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.

```r
#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
```

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

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

```r
here()
```

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

```r
ChemPhy <- read.csv(file = here("./Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv"), stringsAsFactors =
ChemPhy$sampledate <- mdy(ChemPhy$sampledate)

#2
library(ggplot2)

# Define a custom theme
my_theme <- theme_classic() +
  theme(
    line = element_line(
      color = '#000080',  # Navy blue for the Ashoka Chakra
      size = 2,
      linetype = 'solid'
    ),
    rect = element_rect(
      fill = 'white',  # White background as in the flag's middle band
      colour = 'black'
    ),
    text = element_text(
      face = 'plain',
      colour = '#000080',  # Navy blue text
      size = 16
    ),

    # Customize Plot Title
    plot.title = element_text(
      face = "bold",
      size = 20,
      color = "#FF9933",  # Saffron color for the plot title
      hjust = 0.5
    ),

    # Axis Titles are blank
    axis.title.x = element_blank(),
    axis.title.y = element_blank(),

    # Customize Axis Ticks
    axis.ticks = element_line(
      color = "#138808"  # Green color for the ticks
    ),

    # Customize Major Grid Lines
    panel.grid.major = element_line(
      color = "#E5E5E5",
      size = 0.5
    ),

    # Remove Minor Grid Lines
    panel.grid.minor = element_blank(),
```

```r
    # Customize Plot Background
    plot.background = element_rect(
      fill = "#FFFFFF",  # White background
      colour = NA
    ),

    # Customize Panel Background
    panel.background = element_rect(
      fill = "#FFFFFF",
      colour = NA
    ),

    # Customize Legend Key
    legend.key = element_rect(
      fill = "#FFFFFF",
      colour = "#FF9933"  # Saffron border for legend keys
    ),

    # Set Legend Position
    legend.position = "right",

    # Ensure theme completeness
    complete = TRUE
  )
```

```
## Warning: The ‘size‘ argument of ‘element_line()‘ is deprecated as of ggplot2 3.4.0.
## i Please use the ‘linewidth‘ argument instead.
## This warning is displayed once every 8 hours.
## Call ‘lifecycle::last_lifecycle_warnings()‘ to see where this warning was
## generated.
```

```r
# Set this theme as default
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 temprature recorded during July did not change with depth across all lakes Ha: Mean lake temprature recorded during July changed 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)

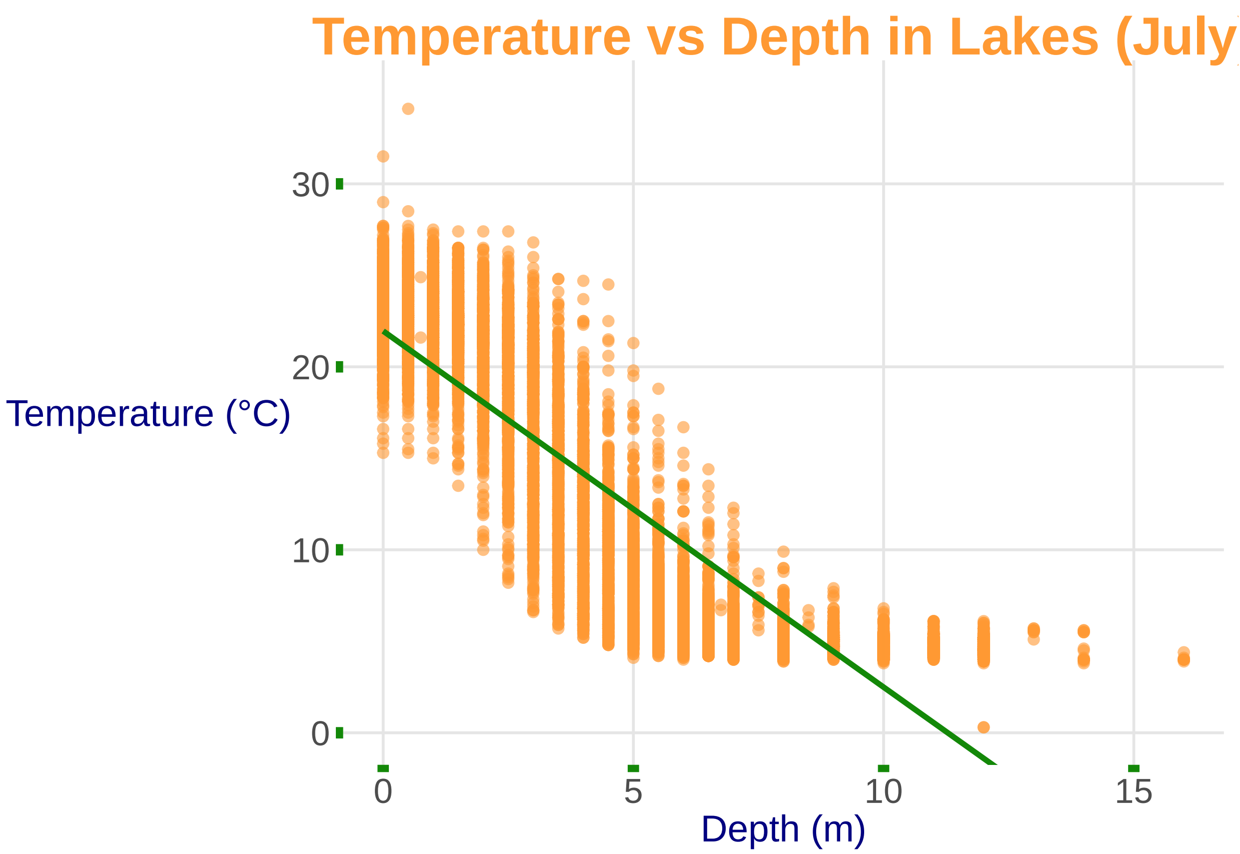
5. Visualize the relationship among the two continuous variables with a scatter plot of temperature by depth. Add a smoothed line showing the linear model, and limit temperature values from 0 to 35 °C. Make this plot look pretty and easy to read.

