Introduction to exploratory data analysis

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Objectives and agenda

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  - What are some tools for pre-processing/organizing the SWMP data?
  - What is the purpose of exploratory data analysis (EDA)?
  - What are some common techniques and tools for EDA?

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  - What is the purpose of exploratory data analysis (EDA)?
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- Agenda
  - Review of data retrieval and import
  - Organizing tools in SWMPr
  - Purpose and overview of EDA
  - Generic EDA tools in R, tools in SWMPr

Interactive portion

You can follow along in this module:

- dataset2
- script2

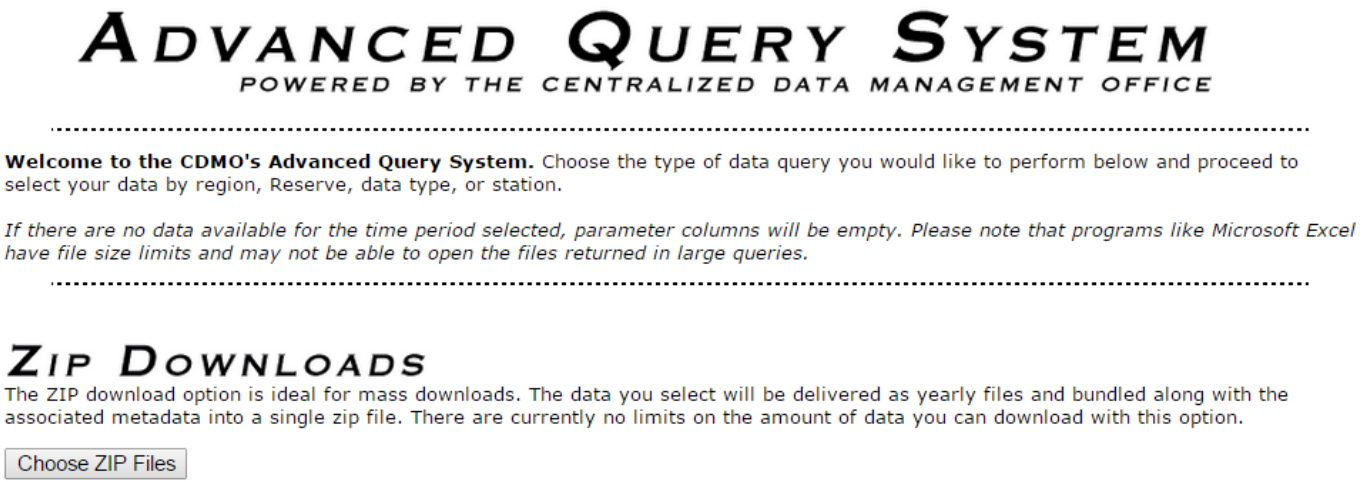
Interactive! Interrupt me!

Retrieve SWMP data

We learned how to import SWMP data in the previous session

To review, the easiest approach is to download the data outside of R, then import using the 'import˙local' function

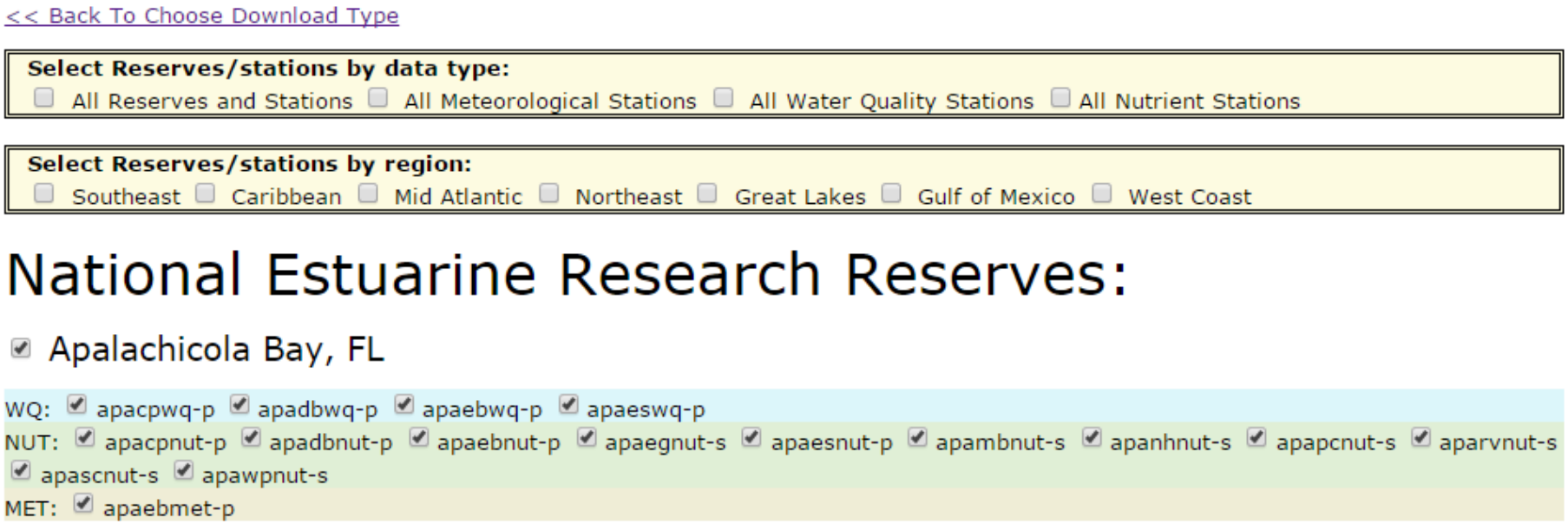
Be sure that you use only the zip downloads feature from CDMO - the 'import˙local' functions works best with these data



