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
# checking work directory
library(here)
```

```
## here() starts at /home/guest/ENV872/EDE_Fall2024
```

```
here()
```

```
## [1] "/home/guest/ENV872/EDE_Fall2024"
```

```
getwd()
```

```
## [1] "/home/guest/ENV872/EDE_Fall2024"
```

```
# loading libraries
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   3.5.1     v tibble    3.2.1
## v lubridate 1.9.3     v tidyr     1.3.1
## 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(corrplot)
```

```
## corrplot 0.94 loaded
```

```r
library(agricolae)
library(lubridate)
library(ggplot2)

# setting working environment
options(scipen = 4)

# importing dataset
PeterPaul <- read.csv(here(
  "Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv"), stringsAsFactors = TRUE)

# setting date format
PeterPaul$sampledate <- mdy(PeterPaul$sampledate)

#2
mytheme <- theme_classic(base_size = 12) +
  theme(axis.text = element_text(color = "black"),
        legend.position = "top",
        plot.background = element_rect(fill = "lightgrey", color = NA),)
theme_set(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, possibly because temperature is constant within lakes. Ha: Mean lake temperature recorded during July varies with depth across all lakes, possibly because heat dissipates unevenly within a lake.

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.

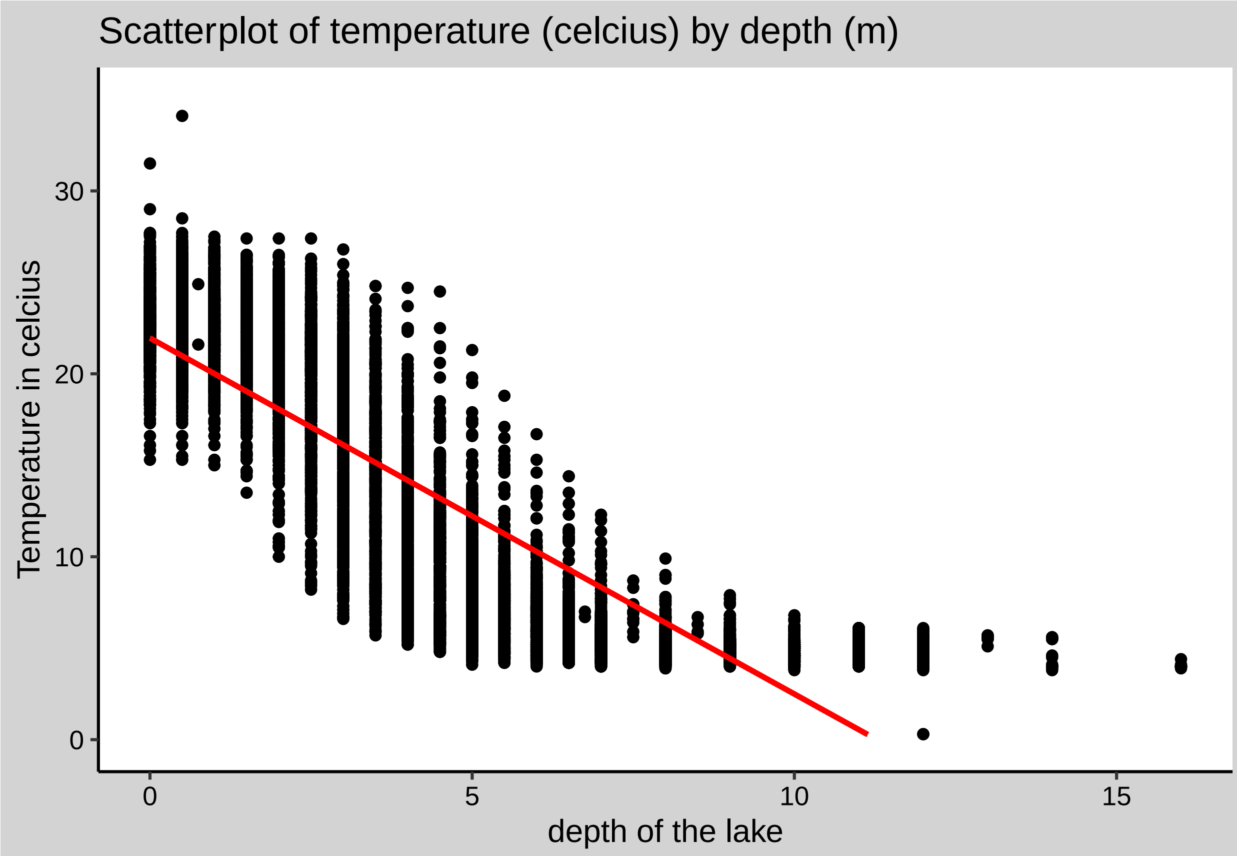
```
#4

PeterPaul.processed <-
  PeterPaul %>%
  # only dates in July
  filter(month(PeterPaul$sampledate) == 7)  %>%
  # selected columns
  select('lakename', 'year4', 'daynum', 'depth', 'temperature_C') %>%
  # remove na
  na.omit()

#5
# scatter plot
scatter.depth <-
  ggplot(PeterPaul.processed, aes(y = temperature_C, x = depth)) +
  geom_point()+
  ylim(0, 35)+
  geom_smooth(method = "lm", col = "red")+
  labs(title='Scatterplot of temperature (celcius) by depth (m)',
       x = 'depth of the lake',
       y = 'Temperature in celcius',
       label = expression("PM2.5 = 0.38 * Ozone + 15.64"))
print(scatter.depth)
```

