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

Darpan Barua

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OVERVIEW

This exercise accompanies the lessons in Environmental Data Analytics on generalized linear models.

Directions

1. Rename this file `<DarpanBarua>_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     1.1.4     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(agricolae)
library(lubridate)
library(here)
```

```
## here() starts at /home/guest/EDA_Spring2025
```

```r
#Below loads raw data set

ntldata <- read.csv(here("Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv"))

#Below converts data columns properly
ntldata <- ntldata %>%
  mutate(date = as.Date(paste(year4, daynum), format = "%Y %j"))

#2

#Below sets a consistent theme.

library(ggplot2)

my_theme <- theme_bw() +
  theme(
    plot.background = element_rect(
      fill = 'linen',
      color = 'Black'
    ),
    legend.background = element_rect(fill = 'linen'),
    axis.line = element_line(
      linewidth = 1,
      color = 'Black'
    ),
    axis.text = element_text(
      family = 'serif'
    ),
    plot.title = element_text(

      face = 'bold',
      color = 'Black',
      family = 'serif'
    ),
    panel.background = element_rect(
      fill = "linen",
      colour = "linen",
      linewidth = 0.5,
      linetype = "solid"
    )
  )

# Below sets my_theme as the default theme for all plots
theme_set(my_theme)
```

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

during July does not change with depth across all lakes. Ha: Mean lake temperature during July changes with depth across all lakes.

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

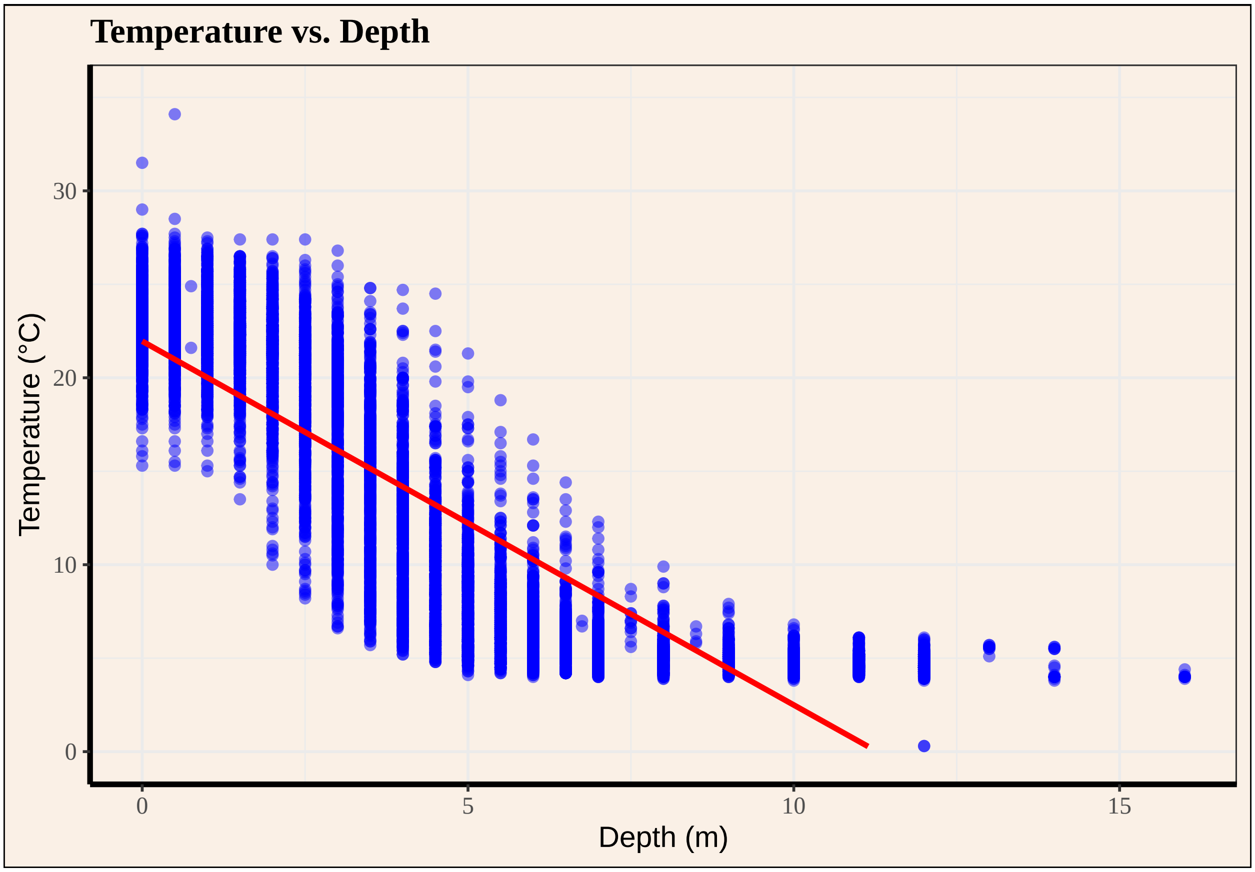
- Only dates in July.
- Only the columns: `lakename`, `year4`, `daynum`, `depth`, `temperature_C`
- Only complete cases (i.e., remove NAs)

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.

