

# Hydroinformatics

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2024-01-09

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**Welcome**

# Introduction

**To help me keep get an idea of who is using this resource so I can improve it in the future, please consider filling out any or all of this survey:**

**<https://forms.gle/6Zcntzvr1wZZUh6S7> Thanks!**

This bookdown contains the notes and most exercises for a course on data analysis techniques in hydrology using the programming language R. The material will be updated each time the course is taught. If new topics are added, the topics they replace will be left, in case they are useful to others.

I hope these materials can be a resource to those teaching themselves R for hydrologic analysis and/or for instructors who may want to use a lesson or two or the entire course. Each chapter in this bookdown is linked to a github repository where the code can be downloaded or copied to another github account.

If you have questions, suggestions, or would like activity answer keys, etc. please email me at jpgannon at vt.edu

The following resources, among others, were very helpful when compiling the chapters of this book. They are also linked in specific chapters, along with other resources. These are great resources if you want to dig deeper into topics covered in this bookdown.

R for Data Science: <https://r4ds.had.co.nz/>

Statistical Methods in Water Resources: <https://pubs.er.usgs.gov/publication/tm4A3>

Geocomputation with R: <https://geocompr.robinlovelace.net/>

## How to use these materials

At the top of each chapter there is a link to a github repository. In each repository is the code that produces each chapter and a version where the code chunks within it are blank. These repositories are all template repositories, so you can easily copy them to your own github space by clicking *Use This Template* on the repo page.

In my class, I work through the each document, live coding with students following along. Typically I ask students to watch as I code and explain the chunk and then replicate it on their computer. Depending on the lesson, I will ask students to try some of the chunks

before I show them the code as an in-class activity. Some chunks are explicitly designed for this purpose and are typically labeled a “challenge”.

Chapters called ACTIVITY are either homework or class-period-long in-class activities. The code chunks in these are therefore blank. If you would like a key for any of these, please just send me an email.

# 1 Intro to Plotting

Get this document and a version with empty code chunks at the template repository on github:  
<https://github.com/VT-Hydroinformatics/1-Intro-plotting-R>

## 1.1 Download and install tidyverse library

We will use the tidyverse a lot this semester. It is a suite of packages that handles plotting and data wrangling efficiently.

You only have to install the library once. You have to load it using the `library()` function each time you start an R session.

```
#install.packages("tidyverse")  
library(tidyverse)
```

```
-- Attaching core tidyverse packages ----- tidyverse 2.0.0 --  
v dplyr      1.1.2      v readr      2.1.4  
v forcats    1.0.0      v stringr    1.5.0  
v ggplot2    3.4.2      v tibble     3.2.1  
v lubridate  1.9.2      v tidyr      1.3.0  
v purrr      1.0.1  
-- Conflicts ----- tidyverse_conflicts() --  
x dplyr::filter() masks stats::filter()  
x dplyr::lag()     masks stats::lag()  
i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become
```

```
#library(webexercises)
```

## 1.2 Reading data

The following lines will read in the data we will use for this exercise. Don't worry about this right now beyond running it, we will talk more about it later.

```
Pine <- read_csv("PINE_Jan-Mar_2010.csv")
```

```
Rows: 2160 Columns: 8
```

```
-- Column specification -----
```

```
Delimiter: ","
```

```
chr (2): StationID, surrogate
```

```
dbl (5): cfs, year, quarter, month, day
```

```
dtm (1): datetime
```

```
i Use `spec()` to retrieve the full column specification for this data.
```

```
i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

```
SNP <- read_csv("PINE_NFDR_Jan-Mar_2010.csv")
```

```
Rows: 4320 Columns: 8
```

```
-- Column specification -----
```

```
Delimiter: ","
```

```
chr (2): StationID, surrogate
```

```
dbl (5): cfs, year, quarter, month, day
```

```
dtm (1): datetime
```

```
i Use `spec()` to retrieve the full column specification for this data.
```

```
i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

```
RBI <- read_csv("Flashy_Dat_Subset.csv")
```

```
Rows: 49 Columns: 26
```

```
-- Column specification -----
```

```
Delimiter: ","
```

```
chr (4): STANAME, STATE, CLASS, AGGECOREGION
```

```
dbl (22): site_no, RBI, RBIRank, DRAIN_SQKM, HUC02, LAT_GAGE, LNG_GAGE, PPTA...
```

```
i Use `spec()` to retrieve the full column specification for this data.
```

```
i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```



Create the plotting space: `ggplot()`

Represent the data on the plotting space: `geom_point()`

+ Lets you know there is more coming

```
ggplot(data = cars, aes(x = speed, y = dist)) +  
geom_point()
```

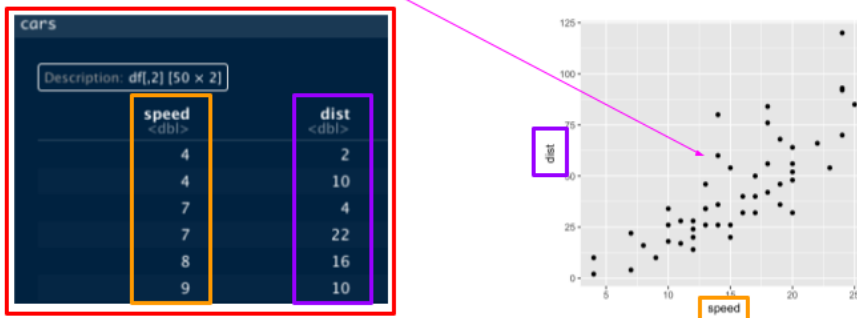
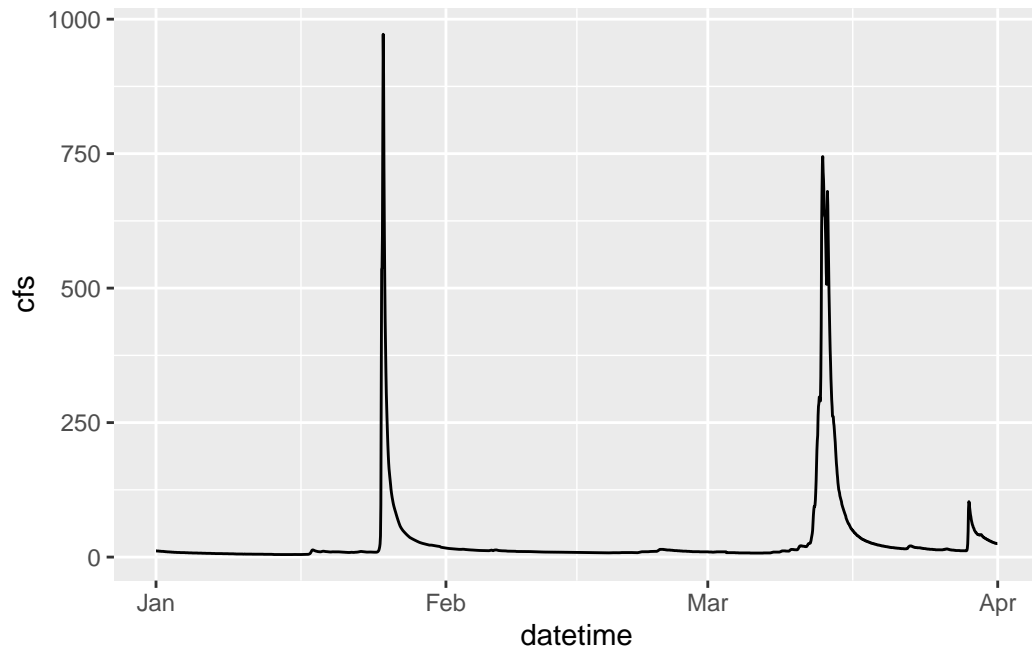


Figure 1.1: Basic ggplot syntax

### 1.3 Our first ggplot

Let's look at the Pine data, plotting streamflow (the cfs column) by the date (datetime column). We will show the time series as a line.

