Assignment 6: GLMs (Linear Regressios, ANOVA, & t-tests)

Susanna Jenkins

Spring 2023

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
library(lubridate)
```

```
## Loading required package: timechange
```

```
##
## Attaching package: 'lubridate'
```

```
## The following objects are masked from 'package:base':
##
##     date, intersect, setdiff, union
```

```
library(tidyverse)
```

```
## -- Attaching packages --------------------------------------- tidyverse 1.3.2 --
```

```
## v ggplot2 3.4.0     v purrr   1.0.0
## v tibble  3.1.8     v dplyr   1.1.0
## v tidyr   1.2.1     v stringr 1.5.0
## v readr   2.1.3     v forcats 0.5.2
## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x lubridate::as.difftime() masks base::as.difftime()
## x lubridate::date()        masks base::date()
## x dplyr::filter()          masks stats::filter()
## x lubridate::intersect()   masks base::intersect()
## x dplyr::lag()             masks stats::lag()
## x lubridate::setdiff()     masks base::setdiff()
## x lubridate::union()       masks base::union()
```

```r
options(scipen = 4)
library(agricolae)
library(here)
```

```
## here() starts at /home/guest/EDA-Spring2023
```

```r
here()
```

```
## [1] "/home/guest/EDA-Spring2023"
```

```r
NTL.LTER.Chem.Phys <-
  read.csv(here("Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv"),
           stringsAsFactors = TRUE)

NTL.LTER.Chem.Phys$sampledate <- mdy(NTL.LTER.Chem.Phys$sampledate)

class(NTL.LTER.Chem.Phys$sampledate)
```

```
## [1] "Date"
```

```r
#2

my_theme <- theme_classic(base_size = 12) +
  theme(
    plot.title = element_text(
      color='black'
    ),
    plot.background = element_rect(
      color = 'blue',
      fill = 'grey'
    ))

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

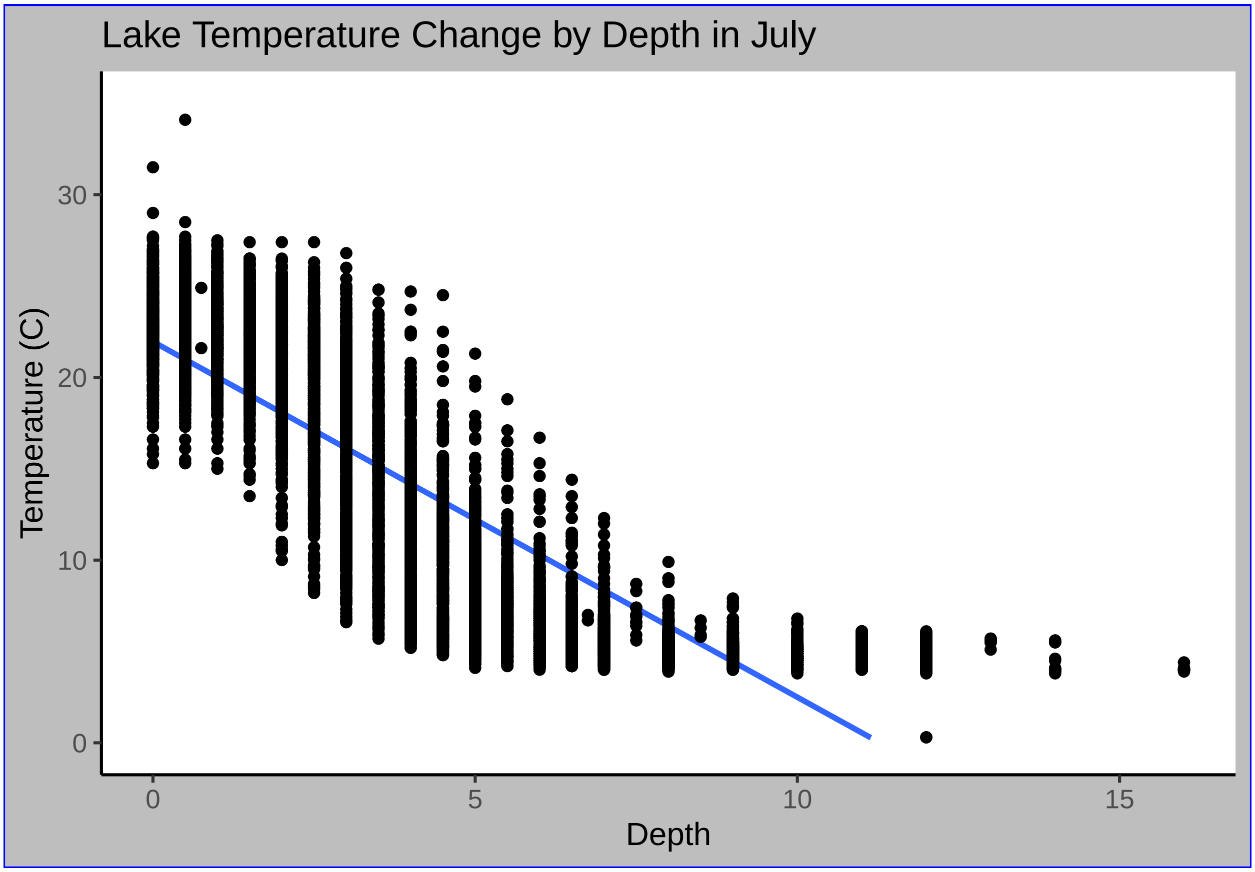
4. Wrangle your NTL-LTER dataset with a pipe function so that the records meet the following criteria:

