

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

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# 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: <a href="https://www.sciencebase.gov/catalog/item/5b8452f5e4b05f6e321b629b">https://www.sciencebase.gov/catalog/item/5b8452f5e4b05f6e321b629b</a>
Variables used	Soil field-saturated hydraulic conductivity (KFS) (mm/hr), soil sorptivity ( $\text{mm}/\sqrt{hr}$ ), soil particle size distribution (gravel, sand, silt+clay) (%), and soil dry bulk density ( $\text{grams}/\text{cm}^3$ )

### 3. Exploration of raw data

Exploring hydraulic properties raw dataframes

```
#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 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
## $ Site : Factor w/ 7 levels "", "BF1", "BF2",...: 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
## $ Site : Factor w/ 5 levels "BF1","BF3","BF4",...: 5 5 5 5 5 5 5 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 relevant 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.

## Exploring particle size raw dataframes

```
#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 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 ...
## $ 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...."
```

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

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

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

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

```
#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
##
```

```
#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
##
```

```
#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.

## Exploring bulk density raw dataframes

```
#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 ...
```

```
#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 ...
```

```
#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)
```

```
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.

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

```
TukeyHSD(sorpitivity.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

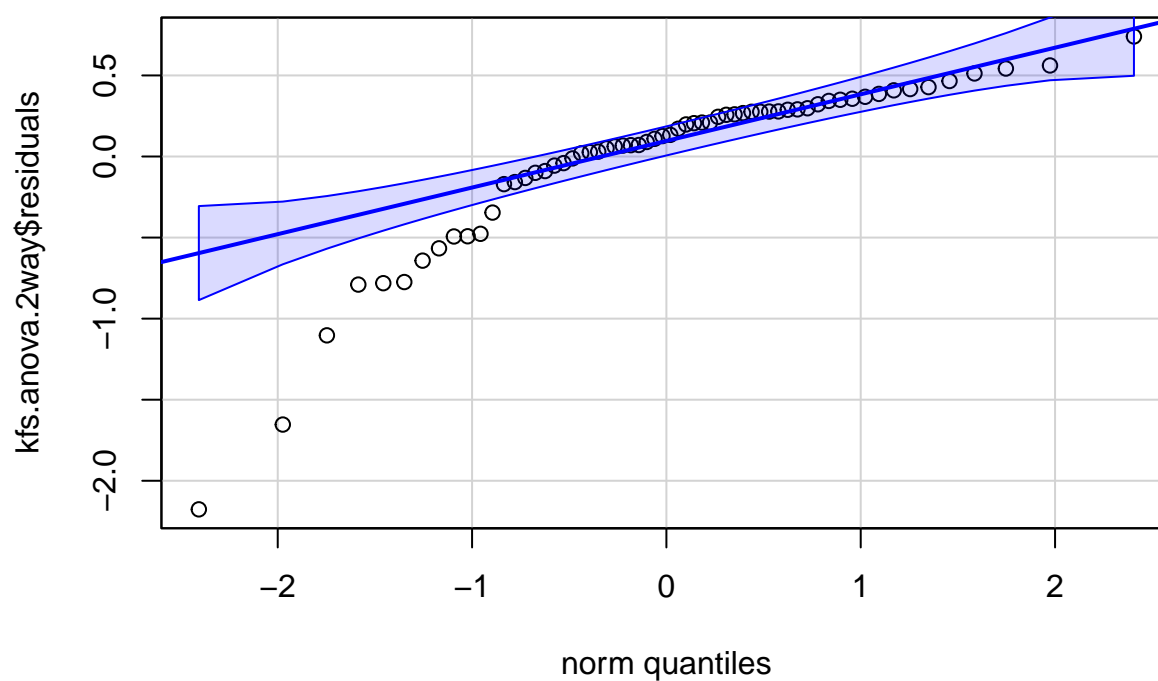
```

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

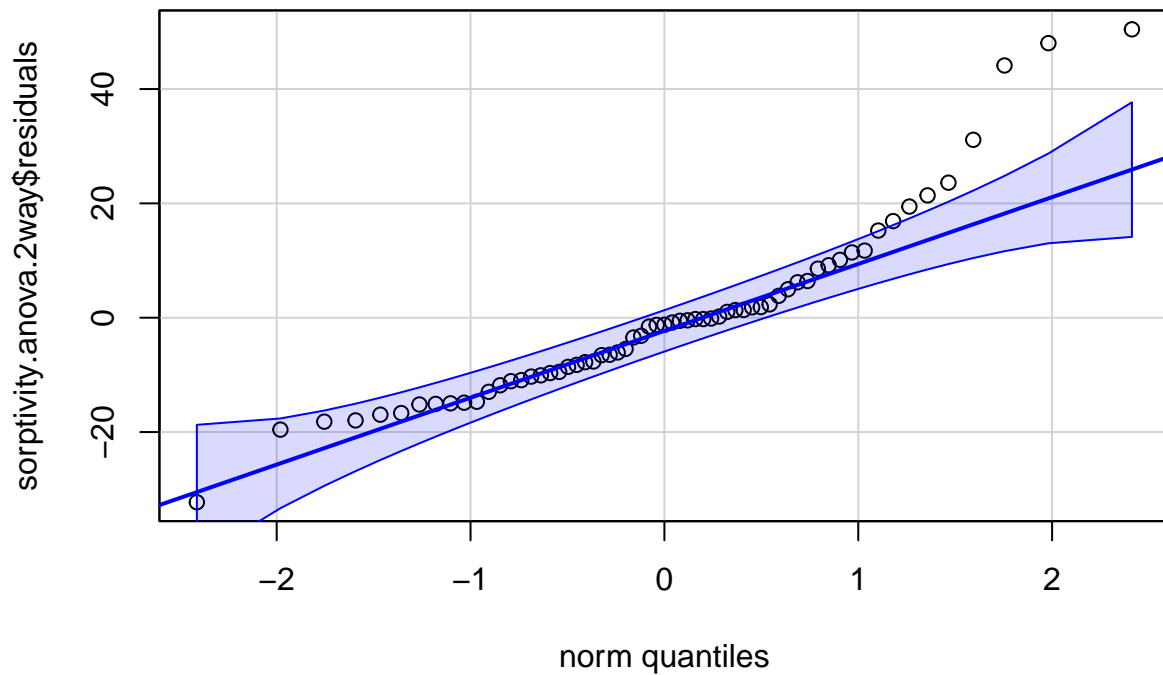
### 5.1.2 Assumptions

Testing for normality and variance.

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



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



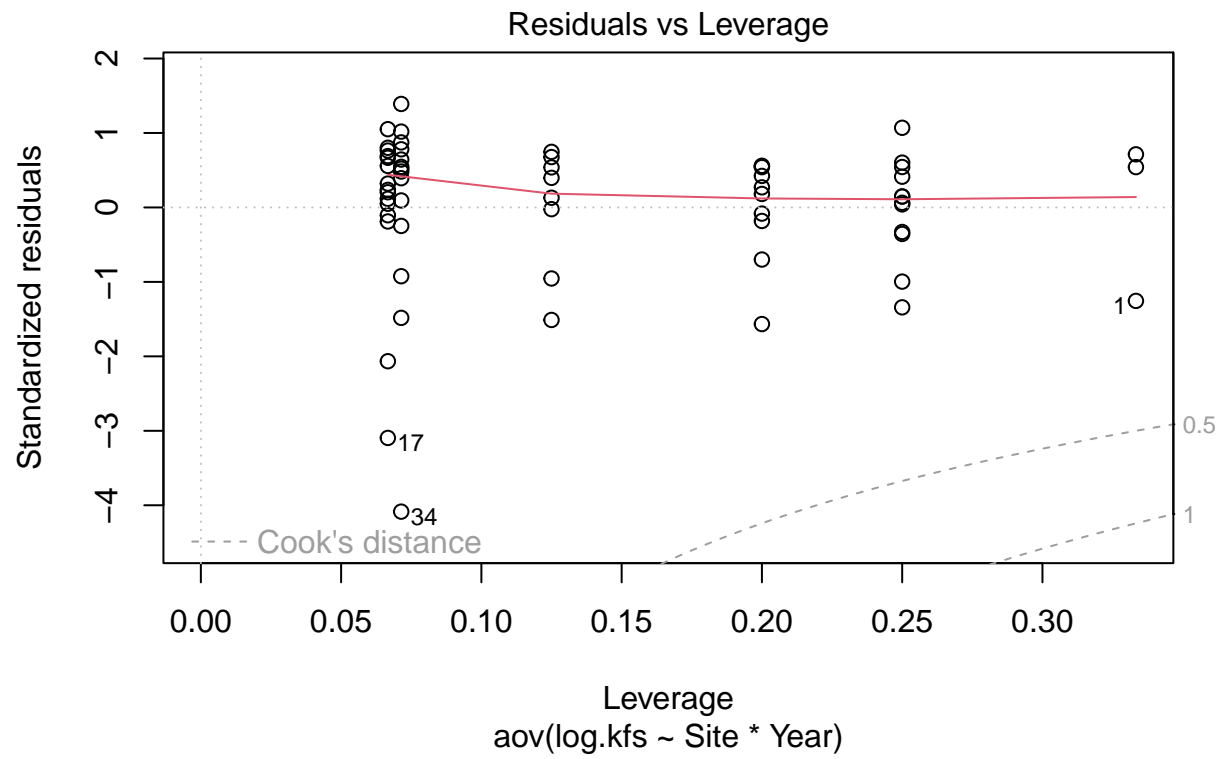
```
#homogeneity of variances
leveneTest(kfs.anova.2way)
```

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

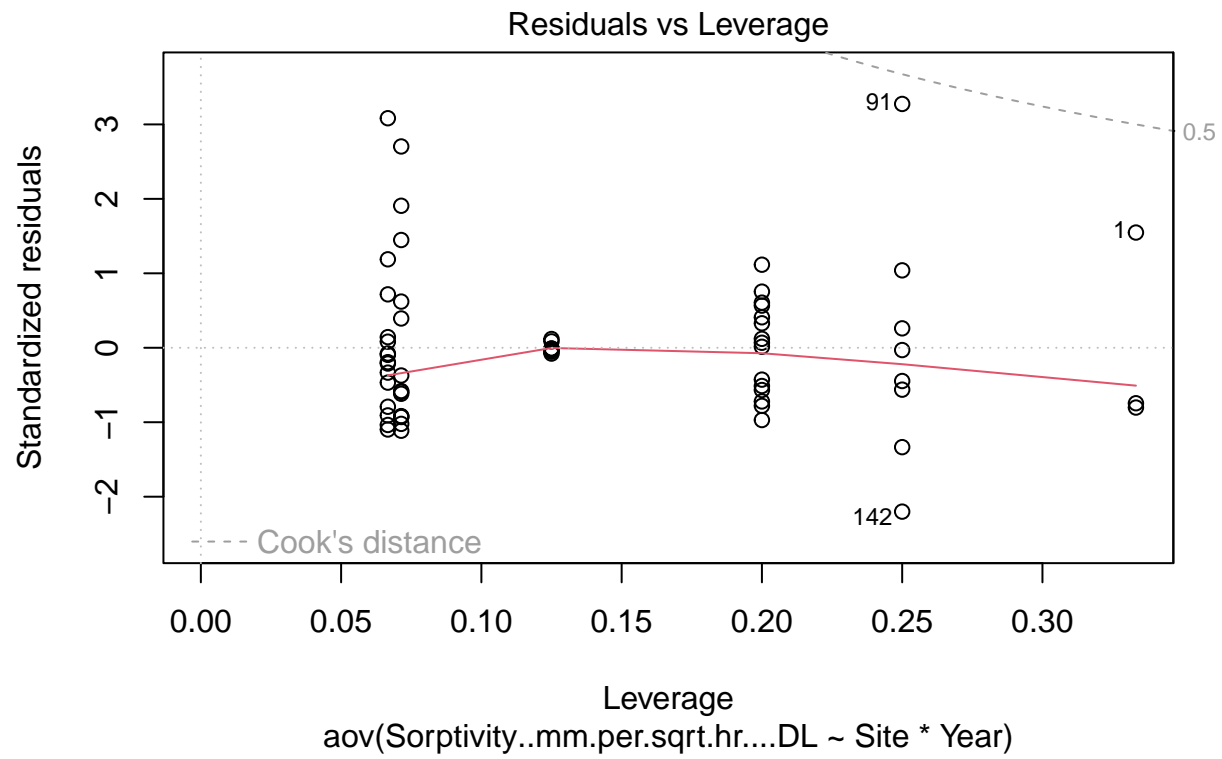
```
#original value after outlier removal p = 0.02207. data was then log transformed
leveneTest(sorptivity.anova.2way)
```

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

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

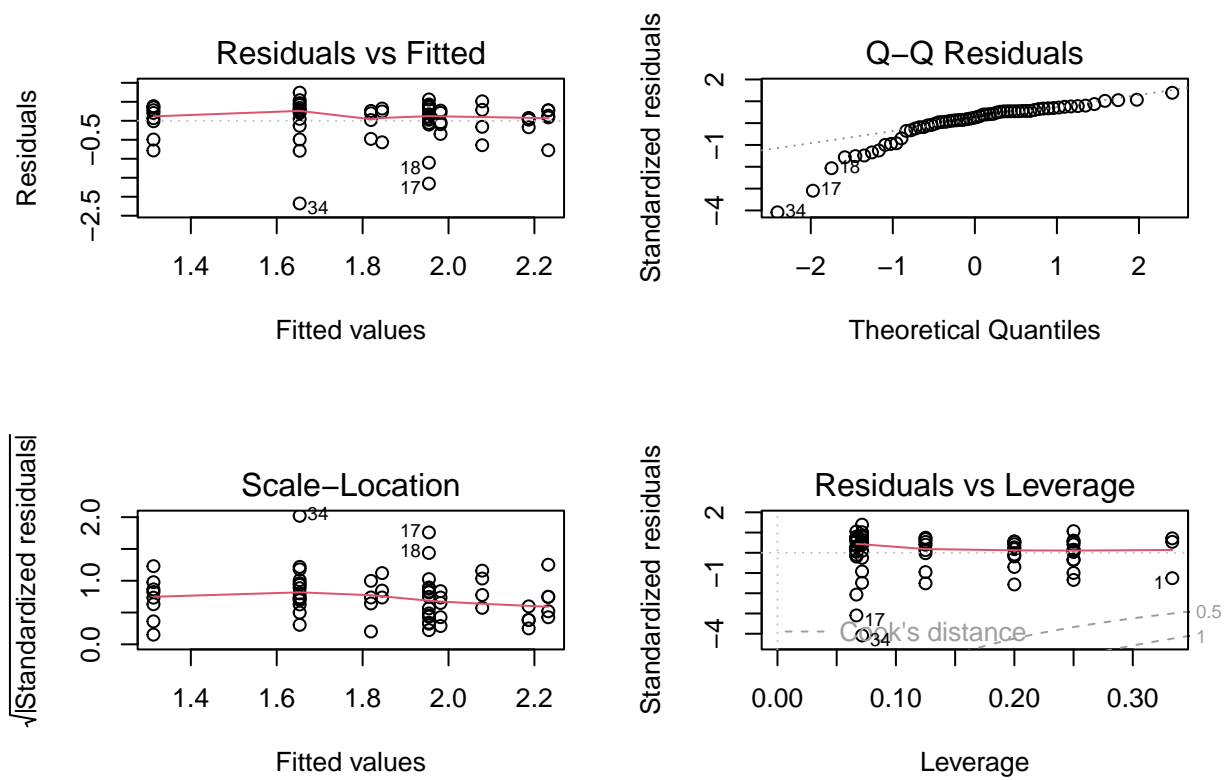


