2013 Black Forest Fire (Colorado) burn severity impact on soil physical and soil hydraulic properties.

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Contents

List of Tables

List of Figures

1. Rationale and Research Questions

Wildfires are becoming more severe, and climate change is creating warmer and drier conditions in many places around the globe, making them more wildfire prone. Depending on their severity, wildfire can have significant and negative impacts on physical properties of soil, which directly relates to how much water an area can hold.

The 2013 Black Forest Fire in Colorado's El Paso County covered 14,280 acres and destroyed 489 homes. It is one of the most destructive forest fires in the state's history. Following the fire, researchers collected soil data at various sites with varying burn severity.

We seek to better understand how the wildfire and its different intensities impacted the soil's physical characteristics.

2. Dataset Information

Table 1: Dataset information

Item	Value
Data Source	Soil-physical and soil-hydraulic properties as a function of burn severity for 2013, 2015, and 2017 in the area affected by the 2013 Black Forest Fire, Colorado USA (ver. 2.0, June 2021)
Date range	2013-07-23 to 2017-06-19
Source	Retrieved from: https://www.sciencebase.gov/catalog/item/5b8452f5e4b05f6e321b629b
Variables used	Soil field-saturated hydraulic conductivity (KFS) (mm/hr), soil sorptivity (mm/$\sqrt{hr}$), soil particle size distribution (gravel, sand, silt+clay) (%), and soil dry bulk density (grams/cm^3)

3. Exploration of raw data

```
#structure of 2013 raw dataset
str(soil_hp_2013_raw)
```

```
## 'data.frame':    33 obs. of  4 variables:
##  $ SampleID                                : Factor w/ 33 levels "BF 1-2","BF 1-3",..: 29 30 31 32 33
##  $ Site                                    : Factor w/ 6 levels "BF1","BF2","BF3",..: 6 6 6 6 6 6 5 5
##  $ Kfs..mm.per.hr...DL.method              : num  85 197 18 8.1 162 791 19 123 147 22 ...
##  $ Sorptivity..mm.per.sqrt.hr....DL.method: num  1.4 0.4 0.3 6 8.6 18 40.8 9.1 8.3 0.5 ...
```

```
#structure of 2015 raw dataset
str(soil_hp_2015_raw)
```

```
## 'data.frame':    78 obs. of  8 variables:
##  $ SampleID                              : Factor w/ 78 levels "","BF 1-10","BF 1-1A",..: 71 72 73 74 7
##  $ Site                                  : Factor w/ 7 levels "","BF1","BF2",..: 7 7 7 7 7 7 7 7 7 6 .
##  $ Kfs..mm.per.hr...CL                   : num  160 NA 771 678 157 ...
##  $ Sorptivity..mm.per.sqrt.hr....CL      : num  99.7 NA 4.9 43.4 20.5 47.8 NA 22.8 19.2 4.9 ...
##  $ Kfs..mm.per.hr...DL                   : num  NA 79.1 NA NA 207.9 ...
##  $ Sorptivity..mm.per.sqrt.hr....DL      : num  NA 48 NA NA 4 36.8 2.9 5.6 7 NA ...
##  $ Average.Kfs..mm.per.hr.               : num  159.5 79.1 770.9 677.6 182.3 ...
##  $ Average.Sorptivity..mm.per.sqrt.hr..: num  99.7 48 4.9 43.4 12.2 42.3 2.9 14.2 13.1 4.9 ...
```

```
#structure of 2017 raw dataset
str(soil_hp_2017_raw)
```

```
## 'data.frame':    38 obs. of  9 variables:
##  $ SampleID                              : Factor w/ 38 levels "BF 1-1A","BF 1-3A",..: 32 33 34 35 36 3
##  $ Site                                  : Factor w/ 5 levels "BF1","BF3","BF4",..: 5 5 5 5 5 5 5 5 4 4
##  $ Kfs..mm.per.hr...CL                   : num  62.3 30.3 246.2 68.1 296.7 ...
##  $ Sorptivity..mm.per.sqrt.hr....CL      : num  3.5 5.7 12.9 6.3 1.5 23.4 22.4 1.6 8.3 46 ...
##  $ Kfs..mm.per.hr...DL                   : num  48.2 39.3 NA 49.4 NA ...
##  $ Sorptivity..mm.per.sqrt.hr....DL      : num  1.8 0.6 NA 2.1 NA 60.6 NA NA 23.3 17.3 ...
##  $ Average.Kfs..mm.per.hr.               : num  55.2 34.8 246.2 58.8 296.7 ...
##  $ Average.Sorptivity..mm.per.sqrt.hr..: num  2.6 3.2 12.9 4.2 1.5 42 22.4 1.6 15.8 31.6 ...
##  $ X                                     : logi  NA NA NA NA NA NA ...
```

```
#column names of 2013 raw dataset
colnames(soil_hp_2013_raw)
```

```
## [1] "SampleID"
## [2] "Site"
## [3] "Kfs..mm.per.hr...DL.method"
## [4] "Sorptivity..mm.per.sqrt.hr....DL.method"
```

```
#column names of 2015 raw dataset
colnames(soil_hp_2015_raw)
```

```
## [1] "SampleID"
## [2] "Site"
## [3] "Kfs..mm.per.hr...CL"
## [4] "Sorptivity..mm.per.sqrt.hr....CL"
## [5] "Kfs..mm.per.hr...DL"
## [6] "Sorptivity..mm.per.sqrt.hr....DL"
## [7] "Average.Kfs..mm.per.hr."
## [8] "Average.Sorptivity..mm.per.sqrt.hr.."
```

```
#column names of 2017 raw dataset
colnames(soil_hp_2017_raw)
```

```
## [1] "SampleID"
## [2] "Site"
## [3] "Kfs..mm.per.hr...CL"
## [4] "Sorptivity..mm.per.sqrt.hr....CL"
## [5] "Kfs..mm.per.hr...DL"
## [6] "Sorptivity..mm.per.sqrt.hr....DL"
## [7] "Average.Kfs..mm.per.hr."
## [8] "Average.Sorptivity..mm.per.sqrt.hr.."
## [9] "X"
```

```
#summary 2013 raw dataset
summary(soil_hp_2013_raw)
```

```
##     SampleID   Site   Kfs..mm.per.hr...DL.method
##  BF 1-2 : 1   BF1:8   Min.   :  3.4
##  BF 1-3 : 1   BF2:5   1st Qu.: 22.0
##  BF 1-4 : 1   BF3:4   Median : 69.0
##  BF 1-5 : 1   BF4:7   Mean   :103.1
##  BF 1-6 : 1   BF5:3   3rd Qu.:123.0
##  BF 1-7 : 1   BF6:6   Max.   :791.0
##  (Other):27
##  Sorptivity..mm.per.sqrt.hr....DL.method
##  Min.   : 0.100
##  1st Qu.: 1.000
##  Median : 2.200
##  Mean   : 6.233
##  3rd Qu.: 8.300
##  Max.   :40.800
##
```

```
#summary of 2015 raw dataset
summary(soil_hp_2015_raw)
```

```
##     SampleID   Site    Kfs..mm.per.hr...CL Sorptivity..mm.per.sqrt.hr....CL
##         : 1      : 1   Min.   :  0.80      Min.   : 0.50
##  BF 1-10: 1   BF1:15   1st Qu.: 62.08      1st Qu.:13.25
##  BF 1-1A: 1   BF2:15   Median :115.25      Median :24.60
##  BF 1-1B: 1   BF3:15   Mean   :152.64      Mean   :26.09
##  BF 1-2 : 1   BF4:13   3rd Qu.:191.57      3rd Qu.:37.58
##  BF 1-3A: 1   BF5:10   Max.   :770.90      Max.   :99.70
```

```
##  (Other):72   BF6: 9   NA's   :8           NA's   :8
##  Kfs..mm.per.hr...DL Sorptivity..mm.per.sqrt.hr....DL Average.Kfs..mm.per.hr.
##  Min.   :  0.30      Min.   : 1.30                     Min.   :  1.4
##  1st Qu.: 46.17      1st Qu.: 6.55                     1st Qu.: 55.4
##  Median :106.50      Median :16.80                     Median :110.1
##  Mean   :136.53      Mean   :20.03                     Mean   :149.6
##  3rd Qu.:205.28      3rd Qu.:26.82                     3rd Qu.:204.4
##  Max.   :810.00      Max.   :71.40                     Max.   :770.9
##  NA's   :10          NA's   :10                        NA's   :1
##  Average.Sorptivity..mm.per.sqrt.hr..
##  Min.   : 1.80
##  1st Qu.:10.90
##  Median :19.30
##  Mean   :23.13
##  3rd Qu.:30.60
##  Max.   :99.70
##  NA's   :1
```

```
#summary of 2017 raw dataset
summary(soil_hp_2017_raw)
```

```
##     SampleID   Site   Kfs..mm.per.hr...CL Sorptivity..mm.per.sqrt.hr....CL
##  BF 1-1A: 1   BF1:5   Min.   : 21.70      Min.   : 0.100
##  BF 1-3A: 1   BF3:8   1st Qu.: 88.65      1st Qu.: 6.675
##  BF 1-4 : 1   BF4:9   Median :158.30      Median :18.650
##  BF 1-5A: 1   BF5:8   Mean   :242.91      Mean   :22.364
##  BF 1-6 : 1   BF6:8   3rd Qu.:303.60      3rd Qu.:35.500
##  BF 3-2 : 1           Max.   :756.30      Max.   :59.900
##  (Other):32           NA's   :2           NA's   :2
##  Kfs..mm.per.hr...DL Sorptivity..mm.per.sqrt.hr....DL Average.Kfs..mm.per.hr.
##  Min.   :  27.30     Min.   : 0.600                    Min.   :  32.4
##  1st Qu.:  81.95     1st Qu.: 4.075                    1st Qu.: 101.7
##  Median : 171.05     Median :15.950                    Median : 158.3
##  Mean   : 290.38     Mean   :24.150                    Mean   : 254.6
##  3rd Qu.: 389.60     3rd Qu.:38.175                    3rd Qu.: 291.0
##  Max.   :1593.00     Max.   :82.200                    Max.   :1171.1
##  NA's   :14          NA's   :14
##  Average.Sorptivity..mm.per.sqrt.hr..     X
##  Min.   : 0.10                        Mode:logical
##  1st Qu.: 7.50                        NA's:38
##  Median :16.10
##  Mean   :21.68
##  3rd Qu.:32.27
##  Max.   :71.10
##
```

Our 2013 raw dataframe has four variables, two related to site location and two related to hydraulic property measurements. Our 2015 raw dataframe has eight variables. Two are related to site location and six are related to hydraulic property measurements. Our 2017 raw dataframe has nine variables. The first eight are the same as the 2015 raw dataframe and the last variable is an empty column. Both KFS and sorptivity are measured with two different methods and then averaged. Methods used to measure KFS and sorptivity are the differentiated linearization method (DL) and cumulative linearization method (CL). The 2013 dataframe only uses the DL method and so this method should be chosen for all datasets.

Our 2013 raw dataframe has no missing data. The 2015 raw dataframe has 38 missing values. The 2017 raw dataframe has 70 missing values. These missing values should be discarded before calculating descriptive statistics and conducting relavant tests.

The site location column in each dataframe is representative of areas with different burn severities. BF1, BF2, and BF4 are high severity burned areas, BF3 is a moderate severity burned area, and BF5 and BF6 are low severity burned areas. This column in each raw dataset is a factor with six levels. KFS and sorptivity columns in each raw dataset are of the numeric class meaning they are continuous. The structure of our data suggests that we are able to conduct a test with two factors (year and site) each with multiple levels and how they change a continuous dependent variable (KFS and sorptivity). This suggests we should conduct a two-way ANOVA. This influences our hypothesis as we now have three hypotheses for each variable: main effect of factor A, main effect of factor B, and interaction effect between A and B.

```
#structure of 2013 raw dataset
str(soil_ps_2013_raw)
```

```
## 'data.frame':    48 obs. of  6 variables:
##  $ SampleID       : Factor w/ 24 levels "Core 1-11","Core 1-12",..: 23 23 24 24 1 1 2 2 13 13 ...
##  $ Site           : Factor w/ 6 levels "BF1","BF2","BF3",..: 1 1 1 1 1 1 1 1 2 2 ...
##  $ Depth..cm.     : Factor w/ 29 levels "0--0.1","0--0.3",..: 7 25 2 20 8 25 3 21 5 23 ...
##  $ Gravel....     : num  0 1.3 0 4.7 0 2.5 0 6.7 0.2 2.2 ...
##  $ Sand....       : num  43.7 63.6 52.3 67.3 56 55.2 40.8 46.6 73.6 68.9 ...
##  $ Silt...Clay....: num  56.3 35.2 47.7 28 44 42.3 59.2 46.7 26.2 29 ...
```

```
#structure of 2015 raw dataset
str(soil_ps_2015_raw)
```

```
## 'data.frame':    180 obs. of  6 variables:
##  $ SampleID       : Factor w/ 90 levels "BF 1-10","BF 1-1A",..: 77 77 78 78 79 79 80 80 81 81 ...
##  $ Site           : Factor w/ 6 levels "BF1","BF2","BF3",..: 6 6 6 6 6 6 6 6 6 6 ...
##  $ Depth..cm.     : Factor w/ 2 levels "0--1","1--3": 1 2 1 2 1 2 1 2 1 2 ...
##  $ Gravel....     : num  17.3 16.2 0 8.8 10.3 15.4 0 0 0 0 ...
##  $ Sand....       : num  32.3 56.2 77.2 60.4 60.1 53.5 99.1 84.3 43.2 75.1 ...
##  $ Silt...Clay....: num  50.5 27.7 22.8 30.8 29.7 31.1 0.9 15.7 56.8 24.9 ...
```

```
#structure of 2017 raw dataset
str(soil_ps_2017_raw)
```

```
## 'data.frame':    100 obs. of  6 variables:
##  $ SampleID       : Factor w/ 50 levels "BF 1-10","BF 1-1A",..: 2 2 3 3 4 4 5 5 6 6 ...
##  $ Site           : Factor w/ 5 levels "BF1","BF3","BF4",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ Depth..cm.     : Factor w/ 2 levels "0--1","1--3": 1 2 1 2 1 2 1 2 1 2 ...
##  $ Gravel....     : num  4.3 8.6 0 1.4 23.7 15.2 0.2 1.1 0.5 1.1 ...
##  $ Sand....       : num  71.5 69.6 83.7 67.9 58 63.5 71.1 71.6 67.4 64.9 ...
##  $ Silt...Clay....: num  24.2 21.8 16.3 30.7 18.4 21.3 28.7 27.3 32.1 34 ...
```

```
#column names of 2013 raw dataset
colnames(soil_ps_2013_raw)
```

```
## [1] "SampleID"        "Site"            "Depth..cm."      "Gravel...."
## [5] "Sand...."        "Silt...Clay...."
```

```r
#column names of 2015 raw dataset
colnames(soil_ps_2015_raw)
```

```
## [1] "SampleID"        "Site"            "Depth..cm."      "Gravel...."
## [5] "Sand...."        "Silt...Clay...."
```

```r
#column names of 2017 raw dataset
colnames(soil_ps_2017_raw)
```

```
## [1] "SampleID"        "Site"            "Depth..cm."      "Gravel...."
## [5] "Sand...."        "Silt...Clay...."
```

```r
#summary 2013 raw dataset
summary(soil_ps_2013_raw)
```

```
##       SampleID   Site      Depth..cm.   Gravel....        Sand....
##  Core 1-11: 2   BF1:8   0.5--2.0: 6   Min.   : 0.000   Min.   :30.60
##  Core 1-12: 2   BF2:8   0--0.5  : 5   1st Qu.: 0.350   1st Qu.:48.10
##  Core 2-11: 2   BF3:8   1.5--3.0: 4   Median : 2.200   Median :55.05
##  Core 2-12: 2   BF4:8   1--2.5  : 3   Mean   : 8.069   Mean   :55.95
##  Core 3-11: 2   BF5:8   0--1    : 2   3rd Qu.:10.025   3rd Qu.:64.03
##  Core 3-12: 2   BF6:8   0--1.0  : 2   Max.   :57.700   Max.   :85.20
##  (Other)  :36           (Other) :26
##  Silt...Clay....
##  Min.   : 5.20
##  1st Qu.:27.75
##  Median :35.70
##  Mean   :35.98
##  3rd Qu.:45.65
##  Max.   :59.20
##
```

```r
#summary of 2015 raw dataset
summary(soil_ps_2015_raw)
```

```
##     SampleID    Site     Depth..cm.   Gravel....        Sand....
##  BF 1-10:  2   BF1:30   0--1:90    Min.   : 0.000   Min.   :32.30
##  BF 1-1A:  2   BF2:30   1--3:90    1st Qu.: 0.000   1st Qu.:61.10
##  BF 1-1B:  2   BF3:30              Median : 3.100   Median :67.45
##  BF 1-2 :  2   BF4:30              Mean   : 5.005   Mean   :69.09
##  BF 1-3A:  2   BF5:30              3rd Qu.: 7.850   3rd Qu.:74.95
##  BF 1-3B:  2   BF6:30              Max.   :29.200   Max.   :99.10
##  (Other):168
##  Silt...Clay....
##  Min.   : 0.90
##  1st Qu.:20.65
##  Median :26.30
##  Mean   :25.91
##  3rd Qu.:33.27
##  Max.   :59.20
##
```

```r
#summary of 2017 raw dataset
summary(soil_ps_2017_raw)
```

```
##     SampleID    Site    Depth..cm.   Gravel....        Sand....   
##  BF 1-10: 2   BF1:20   0--1:50    Min.   : 0.000   Min.   :46.60  
##  BF 1-1A: 2   BF3:20   1--3:50    1st Qu.: 1.925   1st Qu.:68.40  
##  BF 1-2 : 2   BF4:20              Median : 4.850   Median :73.30  
##  BF 1-3A: 2   BF5:20              Mean   : 7.137   Mean   :73.49  
##  BF 1-4 : 2   BF6:20              3rd Qu.:10.325   3rd Qu.:79.58  
##  BF 1-5A: 2                       Max.   :38.400   Max.   :93.20  
##  (Other):88                                                       
##  Silt...Clay....
##  Min.   : 6.30  
##  1st Qu.:14.35  
##  Median :18.75  
##  Mean   :19.36  
##  3rd Qu.:24.50  
##  Max.   :34.00  
##
```