- 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

LakeTemp.Depth.July <-
  NTL.LTER.Chem.Phys %>%
  mutate(month = month(sampledate)) %>%
  filter(month == 7) %>%
  select(lakename, year4, daynum, depth, temperature_C) %>%
  na.omit()

#5

tempbydepth <-
  ggplot(LakeTemp.Depth.July, aes(x = depth, y = temperature_C)) +
  ylim(0, 35) +
  geom_smooth(method = "lm") +
  geom_point() +
  labs(x="Depth", y="Temperature (C)",
       title = "Lake Temperature Change by Depth in July", color = "Lake")
print(tempbydepth)
```

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

## Warning: Removed 24 rows containing missing values (`geom_smooth()`).
```



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: Since the linear model here is downward sloping, it suggests a negative correlation between lake temperatures and depth in the month of July. The tight distribution of points in our model from a depth of 0 to ~10 represents an obviously negative, linear trend. However, a linear distribution seems less fitting starting around a depth of ~10 and below.

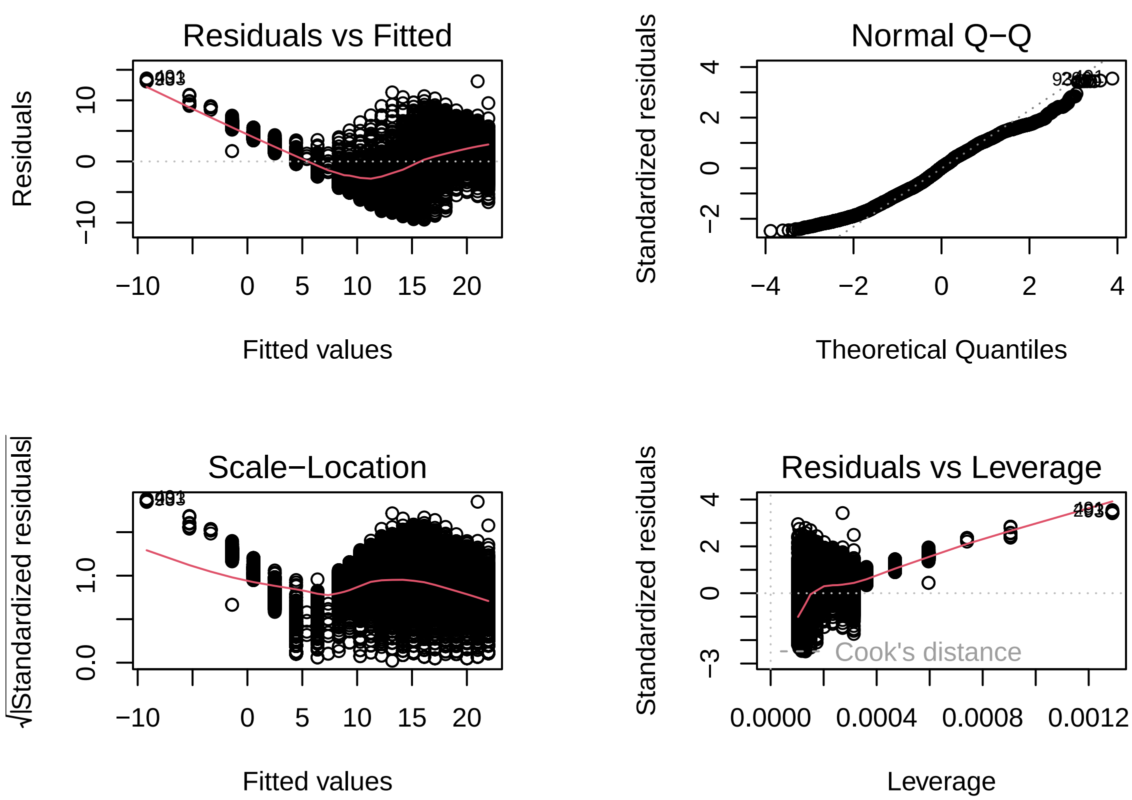
7. Perform a linear regression to test the relationship and display the results

```r
#7

tempbydepth.regression <- lm(data = LakeTemp.Depth.July, temperature_C ~ depth)
summary(tempbydepth.regression)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth, data = LakeTemp.Depth.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
```

```r
par(mfrow = c(2,2), mar=c(4,4,4,4))
plot(tempbydepth.regression)
```




```r
par(mfrow = c(1,1))
```

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: Because the coefficient is negative (aka the slope of the regression line), there is a negative relationship – when depth increases, temperature decreases. The p value is less than .05 (our confidence levels), so our coefficients are statistically different; therefore, it is worthwhile to estimate temperature in these lakes based on depth information. Since all p values are less than our confidence level, this was a meaningful regression. There are 9726 degrees of freedom, which is a representation of the number of observations variables in our linear regression. Our R-squared value of 0.7387 means that depth explains ~70% of the variability in temperature. Temperature is predicted to change by -1.94621 degrees C 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.

```
#9

LakeTemp.July.AIC <-
  NTL.LTER.Chem.Phys %>%
  mutate(month = month(sampledate)) %>%
  filter(month == 7)

