Assignment 7: GLMs (Linear Regressios, ANOVA, & t-tests)

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OVERVIEW

This exercise accompanies the lessons in Environmental Data Analytics on generalized linear models.

Directions

1. Rename this file `<FirstLast>_A07_GLMs.Rmd` (replacing `<FirstLast>` with your first and last name).
2. Change "Student Name" on line 3 (above) with your name.
3. Work through the steps, **creating code and output** that fulfill each instruction.
4. Be sure to **answer the questions** in this assignment document.
5. When you have completed the assignment, **Knit** the text and code into a single PDF file.

Set up your session

1. Set up your session. Check your working directory. Load the tidyverse, agricolae and other needed packages. Import the *raw* NTL-LTER raw data file for chemistry/physics (`NTL-LTER_Lake_ChemistryPhysics_Raw.csv`). Set date columns to date objects.
2. Build a ggplot theme and set it as your default theme.

```
#1
getwd() #getting working directory
```

```
## [1] "/Users/cambervincent/EDA_Fall_2024/Assignments"
```

```
#installing needed packages
library(tidyverse)
```

```
## -- Attaching core tidyverse packages ------------------------ tidyverse 2.0.0 --
## v dplyr     1.1.4     v readr     2.1.5
## v forcats   1.0.0     v stringr   1.5.1
## v ggplot2   3.5.1     v tibble    3.2.1
## v lubridate 1.9.3     v tidyr     1.3.1
## v purrr     1.0.2
## -- 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 errors
```

```r
library(agricolae)
library(lubridate)
library(here)
```

```
## here() starts at /Users/cambervincent/EDA_Fall_2024
```

```r
setwd("~/EDA_Fall_2024") #adjusting working directory

lake_chemphys<-read_csv("Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv",
                        show_col_types=F) #quiet warning message
lake_chemphys$sampledate<-mdy(lake_chemphys$sampledate) #convert date column

#2
theme_standard<-theme(

  text=element_text(family="Times",size=12,color="black"), #setting base font to Times New Roman
  plot.title=element_text(family="Helvetica",face="bold",size=16,  #title text theme
                          margin=margin(b=3)), #added margin for visual clarity
  plot.subtitle=element_text(family="Helvetica",face="italic",size=12, #subtitle text theme
                             color="gray20",
                             margin=margin(b=10)), #added margin for visual clarity

  plot.background=element_rect(fill="white"), #background set to white
  panel.background=element_rect(fill="white"), #graph background set to white
  panel.border=element_rect(color="black",fill=NA), #set a border around the graph

  panel.grid.major=element_line(color="gray85"), #recolor gridlines
  panel.grid.minor=element_line(color="gray95"),
  axis.ticks=element_blank() #turn off ticks

)

theme_set(theme_standard) #set custom theme as the base theme for all graphs
```

Simple regression

Our first research question is: Does mean lake temperature recorded during July change with depth across all lakes?

3. State the null and alternative hypotheses for this question:

   Answer: H0: There is no significant change in mean lake temperature recorded during July across all lakes. Ha: There is a signifianct change in mean lake temperature recorded during July across all lakes.

