

Assignment 6: GLMs (Linear Regressions, 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>_A06_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
setwd("~/R/EDA-Fall2022")
getwd()

## [1] "/home/guest/R/EDA-Fall2022"

library(tidyverse)

## -- Attaching packages ----- tidyverse 1.3.2 --
## v ggplot2 3.3.6      v purrr   0.3.4
## v tibble  3.1.8      v dplyr  1.0.10
## v tidyr   1.2.0      v stringr 1.4.1
## v readr   2.1.2      v forcats 0.5.2
## -- Conflicts ----- tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()

library(lubridate)

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

```
library(agricolae)
library(formatR)

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

LakeChemPhys_Raw$sampleddate <- as.Date(LakeChemPhys_Raw$sampleddate, format = "%m/%d/%y")
class(LakeChemPhys_Raw$sampleddate)

## [1] "Date"

# 2
theme1 <- theme_classic(base_size = 12) + theme(axis.text = element_text(color = "black"),
  legend.position = "left", axis.line = element_line(arrow = arrow()))

theme_set(theme1)
```

Simple regression

Our first research question is: Does mean lake temperature recorded during July change with depth across all lakes?

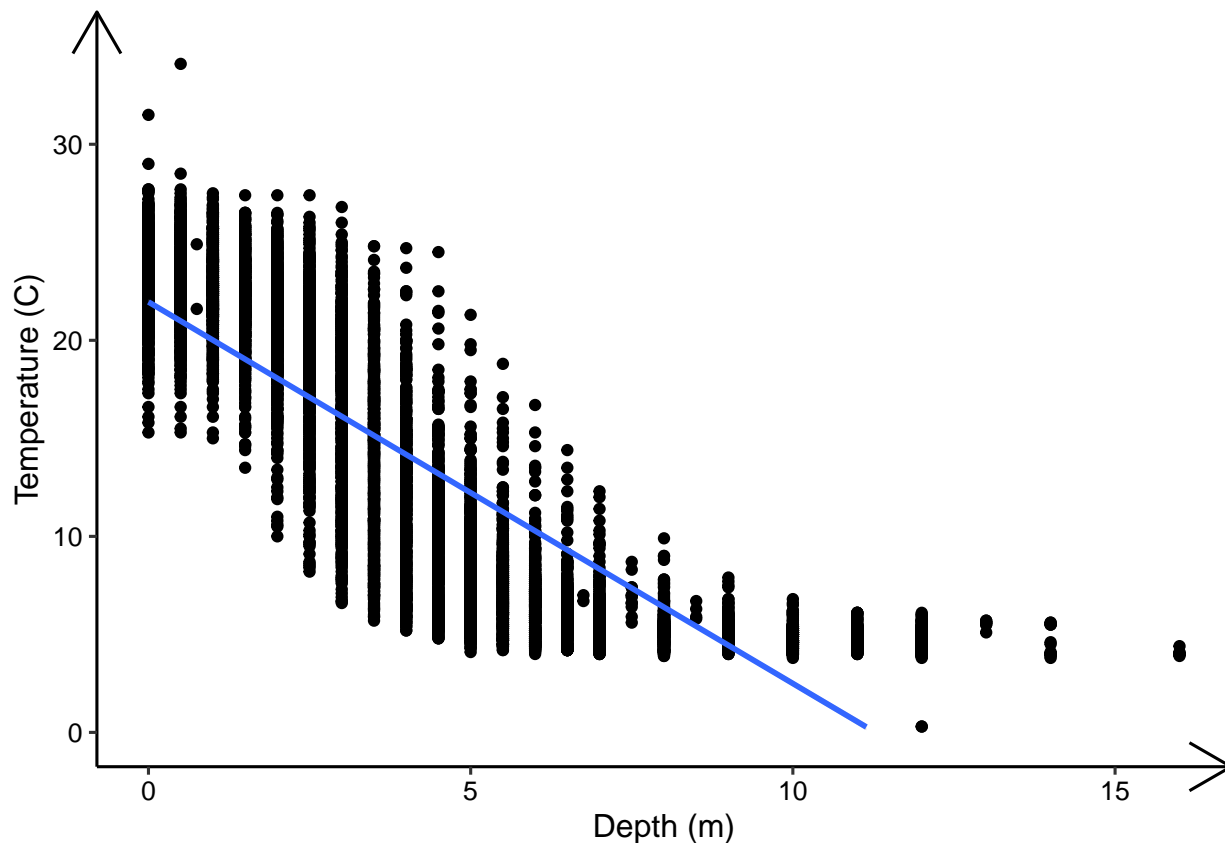
3. State the null and alternative hypotheses for this question: > Answer: H0: The July lake temperature, regardless of lake, does not vary with depth. Ha: The July lake temperature, regardless of lake, is related to depth.
4. Wrangle your NTL-LTER dataset with a pipe function so that the records meet 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.

```
# 4

LakeChemPhys_Filtered <- mutate(LakeChemPhys_Raw, month = month(sampleddate)) %>%
  filter(month == 7) %>%
  select(c(lakename, year4, daynum, depth, temperature_C)) %>%
  drop_na()

# 5
Temp.Depth <- ggplot(LakeChemPhys_Filtered, aes(x = depth, y = temperature_C)) +
  geom_point() + geom_smooth(method = "lm") + xlab("Depth (m)") + ylab("Temperature (C)") +
  ylim(0, 35)
print(Temp.Depth)

## `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: Based on the figure alone (not the regression analysis), there appears to be a relationship between temperature and depth, but it may not be linear. Variability in temperature is high between 0 and 6 m (but decreases overall), and then temperature slowly approaches 0 degrees. This suggests there may be some sort of exponential relationship, as temperature asymptotes towards 0 degrees as depth increases.

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