```
ggplot(data = Pine, aes(x = datetime, y = cfs))+  
  geom_line()
```



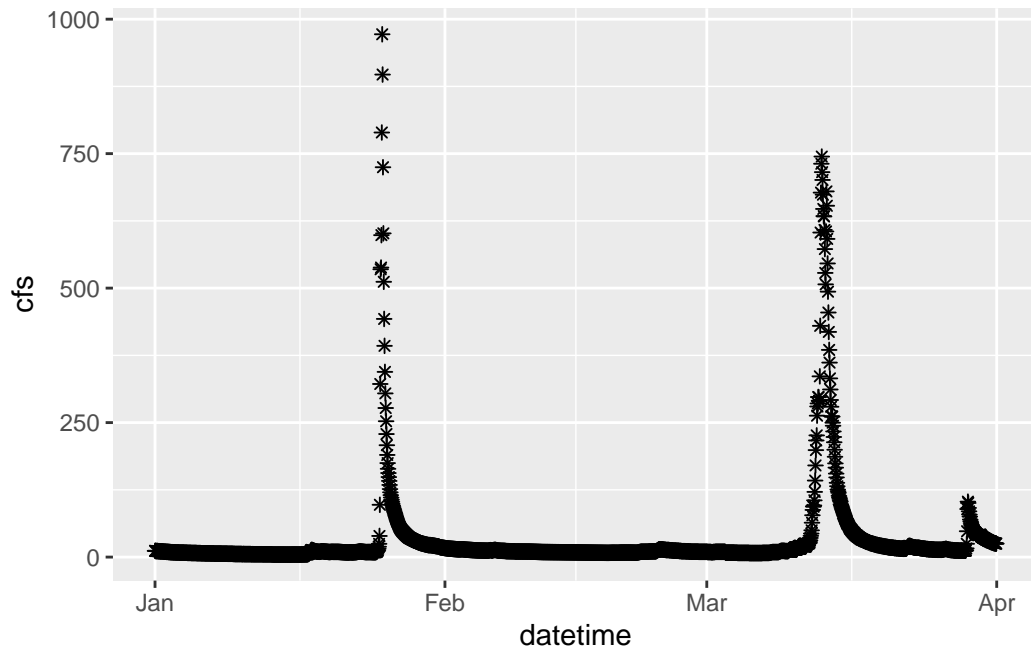
## 1.4 Change point type

Now let's make the same plot but show the data as points, using the `pch` parameter in `geom_point()` we can change the point type to any of the following:



Figure 1.2: pch options from R help file

```
ggplot(data = Pine, aes(x = datetime, y = cfs))+
  geom_point(pch = 8)
```



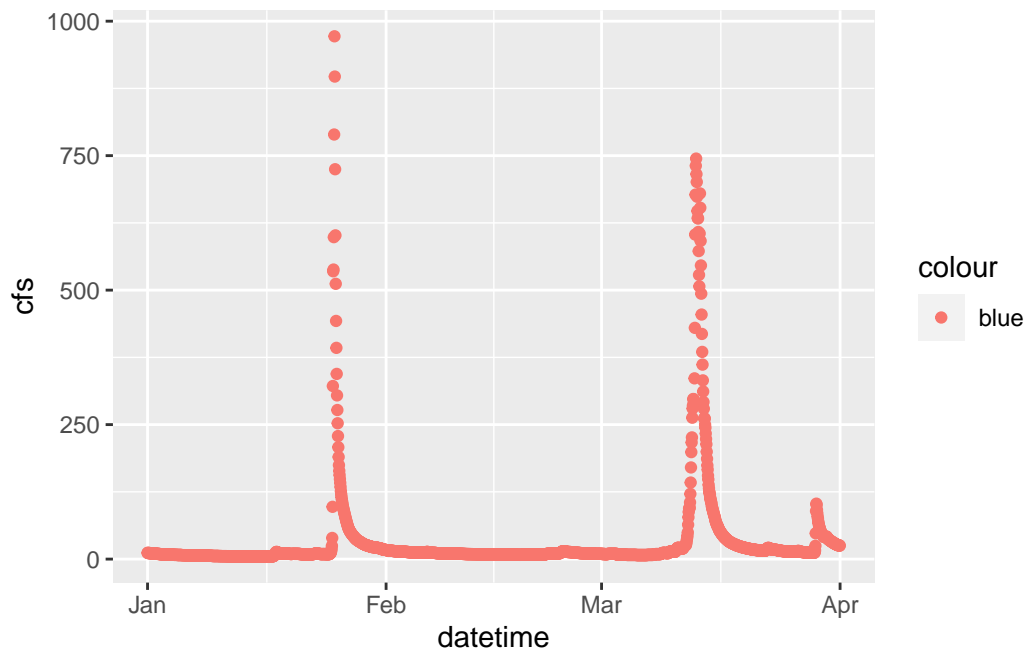
## 1.5 Set colors

We can also “easily” change the color. Easily is in quotes because this often trips people up. If you put `color = “blue”` in the aesthetic function, think about what that is telling ggplot. It says “control the color using”blue“. That doesn’t make a whole lot of sense, so neither does the output... Try it.

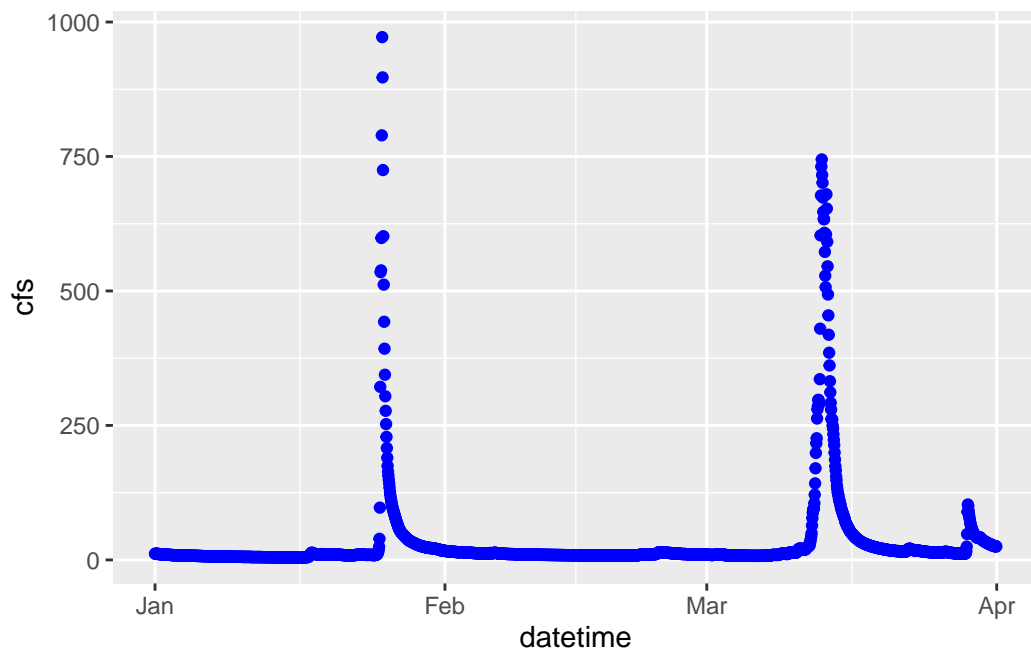
What happens is that if `color = “blue”` is in the aesthetic, you are telling R that the color used in the geom represents “blue”. This is very useful if you have multiple geoms in your plot, are coloring them differently, and are building a legend. But if you are just trying to color the points, it kind of feels like R is trolling you... doesn’t it?

Take the `color = “blue”` out of the aesthetic and you’re golden.