Our 2013, 2015, and 2017 raw dataframes all have six variables, two related to site location and four related to particle size measurements (depth, gravel, sand, and silt+clay). It is uncertain the pattern at which depth was collected and for this analysis, this column will be ignored. There are no missing values in any dataframe. The site column in each raw dataframe has the locations of different burn severities. This column is a factor class with six levels. The gravel, sand, and silt+clay columns are each of numeric class. This suggests that we should conduct a two-way ANOVA for each particle size. This will impact our hypotheses similarly to our hydraulic properties.

```r
#structure of 2013 raw dataset
str(soil_bd_2013_raw)
```

```
## 'data.frame':    60 obs. of  5 variables:
##  $ SampleID   : Factor w/ 60 levels "BF1-1","BF1-10",..: 1 3 4 5 6 7 8 9 10 2 ...
##  $ Site       : Factor w/ 6 levels "BF1","BF2","BF3",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ X0.1.0.cm  : num  0.82 0.47 1.19 0.84 0.63 0.42 0.65 0.89 0.73 0.42 ...
##  $ X1.0.3.0.cm: num  1.01 0.74 1.29 0.98 1.06 0.7 1.09 1.36 1.03 0.66 ...
##  $ X3.0.6.0.cm: num  1.21 1.12 1.75 1.28 1.34 1.29 1.39 1.43 1.4 0.85 ...
```

```r
#structure of 2015 raw dataset
str(soil_bd_2015_raw)
```

```
## 'data.frame':    90 obs. of  5 variables:
##  $ SampleID   : Factor w/ 90 levels "BF1-10","BF1-1A",..: 2 3 4 5 6 7 8 9 10 11 ...
##  $ Site       : Factor w/ 6 levels "BF1","BF2","BF3",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ X0.1.0.cm  : num  0.76 1 1.05 1.54 1.78 1.27 1.51 1.73 0.61 1.26 ...
##  $ X1.0.3.0.cm: num  0.86 0.98 1.13 1.32 1.35 1.06 0.89 0.9 0.57 1.08 ...
##  $ X3.0.6.0.cm: num  1.08 1.35 1.16 1.5 1.55 1.29 1.02 1.05 1.14 1.48 ...
```

```r
#structure of 2017 raw dataset
str(soil_bd_2017_raw)
```

```
## 'data.frame':    50 obs. of  5 variables:
##  $ SampleID   : Factor w/ 50 levels "BF1-10","BF1-1A",..: 2 3 4 5 6 7 8 9 10 1 ...
##  $ Site       : Factor w/ 5 levels "BF1","BF3","BF4",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ X0.1.0.cm  : num  0.82 0.63 1.58 1.23 1.03 0.84 1.59 0.98 1.42 1.53 ...
##  $ X1.0.3.0.cm: num  0.94 1.04 1.34 1.12 1.34 1.21 1.21 1.04 1.06 1.26 ...
##  $ X3.0.6.0.cm: num  1.36 1.03 1.43 1.41 1.38 1.34 1.32 1.31 1.6 1.46 ...
```

```
#column names of 2013 raw dataset
colnames(soil_bd_2013_raw)
```

```
## [1] "SampleID"    "Site"        "X0.1.0.cm"   "X1.0.3.0.cm" "X3.0.6.0.cm"
```

```
#column names of 2015 raw dataset
colnames(soil_bd_2015_raw)
```

```
## [1] "SampleID"    "Site"        "X0.1.0.cm"   "X1.0.3.0.cm" "X3.0.6.0.cm"
```

```
#column names of 2017 raw dataset
colnames(soil_bd_2017_raw)
```

```
## [1] "SampleID"    "Site"        "X0.1.0.cm"   "X1.0.3.0.cm" "X3.0.6.0.cm"
```

```
#summary 2013 raw dataset
summary(soil_bd_2013_raw)
```

```
##     SampleID   Site      X0.1.0.cm       X1.0.3.0.cm      X3.0.6.0.cm
##  BF1-1   : 1   BF1:10   Min.   :0.1800   Min.   :0.3400   Min.   :0.850
##  BF1-10 : 1   BF2:10   1st Qu.:0.5150   1st Qu.:0.8175   1st Qu.:1.205
##  BF1-2   : 1   BF3:10   Median :0.7650   Median :1.0550   Median :1.340
##  BF1-3   : 1   BF4:10   Mean   :0.7820   Mean   :1.0018   Mean   :1.300
##  BF1-4   : 1   BF5:10   3rd Qu.:0.9825   3rd Qu.:1.2100   3rd Qu.:1.430
##  BF1-5   : 1   BF6:10   Max.   :1.7500   Max.   :1.4100   Max.   :1.750
##  (Other):54
```

```
#summary of 2015 raw dataset
summary(soil_bd_2015_raw)
```

```
##     SampleID   Site      X0.1.0.cm       X1.0.3.0.cm     X3.0.6.0.cm
##  BF1-10 : 1   BF1:15   Min.   :0.2000   Min.   :0.280   Min.   :0.600
##  BF1-1A : 1   BF2:15   1st Qu.:0.4150   1st Qu.:0.700   1st Qu.:1.110
##  BF1-1B : 1   BF3:15   Median :0.7700   Median :0.980   Median :1.285
##  BF1-2   : 1   BF4:15   Mean   :0.8576   Mean   :0.953   Mean   :1.274
##  BF1-3A : 1   BF5:15   3rd Qu.:1.2675   3rd Qu.:1.260   3rd Qu.:1.438
##  BF1-3B : 1   BF6:15   Max.   :1.9000   Max.   :1.690   Max.   :1.730
##  (Other):84
```

```
#summary of 2017 raw dataset
summary(soil_bd_2017_raw)
```

```
##     SampleID   Site      X0.1.0.cm       X1.0.3.0.cm      X3.0.6.0.cm
##  BF1-10 : 1   BF1:10   Min.   :0.2700   Min.   :0.3900   Min.   :0.690
##  BF1-1A : 1   BF3:10   1st Qu.:0.6125   1st Qu.:0.7625   1st Qu.:1.170
##  BF1-2  : 1   BF4:10   Median :0.7900   Median :1.0450   Median :1.335
##  BF1-3A : 1   BF5:10   Mean   :0.8716   Mean   :1.0182   Mean   :1.298
##  BF1-4  : 1   BF6:10   3rd Qu.:1.0925   3rd Qu.:1.2550   3rd Qu.:1.458
##  BF1-5A : 1            Max.   :1.9600   Max.   :1.6300   Max.   :1.660
##  (Other):44
```

Our 2013, 2015, and 2017 raw dataframes all have five variables, two related to site location and three related to bulk density measurements at three different depths (0-1cm, 1-3cm, and 3-6cm). There are no missing values in any dataframe. The site column in each raw dataframe has the locations of different burn severities. This column is a factor class with six levels. The 0-1cm, 1-3cm, and 3-6cm columns are each of numeric class. This suggests that we should conduct a two-way ANOVA for each bulk density depth. This will impact our hypotheses similarly to our hydraulic properties and particle sizes.

4. Data wrangling

```
#filter each hp dataset for BF1 (high severity), BF3 (moderate severity), and
#BF5 (low severity)
hp_filtered_2013 <- soil_hp_2013_raw %>%
  filter(Site == "BF1" | Site == "BF3" | Site == "BF5") %>%
  rename(Kfs..mm.per.hr...DL = Kfs..mm.per.hr...DL.method) %>%
  rename(Sorptivity..mm.per.sqrt.hr....DL =
           Sorptivity..mm.per.sqrt.hr....DL.method) %>%
  mutate(Year = "2013")

hp_filtered_2015 <- soil_hp_2015_raw %>%
  filter(Site == "BF1" | Site == "BF3" | Site == "BF5") %>%
  select(SampleID,
         Site,
         Kfs..mm.per.hr...DL,
         Sorptivity..mm.per.sqrt.hr....DL) %>%
  na.omit() %>%
  mutate(Year = "2015")

hp_filtered_2017 <- soil_hp_2017_raw %>%
  filter(Site == "BF1" | Site == "BF3" | Site == "BF5") %>%
  select(SampleID,
         Site,
         Kfs..mm.per.hr...DL,
         Sorptivity..mm.per.sqrt.hr....DL) %>%
  na.omit() %>%
  mutate(Year = "2017")

all_hp <- rbind(hp_filtered_2013, hp_filtered_2015, hp_filtered_2017)
all_hp_new <- all_hp[all_hp$Kfs..mm.per.hr...DL != 682.7, ]
all_hp_new <- all_hp_new %>%
  mutate(log.kfs = log10(Kfs..mm.per.hr...DL))
```

```
#filter each ps dataset for BF1 (high severity), BF3 (moderate severity), and
#BF5 (low severity)
ps_filtered_2013 <- soil_ps_2013_raw %>%
  filter(Site == "BF1" | Site == "BF3" | Site == "BF5") %>%
  mutate(Year = "2013")

ps_filtered_2015 <- soil_ps_2015_raw %>%
  filter(Site == "BF1" | Site == "BF3" | Site == "BF5") %>%
  mutate(Year = "2015")

ps_filtered_2017 <- soil_ps_2017_raw %>%
  filter(Site == "BF1" | Site == "BF3" | Site == "BF5") %>%
  mutate(Year = "2017")

all_ps <- rbind(ps_filtered_2013, ps_filtered_2015, ps_filtered_2017)
```

```
#filter each bd dataset for BF1 (high severity), BF3 (moderate severity), and
#BF5 (low severity)
```

```r
bd_filtered_2013 <- soil_bd_2013_raw %>%
  filter(Site == "BF1" | Site == "BF3" | Site == "BF5") %>%
  mutate(Year = "2013")

bd_filtered_2015 <- soil_bd_2015_raw %>%
  filter(Site == "BF1" | Site == "BF3" | Site == "BF5") %>%
  mutate(Year = "2015")

bd_filtered_2017 <- soil_bd_2017_raw %>%
  filter(Site == "BF1" | Site == "BF3" | Site == "BF5") %>%
  mutate(Year = "2017")

all_bd <- rbind(bd_filtered_2013, bd_filtered_2015, bd_filtered_2017)
```

5. Analysis

5.1 Question 1: Does wildfire severity influence soil field-saturated hydraulic conductivity recovery over time?

H_0: There is no difference in mean soil field-saturated hydraulic conductivity across burn severities. There is no difference in mean soil field-saturated hydraulic conductivity across years. There is no interaction between burn severity and year.

H_a: There is a difference in mean soil field-saturated hydraulic conductivity across burn severities. There is a difference in mean soil field-saturated hydraulic conductivity across years. There is an interaction between burn severity and year.

Question 2: Does wildfire severity influence soil sorptivity recovery over time?

H_0: There is no difference in mean soil sorptivity across burn severities. There is no difference in mean soil sorptivity across years. There is no interaction between burn severity and year.

H_a: There is a difference in mean soil sorptivity across burn severities. There is a difference in mean soil sorptivity across years. There is an interaction between burn severity and year.

5.1.1 Model: two-way ANOVA for hydraulic properties

```
##             Df Sum Sq Mean Sq F value Pr(>F)
## Site         2  2.500  1.2500   4.090 0.0223 *
## Year         2  1.529  0.7647   2.502 0.0915 .
## Site:Year    4  0.456  0.1139   0.373 0.8270
## Residuals   53 16.198  0.3056
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = log.kfs ~ Site * Year, data = all_hp_new)
##
## $Site
##              diff          lwr       upr     p adj
## BF3-BF1 0.3580158 -0.020228089 0.7362596 0.0670973
## BF5-BF1 0.4710122  0.008532723 0.9334917 0.0450467
## BF5-BF3 0.1129964 -0.361695812 0.5876887 0.8345280
##
## $Year
##                diff         lwr       upr     p adj
## 2015-2013 0.2793157 -0.13387029 0.6925018 0.2420983
## 2017-2013 0.4545763 -0.05054346 0.9596961 0.0858001
## 2017-2015 0.1752606 -0.25942022 0.6099414 0.5974858
##
## $`Site:Year`
##                           diff         lwr       upr     p adj
## BF3:2013-BF1:2013  0.50642528 -0.58813575 1.6009863 0.8524209
## BF5:2013-BF1:2013  0.53237904 -0.67770371 1.7424618 0.8840558
## BF1:2015-BF1:2013  0.34048010 -0.45170502 1.1326652 0.8967710
```

```
## BF3:2015-BF1:2013  0.64142570 -0.14109825 1.4239497 0.1911575
## BF5:2015-BF1:2013  0.91935990 -0.09962096 1.9383408 0.1076564
## BF1:2017-BF1:2013  0.66847431 -0.35050655 1.6874552 0.4706371
## BF3:2017-BF1:2013  0.87375537 -0.22080566 1.9683164 0.2191682
## BF5:2017-BF1:2013  0.76556277 -0.32899826 1.8601238 0.3832878
## BF5:2013-BF3:2013  0.02595376 -1.33920369 1.3911112 1.0000000
## BF1:2015-BF3:2013 -0.16594518 -1.17931178 0.8474214 0.9998176
## BF3:2015-BF3:2013  0.13500042 -0.87083175 1.1408326 0.9999596
## BF5:2015-BF3:2013  0.41293462 -0.78609691 1.6119662 0.9695926
## BF1:2017-BF3:2013  0.16204903 -1.03698250 1.3610806 0.9999574
## BF3:2017-BF3:2013  0.36733009 -0.89656012 1.6312203 0.9894470
## BF5:2017-BF3:2013  0.25913749 -1.00475272 1.5230277 0.9990459
## BF1:2015-BF5:2013 -0.19189894 -1.32906572 0.9452678 0.9997717
## BF3:2015-BF5:2013  0.10904666 -1.02141111 1.2395044 0.9999969
## BF5:2015-BF5:2013  0.38698086 -0.91835934 1.6923211 0.9880028
## BF1:2017-BF5:2013  0.13609527 -1.16924492 1.4414355 0.9999943
## BF3:2017-BF5:2013  0.34137633 -1.02378112 1.7065338 0.9961353
## BF5:2017-BF5:2013  0.23318373 -1.13197373 1.5983412 0.9997501
## BF3:2015-BF1:2015  0.30094561 -0.36327707 0.9651683 0.8663090
## BF5:2015-BF1:2015  0.57887980 -0.35233984 1.5100994 0.5436455
## BF1:2017-BF1:2015  0.32799421 -0.60322543 1.2592139 0.9652667
## BF3:2017-BF1:2015  0.53327527 -0.48009133 1.5466419 0.7428957
## BF5:2017-BF1:2015  0.42508267 -0.58828393 1.4384493 0.9087843
## BF5:2015-BF3:2015  0.27793420 -0.64508071 1.2009491 0.9867418
## BF1:2017-BF3:2015  0.02704861 -0.89596630 0.9500635 1.0000000
## BF3:2017-BF3:2015  0.23232967 -0.77350250 1.2381618 0.9977716
## BF5:2017-BF3:2015  0.12413706 -0.88169511 1.1299692 0.9999788
## BF1:2017-BF5:2015 -0.25088559 -1.38134336 0.8795722 0.9983188
## BF3:2017-BF5:2015 -0.04560453 -1.24463606 1.1534270 1.0000000
## BF5:2017-BF5:2015 -0.15379713 -1.35282866 1.0452344 0.9999715
## BF3:2017-BF1:2017  0.20528106 -0.99375047 1.4043126 0.9997458
## BF5:2017-BF1:2017  0.09708846 -1.10194308 1.2961200 0.9999992
## BF5:2017-BF3:2017 -0.10819260 -1.37208281 1.1556976 0.9999988
```

With a p-value of less than 0.05, we reject the null hypothesis and conclude site does lead to significant differences in kfs values.

```r
#sorptivity
sorptivity.anova.2way <- aov(data = all_hp,
                     Sorptivity..mm.per.sqrt.hr....DL ~ Site * Year)
summary(sorptivity.anova.2way)
```

```
##             Df Sum Sq Mean Sq F value Pr(>F)
## Site         2    911   455.6   1.588 0.2136
## Year         2   1483   741.3   2.585 0.0847 .
## Site:Year    4   1530   382.6   1.334 0.2692
## Residuals   54  15488   286.8
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
TukeyHSD(sorptivity.anova.2way)
```

```
##   Tukey multiple comparisons of means
```

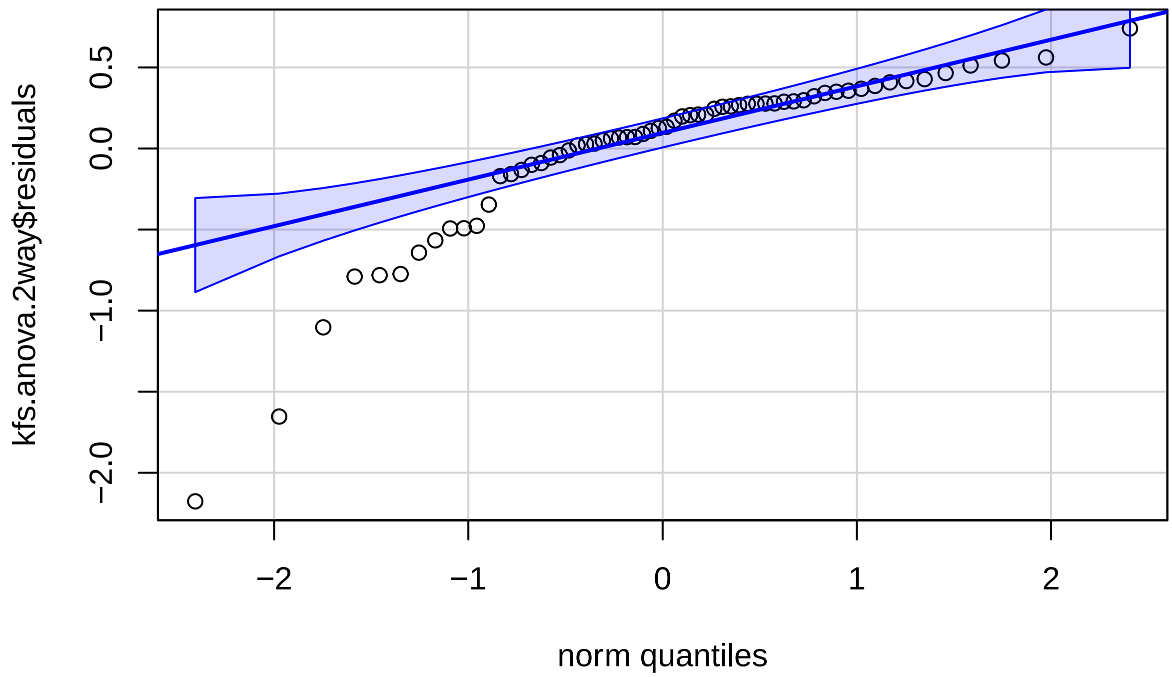
```
##     95% family-wise confidence level
##
## Fit: aov(formula = Sorptivity..mm.per.sqrt.hr....DL ~ Site * Year, data = all_hp)
##
## $Site
##              diff        lwr       upr     p adj
## BF3-BF1  8.564412  -3.016905 20.145729 0.1851916
## BF5-BF1  3.798860  -9.979425 17.577146 0.7849786
## BF5-BF3 -4.765552 -18.927872  9.396768 0.6979159
##
## $Year
##                 diff       lwr      upr     p adj
## 2015-2013 10.9732089  -1.67799 23.62441 0.1013519
## 2017-2013 11.9637141  -3.20358 27.13101 0.1482056
## 2017-2015  0.9905052 -11.97042 13.95143 0.9814798
##
## $`Site:Year`
##                           diff         lwr      upr     p adj
## BF3:2013-BF1:2013   7.21250000 -26.2935608 40.71856 0.9986582
## BF5:2013-BF1:2013  17.86250000 -19.1798439 54.90484 0.8225277
## BF1:2015-BF1:2013  17.94107143  -6.3088350 42.19098 0.3101471
## BF3:2015-BF1:2013  19.42250000  -4.5316648 43.37666 0.2027945
## BF5:2015-BF1:2013  12.28250000 -18.9099450 43.47495 0.9350756
## BF1:2017-BF1:2013   9.34250000 -21.8499450 40.53495 0.9872770
## BF3:2017-BF1:2013  32.63750000  -0.8685608 66.14356 0.0618166
## BF5:2017-BF1:2013  15.56250000 -15.6299450 46.75495 0.7941552
## BF5:2013-BF3:2013  10.65000000 -31.1393999 52.43940 0.9956346
## BF1:2015-BF3:2013  10.72857143 -20.2920131 41.74916 0.9690097
## BF3:2015-BF3:2013  12.21000000 -18.5799450 42.99995 0.9325396
## BF5:2015-BF3:2013   5.07000000 -31.6340506 41.77405 0.9999501
## BF1:2017-BF3:2013   2.13000000 -34.5740506 38.83405 0.9999999
## BF3:2017-BF3:2013  25.42500000 -13.2644664 64.11447 0.4691173
## BF5:2017-BF3:2013   8.35000000 -28.3540506 45.05405 0.9980139
## BF1:2015-BF5:2013   0.07857143 -34.7317115 34.88885 1.0000000
## BF3:2015-BF5:2013   1.56000000 -33.0449108 36.16491 1.0000000
## BF5:2015-BF5:2013  -5.58000000 -45.5383091 34.37831 0.9999458
## BF1:2017-BF5:2013  -8.52000000 -48.4783091 31.43831 0.9987464
## BF3:2017-BF5:2013  14.77500000 -27.0143999 56.56440 0.9647009
## BF5:2017-BF5:2013  -2.30000000 -42.2583091 37.65831 0.9999999
## BF3:2015-BF1:2015   1.48142857 -18.8513668 21.81422 0.9999997
## BF5:2015-BF1:2015  -5.65857143 -34.1645214 22.84738 0.9992515
## BF1:2017-BF1:2015  -8.59857143 -37.1045214 19.90738 0.9866867
## BF3:2017-BF1:2015  14.69642857 -16.3241560 45.71701 0.8360985
## BF5:2017-BF1:2015  -2.37857143 -30.8845214 26.12738 0.9999990
## BF5:2015-BF3:2015  -7.14000000 -35.3947913 21.11479 0.9958799
## BF1:2017-BF3:2015 -10.08000000 -38.3347913 18.17479 0.9627931
## BF3:2017-BF3:2015  13.21500000 -17.5749450 44.00495 0.8979844
## BF5:2017-BF3:2015  -3.86000000 -32.1147913 24.39479 0.9999542
## BF1:2017-BF5:2015  -2.94000000 -37.5449108 31.66491 0.9999989
## BF3:2017-BF5:2015  20.35500000 -16.3490506 57.05905 0.6872046
## BF5:2017-BF5:2015   3.28000000 -31.3249108 37.88491 0.9999973
## BF3:2017-BF1:2017  23.29500000 -13.4090506 59.99905 0.5166114
## BF5:2017-BF1:2017   6.22000000 -28.3849108 40.82491 0.9996384
## BF5:2017-BF3:2017 -17.07500000 -53.7790506 19.62905 0.8492601
```

With p-values greater than 0.05, accept the null hypothesis and conclude sorptivity does not differ significantly across sites or time.

