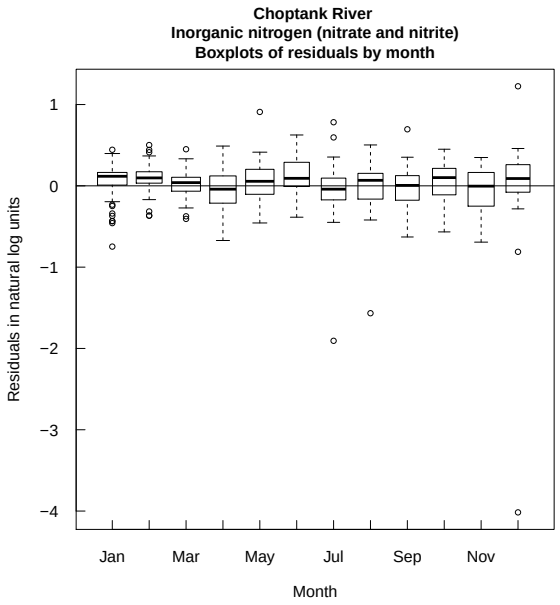
(b) `plotResidQ(eList, qUnit=1)`

Figure 12. Residuals

```
plotResidTime(eList)
boxResidMonth(eList)
```



(a) `plotResidTime(eList)`



(b) `boxResidMonth(eList)`

Figure 13. Residuals with respect to time

```
boxConcThree(eList)
```

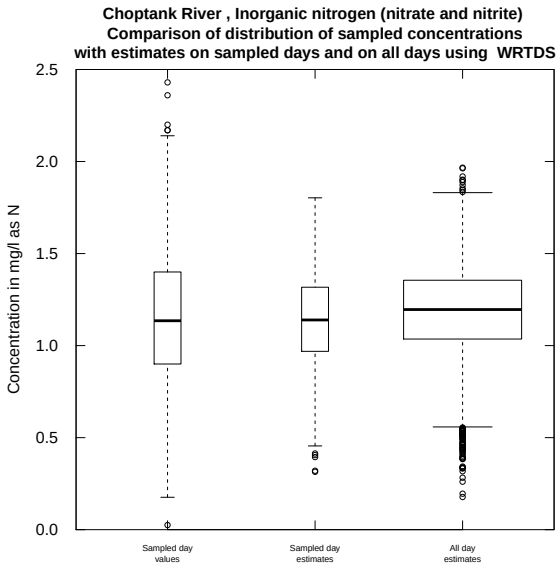
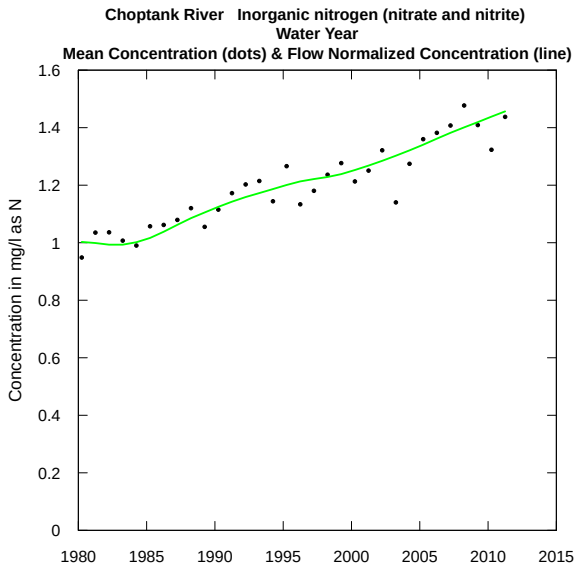
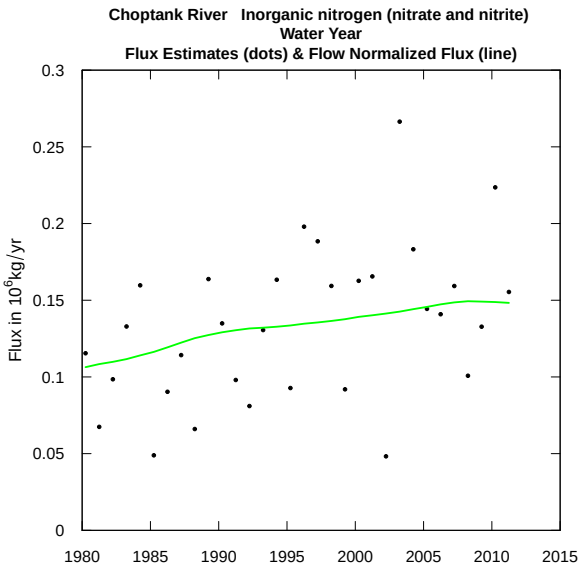


Figure 14. Default `boxConcThree(eList)`

```
plotConcHist(eList)
plotFluxHist(eList)
```



(a) `plotConcHist(eList)`

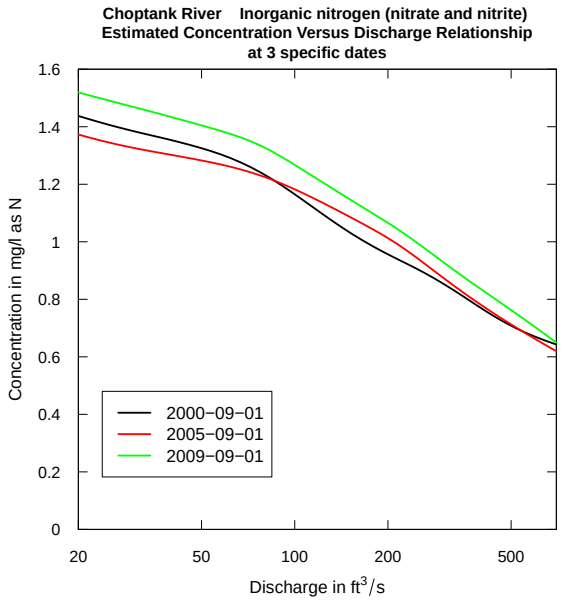


(b) `plotFluxHist(eList)`

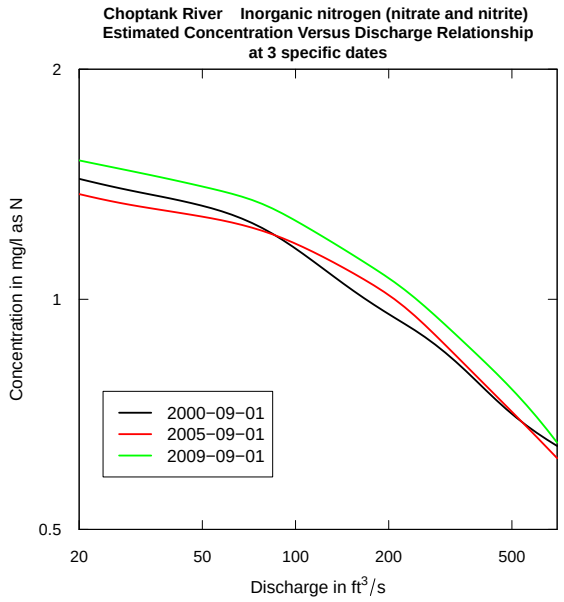
Figure 15. Concentration and flux history

Figures 16 and 17 contain legends. The placement of the legend is controlled by legendLeft and legendTop. If both are set to 0 (the default values), the legend is placed near the lower left corner of the graphic. Otherwise, the value specified for legendLeft places the left edge of the legend, and legendTop specifies the top edge of the legend. The units for legendLeft and legendTop are discharge (in units specified by qUnit) and concentration, respectively. The legend can also be turned off with printLegend=FALSE. These are also functions that do not recognize the period of analysis in the INFO data frame. However, by choosing centering dates and appropriate half-windows, seasonal behavior can easily be observed in these plots.

```
qBottom<-20
qTop<-700
date1 <- "2000-09-01"
date2 <- "2005-09-01"
date3 <- "2009-09-01"
plotConcQSmooth(eList, date1, date2, date3,
                qBottom, qTop, qUnit=1)
plotConcQSmooth(eList, date1, date2, date3,
                qBottom, qTop, qUnit=1,logScale=TRUE)
```



