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
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
```

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

```
## here() starts at /home/guest/EDA_Spring2025
```

```
# Check working directory
here()
```

```
## [1] "/home/guest/EDA_Spring2025"
```

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

# Set date to date format
NTL_LTER$sampledate <- as.Date(NTL_LTER$sampledate, format = "%m/%d/%y")

#2

mytheme <- theme_bw(base_size = 12) +
  theme(axis.text = element_text(color = "black"),
        legend.position = "top") #alternative: legend.position + legend.justification
```

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 for the month of July does change with depth across all lakes Ha: Mean lake temperature for the month of July does not 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.

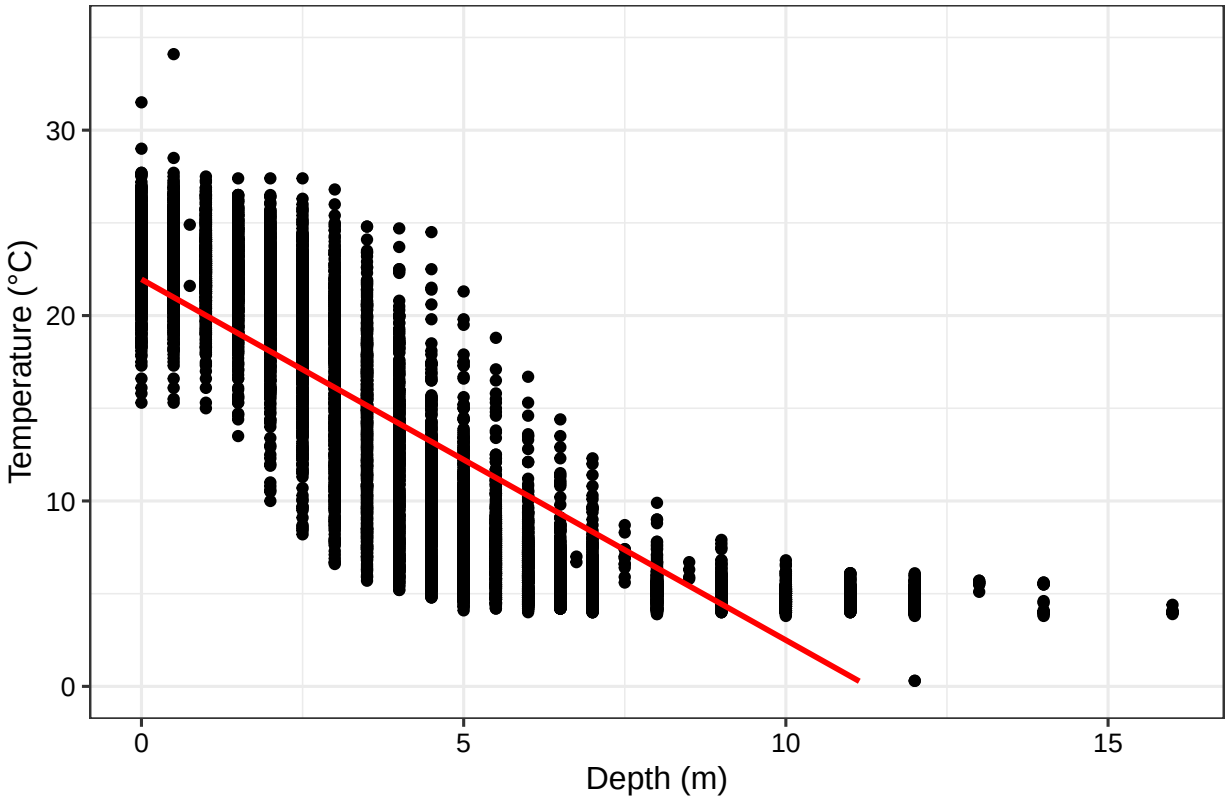
```
#4
NTL_LTER_July <- NTL_LTER %>%
  filter(month(sampledate) == 07) %>%
  select(lakename, year4, daynum, depth, temperature_C) %>%
  na.omit()

#5
depth_by_temp <- ggplot(NTL_LTER_July, aes(x = depth, y = temperature_C)) +
  ylim(0, 35) +
  geom_point() +
  mytheme +
  geom_smooth(method="lm", se = FALSE, color = "red") +
  labs(x = "Depth (m)", y = "Temperature (°C)",
       caption = "Relationship between temperature (°C) and depth.")

print(depth_by_temp)
```

