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()
```

```
## [1] "C:/Users/enewt/OneDrive/Documents/Duke/ENV872/EDE_Fall2023"
```

```
library(tidyverse)
```

```
## -- Attaching core tidyverse packages ------------------------ tidyverse 2.0.0 --
## v dplyr     1.1.3     v readr     2.1.4
## v forcats   1.0.0     v stringr   1.5.0
## v ggplot2   3.4.3     v tibble    3.2.1
## v lubridate 1.9.2     v tidyr     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
```

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

```
## here() starts at C:/Users/enewt/OneDrive/Documents/Duke/ENV872/EDE_Fall2023
```

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

Nutrients$sampledate <- mdy(Nutrients$sampledate)

#read in dataset and coverted sampledate to a date vector

#2
mytheme <- theme_classic(base_size = 14)+
  theme(legend.background = element_rect(
    color = "grey",
    fill = "white"),
    plot.title = element_text(hjust = 0.5),
    legend.position = "bottom")

#created theme and set to mytheme
```

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.

```r
#4
Nutrients_processed <-
  Nutrients %>%
  filter(month(sampledate) == 07) %>%
  select(lakename, year4, daynum, depth, temperature_C) %>%
  na.omit(Nutrients)

#wrangled data by filtering for temperatures recorded in July, selecting
#for the vectors of interest and ommiting NAs
```

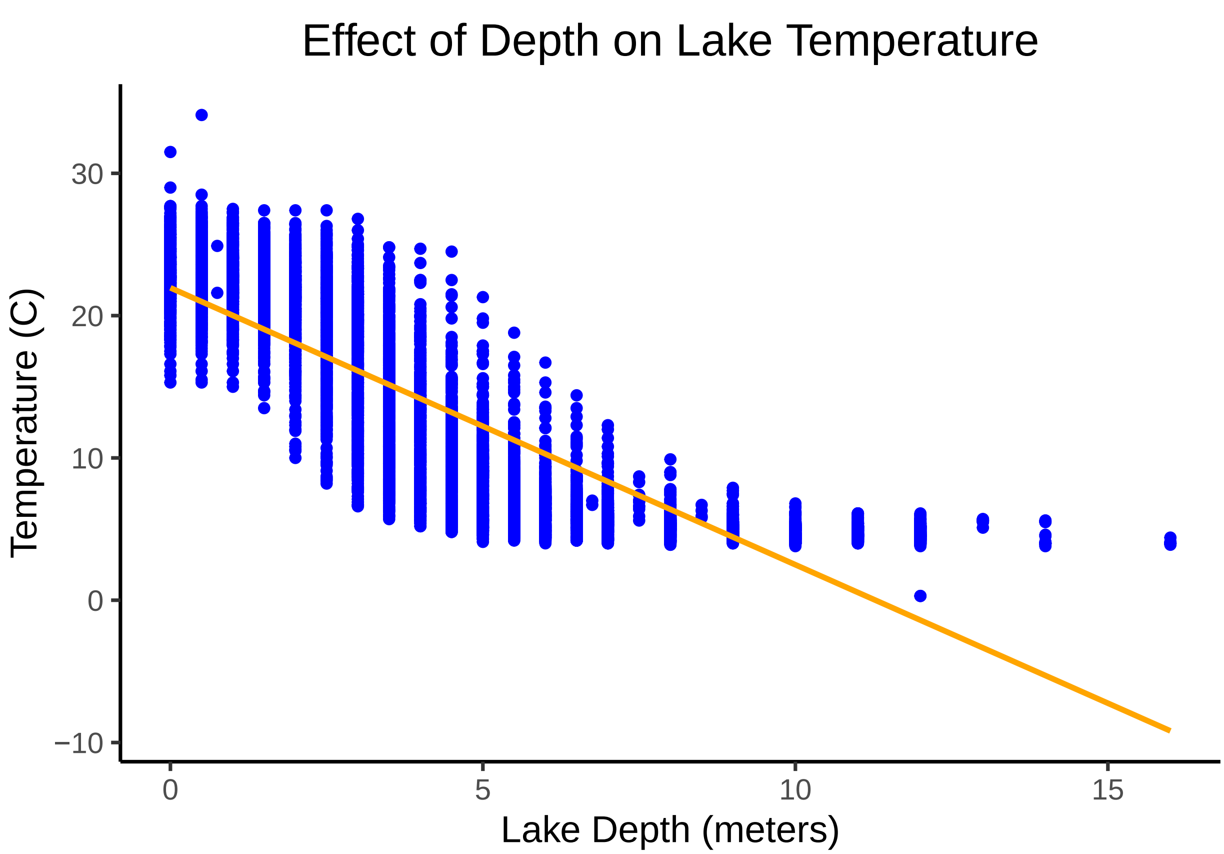
```
#5

tempbydepth <- ggplot(Nutrients_processed, aes(
  x = depth,
  y = temperature_C)) +
  geom_point(color = "blue") +
  geom_smooth(method = "lm", se = FALSE, color = "orange") +
  labs(
    title = "Effect of Depth on Lake Temperature",
    x = "Lake Depth (meters)",
    y = "Temperature (C)"
  ) +
  guides(color = guide_legend(title = NULL)) +
  mytheme
  ylim(0, 35)
```

```
## <ScaleContinuousPosition>
##  Range:
##  Limits:    0 --   35
```

```
print(tempbydepth)
```