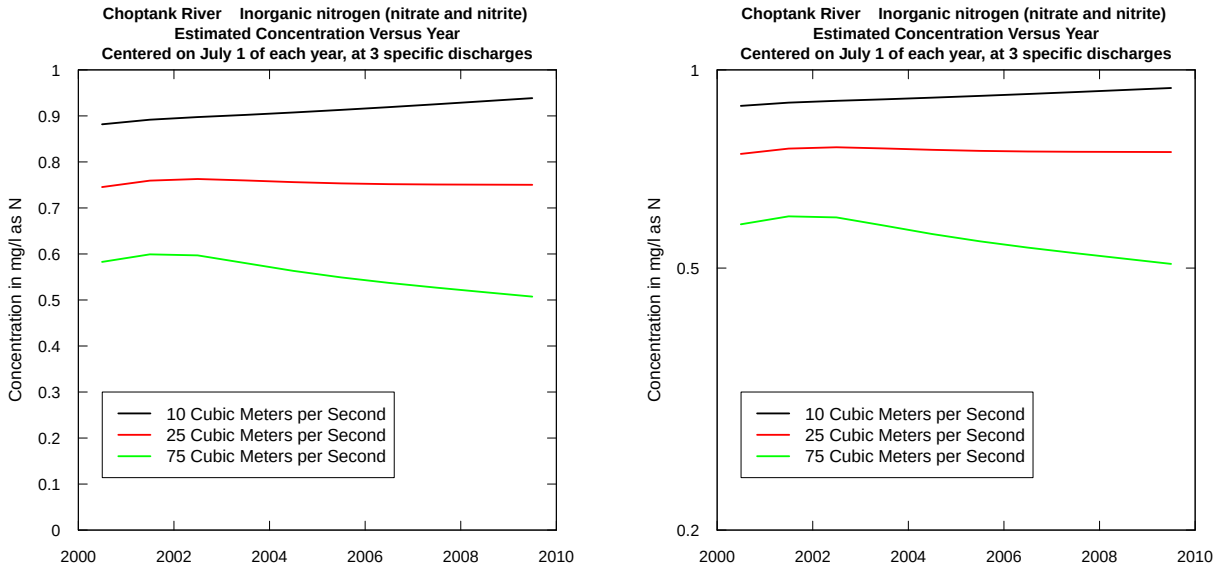
(a) `plotConcQSmooth`



(b) `plotConcQSmooth(logScale=TRUE)`

Figure 16. Concentration vs. discharge

```
q1 <- 10
q2 <- 25
q3 <- 75
centerDate <- "07-01"
plotConcTimeSmooth(eList, q1, q2, q3, centerDate, 2000, 2010)
plotConcTimeSmooth(eList, q1, q2, q3, centerDate,
                   2000, 2010,logScale=TRUE)
```



(a) `plotConcTimeSmooth` **(b)** `plotConcTimeSmooth(logScale=TRUE)`

Figure 17. `plotConcTimeSmooth(eList))`

Figure 18 shows a predefined multipanel graph using `fluxBiasMulti`.

```
fluxBiasMulti(eList, qUnit=1)
```

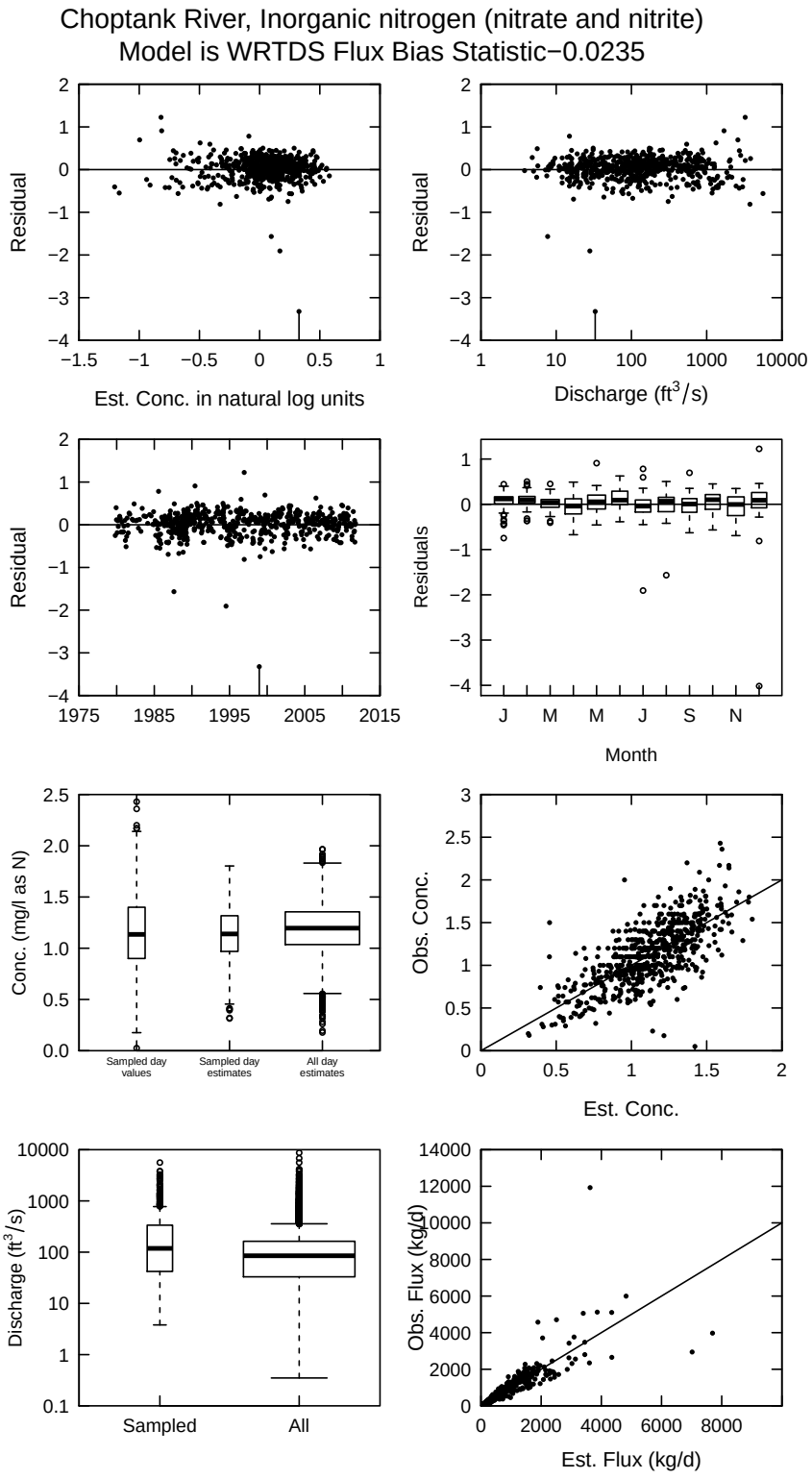


Figure 18. `fluxBiasMulti(eList, qUnit=1)`

The contour plot functions also do not recognize the PA from the INFO dataframe. They represent the overall results of the WRTDS analysis. To specify contourLevels in the contour plots use the `seq` function (type `?seq` for details). In general, use of the `seq` function would look like this: `contourLevels = seq(from,to,by)`. In the example shown above we are requesting contour levels that run from 0 to 2 in steps of 0.2.

```
clevel<-seq(0,2,0.2)
plotContours(eList, yearStart=2008,yearEnd=2010,qBottom=20,qTop=1000,
             contourLevels = clevel,qUnit=1,
             flowDuration=FALSE)
```

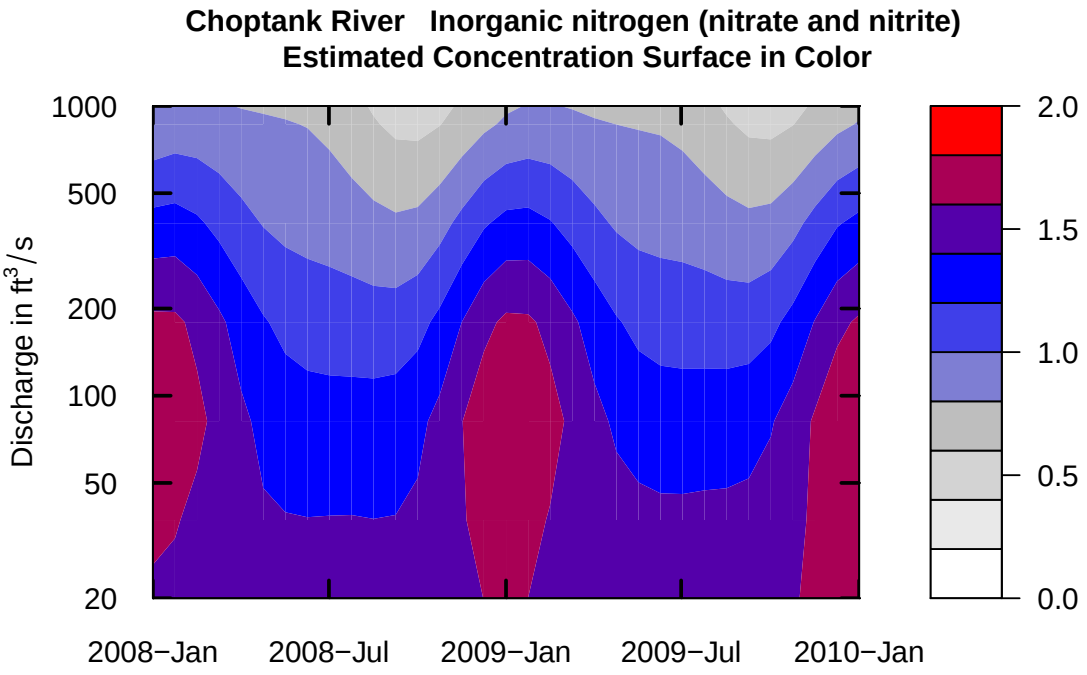


Figure 19. plotContours(eList)

The function `plotDiffContours` plots the difference between two selected years (year0 and year1). It can help clarify what combinations of seasons and flow conditions have been showing increases and decreases over the period covered.

```
plotDiffContours(eList, year0=2000,year1=2010,
                 qBottom=20,qTop=1000,maxDiff=0.6,qUnit=1,
              flowDuration=FALSE)
```

