Assignment 7: GLMs (Linear Regressios, ANOVA, & t-tests)

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Fall 2023

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     1.1.3     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
```

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

```
## here() starts at /Users/lucywang/Documents/EDE_Fall2023
```

```
library(lubridate)
here()
```

```
## [1] "/Users/lucywang/Documents/EDE_Fall2023"
```

```
NTL.Lake.ChemistryPhysics <- read.csv(here("Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv"), stringsA

#2
mytheme <- theme_classic(base_size = 11) +
  theme(axis.text = element_text(color = "black"),
        plot.title = element_text(hjust = 0.5),
        legend.position = "top",
        legend.title = element_blank())
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: There is no significant change in mean lake tempeatures during July across all lakes. Ha: This is a significant change in mean lake temperatures during July across lakes.

4. Wrangle your NTL-LTER dataset with a pipe function so that the records meet the following criteria:

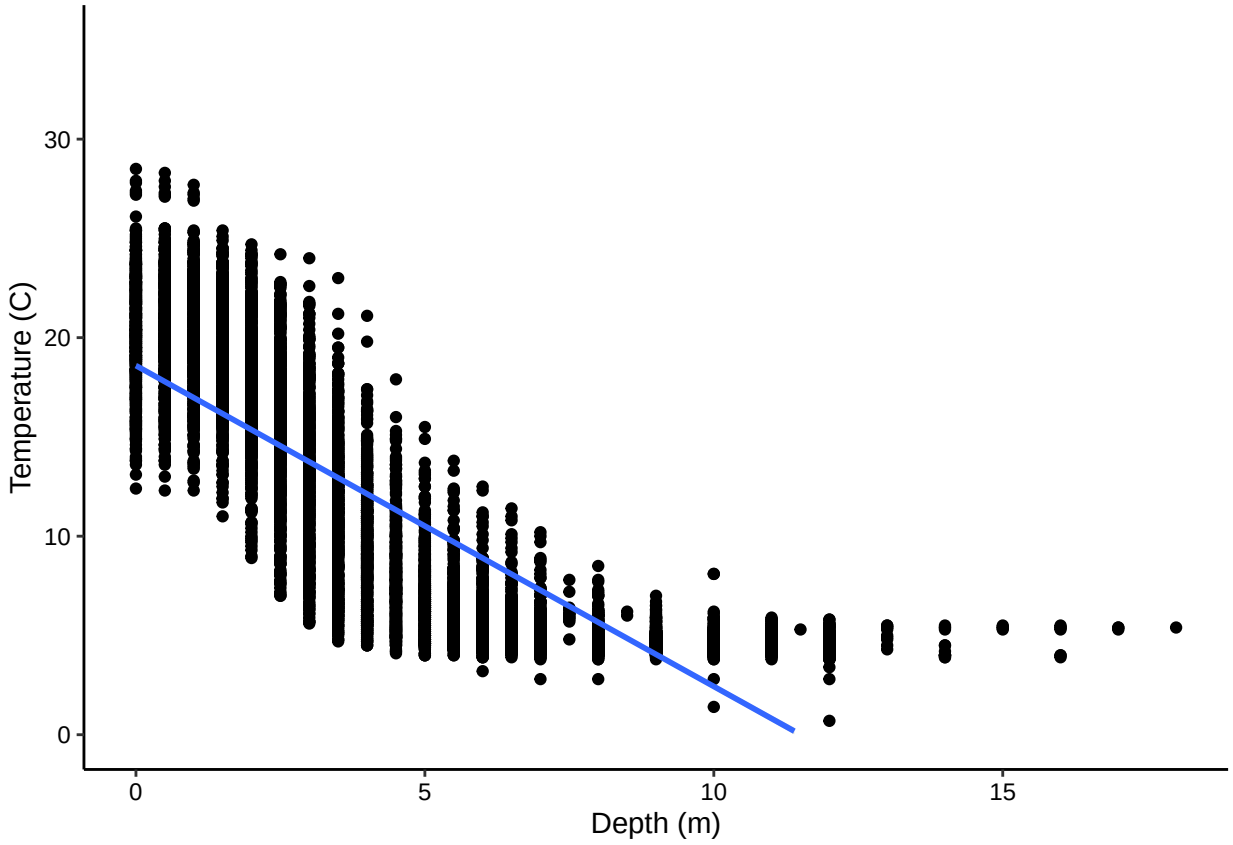
- Only dates in July.
- Only the columns: `lakename`, `year4`, `daynum`, `depth`, `temperature_C`
- Only complete cases (i.e., remove NAs)

