

# 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
```

```
getwd() #checking working directory
```

```
## [1] "/home/guest/EDE_Fall2023"
```

```
#loading packages
```

```
library(tidyverse)
```

```
## -- Attaching core tidyverse packages ----- tidyverse 2.0.0 --
```

```
## v dplyr      1.1.3      v readr      2.1.4
```

```
## v forcats    1.0.0      v stringr    1.5.0
```

```
## v ggplot2     3.4.3      v tibble     3.2.1
```

```
## v lubridate  1.9.2      v tidyr      1.3.0
```

```
## 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(here)
```

```
## here() starts at /home/guest/EDE_Fall2023
```

```
library(corrplot)
```

```
## corrplot 0.92 loaded
```

```
library(ggthemes)
```

```
#importing raw data
```

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

```
# Set dates to date format
```

```
raw_chem$sampdate <- mdy(raw_chem$sampdate)
```

```
#2
```

```
# Set theme
```

```
mytheme <- theme_classic(base_size = 14) +
  theme(axis.text = element_text(color = "forestgreen"),
        legend.position = "top",
        line = element_line(
          color = 'navyblue',
          linewidth = 0.5),
        plot.title = element_text(
          color = 'navyblue',
          size = 15),
        axis.title.x = element_text(
          color = "navyblue"),
        axis.title.y = element_text(
          color = "navyblue")
  )
```

```
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.

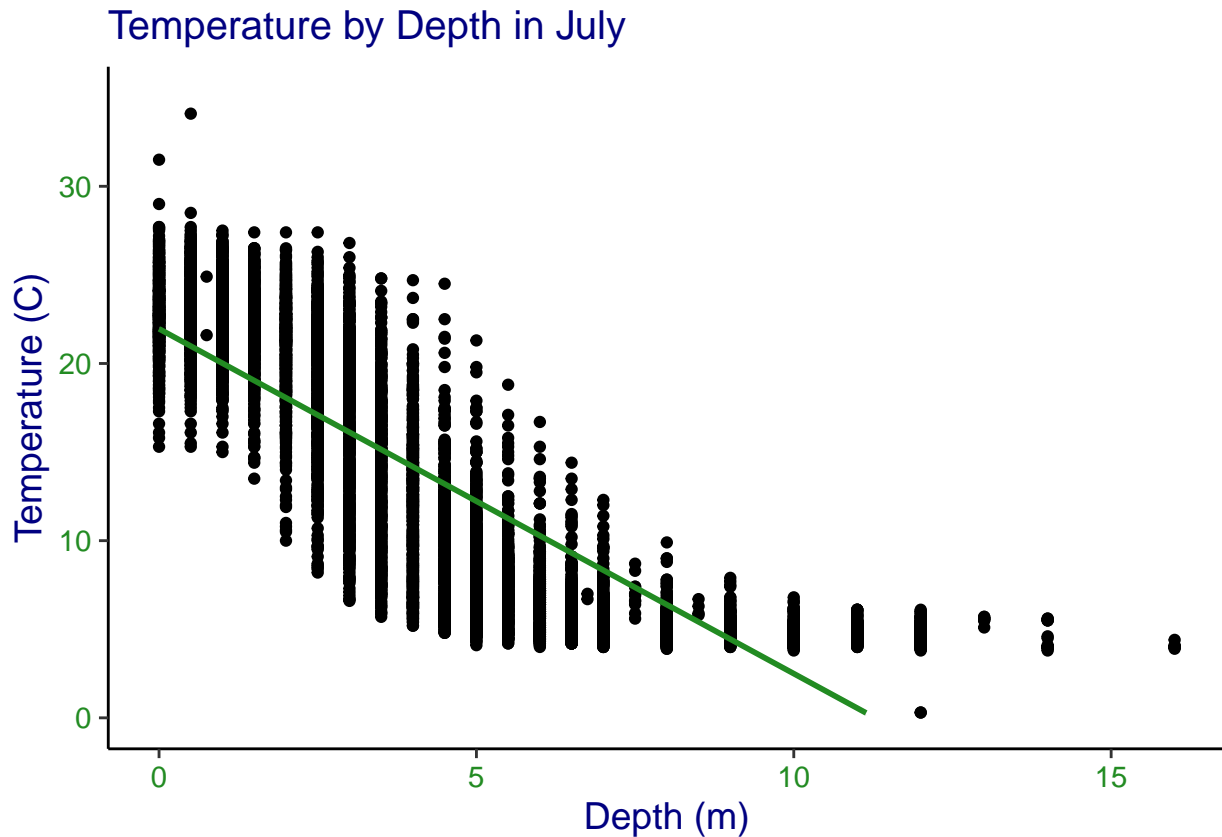
```
#4
#creating a subset of data
chem_subset <- raw_chem %>%
  mutate(month = month(sampledate)) %>%
  filter(month ==7) %>%
  select(lakename:daynum, depth:temperature_C) %>%
  na.omit()

#5
#plotting temperature by depth
tempbydepth <-
  ggplot(chem_subset, aes(x = depth, y = temperature_C)) +
  geom_point() +
  geom_smooth(method = "lm", color = 'forestgreen') +
  labs(x= "Depth (m)", y= "Temperature (C)") +
  ylim(0,35) +
  ggtitle("Temperature by Depth in July") +
  mytheme

print(tempbydepth)
```

```
## '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 decreases by depth. It is not a linear relationship, there is a steady decline of average temperature by depth, and then the slope levels off (doesn't reach below freezing).

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

