

# 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. Set up session.
```

```
#Check working directory.
```

```
getwd()
```

```
## [1] "/home/guest/ede_fall2024"
```

```
#Load required packages.
```

```
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
```

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

```
## here() starts at /home/guest/ede_fall2024
```

```
library(agricolae)

#Import raw NTL-LTER data.
NTL.LTER.raw <- read.csv(here("Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv"),
                        stringsAsFactors = TRUE)
#Check the class of the date column.
class(NTL.LTER.raw$sampleddate)
```

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

```
#Convert to date.
NTL.LTER.raw$sampleddate <- as.Date(NTL.LTER.raw$sampleddate, format = "%m/%d/%y")
#Check that it's in date format.
class(NTL.LTER.raw$sampleddate)
```

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

```
#2. Build ggplot theme.
mytheme <- theme_minimal(base_size = 12) +
  theme(axis.text = element_text(color = "black"),
        legend.position = "right",
        legend.text = element_text(size = 8),
        legend.title = element_text(size = 8),
        plot.title = element_text(hjust = 0.5))
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. Ha: Mean lake temperature recorded during July does change with depth across all 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. Wrangle the NTL-LTER dataset so it meets the criteria listed above.

#Wrangle the data.

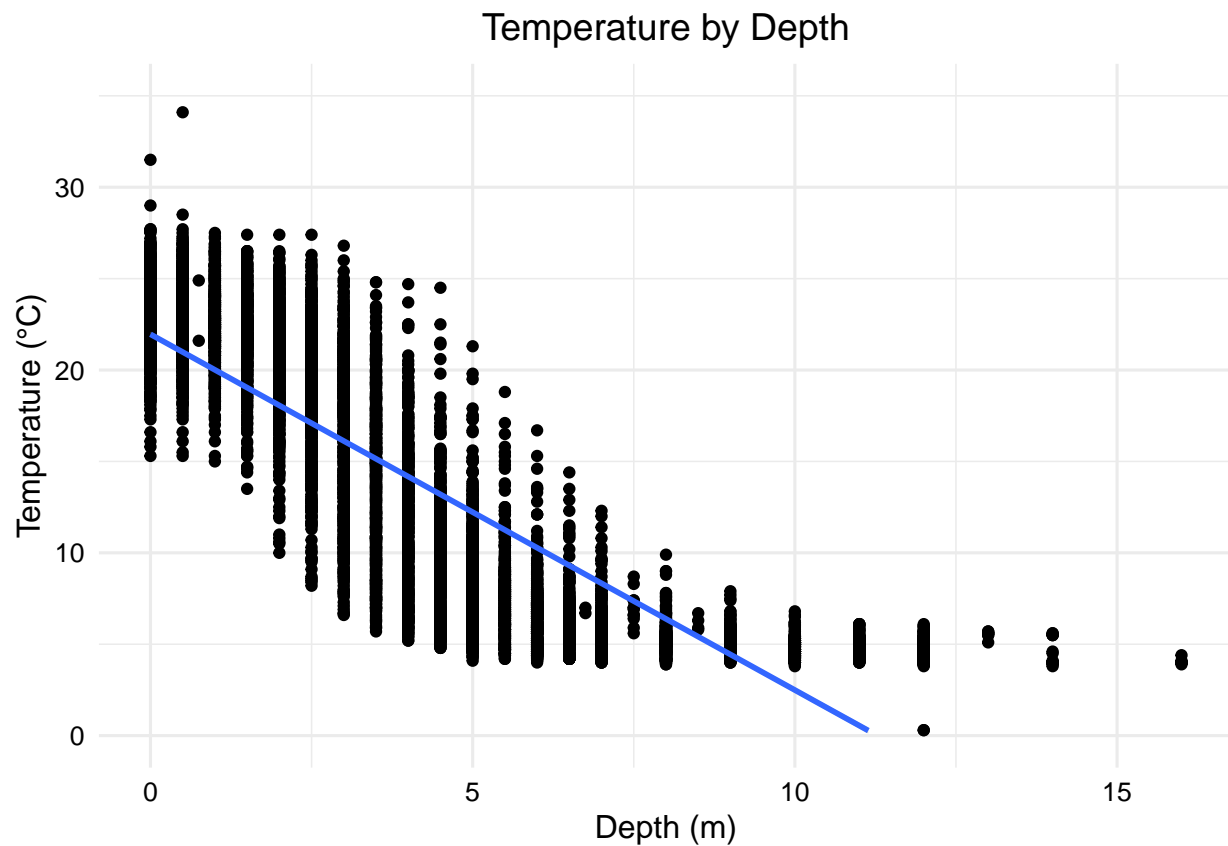
```
NTL.LTER_wrangled <- NTL.LTER.raw %>%  
  mutate(month = month(sampledate)) %>% #create a month column  
  filter(month == 7) %>% #filter for July only  
  select(lakename, year4, daynum, depth, temperature_C) %>%  
  drop_na(temperature_C)
```

