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.

```
knitr::opts_chunk$set(tidy.opts=list(width.cutoff=60), tidy=TRUE)
#1 Import libraries and checking my working directory
library(tidyverse);library(agricolae);library(here); library(corrplot)
getwd()
NTL_LakeChemistry <- read.csv(
  file=here("Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv"),
  stringsAsFactors = TRUE)

#2 Set theme
sayratheme <- theme_classic(base_size = 11) +
  theme(axis.text = element_text(color = "black"),
        legend.position = "right",
        legend.direction = "vertical",
        plot.title =
          element_text(color = "royalblue", size = 11))
theme_set(sayratheme)
```

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: Having the formula July.Temperature_C = B0 + B1*depth + e H0: B1 = 0 Ha: B1 != 0

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.

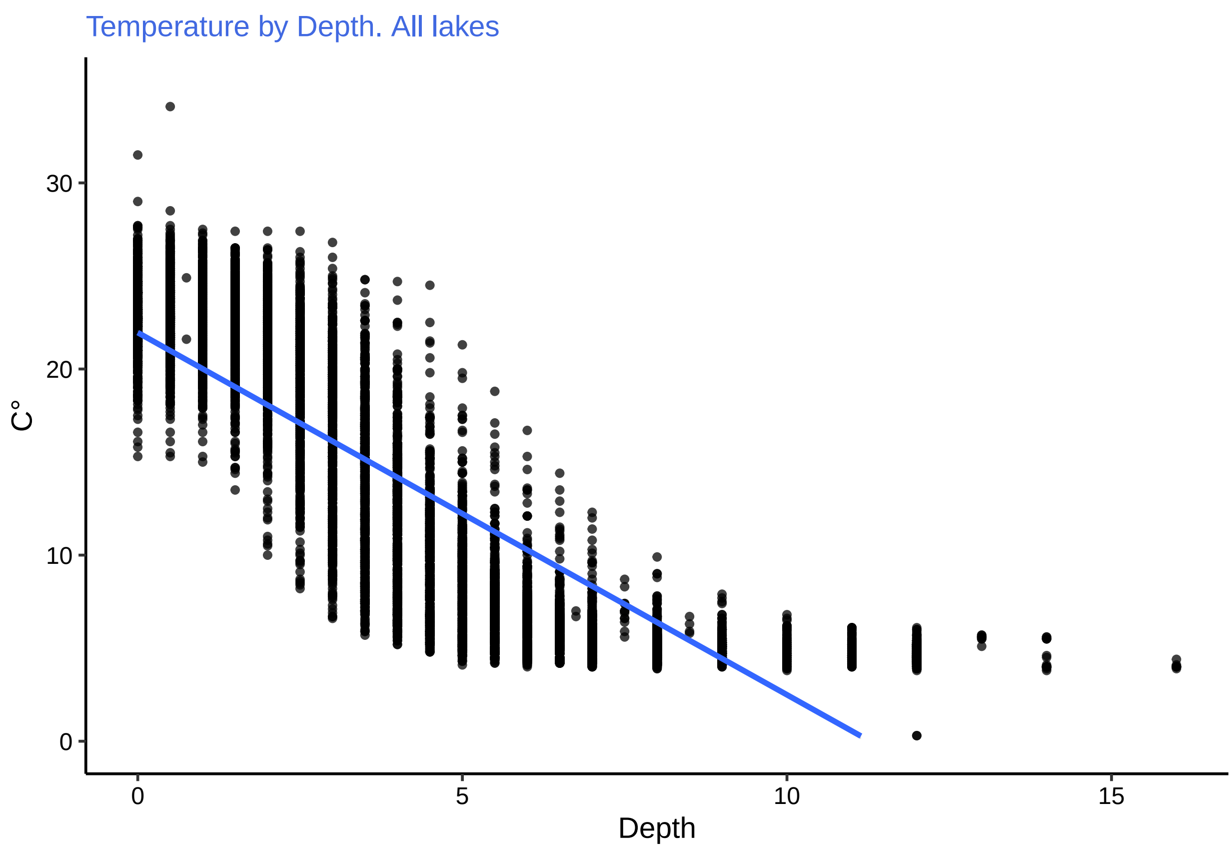
```r
# 4 Wrangling DF
NTL_LakeChemistry$sampledate <- as.Date(NTL_LakeChemistry$sampledate,
    format = "%m/%d/%y")

NTL_LakeChemistry.july <- NTL_LakeChemistry %>%
    mutate(month = month(sampledate)) %>%
    filter(month == 7) %>%
    select(lakename, year4, daynum, depth, temperature_C) %>%
    na.omit()

# 5 Scatterplot
Temp_by_Depth <- ggplot(NTL_LakeChemistry.july, aes(x = depth,
    y = temperature_C)) + geom_point(alpha = 0.75, size = 1) +
    geom_smooth(method = lm) + ylim(0, 35) + ggtitle("Temperature by Depth. All lakes") +
    xlab(expression(paste("Depth"))) + ylab(expression(paste("C°")))
print(Temp_by_Depth)
```

```
## `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: The trend line shows a negative correlation among those variables, thus, as depth increase the temperature lowers. However, given the distribution there is no a linear trend between temperature and depth.

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