Retrieve SWMP data

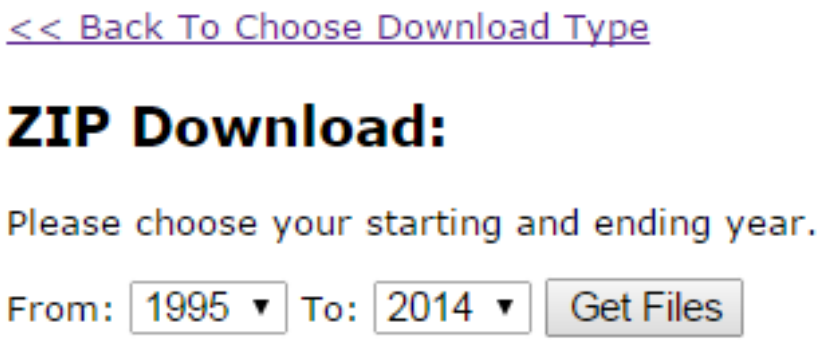
We have provided data for use with the workshop

For future access, it may be best to download all the data possible for a reserve to avoid repeated requests to the server and to centralize the location from which the data are imported into R



Retrieve SWMP data

It may be best to download all the data possible for a reserve to avoid repeated requests to the server and to centralize the location from which the data are imported into R



Here we've made a request for all stations at Apalachicola Bay (water quality, nutrients, weather) and all available years (1995–2014)

This request will take several minutes to be delivered to your email - the files in 'dataset2' are an abbreviate version of these data for this training module

Retrieve SWMP data

Let's import some data for Apalachicola Bay

```
# reload the SWMPr package if you started a new session
library(SWMPr)

# import data
# change this path for the flash drive
path <- 'C:/data/dataset2'
wq_dat <- import_local(path, 'apacpwq')
nut_dat <- import_local(path, 'apacpnut')
met_dat <- import_local(path, 'apaebmet')
```

We've just imported data from 2011–2014 for three stations (apacpwq, apacpnut, apaebmet) and saved them in our workspace as three separate objects (wq_dat, nut_dat, met_dat)

Retrieve SWMP data

But don't take my word for it, take a look at the data!

```
# what are the dimenions of the water quality data?
dim(wq_dat)

## [1] 132035     25

# what are the dimenions of the nutrient data?
dim(nut_dat)

## [1] 48 13

# what are the dimenions of the weather data?
dim(met_dat)

## [1] 133548     23
```

Retrieve SWMP data

View the first six rows

```
# View the first six rows of the met data
head(met_dat)
```

```
##         datetimestamp atemp f_atemp rh f_rh   bp f_bp wspd f_wspd maxwspd
## 1 2011-01-01 00:00:00    15    <0>  94 <0>  1019 <0>     3   <0>        3
## 2 2011-01-01 00:15:00    15    <0>  95 <0>  1019 <0>     3   <0>        4
## 3 2011-01-01 00:30:00    15    <0>  95 <0>  1019 <0>     3   <0>        4
## 4 2011-01-01 00:45:00    15    <0>  95 <0>  1019 <0>     3   <0>        4
## 5 2011-01-01 01:00:00    15    <0>  95 <0>  1018 <0>     3   <0>        4
## 6 2011-01-01 01:15:00    15    <0>  95 <0>  1018 <0>     4   <0>        5
##   f_maxwspd wdir f_wdir sdwdir f_sdwdir totpar  f_totpar totprcp f_totprcp
## 1      <0>   145   <0>       8     <0>     0.8 <1> (CSM)       0      <0>
## 2      <0>   146   <0>       7     <0>     0.8 <1> (CSM)       0      <0>
## 3      <0>   139   <0>       7     <0>     0.8 <1> (CSM)       0      <0>
## 4      <0>   140   <0>       7     <0>     0.8 <1> (CSM)       0      <0>
## 5      <0>   144   <0>       6     <0>     0.8 <1> (CSM)       0      <0>
## 6      <0>   141   <0>       7     <0>     0.8 <1> (CSM)       0      <0>
##   cumprcp f_cumprcp totsorad f_totsorad
## 1       0      <0>        NA      <-1>
## 2       0      <0>        NA      <-1>
## 3       0      <0>        NA      <-1>
## 4       0      <0>        NA      <-1>
## 5       0      <0>        NA      <-1>
## 6       0      <0>        NA      <-1>
```

