Assignment 6: 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>_A06_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

#checking working directory
getwd()
```

```
## [1] "C:/Users/nadia/Documents/Duke_/EDA-Spring2023"
```

```
#loading necessary packages
library(tidyverse); library(lubridate); library(here); library(agricolae); library(ggsci)

#loading in NTL-LTER raw data files for chemistry/physics
Lake_Nutrients <- read.csv("./Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv",
↪  stringsAsFactors = TRUE)

#changing date columns to date format
Lake_Nutrients$sampledate <- mdy(Lake_Nutrients$sampledate)

#2
```

```
nadia_theme <- theme_classic() +
  theme(
    axis.title = element_text(color = "pink3", #making axis titles pink
                              family = "sans",#making axis titles 'sans' font
                              face = 'bold', #making axis titles bold
                              size = 14), #making axis titles larger (size 14)
    plot.title = element_text(color = "pink3", #making plot title pink
                              family = "sans", #making plot title 'sans' font
                              hjust = 0.5, #making plot title centered
                              face = 'bold', #making plot title bold
                              size = 16), #making plot title size 16

    panel.background = element_rect(fill = 'whitesmoke'), #making panel background off
    ↪  white
    plot.background = element_rect(fill = "whitesmoke", #making plot background off white
                                   color = "pink2"), #making plot background outline pink
    axis.line.x.bottom = element_line(linewidth = 1, #making bottom axis line thinner
                                      color='pink2'), #making bottom axis pink
    axis.line.y.left = element_line(linewidth = 1, #making left axis line thinner
                                    color='pink2'), #making left axis pink
    axis.ticks = element_line(color = 'pink3', #making axis tick marks pink
                              linewidth = 1), #making axis tick marks size 1
    axis.text = element_text(color='pink3', #making axis labels pink
                             face = 'bold'), #making axis labels bold

    panel.grid.major = element_line(linetype = 2, #adding grid lines and making them
    ↪  dashed
                                    linewidth = 1, #making grid lines size 1
                                    color="pink2"), #making grid lines pink

    legend.background = element_rect(fill = 'whitesmoke', #making the legend background
    ↪  off white
                                     color='pink2'), #making the legend outline pink
    legend.text = element_text(family = 'sans', #making the legend text 'sans' font
                               size = 12, #making the legend text size 12
                               color = "pink3", #making the legend text pink
                               face='bold'), #making the legend text bold
    legend.title = element_text(color="pink3", #making the legend title pink
                                face="bold", #making the legend title bold
                                size=14, #making the legend title size 14
                                family ='sans'), #making the legend title 'sans' font
    legend.position = 'bottom' #putting the legend on the bottom of the plot
    )