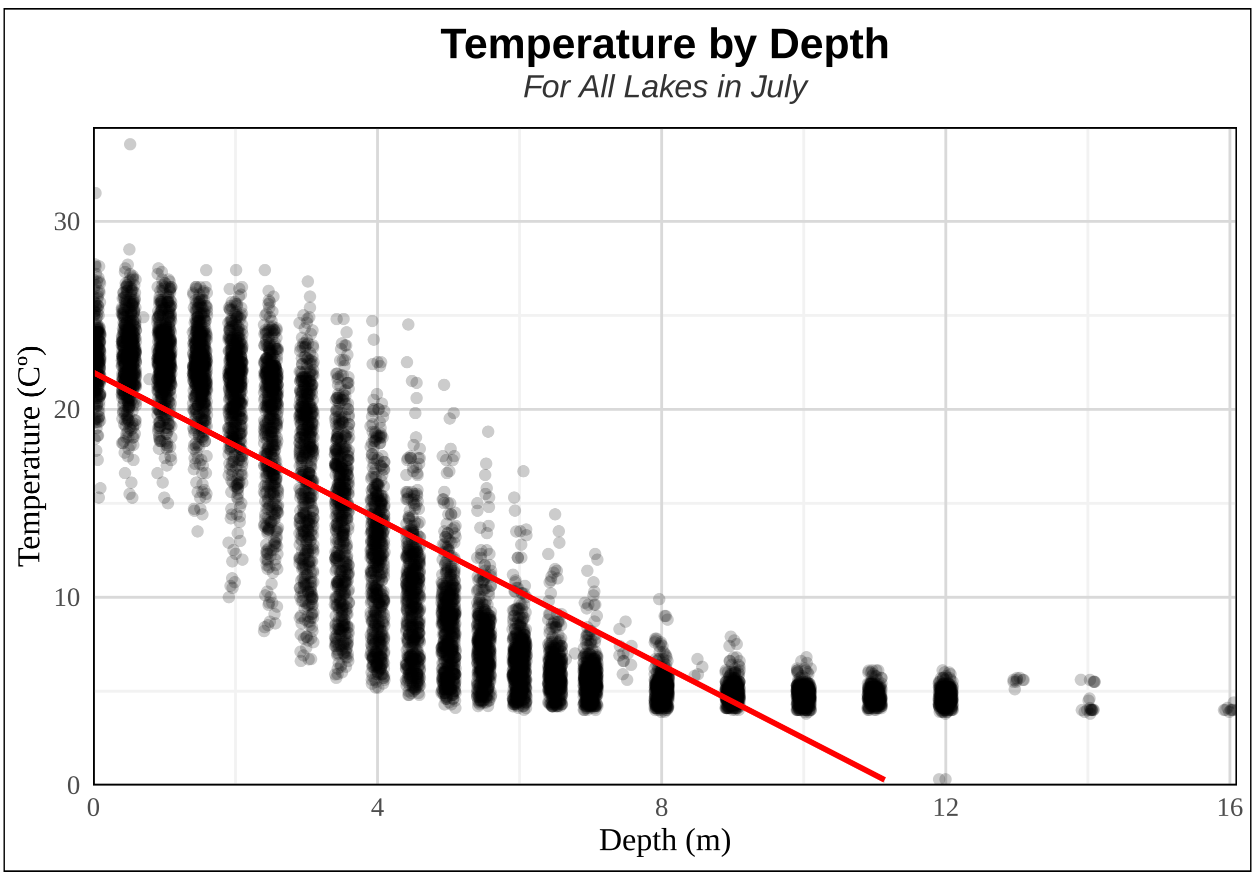
4. Wrangle your NTL-LTER dataset with a pipe function so that the records meet the following criteria:

- Only dates in July.
- Only the columns: `lakename`, `year4`, `daynum`, `depth`, `temperature_C`
- Only complete cases (i.e., remove NAs)

5. Visualize the relationship among the two continuous variables with a scatter plot of temperature by depth. Add a smoothed line showing the linear model, and limit temperature values from 0 to 35 °C. Make this plot look pretty and easy to read.

```
#4
lake_chemphys_july<-lake_chemphys%>% #initiate pipe
  filter(format(sampledate,"%m")=="07")%>% #filtering using the sampledate column for July
  select(lakename,year4,daynum,depth,temperature_C)%>% #selecting columns
  drop_na() #removes the NA values

#5
ggplot(lake_chemphys_july,aes(x=depth,y=temperature_C))+
  geom_jitter(alpha=0.2)+ #jitter used and points made partially transparent for visual clarity
  geom_smooth(method="lm",color="red")+ #line color changed for clarity
  scale_x_continuous(limits=c(0,NA),expand=c(0,0))+ #calling expand to justify 0,0 coordinate
  scale_y_continuous(limits=c(0,35),expand=c(0,0))+ #setting y-limits
  labs(title="Temperature by Depth",
       subtitle="For All Lakes in July",
       x="Depth (m)",
       y="Temperature (Cº)") #adding labels
```



6. Interpret the figure. What does it suggest with regards to the response of temperature to depth? Do the distribution of points suggest about anything about the linearity of this trend?