```
# 7
temp.regression <- lm(data = LakeChemPhys_Filtered, temperature_C ~ depth)
summary(temp.regression)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth, data = LakeChemPhys_Filtered)
##
## 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: Based on the results of the model, there is a strong relationship between temperature and depth. Depth explains 73.87% of variability in temperature, based on 9726 degrees of freedom. The model shows this relationship is statistically significant, with a p value < 2.2e-16. Temperature is expected to decrease by 1.95 degrees for every 1m increase in depth.

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
AIC <- lm(data = LakeChemPhys_Filtered, temperature_C ~ year4 + daynum + depth)
summary(AIC)

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

# All 3 variables appear to have strong relationships with temperature, so we
# will consider them all and run a stepwise function to confirm.

step(AIC)

## 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 = LakeChemPhys_Filtered)
##
## Coefficients:
## (Intercept)      year4      daynum      depth
##   -8.57556      0.01134      0.03978     -1.94644
# The stepwise function does not recommend removing any of the variables from
# the model.
# 10
Tempmodel <- lm(data = LakeChemPhys_Filtered, temperature_C ~ year4 + daynum + depth)
summary(Tempmodel)

##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = LakeChemPhys_Filtered)
##
## 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 AIC method suggests we use year, daynum, and depth to predict temperature. These variables predict 74.11% of variability in temperature, which is a very small improvement compared to depth alone (73.87%).

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

```
Laketemp.anova <- aov(data = LakeChemPhys_Filtered, temperature_C ~ lakename)
summary(Laketemp.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
```

```
Lakedepth.lm <- lm(data = LakeChemPhys_Filtered, temperature_C ~ lakename)
summary(Lakedepth.lm)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = LakeChemPhys_Filtered)
##
## 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
```