Retrieve SWMP data

View the last six rows

```
# View the last six rows of the met data
tail(met_dat)
```

```
##              datetimestamp atemp f_atemp rh f_rh   bp f_bp wspd f_wspd maxwspd
## 133543 2014-10-23 01:30:00    14    <0>  72 <0>  1017 <0>     3   <0>        5
## 133544 2014-10-23 01:45:00    14    <0>  72 <0>  1016 <0>     3   <0>        5
## 133545 2014-10-23 02:00:00    14    <0>  74 <0>  1016 <0>     3   <0>        4
## 133546 2014-10-23 02:15:00    14    <0>  74 <0>  1016 <0>     3   <0>        4
## 133547 2014-10-23 02:30:00    14    <0>  75 <0>  1016 <0>     3   <0>        4
## 133548 2014-10-23 02:45:00    14    <0>  76 <0>  1016 <0>     2   <0>        4
##        f_maxwspd wdir f_wdir sdwdir f_sdwdir totpar f_totpar totprcp f_totprcp
## 133543      <0>    33   <0>      9      <0>       0      <0>        0       <0>
## 133544      <0>    34   <0>     11      <0>       0      <0>        0       <0>
## 133545      <0>    36   <0>     10      <0>       0      <0>        0       <0>
## 133546      <0>    43   <0>     11      <0>       0      <0>        0       <0>
## 133547      <0>    41   <0>     10      <0>       0      <0>        0       <0>
## 133548      <0>    42   <0>     10      <0>       0      <0>        0       <0>
##        cumprcp f_cumprcp totsorad f_totsorad
## 133543      NA     <-2>       NA      <-1>
## 133544      NA     <-2>       NA      <-1>
## 133545      NA     <-2>       NA      <-1>
## 133546      NA     <-2>       NA      <-1>
## 133547      NA     <-2>       NA      <-1>
## 133548      NA     <-2>       NA      <-1>
```

Retrieve SWMP data

We'll first work with the water quality records

What class is the data?

```
# class of the data
class(met_dat)

## [1] "swmpr"      "data.frame"
```

This tells us that the data are two different classes - 'swmpr' and 'data.frame'

The class of an object is important because it defines the types of methods (i.e., functions) that apply

For example, 'head' and 'tail' functions work for a 'data.frame'

Retrieve SWMP data

The swmpr object class was developed to make your life easier working with SWMP data

The online documentation describes the functions that work with the swmpr object class, also...

```
# what functions/methods work with swmpr objects?
methods(class = 'swmpr')

##  [1] aggregate.swmpr comb.swmpr      decomp.swmpr    hist.swmpr
##  [5] lines.swmpr     na.approx.swmpr plot.swmpr      qaqc.swmpr
##  [9] qaqcchk.swmpr   setstep.swmpr   smoother.swmpr  subset.swmpr
```

Documentation of each function can be viewed as follows (although currently not complete):

```
# see help for a swmpr function
?aggregate.swmpr

# or...
help('aggregate.swmpr')
```

Retrieve SWMP data

A side note about R syntax... the convention 'function.class' means that a function applies to a specific class

The 'function' is generic, whereas the 'function.class' is a method for a class that applies to the generic

```
# view the methods that apply to the generic aggregate
methods('aggregate')

## [1] aggregate.data.frame aggregate.default*   aggregate.formula*
## [4] aggregate.swmpr      aggregate.ts         aggregate.zoo*
##
##    Non-visible functions are asterisked
```

A function with a class method can be executed using shorthand...

```
# shorthand for executing aggregate on a swmpr object
aggregate(met_dat, by = 'quarters')

# long also works
aggregate.swmpr(met_dat, by = 'quarters')
```

Retrieve SWMP data

A useful feature of R is that a class will have both ***data*** and ***attributes***

