Assignment 6: 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>_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(tidyverse) #loading necessary packages
library(agricolae)
library(lubridate)
library(here)
here() #checking working directory
```

```
## [1] "/Users/laura/Desktop/EDA/EDA"
```

```
lake.chem <- read.csv(
  here("Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv"),
  stringsAsFactors = TRUE) #importing raw dataset
head(lake.chem)
```

```
##   lakeid  lakename year4 daynum sampledate depth temperature_C dissolvedOxygen
## 1      L Paul Lake  1984    148    5/27/84  0.00          14.5             9.5
## 2      L Paul Lake  1984    148    5/27/84  0.25            NA              NA
## 3      L Paul Lake  1984    148    5/27/84  0.50            NA              NA
```

```
## 4      L Paul Lake  1984    148    5/27/84  0.75            NA               NA
## 5      L Paul Lake  1984    148    5/27/84  1.00          14.5              8.8
## 6      L Paul Lake  1984    148    5/27/84  1.50            NA               NA
##   irradianceWater irradianceDeck comments
## 1            1750           1620     <NA>
## 2            1550           1620     <NA>
## 3            1150           1620     <NA>
## 4             975           1620     <NA>
## 5             870           1620     <NA>
## 6             610           1620     <NA>
```

```
class(lake.chem$sampledate)
```

```
## [1] "factor"
```

```
lake.chem$sampledate <-
  mdy(lake.chem$sampledate) #changing class from factor to date
class(lake.chem$sampledate)
```

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

```
#2 creating a ggplot plot theme
mytheme <- theme_gray(base_size = 12) +
  theme(axis.text = element_text(family = "serif",
                                 color = "darkgoldenrod"),
        axis.title = element_text(family = "serif",
                                  color = "chocolate4"),
        axis.ticks = element_line(color = "darkgoldenrod",
                                  linewidth = 0.5),
        plot.title = element_text(family = "serif",
                                  face = "bold",
                                  color = "chocolate4",
                                  hjust = 0.5),
        panel.background = element_rect(fill = "white"),
        panel.grid.major = element_line(color = "darkgoldenrod",
                                        linewidth = 0.5,
                                        linetype = "solid"),
        panel.grid.minor = element_line(color = "darkgoldenrod2",
                                        linewidth = 0.25,
                                        linetype = "dashed"),
        legend.position = "bottom",
        legend.key = element_rect(color = "white"),
        legend.text = element_text(family = "serif"),
        legend.title = element_text(family = "serif"),
        legend.title.align = 0.5)
theme_set(mytheme) #setting theme as my default
```

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: The lake temperature recorded in July across all lakes does not change with depth. Ha: The lake temperature recorded in July across all lakes does change with 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)

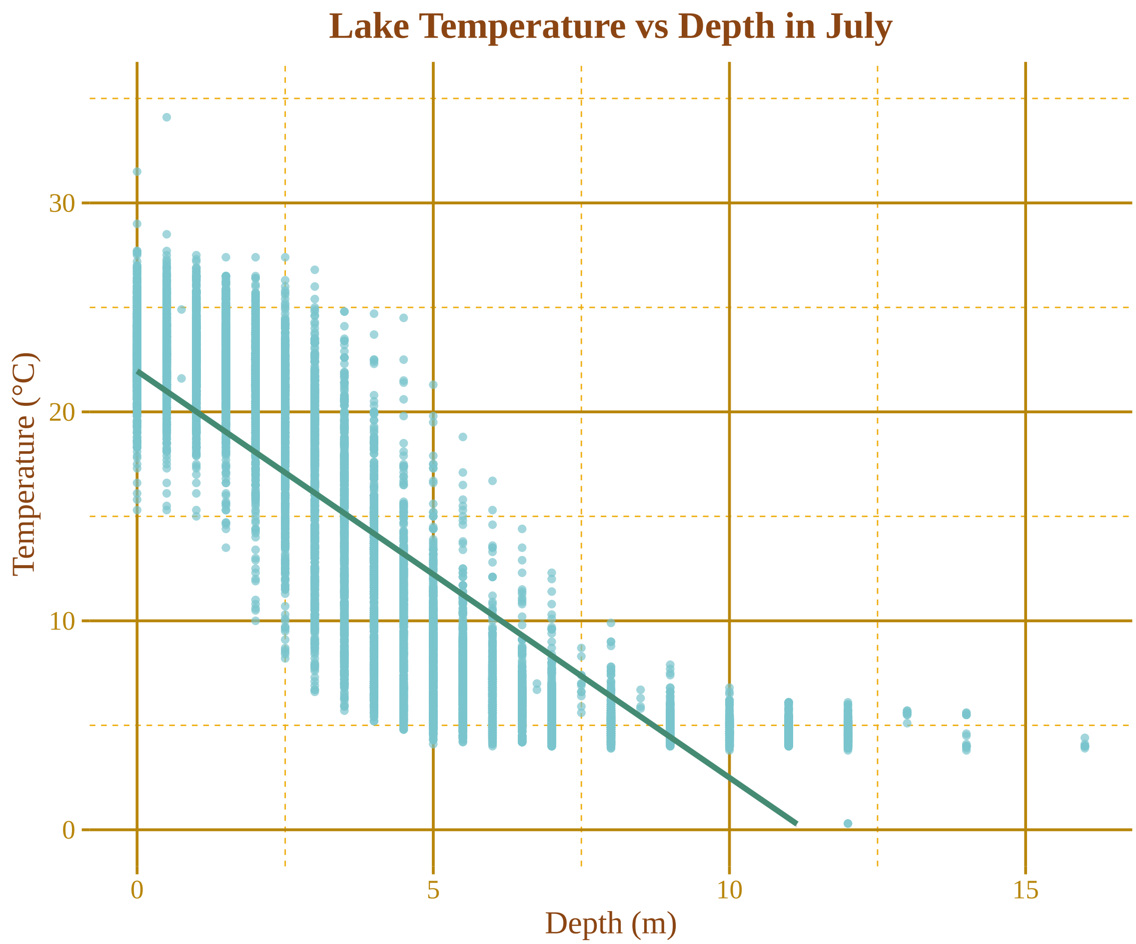
5. Visualize the relationship among the two continuous variables with a scatter plot of temperature by depth. Add a smoothed line showing the linear model, and limit temperature values from 0 to 35 °C. Make this plot look pretty and easy to read.

