Assessing water level changes from hurricanes from 2000 - 2020

Web address for GitHub repository:
https://github.com/Autumn41/Dunn-Artusi-Zarate_ENV872_Project.git

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1 Rationale and Research Questions

From 2000 to 2020, North Carolina was hit with 64 hurricanes and 26 of those hurricanes occurred in September. With climate change, hurricanes are expected to occur more frequently and at higher intensity (Elsner, 2006). Higher intensity storms will likely cause flooding of cities and urban areas which many infrastructures are not designed to accommodate (James et al., 2020; Marsooli & Lin, 2020). Additionally, much of North Carolina Piedmont wetlands have been drained and many streams are degraded due to urban disturbances(Carle, 2011; Violin et al., 2011). Wetlands and streams are natural systems that store flood water, and without them, many areas that have not flooded in the past will be at risk (Ameli & Creed, 2019). Investing in pre-disaster hazard mitigation has been shown to be economically beneficial and save lives (Villa, 2020). In order to update infrastructure, expected water input and time period of elevated water levels are needed. Using stream gage height, we selected Catawba River, Yadkin River, Mills River, and French Broad River, because of their location along the path of Hurrican Florence, which hit North Carolina in 2018. We focused on two questions: has gage height changed over 2000-2020 for September from hurricanes and how much does a stream gage height change after a hurricane?

From 2000 to 2020, North Carolina was hit with 64 hurricanes and 26 of those hurricanes occurred in September. With climate change, hurricanes are expected to occur more frequently and at higher intensity (Elsner, 2006). Higher intensity storms will likely cause flooding of cities and urban areas which many infrastructures are not designed to accommodate (James et al., 2020; Marsooli & Lin, 2020). Additionally, much of North Carolina Piedmont wetlands have been drained and many streams are degraded due to urban disturbances (Carle, 2011; Violin et al., 2011). Wetlands and streams are natural systems that store flood water, and without them, many areas that have not flooded in the past will be at risk (Ameli & Creed, 2019). Investing in pre-disaster hazard mitigation has been shown to be economically beneficial and save lives (Villa, 2020). In order to update infrastructure, expected water input and time period of elevated water levels are needed. Using stream gage height, we selected Catawba River, Yadkin River, Mills River, and French Broad River, because of their location along hurricane paths. We focused on two questions: has gage height changed over 2000-2020 for September from hurricanes and how much does a stream gage height change after a hurricane?

2 Dataset Information

Data were retrieved from USGS National Water Information. USGS uses an eight digit code for each site (listed below). The parameter of interest, represented as GH in the tables, was gage height (feet), identified using the pcode 00065. Daily mean value was used, using the scode 00003.

Site locations and site codes:

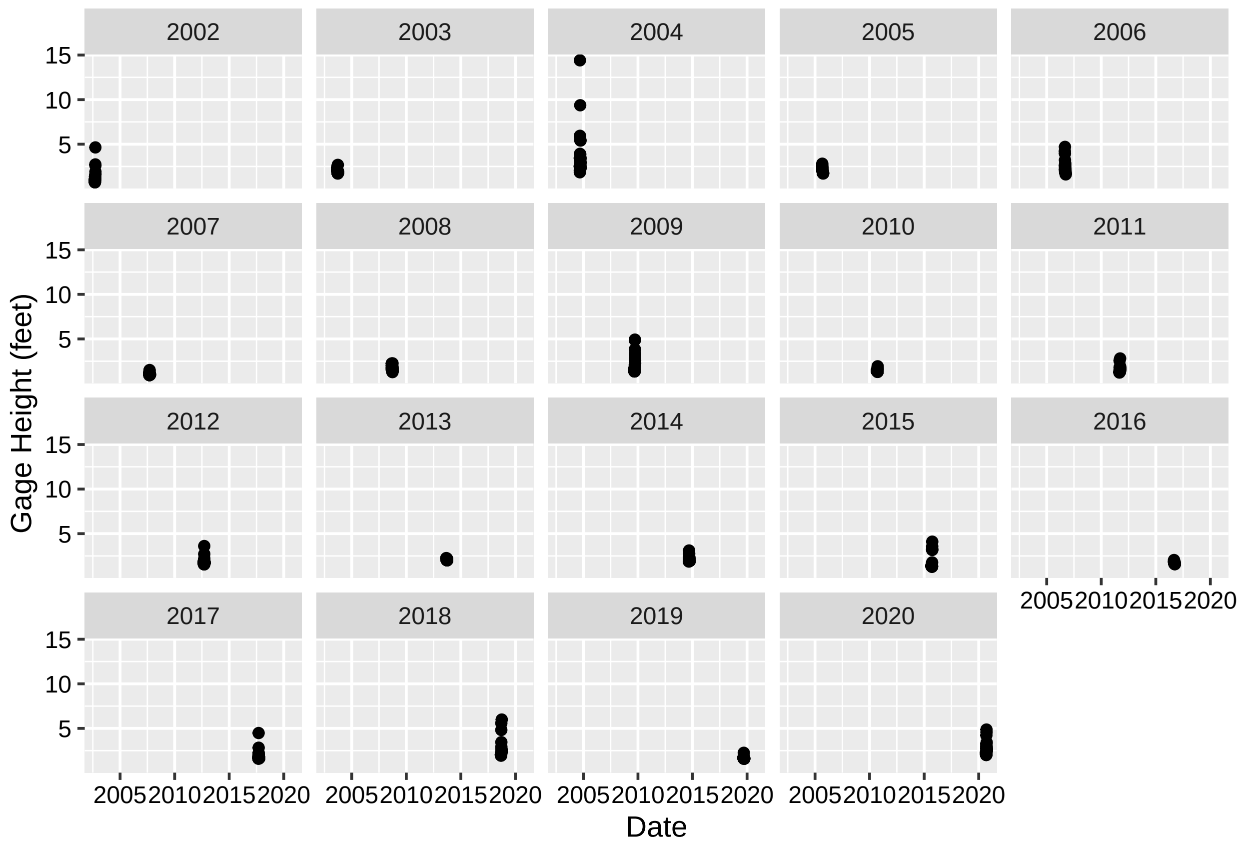
River Names	NC City	Site Code
Catawba River	Pleasant Gardens	02137727
Yadkin River	Patterson	02111000
Mills River	Mills River	03446000
French Broad River	(Fletcher)	03447687

To process the data, gage heights for September for all available years were selected from the raw gage height data. This was done by converting the raw date to a recognized date format and filtering by month. Later, to run the t-tests, each river dataset was subsetted into two datasets, one for 2001 and one for 2018 for each river.