For the swmpr class, the ***data*** are the raw swmpr data as a data.frame

The ***attributes*** are a list of metadata for the imported data

```
# what attributes are available for a swmpr object
names(attributes(met_dat))

## [1] "names"       "row.names"   "class"       "station"     "parameters"
## [6] "qaqc_cols"   "date_rng"    "timezone"    "stamp_class"

# view the parameters
attr(met_dat, 'parameters')

##  [1] "atemp"    "rh"       "bp"       "wspd"     "maxwspd"  "wdir"
##  [7] "sdwdir"   "totpar"   "totprcp"  "cumprcp"  "totsorad"
```

Retrieve SWMP data

You can also view all the attributes as follows:

```
# view all attributes
attributes(met_dat)
```

This is not recommended since they are quite long, e.g., an attribute of the 'data.frame' class is the row names (132035 rows for'wq_dat')

Individual attributes are useful for getting a feel for the dataset - what is the date range? what parameters are included? are QAQC columns present?

However, the intended use of attributes is behind the scenes with swmpr functions - they will be used to process the data and updated automatically

Retrieve SWMP data

A summary of the swmpr object class:

- Throughout 'SWMPr' refers to the ***package***, 'swmpr' refers to the object ***class***
- ***Methods*** aka functions in the SWMPr package are specific for swmpr objects - see the help documentation ('?aggregate.swmpr')
- The swmpr object has both ***data*** and ***attributes*** - the data are in the 'data.frame' format, the attributes are in a 'list'

These are basic concepts that are fundamental to how the R language works – you should have a general understanding of their meaning

Organize SWMP data

Now that we have a feel for the data, what needs to be done before we can start analyzing the information?

Last module:

- How do we handle QAQC data or 'bad' observations?
- How do we deal with data we don't want?
- How do we combine data for comparison?
- How do we handle issues inherent with time series?

Several of these problems are context-dependent - driven by the question or analysis

Others are common to any analysis...

Organize SWMP data

Perhaps the first organizational tool you want to use is 'qaqc.swmpr'

This function does two things:

- Remove observations with a specified QAQC flag value
- Remove QAQC columns

-5 Outside high sensor range
-4 Outside low sensor range
-3 Data rejected due to QAQC
-2 Missing data
-1 Optional SWMP supported parameter
0 Passed initial QAQC checks
1 Suspect data
2 Open - reserved for later flag
3 Calculated data: non-vented depth/level sensor correction for changes in barometric pressure
4 Historical data: Pre-auto QAQC
5 Corrected data

Retrieve SWMP data

Remember, each parameter has a QAQC column preceded by 'f'

```
# View the first six rows of the met data
head(met_dat)
```

```
##         datetimestamp atemp f_atemp rh f_rh   bp f_bp wspd f_wspd maxwspd
## 1 2011-01-01 00:00:00    15    <0>  94 <0>  1019 <0>     3   <0>        3
## 2 2011-01-01 00:15:00    15    <0>  95 <0>  1019 <0>     3   <0>        4
## 3 2011-01-01 00:30:00    15    <0>  95 <0>  1019 <0>     3   <0>        4
## 4 2011-01-01 00:45:00    15    <0>  95 <0>  1019 <0>     3   <0>        4
## 5 2011-01-01 01:00:00    15    <0>  95 <0>  1018 <0>     3   <0>        4
## 6 2011-01-01 01:15:00    15    <0>  95 <0>  1018 <0>     4   <0>        5
##   f_maxwspd wdir f_wdir sdwdir f_sdwdir totpar  f_totpar totprcp f_totprcp
## 1      <0>   145   <0>       8     <0>     0.8 <1> (CSM)       0      <0>
## 2      <0>   146   <0>       7     <0>     0.8 <1> (CSM)       0      <0>
## 3      <0>   139   <0>       7     <0>     0.8 <1> (CSM)       0      <0>
## 4      <0>   140   <0>       7     <0>     0.8 <1> (CSM)       0      <0>
## 5      <0>   144   <0>       6     <0>     0.8 <1> (CSM)       0      <0>
## 6      <0>   141   <0>       7     <0>     0.8 <1> (CSM)       0      <0>
##   cumprcp f_cumprcp totsorad f_totsorad
## 1       0      <0>        NA      <-1>
## 2       0      <0>        NA      <-1>
## 3       0      <0>        NA      <-1>
## 4       0      <0>        NA      <-1>
## 5       0      <0>        NA      <-1>
## 6       0      <0>        NA      <-1>
```

Organize SWMP data

You will have to decide which values to keep - be conservative and only keep those that passed QAQC or keep all the data