```
#7
temperature.regression <- lm(
  data = chem_subset,
  temperature_C ~ depth)
summary(temperature.regression) #looking at results for the linear regression
```

```
##
## Call:
## lm(formula = temperature_C ~ depth, data = chem_subset)
##
## 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: Around 73.9% of the variability in temperature is explained by changes in depth. There are 9726 degrees of freedom on which this finding is based, and the result is highly statistically significant (the p-value is less than 2.2 e-16). The p-value only has to be less than 0.05 to be considered statistically significant and reject the null hypothesis. We can accept the alternative hypothesis, that mean lake temperature recorded during July does change with depth across all lakes. Temperature is predicted to change -1.95 degrees for every 1m change in depth (as depth increases, temperature decreases).

---

## 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
#running AIC
temp2 <- lm(
  data = chem_subset,
  temperature_C ~ year4 + daynum + depth)
summary(temp2)

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

```
step(temp2)
```

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

```
#10
#running multiple regression
temp2 <- lm(
  data = chem_subset,
  temperature_C ~ year4 + daynum + depth)
summary(temp2)
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = chem_subset)
##
## 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 model with the lowest AIC is the one that includes the variables year4, daynum, and depth. 74.1% of the observed variance is explained by the model, which is a very slight improvement (0.2%) over the model using only 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).

```
#12
unique(chem_subset$lakename) #looking at all of the lakes in the dataset

## [1] Paul Lake      Peter Lake      Tuesday Lake   East Long Lake
## [5] West Long Lake   Central Long Lake Hummingbird Lake Crampton Lake
## [9] Ward Lake
## 9 Levels: Central Long Lake Crampton Lake East Long Lake ... West Long Lake

# Format ANOVA as aov
chem.anova <- aov(data = chem_subset, temperature_C ~ lakename)
summary(chem.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 ANOVA as lm
chem.anova2 <- lm(data = chem_subset, temperature_C ~ lakename)
summary(chem.anova2)

##
## Call:
## lm(formula = temperature_C ~ lakename, data = chem_subset)
##
## 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 ***
## lakenamCrampton Lake    -2.3145    0.7699  -3.006 0.002653 **
## lakenamEast Long Lake   -7.3987    0.6918 -10.695 < 2e-16 ***
## lakenamHummingbird Lake -6.8931    0.9429  -7.311 2.87e-13 ***
## lakenamPaul Lake        -3.8522    0.6656  -5.788 7.36e-09 ***
## lakenamPeter Lake       -4.3501    0.6645  -6.547 6.17e-11 ***
## lakenamTuesday Lake    -6.5972    0.6769  -9.746 < 2e-16 ***
## lakenamWard Lake        -3.2078    0.9429  -3.402 0.000672 ***
## lakenamWest 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: There is a significant difference in mean temperature among the lakes compared to Central Long lake. The p-value is below 0.05 for each individual lake compared to Central Long lake, which means that we can attribute the difference in mean temperature to NOT be attributed to chance, and consider the difference to be 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.