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.

```
#4
NTL.Lake.ChemistryPhysics$sampledate <- mdy(NTL.Lake.ChemistryPhysics$sampledate)

NTL.Lake.ChemPhys.July <-
  NTL.Lake.ChemistryPhysics %>%
  mutate(month = month(sampledate)) %>%
  filter(month == 6) %>%
  select(lakename, year4, daynum, depth, temperature_C) %>%
  drop_na()


#5
TempByDepth_scatterplot <- ggplot(NTL.Lake.ChemPhys.July,
                                  aes(x=depth, y=temperature_C))+

  geom_point()+
  geom_smooth(method = 'lm')+
```

```
  ylim(0, 35)+
  labs(y='Temperature (C)', x='Depth (m)')

print(TempByDepth_scatterplot)
```

```
## `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: The figure suggests that the temperature decreases as the depth increases (when the depth is smaller than 10). When depth is smaller than 10, it shows a negative linearity between the two variables. When depth is greater than 10, there is no linearity showing the same linear trend.

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

```
#7
TempByDepth.regression <- lm(data=NTL.Lake.ChemPhys.July,
                             temperature_C ~ depth)
summary(TempByDepth.regression)
```

```
##
## Call:
```

```
## lm(formula = temperature_C ~ depth, data = NTL.Lake.ChemPhys.July)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -8.2359 -2.8873 -0.2792  2.6694 15.8990
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 18.59256    0.06427   289.3   <2e-16 ***
## depth       -1.61620    0.01100  -146.9   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.582 on 9501 degrees of freedom
## Multiple R-squared:  0.6943, Adjusted R-squared:  0.6942
## F-statistic: 2.158e+04 on 1 and 9501 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: 69.43% of the variability in temperature is explained by changes in depth. The degrees of freedom this finding is based is 9501. The p-value is 2.2e-16, which is lower than the signficance level of 0.05, suggesting that this result is significant. Temperature is predicted to decrease by 1.62 C for every 1m change in depth.

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
Temp.AIC <- lm(data=NTL.Lake.ChemPhys.July,
               temperature_C ~ year4 + daynum + depth)
step(Temp.AIC)
```

```
## Start:  AIC=23932.45
## temperature_C ~ year4 + daynum + depth
##
##          Df Sum of Sq    RSS   AIC
## <none>                 117822 23932
## - year4   1        31 117853 23933
## - daynum  1      4040 121862 24251
## - depth   1    276513 394335 35410
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = NTL.Lake.ChemPhys.July)
##
## Coefficients:
## (Intercept)        year4       daynum        depth
##   18.805558    -0.006318     0.074440    -1.615432
```

```
#10
Temp.model <- lm(data = NTL.Lake.ChemPhys.July, temperature_C ~ year4 + daynum + depth)
summary(Temp.model)
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = NTL.Lake.ChemPhys.July)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -8.6228 -2.8170 -0.1937  2.7410 15.7528
##
## Coefficients:
##              Estimate Std. Error  t value Pr(>|t|)
## (Intercept) 18.805558   7.973540    2.358   0.0184 *
## year4       -0.006318   0.003970   -1.591   0.1116
## daynum       0.074440   0.004125   18.047   <2e-16 ***
## depth       -1.615432   0.010819 -149.308   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.522 on 9499 degrees of freedom
## Multiple R-squared:  0.7045, Adjusted R-squared:  0.7044
## F-statistic:  7549 on 3 and 9499 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 final set of explanatory variables that the AIC method suggests we use to predict temperature are year4, daynum, and depth. This model explains 70.45% of the variance, which is an improvement over the previous model using only depth as the explanatory variable.