Answer: The figure suggests that as depth increaes, temperature will decrease. The distribution of points does not appear to be truly linear. The bulk of the data follows an reverse-S curve and appears to hit an asymptote around 5ºC.

7. Perform a linear regression to test the relationship and display the results.

```r
#7
tempdepth_regression<-lm(data=lake_chemphys_july,temperature_C~depth) #setting linear regression

summary(tempdepth_regression) #displaying results
```

```
##
## Call:
## lm(formula = temperature_C ~ depth, data = lake_chemphys_july)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -9.5173 -3.0192  0.0633  2.9365 13.5834
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 21.95597    0.06792   323.3   <2e-16 ***
## depth       -1.94621    0.01174  -165.8   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.835 on 9726 degrees of freedom
## Multiple R-squared:  0.7387, Adjusted R-squared:  0.7387
## F-statistic: 2.75e+04 on 1 and 9726 DF,  p-value: < 2.2e-16
```

8. Interpret your model results in words. Include how much of the variability in temperature is explained by changes in depth, the degrees of freedom on which this finding is based, and the statistical significance of the result. Also mention how much temperature is predicted to change for every 1m change in depth.

   Answer: The intercept of the model is at 21.96ºC, suggesting that at a depth of 0 meters the average temperature is predicted to be 21.96ºC. The coefficient for depth is -1.95 which suggests that for every 1-meter increase in depth, temperature will decrease by approximately 1.95ºC. Both of these values (the intercept and slope) have a p-value less than 2e-16 and are therefore highlighy statistically signifanct at the $p<0.001$ level. The model has an R-squared value of 0.7387 which suggests that 73.87% of the variance in temperature can be explained by variance in depth. The model rests on 9726 degrees of freedom with a residual standard error of 3.835, meaning that the observed temperature deviates from the model's prediction by an average of 3.835ºC.

Multiple regression

Let's tackle a similar question from a different approach. Here, we want to explore what might the best set of predictors for lake temperature in July across the monitoring period at the North Temperate Lakes LTER.

9. Run an AIC to determine what set of explanatory variables (year4, daynum, depth) is best suited to predict temperature.

10. Run a multiple regression on the recommended set of variables.

```r
#9
temp_aic<-lm(data=lake_chemphys_july,temperature_C~year4+daynum+depth) #setting aic
summary(temp_aic) #displaying results for analysis
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = lake_chemphys_july)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -9.6536 -3.0000  0.0902  2.9658 13.6123
##
## Coefficients:
##              Estimate Std. Error  t value Pr(>|t|)
## (Intercept) -8.575564   8.630715   -0.994  0.32044
## year4        0.011345   0.004299    2.639  0.00833 **
## daynum       0.039780   0.004317    9.215  < 2e-16 ***
## depth       -1.946437   0.011683 -166.611  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.817 on 9724 degrees of freedom
## Multiple R-squared:  0.7412, Adjusted R-squared:  0.7411
## F-statistic:  9283 on 3 and 9724 DF,  p-value: < 2.2e-16
```

```r
step(temp_aic) #running step function for analysis
```

```
## Start:  AIC=26065.53
## temperature_C ~ year4 + daynum + depth
##
##          Df Sum of Sq    RSS   AIC
## <none>                141687 26066
## - year4   1       101 141788 26070
## - daynum  1      1237 142924 26148
## - depth   1    404475 546161 39189
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = lake_chemphys_july)
##
## Coefficients:
## (Intercept)        year4       daynum        depth
##    -8.57556      0.01134      0.03978     -1.94644
```

```r
#10
temp_multiregression<-lm(data=lake_chemphys_july,temperature_C~daynum+depth) #new regression model
summary(temp_multiregression) #displaying results for analysis
```

```
##
## Call:
## lm(formula = temperature_C ~ daynum + depth, data = lake_chemphys_july)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -9.6174 -2.9809  0.0845  2.9681 13.4406
##
## Coefficients:
##              Estimate Std. Error  t value Pr(>|t|)
## (Intercept) 14.088588   0.855505   16.468   <2e-16 ***
## daynum       0.039836   0.004318    9.225   <2e-16 ***
## depth       -1.946111   0.011685 -166.541   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.818 on 9725 degrees of freedom
## Multiple R-squared:  0.741,  Adjusted R-squared:  0.741
## F-statistic: 1.391e+04 on 2 and 9725 DF,  p-value: < 2.2e-16
```