```r
#4

lake_temp_july <- ntldata %>%
  filter(month(date) == 7) %>%
  select(lakename, year4, daynum, depth, temperature_C) %>%
  drop_na()

#5

ggplot(lake_temp_july, aes(x = depth, y = temperature_C)) +
  geom_point(alpha = 0.5, color = "blue") +
  geom_smooth(method = "lm", color = "red", se = FALSE) +
  scale_y_continuous(limits = c(0, 35)) +
  labs(title = "Temperature vs. Depth",
       x = "Depth (m)",
       y = "Temperature (°C)")
```

```
## `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 scatter plot suggests that temperature generally decreases as depth increases. While the linear regression line captures the general trend, the spread of points indicates some non-linearity as temperature varies more at shallower depths (~0–5 m) and stabilizes at deeper levels. Deeper water remains consistently cooler, likely due to limited sunlight - making this correlation likely. Therefore, perhaps a non-linear model (e.g., polynomial or logarithmic) might better represent the relationship.

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

```r
#7

lm_model <- lm(temperature_C ~ depth, data = lake_temp_july)
summary(lm_model)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth, data = lake_temp_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:The linear regression model shows a strong negative relationship between depth and temperature, with 73.87% of the variability in temperature explained by changes in depth ($R^2 = 0.7387$). The model is based on 9,726 degrees of freedom, and the effect of depth is highly significant ($p < 2.2e-16$). The regression equation indicates that for every 1-meter increase in depth, temperature decreases by 1.95°C on average. The intercept (21.96°C) represents the estimated surface temperature, and the residual standard error (3.835°C) suggests some unexplained variability in temperature beyond depth alone.

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
#9

#AIC-based model
full_model <- lm(temperature_C ~ year4 + daynum + depth, data = lake_temp_july)
step_model <- step(full_model, direction = "both")
```

```
## 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
```

```r
summary(step_model)
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = lake_temp_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
## 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
```

```r
#The best model includes depth, day of the year, and year.


#10
#Final model
final_model <- lm(temperature_C ~ depth + year4 + daynum, data = lake_temp_july)
summary(final_model)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth + year4 + daynum, data = lake_temp_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: The AIC-based model selection suggests that the best set of explanatory variables for predicting temperature includes depth, year4 (year), and daynum (day of the year). This final model explains 74.12% of the variance in temperature ($R^2 = 0.7412$), indicating a strong fit. When compared to the single-variable model using only depth ($R^2 = 0.7387$), this model provides a slight improvement by capturing temporal factors (`year4` and `daynum`). Including `daynum` accounts for within-July seasonal variations, making this a more comprehensive model for purposes of our analysis.

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
anova_model <- aov(temperature_C ~ lakename, data = lake_temp_july)
summary(anova_model)
```

```