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

```
## Warning: Removed 24 rows containing missing values or values outside the scale range
## (`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 figure suggests that as the depth goes higher, the temperature of the lake will tend to drop. This matches with the alternative hypothesis. When the depth is shallow, from 0 to 5, we can tell from the points that the trend is relatively linear, with a negative coefficient. However, as the depth goes beyond 5, the points start to become flat, meaning that the temperature stops decreasing after reaching a certain depth.

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

```
#7
simple_regression <- lm(
  PeterPaul.processed$temperature_C ~ PeterPaul.processed$depth)
summary(simple_regression)
```

```
##
## Call:
## lm(formula = PeterPaul.processed$temperature_C ~ PeterPaul.processed$depth)
##
## 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 ***
## PeterPaul.processed$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: The adjusted R-squared value is 0.7387, thus 73.87% of the variability in temperature is accounted by changes in depth. The residual standard error is 3.835 based on 9726 degrees of freedom. Depth is statistically significant in predicting the temperature, since the p value is less than 2e-16. Based on the gradient, with every 1m change in depth, the temperature would drop 1.946 (or 1.95) degrees celcius.

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
AIC.model <- lm(data = PeterPaul.processed,
              temperature_C ~ year4 + daynum + depth)
step(AIC.model)
```

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

```
#10
multi_regression <- lm(data = PeterPaul.processed,
                       formula = temperature_C ~ year4 + daynum + depth)
summary(multi_regression)
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = PeterPaul.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: As suggested by the AIC method, the best model is when we use all three variables (i.e. year4 + daynum + depth) in the multiple regression. The adjusted R-squared value is 0.7411, meaning it accounts for 74.11% of the observed variance. This is an improvement over the linear model as it increased from 0.7387 to 0.7411. However, the improvement is not huge, only by 6%. The p values are 0.00833, less than 2e-16, and less than 2e-16 for year4, daynum, depth respectively.

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
# ANOVA model
temp.anova <- aov(data = PeterPaul.processed, temperature_C ~ lakename)
summary(temp.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
# linear model
temp.anova.lm <- lm(data = PeterPaul.processed, temperature_C ~ lakename)
summary(temp.anova.lm)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = PeterPaul.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 a significant difference in mean temperature among the lakes. In the ANOVA model, we can observe that the p value is less than 2e-16, which indicates that the variance of temperature at different lakes are significantly different. In the lm model, we can tell that the p-value is 2.2e-16, which also leads to the same conclusion.

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.

