Hawaii Water Data Exploration

Gaby Garcia

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Set Working Directory and Import Data

```
setwd("~/Desktop/Environmental Data Analytics/Environmental_Data_Analytics/Final Project")
HawaiiWater<-read.csv('HawaiiWaterDataProcessed.csv')
```

Load Necessary Packages

```
library(tidyverse)
library(tidyr)
library(ggplot2)
library(GGally)
library(dplyr)
library(plyr)
library(lubridate)
library(viridis)
library(RColorBrewer)
library(colormap)
library(gridExtra)
library(corrplot)
library(nlme)
library(lsmeans)
library(multcompView)
library(trend)
library(mapview)
library(leaflet)
library(sf)
library(car)
library(stats)
library(wesanderson)
library(scales)
```

Omit NA's from Data (GLM 12 lesson says to do so)

```
HawaiiWaterClean<- na.omit(HawaiiWater)
```

Convert Station Number from Factor to Number

```
HawaiiWaterClean$Station.No<-as.numeric(HawaiiWaterClean$Station.No)
```

```
HawaiiWaterCleanGrouped<-HawaiiWaterClean%>%group_by(Location)
```

Filtering Data Set to Only Include Observations from Oahu

```
HawaiiWaterCleanOahu <-
 HawaiiWaterClean %>%
  dplyr::filter(Location== "Ala Moana Park, Ewa" | Location == "Ala Moana Park, Center"| Location == "Al
"| Location =="Tongg's"| Location =="Kawaikui Beach Park"| Location =="Kanenelu Beach"| Location =="Kala
"| Location =="Kaluahole Beach"| Location =="Outrigger"| Location =="Halona Cove"| Location =="Kokee Bea
"| Location =="Turtle Bay"| Location =="Kaunala Beach"| Location =="Pupukea at Shark's Cove"| Location =
"| Location =="Kualoa Sugar Mill Beach"| Location =="Swanzy Beach Park"| Location =="Makaua Beach"| Loca
```

Recoding Geographical Observations to Regions in Oahu

Convert station number from number to factor

```
HawaiiWaterCleanOahu$Station.No<-as.factor(HawaiiWaterCleanOahu$Station.No)
```

Use Revalue function to recode

```
library(plyr)
HawaiiWaterCleanOahu$Region<-revalue(HawaiiWaterCleanOahu$Station.No, c('28'='East', '39'='South', '40'=
```

Determine Number of Observations for Each Region in Oahu

```
summary(HawaiiWaterCleanOahu$Region)
```

```
##  East South North  West
##   999  2634  1002   969
```

Exploratory Data Analysis

Structure of Water Data

```
str(HawaiiWaterCleanOahu)
```

```
## 'data.frame':    5604 obs. of  17 variables:
##  $ Sample.No                     : Factor w/ 23020 levels "CF01030501","CF01030502",..: 4477 10741
##  $ Sampler                       : Factor w/ 21 levels "","CF","CF ",..: 5 9 18 8 19 9 8 5 19 9 ..
##  $ Lab.No                        : Factor w/ 15097 levels "","1","10","100",..: 14982 13031 12810 
##  $ Station.No                    : Factor w/ 118 levels "28","39","40",..: 2 2 2 2 2 2 2 2 2 2 ...
##  $ Location                      : Factor w/ 240 levels "Airport","Ala Moana DH1",..: 7 7 7 7 7 7 
##  $ Date                          : Factor w/ 1133 levels "1/10/00","1/10/01",..: 226 169 149 1055 
##  $ Time                          : Factor w/ 501 levels "","1:00:00 AM",..: 277 427 437 431 52 422
##  $ Enterococcus                  : num  400 20 10 2.3 6.3 2.3 0.3 1 2.7 2.3 ...
##  $ CP                            : num  4.8 3 0.2 1 0.2 1 0.2 0.2 0.2 1 ...
##  $ Temperature                   : num  25.1 25.6 26.9 26.7 26.4 ...
##  $ Salinity                      : num  35.2 35.3 34.6 35.3 35.1 ...
```

```
##  $ DO                              : num  6.45 5.57 5.46 4.89 6.24 6.62 5.97 4.42 4.8 6.08 ...
##  $ PercentSaturationDissolvedOxygen: num  94 84.4 84.3 75.5 95.6 98.3 88.3 65 71 89.5 ...
##  $ pH                              : num  8.15 8.02 8.05 8.1 8.2 8.15 8.06 8.1 7.99 8.05 ...
##  $ Turbidity                       : num  14.13 28.4 9.57 5.64 2.76 ...
##  $ Remarks                         : Factor w/ 5481 levels ""," "," CLEAR/SUNNY, SWIMMERS",..: 2981
##  $ Region                          : Factor w/ 4 levels "East","South",..: 2 2 2 2 2 2 2 2 2 2 ...
##  - attr(*, "na.action")= 'omit' Named int  2 46 73 80 81 82 83 85 86 87 ...
##   ..- attr(*, "names")= chr  "2" "46" "73" "80" ...
```

Summary of Water Data

```r
summary(HawaiiWaterCleanOahu)
```

```
##       Sample.No       Sampler         Lab.No       Station.No
##  CF01190609:   1   JD     :1011   H038-06:   1   92     : 227
##  CF01250601:   1   SM     : 923   H047-06:   1   48     : 226
##  CF02020601:   1   SN     : 922   H069-06:   1   68     : 226
##  CF02150601:   1   GH     : 851   H084-06:   1   74     : 224
##  CF03020601:   1   JM     : 767   H105-06:   1   71     : 223
##  CF03090602:   1   DM     : 619   H119-06:   1   82     : 223
##  (Other)   :5598   (Other): 511   (Other):5598   (Other):4255
##                  Location          Date              Time
##  San Souci           : 227   12/13/04:  40   8:30:00 AM: 153
##  Kailua Beach        : 226   11/18/04:  38   7:40:00 AM: 139
##  Kuhio Beach         : 226   11/8/04 :  38   7:50:00 AM: 120
##  Hanauma Bay         : 224   11/16/04:  37   7:35:00 AM: 119
##  Waialae-Kahala Beach: 223   11/22/04:  37   7:25:00 AM: 118
##  Waimanalo Beach     : 223   11/4/04 :  37   7:20:00 AM: 116
##  (Other)             :4255   (Other) :5377   (Other)   :4839
##   Enterococcus           CP           Temperature       Salinity
##  Min.   :    0.30   Min.   :  0.200   Min.   :20.29   Min.   : 8.42
##  1st Qu.:    2.30   1st Qu.:  0.500   1st Qu.:24.05   1st Qu.:34.54
##  Median :    3.30   Median :  1.000   Median :25.14   Median :34.95
##  Mean   :   28.51   Mean   :  3.055   Mean   :25.04   Mean   :34.31
##  3rd Qu.:   10.00   3rd Qu.:  2.000   3rd Qu.:26.07   3rd Qu.:35.18
##  Max.   :22000.00   Max.   :290.000   Max.   :28.91   Max.   :37.24
##
##        DO        PercentSaturationDissolvedOxygen       pH
##  Min.   :3.060   Min.   :  5.82                   Min.   :7.340
##  1st Qu.:5.470   1st Qu.: 83.10                   1st Qu.:8.020
##  Median :5.880   Median : 88.80                   Median :8.110
##  Mean   :5.829   Mean   : 87.38                   Mean   :8.103
##  3rd Qu.:6.210   3rd Qu.: 92.70                   3rd Qu.:8.190
##  Max.   :9.340   Max.   :134.60                   Max.   :8.800
##
##    Turbidity                                Remarks       Region
##  Min.   :  0.000                                :3014   East : 999
##  1st Qu.:  1.800   SUNNY, LIGHT BREEZE, SWIMMERS:  18   South:2634
##  Median :  3.440   Tide rising, choppy, no rain :  15   North:1002
##  Mean   :  6.331   SUNNY, LIGHT BREEZE          :  14   West : 969
##  3rd Qu.:  7.425   SUNNY                        :  13
##  Max.   :315.000   SWIMMERS                     :  13
##                    (Other)                      :2517
```

Dimensions of Data

```r
dim(HawaiiWaterCleanOahu)
```

```
## [1] 5604   17
```

View First 10 Rows of Data Frame

```r
head(HawaiiWaterCleanOahu, 10)
```

```
##     Sample.No Sampler   Lab.No Station.No            Location     Date
## 1  GH11160401      GH  0846-04         39 Ala Moana Park, Ewa 11/16/04
## 2  JM10260602      JM 02221-06         39 Ala Moana Park, Ewa 10/26/06
## 3  SM10200502      SM 02120-05         39 Ala Moana Park, Ewa 10/20/05
## 4  JD09140602      JD 01935-06         39 Ala Moana Park, Ewa  9/14/06
## 5  SN05050505      SN 00907-05         39 Ala Moana Park, Ewa   5/5/05
## 6  JM05180601      JM 01043-06         39 Ala Moana Park, Ewa  5/18/06
## 7  JD03100505      JD 00473-05         39 Ala Moana Park, Ewa  3/10/05
## 8  GH11220401      GH  0922-04         39 Ala Moana Park, Ewa 11/22/04
## 9  SN01200505      SN 00113-05         39 Ala Moana Park, Ewa  1/20/05
## 10 JM03020601      JM 00431-06         39 Ala Moana Park, Ewa   3/2/06
##           Time Enterococcus  CP Temperature Salinity   DO
## 1   6:15:00 AM        400.0 4.8       25.14    35.17 6.45
## 2   8:45:00 AM         20.0 3.0       25.62    35.27 5.57
## 3   8:55:00 AM         10.0 0.2       26.91    34.59 5.46
## 4   8:49:00 AM          2.3 1.0       26.66    35.32 4.89
## 5  10:00:00 AM          6.3 0.2       26.40    35.09 6.24
## 6   8:40:00 AM          2.3 1.0       24.60    34.84 6.62
## 7  10:03:00 AM          0.3 0.2       24.71    34.40 5.97
## 8   6:00:00 AM          1.0 0.2       25.51    35.26 4.42
## 9   8:27:00 AM          2.7 0.2       24.20    35.41 4.80
## 10  8:30:00 AM          2.3 1.0       24.17    34.82 6.08
##    PercentSaturationDissolvedOxygen   pH Turbidity
## 1                              94.0 8.15     14.13
## 2                              84.4 8.02     28.40
## 3                              84.3 8.05      9.57
## 4                              75.5 8.10      5.64
## 5                              95.6 8.20      2.76
## 6                              98.3 8.15      2.18
## 7                              88.3 8.06      6.10
## 8                              65.0 8.10      3.31
## 9                              71.0 7.99      3.41
## 10                             89.5 8.05      3.78
##                                                                       Remarks
## 1                       S. CON. 53.2, NO WIND, LITTLE CLOUDS, SMALL WAVES, LITTLE MURKY
## 2
## 3
## 4
## 5        SP COND:  53.1, PEOPLE SURFING, OVERCAST, VERY LITTLE WAVE ACTION, CLEAR WATER
## 6
## 7                                                             CALM, SWIMMERS, WINDY
## 8                                S. COND 53.4, NO WIND, OVERCAST, CALM CLEAN WATER
## 9  SP COND 53.7, DEBRIS ON BEACH, SUNNY, CLEAR SKIES, LIGHT WIND, LOW TIDE, CLEAR WATER
```

```
## 10
##    Region
## 1   South
## 2   South
## 3   South
## 4   South
## 5   South
## 6   South
## 7   South
## 8   South
## 9   South
## 10  South
```

View all Column Names

```
colnames(HawaiiWaterCleanOahu)
```

```
##  [1] "Sample.No"                          "Sampler"
##  [3] "Lab.No"                             "Station.No"
##  [5] "Location"                           "Date"
##  [7] "Time"                               "Enterococcus"
##  [9] "CP"                                 "Temperature"
## [11] "Salinity"                           "DO"
## [13] "PercentSaturationDissolvedOxygen" "pH"
## [15] "Turbidity"                          "Remarks"
## [17] "Region"
```

Change Date from Factor to Date Object

```
HawaiiWaterCleanOahu$Date<-as.Date(HawaiiWaterCleanOahu$Date, format = "%m/%d/%y")
```

Add a Week Column to Dataframe Using Mutate Function

```
HawaiiWaterCleanOahu<-mutate(HawaiiWaterCleanOahu, Week = week(Date))
```

Add a Month Column to DataFrame using Mutate Function

```
HawaiiWaterCleanOahu<- mutate(HawaiiWaterCleanOahu, Month = month(Date))
```

Add a Year Column to Dataframe using Mutate Function

```
HawaiiWaterCleanOahu<- mutate(HawaiiWaterCleanOahu, Year = year(Date))
```

Visualization

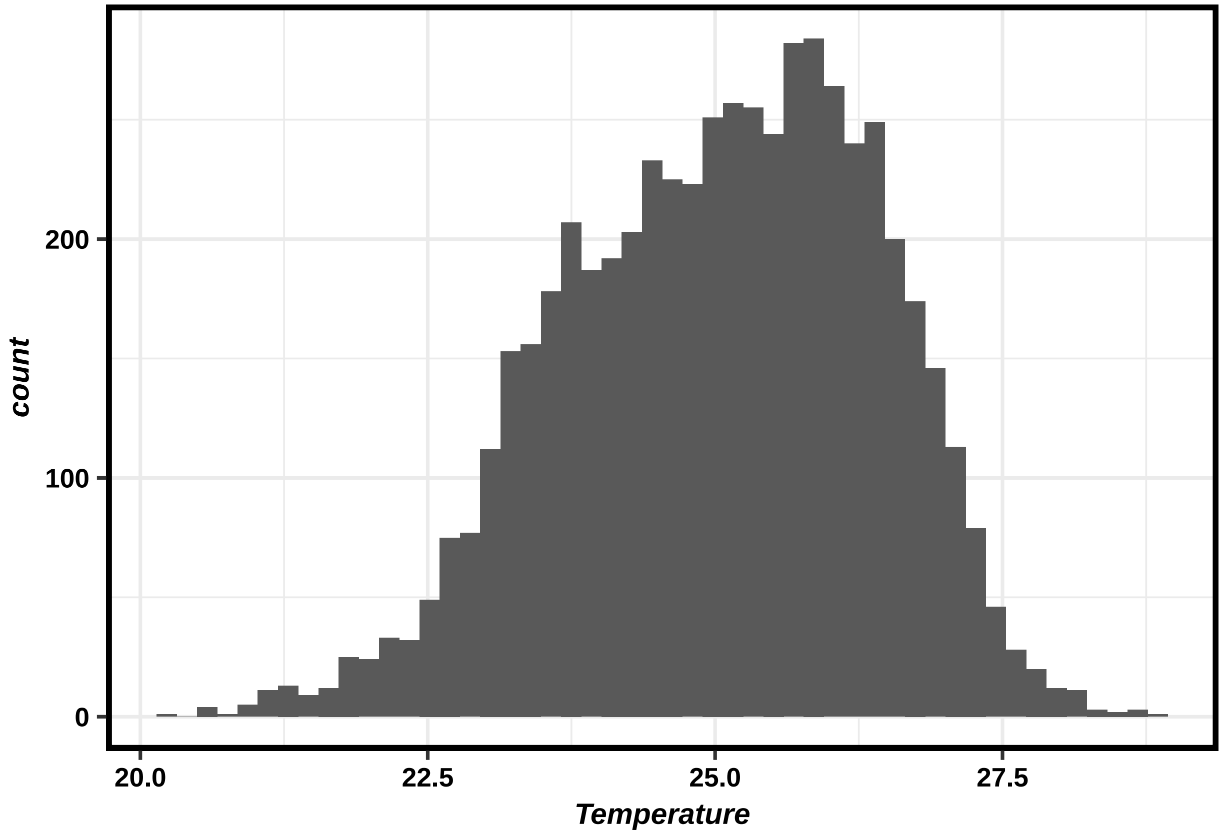
Set GGPlot Theme

```
gabytheme <- theme_bw(base_size = 14) +
  theme(plot.title=element_text(face="bold", size="16", color="Indianred4", hjust=0.5),
        axis.title=element_text(face="bold.italic", size=11, color="black"),
axis.text = element_text(face="bold", size=10, color = "black"),
panel.background=element_rect(fill="white", color="darkblue"),
panel.border = element_rect(color = "black", size = 2),
legend.position = "top", legend.background = element_rect(fill="white", color="black"),
            legend.key = element_rect(fill="transparent", color="NA"))
theme_set(gabytheme)
```

Examine distributions of continuous variables: Temperature, pH, Dissolved Oxygen Concentrations, Salinity, Turbidity, and Enterococcus Concentrations