To help you decide, it may be useful to get an idea of the distribution of QAQC flags in the data, use 'qaqcchk'

```
# use qaqcchk to view distribution of qaqc flags
myqaqc <- qaqcchk(met_dat)
```

This function returns a data.frame

- The first column shows all the QAQC codes in the data
- The remaining columns show the counts for each parameter of the observations assigned to each QAQC code

Organize SWMP data

```
# a subset of results from the qaqcchk function
head(myqaqc)
```

```
##              piece f_atemp f_bp f_cumprcp f_maxwspd f_rh f_sdwdir f_totpar
## 1       <-2> [GPD]       2    2         2         2    2        2        2
## 2       <-3> [GMT]       5   13        70        16    5       16       18
## 3       <-3> [GPD]      15   16        16        16   15       16       16
## 4       <-3> [GPR]      14   14        14        14   14       14       13
## 5       <-3> [SMT]       2   NA       121         3    2        3        2
## 6 <-3> [SQR] (CSM)       3   NA        NA        NA    3       NA     4023
##   f_totprcp f_totsorad f_wdir f_wspd
## 1         2         NA      2      2
## 2        13         NA     16     16
## 3        16         NA     16     16
## 4        14         NA     14     14
## 5        14         NA      3      3
## 6        NA         NA     NA     NA
```

```
# or view all in a separate window
View(myqaqc)
```

Link to QAQC codes

Organize SWMP data

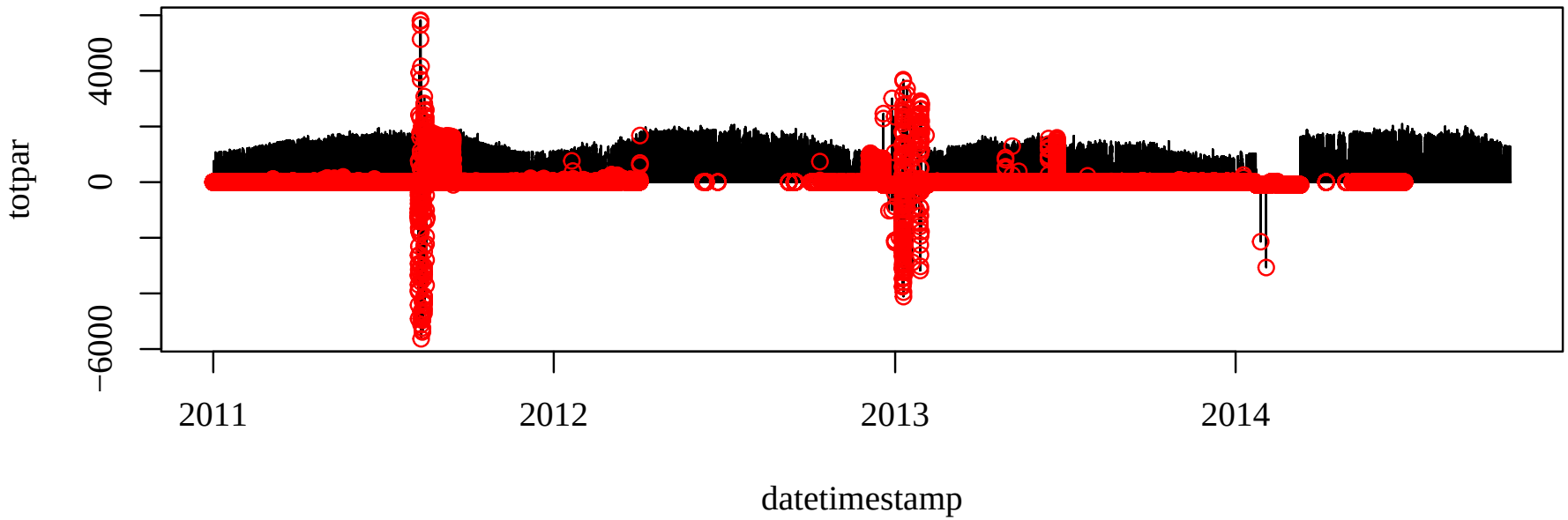
A plot of the data may also be useful to view QAQC flags, but this is tedious

Here's an example for the 'totpar' variable

```
# select values that did not pass qaqc
nopass <- grep('0', met_dat$f_totpar, invert = T)
nopass <- met_dat[nopass, ]

# plot totpar from met_dat
plot(totpar ~ datetimestamp, met_dat, type = 'l')

# add  points that did not pass qaqc
points(nopass$datetimestamp, nopass$totpar, col = 'red')
```

Organize SWMP data

Observations in red are those that did not pass QAQC checks - some are obvious, others are not



Does this plot make sense??