```
# 7

reg_temp.by.depth <- lm(formula = temperature_C ~ depth, data = NTL_LakeChemistry.july)
summary(reg_temp.by.depth)
```

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

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: According to the regression, every additional unit of depth leads to a decrease in temperature of 1.94°. This variability in temperature given a change in depth is statistically significant, so we can reject our null hypothesis in favor of our alternative hypotesis.

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
# 9First, I run a regression with all variables, and then,
# I apply the step() function
regress_all_variables <- lm(formula = temperature_C ~ depth +
    year4 + daynum, data = NTL_LakeChemistry.july)
summary(regress_all_variables)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth + year4 + daynum, data = NTL_LakeChemistry.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
## depth       -1.946437   0.011683 -166.611  < 2e-16 ***
## year4        0.011345   0.004299    2.639  0.00833 **
## daynum       0.039780   0.004317    9.215  < 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
step(regress_all_variables)
```

```
## Start:  AIC=26065.53
## temperature_C ~ depth + year4 + daynum
##
##          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 ~ depth + year4 + daynum, data = NTL_LakeChemistry.july)
##
## Coefficients:
## (Intercept)        depth        year4       daynum
##    -8.57556     -1.94644      0.01134      0.03978
```

```r
# 10 As AIC didn't decrease with the removal of any
# variable, I keep them all in my best model
best.model <- lm(formula = temperature_C ~ depth + year4 + daynum,
    data = NTL_LakeChemistry.july)
summary(best.model)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth + year4 + daynum, data = NTL_LakeChemistry.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
