# 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
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   3.4.4     v tibble    3.2.1
## v lubridate 1.9.3     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
```

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

```
## here() starts at /Users/sarah/Documents/872_EDA/EDA_Spring2024
```

```r
here()
```

```
## [1] "/Users/sarah/Documents/872_EDA/EDA_Spring2024"
```

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

NTL_LTER_Physics$sampledate <- as.Date(
  NTL_LTER_Physics$sampledate,
                                  format = "%m/%d/%y"
                                  )
head(NTL_LTER_Physics$sampledate, 5)
```

```
## [1] "1984-05-27" "1984-05-27" "1984-05-27" "1984-05-27" "1984-05-27"
```

```r
NTL_LTER_Physics$year4 <- year(
  as.Date(NTL_LTER_Physics$sampledate
          ))
head(NTL_LTER_Physics$year4, 5)
```

```
## [1] 1984 1984 1984 1984 1984
```

```r
NTL_LTER_Physics$month <- month(
  as.Date(NTL_LTER_Physics$sampledate
          ))
head(NTL_LTER_Physics$month, 5)
```

```
## [1] 5 5 5 5 5
```

```r
#2
A07theme <- theme_classic(base_size = 12) +
  theme(
    axis.text = element_text(
      color = "black",
      size = 10
      ),
   axis.title.x = element_text( #Updating x-axis
     color = "black",
     size = 12
   ),
   axis.title.y = element_text( #Updating y-axis
     color = "black",
     size = 12
   ),
    legend.position = "top", #Putting legend to top
     legend.title = element_text( #Updating legend title
      color='black',
      size = 12
```

```
    ),
   legend.text = element_text( #Updating legend text
     size = 10
     ),
    plot.background = element_blank() #removing plot edge/background
   )
theme_set(A07theme)
```

### 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 difference in mean lake temperature during July across all lakes' depth. Ha: There is difference in mean lake temperature during July across all lakes' 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.

```
#4
NTL_LTER_Processed <- NTL_LTER_Physics %>%
  filter(NTL_LTER_Physics$month == 7) %>%
  select(lakename:daynum,
         depth:temperature_C
         ) %>%
  na.omit()
head(NTL_LTER_Processed, 5)
```

```
##    lakename year4 daynum depth temperature_C
## 1 Paul Lake  1984    183   0.0          22.8
## 3 Paul Lake  1984    183   0.5          22.9
## 5 Paul Lake  1984    183   1.0          22.8
## 6 Paul Lake  1984    183   1.5          22.7
## 7 Paul Lake  1984    183   2.0          21.7
```

```
#5
plot1 <- NTL_LTER_Processed %>%
  ggplot(aes(
    x=depth,
    y=temperature_C
  )) +
  geom_point(alpha = 1/5, color = "azure4", size = 1.5) +
  geom_smooth(method = "lm", se = FALSE, col="slateblue2") +
```

```
  ylim(0, 35) +
  ylab(expression(paste("Temperature", degree, "C"))) +
  xlab("Depth (meters)") +
  ggtitle(expression(paste("Temperature", degree, "C by Depth (m)"))) +
  A07theme
print(plot1)
```