```
#observation 310 was an outlier. it has been removed.
plot(sorptivity.anova.2way, which = 5)
```



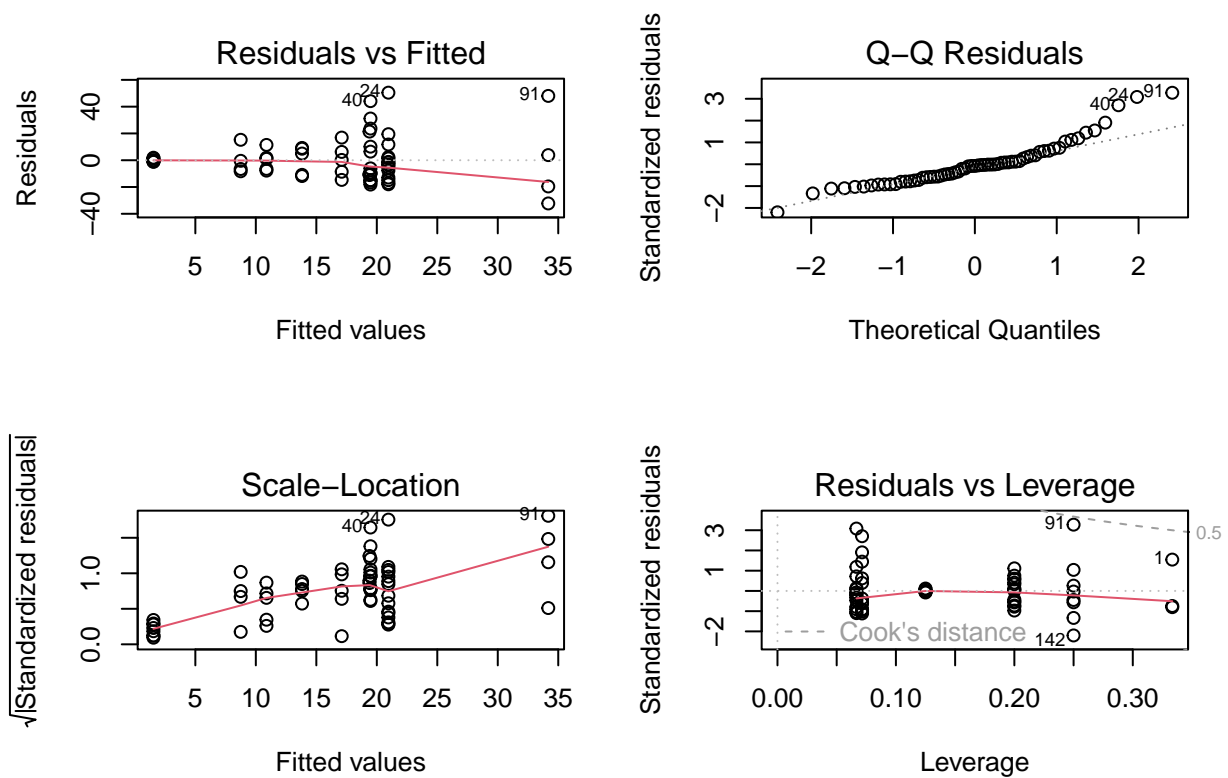
### 5.1.3 Residuals