TempAIC_Redo <- lm(data = LakeTemp.July.AIC, temperature_C ~ year4 + daynum +
                     depth + dissolvedOxygen + irradianceWater + irradianceDeck)

step(TempAIC_Redo)
```

```
## Start:  AIC=11846.16
## temperature_C ~ year4 + daynum + depth + dissolvedOxygen + irradianceWater +
##     irradianceDeck
##
##                   Df Sum of Sq    RSS   AIC
## <none>                          47249 11846
## - year4            1       140  47389 11860
## - dissolvedOxygen  1       181  47429 11865
## - irradianceDeck   1       324  47572 11882
## - irradianceWater  1       585  47833 11912
## - daynum           1      1482  48731 12014
## - depth            1    105034 152283 18284
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth + dissolvedOxygen +
##     irradianceWater + irradianceDeck, data = LakeTemp.July.AIC)
##
## Coefficients:
##     (Intercept)            year4           daynum            depth
##     -22.1150596        0.0177261        0.0581574       -2.8629088
## dissolvedOxygen  irradianceWater   irradianceDeck
##       0.0182867       -0.0015188        0.0006985
```

```r
#10

TempModel <- lm(data = LakeTemp.July.AIC, temperature_C ~ year4 + daynum +
                  depth + irradianceWater + irradianceDeck)
summary(TempModel)
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth + irradianceWater +
##     irradianceDeck, data = LakeTemp.July.AIC)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -8.7782 -1.8863 -0.1134  2.0190 14.7011
##
## Coefficients:
##                   Estimate  Std. Error  t value Pr(>|t|)
## (Intercept)     -19.7259764   8.6647327   -2.277 0.022849 *
## year4             0.0168079   0.0043215    3.889 0.000102 ***
## daynum            0.0559779   0.0043865   12.761  < 2e-16 ***
## depth            -2.8634358   0.0257116 -111.367  < 2e-16 ***
## irradianceWater  -0.0015257   0.0001832   -8.330  < 2e-16 ***
## irradianceDeck    0.0007331   0.0001132    6.474 1.04e-10 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 2.935 on 5563 degrees of freedom
##   (5275 observations deleted due to missingness)
## Multiple R-squared:  0.7715, Adjusted R-squared:  0.7713
## F-statistic:  3756 on 5 and 5563 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 final set of explanatory variables that the AIC method include: year4, daynum, depth, irradianceWater, and irradianceDeck. This model explains 77.15% of the observed variance; it is an improvement from the model that only uses depth, which explains 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).