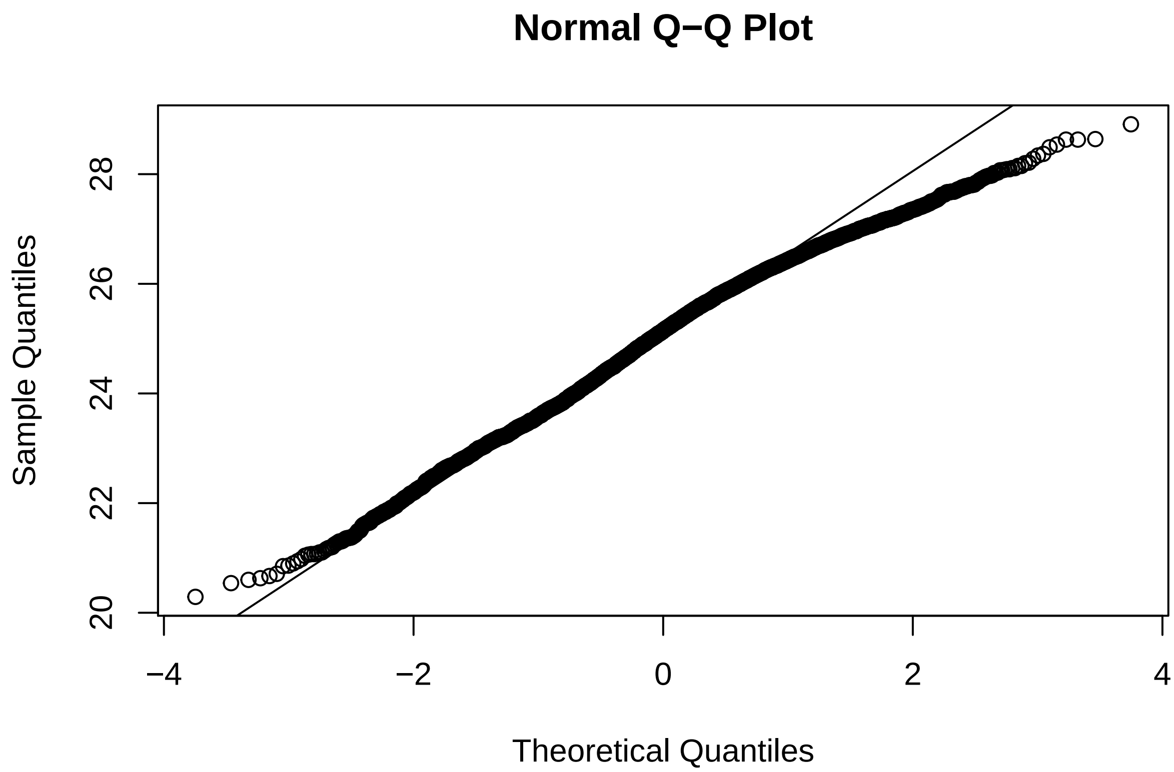
Temperature

```
ggplot(HawaiiWaterCleanOahu) +
  geom_histogram(aes(x =Temperature), bins = 50)
```



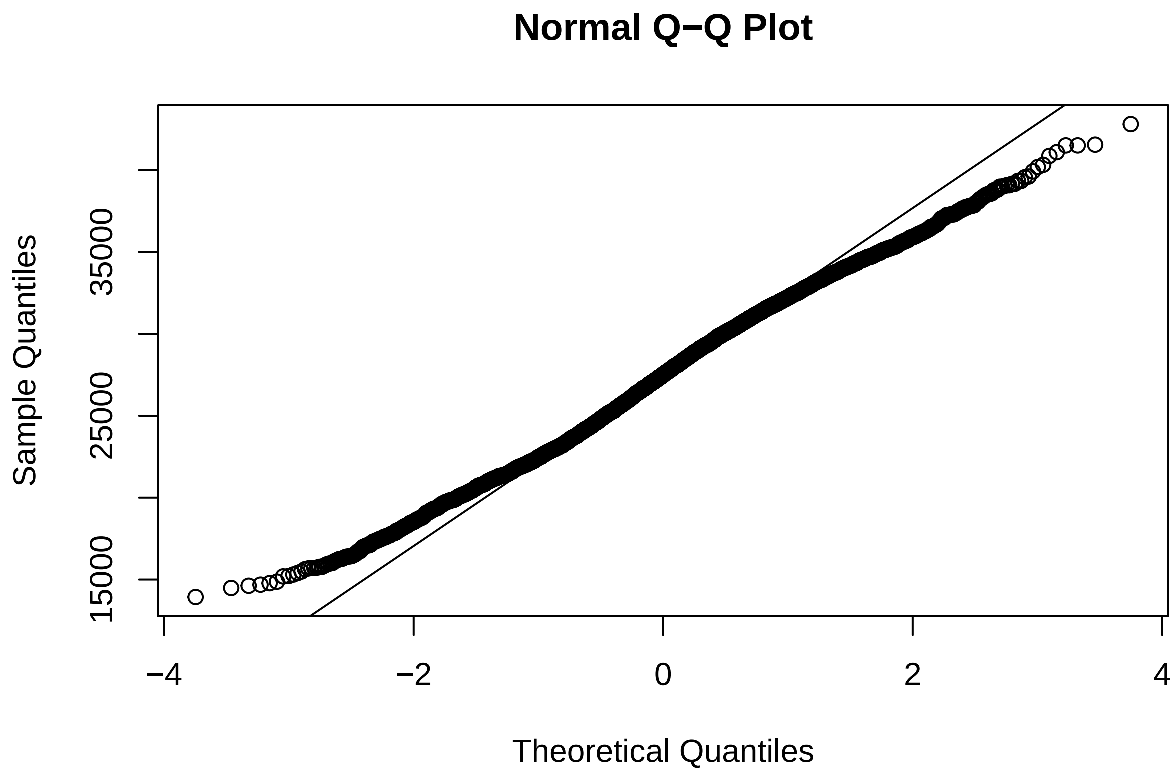
QQNorm for Temperature

```
qqnorm(HawaiiWaterCleanOahu$Temperature)
qqline(HawaiiWaterCleanOahu$Temperature)
```



LogTransform Temperature

```
qqnorm((HawaiiWaterCleanOahu$Temperature)^3.17)
qqline((HawaiiWaterCleanOahu$Temperature)^3.17)
```




```r
summary(powerTransform(HawaiiWaterCleanOahu$Temperature))
```

```
## bcPower Transformation to Normality
##                                     Est Power Rounded Pwr Wald Lwr Bnd
## HawaiiWaterCleanOahu$Temperature    3.1789        3.18       2.7406
##                                     Wald Upr Bnd
## HawaiiWaterCleanOahu$Temperature       3.6172
##
## Likelihood ratio test that transformation parameter is equal to 0
##  (log transformation)
##                              LRT df       pval
## LR test, lambda = (0) 208.668  1 < 2.22e-16
##
## Likelihood ratio test that no transformation is needed
##                               LRT df       pval
## LR test, lambda = (1) 97.03683  1 < 2.22e-16
```

Perform Shapiro Wilks Normality test for first 5,000 Temperature observations

```r
shapiro.test(HawaiiWaterCleanOahu$Temperature[0:5000])
```

```
##
##  Shapiro-Wilk normality test
```

```
##
## data:  HawaiiWaterCleanOahu$Temperature[0:5000]
## W = 0.98892, p-value < 2.2e-16
```

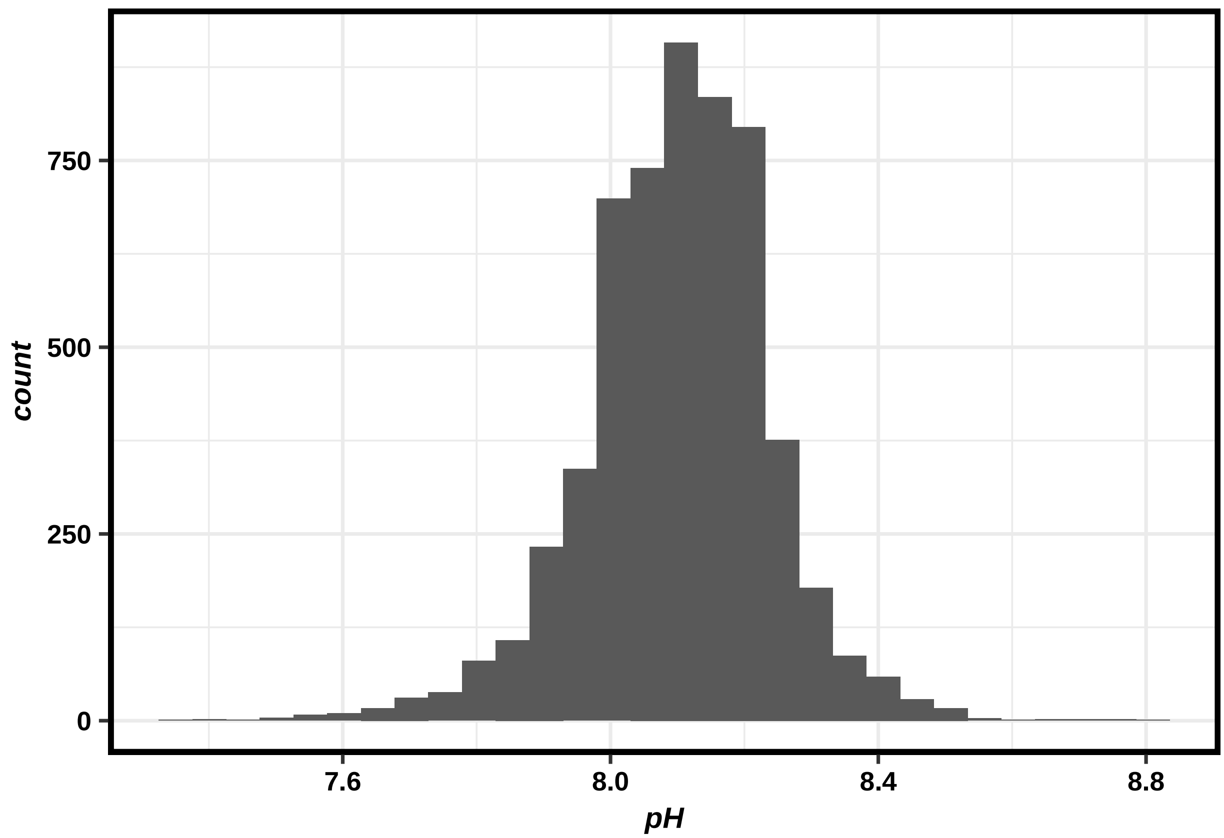
Summary of Temperature

```
summary(HawaiiWaterCleanOahu$Temperature)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   20.29   24.05   25.14   25.04   26.07   28.91
```

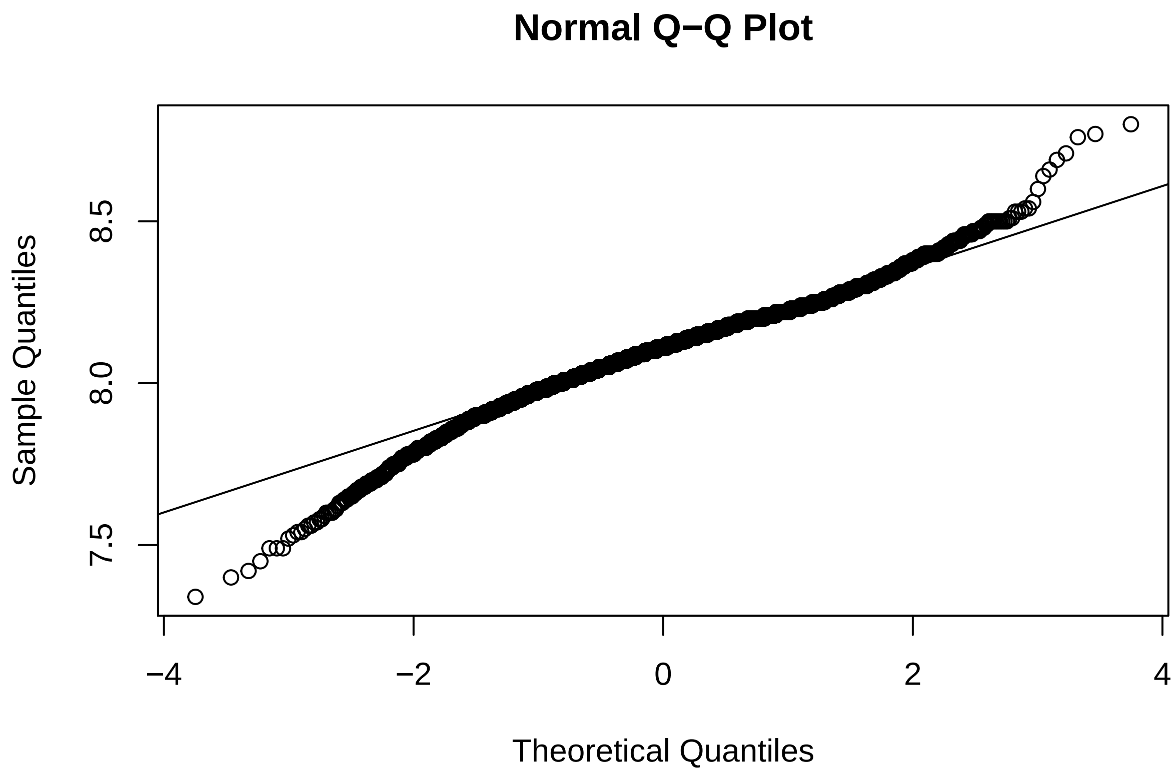
pH

```
ggplot(HawaiiWaterCleanOahu) +
  geom_histogram(aes(x =pH))
```



QQNorm of pH

```
 qqnorm(HawaiiWaterCleanOahu$pH)
qqline(HawaiiWaterCleanOahu$pH)
```



Shapiro Wilks Test for pH

```
shapiro.test(HawaiiWaterCleanOahu$pH[0:5000])
```

```
##
##  Shapiro-Wilk normality test
##
## data:  HawaiiWaterCleanOahu$pH[0:5000]
## W = 0.97762, p-value < 2.2e-16
```

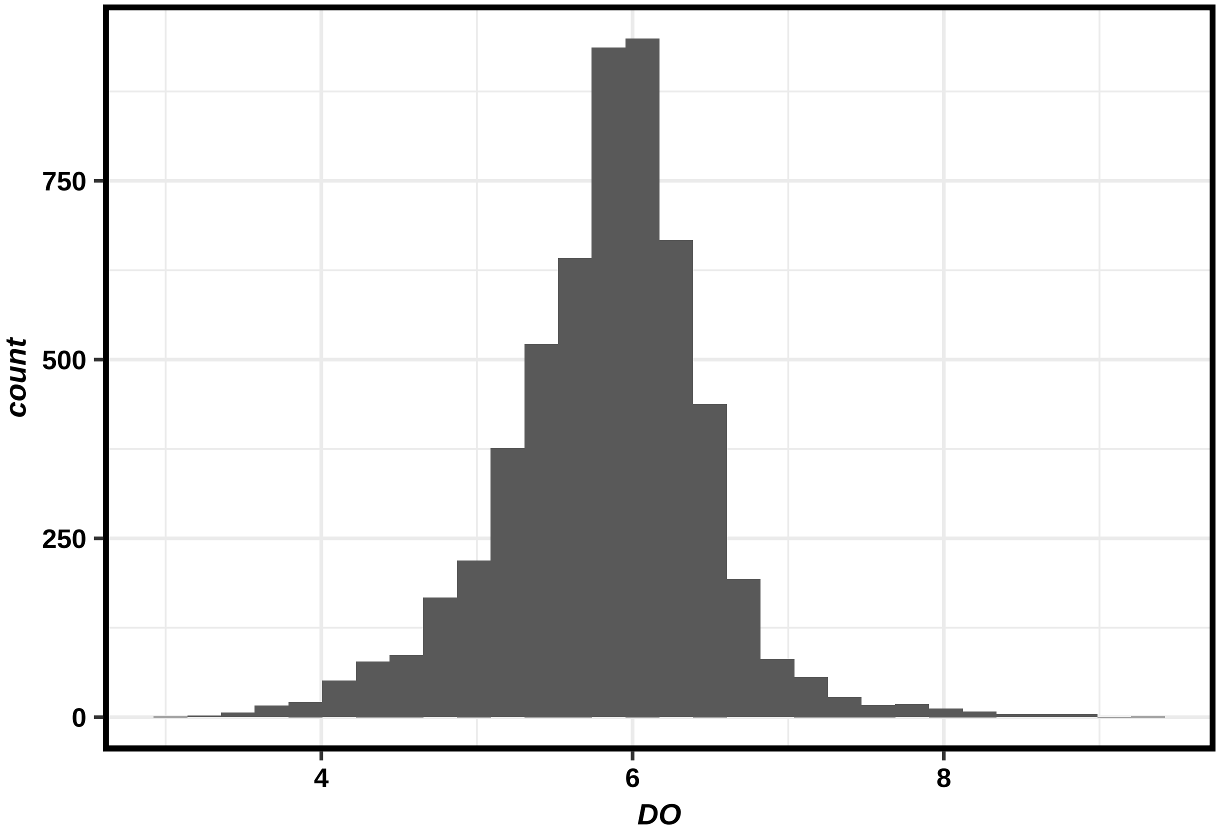
Summary of pH

```
summary(HawaiiWaterCleanOahu$pH)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   7.340   8.020   8.110   8.103   8.190   8.800
```

