Assignment 6: GLMs (Linear Regressios, ANOVA, & t-tests)

Enikoe Bihari

OVERVIEW

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

Directions

1. Change "Student Name" on line 3 (above) with your name.
2. Work through the steps, **creating code and output** that fulfill each instruction.
3. Be sure to **answer the questions** in this assignment document.
4. When you have completed the assignment, **Knit** the text and code into a single PDF file.
5. After Knitting, submit the completed exercise (PDF file) to the dropbox in Sakai. Add your last name into the file name (e.g., "Fay_A06_GLMs.Rmd") prior to submission.

The completed exercise is due on Monday, February 28 at 7:00 pm.

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

# load packages and csv
getwd()
```

```
## [1] "C:/Users/eniko/Documents/Duuuuuke/2021-22/Data Analytics/Environmental_Data_Analytics_2022/Assi
```

```
library(tidyverse)
```

```
## -- Attaching packages --------------------------------------- tidyverse 1.3.1 --

## v ggplot2 3.3.5     v purrr   0.3.4
## v tibble  3.1.6     v dplyr   1.0.8
## v tidyr   1.2.0     v stringr 1.4.0
## v readr   2.1.2     v forcats 0.5.1

## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
```

```
library(agricolae)
library(lubridate)
```

```
##
## Attaching package: 'lubridate'
```

```
## The following objects are masked from 'package:base':
##
##     date, intersect, setdiff, union
```

```
lake <- read.csv("../Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv",
                 stringsAsFactors = TRUE)

# make date object
lake$date <- as.Date(lake$sampledate,
                     format = "%m/%d/%y")

#2

# create a theme with gray defaults
theme1 <- theme_gray(base_size = 10) +
  theme(axis.text = element_text(color = "grey50"),
        legend.position = "top")

# set it as the default theme
theme_set(theme1)
```

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:

   H_0: Temperature does not change statistically significantly with depth (the beta in the regression equation is equal to zero).

$$\beta = 0$$

   H_a: Temperature does change statistically significantly with depth (the beta in the regression equation is not equal to zero).

$$\beta \neq 0$$

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)

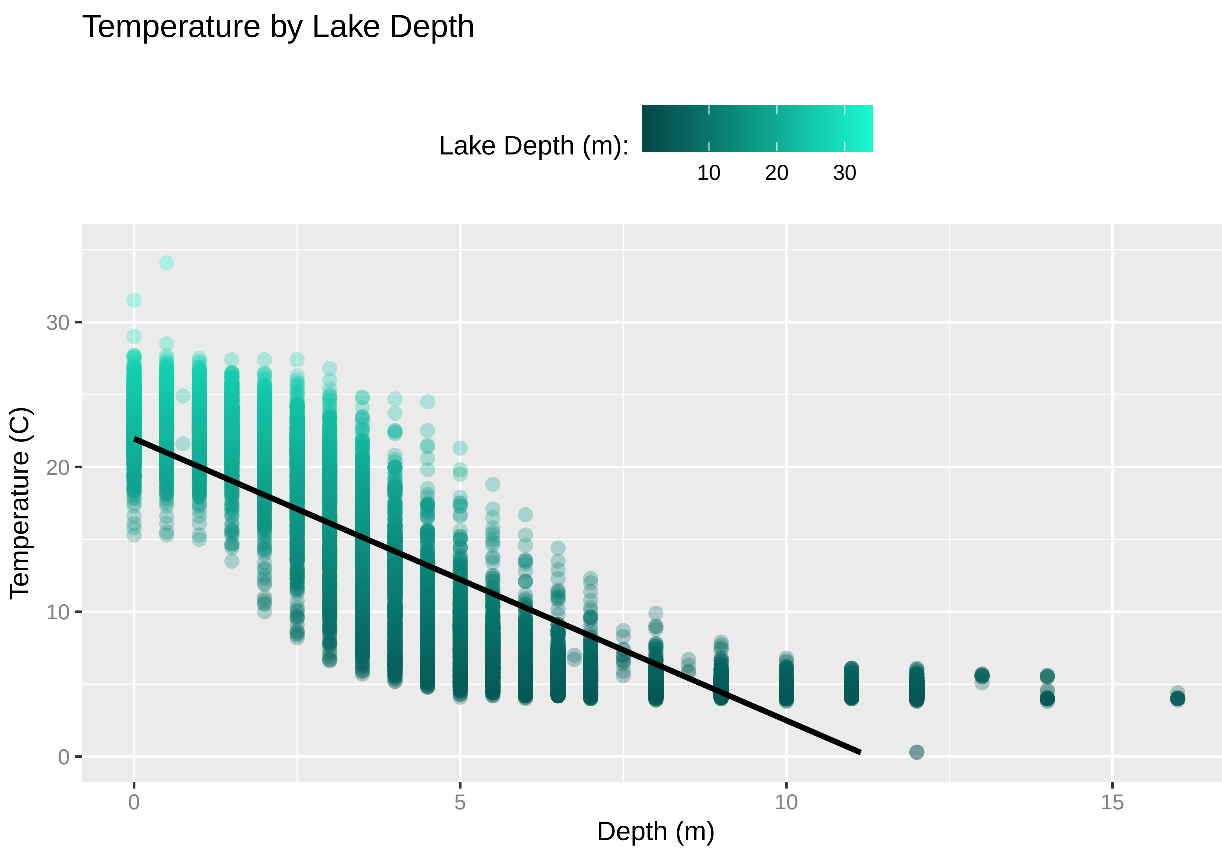
5. Visualize the relationship among the two continuous variables with a scatter plot of temperature by depth. Add a smoothed line showing the linear model, and limit temperature values from 0 to 35 °C. Make this plot look pretty and easy to read.

