

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
```

```
library(tidyverse)
```

```
## -- Attaching core tidyverse packages ----- tidyverse 2.0.0 --
## v dplyr     1.1.3     v readr     2.1.4
## vforcats   1.0.0     v stringr   1.5.0
## v ggplot2   3.4.3     v tibble    3.2.1
## v lubridate 1.9.3     v tidyverse 1.3.0
## 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
```

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

```
## here() starts at /home/guest/R/EDE_Fall2023
#loaded the necessary packages
here()
```

```
## [1] "/home/guest/R/EDE_Fall2023"
```

```

#checked the working directory

Lter <- read.csv(here("./Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv"),
                 stringsAsFactors = TRUE)
Lter$sampledate <- as.Date(Lter$sampledate, format = "%m/%d/%y")
#imported the raw file and set date columns to date objects

#2
my_theme <- theme_light(base_size = 14) +
  theme(axis.title = element_text(color = "darkgreen"),
        axis.text = element_text(color = "darkgreen"),
        title = element_text(color = "darkgreen"),
        legend.position = "right",
        legend.background = element_rect(fill = "darkgreen"),
        panel.background = element_rect(fill = "lightgrey"),
        panel.grid = element_line(color = "black"))
theme_set(my_theme)
#created theme and set it as default

```

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: Mean lake temperature in July does not change with depth across all lakes. Ha: Mean lake temperature in 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.

```

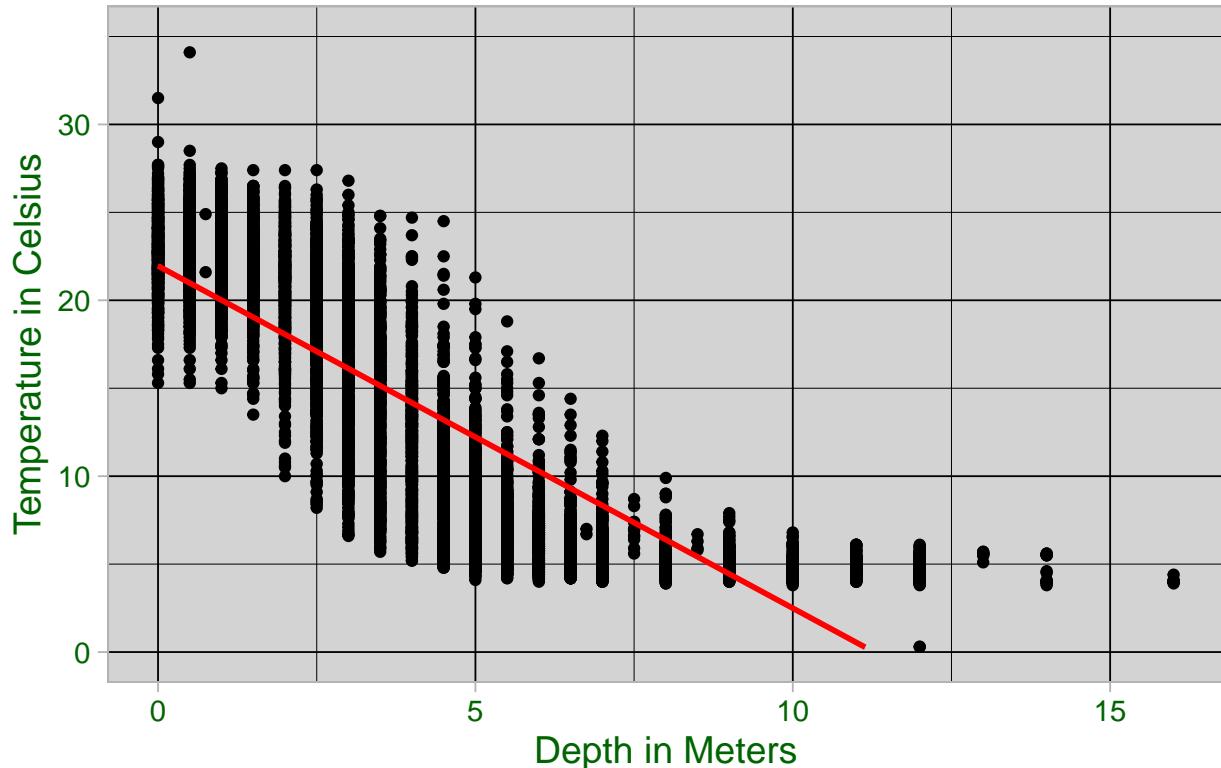
#4
Lter_wr <- Lter %>%
  filter(month(sampledate) == 07) %>% #filtered out dates in July
  select(lakename:daynum, depth, temperature_C) %>% #selected out just the desired columns
  na.omit(Lter) #got rid of any NAs