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
# Format ANOVA as aov
temp.lake.anova <- aov(data = NTL.Lake.ChemPhys.July, temperature_C ~ lakename)
summary(temp.lake.anova)
```

```
##               Df Sum Sq Mean Sq F value Pr(>F)
## lakename       8  12019  1502.4   36.88 <2e-16 ***
## Residuals   9494 386708    40.7
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
# Format ANOVA as lm
temp.lake.anova2 <- lm(data = NTL.Lake.ChemPhys.July, temperature_C ~ lakename)
summary(temp.lake.anova2)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = NTL.Lake.ChemPhys.July)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -10.405  -5.358  -2.914   5.886  19.302
##
## Coefficients:
##                            Estimate Std. Error t value Pr(>|t|)
## (Intercept)                 15.6992     0.5802  27.058  < 2e-16 ***
## lakenameCrampton Lake       -2.8291     0.6918  -4.090 4.36e-05 ***
## lakenameEast Long Lake      -6.5010     0.6169 -10.538  < 2e-16 ***
## lakenameHummingbird Lake    -6.7827     0.8428  -8.048 9.44e-16 ***
## lakenamePaul Lake           -4.0856     0.5935  -6.884 6.20e-12 ***
## lakenamePeter Lake          -4.5938     0.5926  -7.752 9.99e-15 ***
## lakenameTuesday Lake        -6.1413     0.6036 -10.174  < 2e-16 ***
## lakenameWard Lake           -2.5904     0.8139  -3.183  0.00146 **
## lakenameWest Long Lake      -5.3559     0.6124  -8.746  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 6.382 on 9494 degrees of freedom
## Multiple R-squared:  0.03014,    Adjusted R-squared:  0.02933
## F-statistic: 36.88 on 8 and 9494 DF,  p-value: < 2.2e-16
```

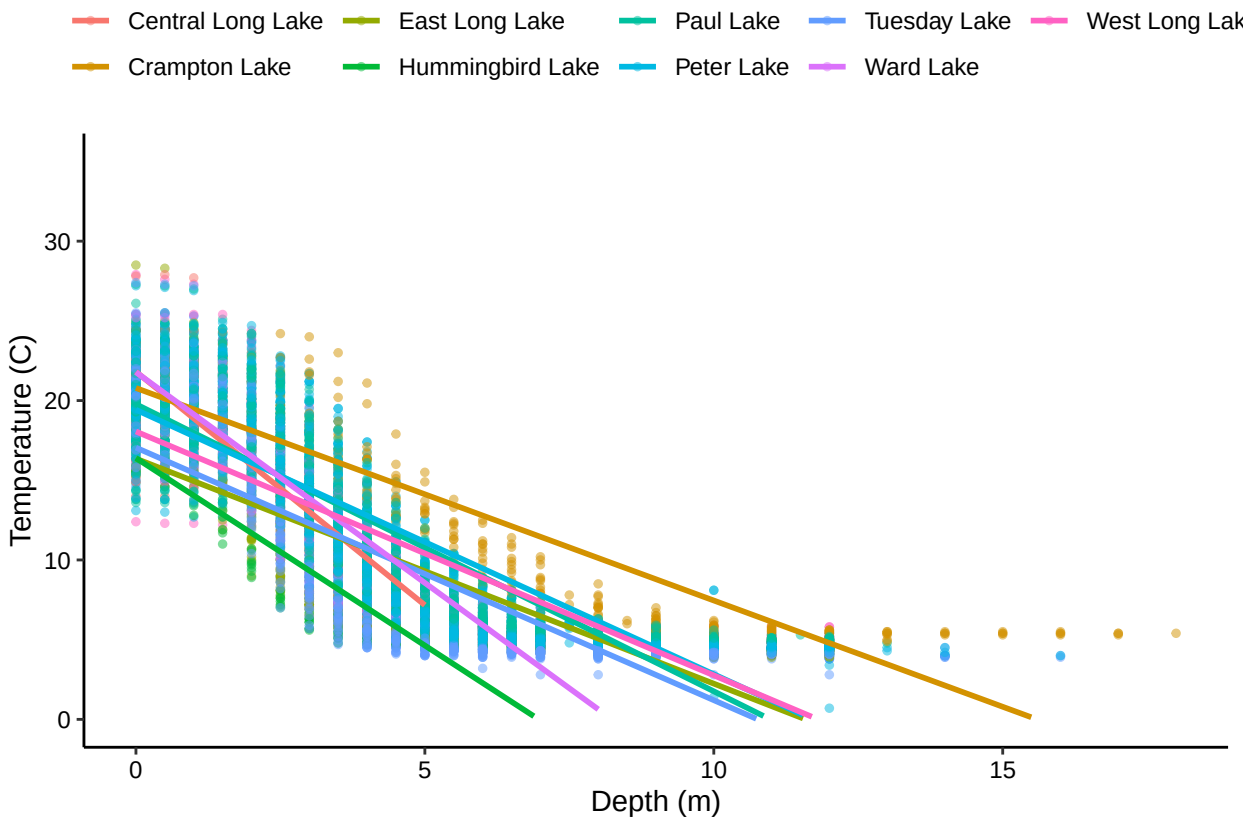
13. Is there a significant difference in mean temperature among the lakes? Report your findings.

    Answer: Yes, there is a significant difference in mean temperature among the lakes. The P value is smaller than 0.05, which means that we reject the null hypothesis. Therefore, there is a significant difference in mean temperature across the lakes.

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.
TempByDepth.plot <- ggplot(NTL.Lake.ChemPhys.July, aes(y=temperature_C, x=depth, color=lakename))+
  geom_point(alpha=0.5, size=1)+
  geom_smooth(method='lm', se=FALSE)+
  ylim(0,35)+
  labs(x='Depth (m)', y='Temperature (C)', fill='')

print(TempByDepth.plot)
```