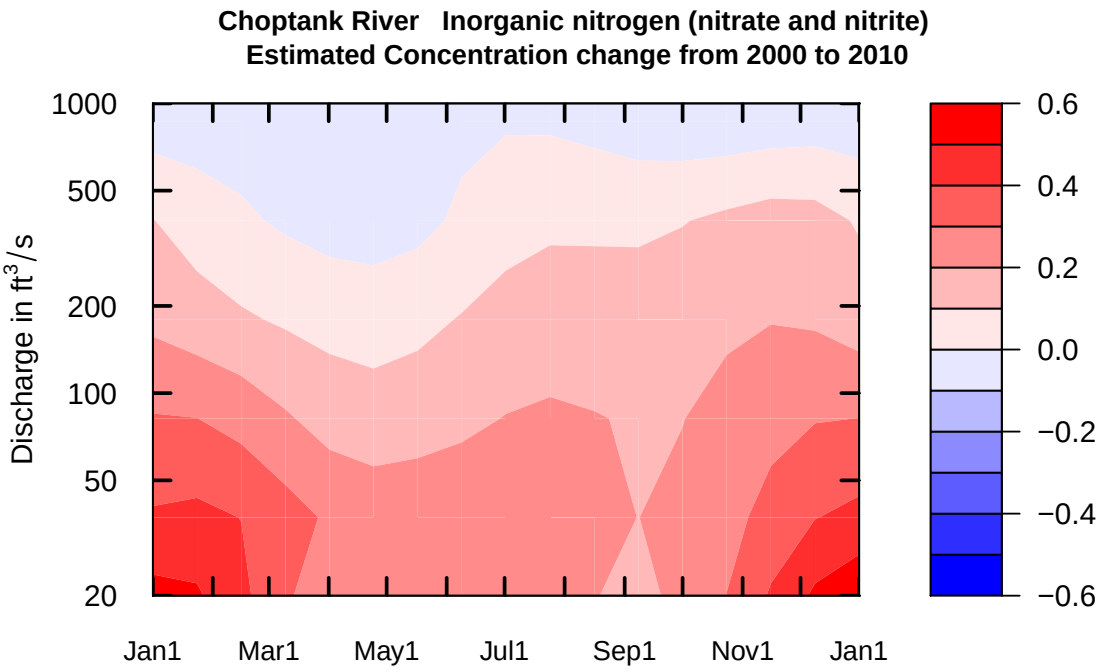


Figure 20. plotDiffContours(eList)

9.2 Table Options

Sometimes it is easier to consider the results in table form rather than graphically. The function `tableResults` produces a simple text table that contains the annual values for the results. Each row of the output represents a year and includes: year, average discharge, average concentration, flow-normalized concentration, average flux, and flow-normalized flux. A small sample of the output is printed below. This function can also return a data frame if returnDataFrame is set to TRUE.

```
tableResults(eList)
returnDF <- tableResults(eList)
```

```
   Choptank River
   Inorganic nitrogen (nitrate and nitrite)
   Water Year

   Year   Discharge    Conc    FN_Conc     Flux    FN_Flux
             cms             mg/L           10^6 kg/yr
   1980      4.25     0.949     1.003    0.1154     0.106
   1981      2.22     1.035     0.999    0.0675     0.108
...
   2010      7.19     1.323     1.438    0.2236     0.149
   2011      5.24     1.438     1.457    0.1554     0.148
```

Table 16. Table created from `head(returnDF)`

Year	Discharge [cms]	Conc [mg/L]	FN Conc [mg/L]	Flux [10^6kg/yr]	FN Flux [10^6kg/yr]
1980	4.25	0.949	1.003	0.115	0.106
1981	2.22	1.035	0.999	0.068	0.108
1982	3.05	1.036	0.993	0.098	0.110
1983	4.99	1.007	0.993	0.133	0.112
1984	5.72	0.990	1.002	0.160	0.114
1985	1.52	1.057	1.017	0.049	0.116

The other table option is `tableChange`. This is a function that provides for the computation of changes or slopes between any selected pairs of time points. These computations are made only on the flow-normalized results. A detailed explaination of "flow-normalized" result is in the official EGRET manual.

```
tableChange(eList, yearPoints=c(2000,2005,2010))
```

```
   Choptank River
   Inorganic nitrogen (nitrate and nitrite)
   Water Year

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

 2000  to  2005     0.088     0.018          7        1.4
 2000  to  2010      0.19     0.019         15        1.5
```

```
2005  to  2010     0.098      0.02       7.3       1.5


                Flux Trends
  time span          change         slope       change         slope
                  10^6 kg/yr    10^6 kg/yr /yr      %         %/yr
2000  to  2005       0.0065        0.0013          4.7         0.93
2000  to  2010       0.0097       0.00097          6.9         0.69
2005  to  2010       0.0032       0.00063          2.2         0.43
```

Finally, `tableChangeSingle` (Table 18) operates exactly the same as `tableChange` except for the addition of two arguments: returnDataFrame and flux. This function provides either concentration results or flux results, but not both. This can be useful when you are producing many output tables for a report that is entirely focused on concentration or one that is entirely focused on flux. The arguments are identical to those for tableChange, except for the final two arguments. The first, "returnDataFrame" is a logical argument to indicate if a dataframe of output should be returned (for later manipulation or printing through other programs such as Excel), and its default is FALSE. The second argument is "flux", and the default is TRUE. When flux=TRUE the output is only for flux, and when flux=FALSE the output is only for concentration. See section 13 for instructions on converting an R dataframe to a table in Microsoft® software.

```
returnDF <- tableChangeSingle(eList, yearPoints=c(2000,2005,2010),
                              returnDataFrame=TRUE)
```

Table 17. Table created from `tableChangeSingle` function

Year1	Year2	change[mg/L]	slope[mg/L/yr]	change[%]	slope [%/yr]
2000	2005	0.088	0.02	7.0	1.4
2000	2010	0.190	0.02	15.0	1.5
2005	2010	0.098	0.02	7.3	1.5

10 Extending Plots Past Defaults

The basic plotting options were shown in the section 9. This section demonstrates some ways to extend the capabilities of the EGRET plots. EGRET plots use R's basic plotting options. You set many of the formatting details of plotting routines in R by using "Graphical Parameters". To read about all of these graphical parameters see `?par`. When the graphical functions in EGRET are coded, a set of default values for many of these parameters are chosen, but you can override all of these default values. Additionally, you can add features to a plot after calling the plot function. To change the plot margins (mar), font, or other graphical parameters initially assigned, set the argument customPar to TRUE.

A few of R's base graphical parameters are especially useful within the plot functions. These are shown in Table 18.

Argument	Description	Values
cex	Size of data point symbols, relative to default	decimal number
cex.main	Size of font for plot title, relative to default	decimal number
cex.lab	Size of font for axis label text, relative to default	decimal number
cex.axis	Size of font for axis annotation (numbers), relative to default	decimal number
col	Color of data point symbols or lines	color name in " "
lwd	Width of lines, relative to default	decimal number
pch	Type of symbol to use for data points	integer values
lty	Line type number (such as dash or dot)	integer values

Table 18. Useful plotting parameters to adjust in EGRET plotting functions. For details of any of these see ?par.

After the plot is made, many other functions that might be useful to call, such as to add text, legend, lines, etc. Table 19 lists a few common options.

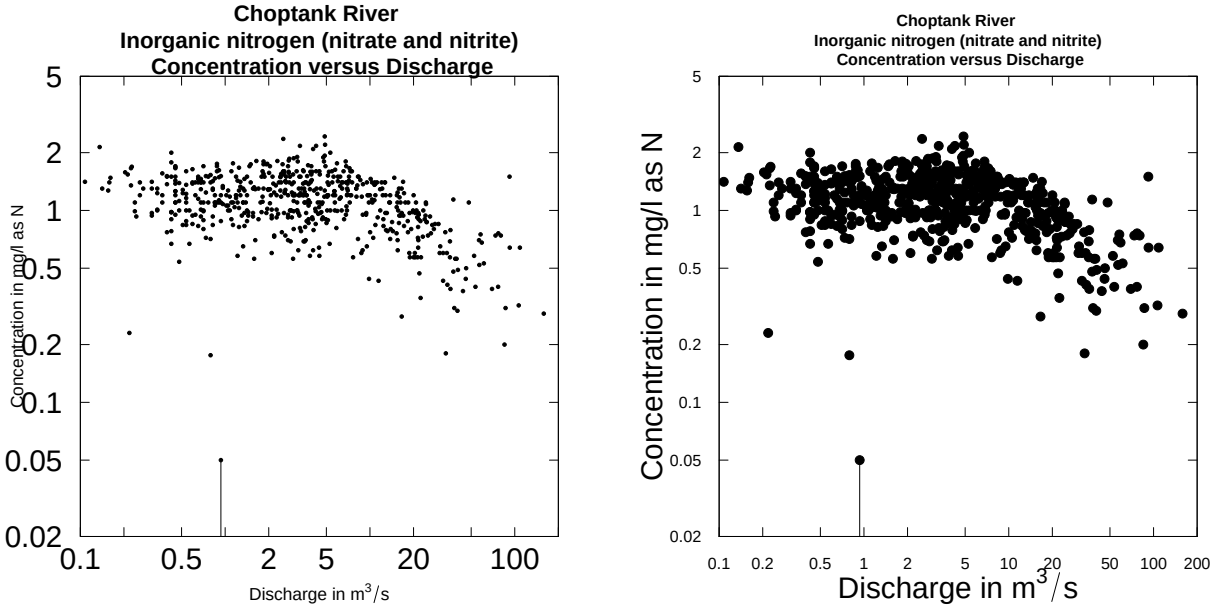
Function	Description
mtext	add text based on specified side of plot
text	add text to a specific point on plot
legend	add a legend
grid	add grid
abline	add line
arrows	add arrow

Table 19. Useful functions to add on to default plots. Type ? then the function name to get help on the individual function.