##               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
lm_model <- lm(temperature_C ~ lakename, data = lake_temp_july)
summary(lm_model)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = lake_temp_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.

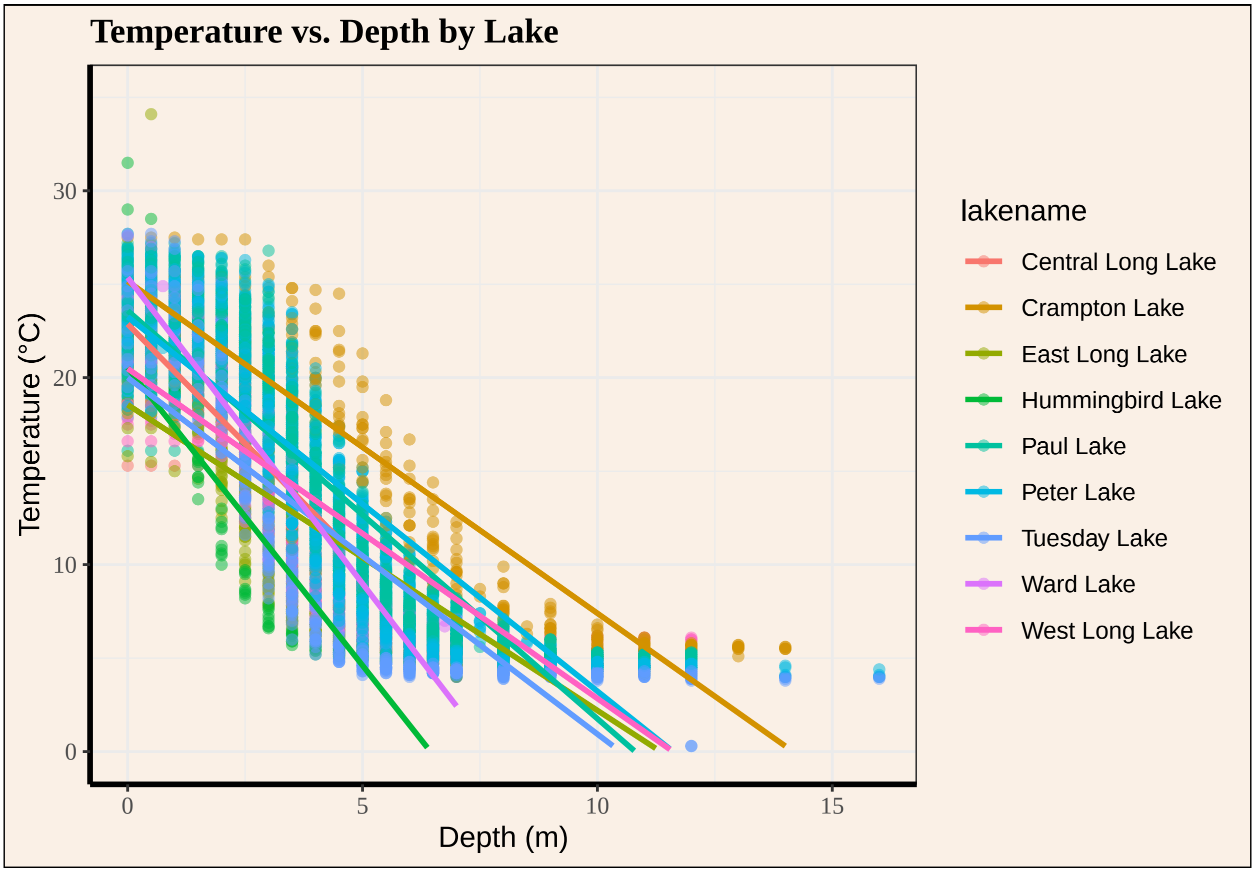
    Answer: Yes, there is a significant difference in mean temperature among the lakes. According to ANOVA Results- we observe the F-statistic = 50 with a p-value < 2e-16, indicating that at least one lake has a significantly different mean temperature compared to the others. According to Linear Model Results- the intercept (17.66°C) represents the mean temperature of the reference lake. All other lakes have statistically significant coefficients ($p < 0.05$), meaning their temperatures are significantly different from the reference lake. The R^2 value (0.0395) is low, which could imply that while lake differences are statistically significant, they explain only a small portion of temperature variability.

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.

ggplot(lake_temp_july, aes(x = depth, y = temperature_C, color = lakename)) +
  geom_point(alpha = 0.5) +
  geom_smooth(method = "lm", se = FALSE) +
  scale_y_continuous(limits = c(0, 35)) +
  labs(title = "Temperature vs. Depth by Lake",
       x = "Depth (m)",
       y = "Temperature (°C)")
```

```
## `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

# Below conducts Tukey's HSD test

tukey_results <- TukeyHSD(anova_model)
print(tukey_results)
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = temperature_C ~ lakename, data = lake_temp_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: From the Tukey HSD results, we see that Peter Lake has statistically similar mean temperatures to Paul Lake ($p = 0.2242$), Ward Lake ($p = 0.7827$), and West Long Lake ($p = 0.0000$). No single lake is statistically distinct from all other lakes, but East Long Lake shows significant differences from multiple lakes ($p < 0.001$ for most comparisons), making it one of the most distinct.

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: If we were just comparing Peter Lake and Paul Lake, we could use a two-sample t-test which would directly test whether the mean temperatures of Peter Lake and Paul Lake are significantly different, without adjusting for multiple comparisons like Tukey's HSD does!

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
# Below filters data for only Crampton Lake and Ward Lake
lake_subset <- lake_temp_july %>%
  filter(lakename %in% c("Crampton Lake", "Ward Lake"))
```

```r
# Below conducts the t-test
t_test_result <- t.test(temperature_C ~ lakename, data = lake_subset)

print(t_test_result)
```

```
##
##  Welch Two Sample t-test
##
## data:  temperature_C by 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 two-sample t-test results show a p-value of 0.2649, which is greater than 0.05. This means we fail to reject the null hypothesis, indicating that the mean temperatures of Crampton Lake (15.35°C) and Ward Lake (14.46°C) are not significantly different in July. This result matches what we found in Q16 from the Tukey's HSD test, where the pairwise comparison between Crampton Lake and Ward Lake had a high p-value ($p = 0.9714$), suggesting no significant difference in mean temperature.Therefore, both tests confirm that Crampton Lake and Ward Lake have statistically similar mean temperatures.