#5
Lter_tbd <- ggplot(Lter_wr, aes(x = depth, y = temperature_C)) +
  geom_point() +
  ylim(0, 35) +
  geom_smooth(method = "lm", color = "red") +
  labs(x = "Depth in Meters", y = "Temperature in Celsius",
       title = "Temperature by Depth in July")
print(Lter_tbd)

## `geom_smooth()` using formula = 'y ~ x'
## Warning: Removed 24 rows containing missing values (`geom_smooth()`).

```

Temperature by Depth in July



```
#made a scatterplot of temperature by depth and added a linear model line, added ylims
#changed the labels to make it look nicer
```

- 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 temperature decreases as depth increases. The trend does not seem linear because the temperature is distributed fairly wide in lower depths and then plateaus out after 10 meters.

- Perform a linear regression to test the relationship and display the results

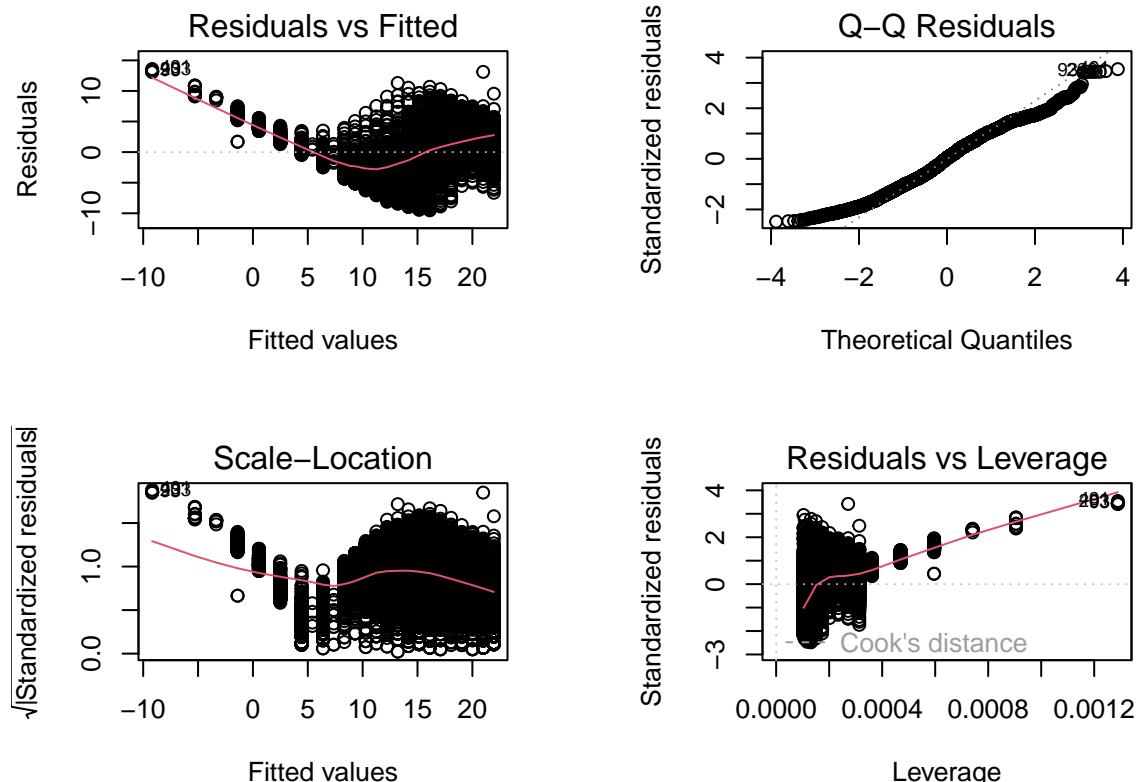
```
#7
Lter_reg <- lm(data = Lter_wr, temperature_C ~ depth) #performed a linear regression
summary(Lter_reg) #checked the summary
```

```
##
## Call:
## lm(formula = temperature_C ~ depth, data = Lter_wr)
##
## 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
par(mfrow = c(2,2), mar = c(4,4,4,4)) #set plot view to show all 4 plots at the same time
plot(Lter_reg) #plotted the regression

```