Some basic examples are shown below.

Figure 21 shows a larger title and axis number (left), and larger axis labels and point size (right).

```
plotConcQ(eList, cex.axis=2,cex.main=1.5,logScale=TRUE)
plotConcQ(eList, cex.lab=2,cex=2,logScale=TRUE)
```

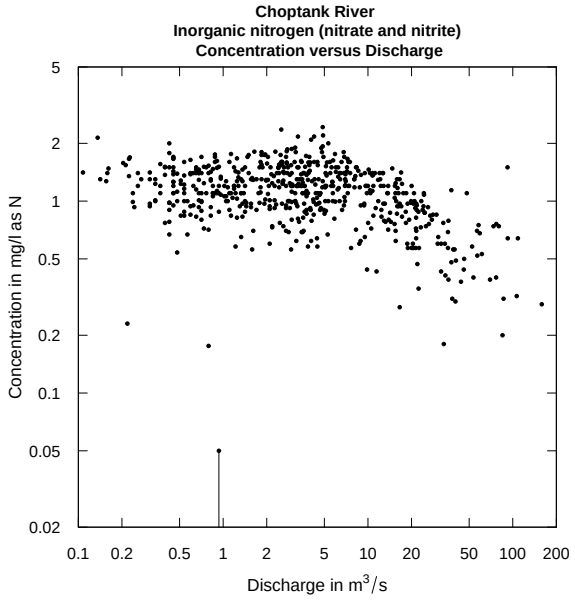


(a) `plotConcQ(cex.axis=2,cex.main=1.5,logScale=TRUE)` **(b)** `plotConcQ(cex.lab=2,cex=2,logScale=TRUE)`

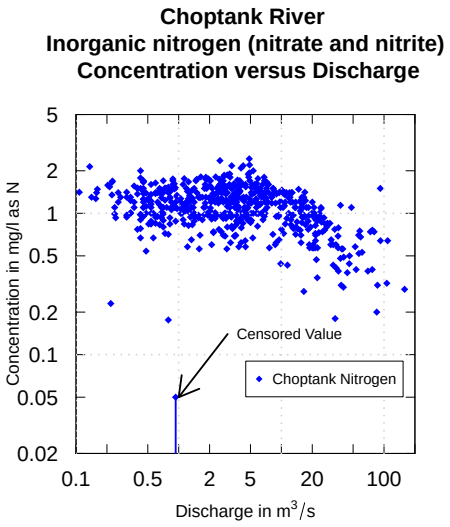
Figure 21. Modifying text and point size

Figure 22 shows the default on the left, and several features on the right. First, the margin is adjusted to c(8,8,8,8), requiring customPar set to TRUE. The margin vector represents the margin spacing of the 4 "sides" of a plot in the order: bottom, left, top, right. Next, the text labels were adjusted, color set to "blue", point and line size increased, and the point type changed form a solid circle(pch=20) to solid diamond (pch=18). A grid, legend, arrow, and text are added after the plot is produced.

```
plotConcQ(eList, logScale=TRUE)
par(mar=c(8,8,8,8))
plotConcQ(eList, customPar=TRUE,col="blue",cex=1.1,
          cex.axis=1.4,cex.main=1.5,cex.lab=1.2,
          pch=18,lwd=2,logScale=TRUE)
grid(lwd=2)
legend(4.5,.09,"Choptank Nitrogen", pch=18, col="blue",bg="white")
arrows(3, 0.14, 1, .05,lwd=2)
text(12,.14,"Censored Value")
```



(a) Default



(b) Modified

Figure 22. Modified plotConcQ

Only a few fonts are consistent on all operating systems. Figure 23 shows how to change to the Serif font, as well as how to use the mtext function. To see the available fonts for pdf output on your computer, type `names(pdfFonts())`.The available fonts are quite limited in base R. To expand the font choices, a useful R library, "extrafont" can help.

```
# Switching to serif font:
par(family="serif")
plotFluxPred(eList, customPar=TRUE)
mtext(side=3,line=-3,"Serif font example",cex=3)
```

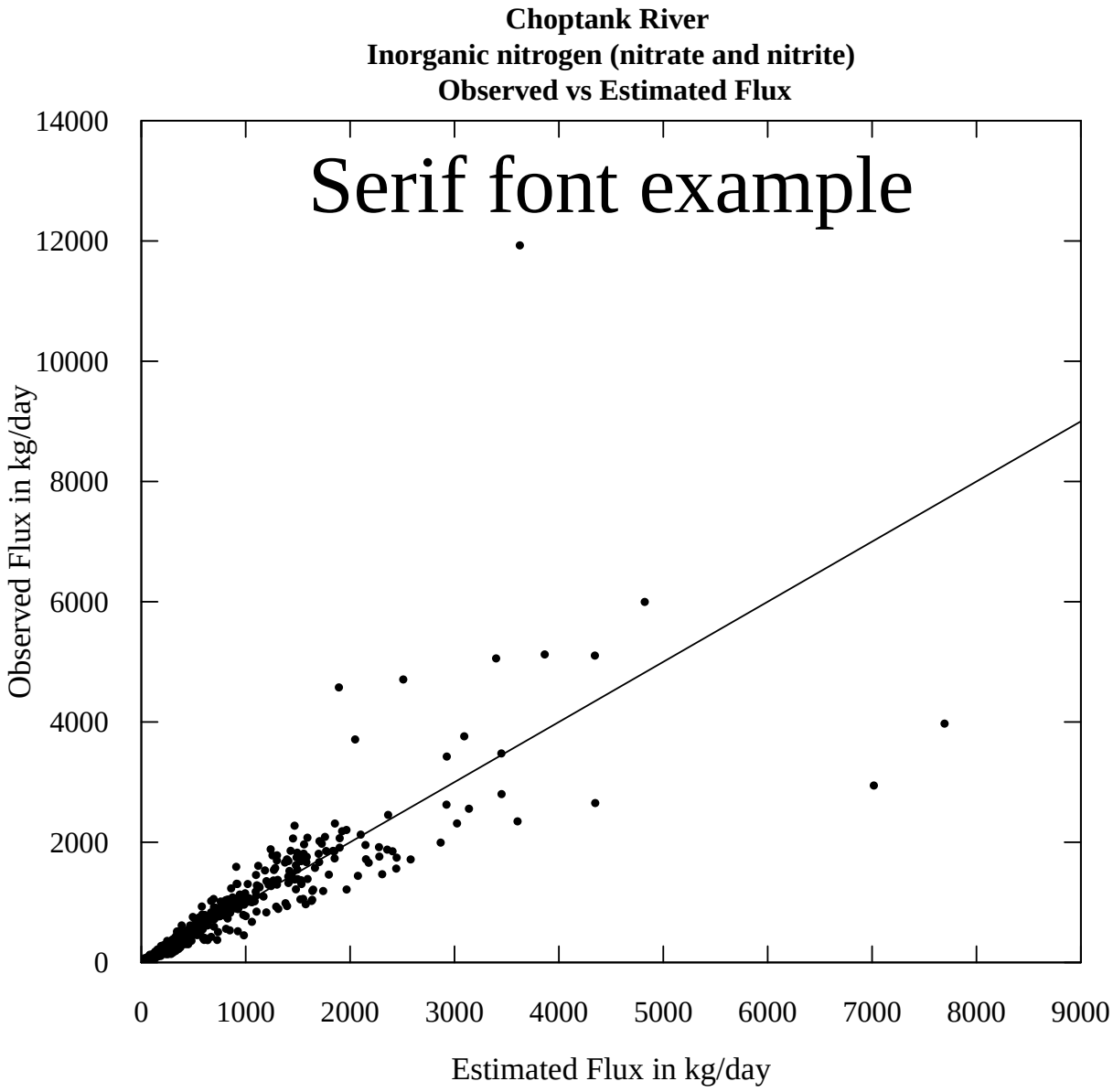


Figure 23. Serif font

You can also extend the contour plots. The default y-axis is determined from qTop and qBottom. Occasionally, you may need to use a custom axis by specifying yTicks. It is also nice to be able to adjust the color scheme of the contour plots. There are some color schemes built into base R such as heat.colors, topo.colors, terrain.colors, and cm.colors. Alternatively, you can set colors by using the `colorRampPalette` function. For example, a black and white color scheme might be required. In another example, the `plotDiffContours` might make more sense to go from yellow to white for the negative values, and white to blue for the positive values. Examples are shown below for modifying a contour plot in Figure 24 and modifying a difference contour plot in Figure 25.

```
colors <- colorRampPalette(c("white","black"))
yTicksModified <- c(.5,1,10,25)
plotContours(eList, 2001,2010,0.5,50,
             contourLevels = seq(0,2.5,0.5),qUnit=2,
             yTicks=yTicksModified,
             color.palette=colors,
             flowDuration=FALSE,
             tcl=0.2,tick.lwd=2.5)
```