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



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

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

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = temperature_C ~ lakename, data = NTL.Lake.ChemPhys.July)
##
## $lakename
##                                       diff         lwr         upr     p adj
## Crampton Lake-Central Long Lake    -2.8291387 -4.97533050 -0.68294692 0.0014395
## East Long Lake-Central Long Lake   -6.5010074 -8.41491151 -4.58710334 0.0000000
```

```
## Hummingbird Lake-Central Long Lake -6.7826598 -9.39740915 -4.16791044 0.0000000
## Paul Lake-Central Long Lake        -4.0856227 -5.92698164 -2.24426374 0.0000000
## Peter Lake-Central Long Lake       -4.5938464 -6.43239794 -2.75529489 0.0000000
## Tuesday Lake-Central Long Lake     -6.1412824 -8.01392896 -4.26863584 0.0000000
## Ward Lake-Central Long Lake        -2.5903736 -5.11555124 -0.06519587 0.0392367
## West Long Lake-Central Long Lake   -5.3558591 -7.25566616 -3.45605194 0.0000000
## East Long Lake-Crampton Lake       -3.6718687 -5.00938971 -2.33434772 0.0000000
## Hummingbird Lake-Crampton Lake     -3.9535211 -6.18126607 -1.72577609 0.0000013
## Paul Lake-Crampton Lake            -1.2564840 -2.48796128 -0.02500667 0.0413505
## Peter Lake-Crampton Lake           -1.7647077 -2.99198326 -0.53743215 0.0002831
## Tuesday Lake-Crampton Lake         -3.3121437 -4.58993033 -2.03435704 0.0000000
## Ward Lake-Crampton Lake             0.2387652 -1.88313397  2.36066428 0.9999938
## West Long Lake-Crampton Lake       -2.5267203 -3.84399049 -1.20945020 0.0000001
## Hummingbird Lake-East Long Lake    -0.2816524 -2.28658065  1.72327592 0.9999656
## Paul Lake-East Long Lake            2.4153847  1.65813576  3.17263372 0.0000000
## Peter Lake-East Long Lake           1.9071610  1.15676448  2.65755754 0.0000000
## Tuesday Lake-East Long Lake         0.3597250 -0.47071364  1.19016370 0.9180513
## Ward Lake-East Long Lake            3.9106339  2.02401108  5.79725666 0.0000000
## West Long Lake-East Long Lake       1.1451484  0.25515383  2.03514292 0.0021540
## Paul Lake-Hummingbird Lake          2.6970371  0.76123976  4.63283444 0.0005285
## Peter Lake-Hummingbird Lake         2.1888134  0.25568630  4.12194045 0.0132248
## Tuesday Lake-Hummingbird Lake       0.6413774 -1.32420489  2.60695968 0.9848376
## Ward Lake-Hummingbird Lake          4.1922862  1.59743925  6.78713323 0.0000193
## West Long Lake-Hummingbird Lake     1.4268007 -0.56467500  3.41827648 0.3907140
## Peter Lake-Paul Lake               -0.5082237 -1.04736090  0.03091344 0.0830294
## Tuesday Lake-Paul Lake             -2.0556597 -2.70157171 -1.40974770 0.0000000
## Ward Lake-Paul Lake                 1.4952491 -0.31773721  3.30823548 0.2044231
## West Long Lake-Paul Lake           -1.2702364 -1.99111377 -0.54935896 0.0000017
## Tuesday Lake-Peter Lake            -1.5474360 -2.18530058 -0.90957138 0.0000000
## Ward Lake-Peter Lake                2.0034729  0.19333794  3.81360778 0.0173703
## West Long Lake-Peter Lake          -0.7620126 -1.47568845 -0.04833682 0.0259997
## Ward Lake-Tuesday Lake              3.5509088  1.70615361  5.39566407 0.0000001
## West Long Lake-Tuesday Lake         0.7854233 -0.01198909  1.58283578 0.0573522
## West Long Lake-Ward Lake           -2.7654855 -4.63780592 -0.89316507 0.0001611
```