```
#4

# get the right month & columns, remove NAs
lake_wr =
  lake %>%
  filter(month(date) == 07) %>%
  select(lakename, year4, daynum, depth, temperature_C) %>%
```

```r
  drop_na(lakename, year4, daynum, depth, temperature_C)
  # filter(!is.na(lakename) | !is.na(year4) | !is.na(daynum) | !is.na(depth) | !is.na(temperature_C))
  # na.omit()

#5

# make plotwith labels and regression line
temp <-
ggplot(lake_wr) +
  geom_point(aes(x=depth, y=temperature_C, color=temperature_C),
             size = 2,
             alpha = 0.3) +
  geom_smooth(aes(x=depth, y=temperature_C),
              method = lm,
              size = 1,
              color = 'black',
              alpha = 0.4) +
  scale_colour_gradient(low = "#034746", high = "#18fbd2") +
  ylim(0, 35) +
  ylab(expression("Temperature (C)")) +
  xlab(expression("Depth (m)")) +
  ggtitle("Temperature by Lake Depth\n") +
  labs(color = "Lake Depth (m):")

print(temp)
```

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

```
## Warning: Removed 24 rows containing missing values (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: **Temperature does not respond linearly to depth, but rather attenuates in a logarithmic pattern. This pattern is very clear, though, and it does seem obvious that temperature decreases predictably with water depth.**

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

```r
#7

# linear regression
temp.regr <- lm(data = lake_wr, temperature_C ~ depth)
summary(temp.regr)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth, data = lake_wr)
##
## 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: **At the surface of the water, the temperature is predicted to be 21.9C, and it is expected to decrease by 1.9C with every meter as you go down. Both of these relationships (the intercept and the slope) are statistically significant (with very small p-values). This allows us to reject the null hypotheses that the relationships between temperature and depth are 0. About 74% of the variability in temperature can be explained by depth, since the $\mathbf{R^2}$ is 0.738. There are 9726 degrees of freedom, since there are 9728 data points.**

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

# create a model with all the variables
temp.regr.full <- lm(data = lake_wr, temperature_C ~ depth + year4 + daynum)
# summary(temp.regr.full)

# choose a model with AIC steps
step(temp.regr.full)
```