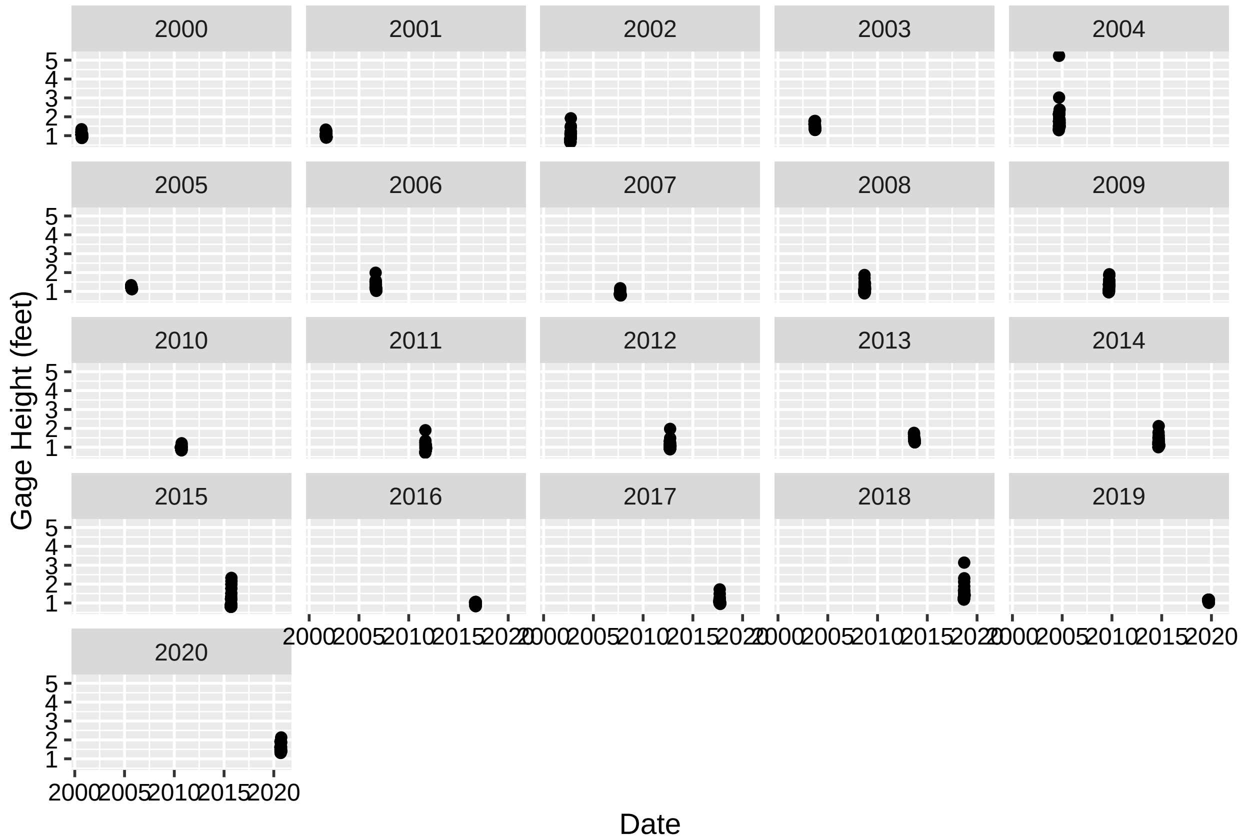
3 Exploratory Analysis

Write to explain the graphs - Autumn Savannah historgrams.

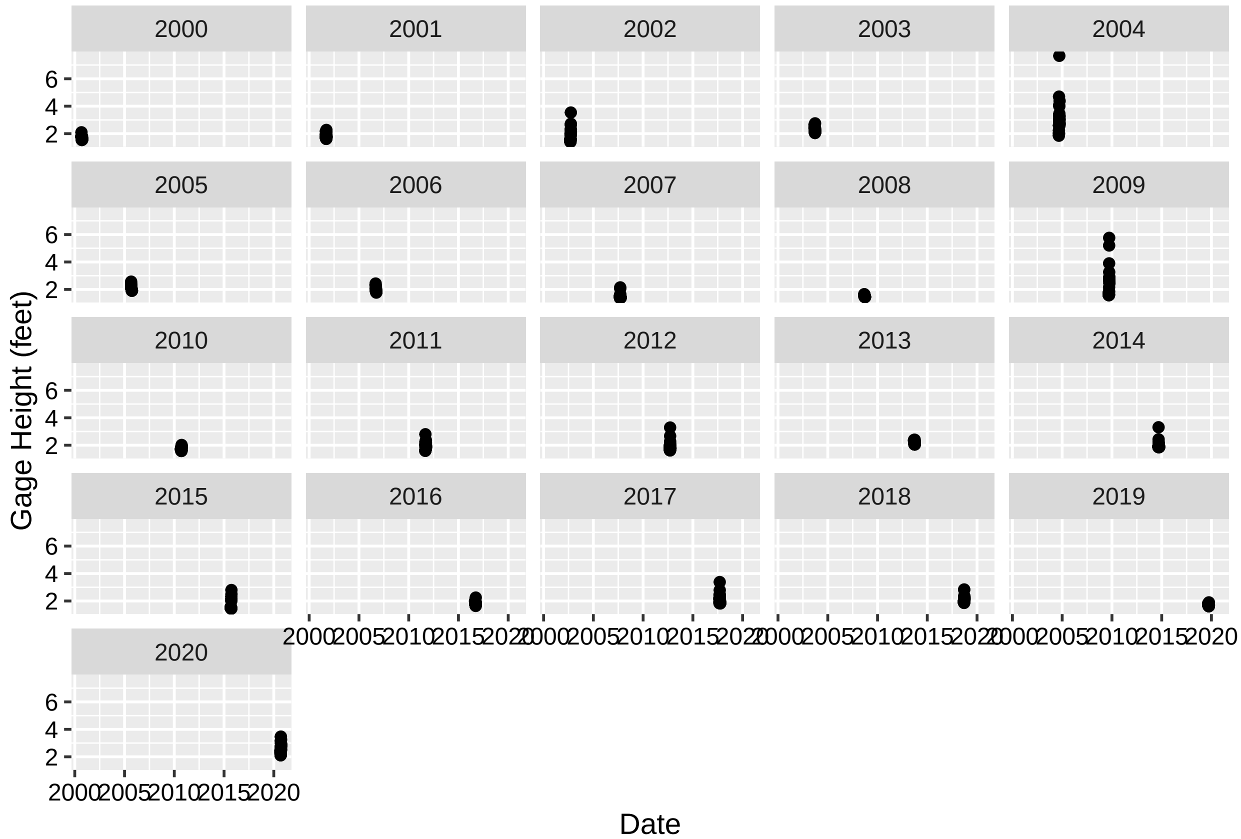
```
#Plot 1 - Catawba Gage Height as points on individual plots for September
ggplot(Catawba_sept, aes(y=GH, x=Date)) +
  geom_point() +
  xlab("Date") +
  ylab("Gage Height (feet)") +
  mytheme +
  facet_wrap(vars(Year))
```