11. What is the final set of explanatory variables that the AIC method suggests we use to predict temperature in our multiple regression? How much of the observed variance does this model explain? Is this an improvement over the model using only depth as the explanatory variable?

    Answer: The AIC suggests the final set of predictor variables in the multiple regression should be daynum and depth. year4 had the lowest significance of the three tested variables, falling under only the 0.01 level as opposed tothe 0.001 level of significance. Removing the year4 variable increased the AIC only slightly from 26066 to 26070, indicating that it has a minimal effect on model fit, while removing daynum or depth results in much larger increases in AIC value. year4 also had the smallest coefficient by absolute value, indicating it had the weakest relationship of the three variables tested. The final multiple regression model explains 74.1% of the observed variance in temperature data. This is a slight improvement over the linear regression model that only explained 73.87% of the variance in temperature.

Analysis of Variance

12. Now we want to see whether the different lakes have, on average, different temperatures in the month of July. Run an ANOVA test to complete this analysis. (No need to test assumptions of normality or similar variances.) Create two sets of models: one expressed as an ANOVA models and another expressed as a linear model (as done in our lessons).

```r
#12
lake_anova<-aov(data=lake_chemphys_july,temperature_C~lakename) #run ANOVA
summary(lake_anova) #displaying results for analysis
```

```
##               Df Sum Sq Mean Sq F value Pr(>F)
## lakename       8  21642  2705.2      50 <2e-16 ***
## Residuals   9719 525813    54.1
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
lake_regression<-lm(data=lake_chemphys_july,temperature_C~lakename) #run linear model
summary(lake_regression) #displaying results for analysis
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = lake_chemphys_july)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -10.769  -6.614  -2.679   7.684  23.832
##
## Coefficients:
##                            Estimate Std. Error t value Pr(>|t|)
## (Intercept)                 17.6664     0.6501  27.174  < 2e-16 ***
## lakenameCrampton Lake       -2.3145     0.7699  -3.006 0.002653 **
## lakenameEast Long Lake      -7.3987     0.6918 -10.695  < 2e-16 ***
## lakenameHummingbird Lake    -6.8931     0.9429  -7.311 2.87e-13 ***
## lakenamePaul Lake           -3.8522     0.6656  -5.788 7.36e-09 ***
## lakenamePeter Lake          -4.3501     0.6645  -6.547 6.17e-11 ***
## lakenameTuesday Lake        -6.5972     0.6769  -9.746  < 2e-16 ***
## lakenameWard Lake           -3.2078     0.9429  -3.402 0.000672 ***
## lakenameWest Long Lake      -6.0878     0.6895  -8.829  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 7.355 on 9719 degrees of freedom
## Multiple R-squared:  0.03953,    Adjusted R-squared:  0.03874
## F-statistic:    50 on 8 and 9719 DF,  p-value: < 2.2e-16
```