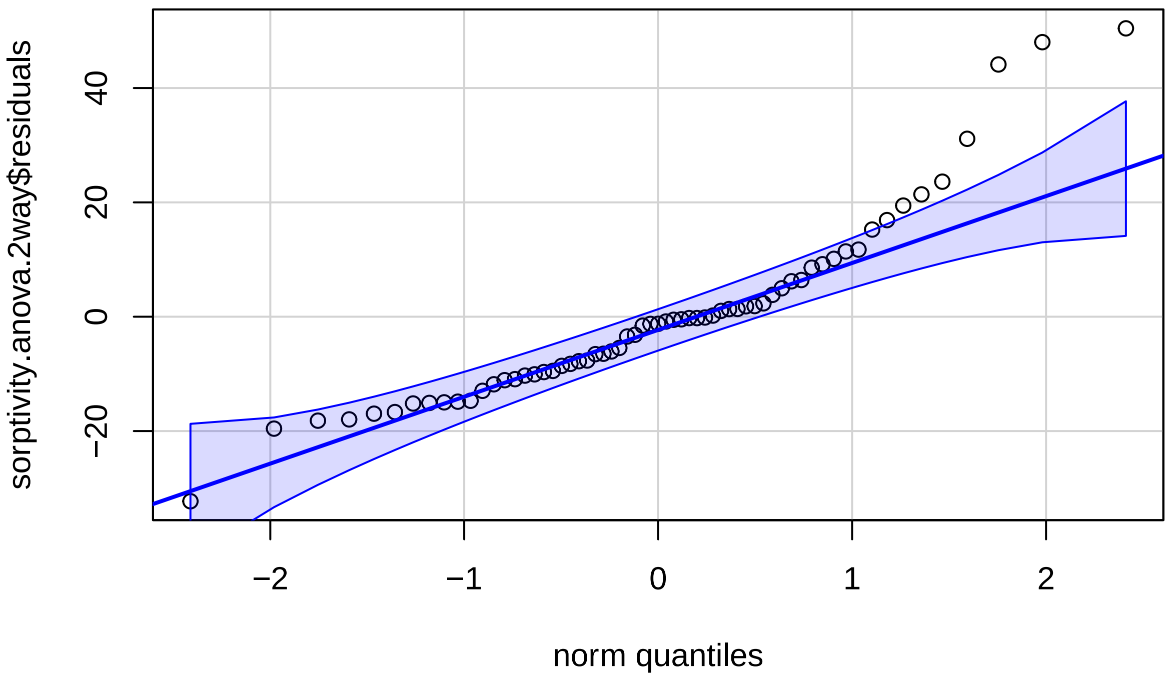
5.1.2 Assumptions

Testing for normality and variance.

```
#normality
qqPlot(kfs.anova.2way$residuals, id = F)
```




```
qqPlot(sorptivity.anova.2way$residuals, id = F)
```



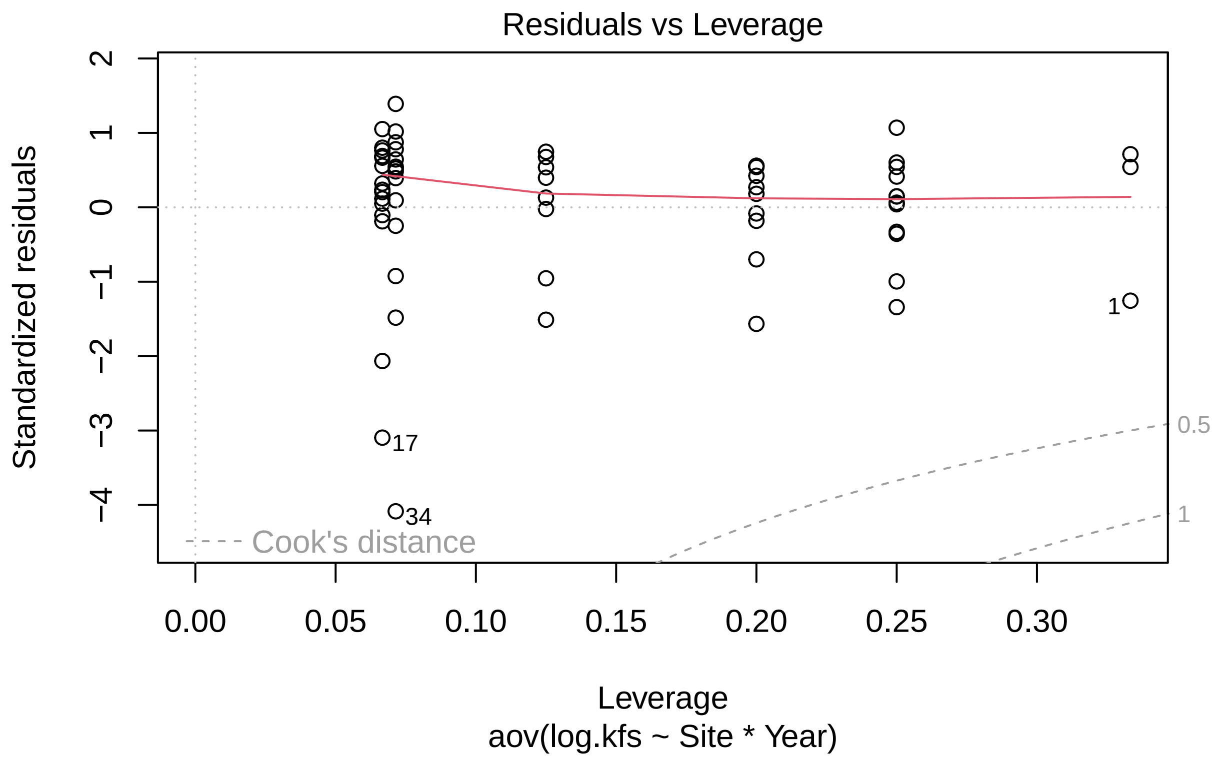

```r
#homogeneity of variances
leveneTest(kfs.anova.2way)
```

```
## Levene's Test for Homogeneity of Variance (center = median)
##       Df F value Pr(>F)
## group  8  0.3904  0.921
##       53
```

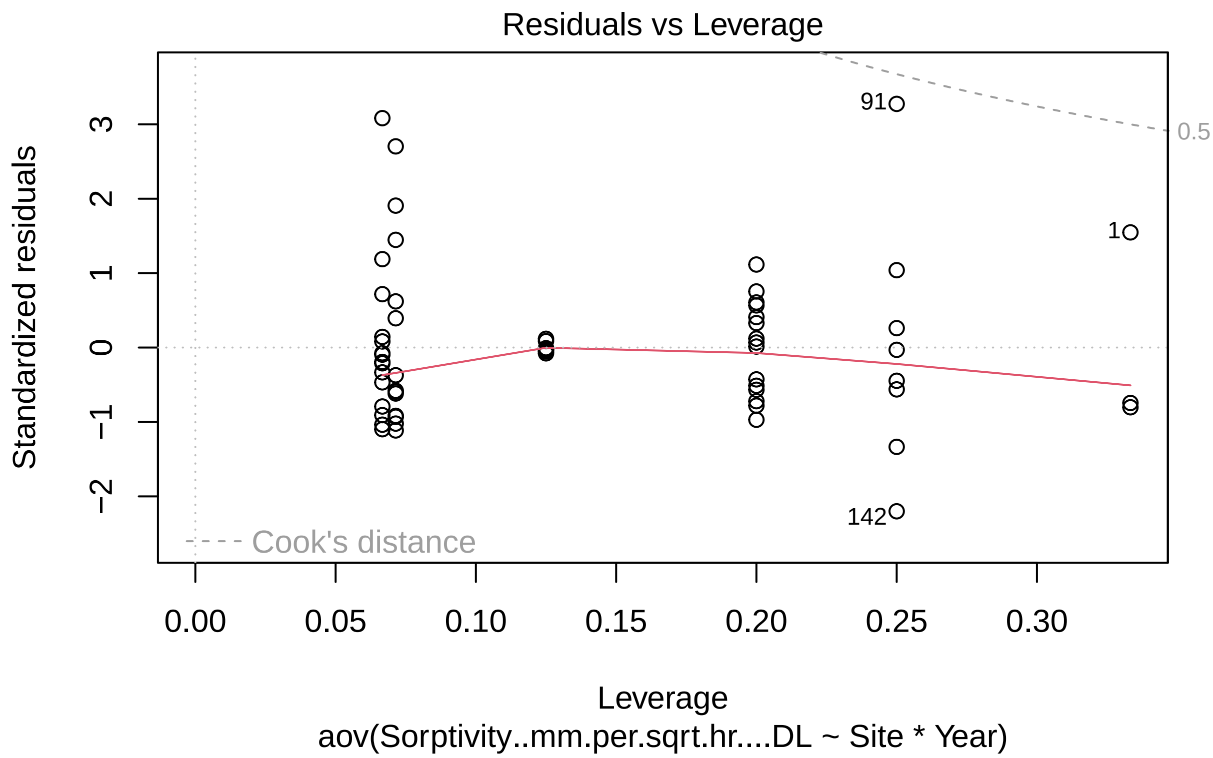
```r
#original value after outlier removal p = 0.02207. data was then log transformed
leveneTest(sorptivity.anova.2way)
```

```
## Levene's Test for Homogeneity of Variance (center = median)
##       Df F value Pr(>F)
## group  8  1.6037 0.1455
##       54
```

```r
#outliers
plot(kfs.anova.2way, which = 5)
```



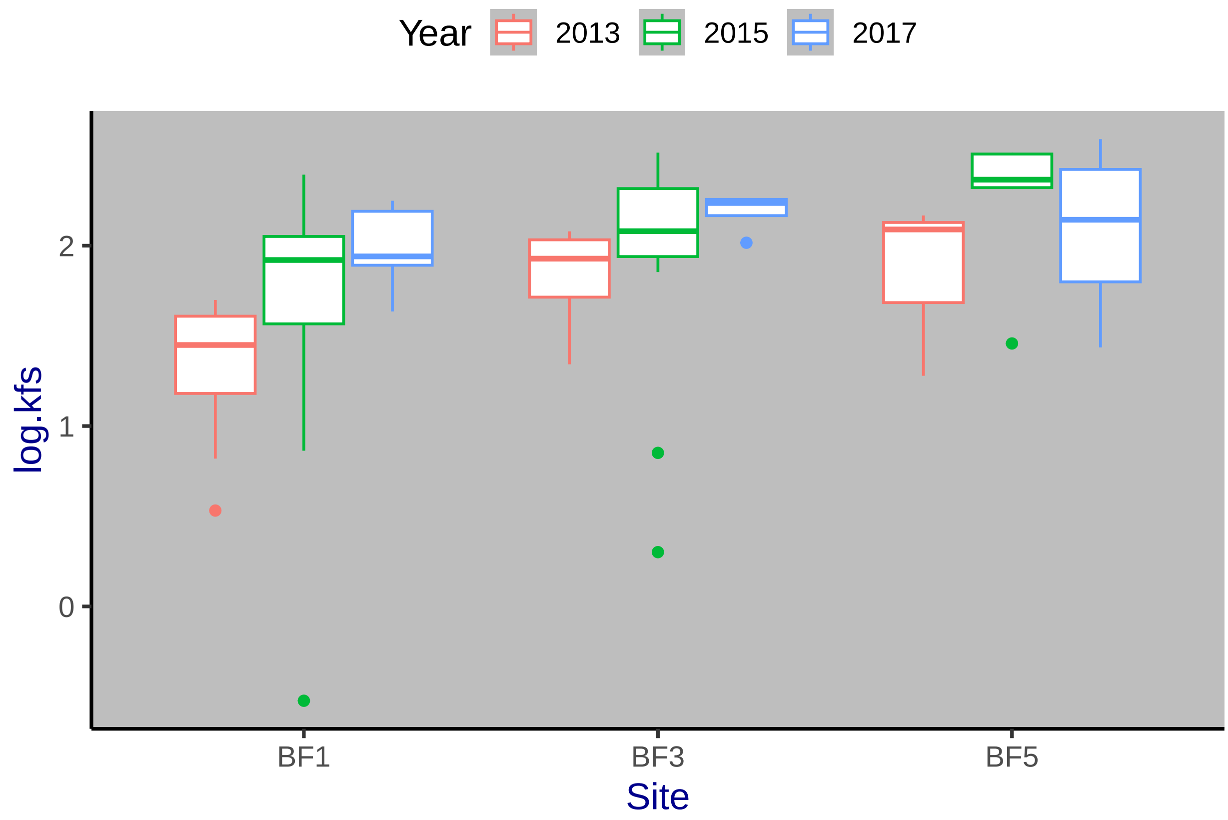

```
#observation 310 was an outlier. it has been removed.
plot(sorptivity.anova.2way, which = 5)
```



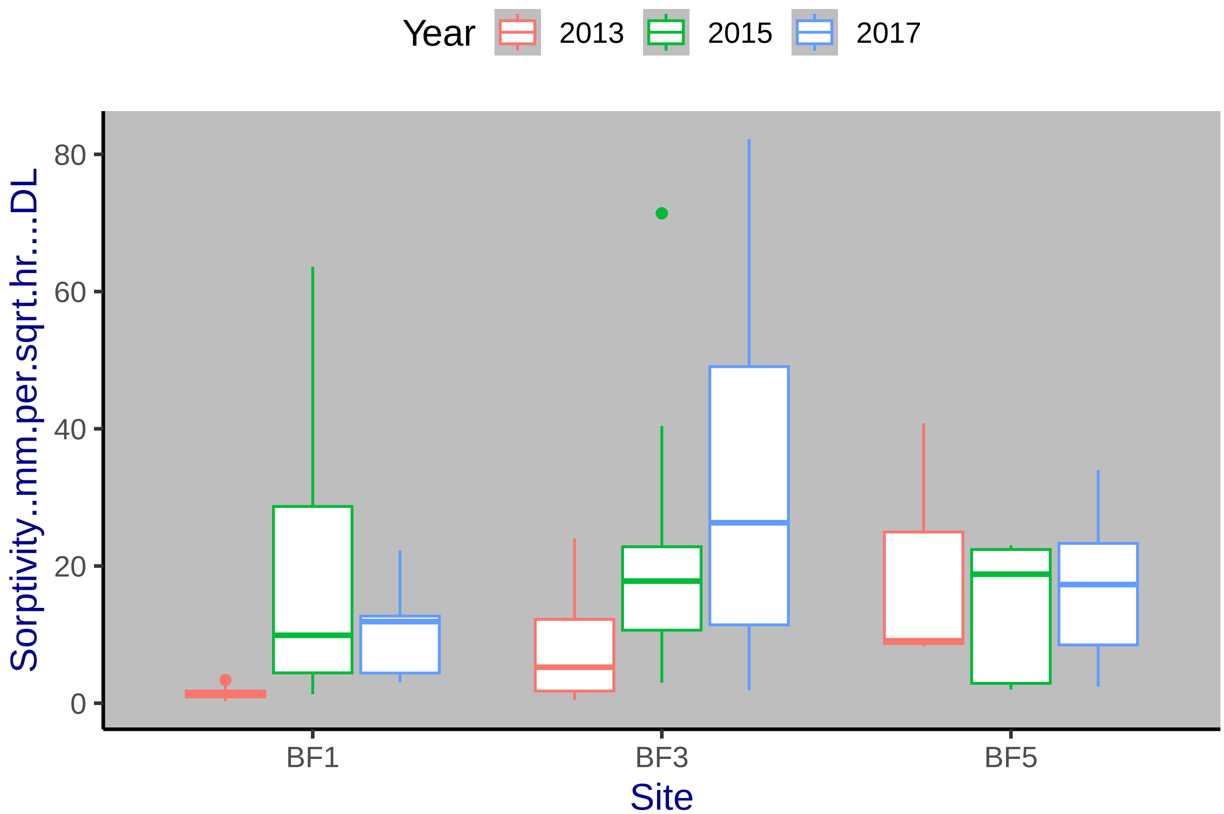
5.1.3 Residuals

5.1.4 Kfs and sorptivity by site and year

```
# plots
print(kfs.anova.plot)
```




```r
print(sorptivity.anova.plot)
```




```r
#sorptivity.anova.plot.alt <- ggplot(all_hp,
#aes(y = Sorptivity..mm.per.sqrt.hr....DL, x = Year, color = Site)) +
#  geom_boxplot()

#print(sorptivity.anova.plot.alt)
```

5.2 Question 3: Does wildfire severity influence soil gravel proportion over time?

H_0: There is no difference in mean soil gravel proportion across burn severities. There is no difference in mean soil gravel proportion across years. There is no interaction between burn severity and year.