```
Lake.groups <- HSD.test(temp.lake.anova, "lakename", group = TRUE)
Lake.groups
```

```
## $statistics
##    MSerror   Df     Mean       CV
##   40.73187 9494 10.84711 58.83735
##
## $parameters
##    test   name.t ntr StudentizedRange alpha
##   Tukey lakename   9         4.387528  0.05
##
## $means
##                   temperature_C      std    r        se Min  Max   Q25   Q50
## Central Long Lake     15.699174 4.949840  121 0.5801957 7.5 27.9 11.40 15.60
## Crampton Lake         12.870035 6.332280  287 0.3767266 4.8 24.4  6.25 12.30
## East Long Lake         9.198166 6.073995  927 0.2096174 3.9 28.5  4.70  5.80
## Hummingbird Lake       8.916514 5.430427  109 0.6112993 4.4 22.2  4.70  5.70
## Paul Lake             11.613551 6.312567 2605 0.1250441 3.9 27.3  5.60  9.50
## Peter Lake            11.105327 6.562172 2797 0.1206760 0.7 27.2  5.00  8.40
```

```
## Tuesday Lake           9.557891 6.633437 1470 0.1664595 2.8 27.4  4.30  5.60
## Ward Lake             13.108800 6.147108  125 0.5708371 5.6 25.2  7.00 12.10
## West Long Lake        10.343315 6.251091 1062 0.1958416 4.5 27.9  5.20  6.85
##                      Q75
## Central Long Lake 19.8
## Crampton Lake     18.4
## East Long Lake    13.7
## Hummingbird Lake  12.8
## Paul Lake         17.6
## Peter Lake        17.5
## Tuesday Lake      15.4
## Ward Lake         18.4
## West Long Lake    15.8
##
## $comparison
## NULL
##
## $groups
##                   temperature_C groups
## Central Long Lake     15.699174      a
## Ward Lake             13.108800      b
## Crampton Lake         12.870035      b
## Paul Lake             11.613551     bc
## Peter Lake            11.105327      c
## West Long Lake        10.343315      d
## Tuesday Lake           9.557891     de
## East Long Lake         9.198166      e
## Hummingbird Lake       8.916514      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: From HSD test, Paul Lake has the same mean temperature as Peter Lake. Central Long Lake has a mean temperature that is statistically distinct from all the 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 might want to explore 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?

```
NTL.July.CramptonWard <- NTL.Lake.ChemPhys.July %>%
  filter(lakename %in% c('Crampton Lake', 'Ward Lake'))

CramptonWard.twosample <- t.test(NTL.July.CramptonWard$temperature_C ~ NTL.July.CramptonWard$lakename)
CramptonWard.twosample
```

```
##
##  Welch Two Sample t-test
##
## data:  NTL.July.CramptonWard$temperature_C by NTL.July.CramptonWard$lakename
## t = -0.35913, df = 242.64, p-value = 0.7198
## alternative hypothesis: true difference in means between group Crampton Lake and group Ward Lake is n
## 95 percent confidence interval:
##  -1.548355  1.070825
## sample estimates:
## mean in group Crampton Lake     mean in group Ward Lake
##                    12.87003                    13.10880
```

Answer: The p value is 0.72, which is greater than 0.05, which means that we cannot reject the null hypothesis. The mean temperature between the two lakes are the same. This result matches with the finding in the HSD test – the mean temperatures of Ward Lake and Crampton Lake are identical.