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

## Warning: Removed 24 rows containing missing values or values outside the scale range
## (`geom_smooth()`).
```



Relationship between temperature (°C) and depth.

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 distribution of points appears to follow a linear pattern. As depth increases, temperature decreases. This makes sense with what we know (as you get further away from the water's surface (increase depth), water temperature also decreases.) It also appears that once a certain depth is hit (~10m) temperature remains the same (around 5°C).

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

```r
#7
regression_depth_temp <- lm(data = NTL_LTER_July, temperature_C ~ depth)
summary(regression_depth_temp)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth, data = NTL_LTER_July)
##
## 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: The model results indicate that depth is a significant factor in water temperature ($p < 0.05$). The degrees of freedom the result is based on is 9726 (9728 observations - 1). The R-squared value is 0.74. Meaning that depth accounts for ~74% of the variance in temperature. Because the R-squared value is cose to 1, it means there are not many other variables that could account for temperature variance. The coefficients indicate that for every 1m increase in depth, the temperature decreases by 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
July_AIC <- lm(data = NTL_LTER_July, temperature_C ~ depth + year4 + daynum)
step(July_AIC)
```

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

```
#10
July_multiple_regression <- lm(temperature_C ~ depth + year4, + daynum, data = NTL_LTER_July)
summary(July_multiple_regression)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth + year4, data = NTL_LTER_July,
##     subset = +daynum)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -9.149 -2.954  1.017  3.260  8.294
##
## Coefficients: (1 not defined because of singularities)
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 22.83025    0.06793   336.1   <2e-16 ***
## depth       -1.69529    0.01082  -156.7   <2e-16 ***
## year4             NA         NA      NA       NA
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 4.396 on 9726 degrees of freedom
## Multiple R-squared:  0.7164, Adjusted R-squared:  0.7163
## F-statistic: 2.456e+04 on 1 and 9726 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 variables that the AIC method suggests we use to predict temperature in the multiple regression is depth, year4, and daynum. The starting AIC is 26065.53. When year4 is removed, the AIC increases slightly to 26066. When daynum is removed, the AIC increases to 26148. When depth is removed, the AIC sharply increases to 39189. The suggests that depth has the greatest influence on temperature variance, when day number and year have little influence on temperature. Because the AIC increases when these variables are removed compared to when none of the variabkes are removed, all variables are suggested for use. No, using other variables other than depth does not improve the model as the R-squared value from the multiple regression is 0.72, a decrase from the R-squared value of 0.74 when depth is the only 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
NTL_LTER_July_anova <- aov(data = NTL_LTER_July, temperature_C ~ lakename)
summary(NTL_LTER_July_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
```