#5. Create a scatterplot of temperature by depth.

```
ggplot(NTL.LTER_wrangled, aes(x = depth, y = temperature_C)) +  
  geom_point() + #specifies scatterplot  
  ylim(0, 35) + #changes y-axis limit to 0 to 35 degrees  
  mytheme + #adds my theme  
  labs(x = "Depth (m)",  
       y = "Temperature (°C)",  
       title = "Temperature by Depth") + #adds titles  
  geom_smooth(method = "lm") #adds linear model line
```

## '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 temperature increases as depth decreases; there is a negative relationship. The distribution of points suggests that this trend is linear.

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

```
#7. Perform a linear regression to test the relationship.
```

```
temp.depth.regression <- lm(  
  data = NTL.LTER_wrangled,  
  temperature_C ~ depth)
```

```
#Display the results.
```

```
summary(temp.depth.regression)
```

```
##  
## Call:  
## lm(formula = temperature_C ~ depth, data = NTL.LTER_wrangled)  
##  
## 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
```

```
#Find the correlation.
```

```
cor.test(NTL.LTER_wrangled$temperature_C, NTL.LTER_wrangled$depth)
```

```
##  
## Pearson's product-moment correlation  
##  
## data:  NTL.LTER_wrangled$temperature_C and NTL.LTER_wrangled$depth  
## t = -165.83, df = 9726, p-value < 2.2e-16  
## alternative hypothesis: true correlation is not equal to 0  
## 95 percent confidence interval:  
##  -0.8646036 -0.8542169  
## sample estimates:  
##      cor  
## -0.8594989
```

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: Our model suggests that there is a statistically significant negative relationship between temperature and depth. About 73.9% of the variability in temperature is explained by changes in depths. This finding is based on 9726 degrees of freedom (degrees of freedom are associated with the number of observations we have and the number of variables we are considering). Since the p-value is less than 0.05, it is statistically significant. Temperature is predicted to change by about -1.9 degrees 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. Run an AIC to determine what set of explanatory variables is best suited  
#to predict temperature.
```

```
temp_AIC <- lm(data = NTL.LTER_wrangled, 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_wrangled)  
##  
## Coefficients:  
## (Intercept)      year4      daynum      depth  
##   -8.57556      0.01134      0.03978     -1.94644
```

```
#10. Run a multiple regression on the recommended set of variables.
```

```
TempBest.reg <- lm(data = NTL.LTER_wrangled, temperature_C ~ year4 + daynum +  
                  depth)  
summary(TempBest.reg)
```

```
##  
## Call:  
## lm(formula = temperature_C ~ year4 + daynum + depth, data = NTL.LTER_wrangled)
```

```
##
## 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: The final set of explanatory variables that the AIC method suggests we use includes year, day number, and depth. This model explains about 74% of the observed variance. This is a very slight improvement over the model using only depth as the explanatory variable (73.9% for depth only versus 74.1% for the entire set of variables).

---

## 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. #Run an ANOVA test.
NTL.LTER.anova <- aov(data = NTL.LTER_wrangled, temperature_C ~ lakename)
summary(NTL.LTER.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 a linear model.
NTL.LTER.anova2 <- lm(data = NTL.LTER_wrangled, temperature_C ~ lakename)
summary(NTL.LTER.anova2)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = NTL.LTER_wrangled)
##
## 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. However, the ANOVA results do not identify which particular differences between pairs of means are statistically significant.