```r
#12

AvgTemps.July.anova <- aov(data = LakeTemp.Depth.July, temperature_C ~ lakename)
summary(AvgTemps.July.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
```

```
AvgTemps.July.linear <- lm(data = LakeTemp.Depth.July, temperature_C ~ lakename)
summary(AvgTemps.July.linear)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = LakeTemp.Depth.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 p-value is less than 0.05, so we reject the null hypothesis (the null hypothesis on the aov states that the mean is the same across all different Lakes). Therefore, there is a statistically significant difference in the mean temperatures among the lakes.

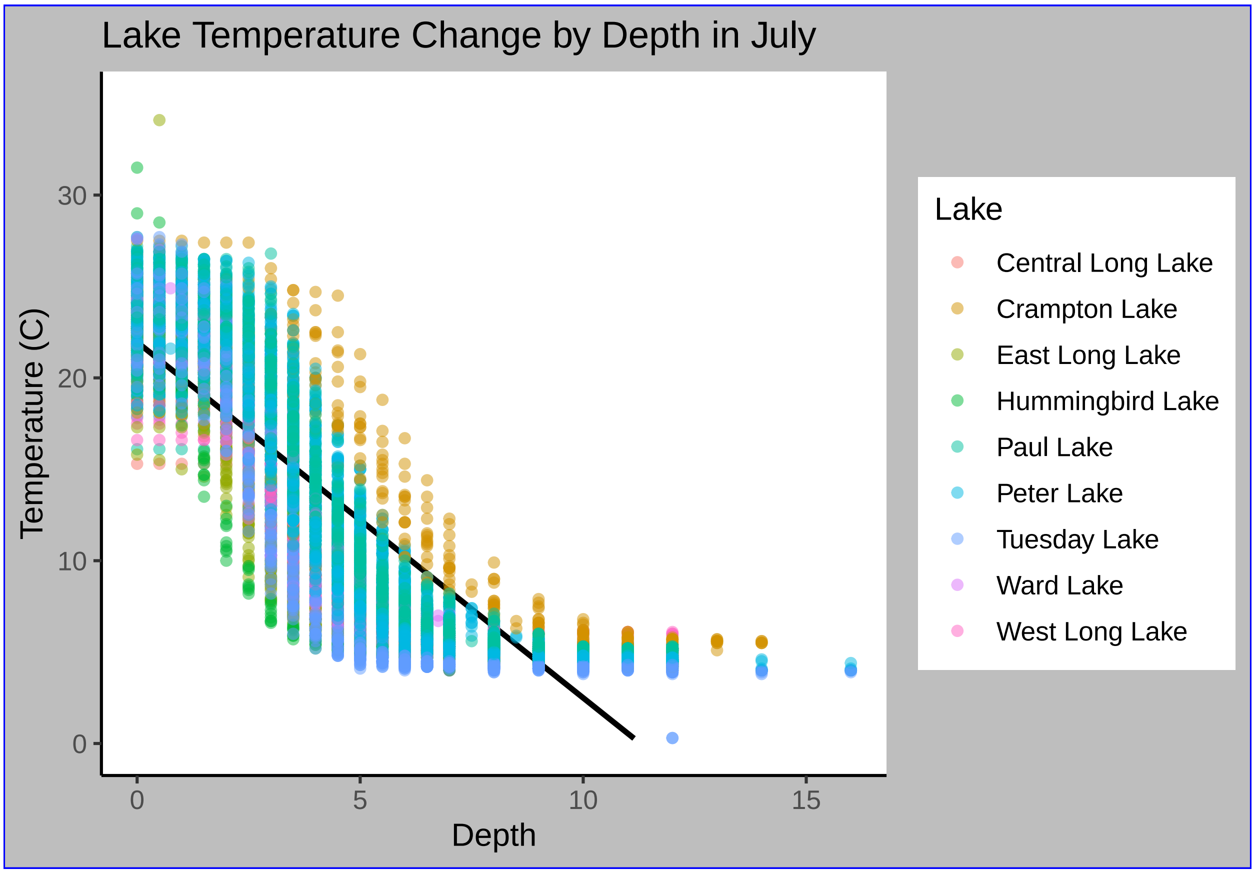
14. Create a graph that depicts temperature by depth, with a separate color for each lake. Add a geom_smooth (method = "lm", se = FALSE) for each lake. Make your points 50 % transparent. Adjust your y axis limits to go from 0 to 35 degrees. Clean up your graph to make it pretty.

```
#14.

tempDepth.lakecolor.plot <-
  ggplot(LakeTemp.Depth.July,
         aes(y = temperature_C, x = depth, color = lakename)) +
  geom_smooth(method = 'lm', se = FALSE, color = "black") +
  ylim(0, 35) +
```

```r
  geom_point(alpha=0.5) +
  labs(x="Depth", y="Temperature (C)",
       title = "Lake Temperature Change by Depth in July", color = "Lake")

print(tempDepth.lakecolor.plot)
```

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

```
## Warning: Removed 24 rows containing missing values (`geom_smooth()`).
```



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