```
ggplot(data = Pine, aes(datetime, y = cfs, color = "blue"))+  
  geom_point()
```



```
ggplot(data = Pine, aes(x = datetime, y = cfs))+  
  geom_point(color = "blue")
```



## 1.6 Controlling color with a third variable and other functions

Let's plot the data as a line again, but play with it a bit.

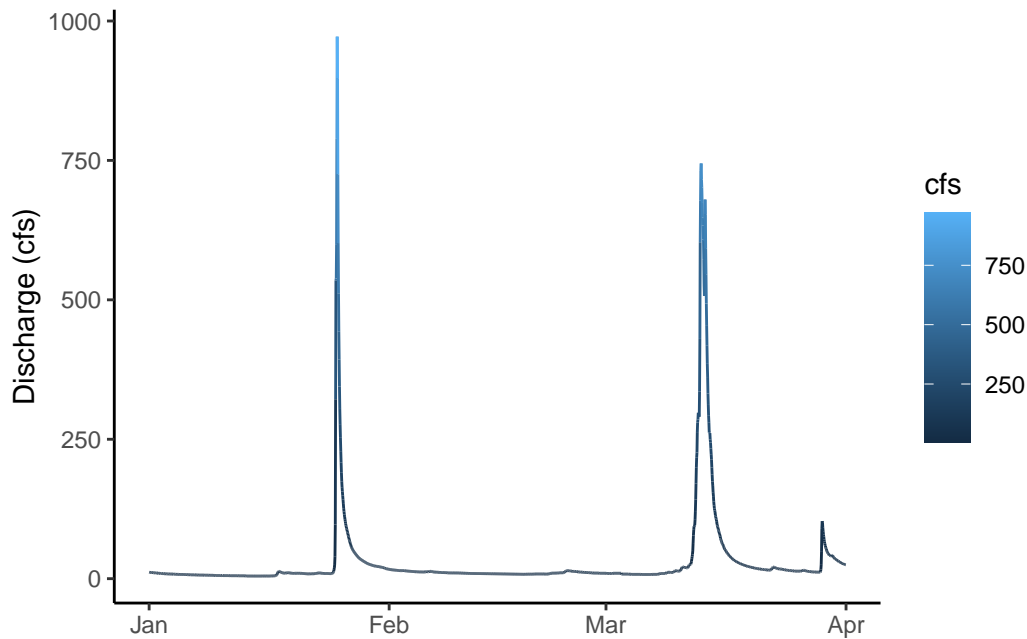
First: make the line blue

Second: change the theme

Third: change the axis labels

Fourth: color by discharge

```
ggplot(data = Pine, aes(x = datetime, y = cfs, color = cfs))+  
  geom_line()+  
  ylab("Discharge (cfs)")+  
  xlab(element_blank())+  
  theme_classic()
```



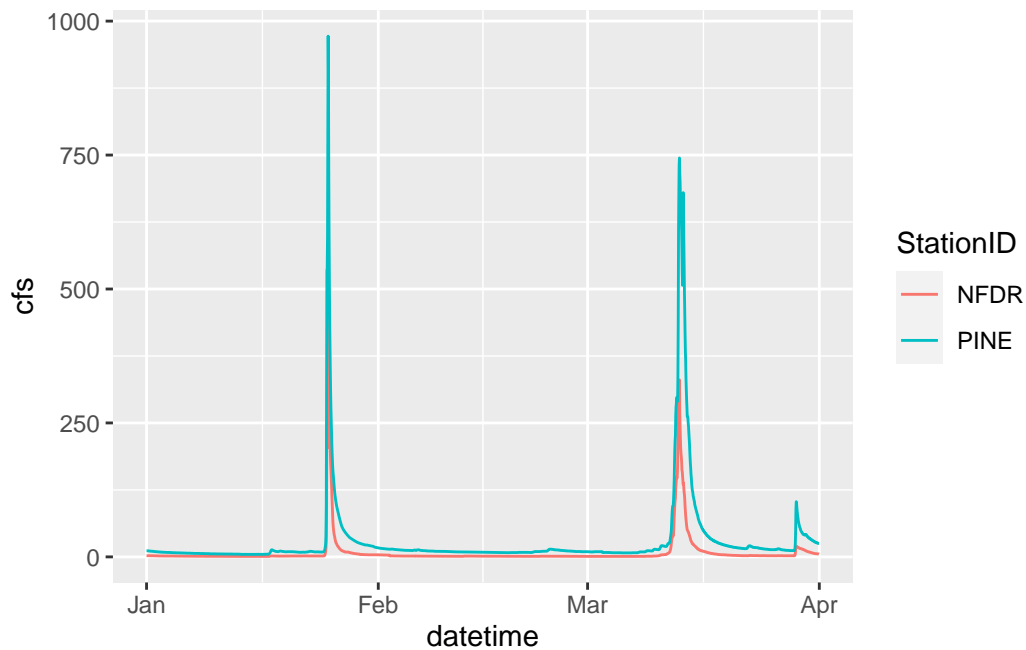
## 1.7 Plotting multiple groups

The SNP dataset has two different streams: Pine and NFDR

We can look at the two of those a couple of different ways

First, make two lines, colored by the stream by adding `color =` to your aesthetic.

```
ggplot(data = SNP, aes(x = datetime, y = cfs, color = StationID)) +  
  geom_line()
```

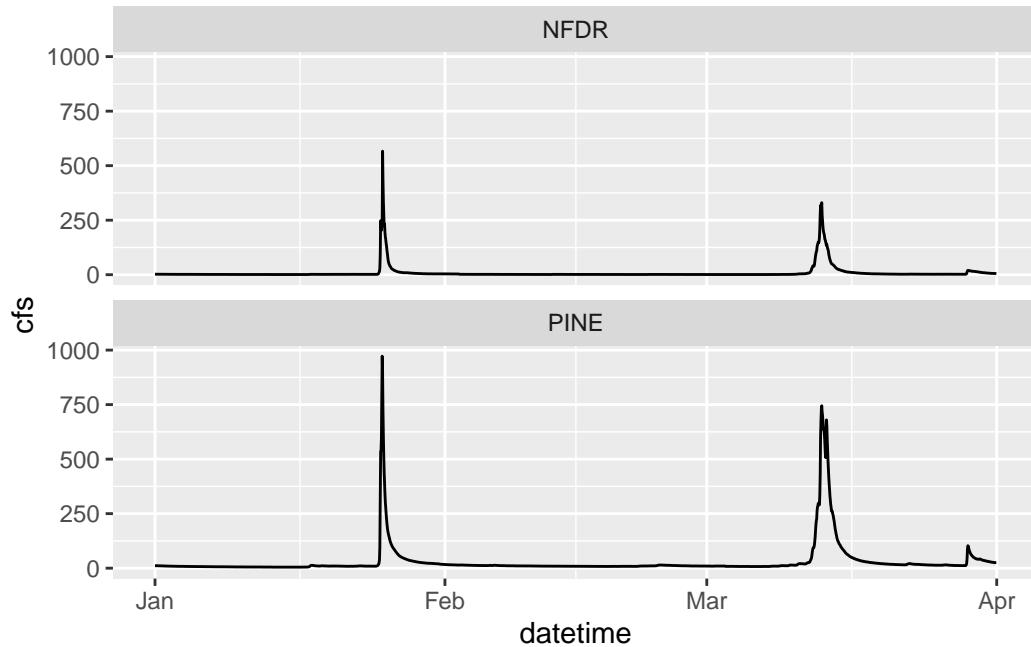


## 1.8 Facets

We can also use facets.

You must tell the `facet_wrap` what variable to use to make the separate panels (`facet =`). It'll decide how to orient them or you can tell it how. We want them to be on top of each other so we are going to tell it we want 2 rows by setting `nrow = 2`. Note that we have to put the column used to make the facets in quotes after `facets =`

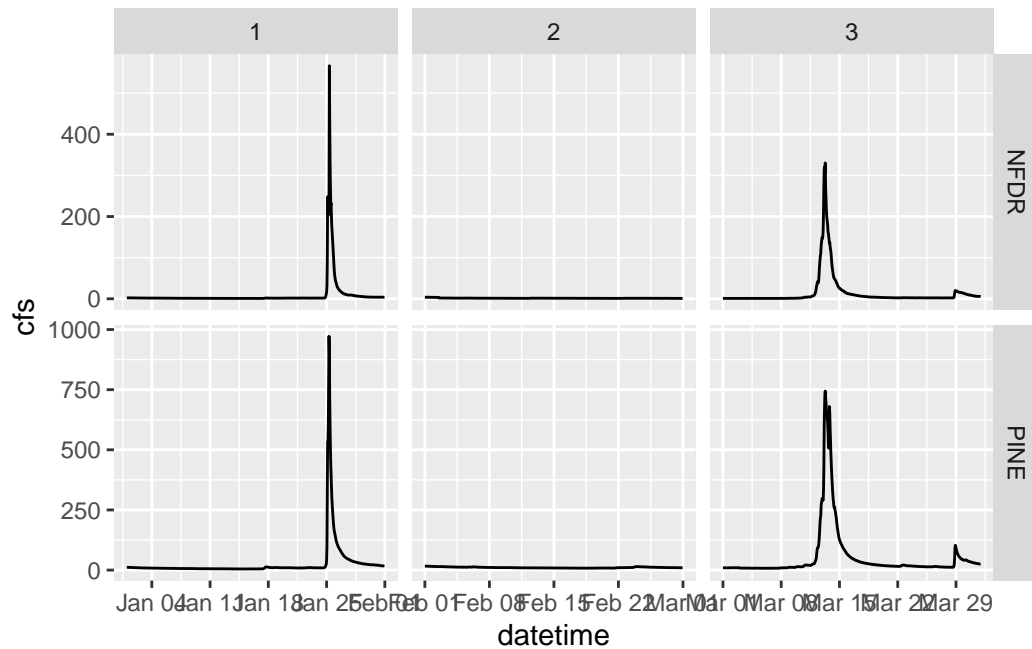
```
ggplot(data = SNP, aes(x = datetime, y = cfs)) +  
  geom_line() +  
  facet_wrap(facets = "StationID", nrow = 2)
```



## 1.9 Two variable faceting

You can also use `facet_grid()` to break your plots up into panels based on two variables. Below we will create a panel for each month in each watershed. Adding `scales = "free"` allows `facet_grid` to change the axes. By default, all axes will be the same. This is often what we want, so we can more easily compare magnitudes, but sometimes we are looking for patterns more, so we may want to let the axes have whatever range works for the individual plots.