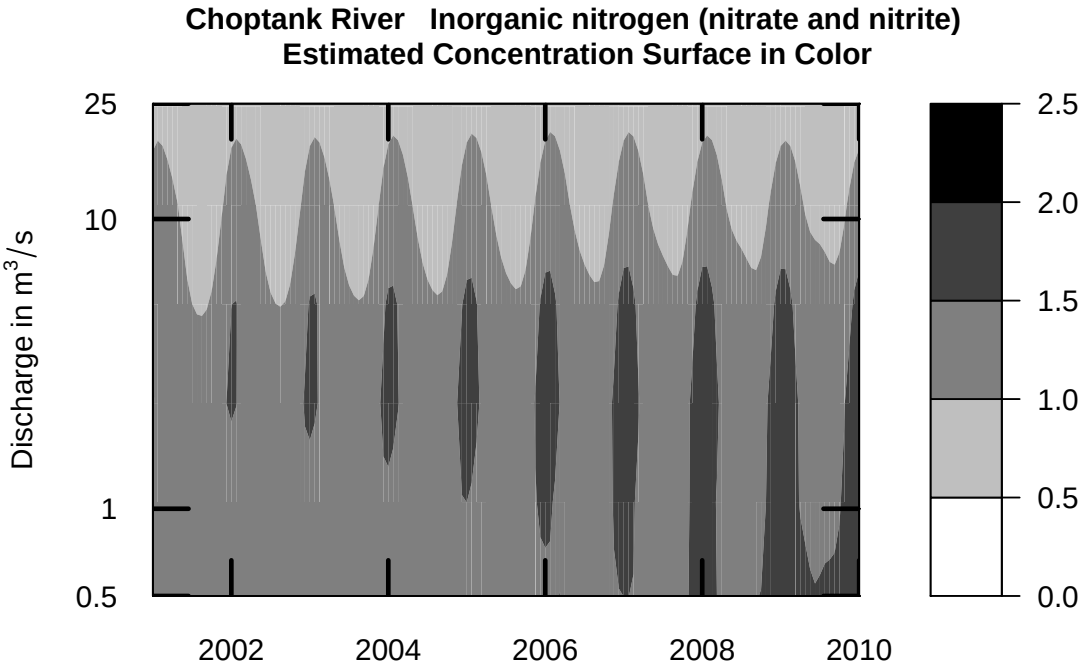


Figure 24. Contour plot with modified axis and color scheme

```
colors <- colorRampPalette(c("yellow","white","blue"))
maxDiff<-0.6
par(oma=c(1,1,1,1))
plotDiffContours(eList, year0=2001,year1=2010,qBottom=0.5,qTop=50,
             maxDiff,lwd=2,qUnit=2,
             color.palette=colors,
             flowDuration=FALSE, customPar=TRUE)
```

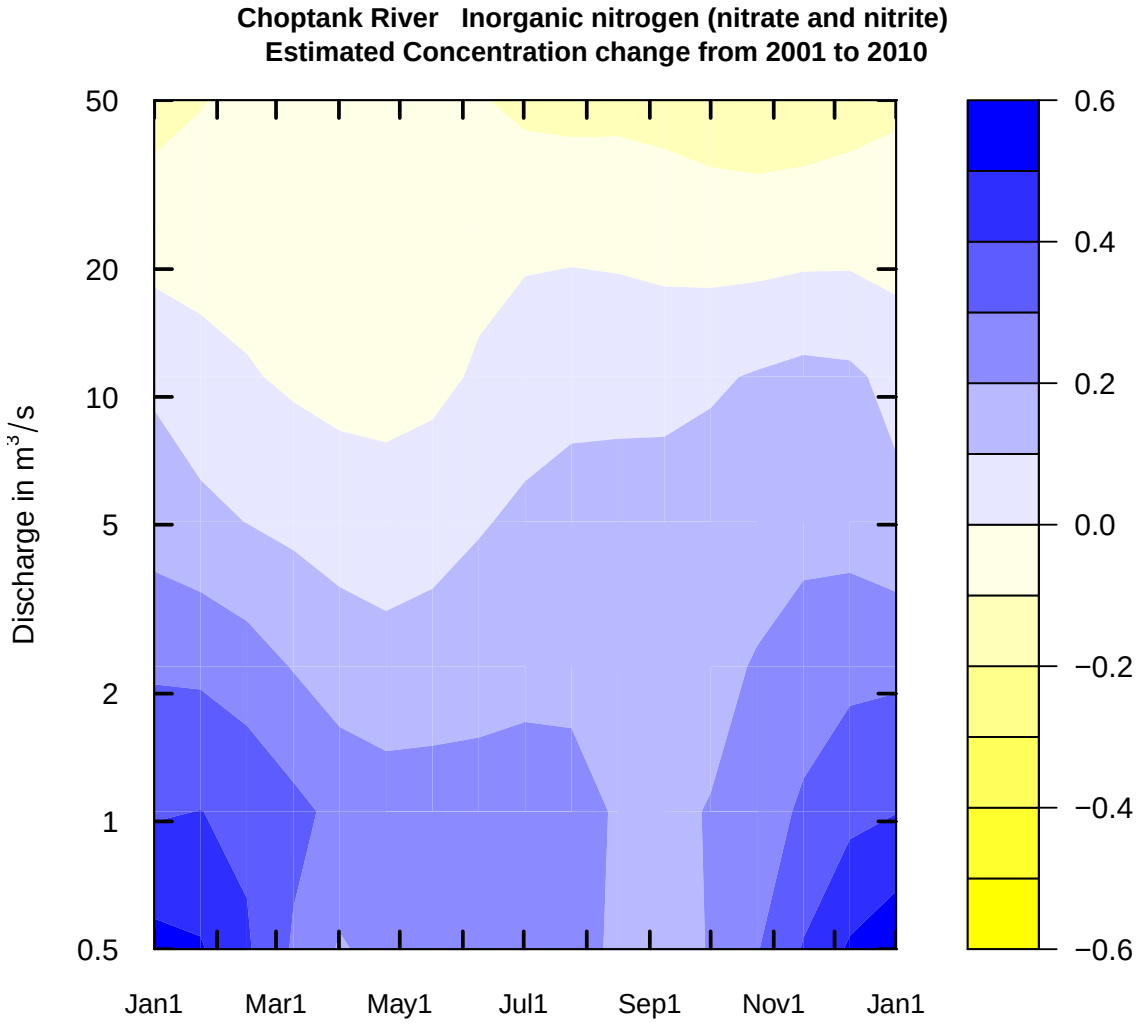


Figure 25. Difference contour plot with modified color scheme

It is also possible to create custom multi-panel plots. In the simplest example (figure 26), you can use the `"tinyPlot=TRUE"` option.

```
par(mfcol = c(2, 2), oma = c(0, 1.7, 6, 1.7))

plotFluxQ(eList, tinyPlot=TRUE,printTitle=FALSE,
          fluxUnit=9,logScale=FALSE,fluxMax=1)
plotConcQ(eList, tinyPlot=TRUE,printTitle=FALSE)
plotFluxHist(eList, tinyPlot=TRUE,printTitle=FALSE,fluxMax=1)
plotConcHist(eList, tinyPlot=TRUE,printTitle=FALSE,concMax=3)
mtext("Custom multi-pane graph using tinyPlot=TRUE", outer=TRUE, font=2)
```