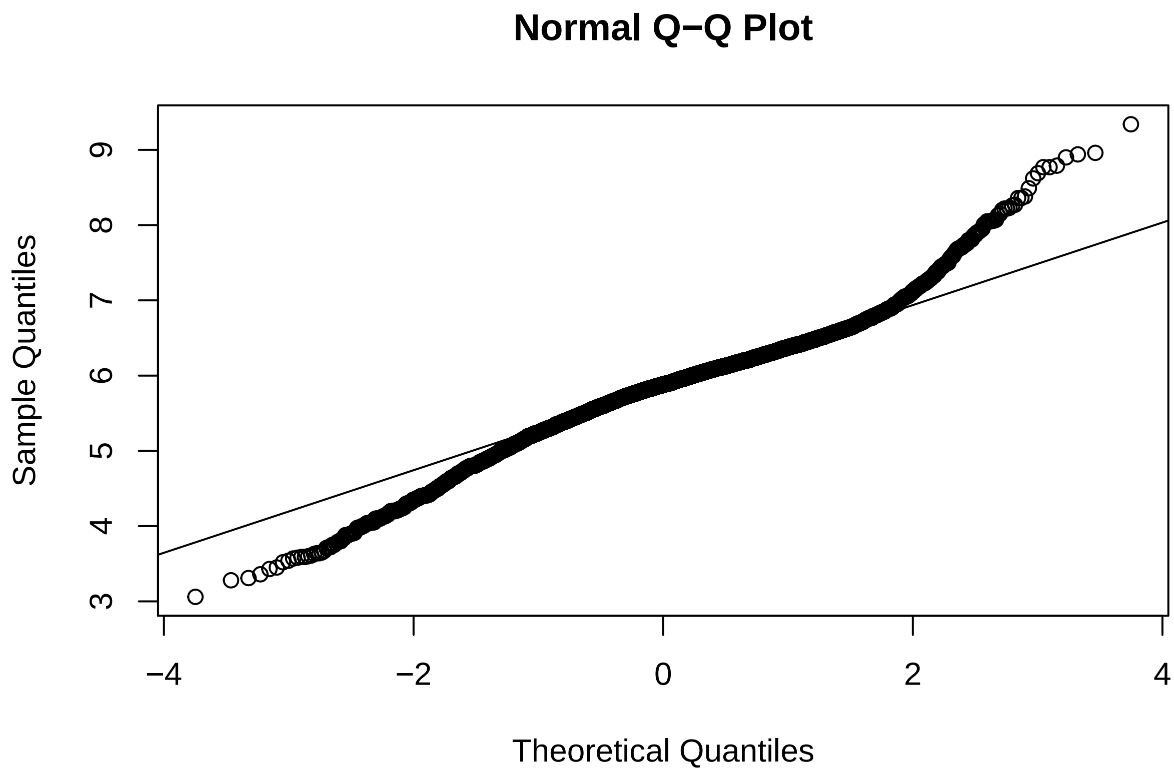
Dissolved Oxygen Concentrations

```
ggplot(HawaiiWaterCleanOahu) +
  geom_histogram(aes(x =DO))
```



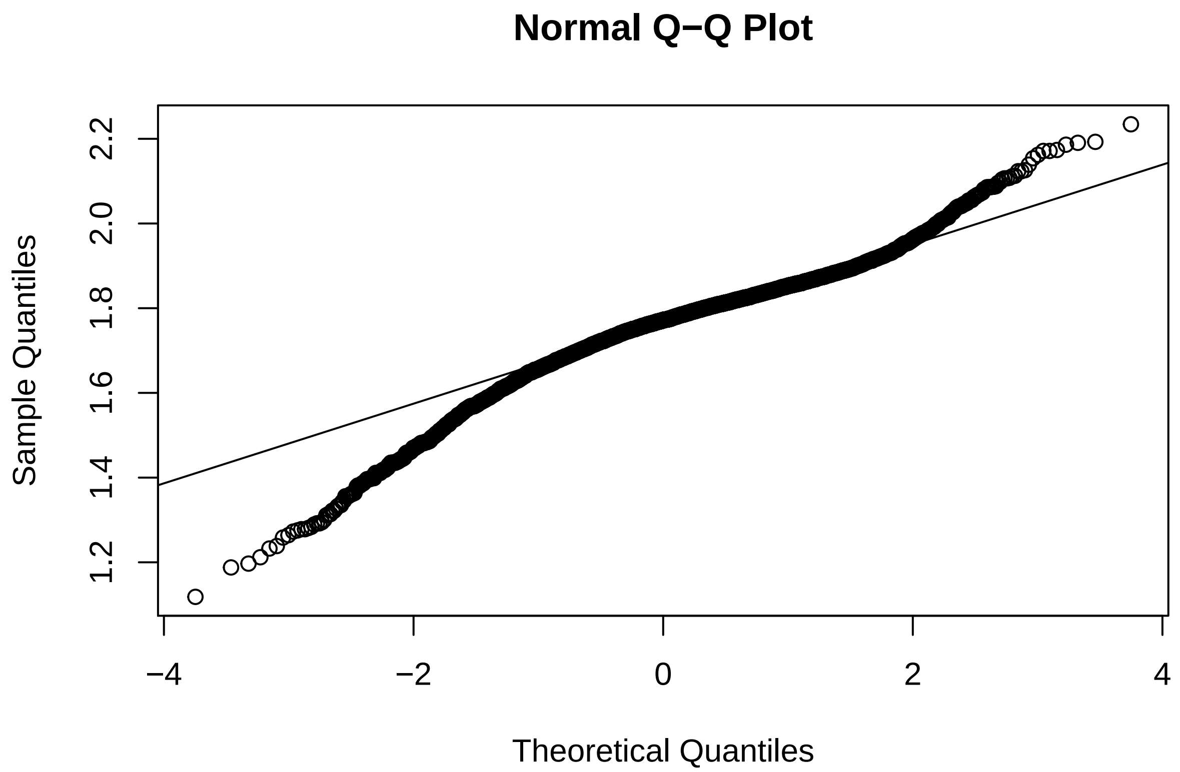
QQNorm of DO

```
qqnorm(HawaiiWaterCleanOahu$DO)
qqline(HawaiiWaterCleanOahu$DO)
```

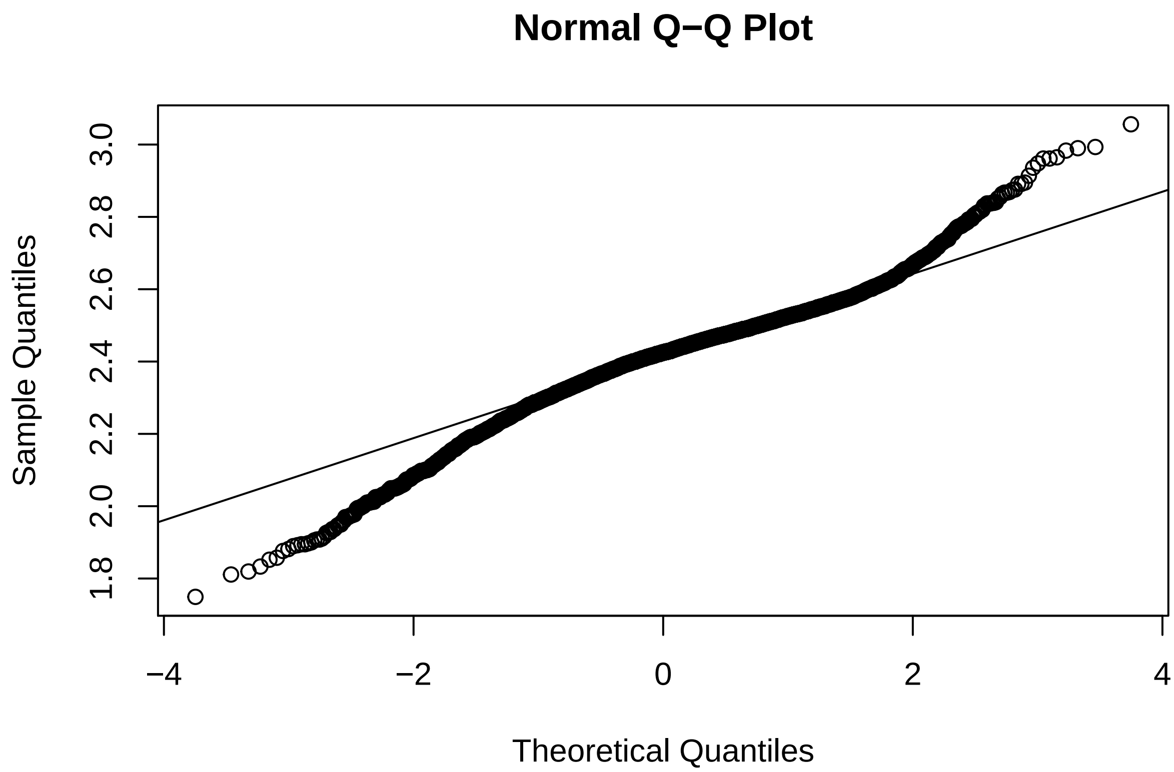


Log Transform Dependent Variable DO

```
qqnorm(log(HawaiiWaterCleanOahu$DO))
qqline(log(HawaiiWaterCleanOahu$DO))
```




```r
qqnorm(sqrt(HawaiiWaterCleanOahu$DO))
qqline(sqrt(HawaiiWaterCleanOahu$DO))
```



Use powertransform Function to generate estimation of Power Lambda that will normalize DV

```r
summary(powerTransform(HawaiiWaterCleanOahu$DO))
```

```
## bcPower Transformation to Normality
##                         Est Power Rounded Pwr Wald Lwr Bnd Wald Upr Bnd
## HawaiiWaterCleanOahu$DO     1.286        1.29       1.1415       1.4306
##
## Likelihood ratio test that transformation parameter is equal to 0
##  (log transformation)
##                              LRT df       pval
## LR test, lambda = (0) 305.8359  1 < 2.22e-16
##
## Likelihood ratio test that no transformation is needed
##                              LRT df       pval
## LR test, lambda = (1) 15.05389  1 0.00010448
```

Shapiro Wilks Test for DO

```r
shapiro.test(HawaiiWaterCleanOahu$DO[0:5000])
```

```
##
```

```
##  Shapiro-Wilk normality test
##
## data:  HawaiiWaterCleanOahu$DO[0:5000]
## W = 0.97535, p-value < 2.2e-16
```

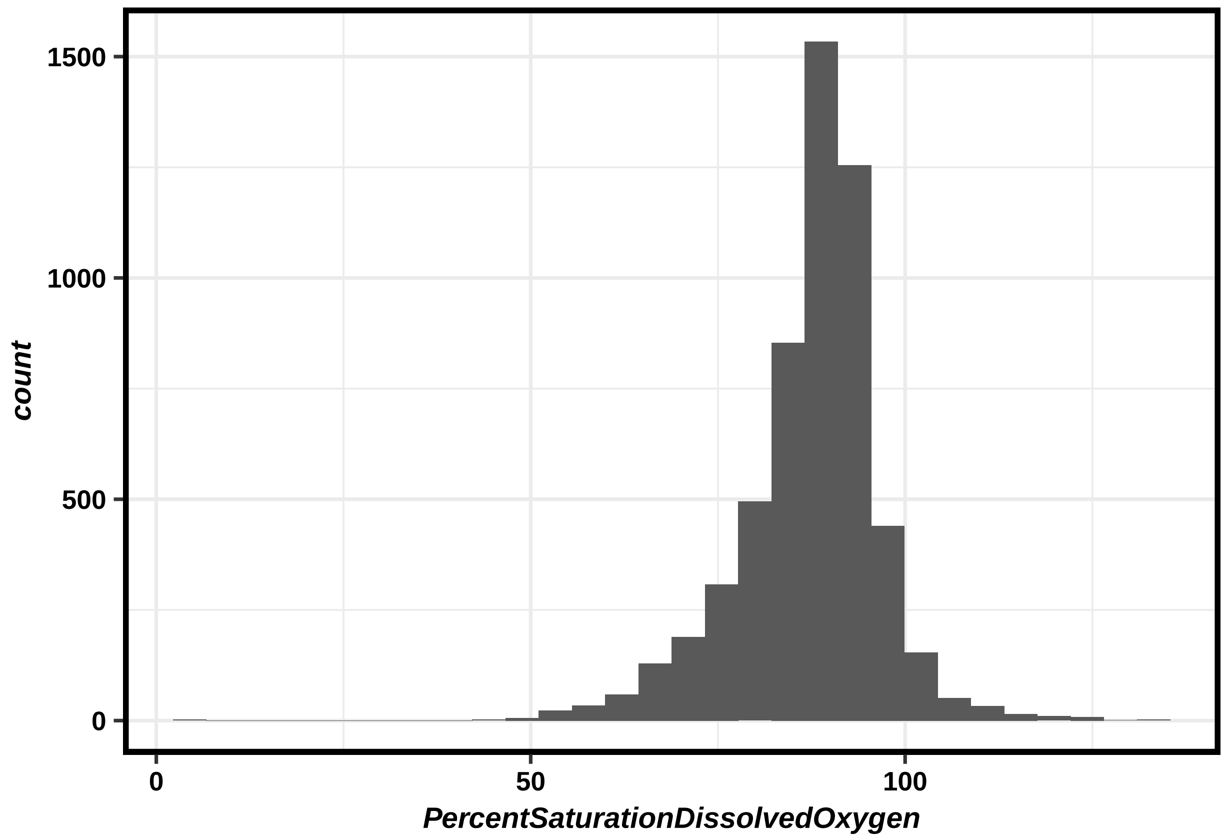
Summary of DO

```
summary(HawaiiWaterCleanOahu$DO)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.060   5.470   5.880   5.829   6.210   9.340
```

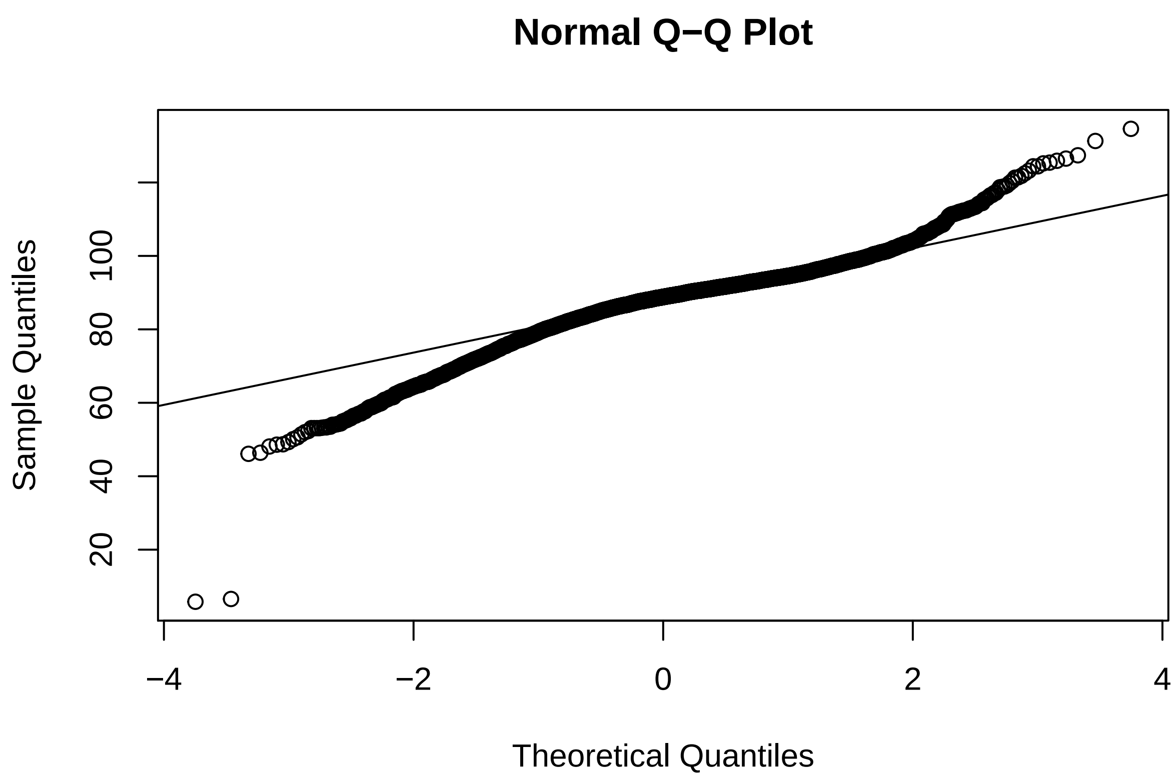
Percent Saturation of Dissolved Oxygen

```
ggplot(HawaiiWaterCleanOahu) +
  geom_histogram(aes(x =PercentSaturationDissolvedOxygen))
```



QQnorm of Percent Saturation of Dissolved Oxygen

```
qqnorm(HawaiiWaterCleanOahu$PercentSaturationDissolvedOxygen)
qqline(HawaiiWaterCleanOahu$PercentSaturationDissolvedOxygen)
```



Shapiro Test for Percent Saturation Dissolved Oxygen

```
shapiro.test(HawaiiWaterCleanOahu$PercentSaturationDissolvedOxygen[0:5000])
```

```
##
##  Shapiro-Wilk normality test
##
## data:  HawaiiWaterCleanOahu$PercentSaturationDissolvedOxygen[0:5000]
## W = 0.95108, p-value < 2.2e-16
```

