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

Jackie Fahrenholz

## 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
#set and get wd
setwd("C:/Users/Jackie/Desktop/ENV872/Environmental_Data_Analytics_2022/Assignments")
getwd()
```

```
## [1] "C:/Users/Jackie/Desktop/ENV872/Environmental_Data_Analytics_2022/Assignments"
```

```
#load packages
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   1.0.7
## v tidyr   1.1.4     v stringr 1.4.0
## v readr   2.1.1     v forcats 0.5.1

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

```
library(agricolae)
#load the data
chem.phys <- read.csv("../Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv", stringsAsFactors = TRUE)
#set the date column as date objects
```

```r
chem.phys$sampledate <- as.Date(chem.phys$sampledate,
                                format = "%m/%d/%y")
#check the class
class(chem.phys$sampledate)
```

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

```r
#2
#build a theme
mytheme <- theme_classic(base_size = 13) +
  theme(axis.text = element_text(color = "black"),
        legend.position = "right") +
  theme(plot.title = element_text(hjust = 0.5))
#set it as my theme
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 difference between lake temperature in July and lake depth. Ha: There is a significant difference between lake temperature in July and lake depth.

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)

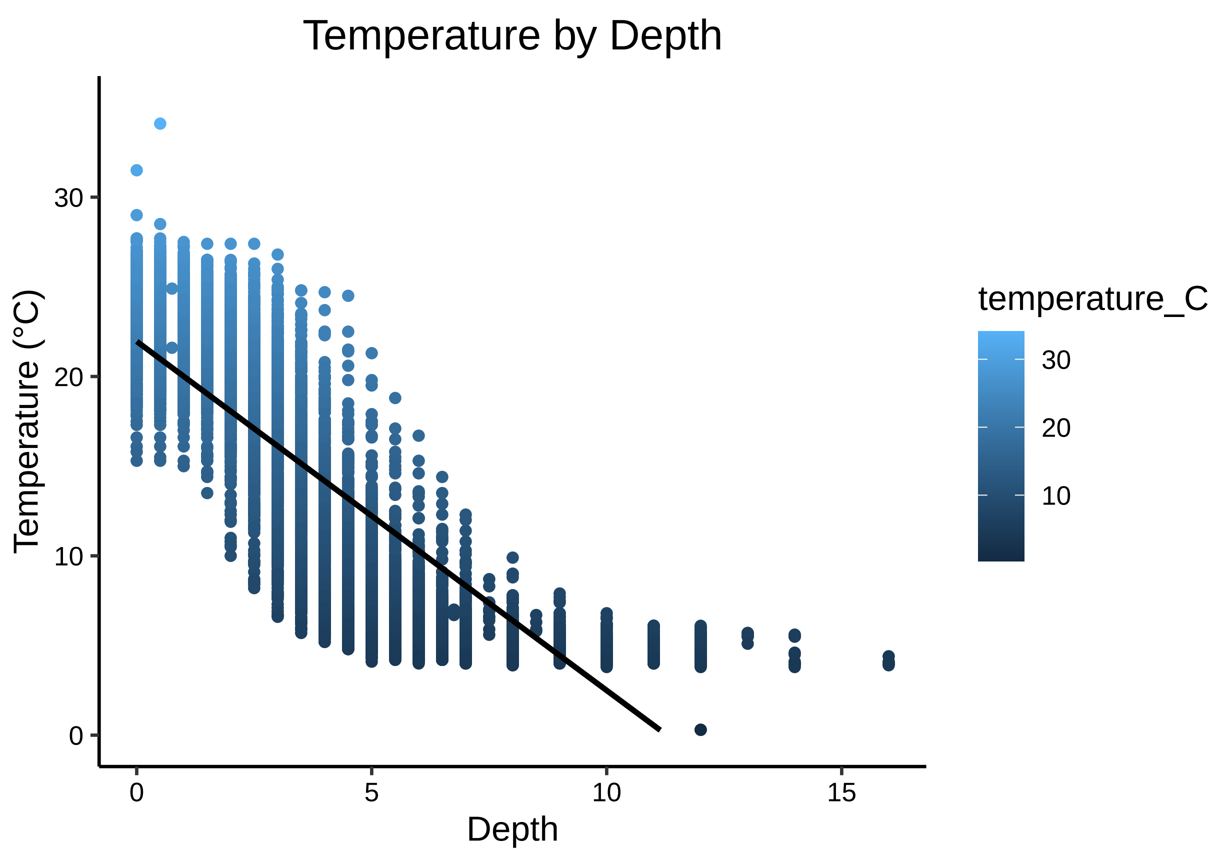
5. Visualize the relationship among the two continuous variables with a scatter plot of temperature by depth. Add a smoothed line showing the linear model, and limit temperature values from 0 to 35 °C. Make this plot look pretty and easy to read.

