# Assignment 7: GLMs (Linear Regressions, 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 Install Packages

#install.packages("tidyverse")
#install.packages("agricolae")
#install.packages("lubridate")
#install.packages("cowplot")
#install.packages("viridisLite")


#Load 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(lubridate)
library(agricolae)
library(cowplot)
```

```
##
## Attaching package: 'cowplot'
##
## The following object is masked from 'package:lubridate':
##
##     stamp
```

```r
library(here)
```

```
## here() starts at /home/guest/AU_EDE_Fall2024
```

```r
library(knitr)
library(viridis)
```

```
## Loading required package: viridisLite
```

```r
library(RColorBrewer)
library(colormap)
library(ggthemes)
```

```
##
## Attaching package: 'ggthemes'
##
## The following object is masked from 'package:cowplot':
##
##     theme_map
```

```r
#Check working directory

getwd()
```

```
## [1] "/home/guest/AU_EDE_Fall2024"
```

```r
#Import NTL Lake Data

NTL_Raw <- read.csv(
  here("Data", "Raw","NTL-LTER_Lake_ChemistryPhysics_Raw.csv"),
  stringsAsFactors = TRUE)

#view(NTL_Raw)
```

```r
#2 Create a custom theme
my_theme <- theme_classic() + theme(

#Text Color
  plot.title = element_text(color = "black"),
  axis.title.x = element_text(color = "black"),
  axis.title.y = element_text(color = "black"),
  axis.text = element_text(color = "darkgray"),

#Line Color
  panel.grid.major = element_line(color = "lightgray"),
  panel.grid.minor = element_line(color = "lightgray"),

#Rectangle Element
  panel.background = element_rect(color = "white"),
  legend.key = element_rect(color = "white"),

#Legend Position
  legend.position = 'right',
complete = TRUE)

theme_set(my_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: There is no correlation between mean lake temperature in July and lake depth. Ha: There is a relationship between the variables of mean lake temperature in July and lake depth.

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.

```r
#4 Wrangle Data for July with specific columns and no N/As

NTL_Raw$sampledate <-
  as.Date(NTL_Raw$sampledate, format = "%m/%d/%y")

NTL_Raw <- NTL_Raw %>%
  mutate(month = month(sampledate))

#view(NTL_Raw)
```

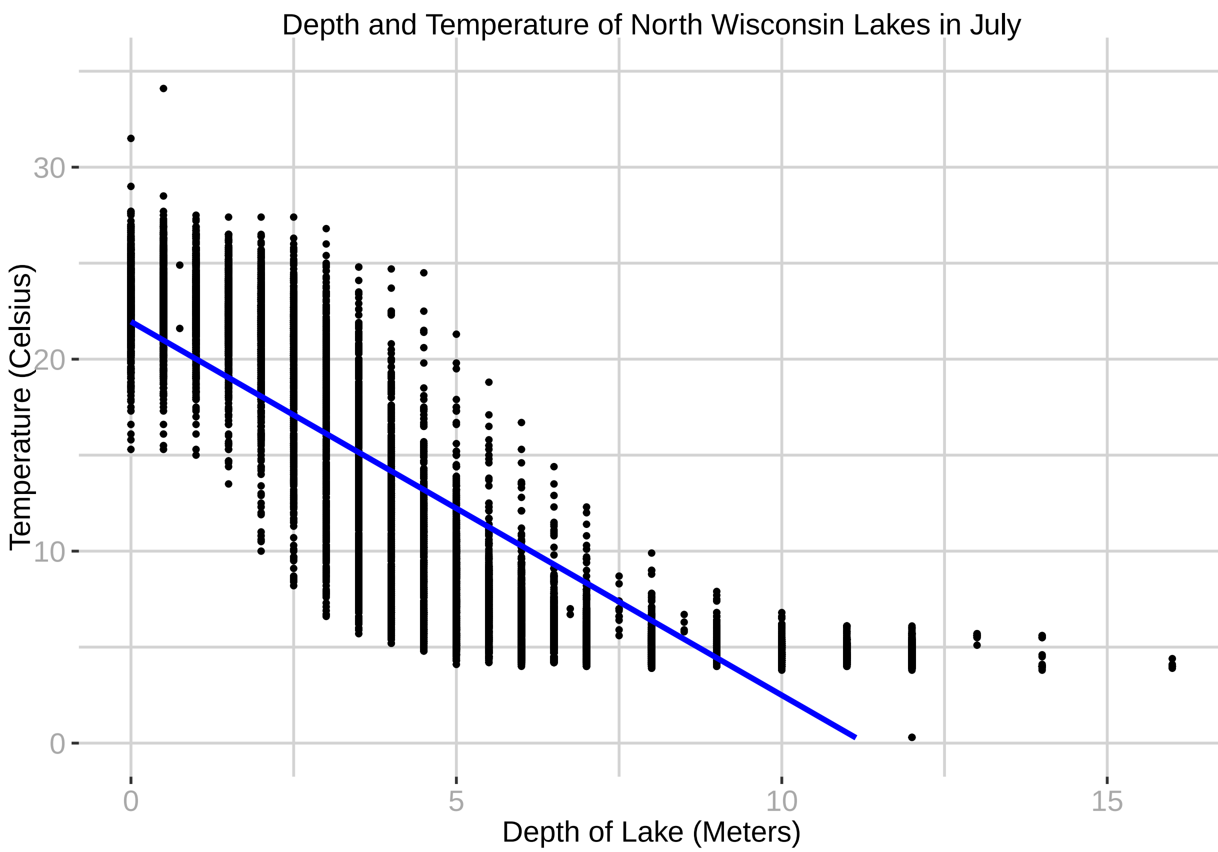
```r
NTL_July <- NTL_Raw %>%
  filter(month == "7") %>%
  select(`lakename`, `year4`, `daynum`,
         `depth`, `temperature_C`) %>%
  drop_na(temperature_C)

#view(NTL_July)

#5 Create scatter plot and linear model

NTL_July_Scatterplot_BW <-
  ggplot(data = NTL_July,
       aes(x = depth,
           y = temperature_C)) +
  geom_point(colour = "black", size = 0.65) +
  labs(
    title = "Depth and Temperature of North Wisconsin Lakes in July",
    x = "Depth of Lake (Meters)",
    y = "Temperature (Celsius)") +
  theme(axis.title.y =
             element_text(angle = 90))  +
  ylim(0, 35) +
  geom_smooth(method = lm,
              se=FALSE, colour="blue")

NTL_July_Scatterplot_BW
```