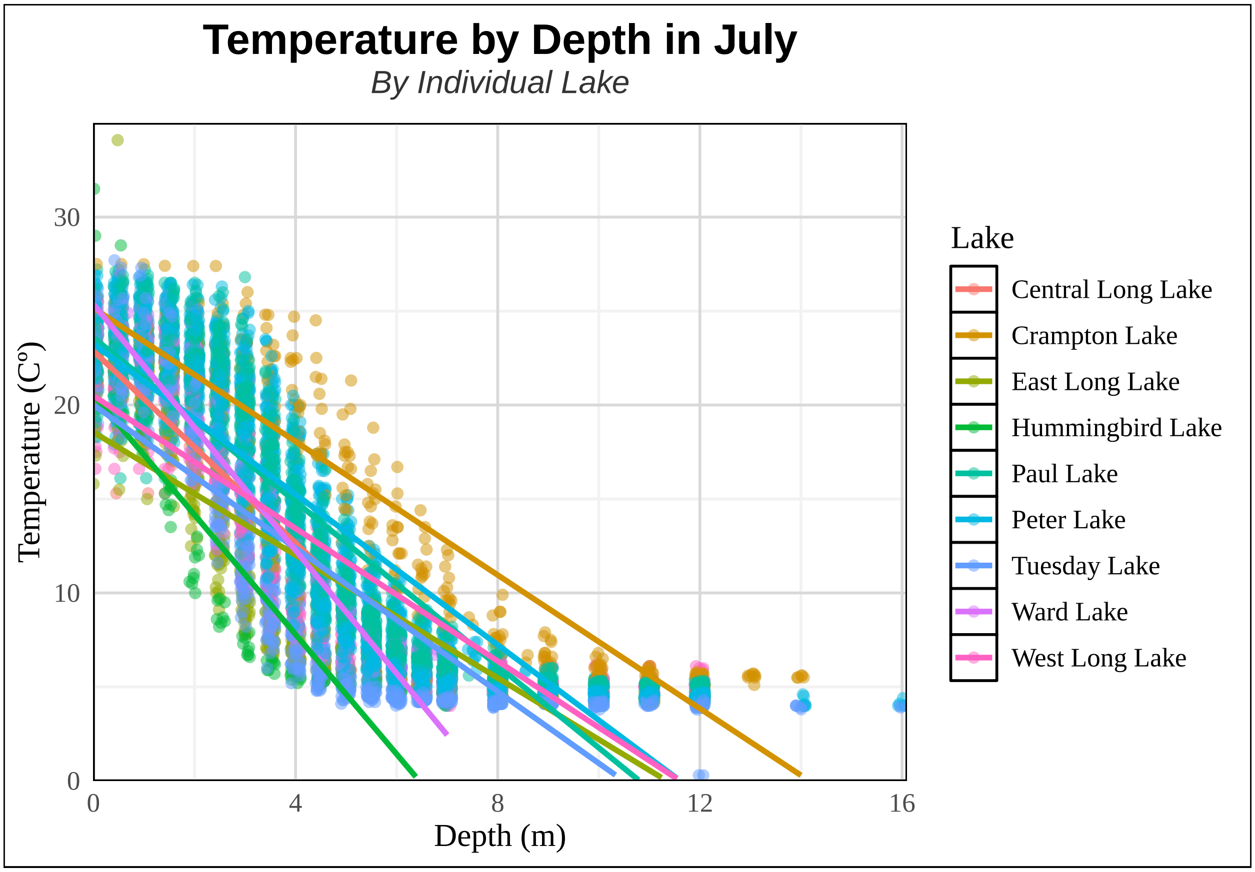
13. Is there a significant difference in mean temperature among the lakes? Report your findings.

    Answer: The anova resulted in a small p-value (<2e-16) that fell into the significance category of less than 0.001, indicating a significant difference in mean temperature among the lakes. The F-value of 50 and 8 and 9719 degrees of freedom also suggests that there is a significant difference – that differences are not due to random chance. The linear model generated coefficient estimates for each lake relative to the reference lake, all of which were found to have a significance factors less than 0.001, with the exception of Crampton Lake which was just shy of reaching the 0.001 level of significance. These various coefficient values wiht highly significant results suggest that there is a significant difference in mean temperature among the lakes.