```
par(mfrow = c(1,1)) #reset the plot view
```

- 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 r-squared value is 0.7387 meaning that there is a strong correlation and that roughly 73.9% of the variability in temperature is explained by changes in depth. The degrees of freedom is 9726. The p-value is 2.2e-16 meaning it is statistically significant and we can reject the null hypothesis. For every 1 meter of depth, the temperature is expected to change by -1.946.

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.

- 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.

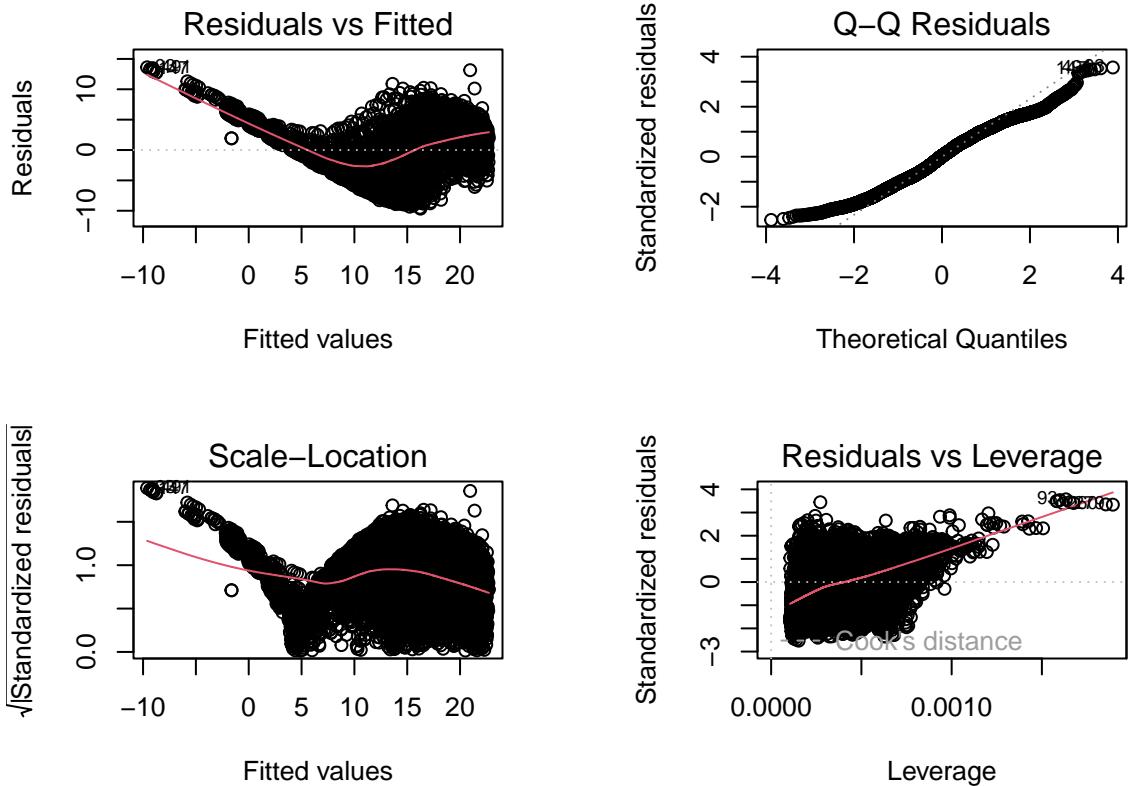
```
#9
TAIC <- lm(data = Lter_wr, temperature_C ~ year4 + daynum + depth) #performed linear regression
step(TAIC) #conducted stepwise regression

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

#10
Treg <- lm(data = Lter_wr, temperature_C ~ year4 + daynum + depth)
#ran multiple regression for the recommended set of variables
summary(Treg)

##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = Lter_wr)
##
## 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
par(mfrow = c(2,2), mar = c(4,4,4,4))
plot(Treg)
```