```r
#4 wrangle the data
chem.phys.wrangle <-
  chem.phys %>%
  #select the specific columns
  select(lakename, year4, daynum, depth, temperature_C)%>%
  #this gets month by itself so we can filter for it
  #using the lubridate function didn't return anything just
  #rlang error
  mutate(chem.phys, Month = format(sampledate,"%m"))%>%
  #filters for only July
  filter(Month == '07') %>%
  #get rid of incomplete instances
  filter(!is.na(temperature_C) & !is.na(depth)
         & !is.na(daynum) & !is.na(year4)) %>%
  #re-select only the columns of interest
  select(lakename, year4, daynum, depth, temperature_C)

#5- visualize the data
#chose to color by temp because we only care about the relationship
#between these two variables, not between sites
ggplot(chem.phys.wrangle, aes(x = depth, y = temperature_C ,
```

```
                              color = temperature_C))+
  #scatter plot
  geom_point()+
  #line of best fit
  geom_smooth(method = "lm", color = "black") +
  #add limits
  ylim(0,35) +
  #label the axis, and plot
  ylab('Temperature (°C)') +
  xlab('Depth') +
  ggtitle("Temperature by Depth")
```

```
## `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: From the chart we can see that as depth increases, temperature decreases. You can see that the trendline follows this by having a negative slope, though the relationship isn't entirely linear because at a certain depth, there is not a decrease in temperature. This can be seen between depths 10 and 15.

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

```
#7- linear regression!
lm.temp.depth <- lm(chem.phys.wrangle$temperature_C ~ chem.phys.wrangle$depth)
#summarize
summary(lm.temp.depth)
```

```
##
## Call:
## lm(formula = chem.phys.wrangle$temperature_C ~ chem.phys.wrangle$depth)
##
## 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 ***
## chem.phys.wrangle$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:There is a significant negative correlation between temperature and depth. The statitiscal signification of a `p-value` of $<$ 2.2e-16. Our model predicts .7387 (~74%) of the variability in the data. For every 1m increase in depth there is a decrease in temperature by 1.946 degrees C. Based on our model, at a depth of 0, temperature is 21.956 C, which aligns with our graph that we created above in number 5.

---

## 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
chemAIC <- lm(data = chem.phys.wrangle, temperature_C ~ depth + year4 + daynum)
#chose which model based on lowest AIC
step(chemAIC)
```

```
## 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 = chem.phys.wrangle)
```