Summary of Percent Saturation of Dissolved Oxygen

```
summary(HawaiiWaterCleanOahu$PercentSaturationDissolvedOxygen)
```

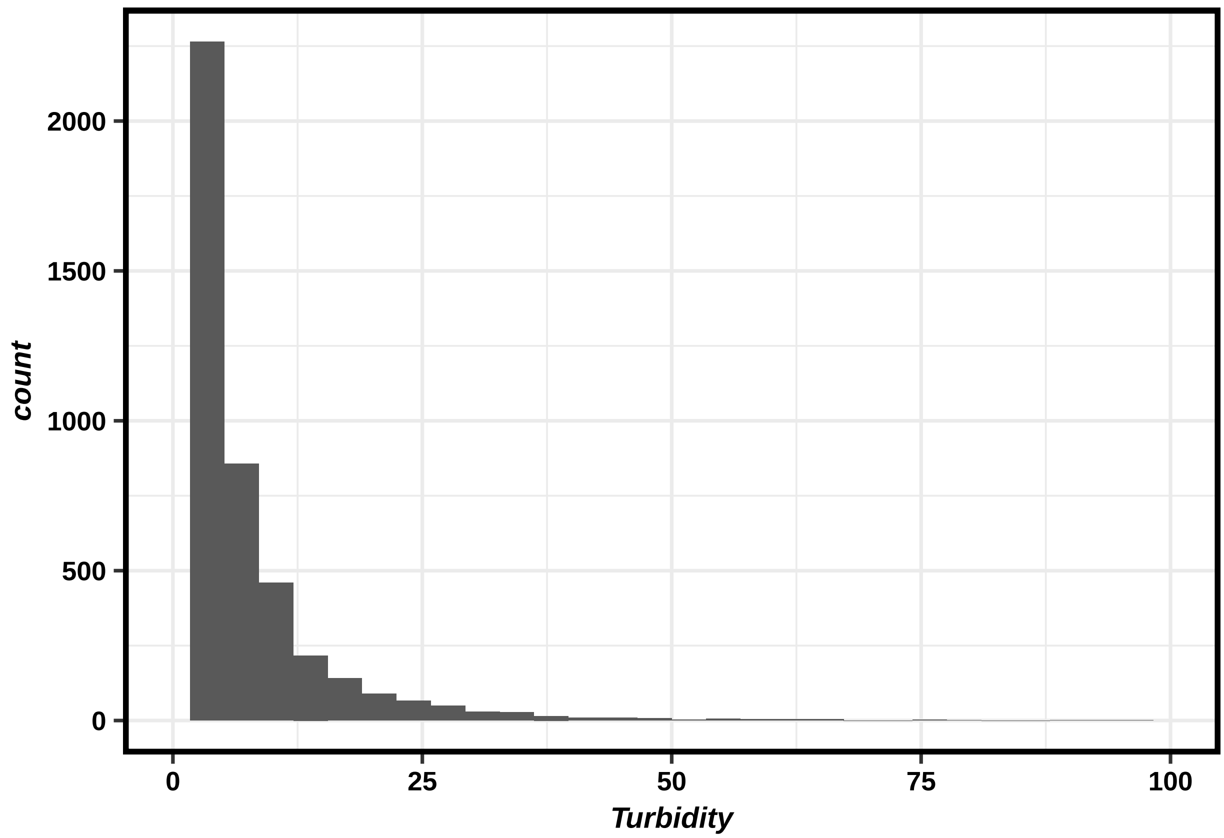
```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    5.82   83.10   88.80   87.38   92.70  134.60
```

Turbidity

```
ggplot(HawaiiWaterCleanOahu) +
  geom_histogram(aes(x =Turbidity))+
   scale_x_continuous(limits = c(0, 100))
```

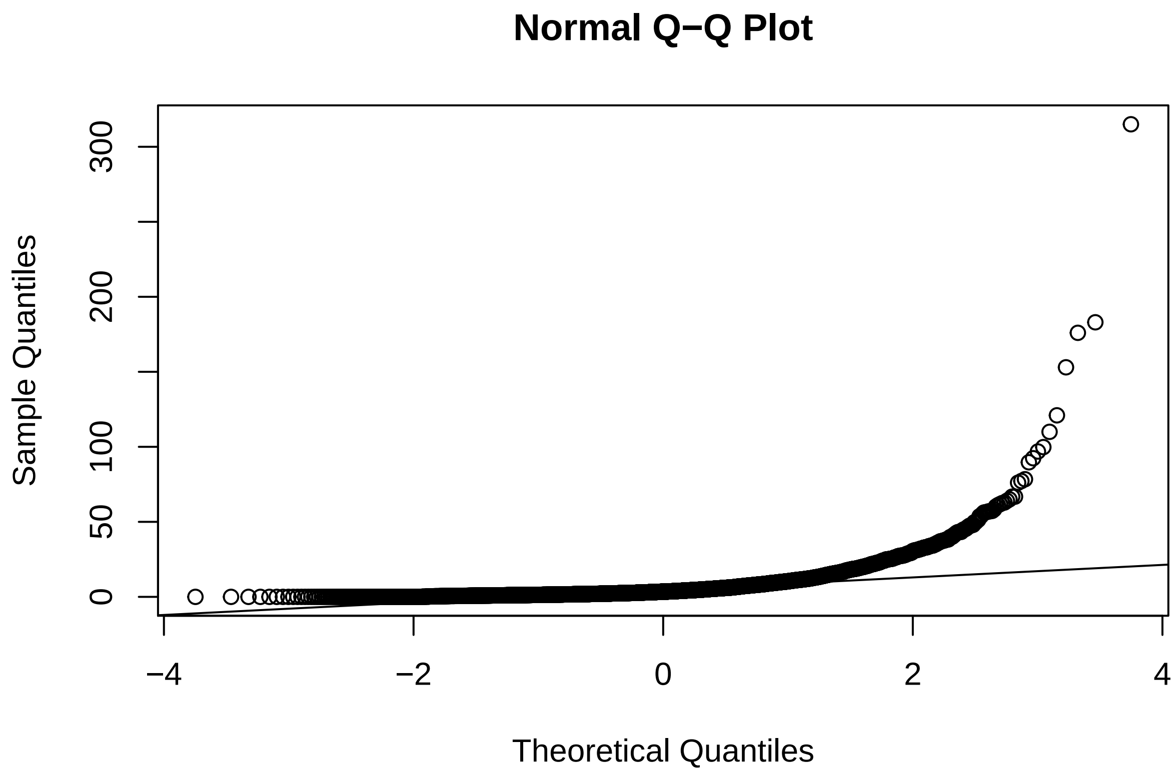
```
## Warning: Removed 6 rows containing non-finite values (stat_bin).
```

```
## Warning: Removed 2 rows containing missing values (geom_bar).
```



QQNorm of Turbidity

```
qqnorm(HawaiiWaterCleanOahu$Turbidity)
qqline(HawaiiWaterCleanOahu$Turbidity)
```



Shapiro Test for Turbidity

```
shapiro.test(HawaiiWaterCleanOahu$Turbidity[0:5000])
```

```
##
##  Shapiro-Wilk normality test
##
## data:  HawaiiWaterCleanOahu$Turbidity[0:5000]
## W = 0.55091, p-value < 2.2e-16
```

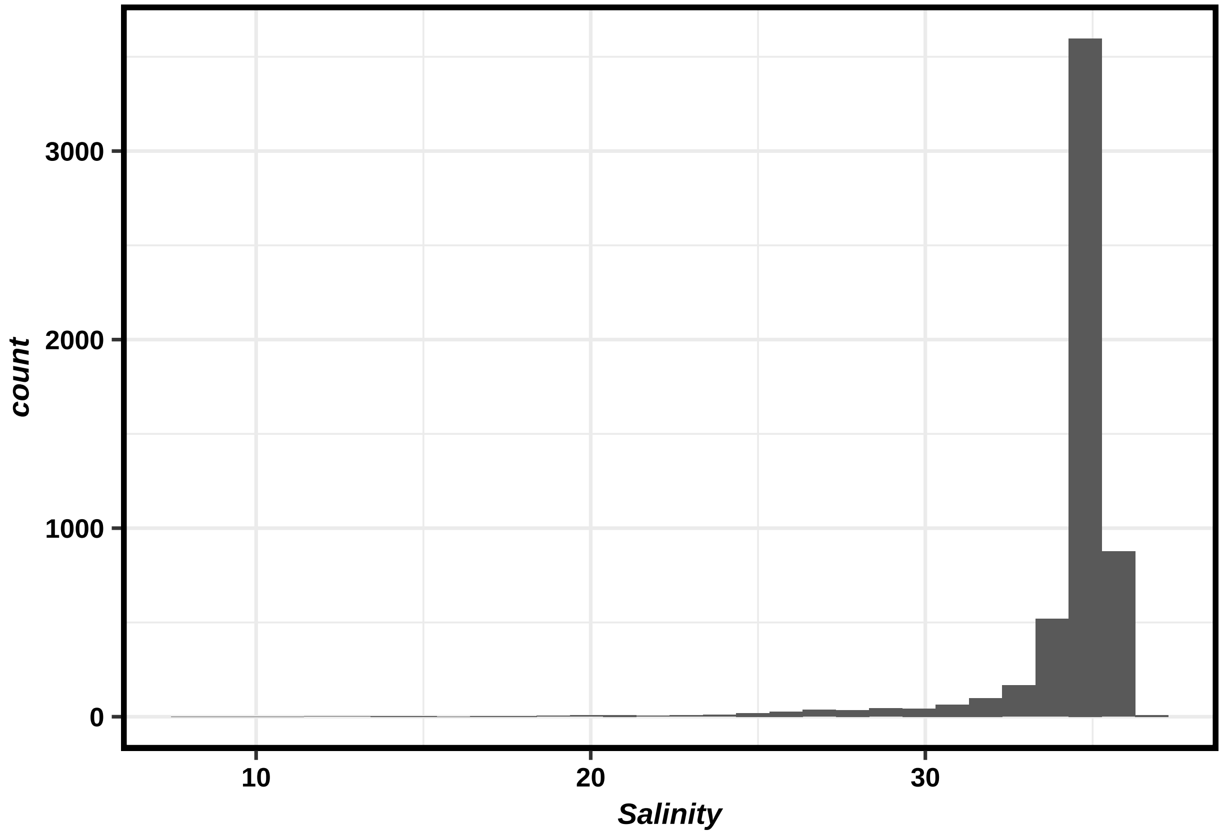
Summary of Turbidity

```
summary(HawaiiWaterCleanOahu$Turbidity)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   0.000   1.800   3.440   6.331   7.425 315.000
```

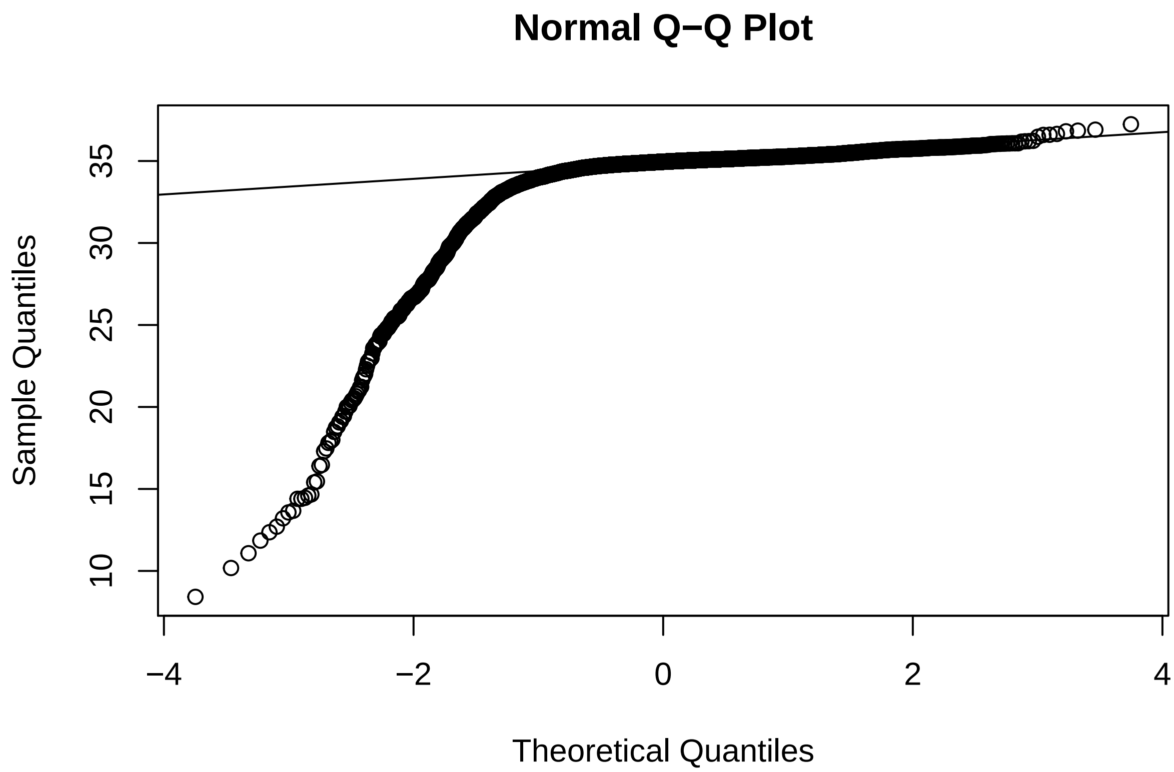
Salinity

```
ggplot(HawaiiWaterCleanOahu) +
  geom_histogram(aes(x =Salinity))
```



QQNorm of Salinity

```
qqnorm(HawaiiWaterCleanOahu$Salinity)
qqline(HawaiiWaterCleanOahu$Salinity)
```



Shapiro Test for Salinity

```
shapiro.test(HawaiiWaterCleanOahu$Salinity[0:5000])
```

```
##
##  Shapiro-Wilk normality test
##
## data:  HawaiiWaterCleanOahu$Salinity[0:5000]
## W = 0.42958, p-value < 2.2e-16
```

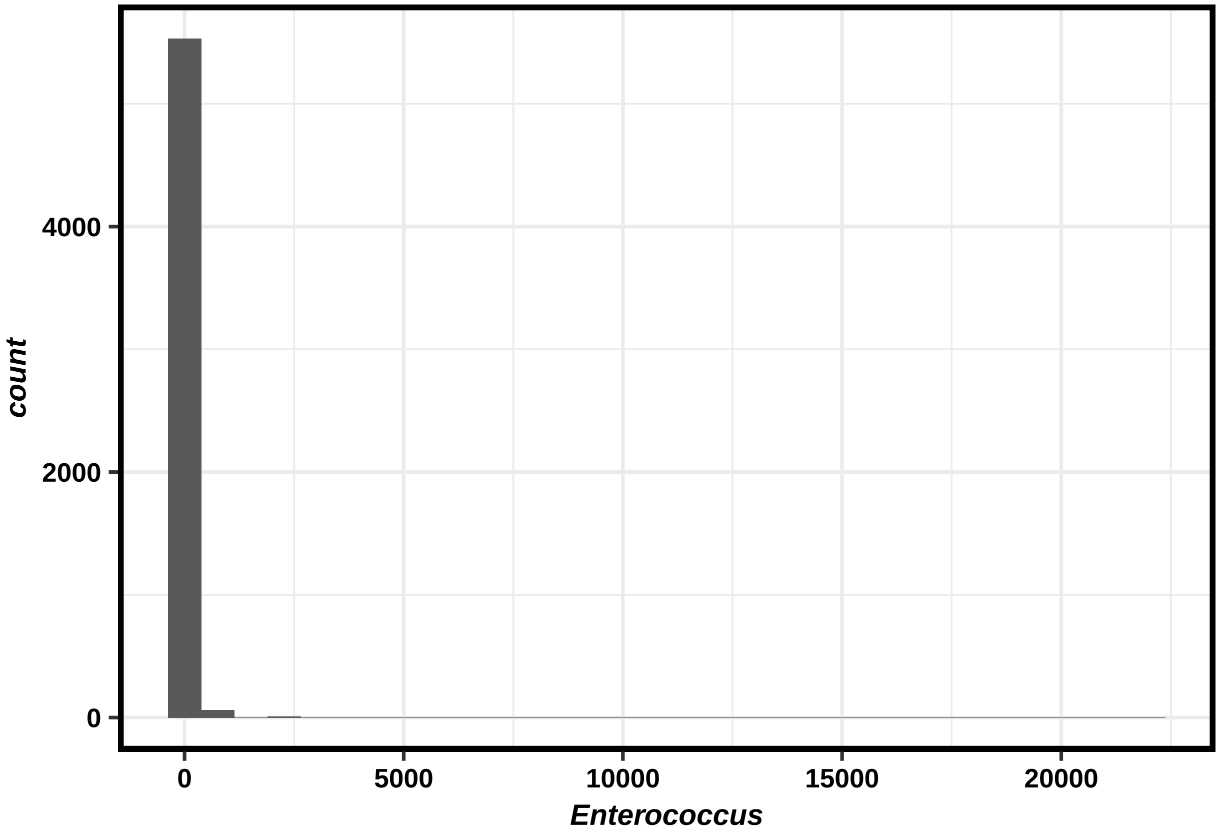
Summary of Salinity

```
summary(HawaiiWaterCleanOahu$Salinity)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    8.42   34.54   34.95   34.31   35.18   37.24
```