## depth       -1.946437   0.011683 -166.611  < 2e-16 ***
## year4        0.011345   0.004299    2.639  0.00833 **
## daynum       0.039780   0.004317    9.215  < 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: As the step() function shows that lowest AIC is the outcome of using all three variables, my best model would keep those 3 predictors (year4, daynum, and depth) to explain temperature. The R-squared for this regression shows that the model explain aroun 74.1% of the variance in temperature, vs the 73.87% of the model that only use depth as predictor. Thus. this is a slight improvement in the model.

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 Format as Anova model
temperature.anova <- aov(data = NTL_LakeChemistry.july, temperature_C ~
    lakename)
summary(temperature.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
```

```
# Format as linear model
temperature.lm <- lm(data = NTL_LakeChemistry.july, temperature_C ~
    lakename)
summary(temperature.lm)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = NTL_LakeChemistry.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: Yes, both models conclude mean temperature differs among the analyzed lakes. In ANOVA model, the F value equals to 50 and the p-value (<2e-16 ***) shows statistical significant differences. In the linear model, we have coefficients that represents the difference in temperature for each lake, and in every case such coefficent is statistical significant.

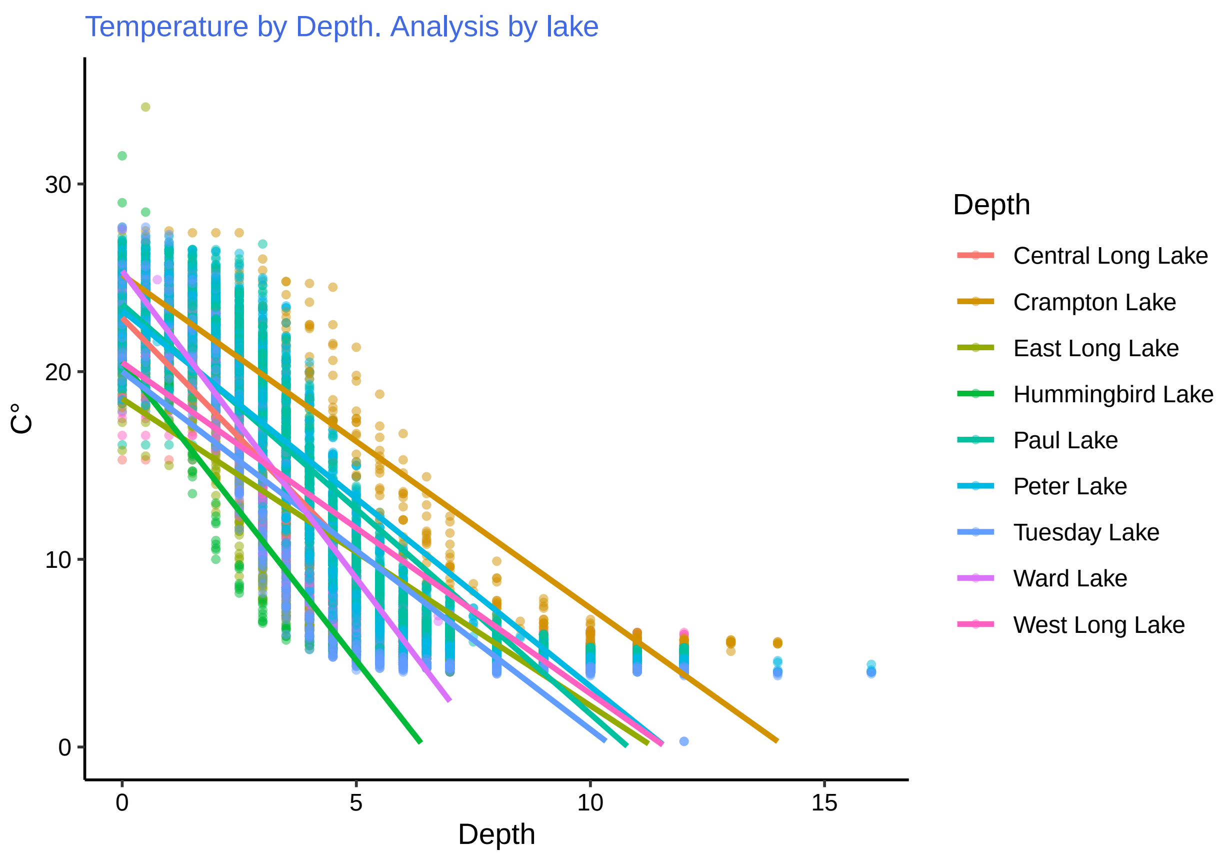
14. Create a graph that depicts temperature by depth, with a separate color for each lake. Add a geom_smooth (method = "lm", se = FALSE) for each lake. Make your points 50 % transparent. Adjust your y axis limits to go from 0 to 35 degrees. Clean up your graph to make it pretty.