```
par(mfrow = c(1,1))
#plotted the regression
```

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 suggested the use of the variables, year4, daynum, and depth. The r-squared increased to 0.7411 meaning that 74% of the observed variance is explained by the variables. This improved from the previous model but not by much.

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
Lter_anova <- aov(data = Lter_wr, temperature_C ~ lakename)
summary(Lter_anova)
```

```
##              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
Lter_anova2 <- lm(data = Lter_wr, temperature_C ~ lakename)
summary(Lter_anova2)

##
## Call:
## lm(formula = temperature_C ~ lakename, data = Lter_wr)
##
## 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 p-value is $<2.2\text{e-}16$ meaning there is a significant difference in mean temperature among the lakes and we would reject the null hypothesis. The different lakes on average have different temperatures in the month of July.

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.

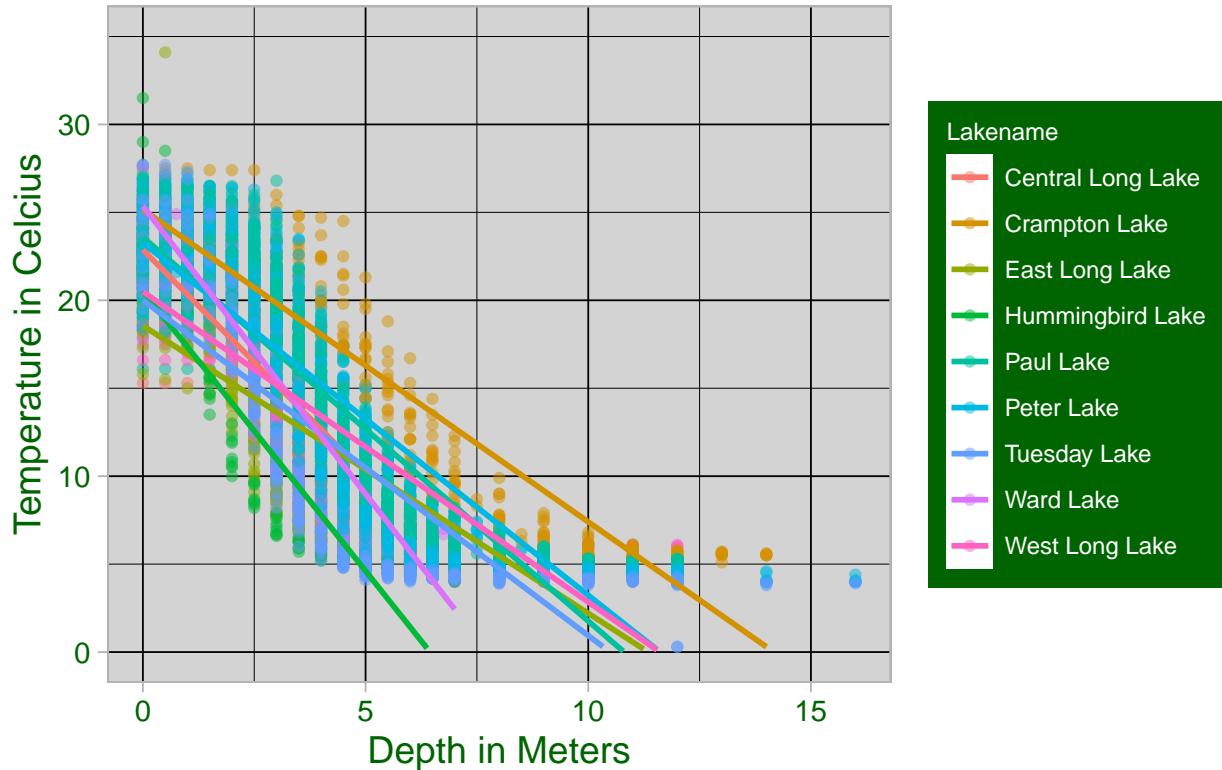
```

#14.
ggplot(Lter_wr, aes(x=depth, y=temperature_C, color = lakename)) +
  geom_point(alpha = 0.5) +
  geom_smooth(method = "lm", se = FALSE) +
  ylim(0,35) +
  labs(x = "Depth in Meters", y = "Temperature in Celcius", color = "Lakename",
       title = "Lake Temperature v Depth in July") +
  theme(legend.text = element_text(color = "white", size = 9),
        legend.title = element_text(color = "white", size = 9))

## `geom_smooth()` using formula = 'y ~ x'
## Warning: Removed 73 rows containing missing values (`geom_smooth()`).

```

Lake Temperature v Depth in July



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

#15

```
TukeyHSD(Lter_anova) #computed Tukey HSD
```

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

```

```
Lter_anova_group <- HSD.test(Lter_anova, "lakename", group = TRUE)
```

```
#extracted groupings for pairwise relationships
```

```
Lter_anova_group
```

```

## $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 was the only lake that had statistically same means as Peter Lake. Central Long Lake's mean was statistically distinct from all the 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: We would do a two sample t-test.

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 your answer for part 16?

```

Lter_wr2 <- filter(Lter_wr, lakename == "Crampton Lake" | lakename == "Ward Lake")  

#filtered out only records for crampton lake and ward lake.  

Lter_2sample <- t.test(Lter_wr2$temperature_C ~ Lter_wr2$lakename) #conducted two sample t-test  

Lter_2sample

```

```

##  

##  Welch Two Sample t-test  

##  

## data: Lter_wr2$temperature_C by Lter_wr2$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 not equal to 0  

## 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 p-value is 0.2649 meaning we would not reject the null hypothesis and the July temperatures are the same. This does match the results from question 16.