```
ggplot(data = SNP, aes(x = datetime, y = cfs)) +  
  geom_line() +  
  facet_grid(StationID ~ month, scales = "free")
```



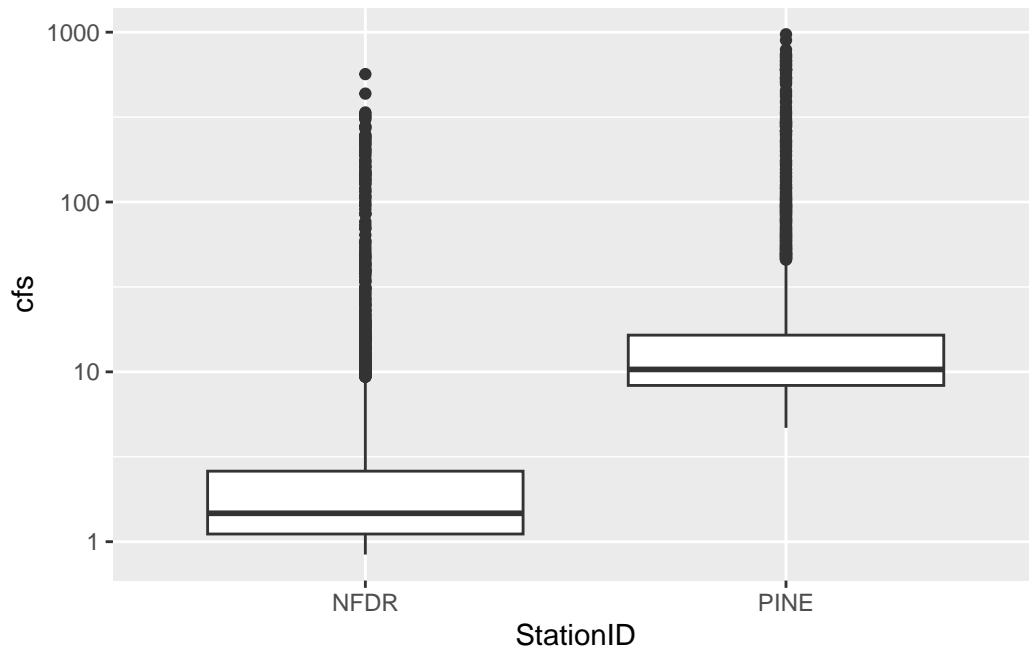
## 1.10 Boxplots

We can look at these data in other ways as well. A very useful way to look at the variation of two groups is to use a boxplot.

Because the data span several orders of magnitude, we will have to log the y axis to see the differences between the two streams. We do that by adding `scale_y_log10()`

```
ggplot(data = SNP, aes(x = StationID, y = cfs)) +
  stat_boxplot()+
  scale_y_log10()
```





## 1.11 More about color, size, etc

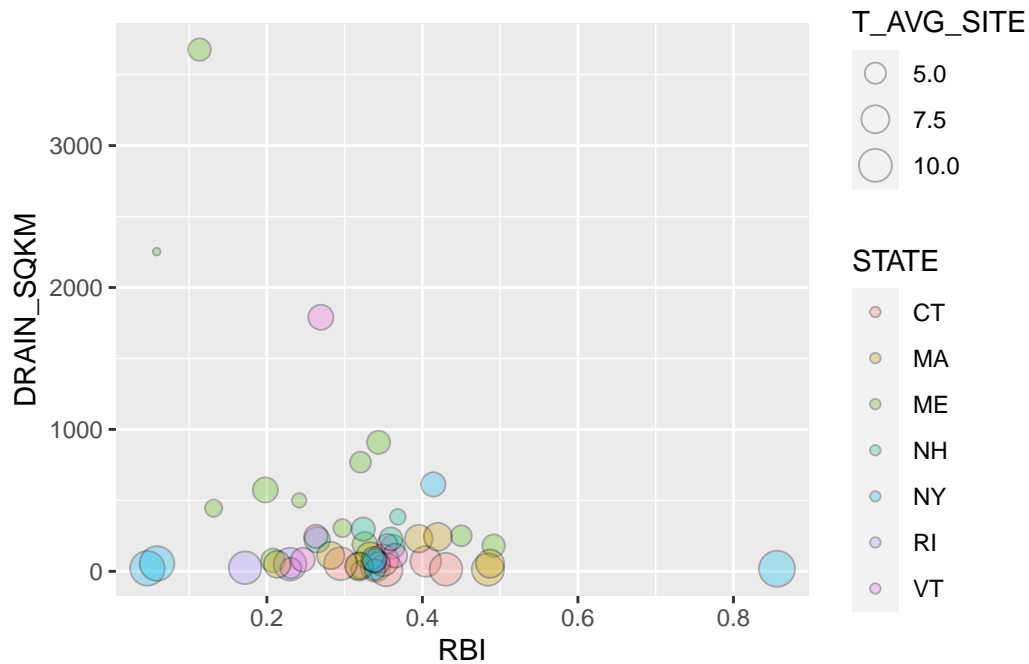
Let's play around a bit with controlling color, point size, etc with other data.

We can control the size of points by putting `size =` in the `aes()` and color by putting `color =`

If you use a point type that has a background, like `#21`, you can also set the background color using `bg =`

If points are too close together to see them all you can use a hollow point type or set the alpha lower so the points are transparent (`alpha =` )

```
ggplot(RBI, aes(RBI, DRAIN_SQKM, size = T_AVG_SITE, bg = STATE))+
  geom_point(pch = 21, alpha = 0.3)
```

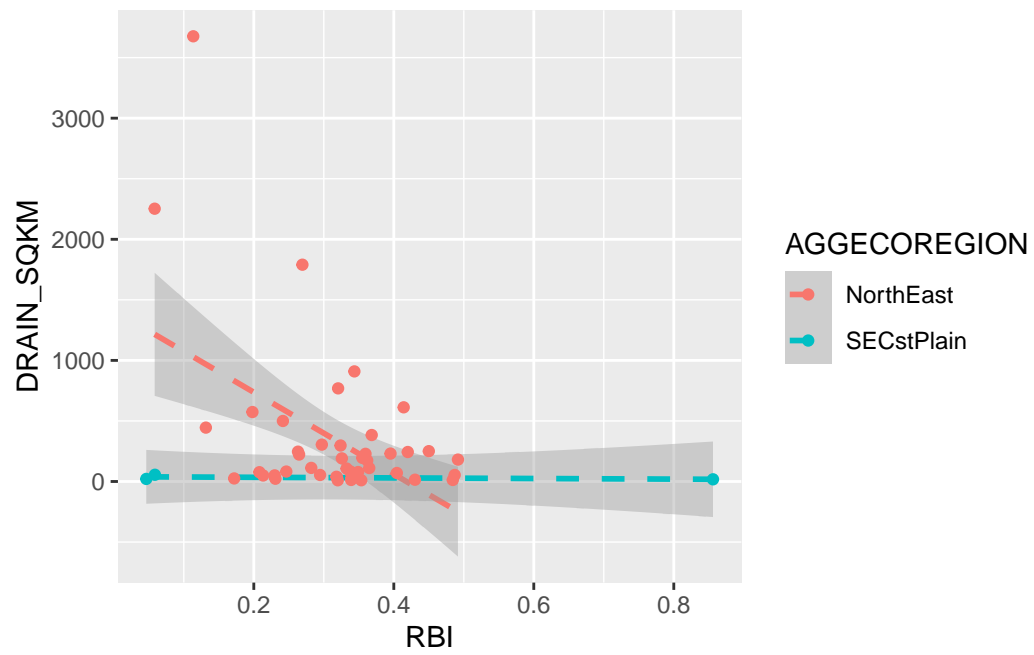


## 1.12 Multiple geoms

Finally: You can add multiple geoms to the same plot. Examples of when you might want to do this are when you are showing a line fit and want to show the points as well, or maybe showing a boxplot and want to show the data behind it. You simply add additional `geom_...` lines to add additional geoms.