theme_set(nadia_theme) #setting my theme as the default theme
```

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: mu_1 = mu_2 = mu_n (The mean lake temperature during July does not change with depth across all lakes) Ha: mu_1 != mu_2 != mu_n (The mean lake temperature during July does change with depth across all lakes)

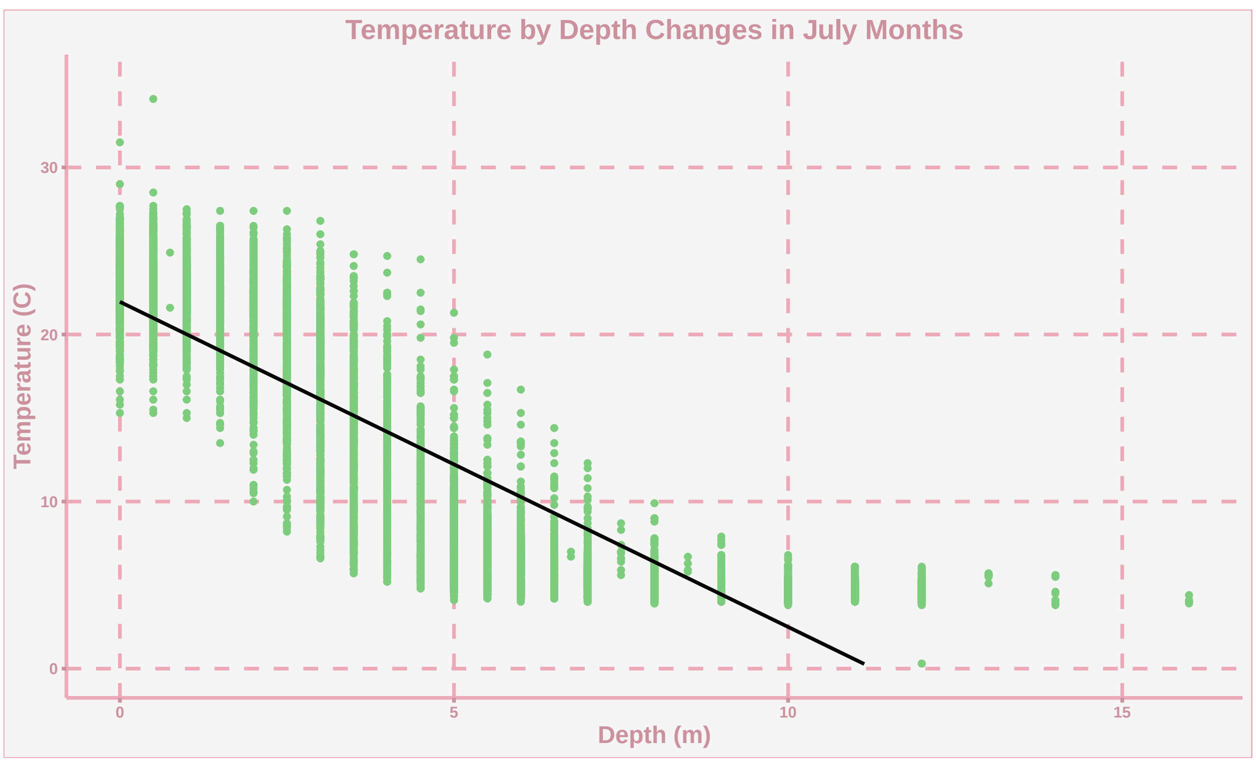
4. Wrangle your NTL-LTER dataset with a pipe function so that the records meet the following criteria:

- 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_Nutrients_processed <-  Lake_Nutrients %>% #creating processed data frame
  filter(month(sampledate) == "7") %>% #filtering for only samples in July
  select(lakename, year4, daynum, depth, temperature_C) %>% #selecting only the columns
  ↪  we want
  drop_na() #dropping NAs

#5
ggplot(Lake_Nutrients_processed, aes(x=depth, y=temperature_C)) + #setting variables to
↪  plot
  geom_point(color='palegreen3') + #make scatterplot with green points
  geom_smooth(method="lm", color='black', se=FALSE) + #adding best fit line
  ylim(0,35) + #limiting temperature values to 0-35
  labs(x="Depth (m)", #adding x label
       y="Temperature (C)", #adding y label
       title="Temperature by Depth Changes in July Months") #adding title
```



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 the depth increases, the temperature decreases. This does not look like a linear relatioship - it looks more like an exponential decrease in temperature as depth increases.

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

```
# 7
Temperature.regression <- lm(Lake_Nutrients_processed$temperature_C ~
↪  Lake_Nutrients_processed$depth)  #performing linear regression
summary(Temperature.regression)  #show summary of linear regression
```

```
##
## Call:
## lm(formula = Lake_Nutrients_processed$temperature_C ~ Lake_Nutrients_processed$depth)
##
## 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 ***
## Lake_Nutrients_processed$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 relationship between decreasing temperatures and increasing depths was found to be statistically significant (p value < 2e-16). About 73.87% of the variability in temperature is explained by changes in depth (given by the R-squared value). These findings are based on 9726 degrees of freedom. According to the linear regression, temperature is predicted to decrease by 1.95 degrees Celcius for every 1m change in depth.

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
Temperature_AIC <- lm(data = Lake_Nutrients_processed, temperature_C ~ year4 + daynum +
    depth)  #running linear multiple regression using 3 designated explanatory variables
step(Temperature_AIC)  #using step function to determine which variables are best suited
↪  to predict temperature
```

```
## 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_Nutrients_processed)
##
## Coefficients:
## (Intercept)        year4       daynum        depth
##    -8.57556      0.01134      0.03978     -1.94644
```

```r
# 10
Temperature_model <- lm(data = Lake_Nutrients_processed, temperature_C ~ year4 +
    daynum + depth)  #the step function kept all four variables
summary(Temperature_model)  #summary of best fit model
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = Lake_Nutrients_processed)
##
## 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
```

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 step function/AIC method suggested we keep all three explanatory variables in the multiple regression model to predict temperature: year4, daynum, and depth. This multiple regression model explains 74.11% of the variance, which is slightly more than the linear regression model using only depth as an explanatory variable (73.87%).