H_a: There is a difference in mean soil gravel proportion across burn severities. There is a difference in mean soil gravel proportion across years. There is an interaction between burn severity and year.

Question 4: Does wildfire severity influence soil sand proportion over time?

H_0: There is no difference in mean soil sand proportion across burn severities. There is no difference in mean soil sand proportion across years. There is no interaction between burn severity and year.

H_a: There is a difference in mean soil sand proportion across burn severities. There is a difference in mean soil sand proportion across years. There is an interaction between burn severity and year.

Question 5: Does wildfire severity influence soil silt+clay proportion over time?

H_0: There is no difference in mean soil silt+clay proportion across burn severities. There is no difference in mean soil silt+clay proportion across years. There is no interaction between burn severity and year.

H_a: There is a difference in mean soil silt+clay proportion across burn severities. There is a difference in mean soil silt+clay proportion across years. There is an interaction between burn severity and year.

5.2.1 Model: two-way ANOVA for particle size

```
#gravel
ps.g.anova.2way <- aov(data = all_ps, Gravel.... ~ Site * Year)
summary(ps.g.anova.2way)
```

```
##               Df Sum Sq Mean Sq F value   Pr(>F)    
## Site           2   1360   679.8  13.706 3.11e-06 ***
## Year           2    473   236.3   4.764  0.00974 ** 
## Site:Year      4   2592   648.0  13.064 2.89e-09 ***
## Residuals    165   8184    49.6                     
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
TukeyHSD(ps.g.anova.2way)
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
## 
## Fit: aov(formula = Gravel.... ~ Site * Year, data = all_ps)
## 
## $Site
##              diff        lwr        upr     p adj
## BF3-BF1  3.501724  0.4087691  6.5946792 0.0221306
## BF5-BF1 -3.344828 -6.4377827 -0.2518725 0.0305798
## BF5-BF3 -6.846552 -9.9395068 -3.7535966 0.0000015
## 
## $Year
##                 diff       lwr         upr     p adj
## 2015-2013 -4.9911111 -8.817580 -1.16464244 0.0067158
## 2017-2013 -4.0583333 -8.081157 -0.03550955 0.0474835
## 2017-2015  0.9327778 -1.843234  3.70878992 0.7068142
## 
## $`Site:Year`
##                           diff         lwr         upr     p adj
## BF3:2013-BF1:2013  23.8500000  12.7810993  34.9189007 0.0000000
## BF5:2013-BF1:2013  -1.5500000 -12.6189007   9.5189007 0.9999604
## BF1:2015-BF1:2013   3.5266667  -5.2822127  12.3355461 0.9416351
## BF3:2015-BF1:2013   5.0933333  -3.7155461  13.9022127 0.6705420
## BF5:2015-BF1:2013  -1.2933333 -10.1022127   7.5155461 0.9999431
## BF1:2017-BF1:2013   4.5700000  -4.6909067  13.8309067 0.8292802
## BF3:2017-BF1:2013   2.8350000  -6.4259067  12.0959067 0.9886554
## BF5:2017-BF1:2013   2.7200000  -6.5409067  11.9809067 0.9913629
## BF5:2013-BF3:2013 -25.4000000 -36.4689007 -14.3310993 0.0000000
```

```
## BF1:2015-BF3:2013 -20.3233333 -29.1322127 -11.5144539 0.0000000
## BF3:2015-BF3:2013 -18.7566667 -27.5655461  -9.9477873 0.0000000
## BF5:2015-BF3:2013 -25.1433333 -33.9522127 -16.3344539 0.0000000
## BF1:2017-BF3:2013 -19.2800000 -28.5409067 -10.0190933 0.0000000
## BF3:2017-BF3:2013 -21.0150000 -30.2759067 -11.7540933 0.0000000
## BF5:2017-BF3:2013 -21.1300000 -30.3909067 -11.8690933 0.0000000
## BF1:2015-BF5:2013   5.0766667  -3.7322127  13.8855461 0.6744909
## BF3:2015-BF5:2013   6.6433333  -2.1655461  15.4522127 0.3072109
## BF5:2015-BF5:2013   0.2566667  -8.5522127   9.0655461 1.0000000
## BF1:2017-BF5:2013   6.1200000  -3.1409067  15.3809067 0.4923832
## BF3:2017-BF5:2013   4.3850000  -4.8759067  13.6459067 0.8595174
## BF5:2017-BF5:2013   4.2700000  -4.9909067  13.5309067 0.8766551
## BF3:2015-BF1:2015   1.5666667  -4.1492891   7.2826224 0.9945738
## BF5:2015-BF1:2015  -4.8200000 -10.5359557   0.8959557 0.1742580
## BF1:2017-BF1:2015   1.0433333  -5.3472995   7.4339661 0.9998726
## BF3:2017-BF1:2015  -0.6916667  -7.0822995   5.6989661 0.9999946
## BF5:2017-BF1:2015  -0.8066667  -7.1972995   5.5839661 0.9999822
## BF5:2015-BF3:2015  -6.3866667 -12.1026224  -0.6707109 0.0163158
## BF1:2017-BF3:2015  -0.5233333  -6.9139661   5.8672995 0.9999994
## BF3:2017-BF3:2015  -2.2583333  -8.6489661   4.1322995 0.9719042
## BF5:2017-BF3:2015  -2.3733333  -8.7639661   4.0172995 0.9621499
## BF1:2017-BF5:2015   5.8633333  -0.5272995  12.2539661 0.1001841
## BF3:2017-BF5:2015   4.1283333  -2.2622995  10.5189661 0.5244334
## BF5:2017-BF5:2015   4.0133333  -2.3772995  10.4039661 0.5635758
## BF3:2017-BF1:2017  -1.7350000  -8.7355875   5.2655875 0.9972939
## BF5:2017-BF1:2017  -1.8500000  -8.8505875   5.1505875 0.9957732
## BF5:2017-BF3:2017  -0.1150000  -7.1155875   6.8855875 1.0000000
```

```r
ps.g.interaction <- with(all_ps, interaction(Site, Year))
ps.g.anova.2way2 <- aov(data = all_ps, Gravel.... ~ ps.g.interaction)
ps.g.groups <- HSD.test(ps.g.anova.2way2, "ps.g.interaction", group = TRUE)
ps.g.groups
```

```
## $statistics
##    MSerror  Df     Mean       CV
##   49.59779 165 5.352299 131.5803
##
## $parameters
##    test           name.t ntr StudentizedRange alpha
##   Tukey ps.g.interaction   9         4.445476  0.05
##
## $means
##           Gravel....       std  r       se Min  Max    Q25   Q50    Q75
## BF1.2013  1.9000000  2.564594  8 2.489924 0.0  6.7  0.000  0.65  3.050
## BF1.2015  5.4266667  7.678269 30 1.285791 0.0 26.8  0.575  3.10  5.550
## BF1.2017  6.4700000  6.463183 20 1.574767 0.0 23.7  1.325  3.85  9.700
## BF3.2013 25.7500000 21.767735  8 2.489924 0.8 57.7 10.325 24.40 34.950
## BF3.2015  6.9933333  7.034052 30 1.285791 0.0 29.2  0.850  5.10 12.000
## BF3.2017  4.7350000  4.672346 20 1.574767 0.0 15.1  0.400  2.45  8.850
## BF5.2013  0.3500000  0.600000  8 2.489924 0.0  1.5  0.000  0.00  0.425
## BF5.2015  0.6066667  1.220495 30 1.285791 0.0  4.3  0.000  0.00  0.275
## BF5.2017  4.6200000  4.712760 20 1.574767 0.0 14.1  0.575  2.60  8.625
##
## $comparison
```

```
## NULL
##
## $groups
##           Gravel.... groups
## BF3.2013 25.7500000      a
## BF3.2015  6.9933333      b
## BF1.2017  6.4700000     bc
## BF1.2015  5.4266667     bc
## BF3.2017  4.7350000     bc
## BF5.2017  4.6200000     bc
## BF1.2013  1.9000000     bc
## BF5.2015  0.6066667      c
## BF5.2013  0.3500000      c
##
## attr(,"class")
## [1] "group"
```

```
ps.g.anova.plot <- ggplot(all_ps, aes(y = Gravel...., x = Site, color = Year)) +
  geom_boxplot()
```

With p-values less than 0.05 across the board, we reject the null hypothesis and conclude that particle size does vary across sites and time.

```
#sand
ps.s.anova.2way <- aov(data = all_ps, Sand.... ~ Site * Year)
summary(ps.s.anova.2way)
```

```
##              Df Sum Sq Mean Sq F value   Pr(>F)    
## Site          2   5383    2692  26.711 8.92e-11 ***
## Year          2   6694    3347  33.212 7.56e-13 ***
## Site:Year     4    550     138   1.365    0.248    
## Residuals   165  16627     101                     
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
TukeyHSD(ps.s.anova.2way)
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = Sand.... ~ Site * Year, data = all_ps)
##
## $Site
##              diff       lwr       upr     p adj
## BF3-BF1  2.912069 -1.496600  7.320737 0.2649932
## BF5-BF1 12.982759  8.574090 17.391427 0.0000000
## BF5-BF3 10.070690  5.662021 14.479358 0.0000007
##
## $Year
##                diff       lwr      upr     p adj
## 2015-2013 13.173056  7.718844 18.62727 0.0000002
## 2017-2013 19.707500 13.973406 25.44159 0.0000000
```

```
## 2017-2015  6.534444  2.577543 10.49135 0.0004005
##
## $`Site:Year`
##                          diff         lwr       upr     p adj
## BF3:2013-BF1:2013 -2.0625000 -17.8400049 13.715005 0.9999767
## BF5:2013-BF1:2013 12.2875000  -3.4900049 28.065005 0.2655542
## BF1:2015-BF1:2013 11.6991667  -0.8569255 24.255259 0.0893615
## BF3:2015-BF1:2013 12.7858333   0.2297411 25.341926 0.0424024
## BF5:2015-BF1:2013 25.2591667  12.7030745 37.815259 0.0000001
## BF1:2017-BF1:2013 16.4375000   3.2370923 29.637908 0.0041136
## BF3:2017-BF1:2013 24.0775000  10.8770923 37.277908 0.0000016
## BF5:2017-BF1:2013 28.8325000  15.6320923 42.032908 0.0000000
## BF5:2013-BF3:2013 14.3500000  -1.4275049 30.127505 0.1066724
## BF1:2015-BF3:2013 13.7616667   1.2055745 26.317759 0.0202155
## BF3:2015-BF3:2013 14.8483333   2.2922411 27.404426 0.0082378
## BF5:2015-BF3:2013 27.3216667  14.7655745 39.877759 0.0000000
## BF1:2017-BF3:2013 18.5000000   5.2995923 31.700408 0.0006284
## BF3:2017-BF3:2013 26.1400000  12.9395923 39.340408 0.0000001
## BF5:2017-BF3:2013 30.8950000  17.6945923 44.095408 0.0000000
## BF1:2015-BF5:2013 -0.5883333 -13.1444255 11.967759 1.0000000
## BF3:2015-BF5:2013  0.4983333 -12.0577589 13.054426 1.0000000
## BF5:2015-BF5:2013 12.9716667   0.4155745 25.527759 0.0370089
## BF1:2017-BF5:2013  4.1500000  -9.0504077 17.350408 0.9865150
## BF3:2017-BF5:2013 11.7900000  -1.4104077 24.990408 0.1210520
## BF5:2017-BF5:2013 16.5450000   3.3445923 29.745408 0.0037489
## BF3:2015-BF1:2015  1.0866667  -7.0608018  9.234135 0.9999728
## BF5:2015-BF1:2015 13.5600000   5.4125315 21.707468 0.0000176
## BF1:2017-BF1:2015  4.7383333  -4.3708134 13.847480 0.7840575
## BF3:2017-BF1:2015 12.3783333   3.2691866 21.487480 0.0010696
## BF5:2017-BF1:2015 17.1333333   8.0241866 26.242480 0.0000007
## BF5:2015-BF3:2015 12.4733333   4.3258648 20.620802 0.0001147
## BF1:2017-BF3:2015  3.6516667  -5.4574800 12.760813 0.9412039
## BF3:2017-BF3:2015 11.2916667   2.1825200 20.400813 0.0043848
## BF5:2017-BF3:2015 16.0466667   6.9375200 25.155813 0.0000042
## BF1:2017-BF5:2015 -8.8216667 -17.9308134  0.287480 0.0658473
## BF3:2017-BF5:2015 -1.1816667 -10.2908134  7.927480 0.9999780
## BF5:2017-BF5:2015  3.5733333  -5.5358134 12.682480 0.9479869
## BF3:2017-BF1:2017  7.6400000  -2.3385702 17.618570 0.2873561
## BF5:2017-BF1:2017 12.3950000   2.4164298 22.373570 0.0042592
## BF5:2017-BF3:2017  4.7550000  -5.2235702 14.733570 0.8551468
```

```r
ps.s.interaction <- with(all_ps, interaction(Site, Year))
ps.s.anova.2way2 <- aov(data = all_ps, Sand.... ~ ps.s.interaction)
ps.s.groups <- HSD.test(ps.s.anova.2way2, "ps.s.interaction", group = TRUE)
ps.s.groups
```

```
## $statistics
##    MSerror  Df     Mean       CV
##   100.7697 165 70.20517 14.29868
##
## $parameters
##    test           name.t ntr StudentizedRange alpha
##   Tukey ps.s.interaction   9         4.445476  0.05
##
```

```
## $means
##          Sand....       std  r       se  Min  Max    Q25   Q50    Q75
## BF1.2013 53.18750  9.313498  8 3.549114 40.8 67.3 45.875 53.75 57.900
## BF1.2015 64.88667  9.365702 30 1.832755 48.1 89.3 58.225 64.80 71.350
## BF1.2017 69.62500  7.258307 20 2.244657 54.8 83.7 66.775 70.05 72.050
## BF3.2013 51.12500 11.730150  8 3.549114 35.9 70.3 43.100 52.45 55.725
## BF3.2015 65.97333 11.776450 30 1.832755 43.3 98.3 59.550 65.45 71.575
## BF3.2017 77.26500  4.358811 20 2.244657 71.5 87.1 73.350 77.45 79.575
## BF5.2013 65.47500 14.151300  8 3.549114 46.8 85.2 52.425 69.05 74.400
## BF5.2015 78.44667 13.479480 30 1.832755 49.4 98.8 70.175 76.55 90.925
## BF5.2017 82.02000  4.909883 20 2.244657 73.7 93.2 78.850 81.50 85.075
##
## $comparison
## NULL
##
## $groups
##          Sand.... groups
## BF5.2017 82.02000      a
## BF5.2015 78.44667     ab
## BF3.2017 77.26500     ab
## BF1.2017 69.62500     bc
## BF3.2015 65.97333      c
## BF5.2013 65.47500     cd
## BF1.2015 64.88667     cd
## BF1.2013 53.18750      d
## BF3.2013 51.12500      d
##
## attr(,"class")
## [1] "group"
```

```r
ps.s.anova.plot <- ggplot(all_ps, aes(y = Sand...., x = Site, color = Year)) +
  geom_boxplot()
```

With p-values less than 0.05 for Site and Year, we reject the null hypothesis and conclude that particle size does vary across sites and time. The interaction effects are insignificant.

```r
#silt+clay
ps.sc.anova.2way <- aov(data = all_ps, Silt...Clay.... ~ Site * Year)
summary(ps.sc.anova.2way)
```

```
##              Df Sum Sq Mean Sq F value   Pr(>F)
## Site          2   2783  1391.5  15.730 5.59e-07 ***
## Year          2   4600  2299.8  25.999 1.53e-10 ***
## Site:Year     4   1429   357.3   4.039  0.00376 **
## Residuals   165  14595    88.5
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
TukeyHSD(ps.sc.anova.2way)
```

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

```
##
## Fit: aov(formula = Silt...Clay.... ~ Site * Year, data = all_ps)
##
## $Site
##              diff        lwr        upr     p adj
## BF3-BF1 -6.408621 -10.539183 -2.2780582 0.0009519
## BF5-BF1 -9.620690 -13.751252 -5.4901272 0.0000004
## BF5-BF3 -3.212069  -7.342631  0.9184935 0.1601348
##
## $Year
##                 diff       lwr        upr     p adj
## 2015-2013  -8.186667 -13.29682  -3.076516 0.0006175
## 2017-2013 -15.666667 -21.03905 -10.294288 0.0000000
## 2017-2015  -7.480000 -11.18729  -3.772707 0.0000119
##
## $`Site:Year`
##                          diff        lwr         upr     p adj
## BF3:2013-BF1:2013 -21.787500 -36.569734  -7.0052659 0.0002464
## BF5:2013-BF1:2013 -10.737500 -25.519734   4.0447341 0.3583112
## BF1:2015-BF1:2013 -15.248333 -27.012367  -3.4843000 0.0022793
## BF3:2015-BF1:2013 -17.888333 -29.652367  -6.1243000 0.0001320
## BF5:2015-BF1:2013 -23.948333 -35.712367 -12.1843000 0.0000001
## BF1:2017-BF1:2013 -21.020000 -33.387704  -8.6522957 0.0000106
## BF3:2017-BF1:2013 -26.930000 -39.297704 -14.5622957 0.0000000
## BF5:2017-BF1:2013 -31.575000 -43.942704 -19.2072957 0.0000000
## BF5:2013-BF3:2013  11.050000  -3.732234  25.8322341 0.3190499
## BF1:2015-BF3:2013   6.539167  -5.224867  18.3032000 0.7162754
## BF3:2015-BF3:2013   3.899167  -7.864867  15.6632000 0.9811091
## BF5:2015-BF3:2013  -2.160833 -13.924867   9.6032000 0.9996914
## BF1:2017-BF3:2013   0.767500 -11.600204  13.1352043 0.9999999
## BF3:2017-BF3:2013  -5.142500 -17.510204   7.2252043 0.9280346
## BF5:2017-BF3:2013  -9.787500 -22.155204   2.5802043 0.2457013
## BF1:2015-BF5:2013  -4.510833 -16.274867   7.2532000 0.9543661
## BF3:2015-BF5:2013  -7.150833 -18.914867   4.6132000 0.6073436
## BF5:2015-BF5:2013 -13.210833 -24.974867  -1.4468000 0.0154041
## BF1:2017-BF5:2013 -10.282500 -22.650204   2.0852043 0.1890986
## BF3:2017-BF5:2013 -16.192500 -28.560204  -3.8247957 0.0019519
## BF5:2017-BF5:2013 -20.837500 -33.205204  -8.4697957 0.0000131
## BF3:2015-BF1:2015  -2.640000 -10.273513   4.9935128 0.9753801
## BF5:2015-BF1:2015  -8.700000 -16.333513  -1.0664872 0.0129669
## BF1:2017-BF1:2015  -5.771667 -14.306193   2.7628601 0.4595241
## BF3:2017-BF1:2015 -11.681667 -20.216193  -3.1471399 0.0009468
## BF5:2017-BF1:2015 -16.326667 -24.861193  -7.7921399 0.0000004
## BF5:2015-BF3:2015  -6.060000 -13.693513   1.5735128 0.2418836
## BF1:2017-BF3:2015  -3.131667 -11.666193   5.4028601 0.9647541
## BF3:2017-BF3:2015  -9.041667 -17.576193  -0.5071399 0.0288834
## BF5:2017-BF3:2015 -13.686667 -22.221193  -5.1521399 0.0000419
## BF1:2017-BF5:2015   2.928333  -5.606193  11.4628601 0.9765546
## BF3:2017-BF5:2015  -2.981667 -11.516193   5.5528601 0.9737988
## BF5:2017-BF5:2015  -7.626667 -16.161193   0.9078601 0.1206182
## BF3:2017-BF1:2017  -5.910000 -15.259106   3.4391057 0.5545519
## BF5:2017-BF1:2017 -10.555000 -19.904106  -1.2058943 0.0144858
## BF5:2017-BF3:2017  -4.645000 -13.994106   4.7041057 0.8238710
```

```r
ps.sc.interaction <- with(all_ps, interaction(Site, Year))
ps.sc.anova.2way2 <- aov(data = all_ps, Silt...Clay.... ~ ps.sc.interaction)
ps.sc.groups <- HSD.test(ps.sc.anova.2way2, "ps.sc.interaction", group = TRUE)
ps.sc.groups
```