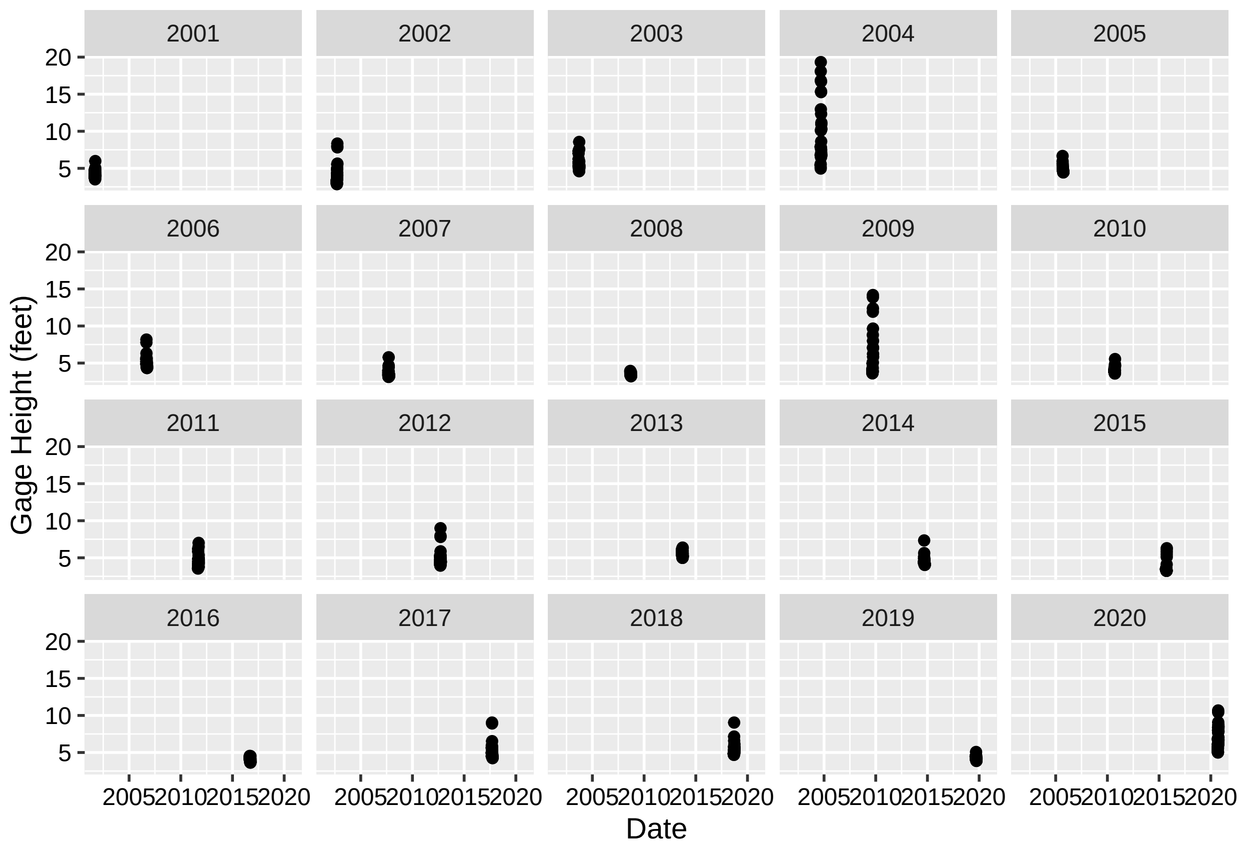

```
#Plot 2 - Yadkin Gage Height as points on individual plots for September
ggplot(Yadkin_sept, aes(y=GH, x=Date)) +
  geom_point() +
  xlab("Date") +
  ylab("Gage Height (feet)") +
  mytheme +
  facet_wrap(vars(Year))
```




```r
#Plot 3 - Mills Gage Height as points on individual plots for September
ggplot(Mills_sept, aes(y=GH, x=Date)) +
  geom_point() +
  xlab("Date") +
  ylab("Gage Height (feet)") +
  mytheme +
  facet_wrap(vars(Year))
```




```
#Plot 4 - FrenchBroad Gage Height as points on individual plots for September
ggplot(FrenchBroad_sept, aes(y=GH, x=Date)) +
  geom_point() +
  xlab("Date") +
  ylab("Gage Height (feet)") +
  mytheme +
  facet_wrap(vars(Year))
```

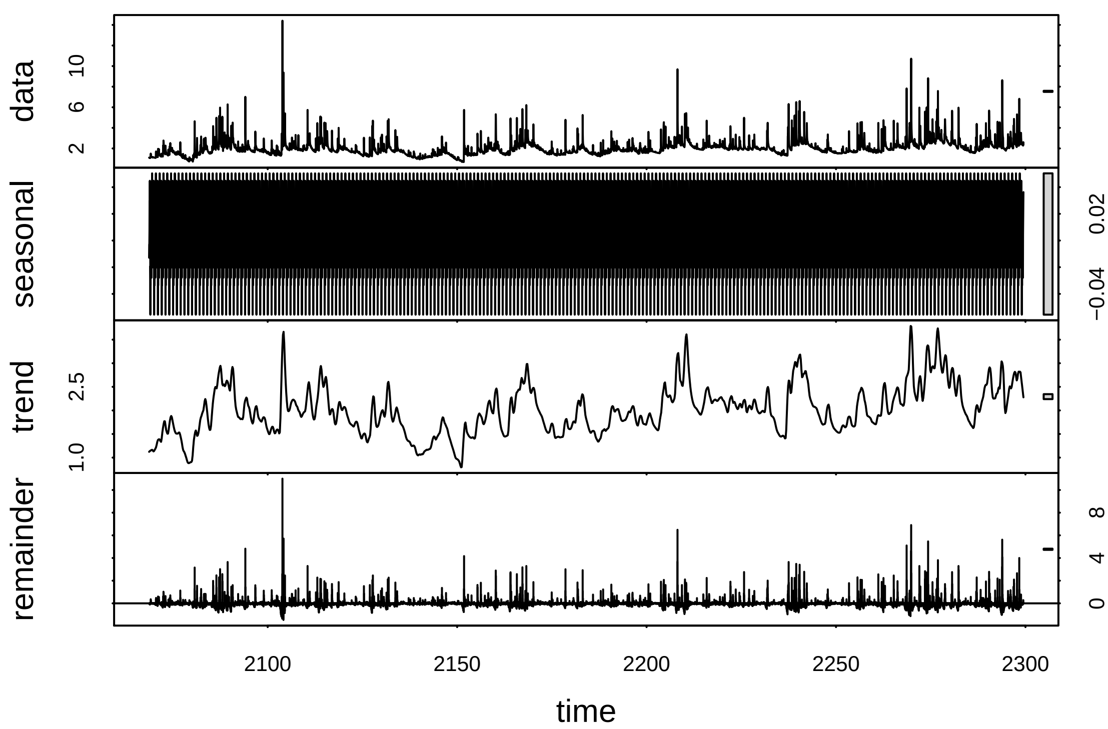

2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
20
15
10
5
Gage Height (feet)
2005
2010
2015
2020
Date

4 Analysis

Time Series of four rivers from 2000 - 2020

Add paragraph explaining ts.

```r
## Catawba ##

# Generate time series
Start_month <- month(first(Catawba_sept))
Start_year <- year(first(Catawba_sept))

Catawba.daily.ts <- ts(Catawba$GH,
                       start=c(Start_year,Start_month),
                       frequency=30)

# Decompose
Day_Catawba_decomp <- stl(Catawba.daily.ts, s.window = "periodic")
plot(Day_Catawba_decomp)
```




```r
# Run SMK test
Month_Catawba_trend <- Kendall::SeasonalMannKendall(Catawba.daily.ts)
```