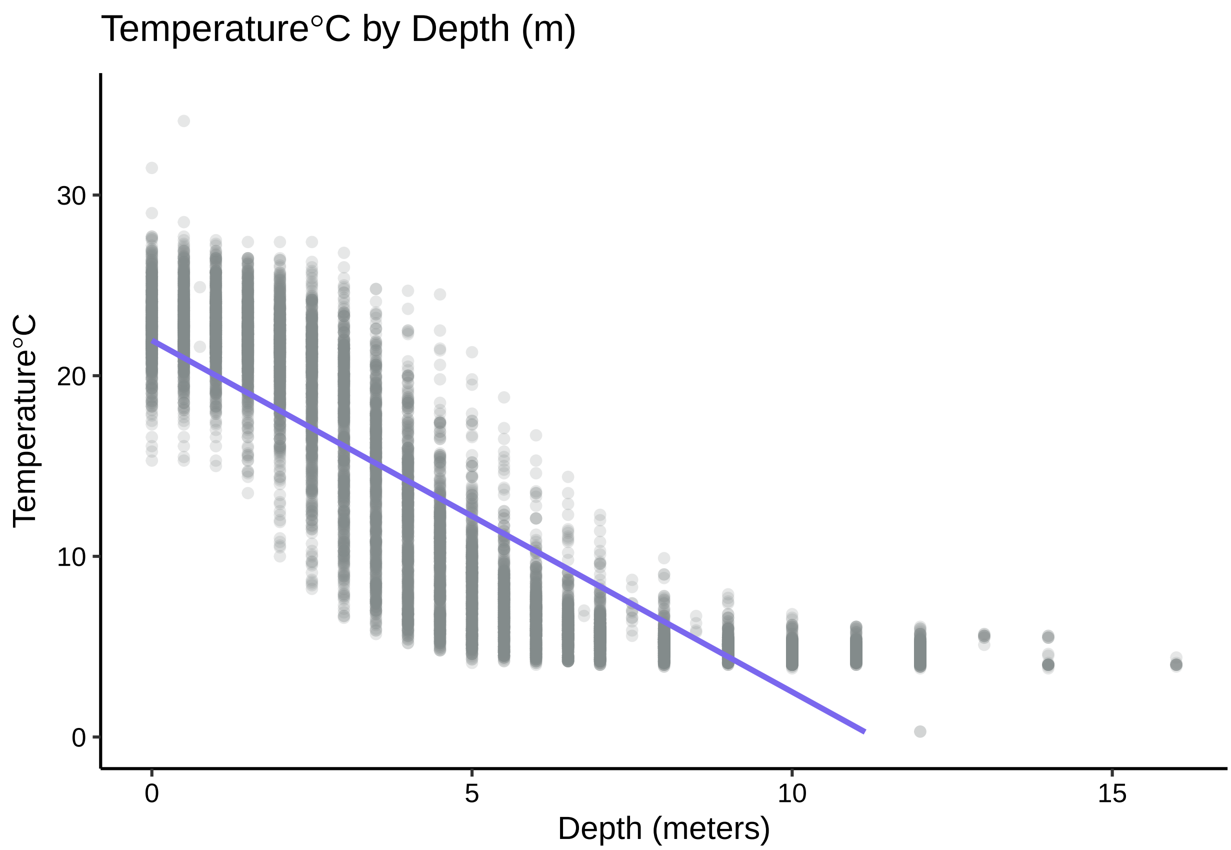


Figure 1: Temperature by Depth

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: Overall, there seems to be a negative correlation between temperature and depth. Temperature decreases as the lake depth increases. There is a ~10-degree range in terms of the temperature distribution by depth. Based on the graph, the points are not necessarily close to smooth line, indicating that the relationship between temperature and depth may not be that linear.

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

```
#7
temp_lr1 <- lm(data = NTL_LTER_Processed,
               temperature_C ~ depth)
summary(temp_lr1)
```

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

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: *Temperature = 21.96 - 1.95[depth]*. A meter increase in depth is associated with a 1.95 decrease of temperature, holding all else constant. Depth's regression coefficient has a p-value that is less than 0.05, meaning that depth has a statistically significant relationship with temperature. The adjusted r-squared is 0.7387, around 73.9% of the changes in temperature is due to changes in depth. The degree of freedom the finding is based off of is 9,726. We are able to reject the null hypothesis.

---

## 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
Temp_AIC <- lm(data = NTL_LTER_Processed,
               temperature_C ~ year4 + daynum + depth)

step(Temp_AIC)
```

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

```
#10
summary(Temp_AIC)
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = NTL_LTER_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: *Temperature = -8.58 + 0.01[year4] + 0.04[daynum] - 1.95[depth]*. The final set of explanatory variables that the AIC method suggests are the three variables should be included. Removing year, daynum, or depth would increase the AIC. The three explanatory variables explain 74.11% of the change in temperature. This is a slight increase and improvement when compared to the previous model that only had depth as an explanatory variable. With the additional two explanatory variables, the explained variance increased from 73.9% to 74.11%.

---

## 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
lake.july.ANOVA <- aov(data = NTL_LTER_Processed,
                       temperature_C ~ lakename)
summary(lake.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
```

```r
lake.july.ANOVA2 <-lm(data = NTL_LTER_Processed,
                       temperature_C ~ lakename)
summary(lake.july.ANOVA2)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = NTL_LTER_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: Yes, there is statistically significant difference in the mean temperature among the different lakes. We confirm this as the p-value is less than 0.05. We are able to reject the null hypothesis that all lake means are equal. At least one lake has a different mean tempature. The linear regression confirms this because it shows that all p-values for each mean temperature are less than 0.05, and are statistically significant.