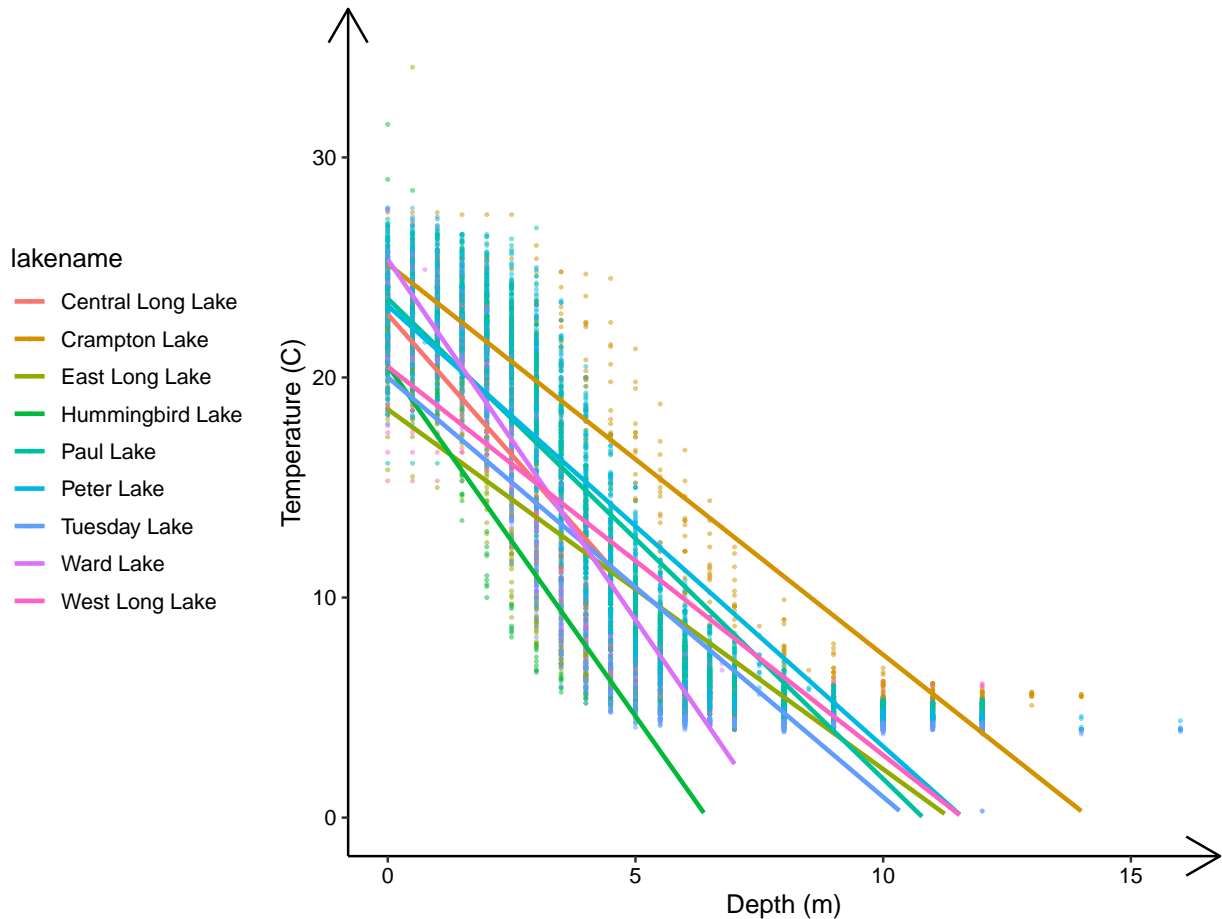
13. Is there a significant difference in mean temperature among the lakes? Report your findings.

Answer: Yes, there is a significant difference in mean temperature among the lakes. Both the lm and anova showed p values of $<2.2e-16$, which means that there are at least two lakes with differences in mean temperature. We will need post hoc tests to determine which lakes have different mean temperatures from one another.

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.
LakeTemps <- ggplot(LakeChemPhys_Filtered, aes(x = depth, y = temperature_C, color = lakename)) +
  geom_point(alpha = 0.5, cex = 0.4) + geom_smooth(method = "lm", se = FALSE) +
  xlab("Depth (m)") + ylab("Temperature (C)") + ylim(0, 35) + theme(legend.position = "left",
    legend.text = element_text(size = 10))
print(LakeTemps)

## `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
TukeyHSD(Laketemp.anova)

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

```
Laketemp.groups <- HSD.test(Laketemp.anova, "lakename", group = TRUE)
Laketemp.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 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: Paul and Ward lake did not have statistically different mean temperatures from Peter Lake ($p=0.22$, 0.78 respectively). According to our groups analysis, no lakes had mean temperatures statistically distinct from 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: We could use a T test because we are comparing the means of just two populations (derived from two samples).

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?

```
LakesCramptonWard <- mutate(LakeChemPhys_Raw, month = month(sampledate)) %>%
  filter(month == 7, (lakename == "Crampton Lake" | lakename == "Ward Lake")) %>%
  select(c(lakename, "sampledate", year4, daynum, depth, temperature_C)) %>%
  drop_na()

Temperature.twosample <- t.test(LakesCramptonWard$temperature_C ~ LakesCramptonWard$lakename)
Temperature.twosample

##
## Welch Two Sample t-test
##
## data: LakesCramptonWard$temperature_C by LakesCramptonWard$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 T test showed there is not a significant difference in the mean temperature of Crampton and Ward Lake ($p=0.26$). This is in agreement with our prior groups analysis, where Ward and Crampton Lake were both found to be in group b.