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).

```
# 12
Temp_Lake.anova <- aov(data = Lake_Nutrients_processed, temperature_C ~ lakename)
↪  #running ANOVA model
summary(Temp_Lake.anova)  #showing summary of anova model
```

```
##               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
```

```
Temp_Lake.anova2 <- lm(data = Lake_Nutrients_processed, temperature_C ~ lakename)
↪  #running linear regression model
summary(Temp_Lake.anova2)  #showing summary of linear regression model
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = Lake_Nutrients_processed)
##
## 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 ***
```

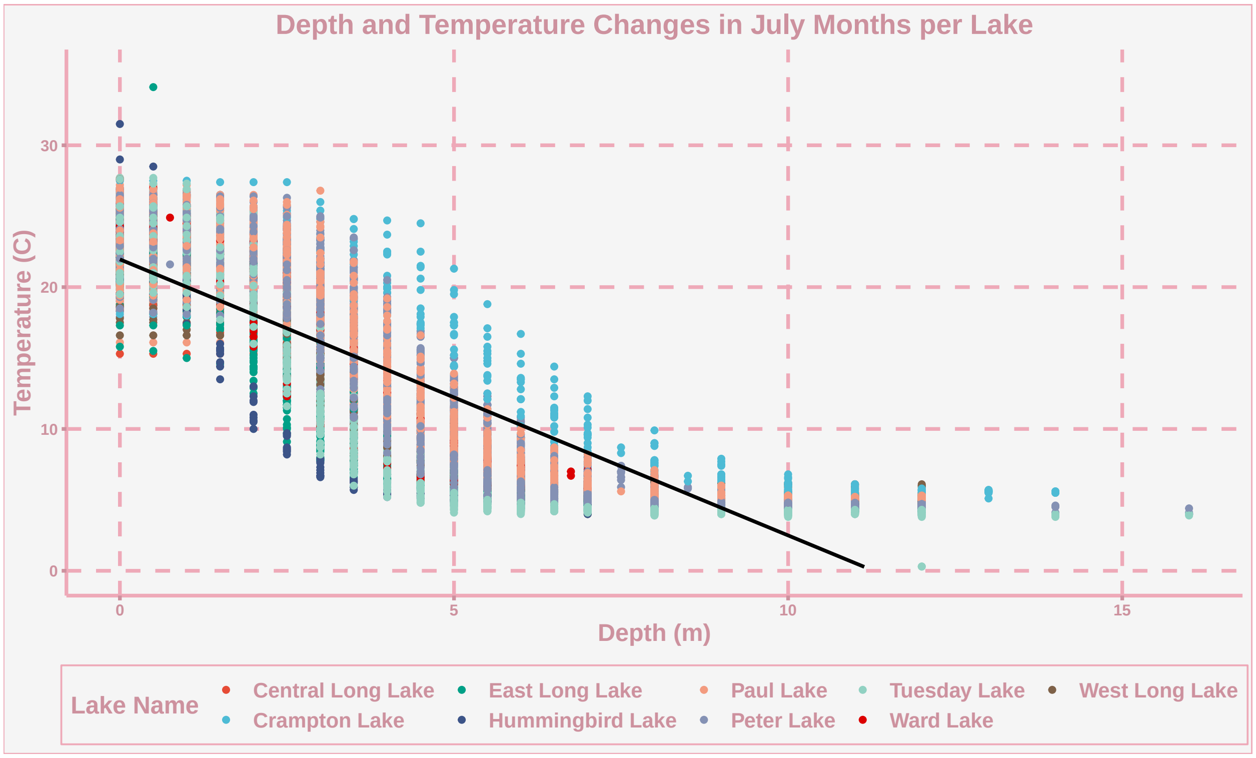
```
## lakenameWest Long Lake    -6.0878     0.6895  -8.829  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 7.355 on 9719 degrees of freedom
## Multiple R-squared:  0.03953,    Adjusted R-squared:  0.03874
## F-statistic:    50 on 8 and 9719 DF,  p-value: < 2.2e-16
```

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

    Answer: There is a significant different in mean temperature among the lakes, with a p value < 2e-16. When looking at the significance of individual lakes on temperature, all lakes were highly significant (p values labeled as either *** or **). According to the linear model, 4.87% of temperature variance can be explained by the lakename variable. The linear model also suggests that the following lakes decrease temperature by the corresponding amount for every 1m change in depth: Crampton Lake - decrease of 2.31 degrees, East Long Lake - decrease of 7.40 degrees, Hummingbird Lake - decrease of 6.89 degrees, Paul Lake - decrease of 3.85 degrees, Peter Lake - decrease of 4.35 degrees, Tuesday Lake - decrease of 6.60 degrees, Ward Lake - decrease of 3.21 degrees, and West Long Lake - decrease of 6.09 degrees.