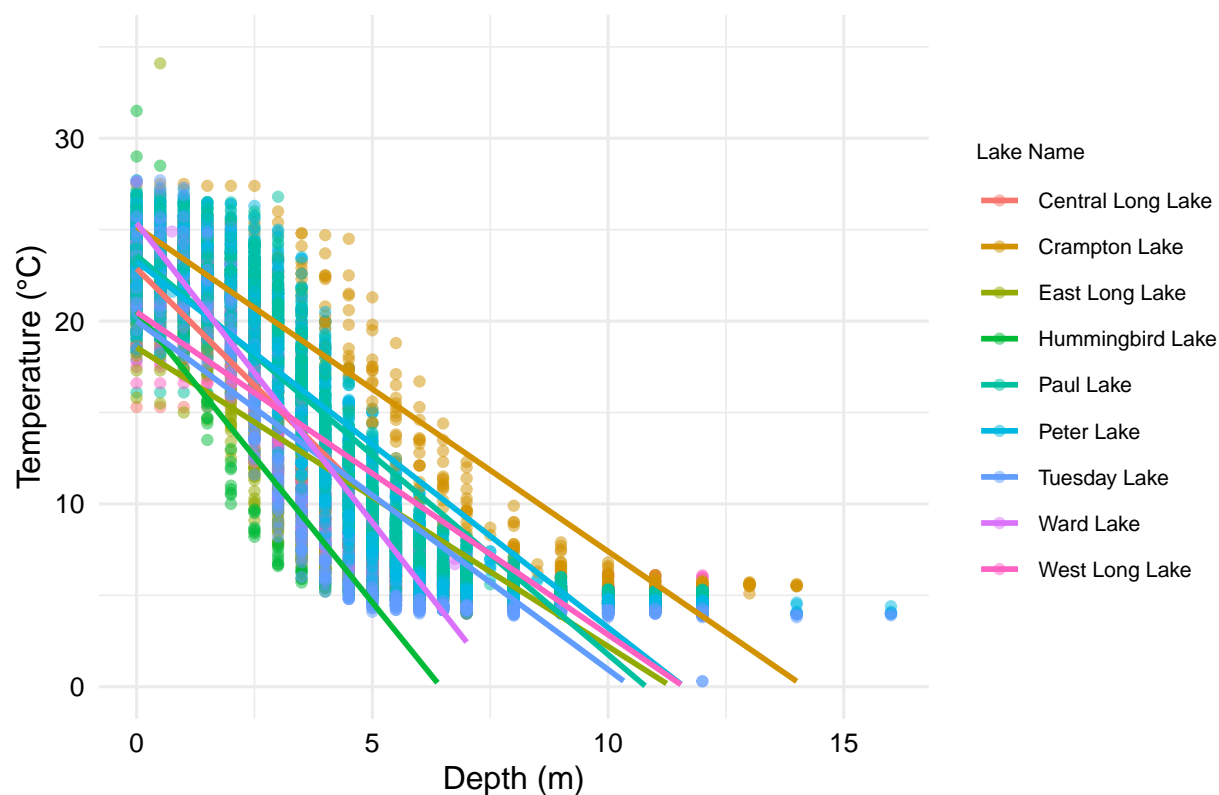
14. Create a graph that depicts temperature by depth, with a separate color for each lake. Add a `geom_smooth` (method = "lm", se = FALSE) for each lake. Make your points 50 % transparent. Adjust your y axis limits to go from 0 to 35 degrees. Clean up your graph to make it pretty.

```
#14.
ggplot(NTL.LTER_wrangled, aes(x = depth, y = temperature_C, color = lakename)) +
  geom_point(alpha = 0.5) + #changes the transparency
  ylim(0, 35) + #changes the y axis limit to go from 0 to 35 degrees
  mytheme + #adds my theme
  labs(x = "Depth (m)",
       y = "Temperature (°C)",
       title = "Temperature by Depth for Each Lake",
       color = "Lake Name") + #adds titles
  geom_smooth(method = "lm", se = FALSE) #adds linear model without standard error
```

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

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

## Temperature by Depth for Each Lake



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

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

`TukeyHSD(NTL.LTER.anova)`

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

```
NTL.LTER.groups <- HSD.test(NTL.LTER.anova, "lakename", group = TRUE)
NTL.LTER.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: Statistically speaking, Ward Lake and Paul Lake have the same mean temperature as Peter Lake. No 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 use the 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 your answer for part 16?

```
#Wrangle the July data to include only records for Crampton Lake and Ward Lake.
Crampton.Ward <- NTL.LTER_wrangled %>%
  filter(lakename == "Crampton Lake" | lakename == "Ward Lake")

#Run the two-sample T-test to determine whether their July temperatures are
#the same or different.
crampton.ward.twosample <- t.test(
  Crampton.Ward$temperature_C ~ Crampton.Ward$lakename)
crampton.ward.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 not equal to 0
## 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 mean temperatures for the lakes are not significantly different according to our t-test. This matches our answer for part 16. The mean for Crampton Lake is 15.4 and the mean for Ward lake is 14.5, but since the p-value is greater than 0.05, this difference is not statistically significant.