```
ggplot(RBI, aes(RBI, DRAIN_SQKM, color = AGGECOREGION))+
  stat_smooth(method = "lm", linetype = 2)+
  geom_point()
```

``geom_smooth()`` using `formula = 'y ~ x'`



## 2 R Tidyverse Programming Basics

Get this document and a version with empty code chunks at the template repository on github:  
<https://github.com/VT-Hydroinformatics/2-Programming-Basics>

### 2.1 Introduction

We have messed around with plotting a bit and you've seen a little of what R can do. So now let's review or introduce you to some basics. Even if you have worked in R before, it is good to be remind of/practice with this stuff, so stay tuned in!

This exercise covers most of the same principles as two chapters in R for Data Science

Workflow: basics (<https://r4ds.had.co.nz/workflow-basics.html>)

Data transformation (<https://r4ds.had.co.nz/transform.html>)

### 2.2 You can use R as a calculator

If you just type numbers and operators in, R will spit out the results

```
1 + 2
```

```
[1] 3
```

### 2.3 You can create new objects using <-

Yea yea, = does the same thing. But use <-. We will call <- assignment or assignment operator. When we are coding in R we use <- to assign values to objects and = to set values for parameters in functions. Using <- helps us differentiate between the two. Norms for formatting are important because they help us understand what code is doing, especially when stuff gets complex.

Oh, one more thing: Surround operators with spaces. Don't code like a gorilla.

`x <- 1` looks better than `x<-1` and if you disagree you are wrong. :)

You can assign single numbers or entire chunks of data using `<-`

So if you had an object called `my_data` and wanted to copy it into `my_new_data` you could do:

```
my_new_data <- my_data
```

You can then recall/print the values in an object by just typing the name by itself.

In the code chunk below, assign a 3 to the object “y” and then print it out.

```
y <- 3
y
```

```
[1] 3
```

If you want to assign multiple values, you have to put them in the function `c()` `c` means combine. R doesn't know what to do if you just give it a bunch of values with space or commas, but if you put them as arguments in the combine function, it'll make them into a vector.

Any time you need to use several values, even passing as an argument to a function, you have to put them in `c()` or it won't work.

```
a <- c(1,2,3,4)
a
```

```
[1] 1 2 3 4
```

When you are creating objects, try to give them meaningful names so you can remember what they are. You can't have spaces or operators that mean something else as part of a name. And remember, everything is case sensitive.

Assign the value 5.4 to `water_pH` and then try to recall it by typing “`water_ph`”

```
water_pH <- 5.4

#water_ph
```

You can also set objects equal to strings, or values that have letters in them. To do this you just have to put the value in quotes, otherwise R will think it is an object name and tell you it doesn't exist.

Try: `name <- “JP”` and then `name <- JP`

What happens if you forget the ending parenthesis?

Try: `name <- "JP"`

R can be cryptic with its error messages or other responses, but once you get used to them, you know exactly what is wrong when they pop up.

```
name <- "JP"
#name <- JP
```

## 2.4 Using functions

`function_name(arg1 = val1, arg2 = val2)`

equivalent: `function_name(arg2 = val2, arg1 = val1)`

equivalent: `function_name(val1, val2)`

NOT equivalent: `function_name(val2, val1)`

You PASS values to function arguments in parentheses after its (CASE SENSITIVE) name.

R knows what values correspond to what arguments by their order, or if you specify using names and =

As an example, let's try the `seq()` function, which creates a sequence of numbers.

```
seq(from = 1, to = 10, by = 1)
```

```
[1] 1 2 3 4 5 6 7 8 9 10
```

```
#or
```

```
seq(1, 10, 1)
```

```
[1] 1 2 3 4 5 6 7 8 9 10
```

```
#or
```

```
seq(1, 10)
```

```
[1] 1 2 3 4 5 6 7 8 9 10
```

```
#what does this do
```

```
seq(10,1)
```

```
[1] 10 9 8 7 6 5 4 3 2 1
```

## 2.5 Read in some data.

For the following demonstration we will use the RBI data from a sample of USGS gages we used last class. First we will load the tidyverse library, everything we have done so far is in base R.

Important: `read_csv()` is the tidyverse csv reading function, the base R function is `read.csv()`. `read.csv()` will not read your data in as a tibble, which is the format used by tidyverse functions.

```
library(tidyverse)
```

```
-- Attaching core tidyverse packages ----- tidyverse 2.0.0 --
v dplyr      1.1.2      v readr      2.1.4
v forcats    1.0.0      v stringr    1.5.0
v ggplot2    3.4.2      v tibble     3.2.1
v lubridate  1.9.2      v tidyr      1.3.0
v purrr      1.0.1
```

```
-- Conflicts ----- tidyverse_conflicts() --
```

```
x dplyr::filter() masks stats::filter()
```

```
x dplyr::lag()     masks stats::lag()
```

```
i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become
```

```
rbi <- read_csv("Flashy_Dat_Subset.csv")
```

```

Rows: 49 Columns: 26
-- Column specification -----
Delimiter: ","
chr  (4): STANAME, STATE, CLASS, AGGECOREGION
dbl (22): site_no, RBI, RBIRank, DRAIN_SQKM, HUC02, LAT_GAGE, LNG_GAGE, PPTA...

i Use `spec()` to retrieve the full column specification for this data.
i Specify the column types or set `show_col_types = FALSE` to quiet this message.

```

## 2.6 Wait, hold up. What is a tibble?

Good question. It's a fancy way to store data that works well with tidyverse functions. Let's look at the rbi tibble.

```

head(rbi)

# A tibble: 6 x 26
  site_no    RBI RBIRank STANAME  DRAIN_SQKM HUC02 LAT_GAGE LNG_GAGE STATE CLASS
  <dbl> <dbl>   <dbl> <chr>         <dbl> <dbl>   <dbl>   <dbl> <chr> <chr>
1 1013500 0.0584     35 Fish Ri~    2253.     1    47.2   -68.6 ME   Ref
2 1021480 0.208     300 Old Str~     76.7     1    44.9   -67.7 ME   Ref
3 1022500 0.198     286 Narragu~    574.     1    44.6   -67.9 ME   Ref
4 1029200 0.132     183 Seboeis~    445.     1    46.1   -68.6 ME   Ref
5 1030500 0.114     147 Mattawa~   3676.     1    45.5   -68.3 ME   Ref
6 1031300 0.297     489 Piscata~    304.     1    45.3   -69.6 ME   Ref
# i 16 more variables: AGGECOREGION <chr>, PPTAVG_BASIN <dbl>,
#   PPTAVG_SITE <dbl>, T_AVG_BASIN <dbl>, T_AVG_SITE <dbl>, T_MAX_BASIN <dbl>,
#   T_MAXSTD_BASIN <dbl>, T_MAX_SITE <dbl>, T_MIN_BASIN <dbl>,
#   T_MINSTD_BASIN <dbl>, T_MIN_SITE <dbl>, PET <dbl>, SNOW_PCT_PRECIP <dbl>,
#   PRECIP_SEAS_IND <dbl>, FLOWYRS_1990_2009 <dbl>, wy00_09 <dbl>

```

Now read in the same data with `read.csv()` which will NOT read the data as a tibble. How is it different? Output each one in the Console.

Knowing the data type for each column is super helpful for a few reasons.... let's talk about them.

Types: int, dbl, fctr, char, logical