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 scatterplot showcases a negative correlation between lake depth and temperature. As lake depth increases, the temperature of the water decreases. The scatterplot does not match the linear model perfectly - there appears to be a cluster of data from the depth of 0 to 10 meters. Within this depth, the temperature of the lake ranges from 5 to 25 degrees Celsius. The scatterplot displays deviation from the linear model in this range, indicating that the relationship between lake depth and temperature may not be linear. However, both the scatterplot and linear model indicate a potential negative correlation.

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

```
#7 Linear regression

depth.temp.regression <-
  lm(NTL_July$temperature_C ~
       NTL_July$depth)

summary(depth.temp.regression)
```

```
##
## Call:
## lm(formula = NTL_July$temperature_C ~ NTL_July$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 ***
## NTL_July$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 correlation of these variables is -1.946. The linear model estimates that if the depth of the lake increase by one meter, the temperature will decrease by 1.946 degrees Celsius. The R-squared value is 0.7387. This indicates that 73.87% of the variability in temperature can be explained by changed in the lake depth.

   The degrees of freedom is 9726 on which the findings of the model are based. The degrees of freedom is related to the sample size analyzed in the study.

   The p-value of this linear model is less than 0.05 (estimated at 2.2e-16). The p-value is the probability that the null hypothesis is true. If the p-value is less than 0.05, that means there is less than a 5% probability that the null hypothesis is true. This is a statistically signifcant threshold, and would lead the researchers to reject the null hypothesis. In this case, there is statistical significance that indicates a negative correlation does exist between these two variables. The null hypothesis is rejected because the p-value is less than 0.05.

---

## 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 AIC to determine explanatory variables

TPAIC <- lm(data = NTL_July, temperature_C ~
              year4 + daynum + depth)

step(TPAIC)
```

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

```r
#10 Create a multiple regression model

NTL_July_MultiRegression_Model <-
  lm(data = NTL_July, temperature_C ~
       year4 + daynum + depth)

summary(NTL_July_MultiRegression_Model)
```

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

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 method recommends predicting temperature by using the year, the day number, and the lake depth variables. This suggests using three variables to predict temperature instead of one variable (lake depth). The model with all three variables explains 74.12% of the variability in temperature, shown because the R-squared value is 0.7412. The model which compared only lake depth to temperature had an R-squared value of 0.7387, which means that 73.87% of the variability in temperature could be explained by lake depth. 74.12% is higher than 73.87%, indicating that the model with three variables (depth, day and year) is an improvement over the model with only depth as the explanatory variable. The new model with three variables has a 0.25% increase in the explanatory relationship.