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_Nutrients_processed, aes(x=depth, y=temperature_C, color=lakename)) +
↪  #setting variables to plot (colored by lakename)
  geom_point() + #making scatterplot
  scale_color_npg() + #setting color of points
  geom_smooth(method="lm", color='black', se=FALSE) + #adding line of best fit
  ylim(0,35) + #setting y axis limits
  labs(x="Depth (m)", #naming x axis
       y="Temperature (C)", #naming y axis
       title="Depth and Temperature Changes in July Months per Lake", #adding title
       color="Lake Name") #changing legend title
```



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

```
# 15
TukeyHSD(Temp_Lake.anova)   #running Tukey HSD test
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = temperature_C ~ lakename, data = Lake_Nutrients_processed)
##
## $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
```

```
Temps.groups <- HSD.test(Temp_Lake.anova, "lakename", group = TRUE)  #finding groupings
↪  from Tukey HSD test
Temps.groups  #showing those groupings
```

```
## $statistics
##   MSerror   Df     Mean       CV
##   54.1016 9719 12.72087 57.82135
## 
## $parameters
##    test   name.t ntr StudentizedRange alpha
##   Tukey lakename   9         4.387504  0.05
## 
## $means
##                     temperature_C      std    r Min  Max    Q25   Q50    Q75
## Central Long Lake        17.66641 4.196292  128 8.9 26.8 14.400 18.40 21.000
## Crampton Lake            15.35189 7.244773  318 5.0 27.5  7.525 16.90 22.300
## East Long Lake           10.26767 6.766804  968 4.2 34.1  4.975  6.50 15.925
## Hummingbird Lake         10.77328 7.017845  116 4.0 31.5  5.200  7.00 15.625
## Paul Lake                13.81426 7.296928 2660 4.7 27.7  6.500 12.40 21.400
## Peter Lake               13.31626 7.669758 2872 4.0 27.0  5.600 11.40 21.500
## Tuesday Lake             11.06923 7.698687 1524 0.3 27.7  4.400  6.80 19.400
## Ward Lake                14.45862 7.409079  116 5.7 27.6  7.200 12.55 23.200
## West Long Lake           11.57865 6.980789 1026 4.0 25.7  5.400  8.00 18.800
## 
## $comparison
## NULL
## 
## $groups
##                     temperature_C groups
## Central Long Lake        17.66641      a
## Crampton Lake            15.35189     ab
## Ward Lake                14.45862     bc
```

```
## Paul Lake               13.81426      c
## Peter Lake              13.31626      c
## West Long Lake          11.57865      d
## Tuesday Lake            11.06923     de
## Hummingbird Lake        10.77328     de
## East Long Lake          10.26767      e
##
## attr(,"class")
## [1] "group"
```

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: Paul Lake and Ward Lake have statistically the same mean temperature as Peter Lake. There are no lakes that have a mean temperature that is statistically distict 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: If we were just looking at Peter Lake and Paul Lake, we could also run a two sample t-test to determine if the two lakes have distinct mean temperatures. A two sample t-test uses a continuous response variable (temperature) and one categorical explanatory variable with two categories (lakename - in this case the two categories are Peter Lake and Paul Lake). This two sample t-test will test the mean response variable of the two categories and determine if they are statistically the same or different.

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?

```
#wranging data
Lake_Nutrients_July_CramptonWard <- Lake_Nutrients_processed %>% #creating processed data
↪  frame
  filter(lakename %in% c("Crampton Lake", "Ward Lake")) #filtering for only samples from
  ↪  Crampton Lake and Ward Lake

Temp.twosample <- t.test(Lake_Nutrients_July_CramptonWard$temperature_C ~
↪  Lake_Nutrients_July_CramptonWard$lakename) #running two-sample t-test
Temp.twosample #showing results of t-test
```

```
##
##  Welch Two Sample t-test
##
## data:  Lake_Nutrients_July_CramptonWard$temperature_C by Lake_Nutrients_July_CramptonWard$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: The t-test tells us that we cannot reject the null hypothesis that the mean temperatures of Crampton Lake and Ward Lake are the same. In other words, the mean temperatures within these two lakes are not statistically different from one another (they are statistically equal). We cannot reject the null hypothesis because the p-value from the t-test is 0.2649. This does match the answer for part 16 because Crampton Lake and Ward Lake were both sorted into group b, meaning that their mean temperatures were statistically the same as one another. You can also confirm this because the estimated mean temperatures of the two lakes (given by the t-test) are within the same within the 95% confidence interval.