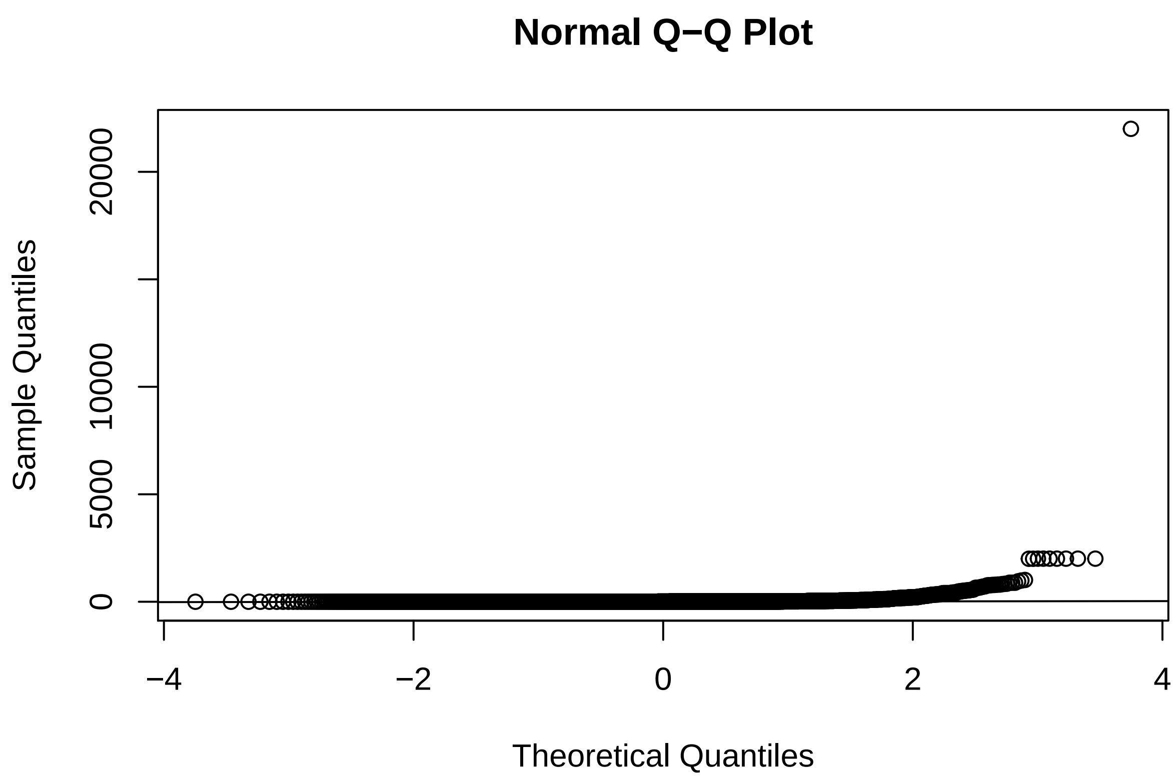
Enterococcus

```
ggplot(HawaiiWaterCleanOahu) +
  geom_histogram(aes(x =Enterococcus))
```



QQNorm of Enterococcus

```
qqnorm(HawaiiWaterCleanOahu$Enterococcus)
qqline(HawaiiWaterCleanOahu$Enterococcus)
```



Shapiro Test for Enterococcus

```r
shapiro.test(HawaiiWaterCleanOahu$Enterococcus[0:5000])
```

```
##
##  Shapiro-Wilk normality test
##
## data:  HawaiiWaterCleanOahu$Enterococcus[0:5000]
## W = 0.03267, p-value < 2.2e-16
```

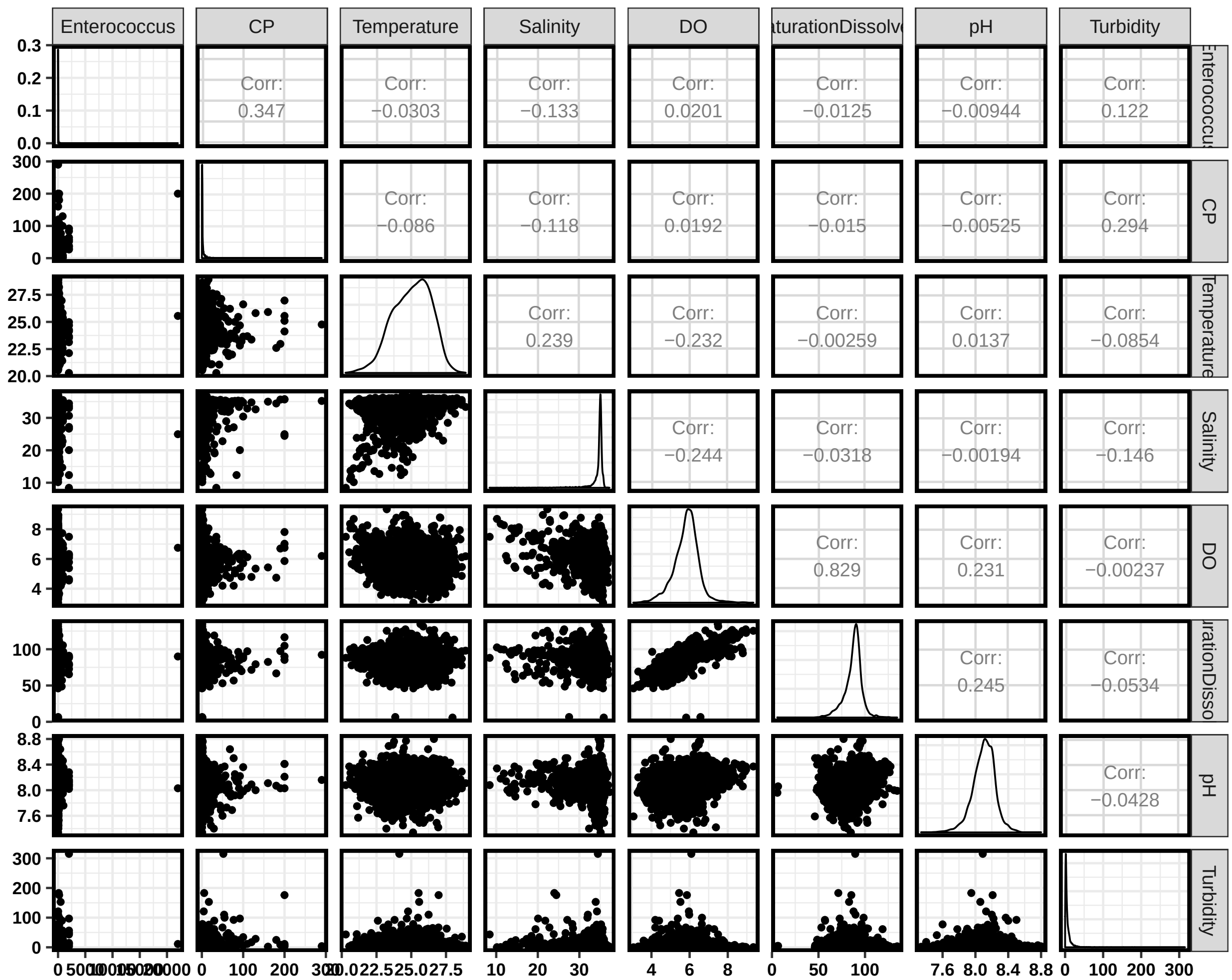
Summary of Enterococcus

```r
summary(HawaiiWaterCleanOahu$Enterococcus)
```

```
##     Min.  1st Qu.   Median     Mean  3rd Qu.     Max.
##     0.30     2.30     3.30    28.51    10.00 22000.00
```

Correlation Plot of Data

```r
ggpairs(HawaiiWaterCleanOahu, columns = 8:15)
```



Research Question Number 1:

Which of the parameters have a relationship with dissolved oxygen concentrations? Of these relevant parameters, which have the most significant effect on dissolved oxygen concentrations over time?

When I did the full maximal model with ALL interactions, the AIC of the maximal model was higher than the 12 subsequent reduced models–>Too many parameters with all of the interactions, so I decided to not include interactions.

Full Maximal Model

```
attach(HawaiiWaterCleanOahu)
HawaiiMod<-glm(DO~Enterococcus + Temperature +Salinity +pH + Turbidity + CP, data=HawaiiWaterCleanOahu,
summary(HawaiiMod)
```

```
##
## Call:
## glm(formula = DO ~ Enterococcus + Temperature + Salinity + pH +
##     Turbidity + CP, family = "gaussian", data = HawaiiWaterCleanOahu)
```

```
##
## Deviance Residuals:
##     Min       1Q   Median       3Q      Max
## -2.6668  -0.3024   0.0875   0.3569   3.2043
##
## Coefficients:
##                Estimate Std. Error t value Pr(>|t|)
## (Intercept)   1.352e+00  4.968e-01   2.721  0.00653 **
## Enterococcus -7.018e-06  2.759e-05  -0.254  0.79925
## Temperature  -9.138e-02  6.128e-03 -14.912  < 2e-16 ***
## Salinity     -5.703e-02  3.602e-03 -15.834  < 2e-16 ***
## pH            1.078e+00  5.745e-02  18.774  < 2e-16 ***
## Turbidity    -2.328e-03  8.498e-04  -2.740  0.00617 **
## CP           -5.034e-04  8.308e-04  -0.606  0.54454
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for gaussian family taken to be 0.3632317)
##
##     Null deviance: 2384.6  on 5603  degrees of freedom
## Residual deviance: 2033.0  on 5597  degrees of freedom
## AIC: 10237
##
## Number of Fisher Scoring iterations: 2
```

Remove Enterococcus Parameter

```
HawaiiMod2<-update(HawaiiMod,.~.-Enterococcus)
summary(HawaiiMod2)
```

```
##
## Call:
## glm(formula = DO ~ Temperature + Salinity + pH + Turbidity +
##     CP, family = "gaussian", data = HawaiiWaterCleanOahu)
##
## Deviance Residuals:
##     Min       1Q   Median       3Q      Max
## -2.6661  -0.3022   0.0873   0.3564   3.2043
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1.3487262  0.4966506   2.716  0.00664 **
## Temperature -0.0914171  0.0061257 -14.924  < 2e-16 ***
## Salinity    -0.0569437  0.0035840 -15.888  < 2e-16 ***
## pH           1.0786085  0.0574404  18.778  < 2e-16 ***
## Turbidity   -0.0023307  0.0008497  -2.743  0.00611 **
## CP          -0.0005717  0.0007862  -0.727  0.46721
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for gaussian family taken to be 0.3631711)
##
##     Null deviance: 2384.6  on 5603  degrees of freedom
```

```
## Residual deviance: 2033.0  on 5598  degrees of freedom
## AIC: 10235
##
## Number of Fisher Scoring iterations: 2
```

Remove CP Parameter

```r
HawaiiMod3<-update(HawaiiMod2,.~.-CP)
summary(HawaiiMod3)
```

```
##
## Call:
## glm(formula = DO ~ Temperature + Salinity + pH + Turbidity, family = "gaussian",
##     data = HawaiiWaterCleanOahu)
##
## Deviance Residuals:
##     Min       1Q   Median       3Q      Max
## -2.6636  -0.3021   0.0880   0.3571   3.2042
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1.3394910  0.4964673   2.698  0.00700 **
## Temperature -0.0912068  0.0061186 -14.907  < 2e-16 ***
## Salinity    -0.0567715  0.0035760 -15.876  < 2e-16 ***
## pH           1.0782888  0.0574363  18.774  < 2e-16 ***
## Turbidity   -0.0025036  0.0008157  -3.069  0.00215 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for gaussian family taken to be 0.3631405)
##
##     Null deviance: 2384.6  on 5603  degrees of freedom
## Residual deviance: 2033.2  on 5599  degrees of freedom
## AIC: 10234
##
## Number of Fisher Scoring iterations: 2
```

AIC Test

```r
AIC(HawaiiMod, HawaiiMod2, HawaiiMod3)
```

```
##            df      AIC
## HawaiiMod   8 10237.21
## HawaiiMod2  7 10235.27
## HawaiiMod3  6 10233.80
```

Check for Multicollinearity of Final Model

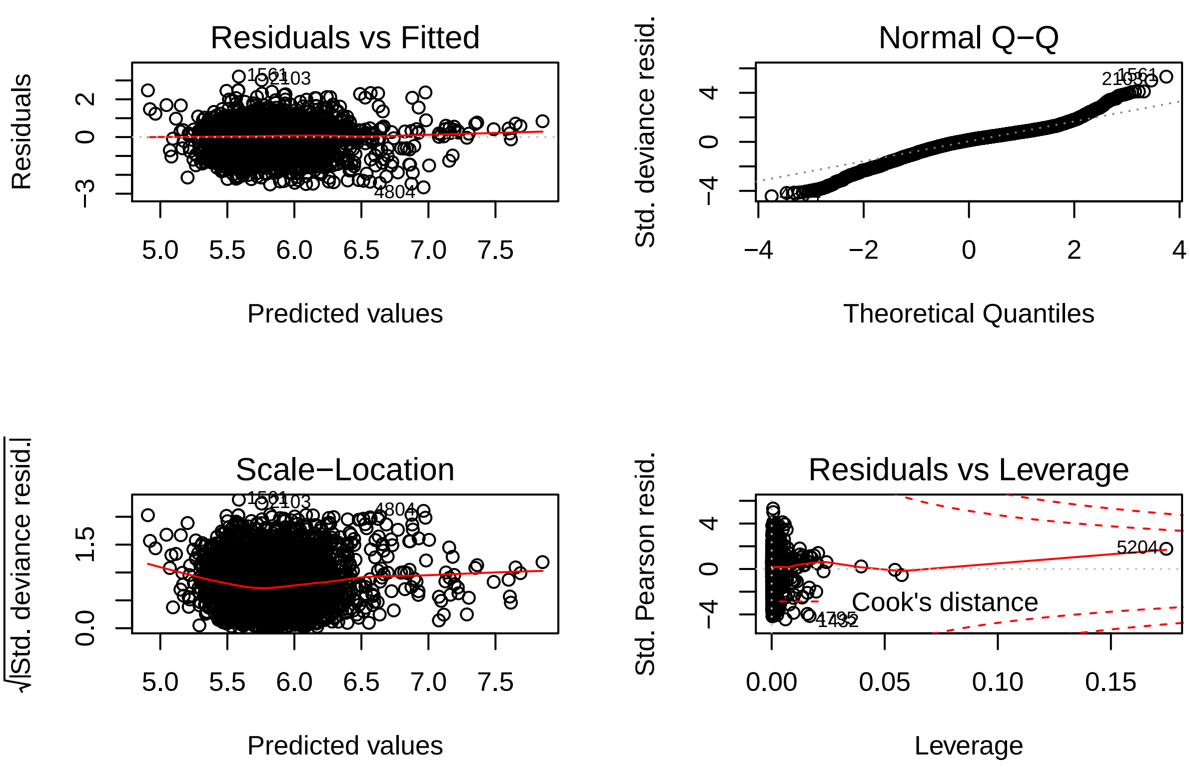
```r
vif(HawaiiMod3)
```

```
## Temperature    Salinity          pH   Turbidity
##    1.063851    1.079097    1.002056    1.026523
```

Temperature, Salinity, pH, and Turbidity have a significant effect on DO Concentrations.