---

## 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 Anova Model

NTL_July.anova.model <- aov(data = NTL_July,
                            temperature_C ~ lakename)

summary(NTL_July.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
```

```
#Anova as Linear Model

NTL_July.anova.lm <- lm(data = NTL_July,
                        temperature_C ~ lakename)

summary(NTL_July.anova.lm)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = NTL_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: There is a statistically significant difference in the mean temperature among the lakes, depicted by the p-value. In the Anova Model, the p-value is 2e-15, which is less than 0.05. This indicates the null hypothesis should be rejected. The null hypothesis is that there is no difference in mean temperature between lakes. Rejecting this hypothesis showcases that there is a statistically significant difference in temperature based on the lake

    The linear model format of the Anova describes each lake's variation from the mean. The p-values from all of the lakes are less than 0.05, which indicates that researchers can reject the null hypothesis. The lakes have a statistically significant difference in mean temperature. The linear model shows that comparing any lake to one other lake has a significantly different mean.

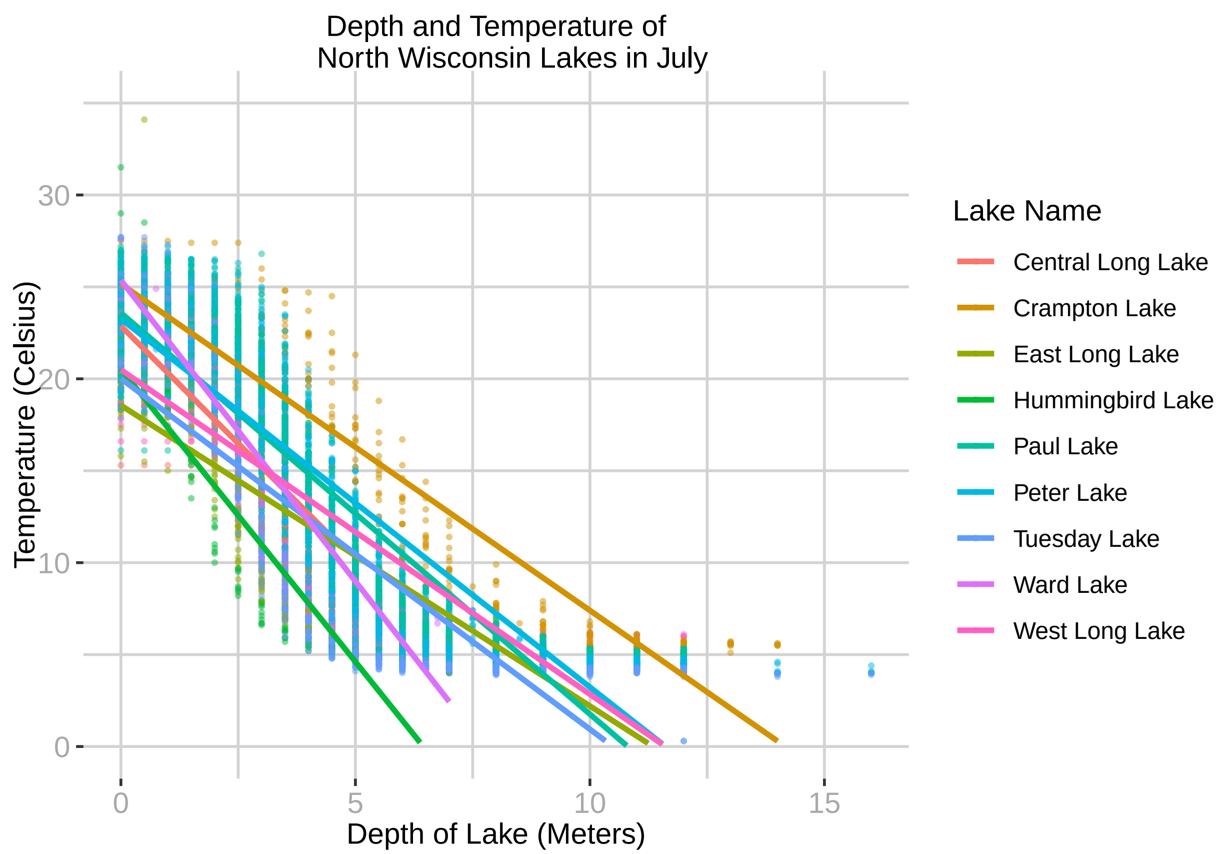
14. Create a graph that depicts temperature by depth, with a separate color for each lake. Add a geom_smooth (method = "lm", se = FALSE) for each lake. Make your points 50 % transparent. Adjust your y axis limits to go from 0 to 35 degrees. Clean up your graph to make it pretty.

```
#14. Graph temperature by depth in each lake

NTL_July_Scatterplot_LakeName <-
  ggplot(data = NTL_July,
       aes(x = depth,
           y = temperature_C,
           color = lakename)) +
  geom_point(size = 0.5, alpha = 0.50) +
  labs(
    title = "Depth and Temperature of
    North Wisconsin Lakes in July",
    x = "Depth of Lake (Meters)",
    y = "Temperature (Celsius)",
    color = "Lake Name") +
  my_theme + theme(axis.title.y =
              element_text(angle = 90)) +
  ylim(0, 35) +
  geom_smooth(method = lm,
```

```r
              se=FALSE)

print(NTL_July_Scatterplot_LakeName)
```