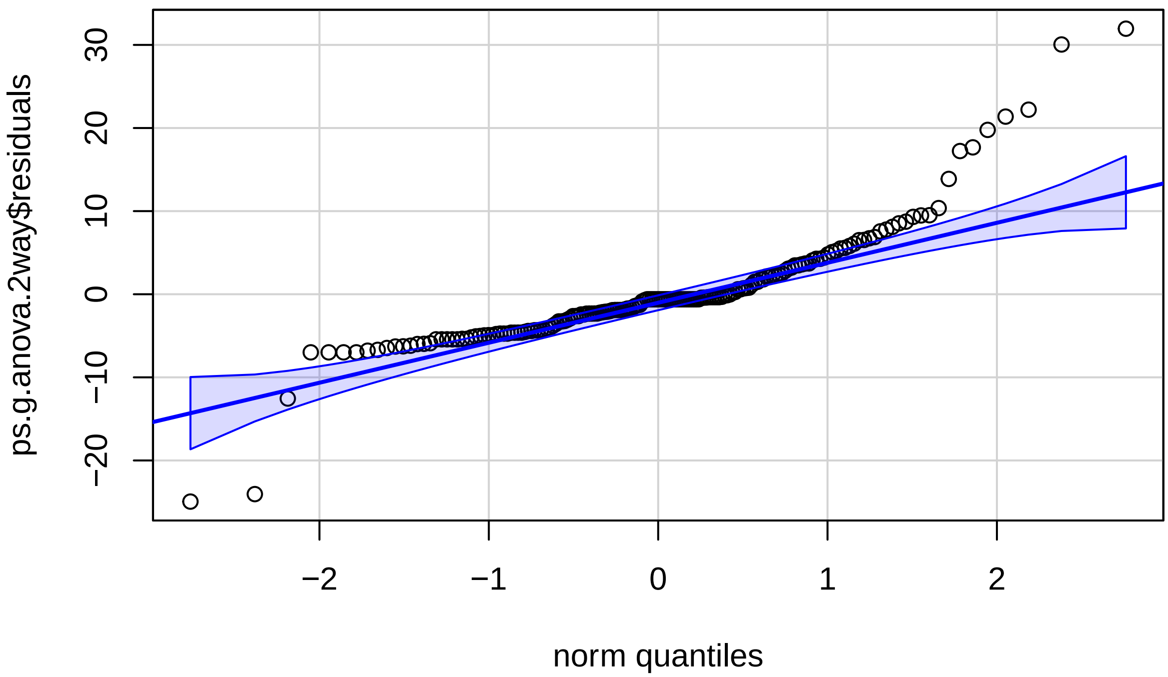
```
## $statistics
##    MSerror  Df     Mean       CV
##   88.45726 165 24.44655 38.47239
##
## $parameters
##    test            name.t ntr StudentizedRange alpha
##   Tukey ps.sc.interaction   9         4.445476  0.05
##
## $means
##          Silt...Clay....       std  r       se  Min  Max    Q25   Q50    Q75
## BF1.2013        44.92500 10.231569  8 3.325231 28.0 59.2 40.525 45.35 49.850
## BF1.2015        29.67667  8.921948 30 1.717142  9.6 44.1 23.425 29.00 37.800
## BF1.2017        23.90500  5.928741 20 2.103060 14.2 34.0 18.300 23.80 28.025
## BF3.2013        23.13750 11.925595  8 3.325231  5.2 36.2 16.325 24.50 33.500
## BF3.2015        27.03667  9.622799 30 1.717142  1.7 44.2 23.075 26.55 33.400
## BF3.2017        17.99500  3.951346 20 2.103060 10.4 24.5 16.125 18.25 20.500
## BF5.2013        34.18750 14.102425  8 3.325231 14.8 53.0 24.550 30.95 46.750
## BF5.2015        20.97667 13.382662 30 1.717142  1.2 50.6  8.200 22.75 29.350
## BF5.2017        13.35000  4.122531 20 2.103060  6.8 21.9 10.125 13.40 15.625
##
## $comparison
## NULL
##
## $groups
##          Silt...Clay.... groups
## BF1.2013        44.92500      a
## BF5.2013        34.18750     ab
## BF1.2015        29.67667      b
## BF3.2015        27.03667     bc
## BF1.2017        23.90500    bcd
## BF3.2013        23.13750   bcde
## BF5.2015        20.97667    cde
## BF3.2017        17.99500     de
## BF5.2017        13.35000      e
##
## attr(,"class")
## [1] "group"
```

```r
ps.sc.anova.plot <- ggplot(all_ps, aes(y = Silt...Clay....,
                                       x = Site, color = Year)) +
  geom_boxplot()
```

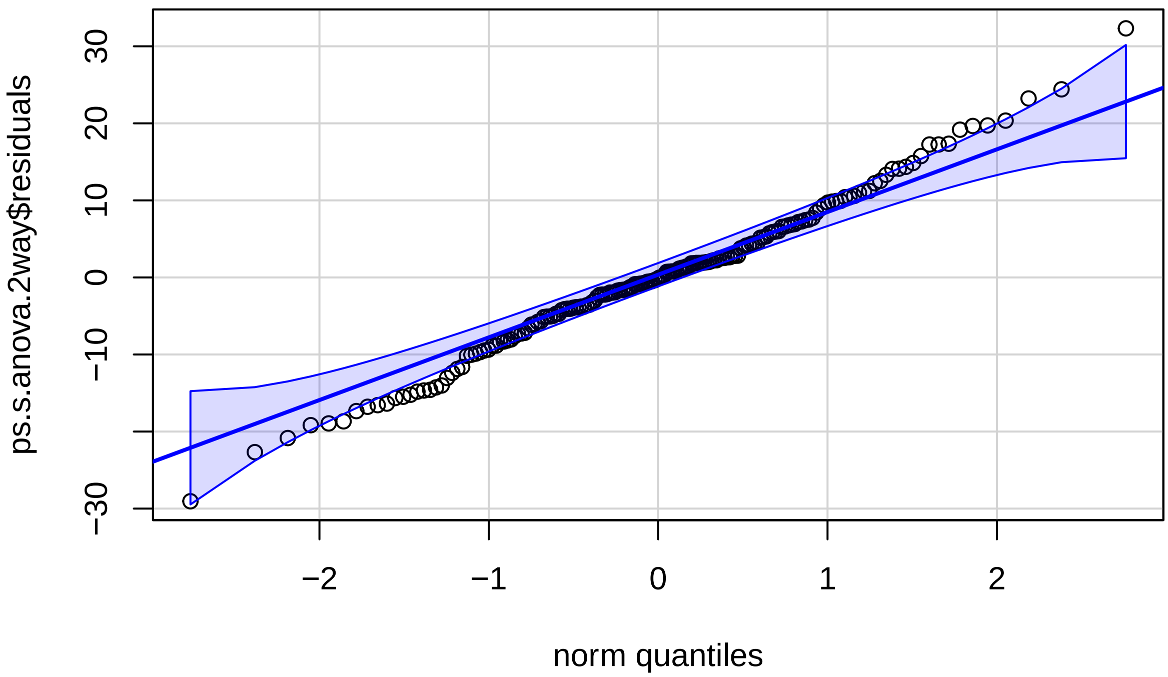
With p-values less than 0.05 across the board, we reject the null hypothesis and conclude that particle size does vary across sites and time.

5.2.1 Assumptions

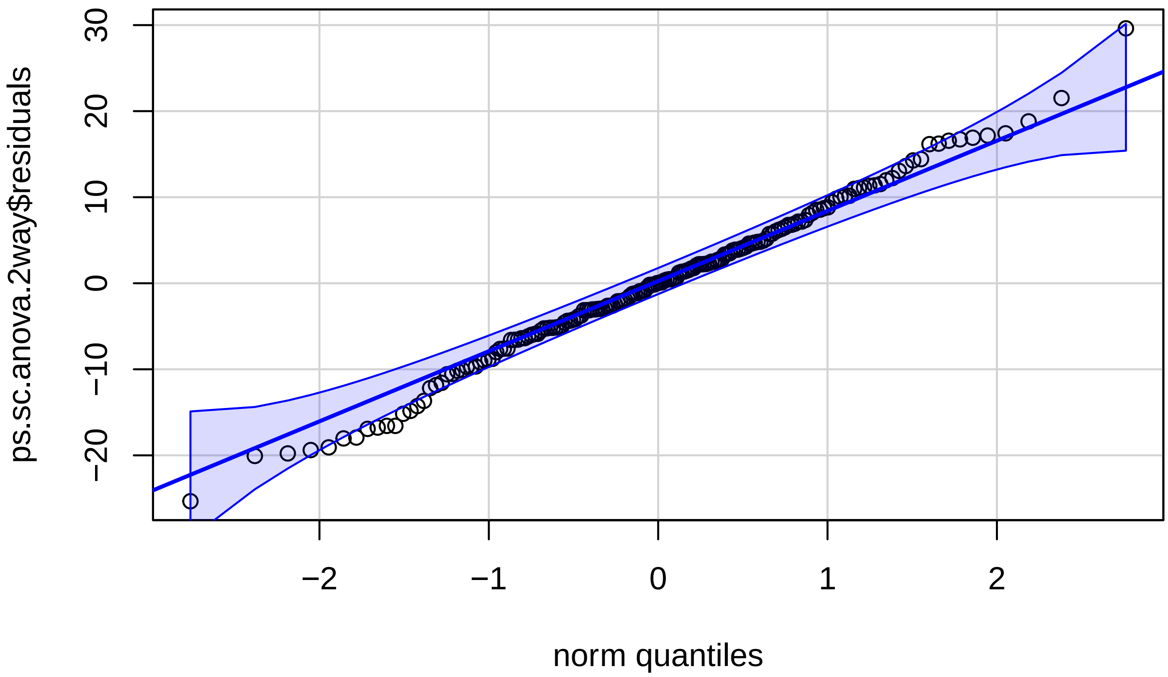
```
#normality
qqPlot(ps.g.anova.2way$residuals, id = F)
```




```
qqPlot(ps.s.anova.2way$residuals, id = F)
```




```r
qqPlot(ps.sc.anova.2way$residuals, id = F)
```




```r
#homogeneity of variances
leveneTest(ps.g.anova.2way)
```

```
## Levene's Test for Homogeneity of Variance (center = median)
##        Df F value    Pr(>F)
## group   8  9.5992 7.082e-11 ***
##       165
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

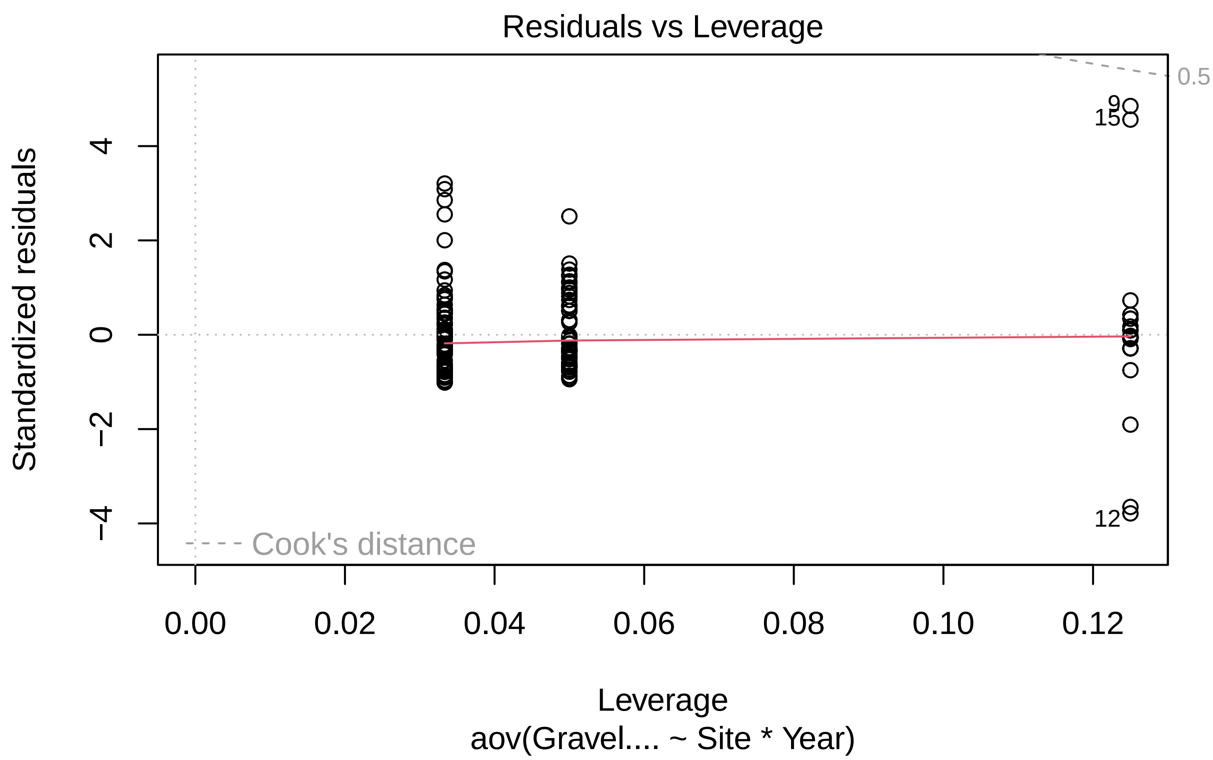
```r
#p-value = 7.0882 * 10^-11. transformations did not work.
#using original, untrasnformed data
leveneTest(ps.s.anova.2way)
```

```
## Levene's Test for Homogeneity of Variance (center = median)
##        Df F value    Pr(>F)
## group   8  4.0447 0.0002052 ***
##       165
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

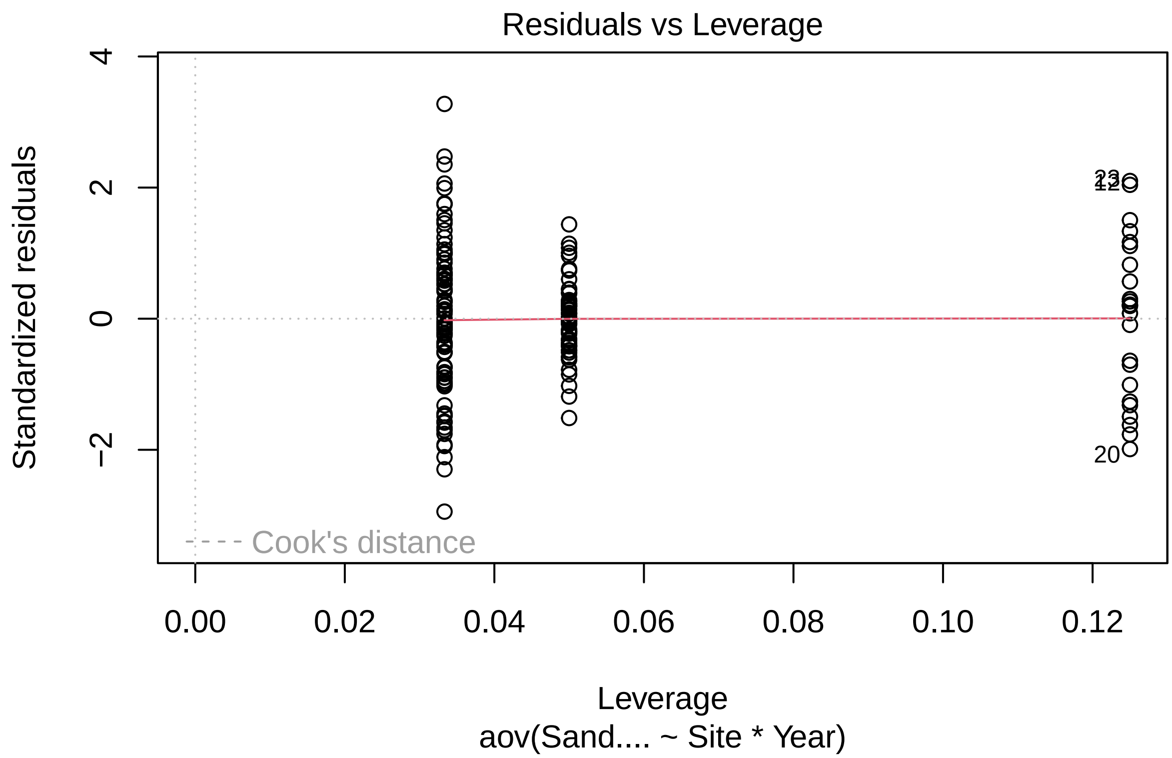
```r
#p-value = 0.0002052. transformations did not work.
#using original, untrasnformed data
leveneTest(ps.sc.anova.2way)
```

```
## Levene's Test for Homogeneity of Variance (center = median)
##        Df F value    Pr(>F)
## group   8  6.1011 7.027e-07 ***
##       165
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

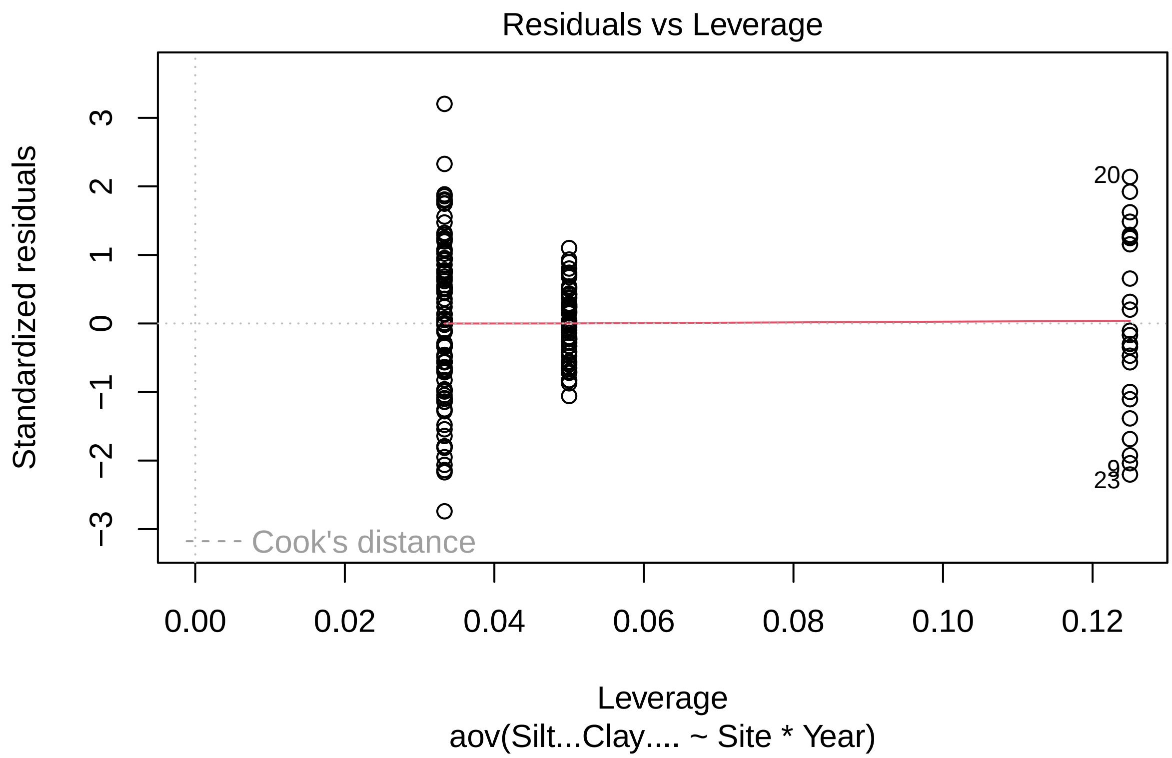
```r
#p-value = 7.027 * 10^-7. transformations did not work.
#using original, untrasnformed data