```
#4 wrangling dataset with a pipe function to fulfill the above requirements
lake.chem.july.proc <-
  lake.chem %>%
  filter(month(sampledate) == 7) %>%
  select("lakename", "year4", "daynum", "depth", "temperature_C") %>%
  drop_na()

#5 creating scatterplot of temperature by depth
july.proc.scatter <- ggplot(
  lake.chem.july.proc,
  aes(x = depth,
      y = temperature_C)) +
  geom_point(size=0.85, alpha=0.7, color = "cadetblue3") +
  ylim(0,35) +
  geom_smooth(method=lm, color = "aquamarine4") +
  labs(
    title = "Lake Temperature vs Depth in July",
    x = "Depth (m)",
    y = "Temperature (°C)")

print(july.proc.scatter)
```

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



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: Lake temperature decreases as depth increases, so they are inversely correlated, which is why our smoothed line has a negative slope. The distribution of points suggests that there is a linear relationship until a certain depth (around 10m), when temperature remains more constant in deeper water.

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

```
#7 performing a linear regression to test temp/depth relationship
lm.temp.depth <- lm(data = lake.chem.july.proc, temperature_C ~ depth)
summary(lm.temp.depth)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth, data = lake.chem.july.proc)
##
## 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: We found a statisically significant relationship between lake temperature and depth (p-value < 0.001). About 74 percent of variability in lake temperature could be explained by lake depth in this model ($R^2 = 0.7387$), with a degrees of freedom of 9726. For every 1m increase in depth, the temperature is predicted to decrease by ~1.95 °C.

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 running AIC to determine which set of variables if best to predict temp
aic.temp.all <- lm(data = lake.chem.july.proc, temperature_C ~ depth + year4 + daynum)
step(aic.temp.all)
```

```
## 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 = lake.chem.july.proc)
## 
## Coefficients:
## (Intercept)        depth        year4       daynum  
##    -8.57556     -1.94644      0.01134      0.03978
```

```r
#10 running multiple regression on variables from AIC
lm.temp.all <- lm(data = lake.chem.july.proc, temperature_C ~ depth + year4 + daynum)
summary(lm.temp.all)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth + year4 + daynum, data = lake.chem.july.proc)
##
## 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: The AIC method suggests the model retain all variables to predict temperature. The full model precits about 74% of the variability in temperature, which is about equal to our model with just depth.

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 running anovas as anova and as linear model
anova.lakes <- aov(data = lake.chem.july.proc, temperature_C ~ lakename)
summary(anova.lakes)
```

```
##               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
#results: reject null hypothesis i.e. difference between a pair of group means is statistically signifi

#ANOVA as linear model
anova.lm.lakes <- lm(data = lake.chem.july.proc, temperature_C ~ lakename)
summary(anova.lm.lakes)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = lake.chem.july.proc)
##
## 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: There is a significant difference in mean temperature among lakes. The ANOVA found that at least one of the mean lake temperatures was significantly different (p-value < 0.001), while the ANOVA as a linear model found a statistical difference among all 9 lakes with at least one other lake (all p-values < 0.003). Our linear model found that only about 3% of the variance in mean temperature could be explained by which lake it was.