Organize SWMP data

You should have an idea of how you want to handle QAQC values after viewing the output from qaqcchk or plotting - or you already knew

Next, use the 'qaqc' function...

```
# filter observations by qaqc flags, remove qaqc columns
met_qaqc <- qaqc(met_dat)
```

The default behavior for this function is to keep only observations with a '0' QAQC flag - data that passed initial checks

See the help documentation for the function

```
# view help file
?qaqc
```

Organize SWMP data

View the data after keeping only values that passed QAQC ('0' flag)

```
# data after qaqc processing
head(met_qaqc)
```

```
##          datetimestamp atemp rh   bp wspd maxwspd wdir sdwdir totpar totprcp
## 1 2011-01-01 00:00:00    15 94 1019    3       3  145      8     NA       0
## 2 2011-01-01 00:15:00    15 95 1019    3       4  146      7     NA       0
## 3 2011-01-01 00:30:00    15 95 1019    3       4  139      7     NA       0
## 4 2011-01-01 00:45:00    15 95 1019    3       4  140      7     NA       0
## 5 2011-01-01 01:00:00    15 95 1018    3       4  144      6     NA       0
## 6 2011-01-01 01:15:00    15 95 1018    4       5  141      7     NA       0
##   cumprcp totsorad
## 1       0       NA
## 2       0       NA
## 3       0       NA
## 4       0       NA
## 5       0       NA
## 6       0       NA
```

Organize SWMP data

What if we want to keep all the values, regardless of flag?

```
# keep all values
met_qaqc <- qaqc(met_dat, qaqc_keep = NULL)

head(met_qaqc) # note the totpar column compared to the last example
```

```
##          datetimestamp atemp rh   bp wspd maxwspd wdir sdwdir totpar totprcp
## 1 2011-01-01 00:00:00    15 94 1019    3       3  145      8    0.8       0
## 2 2011-01-01 00:15:00    15 95 1019    3       4  146      7    0.8       0
## 3 2011-01-01 00:30:00    15 95 1019    3       4  139      7    0.8       0
## 4 2011-01-01 00:45:00    15 95 1019    3       4  140      7    0.8       0
## 5 2011-01-01 01:00:00    15 95 1018    3       4  144      6    0.8       0
## 6 2011-01-01 01:15:00    15 95 1018    4       5  141      7    0.8       0
##   cumprcp totsorad
## 1       0       NA
## 2       0       NA
## 3       0       NA
## 4       0       NA
## 5       0       NA
## 6       0       NA
```

Organize SWMP data

If you're not convinced, try removing only the '0' flag

```
# keep all values
to_keep <- c(-5, -4, -3, -2, -1, 1, 2, 3, 4, 5)
met_qaqc <- qaqc(met_dat, qaqc_keep = to_keep)

# does this result make sense??
head(met_qaqc)
```

```
##         datetimestamp atemp rh bp wspd maxwspd wdir sdwdir totpar totprcp
## 1 2011-01-01 00:00:00    NA NA NA   NA      NA   NA     NA    0.8      NA
## 2 2011-01-01 00:15:00    NA NA NA   NA      NA   NA     NA    0.8      NA
## 3 2011-01-01 00:30:00    NA NA NA   NA      NA   NA     NA    0.8      NA
## 4 2011-01-01 00:45:00    NA NA NA   NA      NA   NA     NA    0.8      NA
## 5 2011-01-01 01:00:00    NA NA NA   NA      NA   NA     NA    0.8      NA
## 6 2011-01-01 01:15:00    NA NA NA   NA      NA   NA     NA    0.8      NA
##   cumprcp totsorad
## 1      NA       NA
## 2      NA       NA
## 3      NA       NA
## 4      NA       NA
## 5      NA       NA
## 6      NA       NA
```

Organize SWMP data

We'll continue by using values that passed the QAQC checks

```
# continue with qaqc processed data

# water quality
# note the column number before/after qaqc processing
dim(wq_dat)

## [1] 132035     25

wq_dat <- qaqc(wq_dat)
dim(wq_dat)

## [1] 132035     13

# nutrients
nut_dat <- qaqc(nut_dat)

# weather
met_dat <- qaqc(met_dat)
```

Organize SWMP data

What is the next logical step after dealing with QAQC values?

How would we further want to organize the data?

Maybe we want to subset the data...