Check Residuals of HawaiiMod3

```
par(mfrow=c(2,2))
plot(HawaiiMod3)
```



Insert the following line of code into your R chunk. This will eliminate duplicate measurements on single dates for each site.

```
HawaiiWaterCleanOahu$Station.No<-as.integer(HawaiiWaterCleanOahu$Station.No) ###Removing duplicate measu
HawaiiWaterCleanOahu2 = HawaiiWaterCleanOahu[order(HawaiiWaterCleanOahu[,'Date'],-HawaiiWaterCleanOahu[
HawaiiWaterCleanOahu2= HawaiiWaterCleanOahu[!duplicated(HawaiiWaterCleanOahu$Date),]
```

Mixed Effects Model with Cleaned Data

```
OahuMixed<- lme(data = HawaiiWaterCleanOahu2,
                     DO~Date, #fixed effects model with an interaction term
```

```r
                    random = ~1|Location)          #specifying a random effect

summary(OahuMixed)
```

```
## Linear mixed-effects model fit by REML
##  Data: HawaiiWaterCleanOahu2
##        AIC      BIC    logLik
##   723.3878 739.3033 -357.6939
##
## Random effects:
##  Formula: ~1 | Location
##         (Intercept)  Residual
## StdDev:   0.5260157 0.5518573
##
## Fixed effects: DO ~ Date
##                  Value Std.Error  DF   t-value p-value
## (Intercept)  8.930163  1.566282 369  5.701505  0.0000
## Date        -0.000230  0.000121 369 -1.899397  0.0583
##  Correlation:
##      (Intr)
## Date -0.997
##
## Standardized Within-Group Residuals:
##          Min           Q1          Med           Q3          Max
## -3.838717881 -0.507522085 -0.003601932  0.610439338  2.802921881
##
## Number of Observations: 397
## Number of Groups: 27
```

ACF

```r
ACF(OahuMixed)
```

```
##    lag          ACF
## 1    0  1.000000000
## 2    1  0.120726729
## 3    2 -0.031955746
## 4    3 -0.131725505
## 5    4 -0.006453162
## 6    5  0.108663754
## 7    6 -0.053261795
## 8    7  0.040269562
## 9    8  0.063945966
## 10   9  0.048108236
## 11  10  0.051939572
## 12  11  0.013056920
## 13  12 -0.029949470
## 14  13 -0.090768228
## 15  14  0.035667951
## 16  15  0.025179464
## 17  16  0.003789559
## 18  17 -0.043719144
## 19  18 -0.075740559
```

```
## 20   19 -0.021585272
## 21   20 -0.054385078
## 22   21  0.009066623
```

0.12-12% of variability associated with time is autocorrelated from previous dates

Repeated Measures ANOVA Model

```
OahuMixedMod<- lme(data = HawaiiWaterCleanOahu2,
                      DO~Date, #fixed effects
                     random = ~1|Location, #random effect
                     correlation = corAR1(form = ~ Date|Location, value = 0.12),method = "REML")
```

Summary of OahuMixedMod

```
summary(OahuMixedMod)
```

```
## Linear mixed-effects model fit by REML
##  Data: HawaiiWaterCleanOahu2
##        AIC      BIC    logLik
##   709.8602 729.7547 -349.9301
##
## Random effects:
##  Formula: ~1 | Location
##         (Intercept)  Residual
## StdDev:   0.5260025 0.5579336
##
## Correlation Structure: ARMA(1,0)
##  Formula: ~Date | Location
##  Parameter estimate(s):
##     Phi1
## 0.701675
## Fixed effects: DO ~ Date
##                 Value Std.Error  DF   t-value p-value
## (Intercept)  8.468782 1.6999775 369  4.981702  0.0000
## Date        -0.000194 0.0001315 369 -1.477164  0.1405
##  Correlation:
##      (Intr)
## Date -0.997
##
## Standardized Within-Group Residuals:
##         Min          Q1         Med          Q3         Max
## -3.78602900 -0.49631030  0.01219029  0.60118603  2.74826863
##
## Number of Observations: 397
## Number of Groups: 27
```

According to the summary of our mixed effects model, the coefficient for the parameter of Date is -0.000194 (p=0.14, t=-1.47, df=369). However, according to the summary, Date is not a significant predictor of PM2.5 concentration because the p-value for Date is 0.14, which is above 0.05. Thus, there is not a significant trend in DO Concentrations

Run a Fixed Effects Model with Date as the only predictor

```
OahuFixedMod<- gls(data =HawaiiWaterCleanOahu2,
                     DO~ Date, method="REML")
summary(OahuFixedMod)
```

```
## Generalized least squares fit by REML
##   Model: DO ~ Date
##   Data: HawaiiWaterCleanOahu2
##        AIC      BIC    logLik
##   824.6624 836.5991 -409.3312
##
## Coefficients:
##                  Value Std.Error   t-value p-value
## (Intercept)  9.035947 1.2967383  6.968211  0.0000
## Date        -0.000261 0.0001001 -2.607028  0.0095
##
##  Correlation:
##      (Intr)
## Date -1
##
## Standardized residuals:
##         Min          Q1         Med          Q3         Max
## -2.89276470 -0.58541595  0.03111128  0.59653678  3.77943705
##
## Residual standard error: 0.6619924
## Degrees of freedom: 397 total; 395 residual
```

Compare Mixed Effects Mod to Fixed Effects Mod

```
anova(OahuMixedMod, OahuFixedMod)
```

```
##              Model df      AIC      BIC    logLik   Test  L.Ratio p-value
## OahuMixedMod     1  5 709.8602 729.7547 -349.9301
## OahuFixedMod     2  3 824.6624 836.5991 -409.3312 1 vs 2 118.8022  <.0001
```

According to the ANOVA test, there is more variability in model structure (error) accounted for by the mixed effects model that includes Location as a random effect. We know this because the AIC score of the OahuMixedMod is 709.86, compared to the OahuFixedMod's AIC score of 824.66. The p-value of <0.0001 indicates that the model fit is significantly different between the two models. Thus, the Mixed Effects model is the best model.

Add More Parameters, keeping Location as the Random Effect

```
library(lme4)
```

```
## Loading required package: Matrix

##
## Attaching package: 'Matrix'

## The following object is masked from 'package:tidyr':
##
##     expand

##
## Attaching package: 'lme4'

## The following object is masked from 'package:nlme':
##
##     lmList
```

```
OahuMixed2<- lme(data =HawaiiWaterCleanOahu2,
                     DO~ Date*Enterococcus*Temperature*Salinity*Turbidity, ###won't let me use pH or ti
                     random = ~1|Location)       ###R won't let me use week, month, or year as a random
```

Determine Temporal Autocorrelation in Model

```
ACF(OahuMixed2)
```

```
##    lag         ACF
## 1    0  1.00000000
## 2    1  0.11490714
## 3    2 -0.02093685
## 4    3 -0.16610857
## 5    4 -0.07356956
## 6    5  0.02492078
## 7    6 -0.06370119
## 8    7  0.06536848
## 9    8  0.07424051
## 10   9  0.05685975
## 11  10  0.07705301
## 12  11  0.03239481
## 13  12 -0.02978971
## 14  13 -0.07084631
## 15  14  0.01754225
## 16  15  0.05875898
## 17  16 -0.01358558
## 18  17  0.01002219
## 19  18 -0.06857067
```

```
## 20   19 -0.04539334
## 21   20 -0.08800294
## 22   21  0.03431040
```