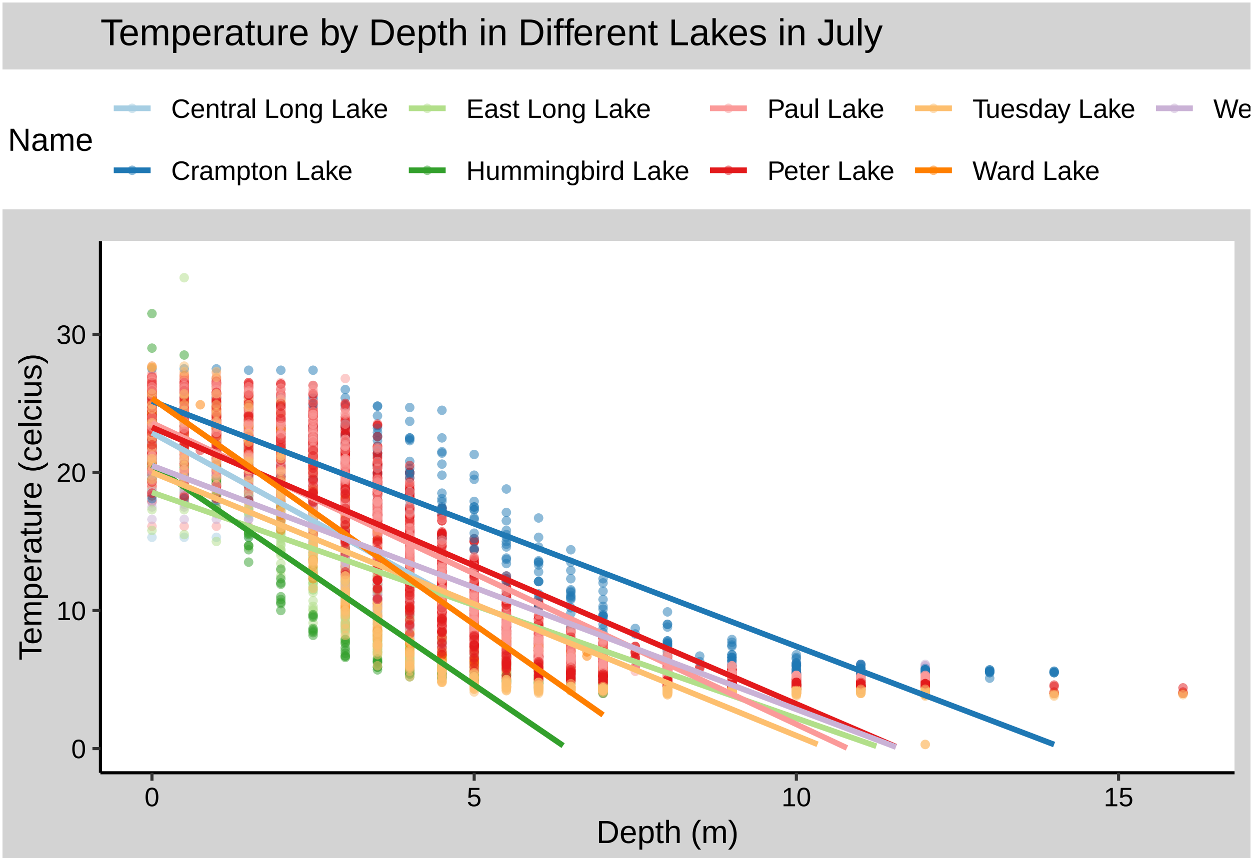
```r
#14.
# Plot temperature by depth, colored by lake, with linear smooth lines
temp_by_depth <- ggplot(PeterPaul.processed,
                        aes(x = depth, y = temperature_C, color = lakename)) +
  geom_point(alpha = 0.5, size = 1) +
  geom_smooth(method = "lm", se = FALSE, size = 1) +
  ylim(0, 35)+
  labs(
    title = "Temperature by Depth in Different Lakes in July",
    x = "Depth (m)",
    y = "Temperature (celcius)",
    color = "Lake Name"
  ) +
  scale_color_brewer(palette = "Paired")+
  mytheme
```

```
## Warning: Using `size` aesthetic for lines was deprecated in ggplot2 3.4.0.
## i Please use `linewidth` instead.
## This warning is displayed once every 8 hours.
## Call `lifecycle::last_lifecycle_warnings()` to see where this warning was
## generated.
```

```r
print(temp_by_depth)
```

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

```
## Warning: Removed 73 rows containing missing values or values outside the scale range
## (`geom_smooth()`).
```



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

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

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = temperature_C ~ lakename, data = PeterPaul.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: By noting the p values of all comparison pairs with Peter lake, we can find that only Ward lake (p = 0.7827) and Paul lake (0.2242) have p values larger than 0.05 when compared with Peter lake. We can list all pairs with same mean temperature statisitcally: Crampton - Central Long (p=0.06616), Ward - Crampton (p=0.9714), Hummingbird - East Long (p=0.9988), Tuesday - East Long (p=0.1657), Tuesday - Hummingbird (p=1.0000), West Long - Hummingbird (p=0.9717), Peter - Paul (p=0.2242), Ward - Paul (p=0.9917), West Long - Tuesday (p=0.7374), and Ward - Peter (0.7827). We can see that all 9 lakes appear here, thus no lake has a mean temperature that is statistically distinct from all 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 can conduct 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 you answer for part 16?

```r
crampton_ward <- PeterPaul.processed %>%
  filter(lakename %in% c('Crampton Lake', 'Ward Lake'))

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

```
##
##  Welch Two Sample t-test
##
## data:  crampton_ward$temperature_C by crampton_ward$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 r
## 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 0.2649 is greater than 0.05, meaning there is no statistically significant difference in the mean July temperature between Crampton Lake and Ward Lake. In other words, the mean temperatures are equal statistically. This result matches with Q16, despite having different p values.