For example, we don't want all the data columns or we only want to work with a specific date range

Use the subset function...

```
# view help file
?subset.swmpr
```

Note that R has a generic subset function, subset.swmpr is a method for swmpr objects

Organize SWMP data

The subset.swmpr function has several arguments

```
# view the arguments for subset.swmpr
formals(subset.swmpr)

## $swmpr_in
##
##
## $subset
## NULL
##
## $select
## NULL
##
## $operator
## NULL
##
## $rem_rows
## F
##
## $rem_cols
## F
```

Organize SWMP data

The subset.swmpr function has several arguments

- swmpr_in: input data (swmpr object)
- subset: dates to keep
- select: parameters to keep
- operator: value symbol if only one date in suset
- rem_rows: remove empty rows
- rem_cols: remove empty columns

We'll go through examples that use the function with different arguments

Organize SWMP data

The simplest use of 'subset.swmpr' is to remove empty rows and columns – this is typically not a major issue but it's convenient if you're a compulsive data cleaner

```
# rows, columns in wq_dat
dim(wq_dat)

## [1] 132035     13

# remove empty rows, columns
tmp <- subset(wq_dat)

# dimensions after removing empty rows, columns
dim(tmp)

## [1] 132035     13
```

Not an issue, further processing may create empty rows/columns

Organize SWMP data

The 'select' argument of 'subset.swmpr' is used to select parameters of interested - one to many

```
# select the DO column
tmp <- subset(wq_dat, select = 'do_mgl')
head(tmp)
```

```
##          datetimestamp do_mgl
## 1 2011-01-01 00:00:00      6
## 2 2011-01-01 00:15:00      6
## 3 2011-01-01 00:30:00      6
## 4 2011-01-01 00:45:00      6
## 5 2011-01-01 01:00:00      6
## 6 2011-01-01 01:15:00      6
```

Note that the datetimestamp is retained, this column will always be included in a subset

Organize SWMP data

The 'select' argument of 'subset.swmpr' is used to select parameters of interested - one to many

```
# select DO and salinity
tmp <- subset(wq_dat, select = c('do_mgl', 'sal'))
head(tmp)
```

```
##          datetimestamp sal do_mgl
## 1 2011-01-01 00:00:00  28      6
## 2 2011-01-01 00:15:00  28      6
## 3 2011-01-01 00:30:00  28      6
## 4 2011-01-01 00:45:00  28      6
## 5 2011-01-01 01:00:00  29      6
## 6 2011-01-01 01:15:00  29      6
```

Note the use of the concatenate function 'c'

Try this...

```
# incorrect syntax
subset(wq_dat, select = 'do_mgl', 'sal')
```

```
## Error:  subset must be of format %Y-%m-%d %H:%M
```

Organize SWMP data

The 'subset' argument of 'subset.swmpr' selects a date range

The dates must have a specific format - 'YYYY-mm-dd HH:MM'

You can also verify the subset by checking the attributes of the swmpr object

```
# select a date range, July 2012
dates <- c('2012-07-01 12:00', '2012-07-31 6:30')
tmp <- subset(wq_dat, subset = dates)

# check the date_rng attribute
class(tmp) # a swmpr object?

## [1] "swmpr"      "data.frame"

attr(tmp, 'date_rng')

## [1] "2012-07-01 12:00:00 EST" "2012-07-31 06:30:00 EST"
```

Organize SWMP data

Observations earlier or later than a date can also be selected

This also requires the 'operator' argument

```
# get observations for 2013
dates <- '2013-01-01 00:00'
tmp <- subset(wq_dat, subset = dates, operator = '>=')
head(tmp)
```

```
##          datetimestamp temp spcond sal do_pct do_mgl depth cdepth level clevel
## 1 2013-01-01 00:00:00   13     42  27     99      9     1     NA    NA     NA
## 2 2013-01-01 00:15:00   13     42  27     99      9     1     NA    NA     NA
## 3 2013-01-01 00:30:00   13     42  27    101      9     1     NA    NA     NA
## 4 2013-01-01 00:45:00   13     42  27    102      9     1     NA    NA     NA
## 5 2013-01-01 01:00:00   13     42  27    100      9     1     NA    NA     NA
## 6 2013-01-01 01:15:00   13     42  27    101      9     1     NA    NA     NA
##   ph turb chlfluor
## 1  8    0       NA
## 2  8    1       NA
## 3  8    1       NA
## 4  8    1       NA
## 5  8    0       NA
## 6  8    0       NA
```

Organize SWMP data

A simple application of 'subset' - plot dissolved oxygen and water temperature for October 2014