14. Create a graph that depicts temperature by depth, with a separate color for each lake. Add a geom_smooth (method = "lm", se = FALSE) for each lake. Make your points 50 % transparent. Adjust your y axis limits to go from 0 to 35 degrees. Clean up your graph to make it pretty.

```r
#14.
ggplot(lake_chemphys_july,aes(x=depth,y=temperature_C,color=lakename))+
  geom_jitter(alpha=0.5)+ #jitter used and points made partially transparent for visual clarity
  geom_smooth(method="lm",se=F)+
  scale_x_continuous(limits=c(0,NA),expand=c(0,0))+ #calling expand to justify 0,0 coordinate
  scale_y_continuous(limits=c(0,35),expand=c(0,0))+ #setting y-limits
  labs(title="Temperature by Depth in July",
       subtitle="By Individual Lake",
```

```
       x="Depth (m)",
       y="Temperature (Cº)",
       color="Lake") #adding labels
```



15. Use the Tukey's HSD test to determine which lakes have different means.

```
#15
lake_tukey<-TukeyHSD(lake_anova) #running Tukey test
print(lake_tukey) #displaying results for analysis
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = temperature_C ~ lakename, data = lake_chemphys_july)
##
## $lakename
##                                          diff        lwr        upr     p adj
## Crampton Lake-Central Long Lake    -2.3145195 -4.7031913  0.0741524 0.0661566
## East Long Lake-Central Long Lake   -7.3987410 -9.5449411 -5.2525408 0.0000000
## Hummingbird Lake-Central Long Lake -6.8931304 -9.8184178 -3.9678430 0.0000000
## Paul Lake-Central Long Lake        -3.8521506 -5.9170942 -1.7872070 0.0000003
## Peter Lake-Central Long Lake       -4.3501458 -6.4115874 -2.2887042 0.0000000
## Tuesday Lake-Central Long Lake     -6.5971805 -8.6971605 -4.4972005 0.0000000
## Ward Lake-Central Long Lake        -3.2077856 -6.1330730 -0.2824982 0.0193405
```

```
## West Long Lake-Central Long Lake   -6.0877513 -8.2268550 -3.9486475 0.0000000
## East Long Lake-Crampton Lake       -5.0842215 -6.5591700 -3.6092730 0.0000000
## Hummingbird Lake-Crampton Lake     -4.5786109 -7.0538088 -2.1034131 0.0000004
## Paul Lake-Crampton Lake            -1.5376312 -2.8916215 -0.1836408 0.0127491
## Peter Lake-Crampton Lake           -2.0356263 -3.3842699 -0.6869828 0.0000999
## Tuesday Lake-Crampton Lake         -4.2826611 -5.6895065 -2.8758157 0.0000000
## Ward Lake-Crampton Lake            -0.8932661 -3.3684639  1.5819317 0.9714459
## West Long Lake-Crampton Lake       -3.7732318 -5.2378351 -2.3086285 0.0000000
## Hummingbird Lake-East Long Lake     0.5056106 -1.7364925  2.7477137 0.9988050
## Paul Lake-East Long Lake            3.5465903  2.6900206  4.4031601 0.0000000
## Peter Lake-East Long Lake           3.0485952  2.2005025  3.8966879 0.0000000
## Tuesday Lake-East Long Lake         0.8015604 -0.1363286  1.7394495 0.1657485
## Ward Lake-East Long Lake            4.1909554  1.9488523  6.4330585 0.0000002
## West Long Lake-East Long Lake       1.3109897  0.2885003  2.3334791 0.0022805
## Paul Lake-Hummingbird Lake          3.0409798  0.8765299  5.2054296 0.0004495
## Peter Lake-Hummingbird Lake         2.5429846  0.3818755  4.7040937 0.0080666
## Tuesday Lake-Hummingbird Lake       0.2959499 -1.9019508  2.4938505 0.9999752
## Ward Lake-Hummingbird Lake          3.6853448  0.6889874  6.6817022 0.0043297
## West Long Lake-Hummingbird Lake     0.8053791 -1.4299320  3.0406903 0.9717297
## Peter Lake-Paul Lake               -0.4979952 -1.1120620  0.1160717 0.2241586
## Tuesday Lake-Paul Lake             -2.7450299 -3.4781416 -2.0119182 0.0000000
## Ward Lake-Paul Lake                 0.6443651 -1.5200848  2.8088149 0.9916978
## West Long Lake-Paul Lake           -2.2356007 -3.0742314 -1.3969699 0.0000000
## Tuesday Lake-Peter Lake            -2.2470347 -2.9702236 -1.5238458 0.0000000
## Ward Lake-Peter Lake                1.1423602 -1.0187489  3.3034693 0.7827037
## West Long Lake-Peter Lake          -1.7376055 -2.5675759 -0.9076350 0.0000000
## Ward Lake-Tuesday Lake              3.3893950  1.1914943  5.5872956 0.0000609
## West Long Lake-Tuesday Lake         0.5094292 -0.4121051  1.4309636 0.7374387
## West Long Lake-Ward Lake           -2.8799657 -5.1152769 -0.6446546 0.0021080
```