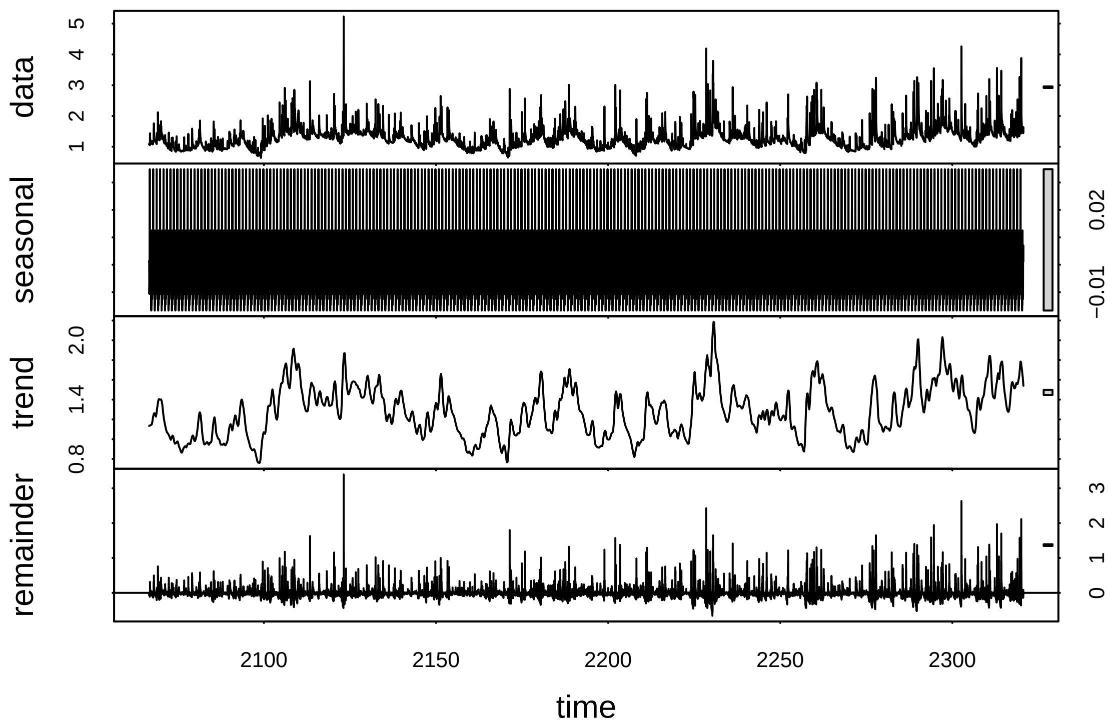
```r
# Inspect results
summary(Month_Catawba_trend)
```

```
## Score =  208802 , Var(Score) = 41240024
## denominator =  793309.8
## tau = 0.263, 2-sided pvalue =< 2.22e-16
```

```r
## Yadkin ##

# Generate time series
Start_month2 <- month(first(Yadkin_sept))
Start_year2 <- year(first(Yadkin_sept))

Yadkin.daily.ts <- ts(Yadkin$GH,
                   start=c(Start_year2,Start_month2),
                   frequency=30)

# Decompose
Day_Yadkin_decomp <- stl(Yadkin.daily.ts, s.window = "periodic")
plot(Day_Yadkin_decomp)

# Run SMK test
Month_Yadkin_trend <- Kendall::SeasonalMannKendall(Yadkin.daily.ts)

# Inspect results
summary(Month_Yadkin_trend)
```

```
## Score =  130395 , Var(Score) = 54970729
## denominator =  959441.5
## tau = 0.136, 2-sided pvalue =< 2.22e-16
```

```r
## Mills ##

# Generate time series
Start_month3 <- month(first(Mills_sept))
Start_year3 <- year(first(Mills_sept))

Mills.daily.ts <- ts(Yadkin$GH,
                   start=c(Start_year3,Start_month3),
                   frequency=30)

# Decompose
Day_Mills_decomp <- stl(Mills.daily.ts, s.window = "periodic")
plot(Day_Mills_decomp)
```

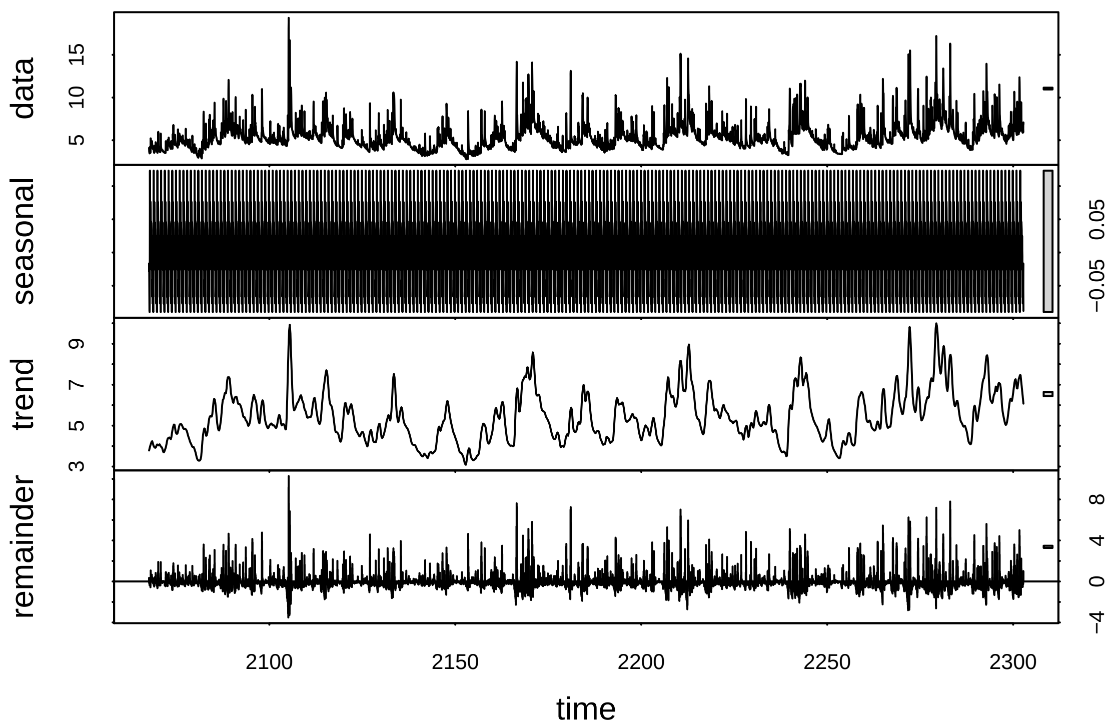



```r
# Run SMK test
Month_Mills_trend <- Kendall::SeasonalMannKendall(Mills.daily.ts)

# Inspect results
summary(Month_Mills_trend)
```

```
## Score =  130395 , Var(Score) = 54970729
## denominator =  959441.5
## tau = 0.136, 2-sided pvalue =< 2.22e-16
```

```r
## FrenchBroad ##

# Generate time series
Start_month4 <- month(first(FrenchBroad_sept))
Start_year4<- year(first(FrenchBroad_sept))

FrenchBroad.daily.ts <- ts(FrenchBroad$GH,
                   start=c(Start_year4,Start_month4),
                   frequency=30)

# Decompose
Day_FrenchBroad_decomp <- stl(FrenchBroad.daily.ts, s.window = "periodic")
```

```
plot(Day_FrenchBroad_decomp)
```




```
# Run SMK test
Month_FrenchBroad_trend <- Kendall::SeasonalMannKendall(FrenchBroad.daily.ts)

# Inspect results
summary(Month_FrenchBroad_trend)
```

```
## Score =  128036 , Var(Score) = 43605765
## denominator =  824809.4
## tau = 0.155, 2-sided pvalue =< 2.22e-16
```