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

```
#10- run multiple regression
#the orginal is the best; kept same variable
chemAIC <- lm(data = chem.phys.wrangle, temperature_C ~ depth + year4 + daynum)
summary(chemAIC)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth + year4 + daynum, data = chem.phys.wrangle)
##
## 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 final set of explanatory varibales include all three; `depth`, `daynum`, and `year4`. This model explains 74.12% of the observed variance, with a overall significane of p < 2e-16. Our first model, where depth explains temperature only explained 73.87% of the variance, meaning that the second model `chemAIC` an improvement from only using depth in `lm.temp.depth`.

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## 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
# Format ANOVA as aov
lake.temp.anova <- aov(data = chem.phys.wrangle, temperature_C ~ lakename)
summary(lake.temp.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
```

```
#results: reject null hypothesis- difference between a pair of group means is
#statistically significant

# Format ANOVA as lm
lake.temp.lm <- lm(data = chem.phys.wrangle, temperature_C ~ lakename)
summary(lake.temp.lm)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = chem.phys.wrangle)
##
## 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.

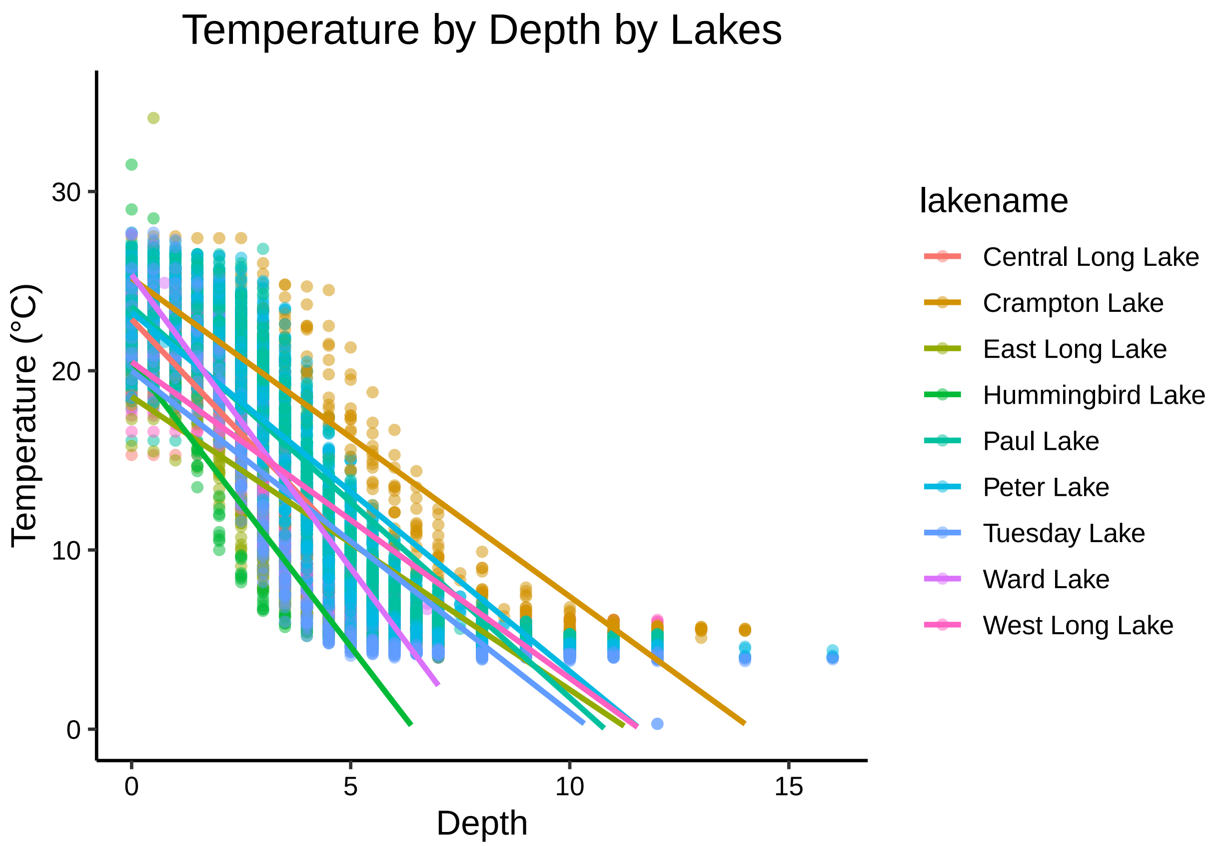
    Answer: Yes there is a significant difference in mean temerpature among the lakes. In both the ANOVA and lm there are p-values <2e-16, meaning that the relationship between temperature and lake name is significant. The adjusted R^2 value is .03874, which was expected as lakename likely doesn't explain a lot about temperature. We therefore reject our null hypothesis that there is not a significant difference between temperature and lake name and accept the alternative.

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(chem.phys.wrangle, aes(x = depth, y = temperature_C , color = lakename))+
  #scatter plot
  geom_point(alpha = 0.5)+
  #line of best fit
  geom_smooth(method = "lm", se = FALSE) +
  #add limits
  ylim(0,35) +
  #label the axis, and plot
```

```
  ylab('Temperature (°C)') +
  xlab('Depth') +
  ggtitle("Temperature by Depth by Lakes")
```

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




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

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

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = temperature_C ~ lakename, data = chem.phys.wrangle)
##
## $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
#Grouping
lake.temp.group <- HSD.test(lake.temp.anova, "lakename", group = TRUE)
#print the groups
lake.temp.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"
```

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: Based on the results from `HSD.test` we see that there is a similarity in the temperature between Peter, Paul, and Ward Lake. None of the lakes have a temperature that is statistically distinct from all the other lakes as their group is shared with at least one other lake.

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 conduct a t (or z) test to determine whether or not these two lakes have distinct mean temperatures. This would come with assumptions, that we would likely have to test first; normality, independence of events, and a known standard deviation.