#outliers
plot(ps.g.anova.2way, which = 5)
```




```r
plot(ps.s.anova.2way, which = 5)
```



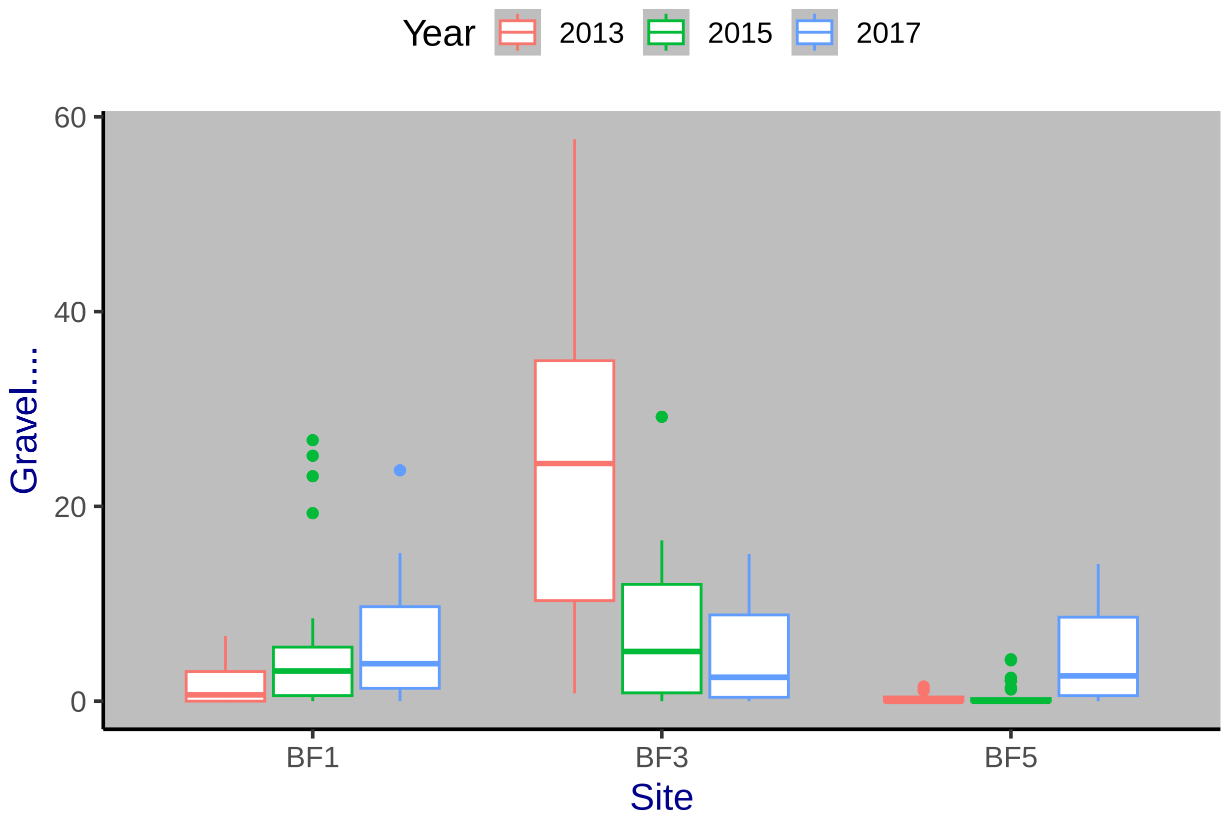

```
plot(ps.sc.anova.2way, which = 5)
```



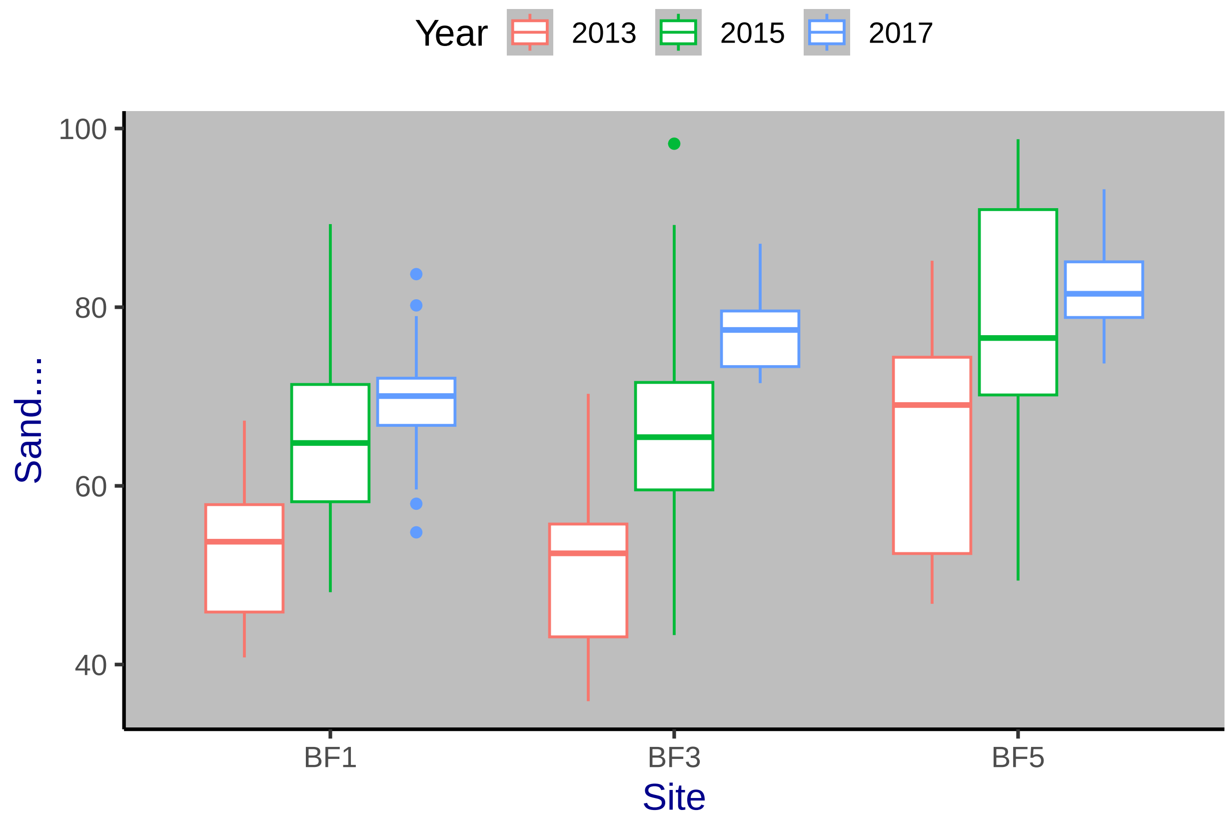
5.2.3 Residuals

5.2.4 Plots

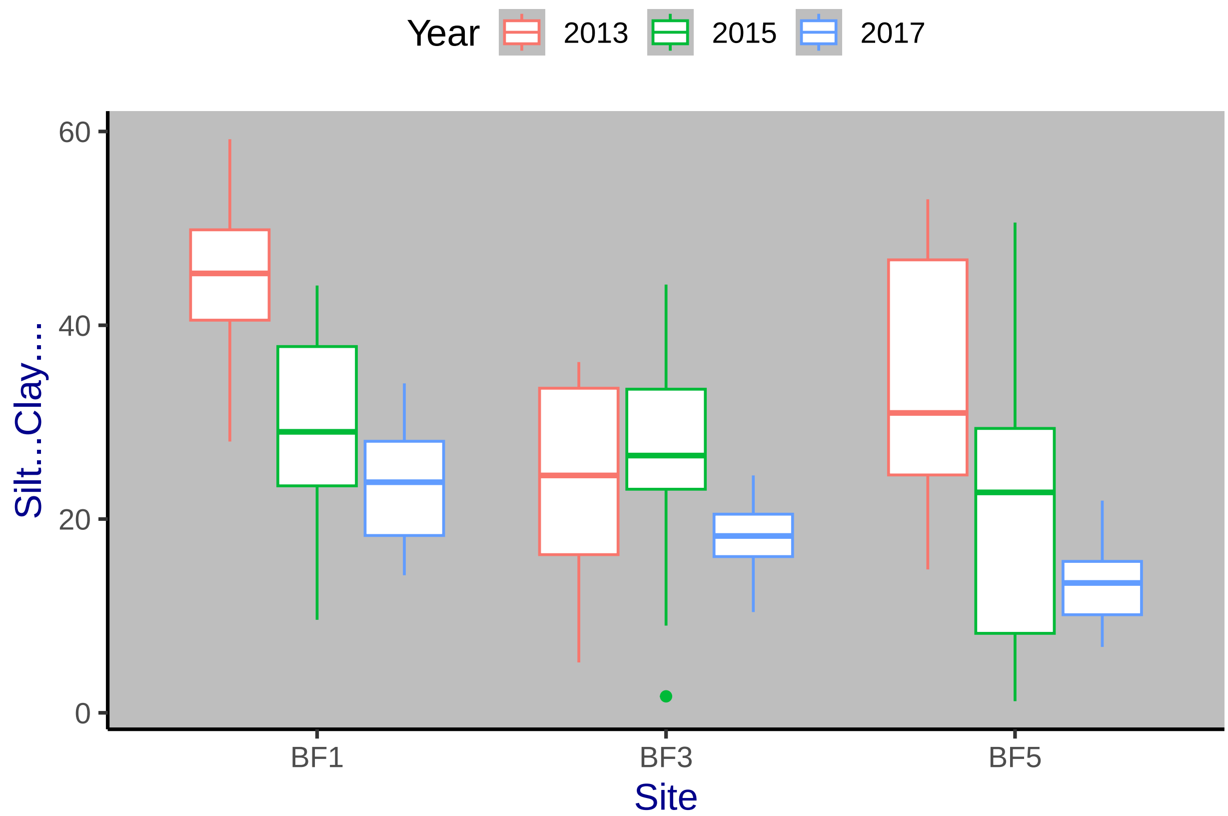
```
print(ps.g.anova.plot)
```




```
print(ps.s.anova.plot)
```




```
print(ps.sc.anova.plot)
```



5.3 Question 6: How does wildfire severity influence 0-1cm bulk density recovery over time?

H_0: There is no difference in mean soil 0-1cm bulk density across burn severities. There is no difference in mean soil 0-1cm bulk density across years. There is no interaction between burn severity and year.

H_a: There is a difference in mean soil 0-1cm bulk density across burn severities. There is a difference in mean soil 0-1cm bulk density across years. There is an interaction between burn severity and year.

Question 7: How does wildfire severity influence 1-3cm bulk density recovery over time?

H_0: There is no difference in mean soil 1-3cm bulk density across burn severities. There is no difference in mean soil 1-3cm bulk density across years. There is no interaction between burn severity and year.

H_a: There is a difference in mean soil 1-3cm bulk density across burn severities. There is a difference in mean soil 1-3cm bulk density across years. There is an interaction between burn severity and year.

Question 8: How does wildfire severity influence 3-6cm bulk density recovery over time?

H_0: There is no difference in mean soil 3-6cm bulk density across burn severities. There is no difference in mean soil 3-6cm bulk density across years. There is no interaction between burn severity and year.

H_a: There is a difference in mean soil 3-6cm bulk density across burn severities. There is a difference in mean soil 3-6cm bulk density across years. There is an interaction between burn severity and year.

5.3.1 Model: two-way ANOVA for bulk density

```
#0-1 cm
bdA.anova.2way <- aov(data = all_bd,
                     X0.1.0.cm ~ Site * Year)
summary(bdA.anova.2way)
```

```
##             Df Sum Sq Mean Sq F value   Pr(>F)
## Site         2  5.136  2.5680  29.229 1.22e-10 ***
## Year         2  0.370  0.1852   2.108  0.12701
## Site:Year    4  1.297  0.3242   3.690  0.00772 **
## Residuals   96  8.434  0.0879
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
TukeyHSD(bdA.anova.2way)
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = X0.1.0.cm ~ Site * Year, data = all_bd)
##
## $Site
##               diff        lwr         upr     p adj
## BF3-BF1 -0.3420000 -0.5106782 -0.17332180 0.0000155
## BF5-BF1 -0.5348571 -0.7035353 -0.36617894 0.0000000
## BF5-BF3 -0.1928571 -0.3615353 -0.02417894 0.0208682
##
## $Year
##                 diff         lwr       upr     p adj
## 2015-2013 0.10200000 -0.06431895 0.2683190 0.3147391
## 2017-2013 0.15366667 -0.02852662 0.3358599 0.1157868
## 2017-2015 0.05166667 -0.11465228 0.2179856 0.7406456
##
## $`Site:Year`
##                           diff         lwr         upr     p adj
## BF3:2013-BF1:2013  0.051000000 -0.36970021  0.47170021 0.9999853
## BF5:2013-BF1:2013 -0.199000000 -0.61970021  0.22170021 0.8523311
## BF1:2015-BF1:2013  0.465333333  0.08128834  0.84937832 0.0064483
## BF3:2015-BF1:2013 -0.076000000 -0.46004499  0.30804499 0.9994017
## BF5:2015-BF1:2013 -0.231333333 -0.61537832  0.15271166 0.6074686
## BF1:2017-BF1:2013  0.459000000  0.03829979  0.87970021 0.0217715
## BF3:2017-BF1:2013  0.023000000 -0.39770021  0.44370021 1.0000000
## BF5:2017-BF1:2013 -0.169000000 -0.58970021  0.25170021 0.9362031
## BF5:2013-BF3:2013 -0.250000000 -0.67070021  0.17070021 0.6249084
## BF1:2015-BF3:2013  0.414333333  0.03028834  0.79837832 0.0244429
## BF3:2015-BF3:2013 -0.127000000 -0.51104499  0.25704499 0.9797208
## BF5:2015-BF3:2013 -0.282333333 -0.66637832  0.10171166 0.3332336
```

```
## BF1:2017-BF3:2013  0.408000000 -0.01270021  0.82870021 0.0646782
## BF3:2017-BF3:2013 -0.028000000 -0.44870021  0.39270021 0.9999999
## BF5:2017-BF3:2013 -0.220000000 -0.64070021  0.20070021 0.7689994
## BF1:2015-BF5:2013  0.664333333  0.28028834  1.04837832 0.0000114
## BF3:2015-BF5:2013  0.123000000 -0.26104499  0.50704499 0.9834158
## BF5:2015-BF5:2013 -0.032333333 -0.41637832  0.35171166 0.9999992
## BF1:2017-BF5:2013  0.658000000  0.23729979  1.07870021 0.0001016
## BF3:2017-BF5:2013  0.222000000 -0.19870021  0.64270021 0.7601569
## BF5:2017-BF5:2013  0.030000000 -0.39070021  0.45070021 0.9999998
## BF3:2015-BF1:2015 -0.541333333 -0.88483361 -0.19783305 0.0000873
## BF5:2015-BF1:2015 -0.696666667 -1.04016695 -0.35316639 0.0000002
## BF1:2017-BF1:2015 -0.006333333 -0.39037832  0.37771166 1.0000000
## BF3:2017-BF1:2015 -0.442333333 -0.82637832 -0.05828834 0.0119806
## BF5:2017-BF1:2015 -0.634333333 -1.01837832 -0.25028834 0.0000325
## BF5:2015-BF3:2015 -0.155333333 -0.49883361  0.18816695 0.8812829
## BF1:2017-BF3:2015  0.535000000  0.15095501  0.91904499 0.0008392
## BF3:2017-BF3:2015  0.099000000 -0.28504499  0.48304499 0.9960650
## BF5:2017-BF3:2015 -0.093000000 -0.47704499  0.29104499 0.9974517
## BF1:2017-BF5:2015  0.690333333  0.30628834  1.07437832 0.0000045
## BF3:2017-BF5:2015  0.254333333 -0.12971166  0.63837832 0.4783253
## BF5:2017-BF5:2015  0.062333333 -0.32171166  0.44637832 0.9998632
## BF3:2017-BF1:2017 -0.436000000 -0.85670021 -0.01529979 0.0362178
## BF5:2017-BF1:2017 -0.628000000 -1.04870021 -0.20729979 0.0002500
## BF5:2017-BF3:2017 -0.192000000 -0.61270021  0.22870021 0.8757685
```

```r
bdA.interaction <- with(all_bd, interaction(Site, Year))
bdA.anova.2way2 <- aov(data = all_bd, X0.1.0.cm ~ bdA.interaction)
bdA.groups <- HSD.test(bdA.anova.2way2, "bdA.interaction", group = TRUE)
bdA.groups
```

```
## $statistics
##      MSerror Df      Mean       CV
##   0.08785788 96 0.7442857 39.82453
##
## $parameters
##    test          name.t ntr StudentizedRange alpha
##   Tukey bdA.interaction   9         4.488305  0.05
##
## $means
##          X0.1.0.cm       std  r         se  Min  Max    Q25   Q50    Q75
## BF1.2013 0.7060000 0.2421753 10 0.09373254 0.42 1.19 0.5100 0.690 0.8350
## BF1.2015 1.1713333 0.3977053 15 0.07653229 0.50 1.78 0.8850 1.260 1.4800
## BF1.2017 1.1650000 0.3525542 10 0.09373254 0.63 1.59 0.8750 1.130 1.5025
## BF3.2013 0.7570000 0.2977714 10 0.09373254 0.42 1.30 0.5200 0.740 0.8825
## BF3.2015 0.6300000 0.2485386 15 0.07653229 0.28 1.23 0.4700 0.630 0.7350
## BF3.2017 0.7290000 0.1975657 10 0.09373254 0.35 1.01 0.6275 0.700 0.8875
## BF5.2013 0.5070000 0.2637360 10 0.09373254 0.18 0.87 0.3050 0.435 0.7700
## BF5.2015 0.4746667 0.3121782 15 0.07653229 0.20 1.36 0.3000 0.400 0.4900
## BF5.2017 0.5370000 0.2514425 10 0.09373254 0.27 1.02 0.3525 0.405 0.7300
##
## $comparison
## NULL
##
## $groups
```

```
##          X0.1.0.cm groups
## BF1.2015 1.1713333      a
## BF1.2017 1.1650000     ab
## BF3.2013 0.7570000     bc
## BF3.2017 0.7290000      c
## BF1.2013 0.7060000      c
## BF3.2015 0.6300000      c
## BF5.2017 0.5370000      c
## BF5.2013 0.5070000      c
## BF5.2015 0.4746667      c
##
## attr(,"class")
## [1] "group"
```

```
bdA.anova.plot <- ggplot(all_bd, aes(y = X0.1.0.cm, x = Site, color = Year)) +
  geom_boxplot()
```

With a p-value of less than 0.05, we reject the null hypothesis and conclude that site location does significantly influence bulk density at this depth and the interaction effects between Site and Year are significant.