```

rbi_NT <- read.csv("Flashy_Dat_Subset.csv")

```



```
head(rbi_NT)
```

	site_no	RBI	RBIrank		STANAME			
1	1013500	0.05837454	35		Fish River near Fort Kent, Maine			
2	1021480	0.20797008	300		Old Stream near Wesley, Maine			
3	1022500	0.19805382	286		Narraguagus River at Cherryfield, Maine			
4	1029200	0.13151299	183		Seboeis River near Shin Pond, Maine			
5	1030500	0.11350485	147		Mattawamkeag River near Mattawamkeag, Maine			
6	1031300	0.29718786	489		Piscataquis River at Blanchard, Maine			
	DRAIN_SQKM	HUC02	LAT_GAGE	LNG_GAGE	STATE	CLASS	AGGECOREGION	PPTAVG_BASIN
1	2252.7	1	47.23739	-68.58264	ME	Ref	NorthEast	97.42
2	76.7	1	44.93694	-67.73611	ME	Ref	NorthEast	115.39
3	573.6	1	44.60797	-67.93524	ME	Ref	NorthEast	120.07
4	444.9	1	46.14306	-68.63361	ME	Ref	NorthEast	102.19
5	3676.2	1	45.50097	-68.30596	ME	Ref	NorthEast	108.19
6	304.4	1	45.26722	-69.58389	ME	Ref	NorthEast	119.83
	PPTAVG_SITE	T_AVG_BASIN	T_AVG_SITE	T_MAX_BASIN	T_MAXSTD_BASIN	T_MAX_SITE		
1	93.53	3.00	3.0	9.67	0.202	10.0		
2	117.13	5.71	5.8	11.70	0.131	11.9		
3	129.56	5.95	6.3	11.90	0.344	12.2		
4	103.24	3.61	4.0	9.88	0.231	10.4		
5	113.13	4.82	5.4	10.75	0.554	11.7		
6	120.93	3.60	4.2	9.57	0.431	11.0		
	T_MIN_BASIN	T_MINSTD_BASIN	T_MIN_SITE	PET	SNOW_PCT_PRECIP	PRECIP_SEAS_IND		
1	-2.49	0.269	-2.7	504.7	36.9	0.102		
2	-0.85	0.123	-0.6	554.2	39.5	0.046		
3	0.06	0.873	1.4	553.1	38.2	0.047		
4	-2.13	0.216	-1.5	513.0	36.4	0.070		
5	-1.49	0.251	-1.2	540.8	37.2	0.033		
6	-2.46	0.268	-1.7	495.8	40.2	0.030		
	FLOWYRS_1990_2009	wy00_09						
1	20	10						
2	11	10						
3	20	10						
4	11	10						
5	20	10						
6	13	10						

## 2.7 Data wrangling in dplyr

If you forget syntax or what the following functions do, here is an excellent cheat sheet: <https://rstudio.com/wp-content/uploads/2015/02/data-wrangling-cheatsheet.pdf>

We will demo five functions below:

- **filter()** - returns rows that meet specified conditions
- **arrange()** - reorders rows
- **select()** - pull out variables (columns)
- **mutate()** - create new variables (columns) or reformat existing ones
- **summarize()** - collapse groups of values into summary stats

With all of these, the first argument is the data and then the arguments after that specify what you want the function to do.

**filter(RiverDat, River == "New")**  
**RiverDat**

River	Flow	Year
New	150	2020
New	175	2021
Roanoke	50	2020
Roanoke	62	2021

**arrange(RiverDat, Flow)**  
**RiverDat**

River	Flow	Year
Roanoke	50	2020
Roanoke	62	2021
New	150	2020
New	175	2021

**select(RiverDat, River, Flow)**  
**RiverDat**

River	Flow	Year
New	150	2020
New	175	2021
Roanoke	50	2020
Roanoke	62	2021

**mutate(RiverDat, Flow10 = Flow \* 10)**  
**RiverDat**

River	Flow	Year	Flow10
New	150	2020	1500
New	175	2021	1750
Roanoke	50	2020	500
Roanoke	62	2021	620

**DatGrouped <- group\_by(RiverDat, River)**  
**summarize(DatGrouped, AvgFlow = mean(Flow))**  
  
**RiverDat**

River	AvgFlow
New	162.5
Roanoke	56

## 2.8 Filter

Write an expression that returns data in rbi for the state of Maine (ME)

Operators:

== equal

!= not equal

>= , <= greater than or equal to, less than or equal to  
 > , < greater than or less then  
 %in% included in a list of values  
 & and  
 | or

```
filter(rbi, STATE == "ME")
```

# A tibble: 13 x 26

	site_no	RBI	RBIrank	STANAME	DRAIN_SQKM	HUC02	LAT_GAGE	LNG_GAGE	STATE	CLASS
	<dbl>	<dbl>	<dbl>	<chr>	<dbl>	<dbl>	<dbl>	<dbl>	<chr>	<chr>
1	1013500	0.0584	35	Fish R~	2253.	1	47.2	-68.6	ME	Ref
2	1021480	0.208	300	Old St~	76.7	1	44.9	-67.7	ME	Ref
3	1022500	0.198	286	Narrag~	574.	1	44.6	-67.9	ME	Ref
4	1029200	0.132	183	Seboei~	445.	1	46.1	-68.6	ME	Ref
5	1030500	0.114	147	Mattaw~	3676.	1	45.5	-68.3	ME	Ref
6	1031300	0.297	489	Piscat~	304.	1	45.3	-69.6	ME	Ref
7	1031500	0.320	545	Piscat~	769	1	45.2	-69.3	ME	Ref
8	1037380	0.318	537	Ducktr~	39	1	44.3	-69.1	ME	Ref
9	1044550	0.242	360	Spence~	500.	1	45.3	-70.2	ME	Ref
10	1047000	0.344	608	Carrab~	909.	1	44.9	-70.0	ME	Ref
11	1054200	0.492	805	Wild R~	181	1	44.4	-71.0	ME	Ref
12	1055000	0.450	762	Swift ~	251.	1	44.6	-70.6	ME	Ref
13	1057000	0.326	561	Little~	191.	1	44.3	-70.5	ME	Ref

```
# i 16 more variables: AGGECOREGION <chr>, PPTAVG_BASIN <dbl>,
# PPTAVG_SITE <dbl>, T_AVG_BASIN <dbl>, T_AVG_SITE <dbl>, T_MAX_BASIN <dbl>,
# T_MAXSTD_BASIN <dbl>, T_MAX_SITE <dbl>, T_MIN_BASIN <dbl>,
# T_MINSTD_BASIN <dbl>, T_MIN_SITE <dbl>, PET <dbl>, SNOW_PCT_PRECIP <dbl>,
# PRECIP_SEAS_IND <dbl>, FLOWYRS_1990_2009 <dbl>, wy00_09 <dbl>
```

## 2.8.1 Multiple conditions

How many gages are there in Maine with an rbi greater than 0.25

```
filter(rbi, STATE == "ME" & RBI > 0.25)
```

# A tibble: 7 x 26

	site_no	RBI	RBIrank	STANAME	DRAIN_SQKM	HUC02	LAT_GAGE	LNG_GAGE	STATE	CLASS
	<dbl>	<dbl>	<dbl>	<chr>	<dbl>	<dbl>	<dbl>	<dbl>	<chr>	<chr>
1	1031300	0.297	489	Piscataq~	304.	1	45.3	-69.6	ME	Ref

```

2 1031500 0.320      545 Piscataq~      769      1      45.2      -69.3 ME      Ref
3 1037380 0.318      537 Ducktrap~      39       1      44.3      -69.1 ME      Ref
4 1047000 0.344      608 Carrabas~      909.     1      44.9      -70.0 ME      Ref
5 1054200 0.492      805 Wild Riv~      181      1      44.4      -71.0 ME      Ref
6 1055000 0.450      762 Swift Ri~      251.     1      44.6      -70.6 ME      Ref
7 1057000 0.326      561 Little A~      191.     1      44.3      -70.5 ME      Ref
# i 16 more variables: AGGECOREGION <chr>, PPTAVG_BASIN <dbl>,
#   PPTAVG_SITE <dbl>, T_AVG_BASIN <dbl>, T_AVG_SITE <dbl>, T_MAX_BASIN <dbl>,
#   T_MAXSTD_BASIN <dbl>, T_MAX_SITE <dbl>, T_MIN_BASIN <dbl>,
#   T_MINSTD_BASIN <dbl>, T_MIN_SITE <dbl>, PET <dbl>, SNOW_PCT_PRECIP <dbl>,
#   PRECIP_SEAS_IND <dbl>, FLOWYRS_1990_2009 <dbl>, wy00_09 <dbl>

```

## 2.9 Arrange

Arrange sorts by a column in your dataset.

Sort the rbi data by the RBI column in ascending and then descending order