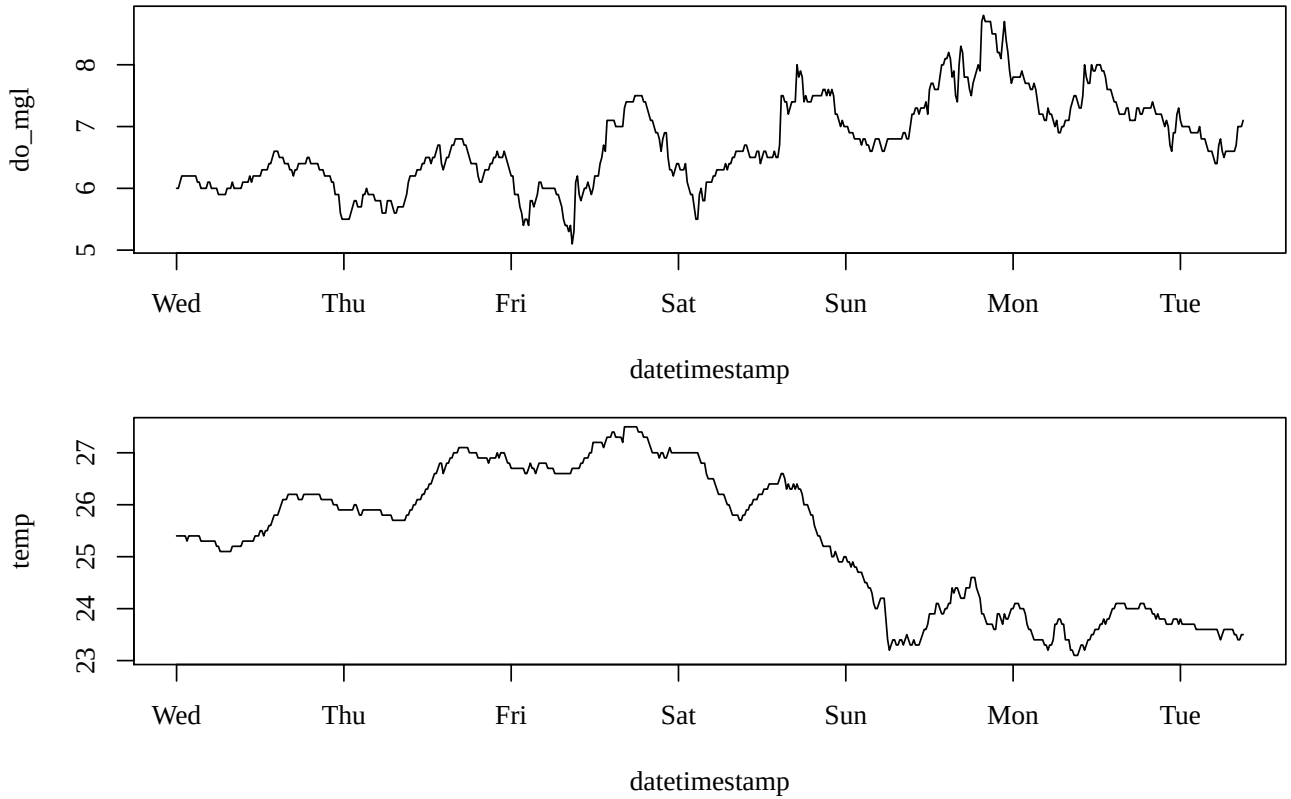
```
# dates and parameters  to select
dates <- '2014-10-01 00:00'
params <- c('do_mgl', 'temp')

# subset
tmp <- subset(wq_dat, select = params, subset = dates, operator = '>=')
head(tmp)
```

```
##          datetimestamp temp do_mgl
## 1 2014-10-01 00:00:00   25      6
## 2 2014-10-01 00:15:00   25      6
## 3 2014-10-01 00:30:00   25      6
## 4 2014-10-01 00:45:00   25      6
## 5 2014-10-01 01:00:00   25      6
## 6 2014-10-01 01:15:00   25      6
```

Organize SWMP data

A simple application of 'subset' - plot dissolved oxygen and water temperature for October 2014

```
# plot DO and water temp
plot(do_mgl ~ datetimestamp, data = tmp, type = 'l')
plot(temp ~ datetimestamp, data = tmp, type = 'l')
```



Organize SWMP data

Common problems with 'subset.swmpr'...

```
# incorrect date format
subset(wq_dat, subset = c('2012-01-01', '2012-01-31'))

## Error:  subset must be of format %Y-%m-%d %H:%M

# forgot to include operator
subset(wq_dat, subset = '2012-01-31 00:00')

## Error:  Binary operator must be included if only one subset value is provided

# incorrect parameter names
subset(wq_dat, select = 'DO')

## Error:  select argument is invalid
```

How do we fix these problems??

Organize SWMP data

Now that we know how to handle QAQC flags and subset the data, what else could we do before we analyze?

What if we want to compare time series from different datasets?

What are some challenges that we need to consider for combining data?


NERRS / SWMP
Data Analysis Workshop: Time Series
November 17, 2014

Questions??