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

```r
# do manually to check
temp.regr1 <- lm(data = lake_wr, temperature_C ~ depth + year4)
```

```
temp.regr2 <- lm(data = lake_wr, temperature_C ~ depth + daynum)
temp.regr3 <- lm(data = lake_wr, temperature_C ~ year4 + daynum)

AIC(temp.regr1, temp.regr2, temp.regr3, temp.regr.full)
```

```
##                df      AIC
## temp.regr1      4 53756.97
## temp.regr2      4 53679.36
## temp.regr3      4 66798.34
## temp.regr.full  5 53674.39
```

```
#10

# full model appears to be the best
temp.regr.full <- lm(data = lake_wr, temperature_C ~ depth + year4 + daynum)
summary(temp.regr.full)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth + year4 + daynum, data = lake_wr)
##
## 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: **Depth, year, and day of the year are all significant variables in the model with the lowest AIC. With an $\mathbf{R^2}$ of 0.741, this model explains about 74% of the variance in temperature, which is just slightly higher than the previous model. When looking only at $\mathbf{R^2}$, this model does not actually offer much of an improvement over the model with just 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

# run anova test
temp.aov <- aov(data = lake_wr, temperature_C ~ lakename)
summary(temp.aov)
```

```
##               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
# run same thing as an lm
temp.aov.lm <- lm(data = lake_wr, temperature_C ~ lakename)
summary(temp.aov.lm)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = lake_wr)
##
## 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, we would reject the null hypothesis that there is no difference in temperature among the lakes (at a significance level of 0.01, all the p-values for the model coefficients are significant). Thus, we conclude that all the lakes do have significantly different temperatures.**

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.

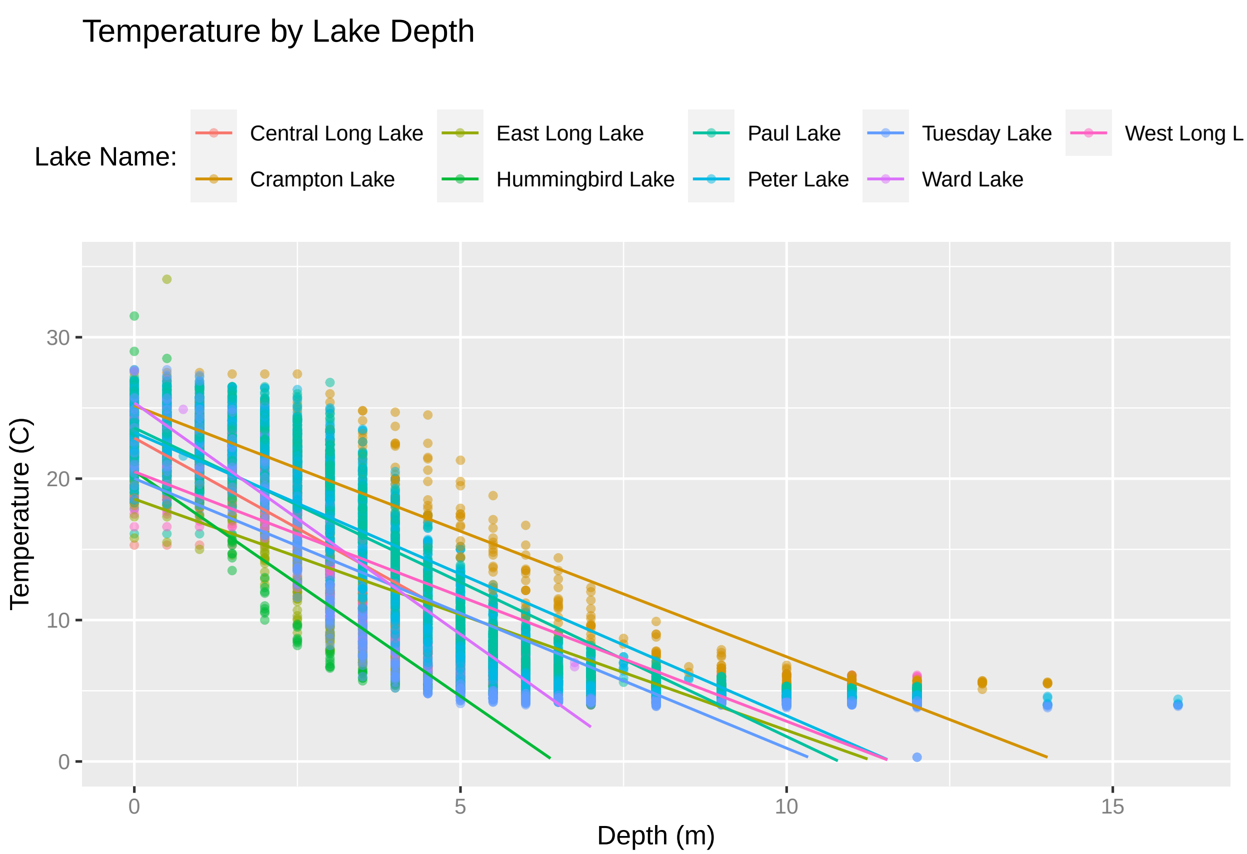
```r
#14.