```
arrange(rbi, RBI)
```

```

# A tibble: 49 x 26
  site_no  RBI RBIrank STANAME DRAIN_SQKM HUC02 LAT_GAGE LNG_GAGE STATE CLASS
  <dbl>  <dbl>  <dbl> <chr>      <dbl> <dbl>  <dbl>  <dbl> <chr> <chr>
1 1305500 0.0464    18 SWAN R~      21.3    2    40.8   -73.0 NY   Non~~
2 1013500 0.0584    35 Fish R~     2253.    1    47.2   -68.6 ME   Ref
3 1306460 0.0587    37 CONNET~      55.7    2    40.8   -73.2 NY   Non~~
4 1030500 0.114    147 Mattaw~    3676.    1    45.5   -68.3 ME   Ref
5 1029200 0.132    183 Seboei~      445.    1    46.1   -68.6 ME   Ref
6 1117468 0.172    244 BEAVER~      25.3    1    41.5   -71.6 RI   Ref
7 1022500 0.198    286 Narrag~      574.    1    44.6   -67.9 ME   Ref
8 1021480 0.208    300 Old St~      76.7    1    44.9   -67.7 ME   Ref
9 1162500 0.213    311 PRIEST~      49.7    1    42.7   -72.1 MA   Ref
10 1117370 0.230    338 QUEEN ~      50.5    1    41.5   -71.6 RI   Ref
# i 39 more rows
# i 16 more variables: AGGECOREGION <chr>, PPTAVG_BASIN <dbl>,
#   PPTAVG_SITE <dbl>, T_AVG_BASIN <dbl>, T_AVG_SITE <dbl>, T_MAX_BASIN <dbl>,
#   T_MAXSTD_BASIN <dbl>, T_MAX_SITE <dbl>, T_MIN_BASIN <dbl>,
#   T_MINSTD_BASIN <dbl>, T_MIN_SITE <dbl>, PET <dbl>, SNOW_PCT_PRECIP <dbl>,
#   PRECIP_SEAS_IND <dbl>, FLOWYRS_1990_2009 <dbl>, wy00_09 <dbl>

```

```
arrange(rbi, desc(RBI))
```

```
# A tibble: 49 x 26
  site_no  RBI RBIRank STANAME DRAIN_SQKM HUC02 LAT_GAGE LNG_GAGE STATE CLASS
    <dbl> <dbl>   <dbl> <chr>      <dbl> <dbl>   <dbl>   <dbl> <chr> <chr>
1 1311500 0.856   1017 VALLEY ~    18.1     2    40.7   -73.7 NY   Non-~
2 1054200 0.492    805 Wild Ri~    181      1    44.4   -71.0 ME   Ref
3 1187300 0.487    800 HUBBARD~    53.9     1    42.0   -72.9 MA   Ref
4 1105600 0.484    797 OLD SWA~    12.7     1    42.2   -70.9 MA   Non-~
5 1055000 0.450    762 Swift R~   251.      1    44.6   -70.6 ME   Ref
6 1195100 0.430    744 INDIAN ~    14.8     1    41.3   -72.5 CT   Ref
7 1181000 0.420    732 WEST BR~   244.      1    42.2   -72.9 MA   Ref
8 1350000 0.414    721 SCHOHAR~   612.      2    42.3   -74.4 NY   Ref
9 1121000 0.404    710 MOUNT H~    70.3     1    41.8   -72.2 CT   Ref
10 1169000 0.395    688 NORTH R~   231.      1    42.6   -72.7 MA   Ref
# i 39 more rows
# i 16 more variables: AGGECOREGION <chr>, PPTAVG_BASIN <dbl>,
#   PPTAVG_SITE <dbl>, T_AVG_BASIN <dbl>, T_AVG_SITE <dbl>, T_MAX_BASIN <dbl>,
#   T_MAXSTD_BASIN <dbl>, T_MAX_SITE <dbl>, T_MIN_BASIN <dbl>,
#   T_MINSTD_BASIN <dbl>, T_MIN_SITE <dbl>, PET <dbl>, SNOW_PCT_PRECIP <dbl>,
#   PRECIP_SEAS_IND <dbl>, FLOWYRS_1990_2009 <dbl>, wy00_09 <dbl>
```

## 2.10 Select

There are too many columns! You will often want to do this when you are manipulating the structure of your data and need to trim it down to only include what you will use.

Select Site name, state, and RBI from the rbi data

Note they come back in the order you put them in in the function, not the order they were in in the original data.

You can do a lot more with select, especially when you need to select a bunch of columns but don't want to type them all out. But we don't need to cover all that today. For a taste though, if you want to select a group of columns you can specify the first and last with a colon in between (first:last) and it'll return all of them. Select the rbi columns from site\_no to DRAIN\_SQKM.

```
select(rbi, STANAME, STATE, RBI)
```

```
# A tibble: 49 x 3
```

	STANAME	STATE	RBI
	<chr>	<chr>	<dbl>
1	Fish River near Fort Kent, Maine	ME	0.0584
2	Old Stream near Wesley, Maine	ME	0.208
3	Narraguagus River at Cherryfield, Maine	ME	0.198
4	Seboeis River near Shin Pond, Maine	ME	0.132
5	Mattawamkeag River near Mattawamkeag, Maine	ME	0.114
6	Piscataquis River at Blanchard, Maine	ME	0.297
7	Piscataquis River near Dover-Foxcroft, Maine	ME	0.320
8	Ducktrap River near Lincolnville, Maine	ME	0.318
9	Spencer Stream near Grand Falls, Maine	ME	0.242
10	Carrabassett River near North Anson, Maine	ME	0.344

```
# i 39 more rows
```

```
select(rbi, site_no:DRAIN_SQKM)
```

```
# A tibble: 49 x 5
```

	site_no	RBI	RBIrank	STANAME	DRAIN_SQKM
	<dbl>	<dbl>	<dbl>	<chr>	<dbl>
1	1013500	0.0584	35	Fish River near Fort Kent, Maine	2253.
2	1021480	0.208	300	Old Stream near Wesley, Maine	76.7
3	1022500	0.198	286	Narraguagus River at Cherryfield, Maine	574.
4	1029200	0.132	183	Seboeis River near Shin Pond, Maine	445.
5	1030500	0.114	147	Mattawamkeag River near Mattawamkeag, Maine	3676.
6	1031300	0.297	489	Piscataquis River at Blanchard, Maine	304.
7	1031500	0.320	545	Piscataquis River near Dover-Foxcroft, Mai~	769
8	1037380	0.318	537	Ducktrap River near Lincolnville, Maine	39
9	1044550	0.242	360	Spencer Stream near Grand Falls, Maine	500.
10	1047000	0.344	608	Carrabassett River near North Anson, Maine	909.