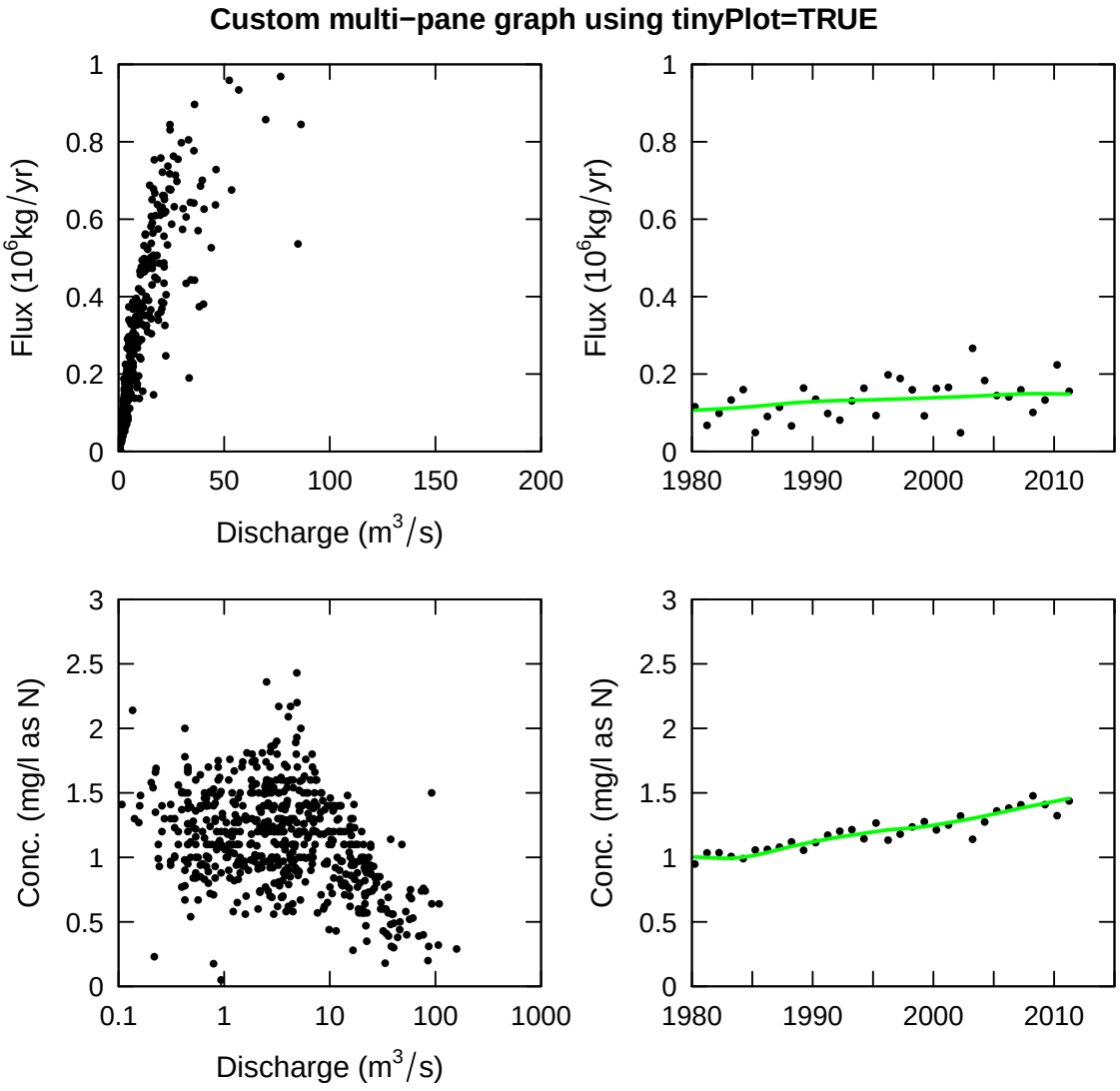


Figure 26. Custom multipanel plot using tinyPlot

Finally, figure 27 shows a method to create a panel of plots with a finer control.

```
par(mar=c(3.5,3.5,0.2,0.2), # whitespace around the plots
    oma=c(1,1,3,1), # outer margin
    mgp=c(2,0.5,0), # spacing between the label numbers and plots
    mfcol = c(2,2)) # rows/columns

plotFluxQ(eList, tinyPlot=TRUE,printTitle=FALSE,
          fluxUnit=9,logScale=FALSE,fluxMax=1,
          showXLabels=FALSE,showXAxis=FALSE,
          showYLabels=TRUE,customPar=TRUE)

plotConcQ(eList, tinyPlot=TRUE,printTitle=FALSE, customPar=TRUE,
          removeLastY=TRUE,removeLastX=TRUE,
          showYLabels=TRUE)

plotFluxHist(eList, tinyPlot=TRUE,printTitle=FALSE,fluxMax=1,
          showYLabels=FALSE,showYAxis=FALSE,
          showXLabels=FALSE,showXAxis=FALSE, customPar=TRUE)
plotConcHist(eList, tinyPlot=TRUE,printTitle=FALSE,concMax=3,
          showYLabels=FALSE, showYAxis=FALSE, customPar=TRUE)
mtext("Custom multi-pane graph using customPar", outer=TRUE, font=2)
```

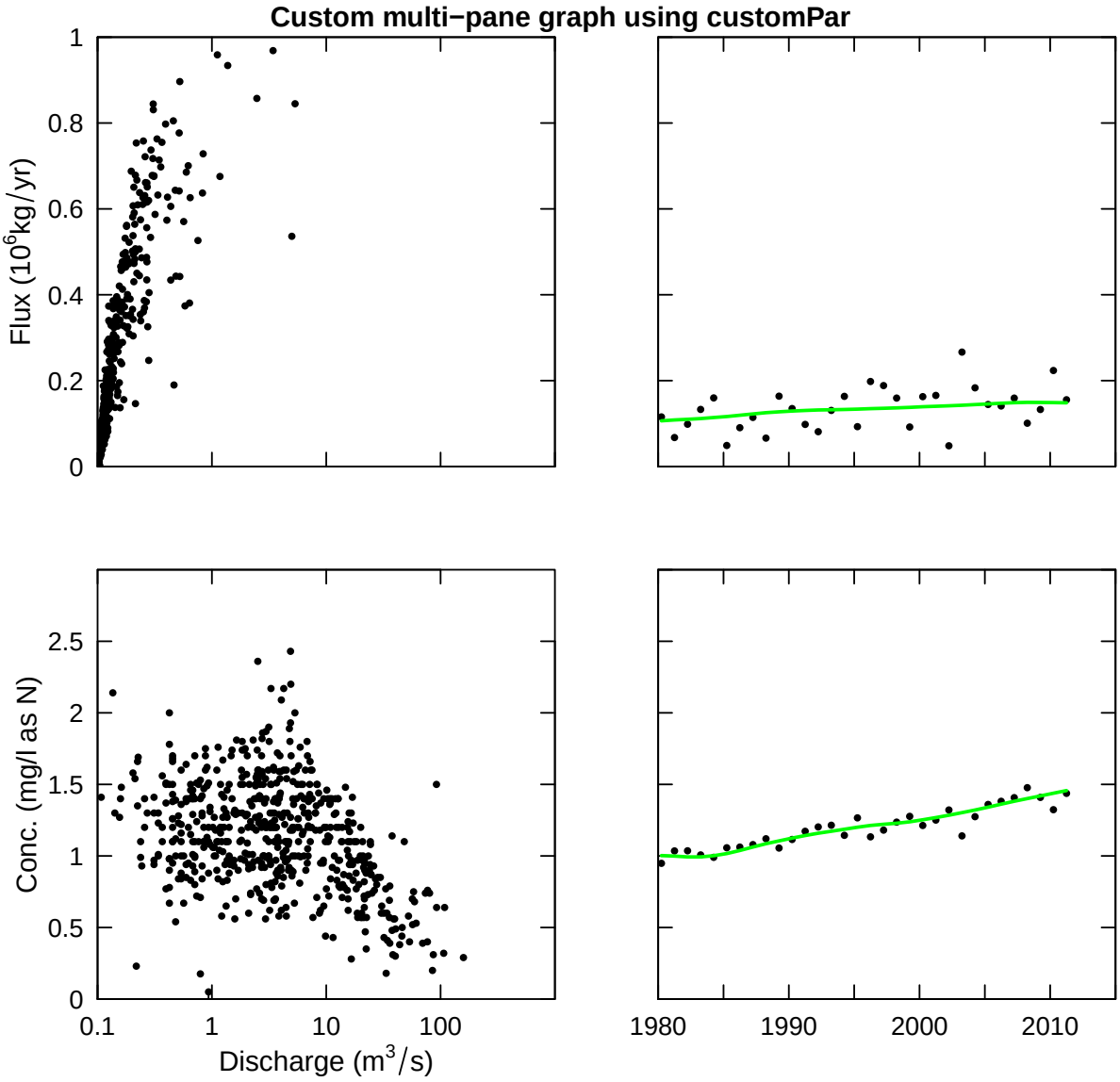


Figure 27. Custom multipanel plot

11 Getting Started in R

This section describes the options for installing the EGRET package.

11.1 New to R?

If you are new to R, you will need to first install the latest version of R, which can be found here: *http://www.r-project.org/*.

At any time, you can get information about any function in R by typing a question mark before the function's name. This opens a file that describes the function, the required arguments, and provides working examples.

```
?getJulian
```

To see the raw code for a particular function, type the name of the function, without parentheses:

```
getJulian
```

11.2 R User: Installing EGRET

To install the EGRET packages and its dependencies:

```
install.packages(c("dataRetrieval","EGRET"),
repos=c("http://usgs-r.github.com","http://cran.us.r-project.org"),
dependencies=TRUE,
type="both")
```

It is a good idea to re-start R after installing the package if installing an updated version.

After installing the package, you need to open the library each time you re-start R. This is done with the simple command:

```
library(dataRetrieval)
library(EGRET)
```

12 Common Function Variables

This section describes variables that are common for a variety of function types.

12.1 flowHistory Plotting Input

Table 20. Variables used in flow history plots (`plot15`, `plotFour`, `plotFourStats`, `plotQTimeDaily`, `plotSDLogQ`)

Argument	Definition	Default
istat	The discharge statistic to be plotted: 1-8. Must be specified, see Table 15.	
yearStart[1]	The decimal year (decYear) value where you want the graph to start	NA
yearEnd[1]	The decimal year (decYear) value where you want the graph to end	NA
qMax	User specified upper limit on y axis (can be used when we want several graphs to all share the same scale). Value is specified in the discharge units that the user selects.	NA
printTitle	can be TRUE or FALSE, you may want FALSE if it is going to be a figure with a caption or if it is a part of a multipanel plot.	TRUE
tinyPlot	Can be TRUE or FALSE, the TRUE option assures that there will be a small number of tick marks, consistent with printing in a small space	FALSE
runoff	Can be TRUE or FALSE. If true then discharge values are reported as runoff in mm/day. This can be very useful in multi-site analyses.	FALSE
qUnit	An index indicating what discharge units to use. Options run from 1 to 6 (see section 5.1). The choice should be based on the units that are customary for the audience but also, the choice should be made so that the discharge values don't have too many digits to the right or left of the decimal point.	1
printStaName[2]	Can be TRUE or FALSE, if TRUE the name of the streamgage is stated in the plot title.	TRUE
printPA[2]	Can be TRUE or FALSE, if TRUE the period of analysis is stated in the plot title.	TRUE
printIstat[2]	Can be TRUE or FALSE, if TRUE the name of the statistic (e.g. 7-day minimum discharge) is stated in the plot title.	TRUE

[1] Setting yearStart and yearEnd will determine where the graphs start and end, but they don't determine where the smoothing analysis starts and ends. There are situations, typically where many sites are be analyzed together, where you may want to run the smoothing on a consistent period of record across all sites, which requires subsetting the Daily data frame before running `makeAnnualSeries` (see `?subset`).