```r
#4
ChemPhy_Wrang <- ChemPhy %>%
                 filter(month(sampledate) == 7) %>%
                 select(lakename, year4, daynum, depth, temperature_C) %>%
                 drop_na()


#5
#Scatterplot

ggplot(ChemPhy_Wrang, aes(x = depth, y = temperature_C)) +
  geom_point(color = "#FF9933", alpha = 0.6) +
  geom_smooth(method = "lm", color = "#138808", se = TRUE) +
  labs(title = "Temperature vs Depth in Lakes (July)",
       x = "Depth (m)",
       y = "Temperature (°C)") +
  coord_cartesian(ylim = c(0, 35)) +
  theme(
    axis.title.x = element_text(color = "#000080", size = 14),
    axis.title.y = element_text(color = "#000080", size = 14)
  )
```

```
## `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 plot shows a clear negative relationship between temperature and depth. As depth increases, the temperature tends to decrease. While the linear trend line fits well, there is noticeable variability, especially at shallower depths, indicating individual measurements can vary around the trend.

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

```r
#7
ChemPhy.simp.reg <- lm(data = ChemPhy_Wrang, temperature_C ~ depth)
summary(ChemPhy.simp.reg)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth, data = ChemPhy_Wrang)
##
## 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: Variability: The model's R-squared value is 0.7387, meaning approximately 73.87% of the variability in temperature is explained by changes in depth. Degrees of Freedom: The model is based on 9726 degrees of freedom, indicating a large sample size and robust analysis. Statistical Significance: The p-value for the depth coefficient is less than 2.2e-16, which is much less than 0.05 and highly significant. Temperature Change per Meter: The coefficient for depth is -1.9461, meaning for every 1-meter increase in depth, the temperature is predicted to decrease by approximately 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.

```r
#9
ChemPhy.all.reg <- lm(data = ChemPhy_Wrang, temperature_C ~ year4 + daynum + depth)
step(ChemPhy.all.reg)
```

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

```r
summary(ChemPhy.all.reg)
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = ChemPhy_Wrang)
##
## 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
#10
ChemPhy.multi.reg <- lm(data = ChemPhy_Wrang, temperature_C ~ year4 + daynum + depth)

summary(ChemPhy.multi.reg)
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = ChemPhy_Wrang)
##
## 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 multi-variable model with year4, daynum, and depth explains 74.12% of the variance in temperature_C (R-squared = 0.7412), which is only a slight improvement over the single-variable model using depth alone, which explains 73.87% (R-squared = 0.7387). The additional predictors year4 and daynum increase the explained variance by just 0.25%. Therefore, while the multi-variable model is statistically better, the gain is minimal, suggesting that depth alone is nearly as effective in predicting temperature.

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
ChemPhy.anova <- aov(data = ChemPhy_Wrang, temperature_C ~ lakename)
summary(ChemPhy.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
ChemPhy.anova2 <- lm(data = ChemPhy_Wrang, temperature_C ~ lakename)
summary(ChemPhy.anova2)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = ChemPhy_Wrang)
##
## 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: The ANOVA test and the linear model results provide strong evidence of a significant difference in mean temperatures among the lakes. The ANOVA yields an extremely low p-value ($p < 2e\text{-}16$), indicating that mean temperatures vary significantly across lakes. Additionally, in the linear model, the t-values for most lake coefficients are highly significant, further confirming that mean temperatures differ from lake to lake.