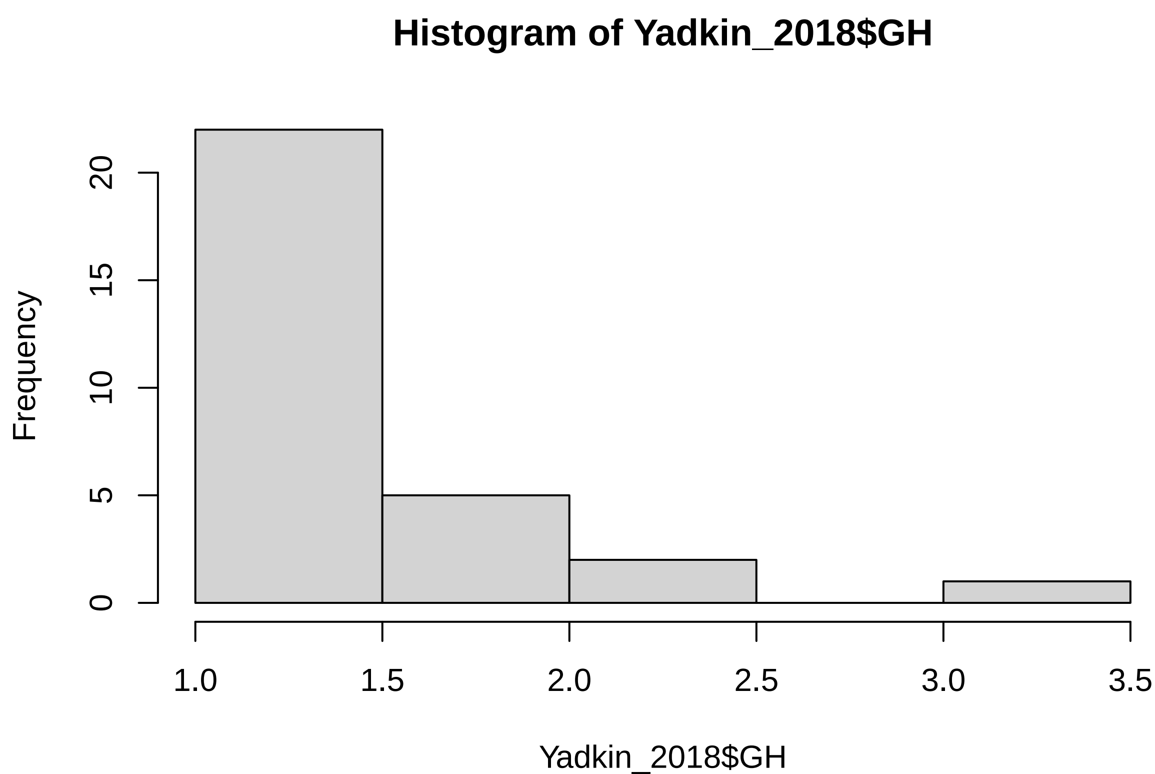
T-Test comparing September 2001 to 2018

```
#H0: Gage Height is the same in September for both years
#Ha: Gage Height is not the same in September for both years

## Yadkin - T-Test
# Create Dataframes
Yadkin_2001 <- Yadkin_sept %>% filter(Year== 2001)
Yadkin_2018 <- Yadkin_sept %>% filter(Year== 2018)

#Check assumptions
```

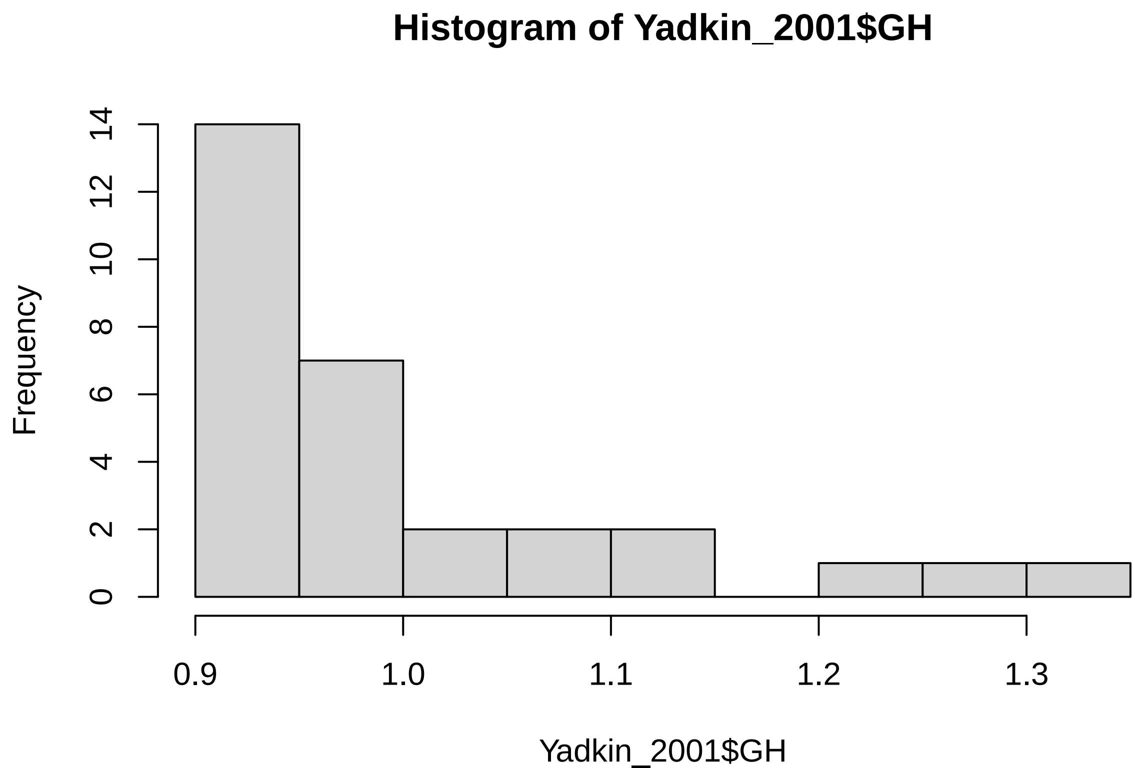
```r
Yadkin_var <- var.test(Yadkin_2001$GH, Yadkin_2018$GH)
sd(Yadkin_2001$GH)/sd(Yadkin_2018$GH)
```

```
## [1] 0.2734779
```

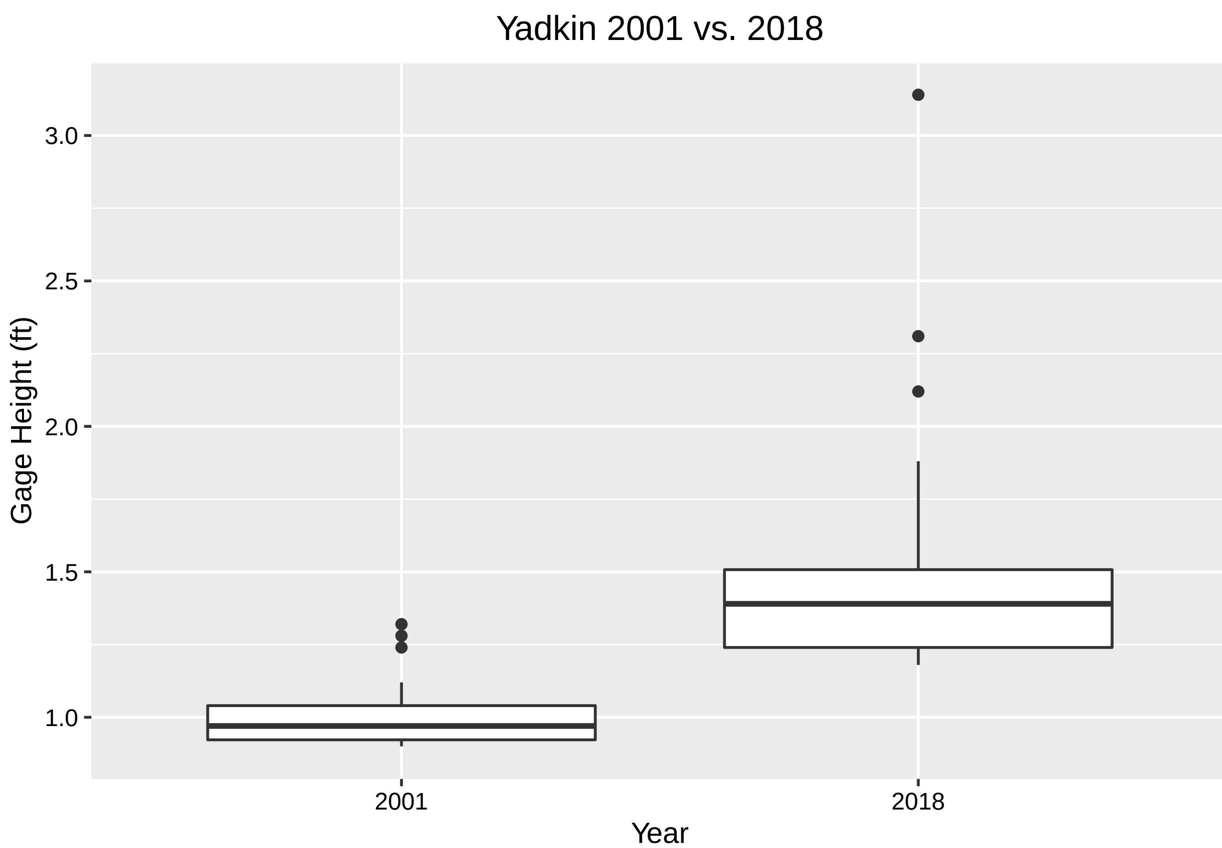
```r
hist(Yadkin_2018$GH)
```




```r
hist(Yadkin_2001$GH)
```