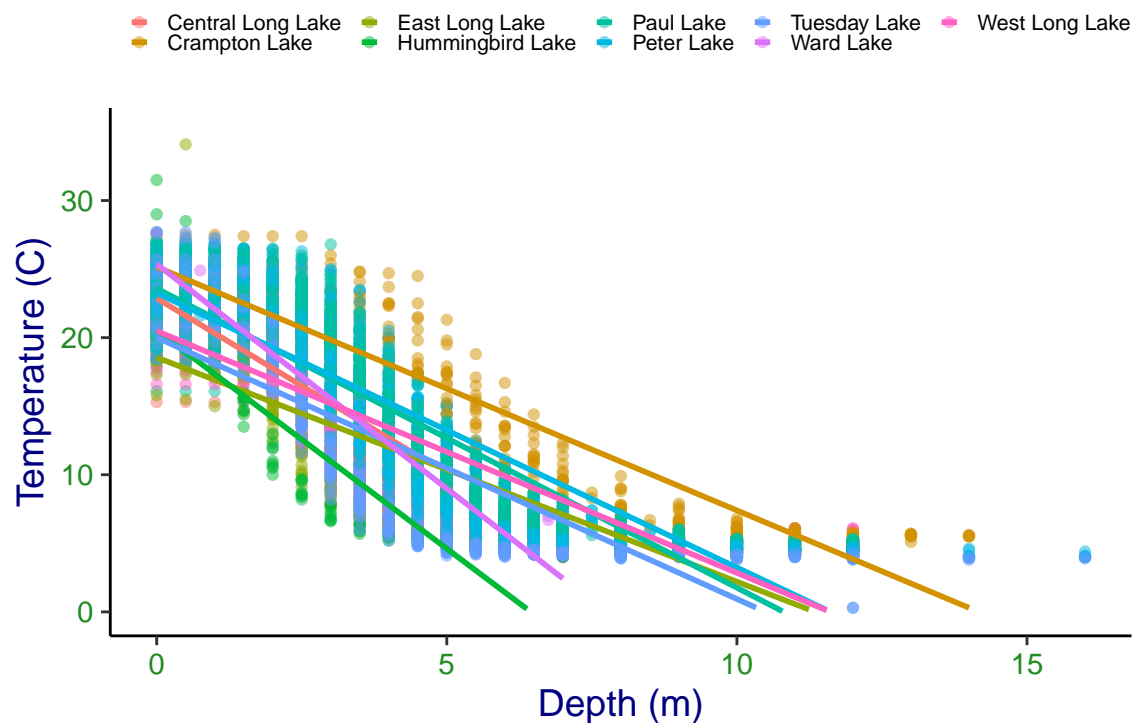
```
#14.
#plotting temp by depth for each lake
plot <- ggplot(chem_subset,
               aes(x = depth, y = temperature_C, color = lakenam)) +
  geom_point(alpha= 0.5) +
  geom_smooth(method = "lm", se = FALSE) +
  ylim(0, 35) +
  labs(x= "Depth (m)", y= "Temperature (C)", color = "") +
  theme(legend.key.size = unit(0.5, "lines"),
        legend.text = element_text(size = 8))

print(plot)
```

```
## '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
#tukey HSD
TukeyHSD(chem.anova)
```

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

```
lake_groups <- HSD.test(chem.anova, 'lakename', group=T)
lake_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: Paul and Ward Lake have the same mean temperature as Peter Lake, statistically speaking (p-values larger than 0.05). None of the lakes have a mean temperature that is statistically distinct from all the other lakes (no p-values less than 0.05).

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 a two-sample T-test on these data to determine whether their July temperature are same or different.

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?

```
chem_subset_2lake <- chem_subset %>%
  filter(lakename == "Crampton Lake" | lakename == "Ward Lake")

twosample <- t.test(chem_subset_2lake$temperature_C ~ chem_subset_2lake$lakename)
twosample
```

```
##
## Welch Two Sample t-test
##
## data:  chem_subset_2lake$temperature_C by chem_subset_2lake$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 July temperature for Crampton Lake is 15.35, and the mean July temperature for Ward Lake is 14.46. The p-value is 0.265, which is greater than 0.05. So, we cannot reject the null hypothesis. This means that the true difference in mean temperature between Crampton and Ward Lake is equal to 0. Thus, the mean temperatures for the lakes are statistically equal. This does match my answer from part 16 that all lakes have mean temperatures that are statistically the same.