16.From the findings above, which lakes have the same mean temperature, statistically speaking, as Peter Lake? Does any lake have a mean temperature that is statistically distinct from all the other lakes?

> Answer: To accept the null hypothesis (that there is no difference in mean temperature between lakes), the p-value must be greater than 0.05. There are two lakes where the Tukey test resulted in a p-value greater than 0.05 when compared to Peter Lake. The Paul Lake and Peter Lake (p-value = 0.2241586) and Ward Lake and Peter Lake (p = 0.7827037) both had high p-values, indicating a low statistical difference in the mean temperature - i.e. the same mean temperature statistically speaking. No lake is statistically distinct from all other lakes.

17. If we were just looking at Peter Lake and Paul Lake. What's another test we might explore to see whether they have distinct mean temperatures?

> Answer: Another test to explore would be the two-sample t-test to determine statistical difference in mean temperature. However, the t-test assumes that the data for each lake will be normally distributed, which might not be true.

18. Wrangle the July data to include only records for Crampton Lake and Ward Lake. Run the two-sample T-test on these data to determine whether their July temperature are same or different. What does the test say? Are the mean temperatures for the lakes equal? Does that match you answer for part 16?

```r
crampton_ward_july<-lake_chemphys_july%>%
  filter(lakename%in%c("Crampton Lake","Ward Lake")) #filter to two lakes of interest

crampton_ward_t_test<-t.test(data=crampton_ward_july,temperature_C~lakename) #run t-test
print(crampton_ward_t_test) #displaying results for analysis
```

```
##
##  Welch Two Sample t-test
##
## data:  temperature_C by lakename
## t = 1.1181, df = 200.37, p-value = 0.2649
## alternative hypothesis: true difference in means between group Crampton Lake and group Ward Lake is n
## 95 percent confidence interval:
##  -0.6821129  2.4686451
## sample estimates:
## mean in group Crampton Lake     mean in group Ward Lake
##                    15.35189                    14.45862
```

> Answer: Since the p-value returned by the t-test (0.2649) is greater than 0.05, we fail to reject the null hypothesis and conclude that there is no difference in mean temperature between Crampton and Ward Lakes in July. The confidence interval of the true difference ranges from -0.6821129 to 2.4686451, a range that includes zero. This means that zero is a plausible value for the true difference in mean temperature, so we cannot confidently say there is a difference in mean temperature (difference in sample means could be due to random sampling variation rather than true difference) and statistically find that the mean temperature for the lakes are equal (accepting the null hypothesis that there is no difference in mean temperature). These results do match my answer in part 16. Part 16 identified Peter and Paul Lakes as a pair that do not have a statistically significant difference in mean temperature, which my t-test concurred with.