[2] If the printTitle argument is set to FALSE, then it really makes no difference what you do with printSta, printPA, or printIstat. They can all be left as their default values and thus there is no need to include them in the call for the function.

12.2 Water Quality Plotting Input

Table 21. Selected variables used in water quality analysis plots

Argument	Definition	Default
qUnit	Determines what units will be used for discharge, see section 5.1	2
printTitle	If TRUE the plot has a title. If FALSE no title (useful for publications where there will be a caption)	TRUE
qLower	The lower bound on the discharge on the day of sampling that will be used in forming a subset of the sample data set that will be displayed in the graph. It is expressed in the units specified in qUnit. If qLower = NA, then the lower bound is set to zero.	
qUpper	The upper bound on the discharge on the day of sampling that will be used in forming a subset of the sample data set that will be displayed in the graph. It is expressed in the units specified in qUnit. If qUpper = NA, then the upper bound is set to infinity.	
concMax	The upper limit on the vertical axis of graphs showing concentration values in mg/L (NA sets value to just above maximum).	NA
concMin	The lower limit on the vertical axis of graphs showing concentration values in mg/L (NA sets value to just below minimum for log scales, zero for linear).	NA
fluxUnit	Determines what units will be used for flux (see Section 5.1).	9
fluxMax	The upper limit on the vertical axis of graphs showing flux values.	

12.3 WRTDS Estimation Input

Table 22. Selected variables in WRTDS

Argument	Definition	Default
windowY	The half window width for the time weighting, measured in years. Values much shorter than 7 usually result in a good deal of oscillations in the system that are likely not very realistic	7
windowQ	The half window width for the weighting in terms of ln(Q). For very large rivers (average discharge values in the range of many tens of thousands of cfs) a smaller value than 2 may be appropriate, but probably not less than 1	2
windowS	The half window width for the seasonal weighting, measured in years. Any value >0.5 will make data from all seasons have some weight. Values should probably not be lower than 0.3	0.5
minNumObs	This is the minimum number of observations with non-zero weight that the individual regressions will require before they will be used. If there too few observations the program will iterate, making the windows wider until the number increases above this minimum. The only reason to lower this is in cases where the data set is rather small. It should always be set to a number at least slightly smaller than the sample size. Any value less than about 60 is probably in the "dangerous" range, in terms of the reliability of the regression	100
minNumUncen	This is the minimum number of uncensored observations with non-zero weight that the individual regressions will require before they will be used. If there are too few uncensored observations the program will iterate, making the windows wider until the number increases above this minimum. The only reason to lower this is in cases where the number of uncensored values is rather small. The method has never been tested in situations where there are very few uncensored values	50

12.4 WRTDS Plotting Input

Table 23. Selected variables used in plots for analysis of WRTDS results

Argument	Definition	Default
qUnit	Determines what units will be used for discharge, see section 5.1	2
fluxUnit	An index indicating what flux units will be used , see section 5.1	3
stdResid	This is an option. If FALSE, it prints the regular residuals (they are in ln concentration units). If TRUE, it is the standardized residuals. These are the residuals divided by their estimated standard error (each residual has its own unique standard error). In theory, the standardized residuals should have mean zero and standard deviation of 1	FALSE
printTitle	If TRUE the plot has a title. If FALSE no title (useful for publications where there will be a caption)	TRUE
startYear	The starting date for the graph, expressed as decimal years, for example, 1989	NA
endYear	The ending date for the graph, expressed as decimal years, for example, 1996	NA
moreTitle	A character variable that adds additional information to the graphic title. Typically used to indicate the estimation method.	
fluxMax	The upper limit on the vertical axis of graphs showing flux values.	NA
concMax	The upper limit on the vertical axis of graphs showing concentration values.	NA
plotFlowNorm	If TRUE the graph shows the annual values as circles and the flow-normalized values as a green curve. If false, it only shows the annual values.	TRUE

Table 24. Variables used in WRTDS contour plots: `plotContours` and `plotDiffContours`

Argument	Definition	Defaults
qUnit	Determines what units will be used for discharge, see section 5.1	2
qBottom	The lower limit of the discharge value for the graphs in the units specified by qUnit	
qTop	The upper limit of the discharge value for the graphs in the units specified by qUnit	
printTitle	If TRUE the plot has a title. If FALSE no title (useful for publications where there will be a caption)	TRUE
yearStart	The starting date for the graph, expressed as decimal years, for example, 1989	
yearEnd	The ending date for the graph, expressed as decimal years, for example, 1996	
whatSurface	This should generally be at its default value. At whatSurface = 3, the plotted surface shows the expected value of concentration. For whatSurface = 1, it shows the yHat surface (natural log of concentration). For whatSurface = 2, it shows the SE surface (the standard error in log concentration).	3
contourLevels	With the default value the contour intervals are set automatically, which generally will NOT be a very good choice, but they may provide a starting point. If you want to specify contourLevels, use the `seq` function. In general it would look like: contourLevels = seq(from,to,by).	NA
maxDiff	In the `plotDiffCountours` function instead of using contourLevels, the contours are set by maxDiff which is the absolute value of the maximum difference to be plotted. Contour intervals are set to run from -maxDiff to maxDiff.	
span	Specifies the smoothness of the discharge duration information that goes on this graph. A larger value will make it smoother. The default should work well in most cases.	60
pval	The probability value for the discharge frequency information shown on the plot. When flowDuration=TRUE, the plot has two black curves on it. In the default value case these are at the 5 and 95 percent levels on the seasonal discharge duration curve. pval = 0.01 would place these at the 1 and 99 percent points. pval = 0.1 would place them at 10 and 90.	0.05
vert1	This simply plots a vertical black line on the graph at a particular time (defined in decimal years). It is used to illustrate the idea of a "vertical slice" through the contour plot, which might then be shown in a subsequent use of `plotConcQSmooth`.	NA
vert2	This gives the location of a second vertical black line on the graph at a particular time (defined in decimal years).	NA
horiz	This simply plots a horizontal black line on the graph at a particular discharge value (defined in the units specified by qUnit). It is used to illustrate the idea of the seasonal cycle in concentrations for a given discharge and the long-term change in this cycle.	NA
flowDuration	If TRUE it draws the discharge duration lines at the specified probabilities. If FALSE, the discharge duration lines are left off.	TRUE

Table 25. Variables used in WRTDS `plotConcQSmooth` and/or `plotConcTimeSmooth` functions

Argument	Definition	Default
date1	This is the date for the first curve to be shown on the `plotConcQSmooth` graph. It must be in the form `"yyyy-mm-dd"` (it must be in quotes)	
date2	This is the date for the second curve to be shown on the plot (`"yyyy-mm-dd"`), If you don't want a second curve then the argument must be date2=NA	
date3	This is the date for the third curve to be shown on the plot (`"yyyy-mm-dd"`), If you don't want a third curve then the argument must be date3=NA	
q1	This is the discharge for the first curve on the `plotConcTime` smooth graph. It is in units specified by qUnit	
q2	This is the discharge for the second curve. If you don't want a second curve then the argument must be q2=NA	
q3	This is the discharge for the third curve. If you don't want a third curve then the argument must be q3=NA	
qUnit	Determines what units will be used for discharge, see `printqUnitCheatSheet`	2
qLow	The discharge value that should form the left edge of the plotConcQSmooth graph in the user-selected discharge units.	
qHigh	The discharge value that should form the right edge of the `plotConcQSmooth` graph in the user-selected discharge units.	
centerDate	This is the month and day at the center of the time window for the `plotConcTimeSmooth` graph. It must be in the form `"mm-dd"` in quotes	
yearStart	The starting year for the `plotConcTimeSmooth` graph	
yearEnd	The ending year for the `plotConcTimeSmooth` graph	
legendLeft	This determines the placement of the legend on the graph. It establishes the left edge of the legend and is expressed in the discharge units being used. The default (which is NA) will let it be placed automatically. The legend can end up conflicting with one or more of the curves. Once the location of the curves is established then this can be set in a way that avoids conflict.	0
legendTop	This determines the placement of the legend on the graph. It establishes the top edge of the legend and is expressed according to the concentration values on the y-axis. The default (which is NA) will let it be placed automatically. The legend can end up conflicting with one or more of the curves. Once the location of the curves is established then this can be set in a way that avoids conflict.	0
concMax	Maximum value for the vertical axis of the graph. The reason to set concMax is if you want to make several plots that have the same vertical axis.	NA
concMin	[This one is only used when logScale=TRUE]. Minimum value for the vertical axis of the graph. The reason to set concMin is if you want to make several plots that have the same vertical axis.	NA
bw	Default is FALSE, which means we want a color plot. If bw=TRUE that means it should be black and white.	
printTitle	If TRUE the plot has a title. If FALSE no title (useful for publications where there will be a caption).	FALSE
printValues	If TRUE the estimated values that make up the plotted lines are printed on the console. If FALSE they are not printed. This could be useful if you wanted to compute various comparisons across time periods.	FALSE
windowY	This is the half-window width for time in WRTDS. It has units of years.	7
windowQ	This is the half-window width for discharge in WRTDS. It has units of ln(discharge).	2
windowS	This is the half-window width for seasons in WRTDS. It has units of years.	0.5