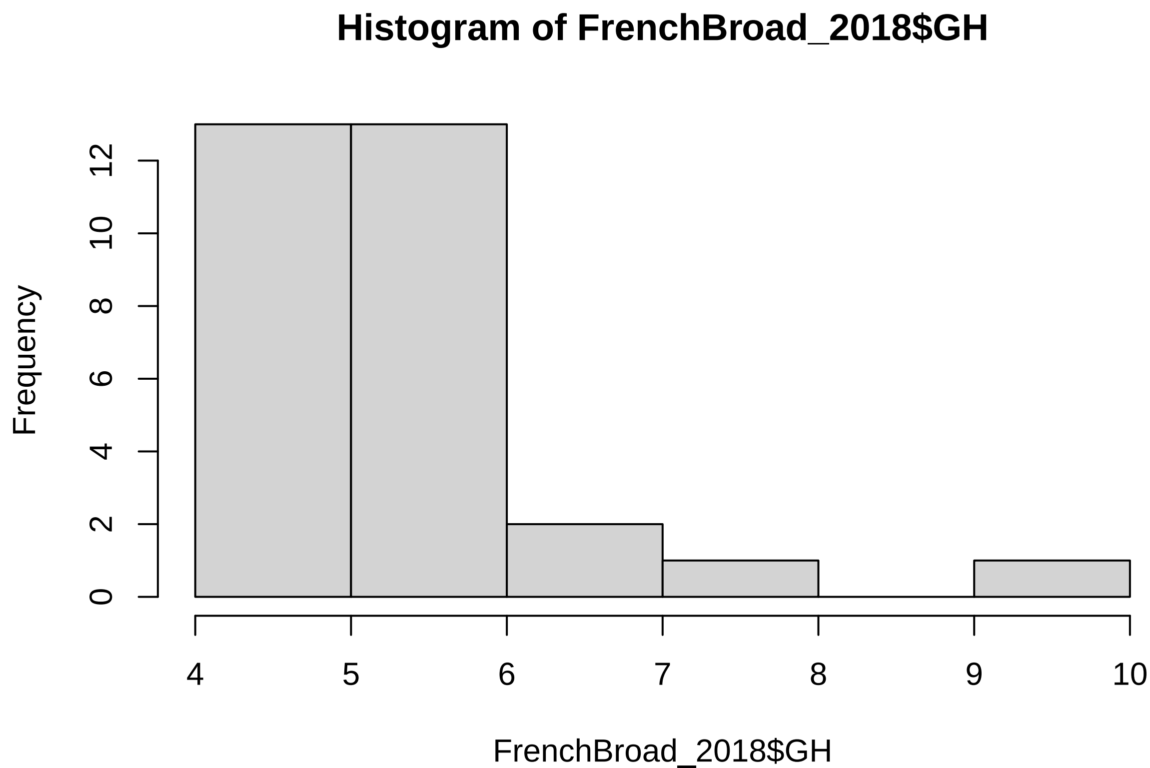

```r
#Run t-test
Yadkin_test <- t.test(Yadkin_2001$GH, Yadkin_2018$GH, var.equal = T)

#Graph
Yadkin_df <- rbind(Yadkin_2001, Yadkin_2018)
ggplot(Yadkin_df, aes(x = factor(Year), y = GH)) +
  geom_boxplot() +
  labs(x = "Year", y = "Gage Height (ft)", title = "Yadkin 2001 vs. 2018")
```



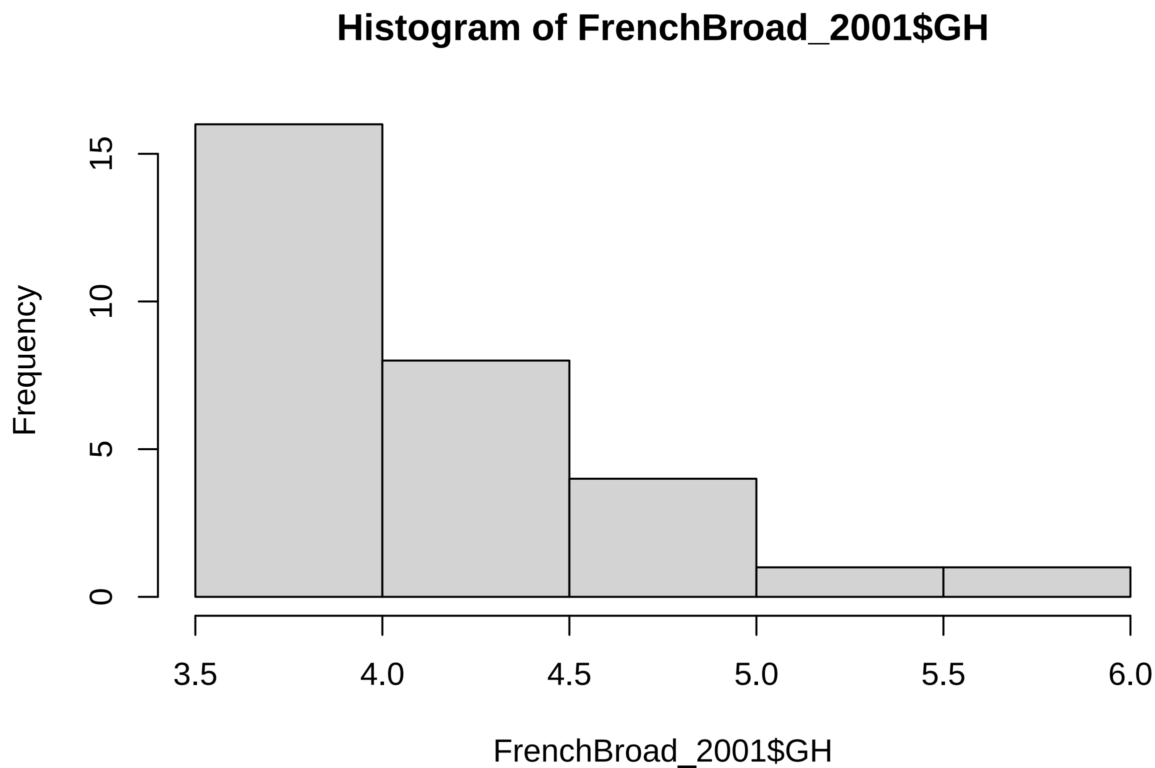

```
## French Broad - T-Test
# Create Dataframes
FrenchBroad_2001 <- FrenchBroad_sept %>% filter(Year== 2001)
FrenchBroad_2018 <- FrenchBroad_sept %>% filter(Year== 2018)

#Check assumptions
FrenchBroad_var <- var.test(FrenchBroad_2001$GH, FrenchBroad_2018$GH)
sd(FrenchBroad_2001$GH)/sd(FrenchBroad_2018$GH)
```

```
## [1] 0.5959884
```