```r
#15

TukeyHSD(AvgTemps.July.anova)
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = temperature_C ~ lakename, data = LakeTemp.Depth.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
AvgTemps.July.groups <- HSD.test(AvgTemps.July.anova, "lakename", group = TRUE)
AvgTemps.July.groups
```

```
## $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 the same mean temperatures statistically speaking as Peter Lake. Not only are the P values greater that 0.05, meaning we accept the null hypothesis, but the HSD test also shows they share 'c' with Peter Lake – Ward Lake returns 'bc'; Paul Lake returns 'c'.

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 could use a one-sample t-test to explore whether the mean temperatures are distinct or equal by testing the null hypothesis.

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?

```
Crampton.Ward.Data <- LakeTemp.Depth.July %>%
  filter(lakename == "Crampton Lake" | lakename == "Ward Lake")


twosample.JulyTemps <- t.test(Crampton.Ward.Data$temperature_C ~
                                Crampton.Ward.Data$lakename)
twosample.JulyTemps
```

```
##
```

```
##  Welch Two Sample t-test
##
## data:  Crampton.Ward.Data$temperature_C by Crampton.Ward.Data$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 p-value is 0.2649 which is great than 0.05 so we accept the null hypothesis that the two means are the same. This t test shows us that the difference in the means of the two lakes is equal to zero. This supports the results from part 16.