MixedMod-DOESN'T WORK, NONE OF THE PARAMETERS ARE SIGNIFICANT

```
OahuMixedMod2<- lme(data = HawaiiWaterCleanOahu2,  DO~ Date*Enterococcus*Temperature*Salinity*Turbidity
                     random = ~1|Location,
                     correlation = corAR1(form = ~ Date|Location, value = 0.114),
                    method = "REML")

summary(OahuMixedMod2)
```

```
## Linear mixed-effects model fit by REML
##  Data: HawaiiWaterCleanOahu2
##        AIC      BIC    logLik
##   1267.142 1403.638 -598.5708
##
## Random effects:
##  Formula: ~1 | Location
##         (Intercept)  Residual
## StdDev:   0.4824398 0.5432436
##
## Correlation Structure: ARMA(1,0)
##  Formula: ~Date | Location
##  Parameter estimate(s):
##      Phi1
## 0.7146498
## Fixed effects: DO ~ Date * Enterococcus * Temperature * Salinity * Turbidity
##                                                        Value Std.Error  DF
## (Intercept)                                         822.2587  865.3249 339
## Date                                                 -0.0603    0.0671 339
## Enterococcus                                        -24.4716   36.9506 339
## Temperature                                         -32.3861   35.5400 339
## Salinity                                            -22.4792   25.0261 339
## Turbidity                                          -286.4471  146.4014 339
## Date:Enterococcus                                     0.0019    0.0029 339
## Date:Temperature                                      0.0024    0.0028 339
## Enterococcus:Temperature                              0.9394    1.4869 339
## Date:Salinity                                         0.0017    0.0019 339
## Enterococcus:Salinity                                 0.7740    1.0733 339
## Temperature:Salinity                                  0.8958    1.0271 339
## Date:Turbidity                                        0.0220    0.0114 339
## Enterococcus:Turbidity                                1.9606    2.1668 339
## Temperature:Turbidity                                11.5428    5.8919 339
## Salinity:Turbidity                                    7.9931    4.2307 339
## Date:Enterococcus:Temperature                        -0.0001    0.0001 339
## Date:Enterococcus:Salinity                           -0.0001    0.0001 339
## Date:Temperature:Salinity                            -0.0001    0.0001 339
## Enterococcus:Temperature:Salinity                    -0.0298    0.0431 339
## Date:Enterococcus:Turbidity                          -0.0002    0.0002 339
## Date:Temperature:Turbidity                           -0.0009    0.0005 339
```

```
## Enterococcus:Temperature:Turbidity              -0.0761    0.0900 339
## Date:Salinity:Turbidity                         -0.0006    0.0003 339
## Enterococcus:Salinity:Turbidity                 -0.0588    0.0617 339
## Temperature:Salinity:Turbidity                  -0.3224    0.1702 339
## Date:Enterococcus:Temperature:Salinity           0.0000    0.0000 339
## Date:Enterococcus:Temperature:Turbidity          0.0000    0.0000 339
## Date:Enterococcus:Salinity:Turbidity             0.0000    0.0000 339
## Date:Temperature:Salinity:Turbidity              0.0000    0.0000 339
## Enterococcus:Temperature:Salinity:Turbidity      0.0023    0.0026 339
## Date:Enterococcus:Temperature:Salinity:Turbidity  0.0000    0.0000 339
##                                                  t-value p-value
## (Intercept)                                     0.9502312  0.3427
## Date                                           -0.8979768  0.3698
## Enterococcus                                   -0.6622804  0.5082
## Temperature                                    -0.9112572  0.3628
## Salinity                                       -0.8982282  0.3697
## Turbidity                                      -1.9565875  0.0512
## Date:Enterococcus                               0.6516130  0.5151
## Date:Temperature                                0.8670360  0.3865
## Enterococcus:Temperature                        0.6317565  0.5280
## Date:Salinity                                   0.8562596  0.3925
## Enterococcus:Salinity                           0.7212057  0.4713
## Temperature:Salinity                            0.8721919  0.3837
## Date:Turbidity                                  1.9345236  0.0539
## Enterococcus:Turbidity                          0.9048303  0.3662
## Temperature:Turbidity                           1.9591074  0.0509
## Salinity:Turbidity                              1.8893018  0.0597
## Date:Enterococcus:Temperature                  -0.6214047  0.5348
## Date:Enterococcus:Salinity                     -0.7099956  0.4782
## Date:Temperature:Salinity                      -0.8314765  0.4063
## Enterococcus:Temperature:Salinity              -0.6904172  0.4904
## Date:Enterococcus:Turbidity                    -0.9003284  0.3686
## Date:Temperature:Turbidity                     -1.9367056  0.0536
## Enterococcus:Temperature:Turbidity             -0.8451487  0.3986
## Date:Salinity:Turbidity                        -1.8691288  0.0625
## Enterococcus:Salinity:Turbidity                -0.9523952  0.3416
## Temperature:Salinity:Turbidity                 -1.8942091  0.0590
## Date:Enterococcus:Temperature:Salinity          0.6795228  0.4973
## Date:Enterococcus:Temperature:Turbidity         0.8404840  0.4012
## Date:Enterococcus:Salinity:Turbidity            0.9488519  0.3434
## Date:Temperature:Salinity:Turbidity             1.8738031  0.0618
## Enterococcus:Temperature:Salinity:Turbidity     0.8907632  0.3737
## Date:Enterococcus:Temperature:Salinity:Turbidity -0.8870087  0.3757
##  Correlation:
##                                                  (Intr) Date   Entrcc
## Date                                             -1.000
## Enterococcus                                     -0.328  0.328
## Temperature                                      -0.999  0.999  0.330
## Salinity                                         -0.999  0.998  0.324
## Turbidity                                        -0.610  0.608 -0.137
## Date:Enterococcus                                 0.321 -0.322 -1.000
## Date:Temperature                                  0.999 -0.999 -0.330
## Enterococcus:Temperature                          0.334 -0.333 -0.999
## Date:Salinity                                     0.999 -0.999 -0.324
```

```
## Enterococcus:Salinity                              0.329 -0.329 -0.999
## Temperature:Salinity                               0.998 -0.998 -0.326
## Date:Turbidity                                     0.605 -0.604  0.144
## Enterococcus:Turbidity                             0.424 -0.422 -0.848
## Temperature:Turbidity                              0.618 -0.616  0.126
## Salinity:Turbidity                                 0.609 -0.607  0.143
## Date:Enterococcus:Temperature                     -0.327  0.327  0.999
## Date:Enterococcus:Salinity                        -0.323  0.323  0.999
## Date:Temperature:Salinity                         -0.998  0.998  0.326
## Enterococcus:Temperature:Salinity                 -0.335  0.335  0.999
## Date:Enterococcus:Turbidity                       -0.420  0.417  0.850
## Date:Temperature:Turbidity                        -0.614  0.612 -0.132
## Enterococcus:Temperature:Turbidity                -0.419  0.416  0.839
## Date:Salinity:Turbidity                           -0.605  0.603 -0.150
## Enterococcus:Salinity:Turbidity                   -0.432  0.429  0.850
## Temperature:Salinity:Turbidity                    -0.618  0.615 -0.132
## Date:Enterococcus:Temperature:Salinity             0.329 -0.329 -0.999
## Date:Enterococcus:Temperature:Turbidity            0.414 -0.412 -0.840
## Date:Enterococcus:Salinity:Turbidity               0.428 -0.425 -0.852
## Date:Temperature:Salinity:Turbidity                0.613 -0.611  0.138
## Enterococcus:Temperature:Salinity:Turbidity        0.426 -0.423 -0.841
## Date:Enterococcus:Temperature:Salinity:Turbidity -0.422  0.419  0.843
##                                                  Tmprtr Salnty Trbdty
## Date
## Enterococcus
## Temperature
## Salinity                                           0.998
## Turbidity                                          0.601  0.609
## Date:Enterococcus                                 -0.323 -0.318  0.143
## Date:Temperature                                  -1.000 -0.997 -0.599
## Enterococcus:Temperature                          -0.336 -0.330  0.135
## Date:Salinity                                     -0.997 -1.000 -0.607
## Enterococcus:Salinity                             -0.330 -0.326  0.133
## Temperature:Salinity                              -0.999 -0.999 -0.601
## Date:Turbidity                                    -0.597 -0.604 -1.000
## Enterococcus:Turbidity                            -0.428 -0.419 -0.065
## Temperature:Turbidity                             -0.611 -0.617 -0.999
## Salinity:Turbidity                                -0.600 -0.609 -0.999
## Date:Enterococcus:Temperature                      0.330  0.323 -0.140
## Date:Enterococcus:Salinity                         0.324  0.320 -0.138
## Date:Temperature:Salinity                          0.999  0.999  0.598
## Enterococcus:Temperature:Salinity                  0.337  0.332 -0.131
## Date:Enterococcus:Turbidity                        0.423  0.414  0.060
## Date:Temperature:Turbidity                         0.606  0.613  0.999
## Enterococcus:Temperature:Turbidity                 0.423  0.413  0.060
## Date:Salinity:Turbidity                            0.596  0.605  0.999
## Enterococcus:Salinity:Turbidity                    0.435  0.427  0.074
## Temperature:Salinity:Turbidity                     0.610  0.618  0.999
## Date:Enterococcus:Temperature:Salinity            -0.331 -0.326  0.136
## Date:Enterococcus:Temperature:Turbidity           -0.418 -0.408 -0.055
## Date:Enterococcus:Salinity:Turbidity              -0.431 -0.422 -0.069
## Date:Temperature:Salinity:Turbidity               -0.605 -0.613 -0.999
## Enterococcus:Temperature:Salinity:Turbidity       -0.430 -0.421 -0.068
## Date:Enterococcus:Temperature:Salinity:Turbidity  0.426  0.417  0.064
```

```
##                                                Dt:Ent Dt:Tmp Entrcccs:Tm
## Date
## Enterococcus
## Temperature
## Salinity
## Turbidity
## Date:Enterococcus
## Date:Temperature                                0.323
## Enterococcus:Temperature                        0.998  0.336
## Date:Salinity                                   0.318  0.998  0.330
## Enterococcus:Salinity                           0.999  0.330  0.998
## Temperature:Salinity                            0.319  0.999  0.332
## Date:Turbidity                                 -0.149  0.595 -0.142
## Enterococcus:Turbidity                          0.841  0.425  0.864
## Temperature:Turbidity                          -0.131  0.608 -0.123
## Salinity:Turbidity                             -0.149  0.598 -0.141
## Date:Enterococcus:Temperature                  -0.999 -0.330 -1.000
## Date:Enterococcus:Salinity                     -0.999 -0.324 -0.997
## Date:Temperature:Salinity                      -0.320 -0.999 -0.332
## Enterococcus:Temperature:Salinity              -0.998 -0.337 -0.999
## Date:Enterococcus:Turbidity                    -0.843 -0.421 -0.866
## Date:Temperature:Turbidity                      0.138 -0.604  0.130
## Enterococcus:Temperature:Turbidity             -0.832 -0.420 -0.857
## Date:Salinity:Turbidity                         0.155 -0.594  0.148
## Enterococcus:Salinity:Turbidity                -0.843 -0.432 -0.866
## Temperature:Salinity:Turbidity                  0.138 -0.607  0.130
## Date:Enterococcus:Temperature:Salinity          0.999  0.331  0.999
## Date:Enterococcus:Temperature:Turbidity         0.834  0.416  0.858
## Date:Enterococcus:Salinity:Turbidity            0.845  0.428  0.868
## Date:Temperature:Salinity:Turbidity            -0.144  0.603 -0.136
## Enterococcus:Temperature:Salinity:Turbidity     0.834  0.427  0.858
## Date:Enterococcus:Temperature:Salinity:Turbidity -0.836 -0.423 -0.860
##                                                Dt:Sln Entr:S Tmpr:S
## Date
## Enterococcus
## Temperature
## Salinity
## Turbidity
## Date:Enterococcus
## Date:Temperature
## Enterococcus:Temperature
## Date:Salinity
## Enterococcus:Salinity                           0.326
## Temperature:Salinity                            0.999  0.327
## Date:Turbidity                                  0.603 -0.139  0.596
## Enterococcus:Turbidity                          0.416  0.843  0.422
## Temperature:Turbidity                           0.615 -0.122  0.610
## Salinity:Turbidity                              0.607 -0.139  0.601
## Date:Enterococcus:Temperature                  -0.324 -0.998 -0.326
## Date:Enterococcus:Salinity                     -0.320 -1.000 -0.321
## Date:Temperature:Salinity                      -0.999 -0.328 -1.000
## Enterococcus:Temperature:Salinity              -0.332 -0.999 -0.334
## Date:Enterococcus:Turbidity                    -0.412 -0.845 -0.417
## Date:Temperature:Turbidity                     -0.611  0.128 -0.605
```

```
## Enterococcus:Temperature:Turbidity              -0.410 -0.833 -0.417
## Date:Salinity:Turbidity                         -0.603  0.145 -0.596
## Enterococcus:Salinity:Turbidity                 -0.424 -0.846 -0.430
## Temperature:Salinity:Turbidity                  -0.615  0.128 -0.610
## Date:Enterococcus:Temperature:Salinity           0.326  0.999  0.328
## Date:Enterococcus:Temperature:Turbidity          0.406  0.835  0.412
## Date:Enterococcus:Salinity:Turbidity             0.420  0.848  0.425
## Date:Temperature:Salinity:Turbidity              0.611 -0.134  0.605
## Enterococcus:Temperature:Salinity:Turbidity      0.418  0.837  0.425
## Date:Enterococcus:Temperature:Salinity:Turbidity -0.414 -0.839 -0.420
##                                                  Dt:Trb Entrcccs:Tr Tmpr:T
## Date
## Enterococcus
## Temperature
## Salinity
## Turbidity
## Date:Enterococcus
## Date:Temperature
## Enterococcus:Temperature
## Date:Salinity
## Enterococcus:Salinity
## Temperature:Salinity
## Date:Turbidity
## Enterococcus:Turbidity                           0.060
## Temperature:Turbidity                            0.999  0.076
## Salinity:Turbidity                               0.999  0.057       0.999
## Date:Enterococcus:Temperature                    0.147 -0.858       0.129
## Date:Enterococcus:Salinity                       0.144 -0.837       0.127
## Date:Temperature:Salinity                       -0.594 -0.420      -0.607
## Enterococcus:Temperature:Salinity                0.138 -0.860       0.120
## Date:Enterococcus:Turbidity                     -0.056 -1.000      -0.072
## Date:Temperature:Turbidity                      -0.999 -0.072      -1.000
## Enterococcus:Temperature:Turbidity              -0.055 -0.999      -0.071
## Date:Salinity:Turbidity                         -0.999 -0.053      -0.998
## Enterococcus:Salinity:Turbidity                 -0.069 -0.999      -0.085
## Temperature:Salinity:Turbidity                  -0.998 -0.069      -0.999
## Date:Enterococcus:Temperature:Salinity          -0.143  0.854      -0.125
## Date:Enterococcus:Temperature:Turbidity          0.051  0.999       0.067
## Date:Enterococcus:Salinity:Turbidity             0.065  0.999       0.080
## Date:Temperature:Salinity:Turbidity              0.999  0.064       0.999
## Enterococcus:Temperature:Salinity:Turbidity      0.063  0.999       0.080
## Date:Enterococcus:Temperature:Salinity:Turbidity -0.059 -0.999      -0.075
##                                                  Slnt:T Dt:Entrcccs:Tm
## Date
## Enterococcus
## Temperature
## Salinity
## Turbidity
## Date:Enterococcus
## Date:Temperature
## Enterococcus:Temperature
## Date:Salinity
## Enterococcus:Salinity
## Temperature:Salinity
```

```
## Date:Turbidity
## Enterococcus:Turbidity
## Temperature:Turbidity
## Salinity:Turbidity
## Date:Enterococcus:Temperature                       0.147
## Date:Enterococcus:Salinity                          0.144  0.998
## Date:Temperature:Salinity                          -0.598  0.326
## Enterococcus:Temperature:Salinity                   0.137  0.999
## Date:Enterococcus:Turbidity                        -0.053  0.860
## Date:Temperature:Turbidity                         -0.998 -0.135
## Enterococcus:Temperature:Turbidity                 -0.052  0.850
## Date:Salinity:Turbidity                            -1.000 -0.153
## Enterococcus:Salinity:Turbidity                    -0.067  0.859
## Temperature:Salinity:Turbidity                     -0.999 -0.135
## Date:Enterococcus:Temperature:Salinity             -0.143 -0.999
## Date:Enterococcus:Temperature:Turbidity             0.048 -0.852
## Date:Enterococcus:Salinity:Turbidity                0.062 -0.861
## Date:Temperature:Salinity:Turbidity                 0.999  0.141
## Enterococcus:Temperature:Salinity:Turbidity         0.061 -0.852
## Date:Enterococcus:Temperature:Salinity:Turbidity -0.057  0.854
##                                                    Dt:E:S Dt:T:S En:T:S
## Date
## Enterococcus
## Temperature
## Salinity
## Turbidity
## Date:Enterococcus
## Date:Temperature
## Enterococcus:Temperature
## Date:Salinity
## Enterococcus:Salinity
## Temperature:Salinity
## Date:Turbidity
## Enterococcus:Turbidity
## Temperature:Turbidity
## Salinity:Turbidity
## Date:Enterococcus:Temperature
## Date:Enterococcus:Salinity
## Date:Temperature:Salinity                           0.321
## Enterococcus:Temperature:Salinity                   0.998  0.334
## Date:Enterococcus:Turbidity                         0.839  0.415  0.862
## Date:Temperature:Turbidity                         -0.133  0.603 -0.126
## Enterococcus:Temperature:Turbidity                  0.827  0.414  0.852
## Date:Salinity:Turbidity                            -0.150  0.594 -0.144
## Enterococcus:Salinity:Turbidity                     0.839  0.428  0.863
## Temperature:Salinity:Turbidity                     -0.133  0.608 -0.126
## Date:Enterococcus:Temperature:Salinity             -0.999 -0.328 -1.000
## Date:Enterococcus:Temperature:Turbidity            -0.829 -0.410 -0.853
## Date:Enterococcus:Salinity:Turbidity               -0.842 -0.423 -0.864
## Date:Temperature:Salinity:Turbidity                 0.139 -0.603  0.132
## Enterococcus:Temperature:Salinity:Turbidity        -0.830 -0.422 -0.855
## Date:Enterococcus:Temperature:Salinity:Turbidity  0.832  0.418  0.856
##                                                    Dt:Entrcccs:Tr Dt:T:T
## Date
```

```
## Enterococcus
## Temperature
## Salinity
## Turbidity
## Date:Enterococcus
## Date:Temperature
## Enterococcus:Temperature
## Date:Salinity
## Enterococcus:Salinity
## Temperature:Salinity
## Date:Turbidity
## Enterococcus:Turbidity
## Temperature:Turbidity
## Salinity:Turbidity
## Date:Enterococcus:Temperature
## Date:Enterococcus:Salinity
## Date:Temperature:Salinity
## Enterococcus:Temperature:Salinity
## Date:Enterococcus:Turbidity
## Date:Temperature:Turbidity                          0.067
## Enterococcus:Temperature:Turbidity                  0.999          0.067
## Date:Salinity:Turbidity                             0.048          0.999
## Enterococcus:Salinity:Turbidity                     0.999          0.080
## Temperature:Salinity:Turbidity                      0.064          0.999
## Date:Enterococcus:Temperature:Salinity             -0.856          0.131
## Date:Enterococcus:Temperature:Turbidity            -0.999         -0.063
## Date:Enterococcus:Salinity:Turbidity               -0.999         -0.076
## Date:Temperature:Salinity:Turbidity                -0.060         -0.999
## Enterococcus:Temperature:Salinity:Turbidity        -0.998         -0.075
## Date:Enterococcus:Temperature:Salinity:Turbidity  0.999          0.071
##                                                    En:T:T Dt:S:T En:S:T
## Date
## Enterococcus
## Temperature
## Salinity
## Turbidity
## Date:Enterococcus
## Date:Temperature
## Enterococcus:Temperature
## Date:Salinity
## Enterococcus:Salinity
## Temperature:Salinity
## Date:Turbidity
## Enterococcus:Turbidity
## Temperature:Turbidity
## Salinity:Turbidity
## Date:Enterococcus:Temperature
## Date:Enterococcus:Salinity
## Date:Temperature:Salinity
## Enterococcus:Temperature:Salinity
## Date:Enterococcus:Turbidity
## Date:Temperature:Turbidity
## Enterococcus:Temperature:Turbidity
## Date:Salinity:Turbidity                             0.047
```

```
## Enterococcus:Salinity:Turbidity                   0.998  0.062
## Temperature:Salinity:Turbidity                    0.064  0.999  0.078
## Date:Enterococcus:Temperature:Salinity           -0.846  0.149 -0.857
## Date:Enterococcus:Temperature:Turbidity          -1.000 -0.043 -0.997
## Date:Enterococcus:Salinity:Turbidity             -0.998 -0.058 -1.000
## Date:Temperature:Salinity:Turbidity              -0.059 -0.999 -0.074
## Enterococcus:Temperature:Salinity:Turbidity      -0.999 -0.056 -0.999
## Date:Enterococcus:Temperature:Salinity:Turbidity  0.999  0.052  0.999
##                                                  Tm:S:T Dt:E:T:S D:E:T:T
## Date
## Enterococcus
## Temperature
## Salinity
## Turbidity
## Date:Enterococcus
## Date:Temperature
## Enterococcus:Temperature
## Date:Salinity
## Enterococcus:Salinity
## Temperature:Salinity
## Date:Turbidity
## Enterococcus:Turbidity
## Temperature:Turbidity
## Salinity:Turbidity
## Date:Enterococcus:Temperature
## Date:Enterococcus:Salinity
## Date:Temperature:Salinity
## Enterococcus:Temperature:Salinity
## Date:Enterococcus:Turbidity
## Date:Temperature:Turbidity
## Enterococcus:Temperature:Turbidity
## Date:Salinity:Turbidity
## Enterococcus:Salinity:Turbidity
## Temperature:Salinity:Turbidity
## Date:Enterococcus:Temperature:Salinity            0.131
## Date:Enterococcus:Temperature:Turbidity          -0.059  0.848
## Date:Enterococcus:Salinity:Turbidity             -0.073  0.859    0.998
## Date:Temperature:Salinity:Turbidity              -1.000 -0.137    0.055
## Enterococcus:Temperature:Salinity:Turbidity      -0.073  0.848    0.999
## Date:Enterococcus:Temperature:Salinity:Turbidity  0.068 -0.850   -0.999
##                                                  D:E:S: D:T:S: E:T:S:
## Date
## Enterococcus
## Temperature
## Salinity
## Turbidity
## Date:Enterococcus
## Date:Temperature
## Enterococcus:Temperature
## Date:Salinity
## Enterococcus:Salinity
## Temperature:Salinity
## Date:Turbidity
## Enterococcus:Turbidity
```

```
## Temperature:Turbidity
## Salinity:Turbidity
## Date:Enterococcus:Temperature
## Date:Enterococcus:Salinity
## Date:Temperature:Salinity
## Enterococcus:Temperature:Salinity
## Date:Enterococcus:Turbidity
## Date:Temperature:Turbidity
## Enterococcus:Temperature:Turbidity
## Date:Salinity:Turbidity
## Enterococcus:Salinity:Turbidity
## Temperature:Salinity:Turbidity
## Date:Enterococcus:Temperature:Salinity
## Date:Enterococcus:Temperature:Turbidity
## Date:Enterococcus:Salinity:Turbidity
## Date:Temperature:Salinity:Turbidity               0.069
## Enterococcus:Temperature:Salinity:Turbidity       0.999  0.068
## Date:Enterococcus:Temperature:Salinity:Turbidity -0.999 -0.064 -1.000
##
## Standardized Within-Group Residuals:
##         Min          Q1         Med          Q3         Max
## -3.03492976 -0.52735363  0.04169885  0.53628126  3.03140796
##
## Number of Observations: 397
## Number of Groups: 27
```

Research question: Is there a trend over time in DO concentrations by region?

Split Dataset by Region (Use full dataset)

```r
HawaiiWaterCleanOahuNorth<- filter(HawaiiWaterCleanOahu, Region== "North")
HawaiiWaterCleanOahuSouth<- filter(HawaiiWaterCleanOahu, Region== "South")
HawaiiWaterCleanOahuEast<- filter(HawaiiWaterCleanOahu, Region== "East")
HawaiiWaterCleanOahuWest<- filter(HawaiiWaterCleanOahu, Region== "West")
```

Run a Mann Kendall Test for North Oahu

```r
library(trend)
mk.test(HawaiiWaterCleanOahuNorth$DO)
```

```
##
##  Mann-Kendall trend test
##
## data:  HawaiiWaterCleanOahuNorth$DO
## z = 3.808, n = 1002, p-value = 0.0001401
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS          tau
## 4.029000e+04 1.119384e+08 8.057285e-02
```

Run a Mann Kendall Test for South Oahu

```
library(trend)
mk.test(HawaiiWaterCleanOahuSouth$DO)
```

```
##
##  Mann-Kendall trend test
##
## data:  HawaiiWaterCleanOahuSouth$DO
## z = 7.1428, n = 2634, p-value = 9.147e-13
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS          tau
## 3.219490e+05 2.031599e+09 9.305543e-02
```

Run a Mann Kendall Test for East Oahu

```
library(trend)
mk.test(HawaiiWaterCleanOahuEast$DO)
```

```
##
##  Mann-Kendall trend test
##
## data:  HawaiiWaterCleanOahuEast$DO
## z = 2.4076, n = 999, p-value = 0.01606
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS          tau
## 2.535900e+04 1.109376e+08 5.100554e-02
```

Run a Mann Kendall Test for West Oahu

```
library(trend)
mk.test(HawaiiWaterCleanOahuWest$DO)
```

```
##
##  Mann-Kendall trend test
##
## data:  HawaiiWaterCleanOahuWest$DO
## z = -4.0098, n = 969, p-value = 6.078e-05
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##             S          varS           tau
## -4.034700e+04  1.012427e+08 -8.630965e-02
```

For North Oahu, the z-value is 3.808, so we see a positive trend in DO concentrations over time. The p-value is 0.00014,so we reject the null hypothesis that the data come from a population with independent realizations and are identically distributed . For South Oahu, the z-value is 7.14, so we see a positive trend in DO concentrations over time. The p-value for Paul Lake is listed as 9.14e-13, so we reject the null hypothesis that the data come from a population with independent realizations and are identically distributed. For East Oahu, the z-value is 2.4. For West Oahu, the z-value is -4.009.

Pettit's Test for North Oahu

```
pettitt.test(HawaiiWaterCleanOahuNorth$DO)
```

```
##
##  Pettitt's test for single change-point detection
##
## data:  HawaiiWaterCleanOahuNorth$DO
## U* = 59236, p-value = 1.665e-09
## alternative hypothesis: two.sided
## sample estimates:
## probable change point at time K
##                             347
```

Because the p-value is <0.05, the change point is significant. Given 1st change point for Peter Lake is 347, we scroll to observation 347 in data set, so first change point occurred in 2004-08-16

Run a separate Mann-Kendall Test for Each Change Point

```
mk.test(HawaiiWaterCleanOahuNorth$DO[1:346])
```

```
##
##  Mann-Kendall trend test
##
## data:  HawaiiWaterCleanOahuNorth$DO[1:346]
## z = -1.3187, n = 346, p-value = 0.1873
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##             S          varS           tau
## -2.836000e+03  4.621646e+06 -4.766932e-02
```

```
mk.test(HawaiiWaterCleanOahuNorth$DO[347:1002])
```

```
##
##  Mann-Kendall trend test
##
## data:  HawaiiWaterCleanOahuNorth$DO[347:1002]
## z = -2.6982, n = 656, p-value = 0.006972
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##             S          varS           tau
## -1.512900e+04  3.143569e+07 -7.062577e-02
```

p-value for [347:1002] is significant, so run a Pettit's Test

Is there a second change point?

```r
pettitt.test(HawaiiWaterCleanOahuNorth$DO[347:1002])
```

```
##
##  Pettitt's test for single change-point detection
##
## data:  HawaiiWaterCleanOahuNorth$DO[347:1002]
## U* = 23298, p-value = 1.988e-05
## alternative hypothesis: two.sided
## sample estimates:
## probable change point at time K
##                             361
```

347 + 360=707, so look at 707th row->Observation occurred on 2005-08-17

Run another Mann-Kendall for the second change point

Now split dataset into three pieces

```r
mk.test(HawaiiWaterCleanOahuNorth$DO[347:706])
```

```
##
##  Mann-Kendall trend test
##
## data:  HawaiiWaterCleanOahuNorth$DO[347:706]
## z = 3.7634, n = 360, p-value = 0.0001676
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS          tau
## 8.587000e+03 5.205018e+06 1.332158e-01
```

```r
mk.test(HawaiiWaterCleanOahuNorth$DO[707:1002])
```

```
##
##  Mann-Kendall trend test
##
## data:  HawaiiWaterCleanOahuNorth$DO[707:1002]
## z = -0.53066, n = 296, p-value = 0.5957
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##             S          varS           tau
## -9.040000e+02  2.895633e+06 -2.078175e-02
```

If z-score is positive, it's a positive trend. If z-score is negative, it is a negative trend

There is a significant trend in DO concentrations over time at North Oahu for rows:347:706 because the p-value is 0.00016, which is below 0.05.