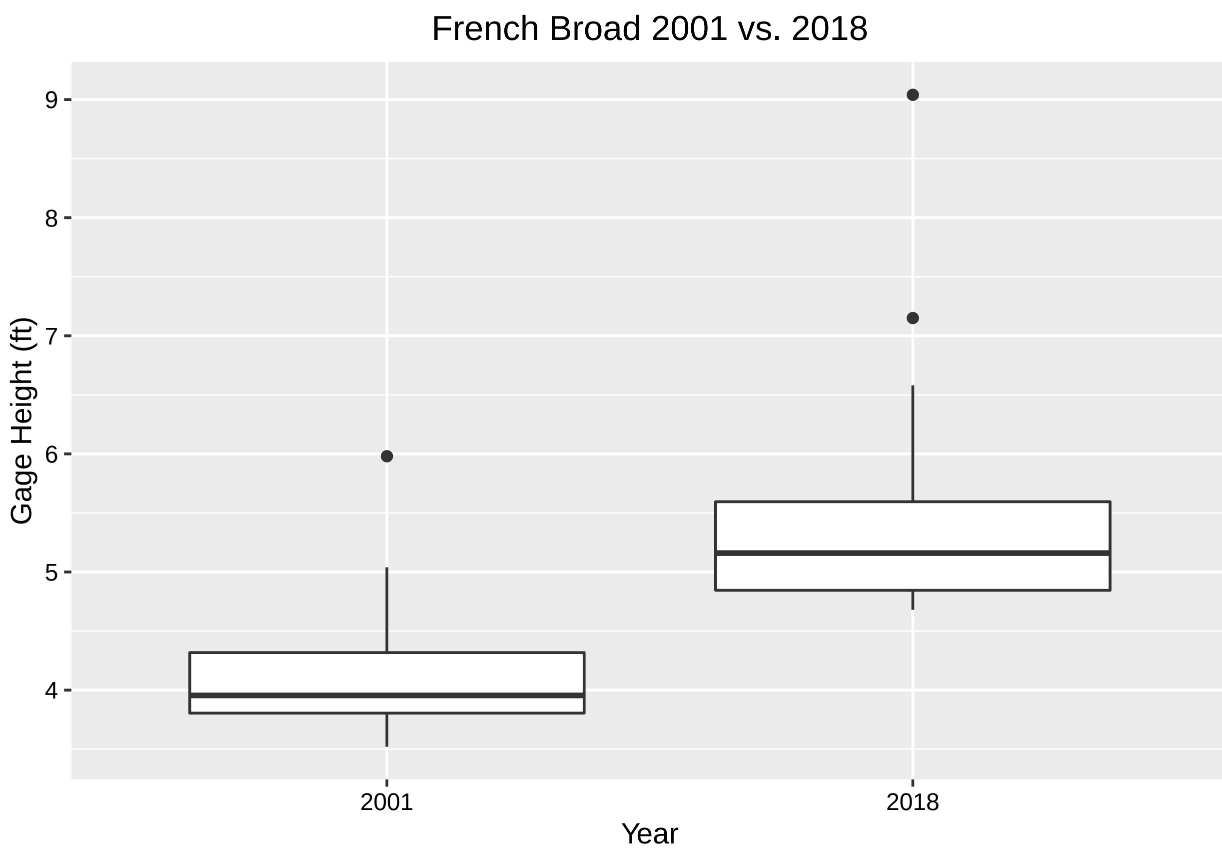
```
hist(FrenchBroad_2018$GH)
```




```
hist(FrenchBroad_2001$GH)
```



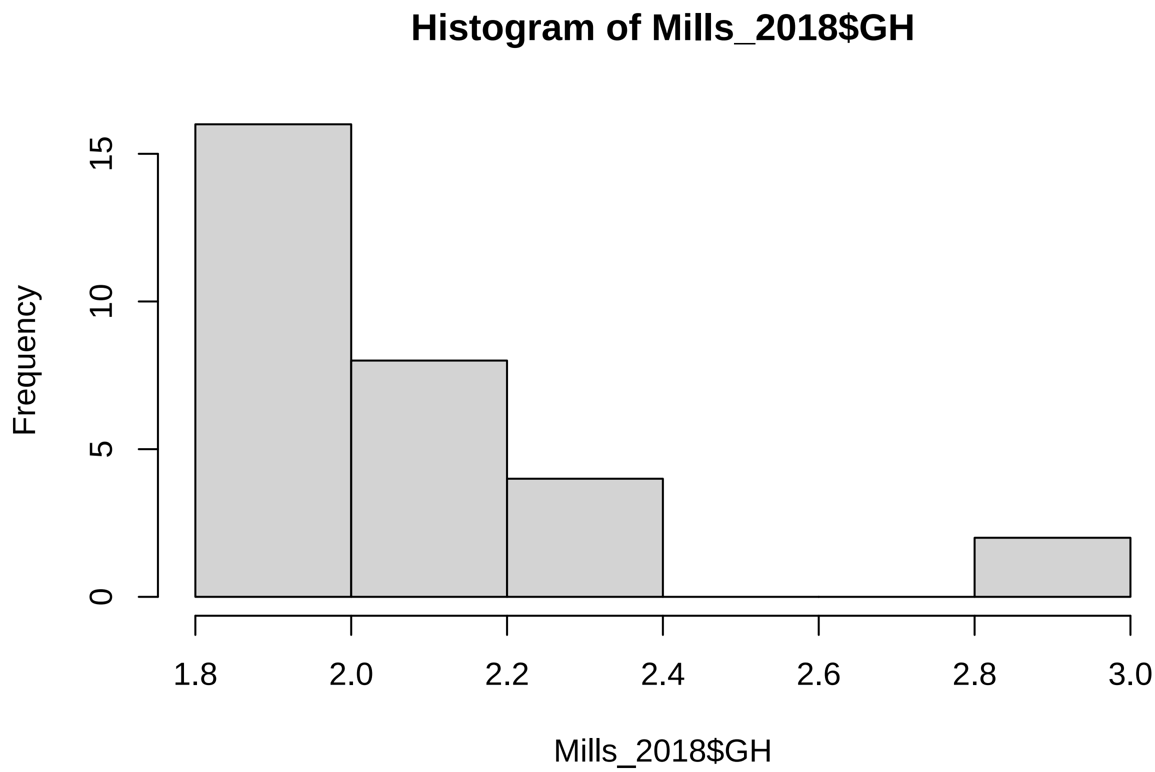

```r
#Run t-test
FrenchBroad_test <- t.test(FrenchBroad_2001$GH, FrenchBroad_2018$GH, var.equal = T)

#Graph
FrenchBroad_df <- rbind(FrenchBroad_2001, FrenchBroad_2018)
ggplot(FrenchBroad_df, aes(x = factor(Year), y = GH)) +
  geom_boxplot() +
  labs(x = "Year", y = "Gage Height (ft)", title = "French Broad 2001 vs. 2018")
```




```
## Mills - T-Test
# Create Dataframes
Mills_2001 <- Mills_sept %>% filter(Year== 2001)
Mills_2018 <- Mills_sept %>% filter(Year== 2018)

#Check assumptions
Mills_var <- var.test(Mills_2001$GH, Mills_2018$GH)
sd(Mills_2001$GH)/sd(Mills_2018$GH)
```