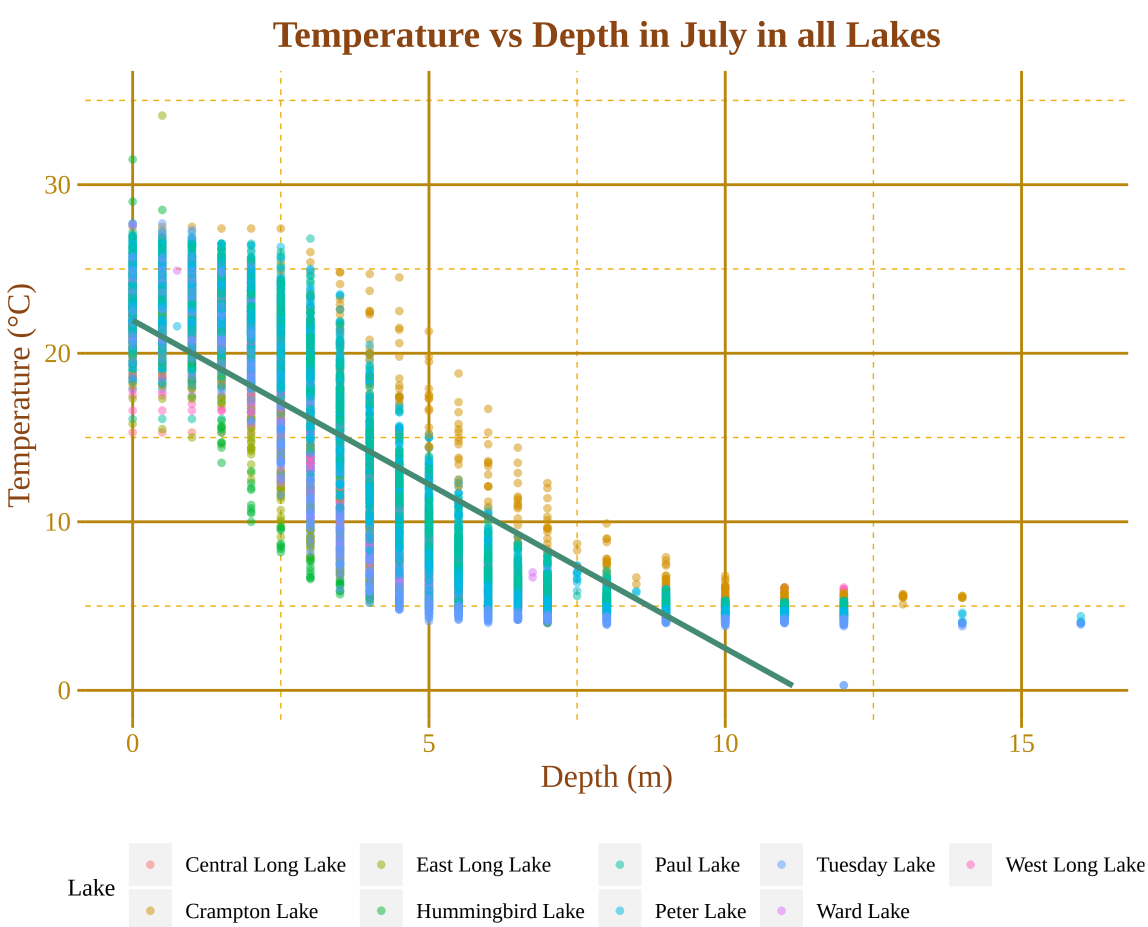
14. Create a graph that depicts temperature by depth, with a separate color for each lake. Add a geom_smooth (method = "lm", se = FALSE) for each lake. Make your points 50 % transparent. Adjust your y axis limits to go from 0 to 35 degrees. Clean up your graph to make it pretty.

```r
#14 creating scatterplot of temperature by depth by lake
by.lake.scatter <- ggplot(
  lake.chem.july.proc,
  aes(x = depth,
      y = temperature_C,
      color = lakename)) +
  geom_point(size=0.85, alpha=0.5) +
  ylim(0,35) +
```

```
  geom_smooth(method=lm, se = F, color = "aquamarine4") +
  labs(
    title = "Temperature vs Depth in July in all Lakes",
    x = "Depth (m)",
    y = "Temperature (°C)",
    col = "Lake") +
  theme(legend.text = element_text(size = 8),
        legend.title = element_text(size = 9))

print(by.lake.scatter)
```

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



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

```
#15 using tukey test to determine if lakes have different means
TukeyHSD(anova.lakes)
```

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

```
##
## $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: Statistically speaking, Peter Lake has the same mean temperature as Paul Lake and Ward Lake. None of the lakes have 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 could also run a two-sample t-test to see if Peter and Paul Lakes have distinct mean temperatures.

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?

```
#wrangling dataset to only have data for Crampton and Ward lakes
cramp.ward <-
  lake.chem.july.proc %>%
  filter(lakename == "Crampton Lake" | lakename == "Ward Lake")

#two-sample t-test
cramp.ward.ttest <- t.test(cramp.ward$temperature_C ~ cramp.ward$lakename)
cramp.ward.ttest
```

```
##
##  Welch Two Sample t-test
##
## data:  cramp.ward$temperature_C by cramp.ward$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: The t-test results accept the null hypothesis that the difference in mean temperature between Crampton and Ward Lakes is 0, meaning there is no statistically significant difference in mean temperature between these two lakes (p-value ~ 0.26). This result does match the result from the Tukey test.