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.
plot2 <- NTL_LTER_Processed %>%
  ggplot(aes(
    x=depth,
    y=temperature_C,
    color=lakename
  )) +
  geom_point(alpha = .5, size = 1.5) +
  geom_smooth(method = "lm", se = FALSE, size = 1, aes(group = lakename)) +
  ylim(0, 35) +
  ylab(expression(paste("Temperature", degree, "C"))) +
  xlab("Depth (meters)") +
  ggtitle(expression(paste("Temperature", degree, "C by Depth (m)"))) +
  guides(color=guide_legend(title="Lake", nrow=3, byrow=TRUE)) +
  A07theme
print(plot2)
```

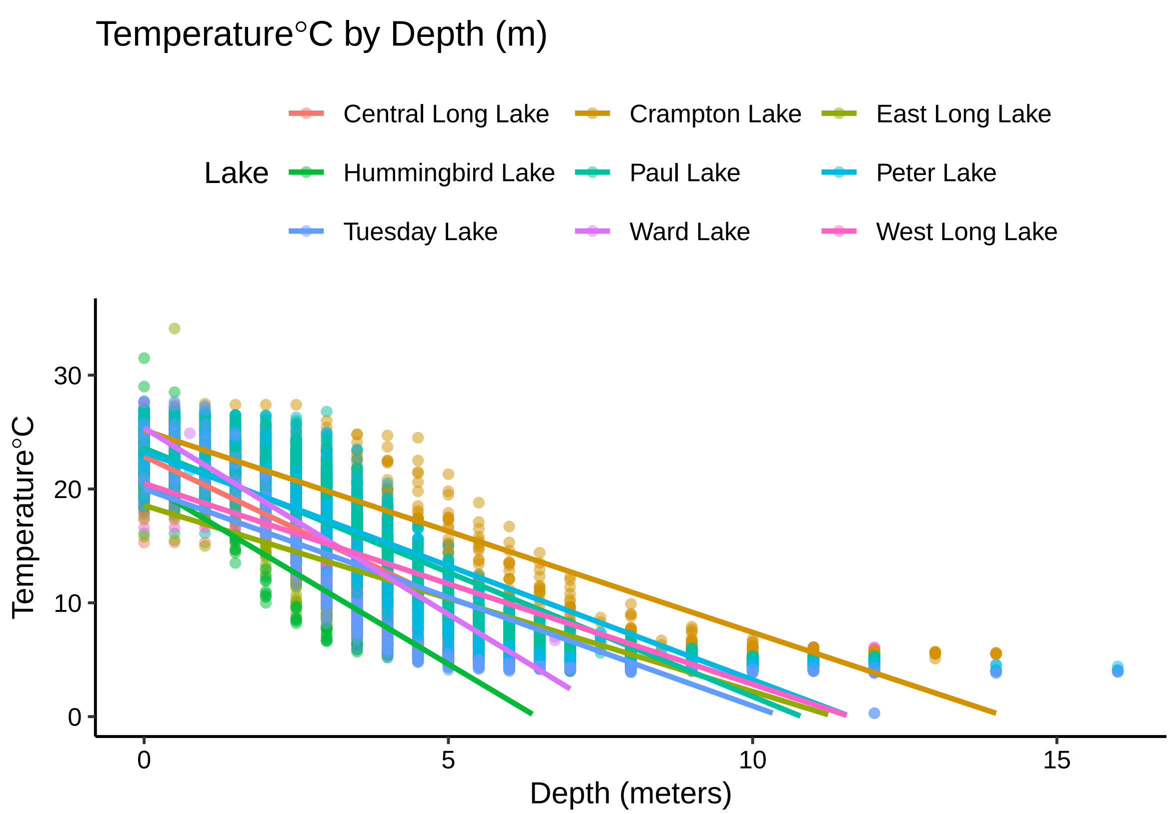


Figure 2: Temperature by Depth per Lake

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

```r
#15
TukeyHSD(lake.july.ANOVA)
```

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

```r
lake.july.groups <- HSD.test(lake.july.ANOVA, "lakename", group = TRUE)
lake.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         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: Using the HSD.test(), Paul Lake and Ward Lake have the same mean as Peter Lake, statistically speaking. Of the lakes samppled, there is not one lake that has a mean temperature that is statistically distinct from the other lakes. All lakes are grouped with other lakes with statistically similiar mean temparature.

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 the two-sample t-test to test for equal variances.

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_LTER_Crampton_Ward <- NTL_LTER_Processed %>%
  filter(lakename %in% c("Crampton Lake", "Ward Lake"))
head(NTL_LTER_Crampton_Ward, 5)
```

```
##        lakename year4 daynum depth temperature_C
## 1 Crampton Lake  1999    196   0.0          22.8
## 2 Crampton Lake  1999    196   0.5          22.6
## 3 Crampton Lake  1999    196   1.0          22.4
## 4 Crampton Lake  1999    196   1.5          22.2
## 5 Crampton Lake  1999    196   2.0          22.0
```

```
temp.twosample <- t.test(NTL_LTER_Crampton_Ward$temperature_C ~ NTL_LTER_Crampton_Ward$lakename)
temp.twosample
```

```
##
##  Welch Two Sample t-test
##
## data:  NTL_LTER_Crampton_Ward$temperature_C by NTL_LTER_Crampton_Ward$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: We cannot reject the null hypothesis, as the p-value is greater than 0.05. The mean from both lakes are statistically the same. The mean temperature amounts for each lake are the same as the lake's respetive outputs from Question 16. The two-sample t-test confirms the results we received from the Tukey's HSD test.