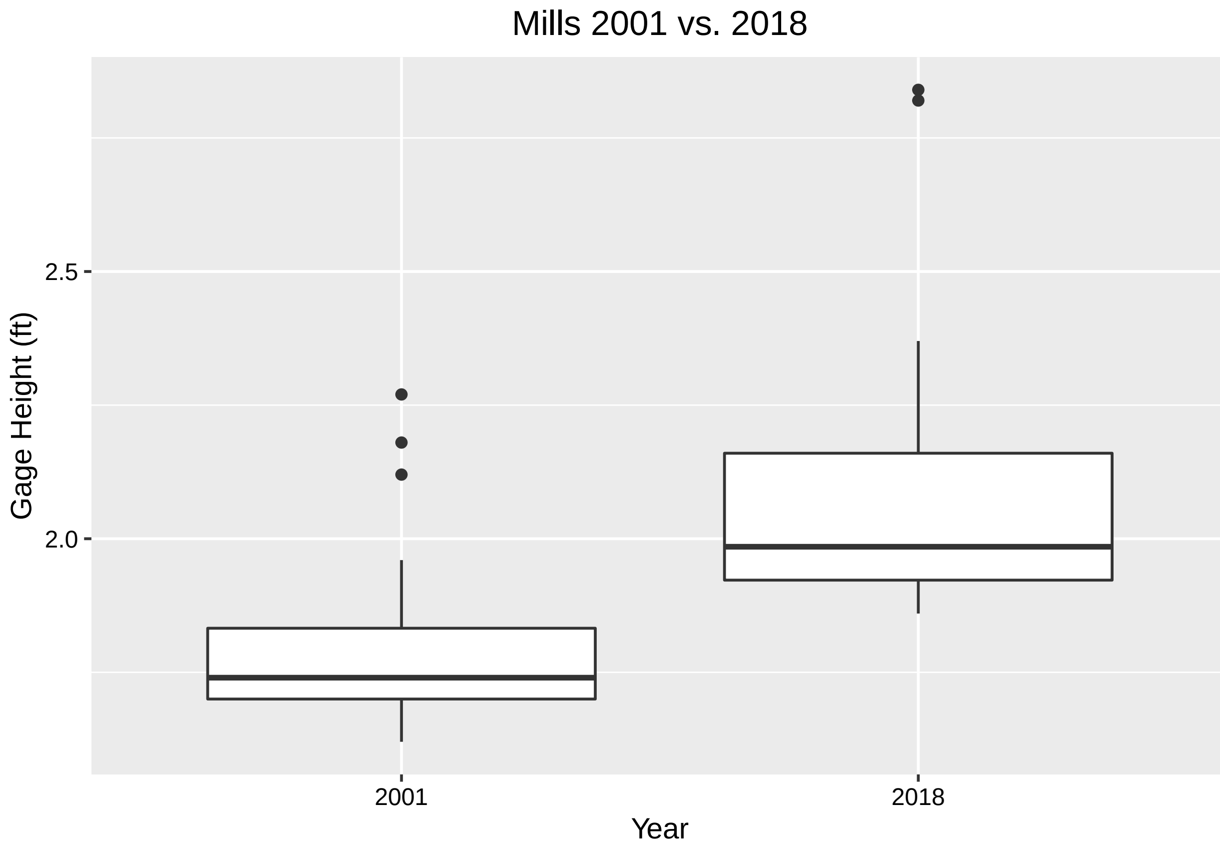
```
## [1] 0.6612318
```

```
hist(Mills_2018$GH)
```




```
hist(Mills_2001$GH)
```


```
#Run t-test
Mills_test <- t.test(Mills_2001$GH, Mills_2018$GH, var.equal = T)

#Graph
Mills_df <- rbind(Mills_2001, Mills_2018)
ggplot(Mills_df, aes(x = factor(Year), y = GH)) +
  geom_boxplot() +
  labs(x = "Year", y = "Gage Height (ft)", title = "Mills 2001 vs. 2018")
```




```r
#Create Table of Results
Results_df <- data.frame("River_Name" = c('Yadkin', 'Mills',
                                          'French Broad'),
                 "Average_GH_2001" = c(mean(Yadkin_2001$GH), mean(Mills_2001$GH),
                                       mean(FrenchBroad_2001$GH)),
                 "Average_GH_2018" = c(mean(Yadkin_2018$GH), mean(Mills_2018$GH),
                                       mean(FrenchBroad_2018$GH)),
                 "var.test_Result" = c(Yadkin_var$statistic, Mills_var$statistic,
                                       FrenchBroad_var$statistic),
                 "T-Statistic" = c(Yadkin_test$statistic, Mills_test$statistic,
                                       FrenchBroad_test$statistic),
                 "P-Value" = c(Yadkin_test$p.value, Mills_test$p.value,
                               FrenchBroad_test$p.value))

kable(Results_df, col.names = c("River Name", "2001 Avg GH",
                                "2018 Avg GH", "var.test Result",
                                "T-Stat", "P-Value"),
                 caption = "Results", digits = c(0, 2, 2, 2, 2, 8)) %>%
  column_spec(1:5,border_left = T, border_right = T) %>%
  kable_styling()
```

Table 2: Results

River Name	2001 Avg GH	2018 Avg GH	var.test Result	T-Stat	P-Value
Yadkin	1.00	1.49	0.07	-6.22	6.00e-08
Mills	1.80	2.08	0.44	-5.37	1.46e-06
French Broad	4.12	5.40	0.36	-6.72	1.00e-08

4.1 Question 1: Has gage height changed over 2000-2020 for September from hurricanes?

Yadkin River, Mills River, and French Broad River had a significant (p-value < 0.05) monotonic upward trend. French Broad River had the largest upward trend ( ) and Yadkin River and Mills River had the smallest upward trend (0.0218).

4.2 Question 2: Are gage heights significantly different between 2001 and 2018?

The mean gage heights for each river was higher in 2018 than in 2001, and these differences were statistically significant. Since the t-statistic for the Yadkin, Mills, and French Broad Rivers (-6.22, -5.37, and -6.72) are negative, this indicates that the 2018 gage heights are greater than the 2001 heights. The Yadkin River gage was 0.49 feet higher in 2018 (p-value < 0.05). The Mills River gage was 0.28 feet higher in 2018 (p-value < 0.05). The French Broad River gage was 1.28 feet higher in 2018 (p-value < 0.05). A necessary assumption for statistical t-tests is that variances are approximately equal, with the ratio of variances produced using the var.test function at around 0.5. It is important to note that this was not the case for all three rivers studied. Yadkin River was especially low (0.07) and French Broad River was 0.36. The ratio for Mills River was appropriate (0.44). Another necessary assumption is that the data are normally distributed, which was again not the case for all three rivers in both years. All samples were notably right-skewed; however, this makes sense given that gage heights are expected to remain around the same level. The high values that are skewing the distribution of the data could reflect the increases in gage height due to hurricanes (especially in 2018) or other unusual events (for example, human regulation of river flow).

With these results, we reject the null hypothesis and conclude that the average gage heights for 2001 and 2018 are different and that this difference is statistically significant for all three rivers.

5 Summary and Conclusions

Water level has been increasing for the month of September over the last 20 years, based on the significant upward trend from the time series analysis. Based on National Climatic Data Center Event Report for Hurricanes, in 2018, 46 people died due to hurricane Florence and Michael, the only 2 hurricanes to hit that year and in 2016, 28 people died due to hurricane Matthew. From 2000 - 2012, 41 people in total died due to hurricanes. Death from hurricanes are usually linked to flooding, which can cause expose individuals to sewage water, damage infrastructure making roads and homes dangerous, and potentially drown victims (Choudhary et al., 2012). Though storms appeared to have decreased in frequency (there were 48 storms from 2000 - 2010, but only 18 storms from 2011 – 2020) it is evident that the severity of the storms has increased, based on both deaths and increasing water levels. Further research should be done to quantify how much additional water is deposited per storm and what updates to infrastructure should be done to account for this additional water. To evaluate increase in hurricane intensity due to climate change, we compared gage heights between 2001, a year with no September hurricanes impacting North Carolina, and 2018, a year with the major Hurricane Florence. The results of our t-test showed that there was a significant difference in gage height, indicating that hurricane intensity and flood potential increased. While it is possible that other factors contributed to this increase in gage height, our conclusions are supported by existing research studies that link climate change to increases in hurricane intensity (Emanuel, 1987).

6 References

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