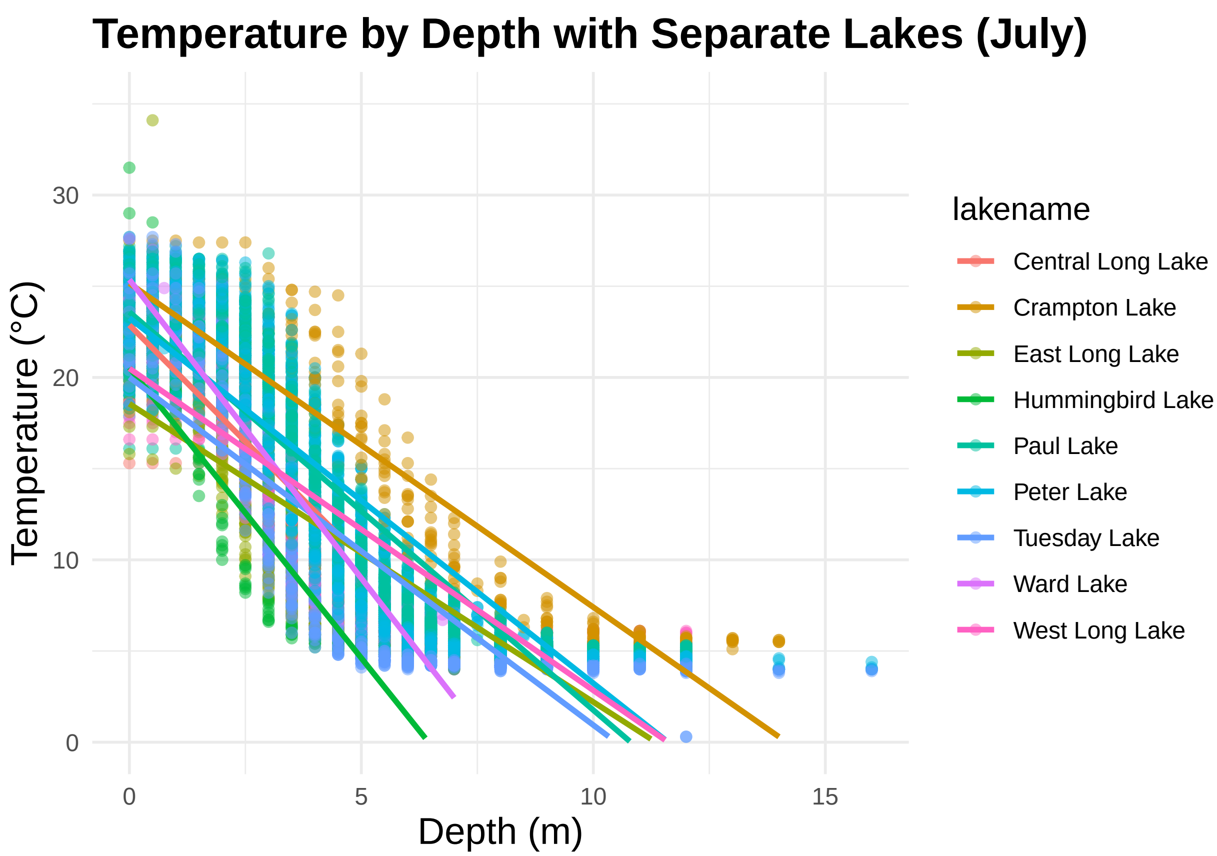
14. Create a graph that depicts temperature by depth, with a separate color for each lake. Add a geom_smooth (method = "lm", se = FALSE) for each lake. Make your points 50 % transparent. Adjust your y axis limits to go from 0 to 35 degrees. Clean up your graph to make it pretty.

```r
#14.
ggplot(ChemPhy_Wrang, 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 by Depth with Separate Lakes (July)",
       x = "Depth (m)",
       y = "Temperature (°C)") +
  theme_minimal() +  # Use your custom theme if set globally
  theme(
    plot.title = element_text(size = 16, face = "bold"),
```

```r
    axis.title = element_text(size = 14),
    legend.title = element_text(size = 12)
  )
```

```
## `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.

```r
#15
tukey.test <- TukeyHSD(ChemPhy.anova)
print(tukey.test)
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = temperature_C ~ lakename, data = ChemPhy_Wrang)
##
## $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 test results: Lakes with the same mean temperature as Peter Lake (statistically speaking): Paul Lake: p-value = 0.2242 Ward Lake: p-value = 0.7827 These p-values are greater than 0.05, indicating that Peter Lake, Paul Lake, and Ward Lake have statistically similar mean temperatures. East Long Lake shows a statistically significant difference in mean temperature from almost 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: To determine whether Peter Lake and Paul Lake have distinct mean temperatures, we can use 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
ChemPhy_Wrang_CW <- subset(ChemPhy_Wrang, lakename %in% c("Crampton Lake", "Ward Lake"))

ttest <- t.test(data = ChemPhy_Wrang_CW, temperature_C ~ lakename)
print(ttest)
```

```
##
##  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: Since the p-value (0.2649) is greater than 0.05, we fail to reject the null hypothesis. This suggests there is no statistically significant difference in mean temperatures between Crampton Lake and Ward Lake.In part 16, the Tukey's HSD test also indicated that Crampton Lake and Ward Lake did not have significantly different mean temperatures (p-value was not significant for this pair). Thus, the results from the Welch Two Sample t-test are consistent with the findings from part 16.