```
# i 39 more rows
```

## 2.11 Mutate

Use `mutate` to add new columns based on additional ones. Common uses are to create a column of data in different units, or to calculate something based on two columns. You can also use it to just update a column, by naming the new column the same as the original one (but be careful because you'll lose the original one!). I commonly use this when I am changing the datatype of a column, say from a character to a factor or a string to a date.

Create a new column in rbi called T\_RANGE by subtracting T\_MIN\_SITE from T\_MAX\_SITE

```
mutate(rbi, T_RANGE = T_MAX_SITE - T_MIN_SITE)
```

# A tibble: 49 x 27

	site_no	RBI	RBIrank	STANAME	DRAIN_SQKM	HUC02	LAT_GAGE	LNG_GAGE	STATE	CLASS
	<dbl>	<dbl>	<dbl>	<chr>	<dbl>	<dbl>	<dbl>	<dbl>	<chr>	<chr>
1	1013500	0.0584	35	Fish R~	2253.	1	47.2	-68.6	ME	Ref
2	1021480	0.208	300	Old St~	76.7	1	44.9	-67.7	ME	Ref
3	1022500	0.198	286	Narrag~	574.	1	44.6	-67.9	ME	Ref
4	1029200	0.132	183	Seboei~	445.	1	46.1	-68.6	ME	Ref
5	1030500	0.114	147	Mattaw~	3676.	1	45.5	-68.3	ME	Ref
6	1031300	0.297	489	Piscat~	304.	1	45.3	-69.6	ME	Ref
7	1031500	0.320	545	Piscat~	769	1	45.2	-69.3	ME	Ref
8	1037380	0.318	537	Ducktr~	39	1	44.3	-69.1	ME	Ref
9	1044550	0.242	360	Spence~	500.	1	45.3	-70.2	ME	Ref
10	1047000	0.344	608	Carrab~	909.	1	44.9	-70.0	ME	Ref

# i 39 more rows

```
# i 17 more variables: AGGECOREGION <chr>, PPTAVG_BASIN <dbl>,
# PPTAVG_SITE <dbl>, T_AVG_BASIN <dbl>, T_AVG_SITE <dbl>, T_MAX_BASIN <dbl>,
# T_MAXSTD_BASIN <dbl>, T_MAX_SITE <dbl>, T_MIN_BASIN <dbl>,
# T_MINSTD_BASIN <dbl>, T_MIN_SITE <dbl>, PET <dbl>, SNOW_PCT_PRECIP <dbl>,
# PRECIP_SEAS_IND <dbl>, FLOWYRS_1990_2009 <dbl>, wy00_09 <dbl>,
# T_RANGE <dbl>
```

When downloading data from the USGS through R, you have to enter the gage ID as a character, even though they are all made up of numbers. So to practice doing this, update the site\_no column to be a character datatype

```
mutate(rbi, site_no = as.character(site_no))
```

# A tibble: 49 x 26

	site_no	RBI	RBIrank	STANAME	DRAIN_SQKM	HUC02	LAT_GAGE	LNG_GAGE	STATE	CLASS
	<chr>	<dbl>	<dbl>	<chr>	<dbl>	<dbl>	<dbl>	<dbl>	<chr>	<chr>
1	1013500	0.0584	35	Fish R~	2253.	1	47.2	-68.6	ME	Ref
2	1021480	0.208	300	Old St~	76.7	1	44.9	-67.7	ME	Ref
3	1022500	0.198	286	Narrag~	574.	1	44.6	-67.9	ME	Ref
4	1029200	0.132	183	Seboei~	445.	1	46.1	-68.6	ME	Ref
5	1030500	0.114	147	Mattaw~	3676.	1	45.5	-68.3	ME	Ref
6	1031300	0.297	489	Piscat~	304.	1	45.3	-69.6	ME	Ref

```

7 1031500 0.320      545 Piscat~      769      1      45.2      -69.3 ME      Ref
8 1037380 0.318      537 Ducktr~      39       1      44.3      -69.1 ME      Ref
9 1044550 0.242      360 Spence~     500.      1      45.3      -70.2 ME      Ref
10 1047000 0.344      608 Carrab~     909.      1      44.9      -70.0 ME      Ref
# i 39 more rows
# i 16 more variables: AGGECOREGION <chr>, PPTAVG_BASIN <dbl>,
#   PPTAVG_SITE <dbl>, T_AVG_BASIN <dbl>, T_AVG_SITE <dbl>, T_MAX_BASIN <dbl>,
#   T_MAXSTD_BASIN <dbl>, T_MAX_SITE <dbl>, T_MIN_BASIN <dbl>,
#   T_MINSTD_BASIN <dbl>, T_MIN_SITE <dbl>, PET <dbl>, SNOW_PCT_PRECIP <dbl>,
#   PRECIP_SEAS_IND <dbl>, FLOWYRS_1990_2009 <dbl>, wy00_09 <dbl>

```

## 2.12 Summarize

Summarize will perform an operation on all of your data, or groups if you assign groups.

Use summarize to compute the mean, min, and max rbi

```
summarize(rbi, meanrbi = mean(RBI), maxrbi = max(RBI), minrbi = min(RBI))
```

```

# A tibble: 1 x 3
  meanrbi maxrbi minrbi
  <dbl>   <dbl>   <dbl>
1  0.316  0.856 0.0464

```

Now use the group function to group by state and then summarize in the same way as above

```
rbistate <- group_by(rbi, STATE)
summarize(rbistate, meanrbi = mean(RBI), maxrbi = max(RBI), minrbi = min(RBI))
```

```

# A tibble: 7 x 4
  STATE meanrbi maxrbi minrbi
  <chr>   <dbl>   <dbl>   <dbl>
1 CT      0.366   0.430   0.295
2 MA      0.367   0.487   0.213
3 ME      0.269   0.492   0.0584
4 NH      0.336   0.368   0.265
5 NY      0.342   0.856   0.0464
6 RI      0.201   0.230   0.172
7 VT      0.299   0.365   0.231

```



## 2.13 Multiple operations with pipes

The pipe operator `%>%` allows you to perform multiple operations in a sequence without saving intermediate steps. Not only is this more efficient, but structuring operations with pipes is also more intuitive than nesting functions within functions (the other way you can do multiple operations).

**2.13.1 Let's say we want to tell R to make a PB&J sandwich by using the `pbbread()`, `jbread()`, and `joinslices()` functions and the data "ingredients". If we do this saving each step it would look like this:**

```
sando <- pbbread(ingredients)
sando <- jbread(sando)
sando <- joinslices(sando)
```

**2.13.2 If we nest the functions together we get this**

```
joinslice(jbread(pbbread(ingredients)))
```

Efficient... but tough to read/interpret

**2.13.3 Using the pipe it would look like this**

```
ingredients %>%
  pbbread() %>%
  jbread() %>%
  joinslices()
```

Much easier to follow!

**2.13.4 When you use the pipe, it basically takes whatever came out of the first function and puts it into the data argument for the next one**

so `rbi %>% group_by(STATE)` is the same as `group_by(rbi, STATE)`

Take the groupby and summarize code from above and perform the operation using the pipe

```
rbi %>%
  group_by(STATE) %>%
```

```
summarize(meanrbi = mean(RBI), maxrbi = max(RBI), minrbi = min(RBI))
```

```
# A tibble: 7 x 4
  STATE meanrbi maxrbi minrbi
  <chr>   <dbl>   <dbl>   <dbl>
1 CT      0.366   0.430   0.295
2 MA      0.367   0.487   0.213
3 ME      0.269   0.492   0.0584
4 NH      0.336   0.368   0.265
5 NY      0.342   0.856   0.0464
6 RI      0.201   0.230   0.172
7 VT      0.299   0.365   0.231
```

## 2.14 Save your results to a new tibble

We have just been writing everything to the screen so we can see what we are doing... In order to save anything we do with these functions to work with it later, we just have to use the assignment operator (<-) to store the data.

One kind of awesome thing about the assignment operator is that it works both ways...

x <- 3 and 3 -> x do the same thing (WHAT?!)

So you can do the assignment at the beginning or the end of your dplyr workings, whatever you like best.

Use the assignment operator to save the summary table you just made.

```
stateRBIs <- rbi %>%
  group_by(STATE) %>%
  summarize(meanrbi = mean(RBI), maxrbi = max(RBI), minrbi = min(RBI))

# Notice when you do this it doesn't output the result...
# You can see what you did by clicking on stateRBIs in your environment panel
# or just type stateRBIs

stateRBIs
```

```
# A tibble: 7 x 4
  STATE meanrbi maxrbi minrbi
  <chr>   <dbl>   <dbl>   <dbl>
```

1	CT	0.366	0.430	0.295
2	MA	0.367	0.487	0.213
3	ME	0.269	0.492	0.0584
4	NH	0.336	0.368	0.265
5	NY	0.342	0.856	0.0464
6	RI	0.201	0.230	0.172
7	VT	0.299	0.365	0.231

## 2.15 What about NAs?

We will talk more about this when we discuss stats, but some operations will fail if there are NA's in the data. If appropriate, you can tell functions like `mean()` to ignore NAs. You can also use `drop_na()` if you're working with a tibble. But be aware if you use that and save the result, `drop_na()` gets rid of the whole row, not just the NA. Because what would you replace it with.... an NA?

```
x <- c(1,2,3,4,NA)
mean(x, na.rm = TRUE)
```

```
[1] 2.5
```

## 2.16 What are some things you think I'll ask you to do for the activity next class?