13 Creating tables in Microsoft® software from an R dataframe

A few steps that are required to create a table in Microsoft® software (Excel, Word, PowerPoint, etc.) from an R dataframe. There are a variety of good methods, one of which is detailed here. The example we will step through is creation of a table in Microsoft® Excel based on the dataframe tableData:

```
tableData <- tableResults(eList)
```

```
   Choptank River
   Inorganic nitrogen (nitrate and nitrite)
   Water Year

   Year   Discharge    Conc    FN_Conc     Flux    FN_Flux
             cms             mg/L             10^6 kg/yr

   1980      4.25     0.949     1.003    0.1154     0.106
   1981      2.22     1.035     0.999    0.0675     0.108
   1982      3.05     1.036     0.993    0.0985     0.110
   1983      4.99     1.007     0.993    0.1329     0.112
   1984      5.72     0.990     1.002    0.1597     0.114
   1985      1.52     1.057     1.017    0.0489     0.116
   1986      2.63     1.062     1.038    0.0903     0.119
   1987      3.37     1.079     1.062    0.1142     0.122
   1988      1.87     1.120     1.085    0.0660     0.125
   1989      5.61     1.055     1.105    0.1638     0.127
   1990      4.01     1.115     1.125    0.1349     0.129
   1991      2.75     1.172     1.143    0.0980     0.130
   1992      2.19     1.203     1.159    0.0810     0.132
   1993      3.73     1.215     1.173    0.1306     0.132
   1994      5.48     1.144     1.187    0.1634     0.133
   1995      2.41     1.266     1.201    0.0928     0.134
   1996      6.24     1.134     1.213    0.1980     0.135
   1997      5.83     1.180     1.221    0.1884     0.136
   1998      4.88     1.236     1.229    0.1593     0.137
   1999      2.90     1.277     1.238    0.0919     0.138
   2000      4.72     1.213     1.253    0.1627     0.139
   2001      4.88     1.251     1.268    0.1655     0.140
   2002      1.24     1.321     1.285    0.0483     0.141
   2003      8.64     1.140     1.303    0.2664     0.143
   2004      5.28     1.274     1.321    0.1832     0.144
   2005      3.81     1.360     1.341    0.1444     0.146
   2006      3.59     1.382     1.362    0.1409     0.147
   2007      4.28     1.408     1.382    0.1593     0.149
   2008      2.56     1.477     1.401    0.1008     0.149
   2009      3.68     1.409     1.419    0.1328     0.149
   2010      7.19     1.323     1.438    0.2236     0.149
   2011      5.24     1.438     1.457    0.1554     0.148
```

First, save the dataframe as a tab delimited file (you don't want to use comma delimited because there are commas in some of the data elements):

```
write.table(tableData, file="tableData.tsv",sep="\t",
            row.names = FALSE,quote=FALSE)
```

This will save a file in your working directory called tableData.tsv. You can see your working directory by typing getwd() in the R console. Opening the file in a general-purpose text editor, you should see the following:

```
Year  Discharge [cms] Conc [mg/L] FN_Conc [mg/L] Flux [10^6kg/yr] FN_Flux [10^6kg/yr]
1980    4.25            0.949       1.003          0.1154             0.106
1981    2.22            1.035       0.999          0.0675             0.108
1982    3.05            1.036       0.993          0.0985             0.110
...
```

Next, follow the steps below to open this file in Excel:

1. Open Excel
2. Click on the File tab
3. Click on the Open option
4. Navigate to the working directory (as shown in the results of getwd())
5. Next to the File name text box, change the dropdown type to All Files (*.*)
6. Double click tableData.tsv
7. A text import wizard will open up, in the first window, choose the Delimited radio button if it is not automatically picked, then click on Next.
8. In the second window, click on the Tab delimiter if it is not automatically checked, then click Finished.
9. Use the many formatting tools within Excel to customize the table

From Excel, it is simple to copy and paste the tables in other word processing or presentation software products. An example using one of the default Excel table formats is here.

Year	Discharge [cms]	Conc [mg/L]	FN_Conc [mg/L]	Flux [10^6kg/yr]	FN_Flux [10^6kg/yr]
1980	4.25	0.949	1.003	0.1154	0.106
1981	2.22	1.035	0.999	0.0675	0.108
1982	3.05	1.036	0.993	0.0985	0.11
1983	4.99	1.007	0.993	0.1329	0.112
1984	5.72	0.99	1.002	0.1597	0.114
1985	1.52	1.057	1.017	0.0489	0.116
1986	2.63	1.062	1.038	0.0903	0.119
1987	3.37	1.079	1.062	0.1142	0.122
1988	1.87	1.12	1.085	0.066	0.125
1989	5.61	1.055	1.105	0.1638	0.127
1990	4.01	1.115	1.125	0.1349	0.129
1991	2.75	1.172	1.143	0.098	0.13
1992	2.19	1.203	1.159	0.081	0.132
1993	3.73	1.215	1.173	0.1306	0.132
1994	5.48	1.144	1.187	0.1634	0.133
1995	2.41	1.266	1.201	0.0928	0.134
1996	6.24	1.134	1.213	0.198	0.135
1997	5.83	1.18	1.221	0.1884	0.136
1998	4.88	1.236	1.229	0.1593	0.137
1999	2.9	1.277	1.238	0.0919	0.138
2000	4.72	1.213	1.253	0.1627	0.139
2001	4.88	1.251	1.268	0.1655	0.14
2002	1.24	1.321	1.285	0.0483	0.141
2003	8.64	1.14	1.303	0.2664	0.143
2004	5.28	1.274	1.321	0.1832	0.144
2005	3.81	1.36	1.341	0.1444	0.146
2006	3.59	1.382	1.362	0.1409	0.147
2007	4.28	1.408	1.382	0.1593	0.149
2008	2.56	1.477	1.401	0.1008	0.149
2009	3.68	1.409	1.419	0.1328	0.149
2010	7.19	1.323	1.438	0.2236	0.149

Figure 28. A simple table produced in Microsoft® Excel

14 Saving Plots

Plots can be saved from R as JPG, PNG, PDF, and Postscript files. JPG and PNG are easy to use in any number of programs (Microsoft® Word or PowerPoint, for example), but the images cannot be resized later. PDF and Postscript images are easily re-sizable.

There are three steps to saving plots. The first is to open the "device" (and declare the output type and file name). The second step is to execute the function just as you would when plotting to the screen, but no output will appear. The third step is to turn off the device. It is also possible to put many plots within the same pdf. Some simple examples should demonstrate this easily:

```
jpeg("plotFlowSingle.jpg")
plotFlowSingle(1)
dev.off()
```

```
png("plotFlowSingle.png")
plotFlowSingle(1)
dev.off()

pdf("plotFlowSingle.pdf")
plotFlowSingle(1)
dev.off()

postscript("plotFlowSingle.ps")
plotFlowSingle(1)
dev.off()

#Many plots saved to one pdf:
pdf("manyPlots.pdf")
plotFlowSingle(1)
plotFlowSingle(2)
plotFlowSingle(3)
plotFlowSingle(4)
dev.off()
```

There are many additional options for each of these devices. See the R help files for more information. One useful option for the larger `fluxBiasMulti` graph is to adjust the height and width of the output. The output of fluxBiasMulti is larger than the default pdf or postscript devices. Therefore, specifying the height and width eliminates R having to re-size the graphic:

```
postscript("fluxBiasMulti.ps", height=10,width=8)
fluxBiasMulti()
dev.off()
```

15 Disclaimer

This information is preliminary and is subject to revision. It is being provided to meet the need for timely best science. The information is provided on the condition that neither the U.S. Geological Survey nor the U.S. Government may be held liable for any damages resulting from the authorized or unauthorized use of the information.

References

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[2] Sprague, L. A., Hirsch, R. M., and Aulenbach, B. T. (2011), Nitrate in the Mississippi River and Its Tributaries, 1980 to 2008: Are We Making Progress? Environmental Science & Technology, 45 (17): 7209-7216. doi: 10.1021/es201221s

[3] Moyer, D.L., Hirsch, R.M., and Hyer, K.E. (2012), Comparison of Two Regression-Based Approaches for Determining Nutrient and Sediment Fluxes and Trends in the Chesapeake Bay Watershed: U.S. Geological Survey Scientific Investigations Report 2012-5244, 118 p. *http://pubs.usgs.gov/sir/2012/5244/*

[4] Rice, K.C., and Hirsch, R.M. (2012), Spatial and temporal trends in runoff at long-term streamgages within and near the Chesapeake Bay Watershed: U.S. Geological Survey Scientific Investigations Report 2012-5151, 56 p. *http://pubs.usgs.gov/sir/2012/5151*