```
NTL_LTER_July_anova2 <- lm(data = NTL_LTER_July, temperature_C ~ lakename)
summary(NTL_LTER_July_anova2)
```

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

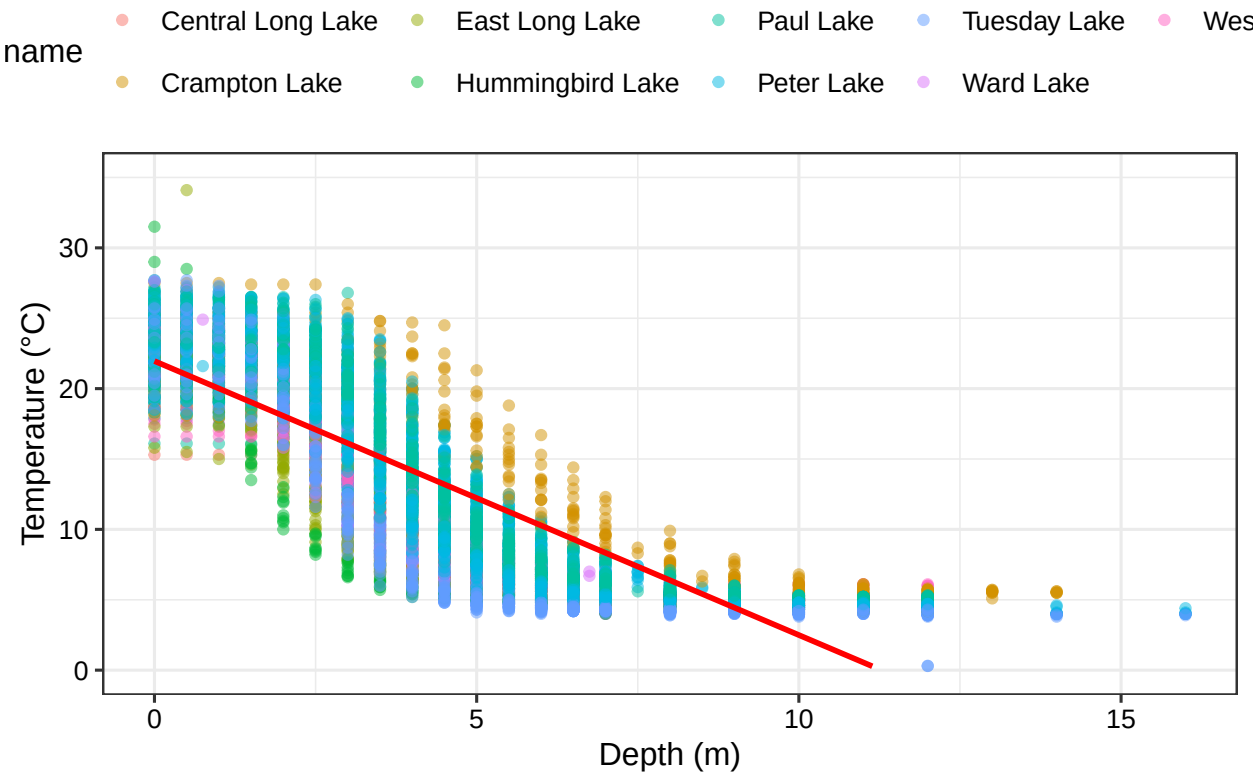
    Answer: The results of the Anova test find that there are significant differences ($p < 0.05$) between the lakes and their mean temperatures in the month of July. The results of the linear model show that there are significant differences between each lake's mean temperatures and the initial lake used for the analysis (the first lake listed alphabetically, Central Long Lake), as all p-values are < 0.05.

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(data = NTL_LTER_July,
       aes(x = depth, y= temperature_C, color = lakename)) +
  geom_point(alpha=0.5) +
  geom_smooth(method = "lm", se = FALSE, color = "red") +
  ylim(0, 35) +
  mytheme +
  labs(x= "Depth (m)",
       y= "Temperature (°C)",
       caption = "Relationship between temperature (C) and depth (m) among each lake in the month of Ju
```

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

```
## Warning: Removed 24 rows containing missing values or values outside the scale range
## (`geom_smooth()`).
```



Relationship between temperature (C) and depth (m) among each lake in the month of July.

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

```
#15
TukeyHSD(NTL_LTER_July_anova)
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
```

```
##
## Fit: aov(formula = temperature_C ~ lakename, data = NTL_LTER_July)
##
## $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: Paul Lake (0.22) and Ward Lake (0.78) have the same mean temperature, statistically speaking, as Peter Lake. The p-value for Peter Lake - Paul Lake is 0.22, which is less than 0.05. The p-value for Ward Lake - Peter Lake is 0.77, which is less than 0.05. A value less than 0.05 would indicate that the mean temperature of the lakes are significantly different. There are few lake pairs that statistically similar, as it seems that the mean temperature of most lakes are statistically different from one another - for this reason it is difficult to point to one lake that is especially statistically distinct 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: A two-sample t-test may be another test that could explore whether they have distinct means. A two-sample t-test is used to test the hypothesis that the mean of two samples is equivalent

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?

```
NTL_LTER_July_two_lakes <- NTL_LTER_July %>%
  filter(lakename %in% c("Crampton Lake", "Ward Lake"))

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

```
##
##  Welch Two Sample t-test
##
## data:  NTL_LTER_July_two_lakes$temperature_C by NTL_LTER_July_two_lakes$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: The test result indicates that their mean July temperature is statistically the same, as p-value > 0.05 (it is 0.26). The test reports that the mean temperature for Crampton Lake is 15.35 and the mean temperature for Ward Lake is 14.45. In part 16, The Tukey test result indicates that Crampton Lake and Ward Lake are statistically similar, as the p-value is well above 0.05 with a value of 0.97. So yes, the results of the t-test match the results of the Tukey test in part 16.