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



```
#created scatter plot with a linear regression line using geom_point and
#geom_smooth and changed color, labels, and legend to make it easier to read
```

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 temperature decreases with increasing depth. Temperature appears to fall somewhat linearly at low depths but flattens to a temperature around 7 or 8C at lower depths.

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

```
#7
tempbydepth_regression <- lm(data = Nutrients_processed,
                             temperature_C ~ depth)
summary(tempbydepth_regression)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth, data = Nutrients_processed)
##
## 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
```

```
#used lm function to perform a linear regression for the relationship between
#temperature and depth
```

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: Approximately 74% of variablity in lake temperature can be explained by changes in depth. There are 9,726 degrees of freedom, meaning that there are 9,727 levels in the data. The p-value is less than 0.05, so that the null hypothesis can be rejected and the findings are significant.

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
tempAIC <- lm(data = Nutrients_processed,
              temperature_C ~ year4 + daynum + depth)
step(tempAIC)
```

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

```
summary(tempAIC)
```

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

```r
#10
temp_multiple <- lm(data = Nutrients_processed,
              temperature_C ~ year4 + daynum + depth)

#ran an AIC using step function to assess which variables most explain variance
#in temperature. Then ran a multiple analysis with the variables outputted by
#the AIC analysis.
```

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 that we use all three explanatory variables - year, day number, and depth. The model explains 74.1% of the observed variance. There is a slight improvement, as the R-squred value increased by ~0.3%.

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
tempbylake_anova1 <- aov(data = Nutrients_processed,
                        temperature_C ~ lakename)
summary(tempbylake_anova1)
```

```
##               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
tempbylake_anova2 <- lm(data = Nutrients_processed,
                        temperature_C ~ lakename)
summary(tempbylake_anova2)
```

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

```
#perfomed an anova test uisng aov and lm functions and summarized the tests to
#mean estimates and p-values
```

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

    Answer: There are significant differences in mean temperature among the lakes, including a 7 degree difference bewteen Central Long Lake and East Long Lake. All values had a p-value less than 0.05.