```
#1-3 cm
bdB.anova.2way <- aov(data = all_bd,
                     X1.0.3.0.cm ~ Site * Year)
summary(bdB.anova.2way)
```

```
##             Df Sum Sq Mean Sq F value   Pr(>F)
## Site         2  3.044  1.5221  26.191 8.37e-10 ***
## Year         2  0.197  0.0987   1.698    0.188
## Site:Year    4  0.181  0.0453   0.779    0.541
## Residuals   96  5.579  0.0581
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
TukeyHSD(bdB.anova.2way)
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = X1.0.3.0.cm ~ Site * Year, data = all_bd)
##
## $Site
##                 diff        lwr        upr     p adj
## BF3-BF1 -0.007428571 -0.1446162  0.1297590 0.9908815
## BF5-BF1 -0.364857143 -0.5020448 -0.2276695 0.0000000
## BF5-BF3 -0.357428571 -0.4946162 -0.2202410 0.0000000
##
## $Year
##                 diff         lwr       upr     p adj
## 2015-2013 0.01722222 -0.11804660 0.1524910 0.9506474
## 2017-2013 0.10500000 -0.04317957 0.2531796 0.2154399
## 2017-2015 0.08777778 -0.04749104 0.2230466 0.2747822
##
```

```
## $`Site:Year`
##                          diff          lwr          upr     p adj
## BF3:2013-BF1:2013  0.03700000 -0.305159567  0.379159567 0.9999940
## BF5:2013-BF1:2013 -0.32000000 -0.662159567  0.022159567 0.0858215
## BF1:2015-BF1:2013  0.04733333 -0.265014189  0.359680856 0.9999186
## BF3:2015-BF1:2013 -0.00600000 -0.318347522  0.306347522 1.0000000
## BF5:2015-BF1:2013 -0.27266667 -0.585014189  0.039680856 0.1380641
## BF1:2017-BF1:2013  0.16400000 -0.178159567  0.506159567 0.8428789
## BF3:2017-BF1:2013  0.18100000 -0.161159567  0.523159567 0.7577125
## BF5:2017-BF1:2013 -0.31300000 -0.655159567  0.029159567 0.1008256
## BF5:2013-BF3:2013 -0.35700000 -0.699159567 -0.014840433 0.0339852
## BF1:2015-BF3:2013  0.01033333 -0.302014189  0.322680856 1.0000000
## BF3:2015-BF3:2013 -0.04300000 -0.355347522  0.269347522 0.9999609
## BF5:2015-BF3:2013 -0.30966667 -0.622014189  0.002680856 0.0538484
## BF1:2017-BF3:2013  0.12700000 -0.215159567  0.469159567 0.9592678
## BF3:2017-BF3:2013  0.14400000 -0.198159567  0.486159567 0.9179281
## BF5:2017-BF3:2013 -0.35000000 -0.692159567 -0.007840433 0.0408693
## BF1:2015-BF5:2013  0.36733333  0.054985811  0.679680856 0.0093540
## BF3:2015-BF5:2013  0.31400000  0.001652478  0.626347522 0.0477481
## BF5:2015-BF5:2013  0.04733333 -0.265014189  0.359680856 0.9999186
## BF1:2017-BF5:2013  0.48400000  0.141840433  0.826159567 0.0006497
## BF3:2017-BF5:2013  0.50100000  0.158840433  0.843159567 0.0003556
## BF5:2017-BF5:2013  0.00700000 -0.335159567  0.349159567 1.0000000
## BF3:2015-BF1:2015 -0.05333333 -0.332705450  0.226038784 0.9995407
## BF5:2015-BF1:2015 -0.32000000 -0.599372117 -0.040627883 0.0127716
## BF1:2017-BF1:2015  0.11666667 -0.195680856  0.429014189 0.9577481
## BF3:2017-BF1:2015  0.13366667 -0.178680856  0.446014189 0.9103819
## BF5:2017-BF1:2015 -0.36033333 -0.672680856 -0.047985811 0.0117581
## BF5:2015-BF3:2015 -0.26666667 -0.546038784  0.012705450 0.0734139
## BF1:2017-BF3:2015  0.17000000 -0.142347522  0.482347522 0.7282994
## BF3:2017-BF3:2015  0.18700000 -0.125347522  0.499347522 0.6153664
## BF5:2017-BF3:2015 -0.30700000 -0.619347522  0.005347522 0.0579263
## BF1:2017-BF5:2015  0.43666667  0.124319144  0.749014189 0.0007913
## BF3:2017-BF5:2015  0.45366667  0.141319144  0.766014189 0.0004108
## BF5:2017-BF5:2015 -0.04033333 -0.352680856  0.272014189 0.9999761
## BF3:2017-BF1:2017  0.01700000 -0.325159567  0.359159567 1.0000000
## BF5:2017-BF1:2017 -0.47700000 -0.819159567 -0.134840433 0.0008291
## BF5:2017-BF3:2017 -0.49400000 -0.836159567 -0.151840433 0.0004566
```

With a p-value of less than 0.05, we reject the null hypothesis and conclude that site locatioin does significantly influence bulk density at this depth.

```r
#3-6 cm
bdC.anova.2way <- aov(data = all_bd,
                      X3.0.6.0.cm ~ Site * Year)
summary(bdC.anova.2way)
```

```
##              Df Sum Sq Mean Sq F value   Pr(>F)    
## Site          2 1.3394  0.6697  21.746 1.62e-08 ***
## Year          2 0.0315  0.0158   0.512    0.601    
## Site:Year     4 0.0487  0.0122   0.395    0.812    
## Residuals    96 2.9565  0.0308                     
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
TukeyHSD(bdC.anova.2way)
```

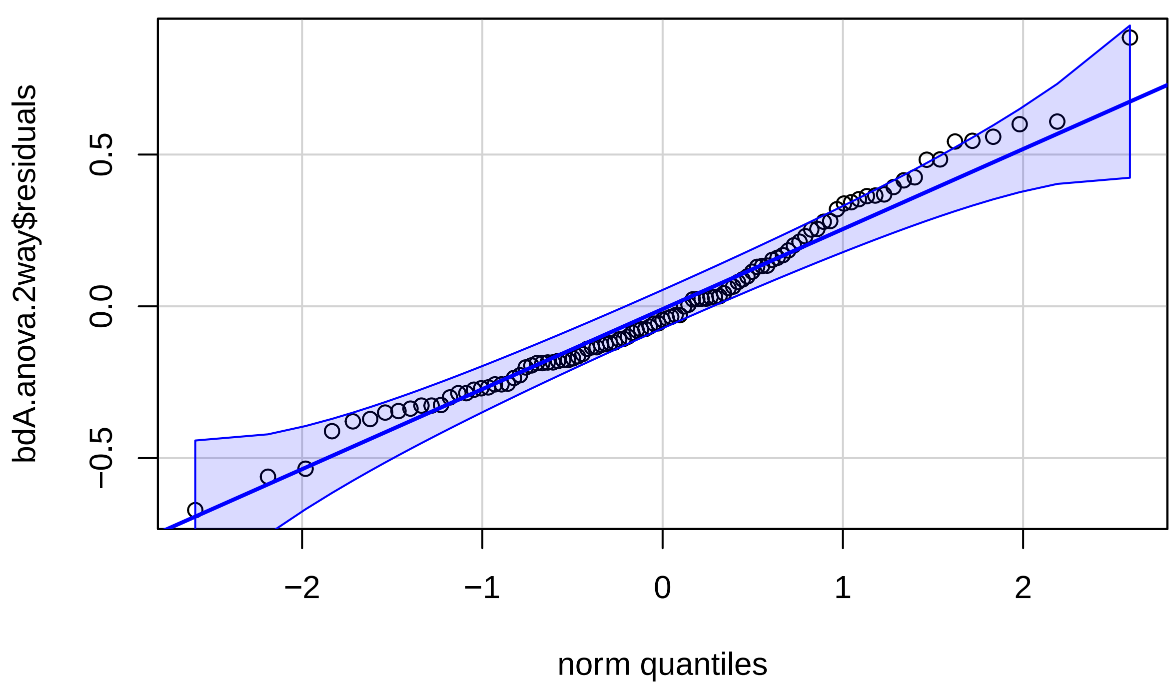
```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = X3.0.6.0.cm ~ Site * Year, data = all_bd)
##
## $Site
##                 diff        lwr        upr     p adj
## BF3-BF1  0.003714286 -0.0961532  0.1035818 0.9956876
## BF5-BF1 -0.237714286 -0.3375818 -0.1378468 0.0000005
## BF5-BF3 -0.241428571 -0.3412961 -0.1415611 0.0000003
##
## $Year
##                  diff         lwr       upr     p adj
## 2015-2013 0.006222222 -0.09224845 0.1046929 0.9876040
## 2017-2013 0.041666667 -0.06620255 0.1495359 0.6293162
## 2017-2015 0.035444444 -0.06302623 0.1339151 0.6686437
##
## $`Site:Year`
##                            diff         lwr           upr     p adj
## BF3:2013-BF1:2013  0.020000000 -0.22907945  2.690794e-01 0.9999994
## BF5:2013-BF1:2013 -0.260000000 -0.50907945 -1.092055e-02 0.0338396
## BF1:2015-BF1:2013 -0.009333333 -0.23671072  2.180441e-01 1.0000000
## BF3:2015-BF1:2013 -0.012666667 -0.24004405  2.147107e-01 1.0000000
## BF5:2015-BF1:2013 -0.199333333 -0.42671072  2.804405e-02 0.1343857
## BF1:2017-BF1:2013  0.058000000 -0.19107945  3.070794e-01 0.9980663
## BF3:2017-BF1:2013  0.056000000 -0.19307945  3.050794e-01 0.9984933
## BF5:2017-BF1:2013 -0.229000000 -0.47807945  2.007945e-02 0.0972727
## BF5:2013-BF3:2013 -0.280000000 -0.52907945 -3.092055e-02 0.0157853
## BF1:2015-BF3:2013 -0.029333333 -0.25671072  1.980441e-01 0.9999763
## BF3:2015-BF3:2013 -0.032666667 -0.26004405  1.947107e-01 0.9999458
## BF5:2015-BF3:2013 -0.219333333 -0.44671072  8.044051e-03 0.0675388
## BF1:2017-BF3:2013  0.038000000 -0.21107945  2.870794e-01 0.9999144
## BF3:2017-BF3:2013  0.036000000 -0.21307945  2.850794e-01 0.9999433
## BF5:2017-BF3:2013 -0.249000000 -0.49807945  7.944548e-05 0.0501386
## BF1:2015-BF5:2013  0.250666667  0.02328928  4.780441e-01 0.0195133
## BF3:2015-BF5:2013  0.247333333  0.01995595  4.747107e-01 0.0224626
## BF5:2015-BF5:2013  0.060666667 -0.16671072  2.880441e-01 0.9950187
## BF1:2017-BF5:2013  0.318000000  0.06892055  5.670794e-01 0.0031880
## BF3:2017-BF5:2013  0.316000000  0.06692055  5.650794e-01 0.0034836
## BF5:2017-BF5:2013  0.031000000 -0.21807945  2.800794e-01 0.9999820
## BF3:2015-BF1:2015 -0.003333333 -0.20670585  2.000392e-01 1.0000000
## BF5:2015-BF1:2015 -0.190000000 -0.39337252  1.337252e-02 0.0865026
## BF1:2017-BF1:2015  0.067333333 -0.16004405  2.947107e-01 0.9899956
## BF3:2017-BF1:2015  0.065333333 -0.16204405  2.927107e-01 0.9918002
## BF5:2017-BF1:2015 -0.219666667 -0.44704405  7.710718e-03 0.0667200
## BF5:2015-BF3:2015 -0.186666667 -0.39003918  1.670585e-02 0.0984406
## BF1:2017-BF3:2015  0.070666667 -0.15671072  2.980441e-01 0.9863098
## BF3:2017-BF3:2015  0.068666667 -0.15871072  2.960441e-01 0.9886287
## BF5:2017-BF3:2015 -0.216333333 -0.44371072  1.104405e-02 0.0752963
## BF1:2017-BF5:2015  0.257333333  0.02995595  4.847107e-01 0.0146410
## BF3:2017-BF5:2015  0.255333333  0.02795595  4.827107e-01 0.0159714
```

```
## BF5:2017-BF5:2015 -0.029666667 -0.25704405  1.977107e-01 0.9999741
## BF3:2017-BF1:2017 -0.002000000 -0.25107945  2.470794e-01 1.0000000
## BF5:2017-BF1:2017 -0.287000000 -0.53607945 -3.792055e-02 0.0119241
## BF5:2017-BF3:2017 -0.285000000 -0.53407945 -3.592055e-02 0.0129280
```

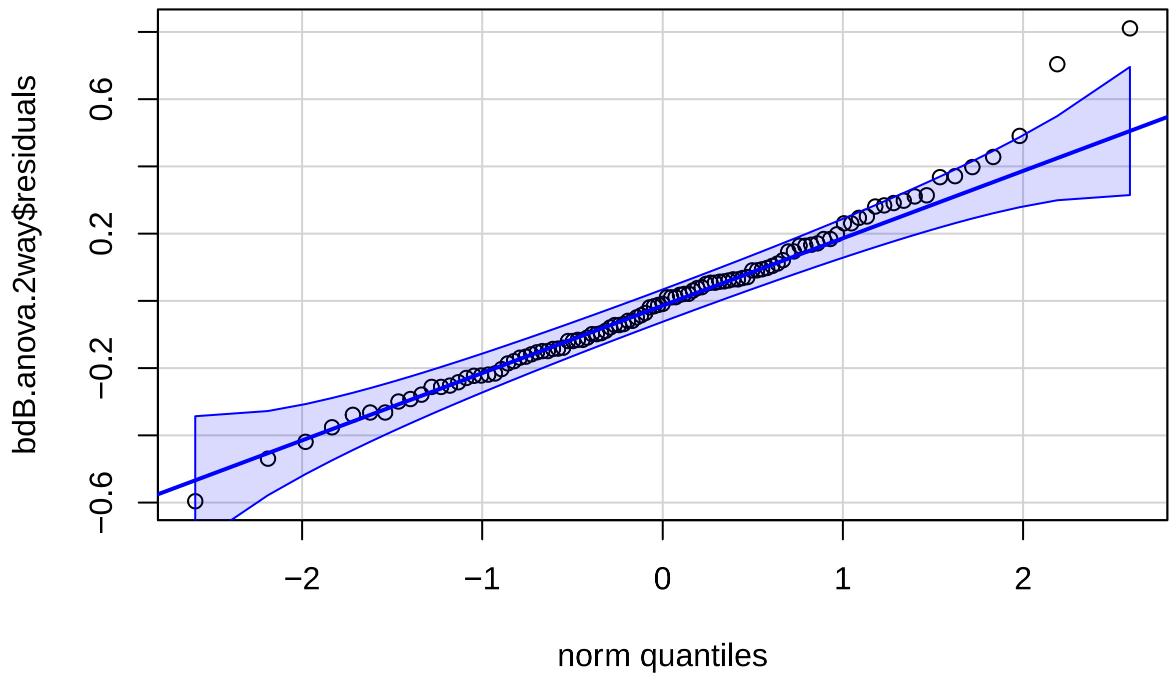
With a p-value of less than 0.05, we reject the null hypothesis and conclude that site locatioin does significantly influence bulk density at this depth.

5.3.2 Assumptions

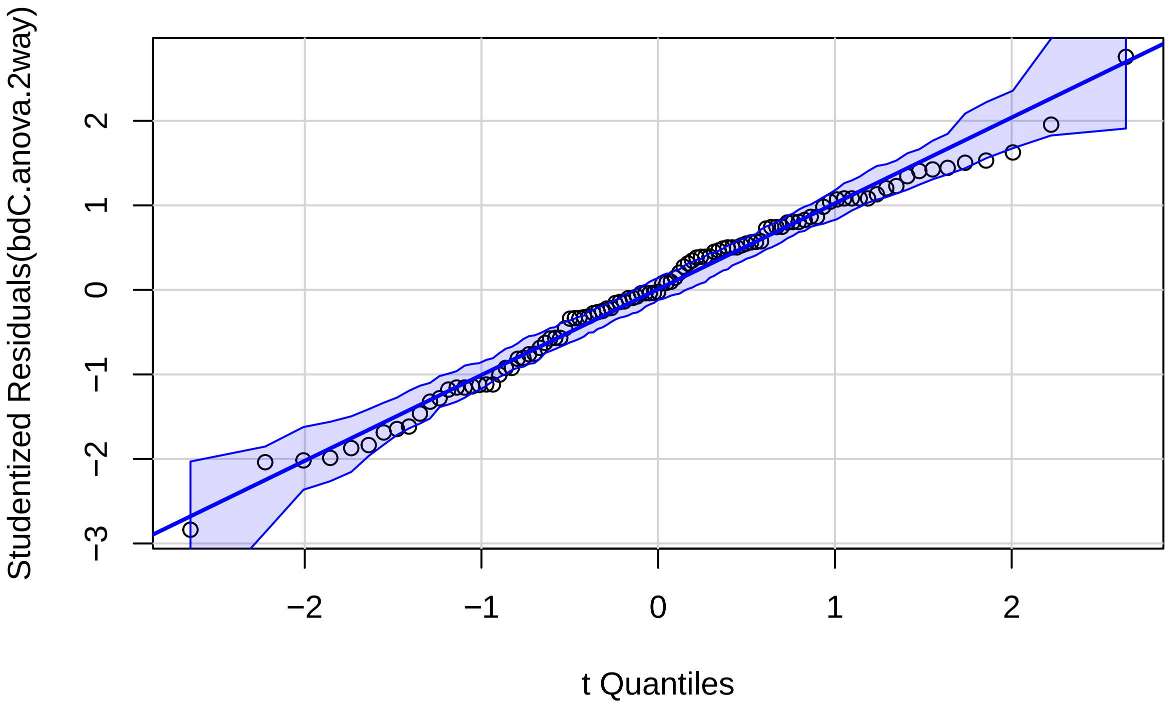
```r
#normality
qqPlot(bdA.anova.2way$residuals, id = F)
```