There is also not a significant trend in DO concentrations over time at North Oahu for rows 707:1002 because the p-value is 0.59, which is above 0.05.

Pettit's Test for South Oahu

```r
pettitt.test(HawaiiWaterCleanOahuSouth$DO)
```

```
##
##  Pettitt's test for single change-point detection
##
## data:  HawaiiWaterCleanOahuSouth$DO
## U* = 381900, p-value < 2.2e-16
## alternative hypothesis: two.sided
## sample estimates:
## probable change point at time K
##                            2260
```

Change point is significant bc p<0.05. Given 1st change point for South Oahu is 2260, we scroll to observation 2260 in data set, so first change point occurred in 2005-02-28

.

Run separate Mann-Kendall Test for each change point in South Oahu

```r
mk.test(HawaiiWaterCleanOahuSouth$DO[1:2259])
```

```
##
##  Mann-Kendall trend test
##
## data:  HawaiiWaterCleanOahuSouth$DO[1:2259]
## z = -1.8701, n = 2259, p-value = 0.06146
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##             S          varS           tau
## -6.695300e+04  1.281678e+09 -2.631344e-02
```

```r
mk.test(HawaiiWaterCleanOahuSouth$DO[2260:2634])
```

```
##
##  Mann-Kendall trend test
##
## data:  HawaiiWaterCleanOahuSouth$DO[2260:2634]
## z = 3.6784, n = 375, p-value = 0.0002347
## alternative hypothesis: true S is not equal to 0
## sample estimates:
```

```
##             S          varS           tau
## 8.922000e+03 5.881904e+06 1.276411e-01
```

Is there a second change point?

```r
pettitt.test(HawaiiWaterCleanOahuSouth$DO[2260:2634])
```

```
##
##  Pettitt's test for single change-point detection
##
## data:  HawaiiWaterCleanOahuSouth$DO[2260:2634]
## U* = 13508, p-value = 2.036e-09
## alternative hypothesis: two.sided
## sample estimates:
## probable change point at time K
##                             188
```

The p-value is significant, so there is a second change point. 2260+187=2447. Look at 2447'th row for second change point, it occurred in 2006-10-12

Run another Mann-Kendall for the second change point

Now split dataset into three pieces

```r
mk.test(HawaiiWaterCleanOahuSouth$DO[2260:2446])
```

```
##
##  Mann-Kendall trend test
##
## data:  HawaiiWaterCleanOahuSouth$DO[2260:2446]
## z = -3.5527, n = 187, p-value = 0.0003813
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##              S           varS            tau
## -3.041000e+03  7.322083e+05 -1.753959e-01
```

```r
mk.test(HawaiiWaterCleanOahuSouth$DO[2447:2634])
```

```
##
##  Mann-Kendall trend test
##
## data:  HawaiiWaterCleanOahuSouth$DO[2447:2634]
## z = -1.5432, n = 188, p-value = 0.1228
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##              S           varS            tau
## -1.332000e+03  7.438500e+05 -7.613252e-02
```

If z-score is positive, it's a positive trend. If z-score is negative, it is a negative trend

There is a significant trend in DO concentrations over time at South Oahu for rows:2260:2446 because the p-value is 0.00038, which is below 0.05.

There is also not a significant trend in DO concentrations over time for rows 2447:2634 because the p-value is 0.12, which is above 0.05.

Petitt Test for East Oahu

```
pettitt.test(HawaiiWaterCleanOahuEast$DO)
```

```
##
##  Pettitt's test for single change-point detection
##
## data:  HawaiiWaterCleanOahuEast$DO
## U* = 38689, p-value = 0.0002471
## alternative hypothesis: two.sided
## sample estimates:
## probable change point at time K
##                             675
```

Because the p-value is $<$0.05, the change point is significant. Given 1st change point for East Oahu is 675, we scroll to observation 675 in data set, so first change point occurred in 2006-09-25

Run separate Mann-Kendall Test for each change point

```
mk.test(HawaiiWaterCleanOahuEast$DO[1:674])
```

```
##
##  Mann-Kendall trend test
##
## data:  HawaiiWaterCleanOahuEast$DO[1:674]
## z = -2.7967, n = 674, p-value = 0.005162
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##             S          varS           tau
## -1.633100e+04  3.409347e+07 -7.219551e-02
```

```
mk.test(HawaiiWaterCleanOahuEast$DO[675:999])
```

```
##
##  Mann-Kendall trend test
##
## data:  HawaiiWaterCleanOahuEast$DO[675:999]
## z = 1.8734, n = 325, p-value = 0.06101
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS          tau
## 3.668000e+03 3.831328e+06 6.985628e-02
```

There are no more change points because p-value is >0.05 for interval [675:999]

Petitt Test for West Oahu

```
pettitt.test(HawaiiWaterCleanOahuWest$DO)
```

```
##
##  Pettitt's test for single change-point detection
##
## data:  HawaiiWaterCleanOahuWest$DO
## U* = 53608, p-value = 1.2e-08
## alternative hypothesis: two.sided
## sample estimates:
## probable change point at time K
##                              663
```

Because the p-value is <0.05, the change point is significant. Given 1st change point for West Oahu is 663, we scroll to observation 663 in data set, so first change point occurred in 2003-12-03

Run separate Mann-Kendall Test for each change point

```
mk.test(HawaiiWaterCleanOahuWest$DO[1:662])
```

```
##
##  Mann-Kendall trend test
##
## data:  HawaiiWaterCleanOahuWest$DO[1:662]
## z = 0.67807, n = 662, p-value = 0.4977
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS          tau
## 3.855000e+03 3.230499e+07 1.767791e-02
```

```
mk.test(HawaiiWaterCleanOahuWest$DO[663:969])
```

```
##
##  Mann-Kendall trend test
##
## data:  HawaiiWaterCleanOahuWest$DO[663:969]
## z = 5.0599, n = 307, p-value = 4.194e-07
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS          tau
## 9.095000e+03 3.230146e+06 1.942265e-01
```

p-value for [663:969] is significant, so there is a second change point

What is the second change point?

```
pettitt.test(HawaiiWaterCleanOahuWest$DO[663:969])
```

```
##
##  Pettitt's test for single change-point detection
##
## data:  HawaiiWaterCleanOahuWest$DO[663:969]
## U* = 9574, p-value = 1.183e-08
## alternative hypothesis: two.sided
## sample estimates:
## probable change point at time K
##                             165
```

663+164=827, second change point occurred on 2004-10-20

Run another Mann-Kendall for the third change point (if it exists)

Now split dataset into three pieces

```
mk.test(HawaiiWaterCleanOahuWest$DO[663:826])
```

```
##
##  Mann-Kendall trend test
##
## data:  HawaiiWaterCleanOahuWest$DO[663:826]
## z = -0.08533, n = 164, p-value = 0.932
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##             S          varS           tau
## -6.100000e+01  4.944290e+05 -4.579434e-03
```

```
mk.test(HawaiiWaterCleanOahuWest$DO[827:969])
```

```
##
##  Mann-Kendall trend test
##
## data:  HawaiiWaterCleanOahuWest$DO[827:969]
## z = -0.39801, n = 143, p-value = 0.6906
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS          tau
## -2.29000e+02  3.28165e+05 -2.26488e-02
```

There is not a third changepoint

Generate a graph that illustrates the Dissolved Oxygen concentrations over time, coloring by Region and adding vertical line(s) representing changepoint(s).

```
library(wesanderson)
OahuDOPlot<-ggplot(HawaiiWaterCleanOahu, aes(x = Date, y = DO, color = Region)) +
  geom_point(alpha=1) +
scale_color_manual(values=wes_palette(name="GrandBudapest2")) +
  ##geom_vline(xintercept=as.Date("2004-08-16"),color="253494", origin= "1970-01-01", lty=2) + ###First
 ## geom_vline(xintercept=as.Date("2005-08-17"), color="253494", origin= "1970-01-01", lty=2)  ###Secon

  geom_smooth(aes(x = Date, y = DO, span=0.1), color="black", linetype=1, size=0.5) +
  labs(title="The Effect of Sample Date on Dissolved Oxygen Concentrations in Oahu",
       x="Sample Date",
       y="Dissolved Oxygen (mg/L)")+
  scale_x_date(labels = date_format("%m/%Y"), breaks = date_breaks("3 month"))+
  scale_y_continuous(limits=c())
```

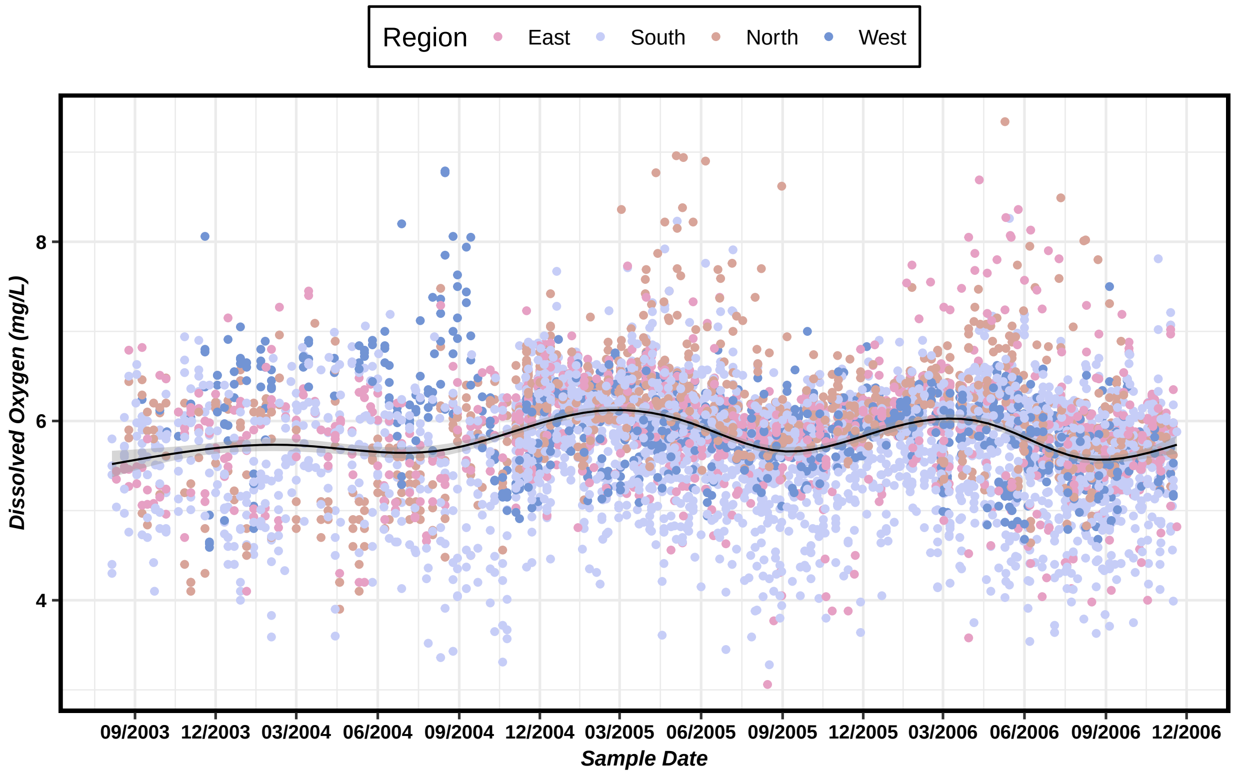
```
library(wesanderson)
OahuTemperaturePlot<-ggplot(HawaiiWaterCleanOahu, aes(x = Date, y = Temperature, color = Region)) +
  geom_point(alpha=1) +
scale_color_manual(values=wes_palette(name="GrandBudapest2")) +
  ##geom_vline(xintercept=as.Date("2004-08-16"),color="253494", origin= "1970-01-01", lty=2) + ###First
 ## geom_vline(xintercept=as.Date("2005-08-17"), color="253494", origin= "1970-01-01", lty=2)  ###Secon

  geom_smooth(aes(x = Date, y = Temperature, span=0.1), color="black", linetype=1, size=0.5) +
  labs(title="The Effect of Sample Date on Temperature in Oahu",
       x="Sample Date",
       y="Temperature(degrees C") +
  scale_x_date(labels = date_format("%m/%Y"), breaks = date_breaks("3 month"))
```

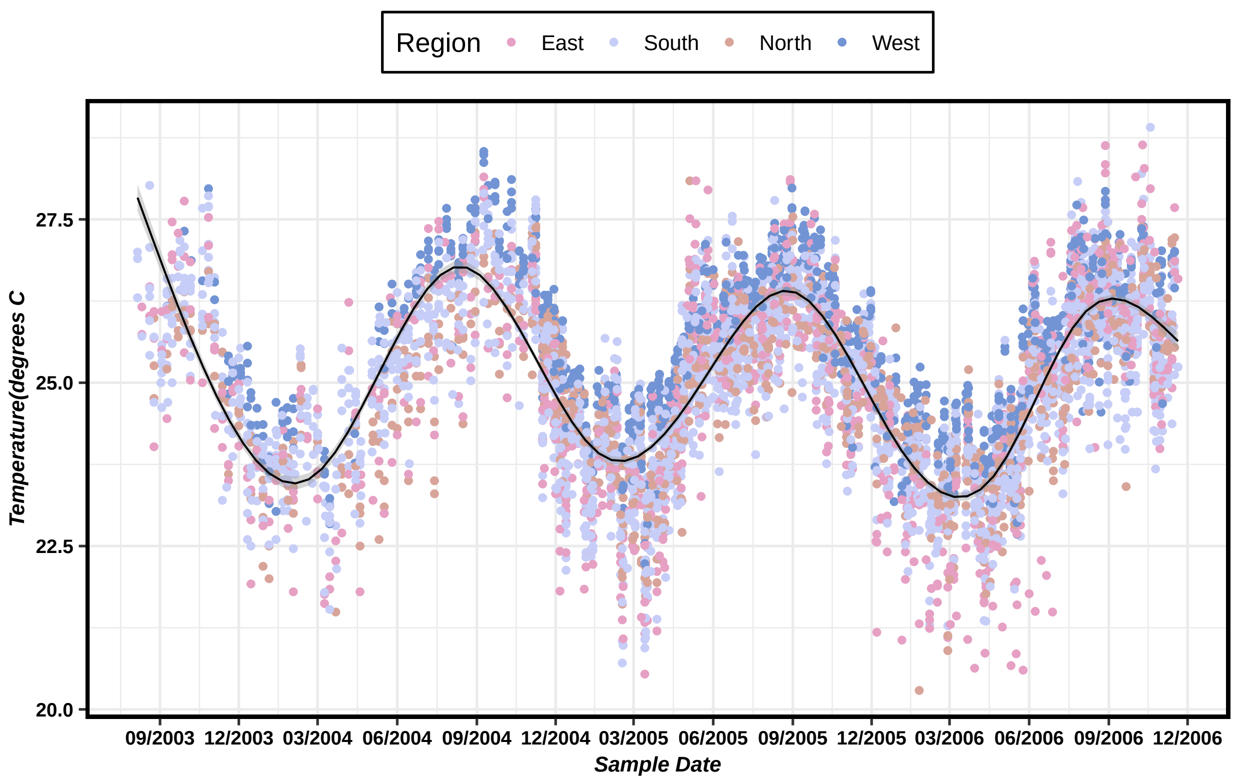
```
grid.arrange(OahuDOPlot, OahuTemperaturePlot, nrow=2)
```

```
## `geom_smooth()` using method = 'gam' and formula 'y ~ s(x, bs = "cs")'
## `geom_smooth()` using method = 'gam' and formula 'y ~ s(x, bs = "cs")'
```

The Effect of Sample Date on Dissolved Oxygen Concentrations in Oahu



The Effect of Sample Date on Temperature in Oahu



Cold water can hold more dissolved oxygen than warm water. In winter and early spring, when the water temperature is low, the dissolved oxygen concentration is high. In summer and fall, when the water temperature is high, the dissolved-oxygen concentration is low.