# unique(lake_wr$lakename)
```

```r
# make graph
temp2 <-
ggplot(lake_wr,
       aes(x=depth,
           y=temperature_C,
           color = lakename)) +
  geom_point(size = 1,
             alpha = 0.5) +
  geom_smooth(method = lm,
              size = .5,
              alpha = 0.4,
              se = F) +
  # geom_smooth(data =subset(lake_wr, lakename == "Paul Lake"),
  #             aes(x=depth, y=temperature_C),
  #             method = lm,
  #             size = .5,
  #             color = 'black',
  #             alpha = 0.4,
  #             se = F) +
  # geom_smooth(data =subset(lake_wr, lakename == "Peter Lake"),
  #             aes(x=depth, y=temperature_C),
  #             method = lm,
  #             size = .5,
  #             color = 'black',
  #             alpha = 0.4,
  #             se = F) +
  # geom_smooth(data =subset(lake_wr, lakename == "Tuesday Lake"),
  #             aes(x=depth, y=temperature_C),
  #             method = lm,
  #             size = .5,
  #             color = 'black',
  #             alpha = 0.4,
  #             se = F) +
  # geom_smooth(data =subset(lake_wr, lakename == "East Long Lake"),
  #             aes(x=depth, y=temperature_C),
  #             method = lm,
  #             size = .5,
  #             color = 'black',
  #             alpha = 0.4,
  #             se = F) +
  # geom_smooth(data =subset(lake_wr, lakename == "West Long Lake"),
  #             aes(x=depth, y=temperature_C),
  #             method = lm,
  #             size = .5,
  #             color = 'black',
  #             alpha = 0.4,
  #             se = F) +
  # geom_smooth(data =subset(lake_wr, lakename == "Central Long Lake"),
  #             aes(x=depth, y=temperature_C),
  #             method = lm,
  #             size = .5,
  #             color = 'black',
  #             alpha = 0.4,
```

```r
  #             se = F) +
  # geom_smooth(data =subset(lake_wr, lakename == "Hummingbird Lake"),
  #             aes(x=depth, y=temperature_C),
  #             method = lm,
  #             size = .5,
  #             color = 'black',
  #             alpha = 0.4,
  #             se = F) +
  # geom_smooth(data =subset(lake_wr, lakename == "Crampton Lake"),
  #             aes(x=depth, y=temperature_C),
  #             method = lm,
  #             size = .5,
  #             color = 'black',
  #             alpha = 0.4,
  #             se = F) +
  # geom_smooth(data =subset(lake_wr, lakename == "Ward Lake"),
  #             aes(x=depth, y=temperature_C),
  #             method = lm,
  #             size = .5,
  #             color = 'black',
  #             alpha = 0.4,
  #             se = F) +
  ylim(0, 35) +
  ylab(expression("Temperature (C)")) +
  xlab(expression("Depth (m)")) +
  ggtitle("Temperature by Lake Depth\n") +
  labs(color = "Lake Name:")

print(temp2)
```

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

```
## Warning: Removed 73 rows containing missing values (geom_smooth).
```



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