```r
qqPlot(bdB.anova.2way$residuals, id = F)
```




```
qqPlot(bdC.anova.2way, id = F)
```




```
#homogeneity of variances
leveneTest(bdA.anova.2way)
```

```
## Levene's Test for Homogeneity of Variance (center = median)
##       Df F value Pr(>F)
## group  8  1.2933 0.2562
##       96
```

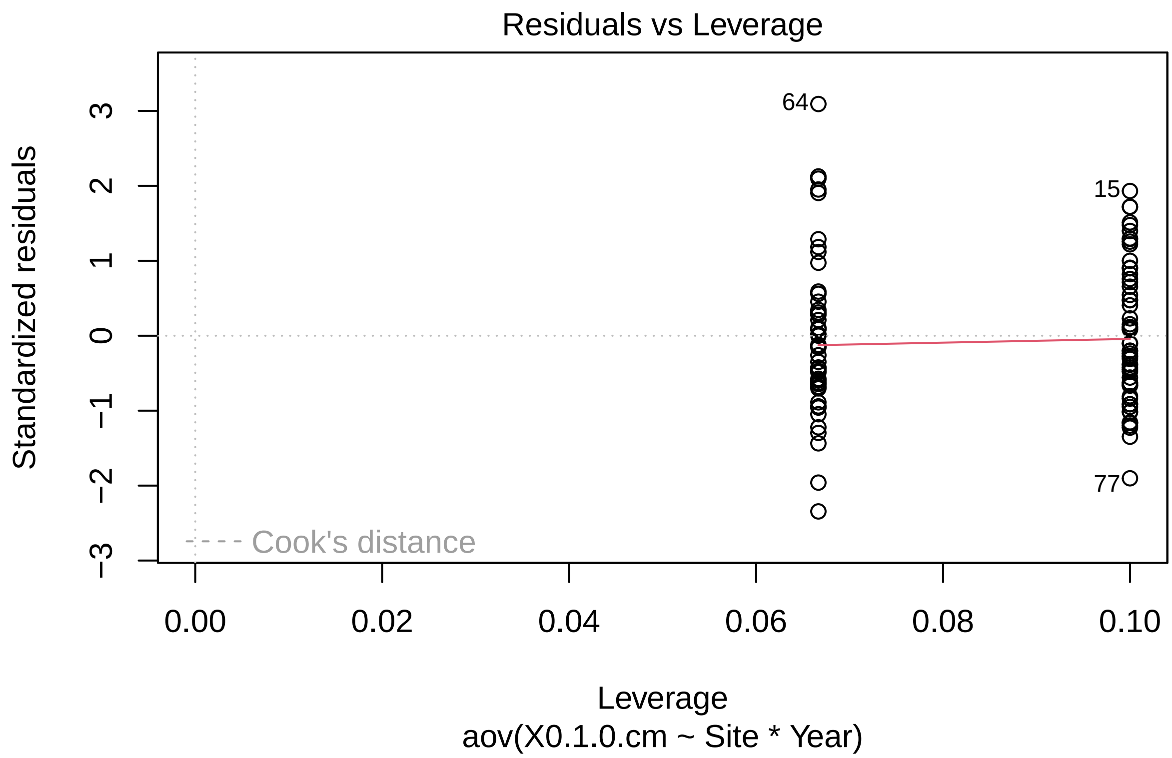
```
leveneTest(bdB.anova.2way)
```

```
## Levene's Test for Homogeneity of Variance (center = median)
##       Df F value Pr(>F)
## group  8  0.7243 0.6696
##       96
```

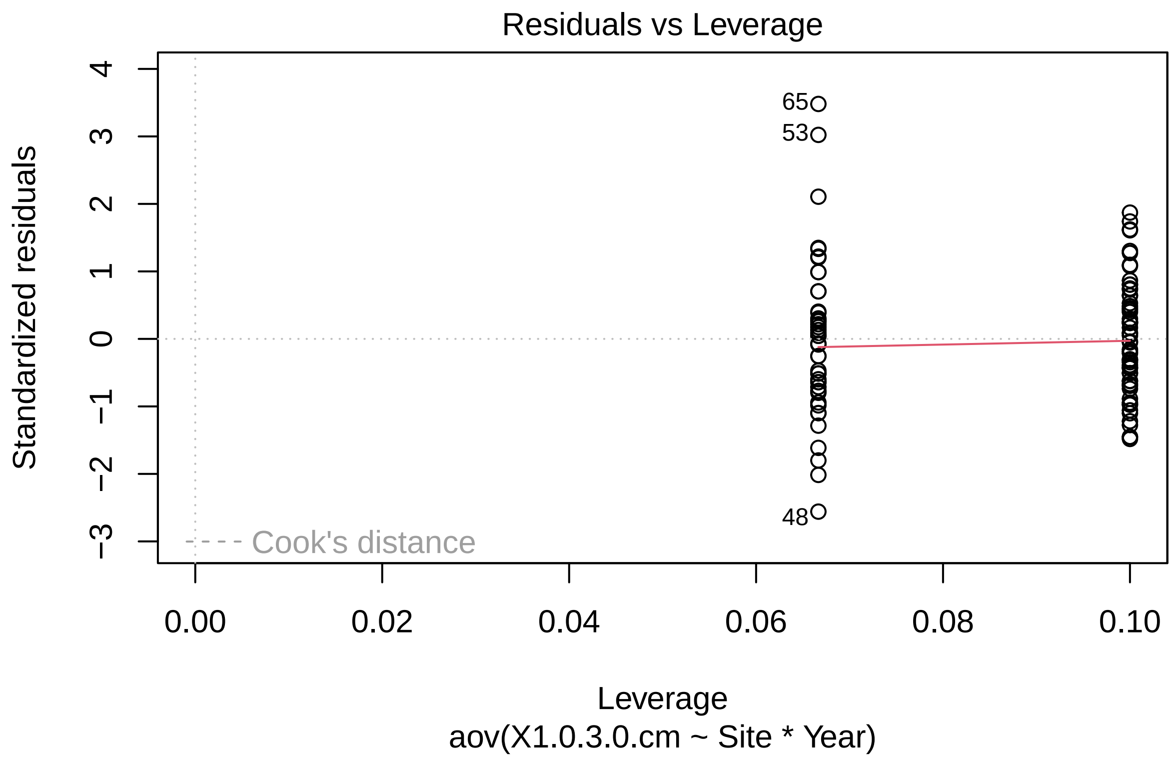
```
leveneTest(bdC.anova.2way)
```

```
## Levene's Test for Homogeneity of Variance (center = median)
##       Df F value Pr(>F)
## group  8  0.4454 0.8907
##       96
```

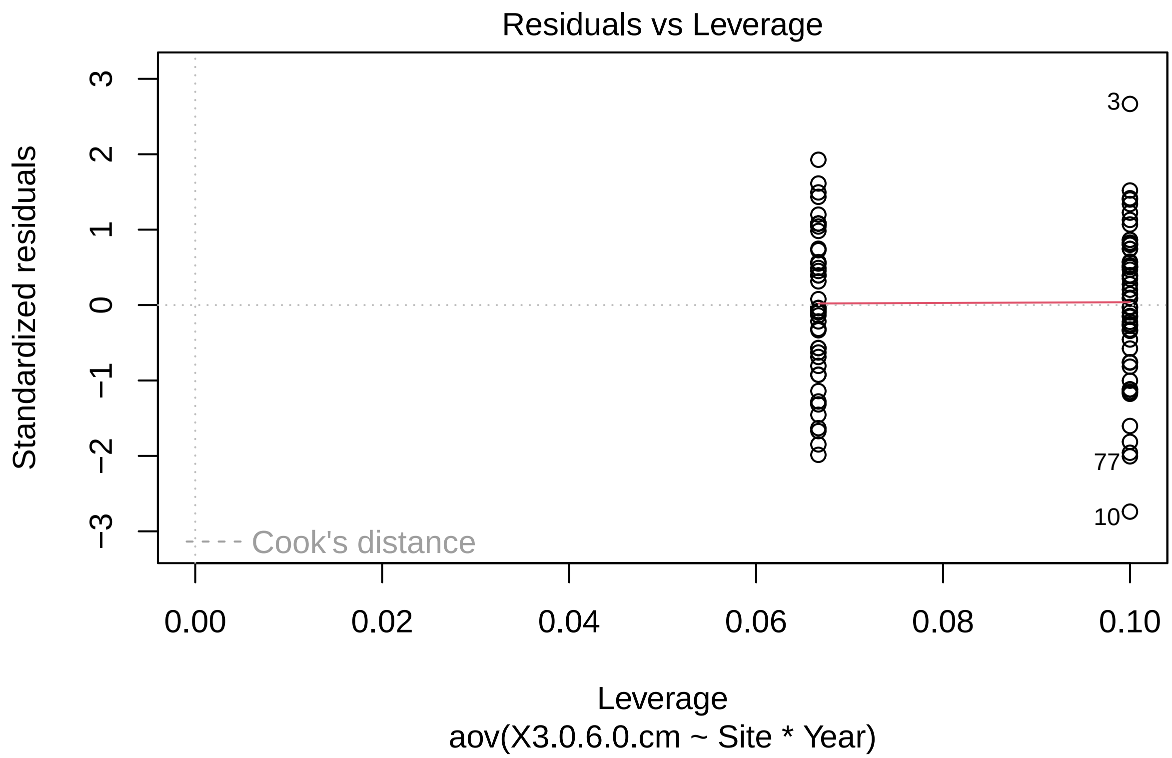
```r
#outliers
plot(bdA.anova.2way, which = 5)
```




```r
plot(bdB.anova.2way, which = 5)
```



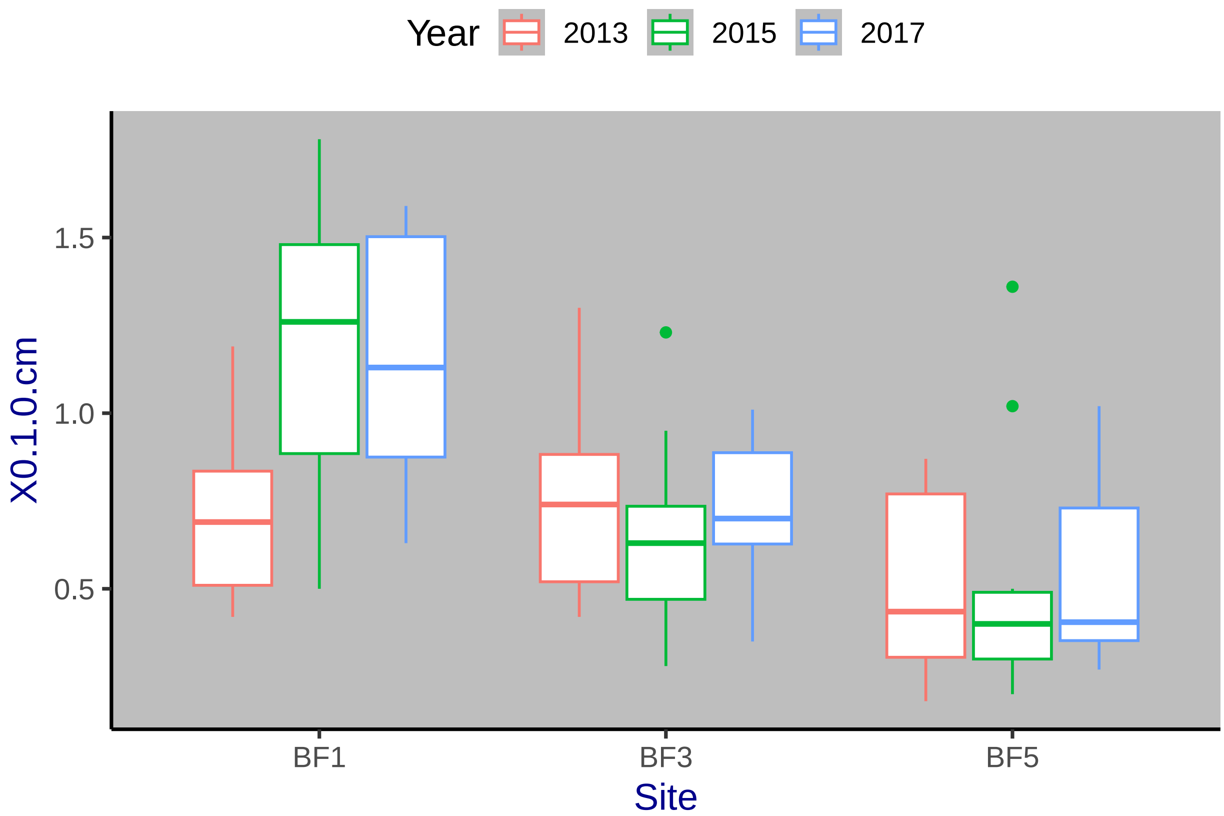

```
plot(bdC.anova.2way, which = 5)
```



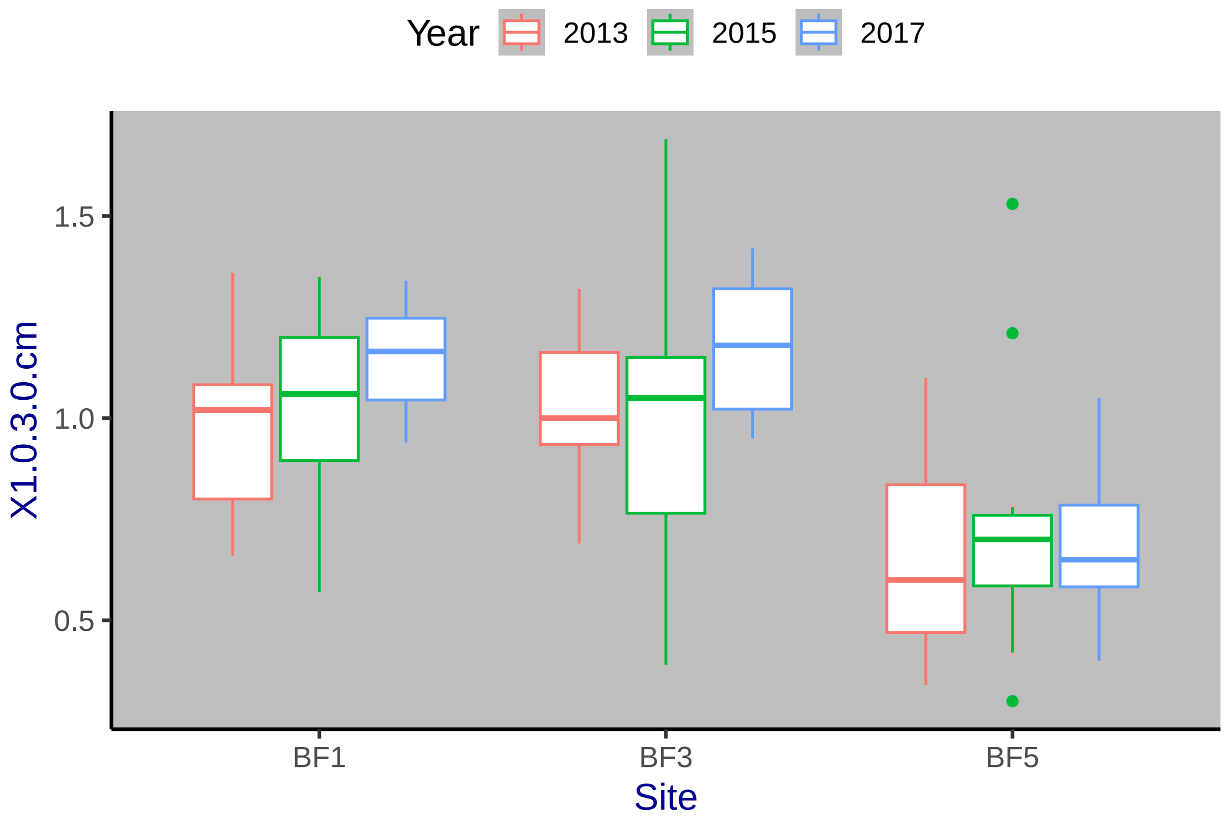
5.3.3 Residuals

5.3.4 Plots

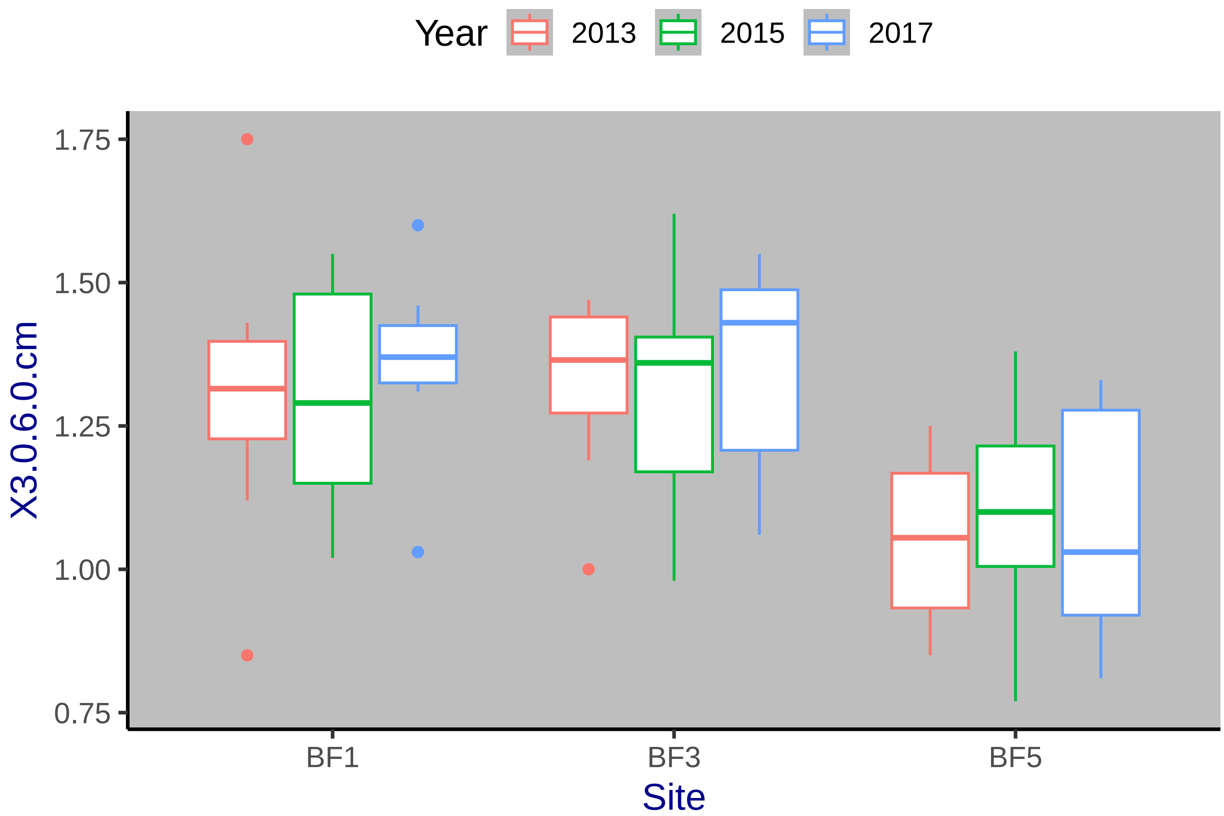
```
print(bdA.anova.plot)
```




```
print(bdB.anova.plot)
```




```
print(bdC.anova.plot)
```



Year
2013
2015
2017
1.75
1.50
1.25
1.00
0.75
X3.0.6.0.cm
BF1
BF3
BF5
Site

6. Summary and Conclusions

7. References

<add references here if relevant, otherwise delete this section>