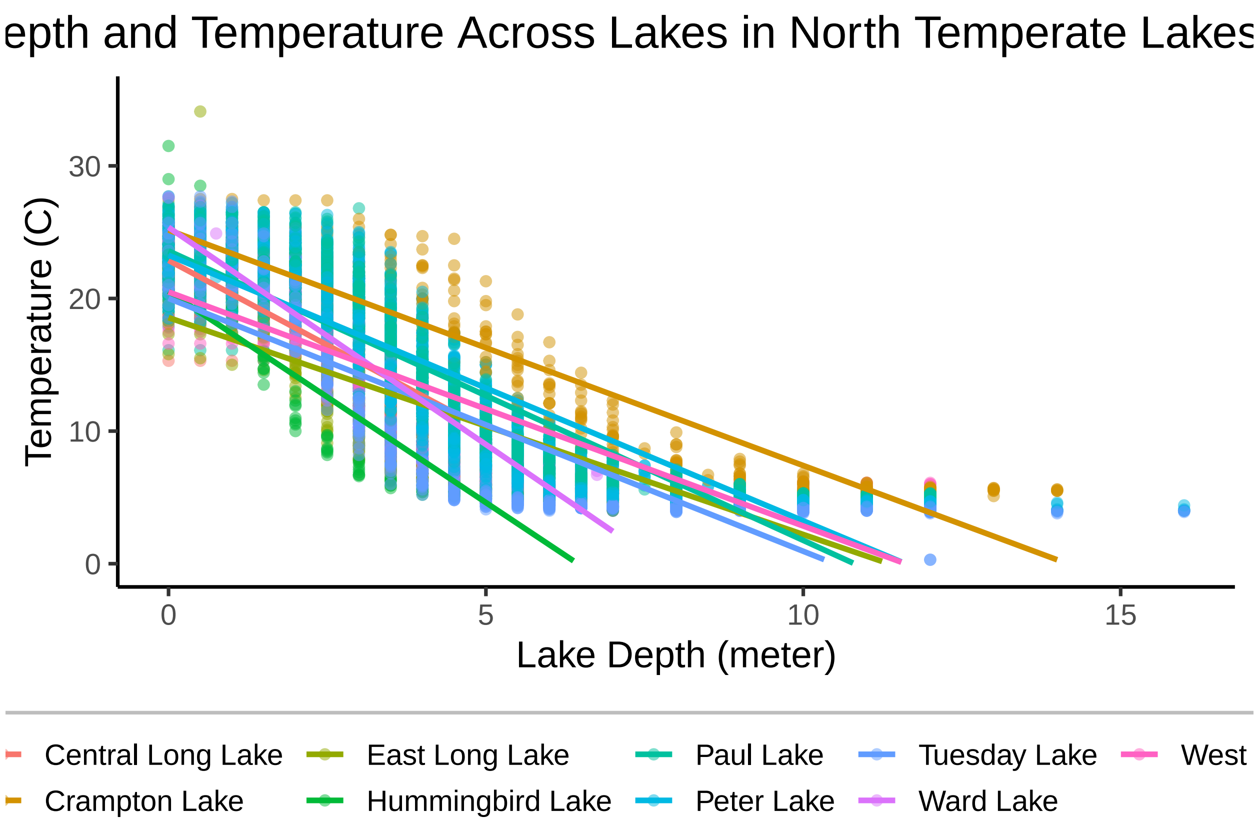
14. Create a graph that depicts temperature by depth, with a separate color for each lake. Add a geom_smooth (method = "lm", se = FALSE) for each lake. Make your points 50 % transparent. Adjust your y axis limits to go from 0 to 35 degrees. Clean up your graph to make it pretty.

```
#14.
tempbydepth2 <-
ggplot(Nutrients_processed, aes(
  x = depth,
  y = temperature_C,
  color = lakename,
  group = lakename)) +
geom_point(alpha = 0.5) +
geom_smooth(method = "lm", se = FALSE) +
  labs(title = "Depth and Temperature Across Lakes in North Temperate Lakes LTER",
       x = "Lake Depth (meter)",
       y = "Temperature (C)") +
  guides(color = guide_legend(title = NULL)) +
  mytheme +
  ylim(0, 35)

print(tempbydepth2)
```

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

```
## Warning: Removed 73 rows containing missing values (`geom_smooth()`).
```




```r
#created a scatterplot with a linear regression line using ggplot and
#selected color and group as 'lakename' in aesthetics to differentiate plot
#points and lm line by lakename
```

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

```r
#15
TukeyHSD(tempbylake_anova1)
```

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

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: Lakes with the same mean temperature based on the p-values in the Tukey HSD test are Paul Lake and Ward Lake.

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 can use a two-sample t-test to assess the difference in means between two variables, such as Peter Lake and Paul Lake.

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?

```
CramptonandWard <-
  Nutrients_processed %>%
  filter(lakename %in% c("Crampton Lake", "Ward Lake"))

temp_t.test <- t.test(CramptonandWard$temperature_C ~ CramptonandWard$lakename)
temp_t.test
```

```
##
##  Welch Two Sample t-test
##
## data:  CramptonandWard$temperature_C by CramptonandWard$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
```

```
#wrangled the processed dataset to filter for Crampton and Ward Lakes, then
#ran a two-sample t-test to determine if the mean temperature in each lake
#is equal
```

> Answer: The two-sample T-test showed that the means are the same. The null hypothesis is accepted, as the p-value is greater than 0.05. That does match the results of the Tukey HSD test, which showed that Crampton and Ward lake have the same means, statistically speaking.