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

```r
#15 Tukey HSD test

TukeyHSD(NTL_July.anova.model)
```

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

```r
HSD_Test_Lakenames <- HSD.test(NTL_July.anova.model, "lakename", group = T)
print(HSD_Test_Lakenames)
```

```
## $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         se Min  Max    Q25   Q50
## Central Long Lake       17.66641 4.196292  128 0.6501298 8.9 26.8 14.400 18.40
## Crampton Lake           15.35189 7.244773  318 0.4124692 5.0 27.5  7.525 16.90
## East Long Lake          10.26767 6.766804  968 0.2364108 4.2 34.1  4.975  6.50
## Hummingbird Lake        10.77328 7.017845  116 0.6829298 4.0 31.5  5.200  7.00
## Paul Lake               13.81426 7.296928 2660 0.1426147 4.7 27.7  6.500 12.40
## Peter Lake              13.31626 7.669758 2872 0.1372501 4.0 27.0  5.600 11.40
## Tuesday Lake            11.06923 7.698687 1524 0.1884137 0.3 27.7  4.400  6.80
## Ward Lake               14.45862 7.409079  116 0.6829298 5.7 27.6  7.200 12.55
## West Long Lake          11.57865 6.980789 1026 0.2296314 4.0 25.7  5.400  8.00
##                       Q75
## Central Long Lake 21.000
```

```
## Crampton Lake     22.300
## East Long Lake    15.925
## Hummingbird Lake  15.625
## Paul Lake         21.400
## Peter Lake        21.500
## Tuesday Lake      19.400
## Ward Lake         23.200
## West Long Lake    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 the same mean level temperature as Peter Lake. The adjusted p-value of the Peter Lake-Paul Lake comparison in the Tukey HSD Test is 0.224, which is above 0.05. This means the null hypothesis (that the temperatures are the same) would not be rejected. Ward Lake-Peter Lake has an adjusted p-value of 0.783, which is also above 0.05. If the null hypothesis is that the mean lake temperatures are the same, then the null hypothesis would not be rejected for Ward Lake either.
>
> None of the lakes have a statistically significant mean temperature from all of the other lakes. Every lake has at least one lake in which the p-adjusted value is above 0.05, which signifies that the average temperature is not statistically different. For example, Central Long Lake has a significantly different mean temperature from all of the lakes except for Crampton Lake, where the p-value is 0.066 (which is greater than 0.05.)

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: For comparing two lakes, the two-sample T test (or two-variable T test) would be able to compare the mean temperatures of Peter Lake and Paul Lake. This test determines if the mean value of two independent subjects are the same or if there is a statistical difference in the average value of the subjects.

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?

```
NTL_July_Crampton_Ward <-
  NTL_July %>%
  filter(lakename == "Crampton Lake" |
           lakename == "Ward Lake")

#Two-sample test
NTL_July_Crampton_Ward.twosample <-
  t.test(NTL_July_Crampton_Ward$temperature_C ~
           NTL_July_Crampton_Ward$lakename)

NTL_July_Crampton_Ward.twosample
```

```
##
##  Welch Two Sample t-test
##
## data:  NTL_July_Crampton_Ward$temperature_C by NTL_July_Crampton_Ward$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: In a two-sample T-test, the null hypothesis states that there is no difference in the means between two groups of data. In other words, the mean of sample one is the same as the mean from sample two. Examining Crampton Lake and Ward Lake, the p-value of the two-sample T-test is 0.2649. This p-value is above 0.05. In this case, the null hypothesis cannot be rejected. There is no statistical significance to suggest that the average temperatures of these lakes are different. Therefore, the mean temperatures of Lake Crampton and Lake Ward are statistically the same.

In the HSD Tukey test, the p-value of comparing Ward Lake with Crampton Lake is 0.9714459. This p-value is above 0.05, which shows that the mean temperature of Ward Lake is not statistically different than the mean temperature of Crampton Lake.