```r
# 14. I created this one differentiating by lake, but in
# the same plot
Temp_Depth_byLake <- ggplot(NTL_LakeChemistry.july, aes(x = depth,
    y = temperature_C, color = lakename)) + geom_point(alpha = 0.5,
    size = 1) + geom_smooth(method = lm, se = FALSE) + ylim(0,
    35) + ggtitle("Temperature by Depth. Analysis by lake") +
    labs(x = "Depth", y = "C°", color = "Depth")

print(Temp_Depth_byLake)
```

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

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

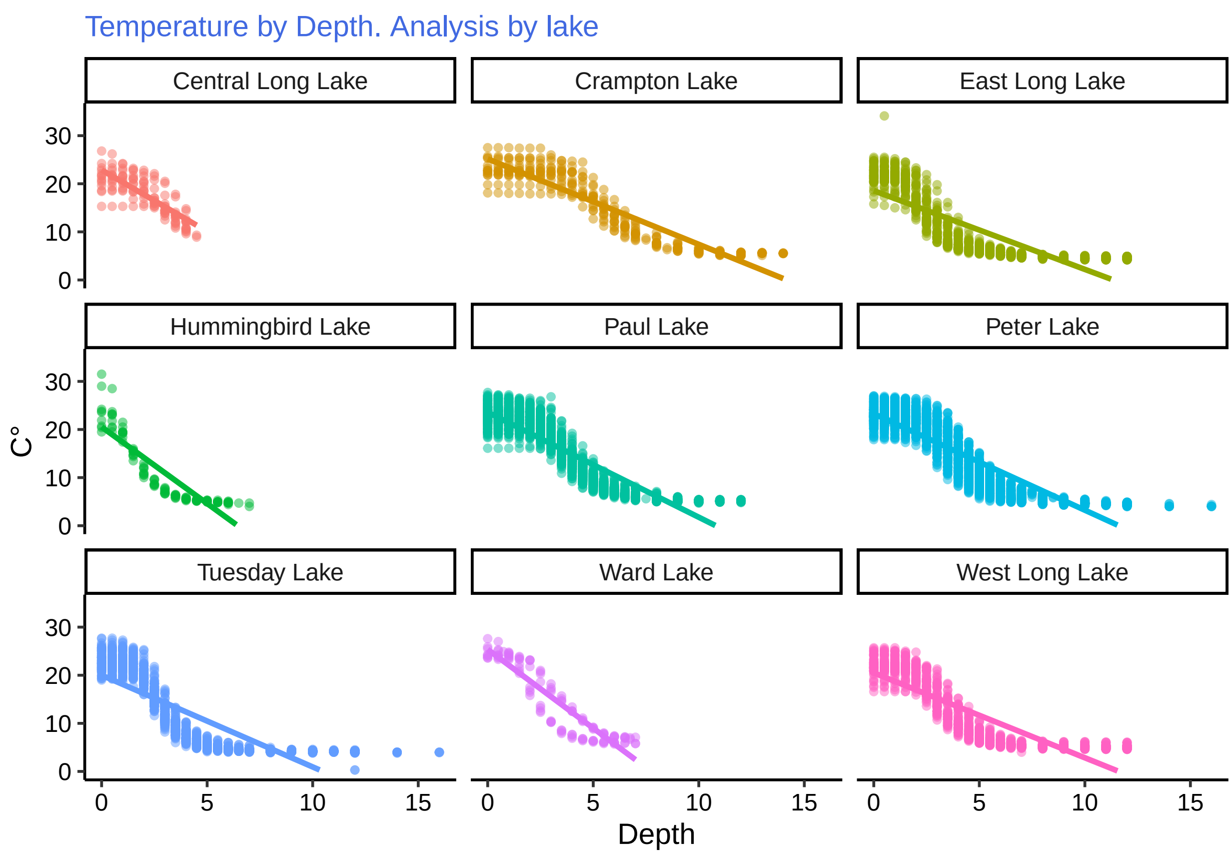



```
# I created this one, to see outcomes separately
Temp_Depth_byLake2 <- ggplot(NTL_LakeChemistry.july, aes(x = depth,
    y = temperature_C, color = lakename)) + geom_point(alpha = 0.5,
    size = 1) + facet_wrap(vars(lakename)) + geom_smooth(method = lm,
    se = F) + ylim(0, 35) + ggtitle("Temperature by Depth. Analysis by lake") +
    labs(x = "Depth", y = "C°", color = "Depth") + theme(legend.position = "none")

print(Temp_Depth_byLake2)
```

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

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



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

```
# 15
TukeyHSD(temperature.anova)
```

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

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: Only Paul Lake and Ward Lake have the same mean temperature than Peter Lake, as the differences for those were not statistically significant. And yes, actually in most of the comparisons the mean temperature is statistically distinct between lakes, with a few of exceptions: (Crampton Lake-Central Long Lake; Ward Lake-Crampton Lake; Hummingbird Lake-East Long Lake; Tuesday Lake-East Long Lake; Tuesday Lake-Hummingbird Lake; West Long Lake-Hummingbird Lake; Peter Lake-Paul Lake; Ward Lake-Paul Lake; Ward Lake-Peter Lake; and West Long Lake-Tuesday Lake. In this comparisons differences were not statistically significant).

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() as it tests as its Null Hypothesis that there is no difference in means between them. Iniatially, I also though about the HSD.test(), but that one would be more usefull only to extract groupings to identify the pairwise relationship, so t.test() is the option.

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?

```r
Crampton_Ward.Chemistry.july <- NTL_LakeChemistry.july %>%
    filter(lakename %in% c("Crampton Lake", "Ward Lake"))

Crampton_Ward.twosample <- t.test(Crampton_Ward.Chemistry.july$temperature_C ~
    Crampton_Ward.Chemistry.july$lakename)
Crampton_Ward.twosample
```

```
##
##  Welch Two Sample t-test
##
## data:  Crampton_Ward.Chemistry.july$temperature_C by Crampton_Ward.Chemistry.july$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: Given the p-value 0.2649, there is no evidence to reject the null hypothesis, this is, there is no statistical difference in the mean temperature between lakes at the 95% confidence level.