```
#15

# do a Tukey test
temp.tuk = TukeyHSD(temp.aov)
print(temp.tuk)
```

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

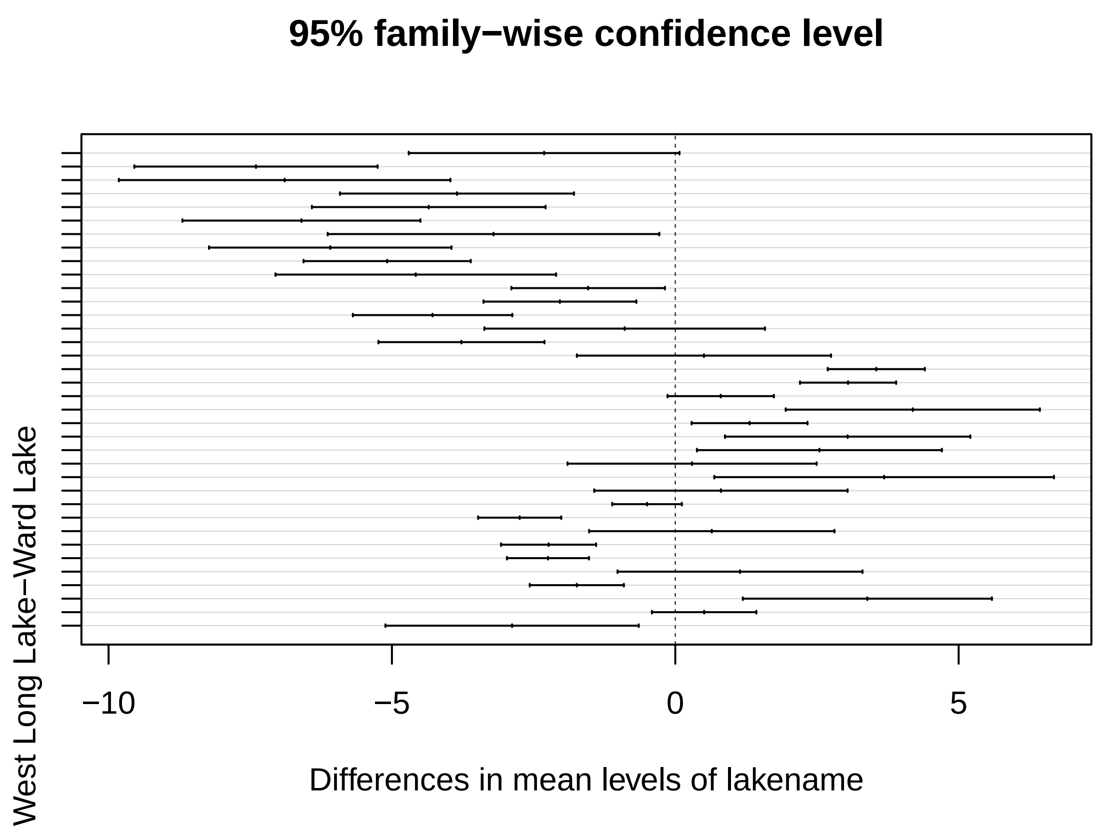
```
## Tuesday Lake-Crampton Lake         -4.2826611 -5.6895065 -2.8758157 0.0000000
## Ward Lake-Crampton Lake            -0.8932661 -3.3684639  1.5819317 0.9714459
## West Long Lake-Crampton Lake       -3.7732318 -5.2378351 -2.3086285 0.0000000
## Hummingbird Lake-East Long Lake     0.5056106 -1.7364925  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
```

```r
# group for easier understanding
temp.tuk.group <- HSD.test(temp.aov,
                           "lakename",
                           group = TRUE)
temp.tuk.group
```

```
## $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 Min  Max    Q25   Q50    Q75
## Central Long Lake       17.66641 4.196292  128 8.9 26.8 14.400 18.40 21.000
## Crampton Lake           15.35189 7.244773  318 5.0 27.5  7.525 16.90 22.300
## East Long Lake          10.26767 6.766804  968 4.2 34.1  4.975  6.50 15.925
## Hummingbird Lake        10.77328 7.017845  116 4.0 31.5  5.200  7.00 15.625
## Paul Lake               13.81426 7.296928 2660 4.7 27.7  6.500 12.40 21.400
## Peter Lake              13.31626 7.669758 2872 4.0 27.0  5.600 11.40 21.500
## Tuesday Lake            11.06923 7.698687 1524 0.3 27.7  4.400  6.80 19.400
## Ward Lake               14.45862 7.409079  116 5.7 27.6  7.200 12.55 23.200
## West Long Lake          11.57865 6.980789 1026 4.0 25.7  5.400  8.00 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"
```

```
# plot it for easier visualization
plot(temp.tuk)
```



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: **Central Long Lake, Crampton Lake, East Long Lake, Hummingbird Lake, Paul Lake, and West Long Lake all have different temperatures from Peter Lake. None of the lakes have statistically distinct temperatures 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 use a simple t-test to test if their means (and distributions) are truly different, or if they overlap enough to be considered the "same". You**

would need to check all the assumptions, including normality, equal variances, and independence of events.