```
#kfs diagnostic plots
par(mfrow=c(2,2))
plot(kfs.anova.2way)
```



```
#sorptivity diagnostic plots
par(mfrow=c(2,2))
plot(sorptivity.anova.2way)
```



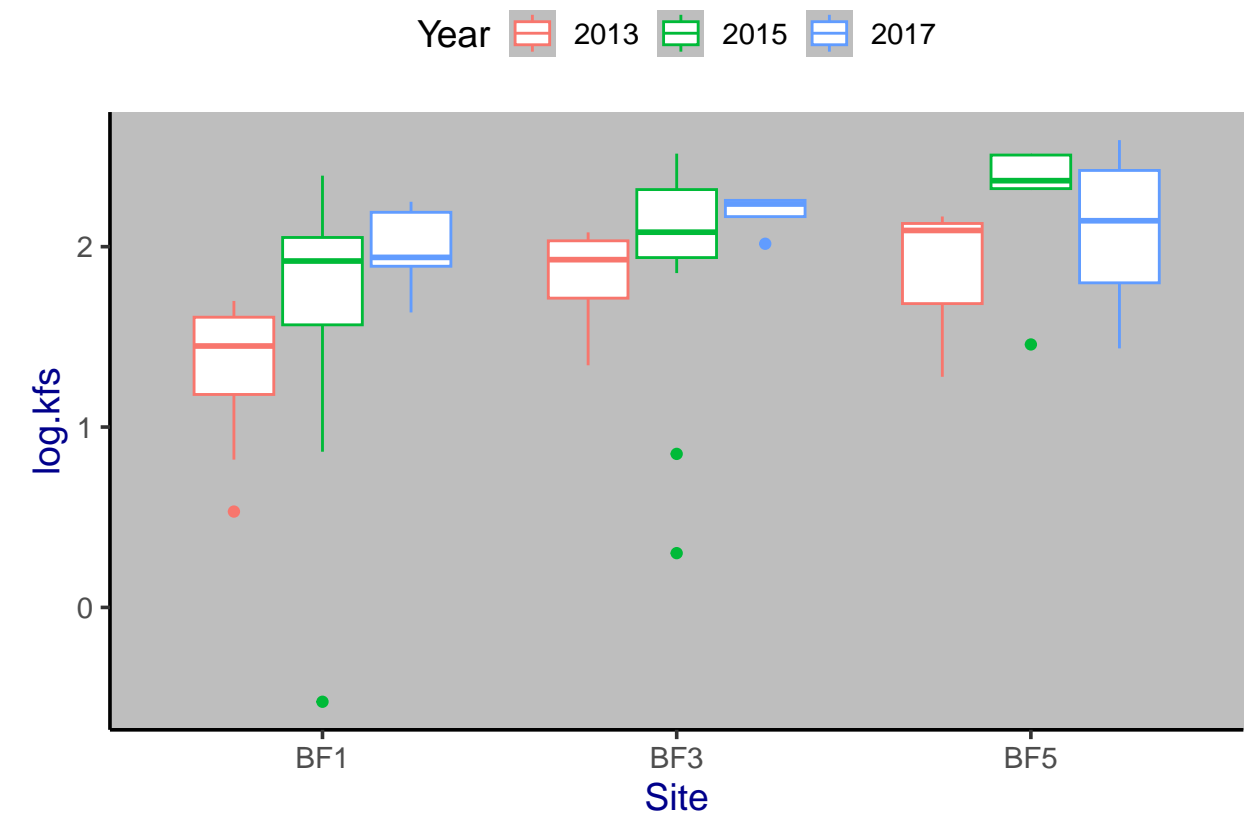


```
dev.off()
```

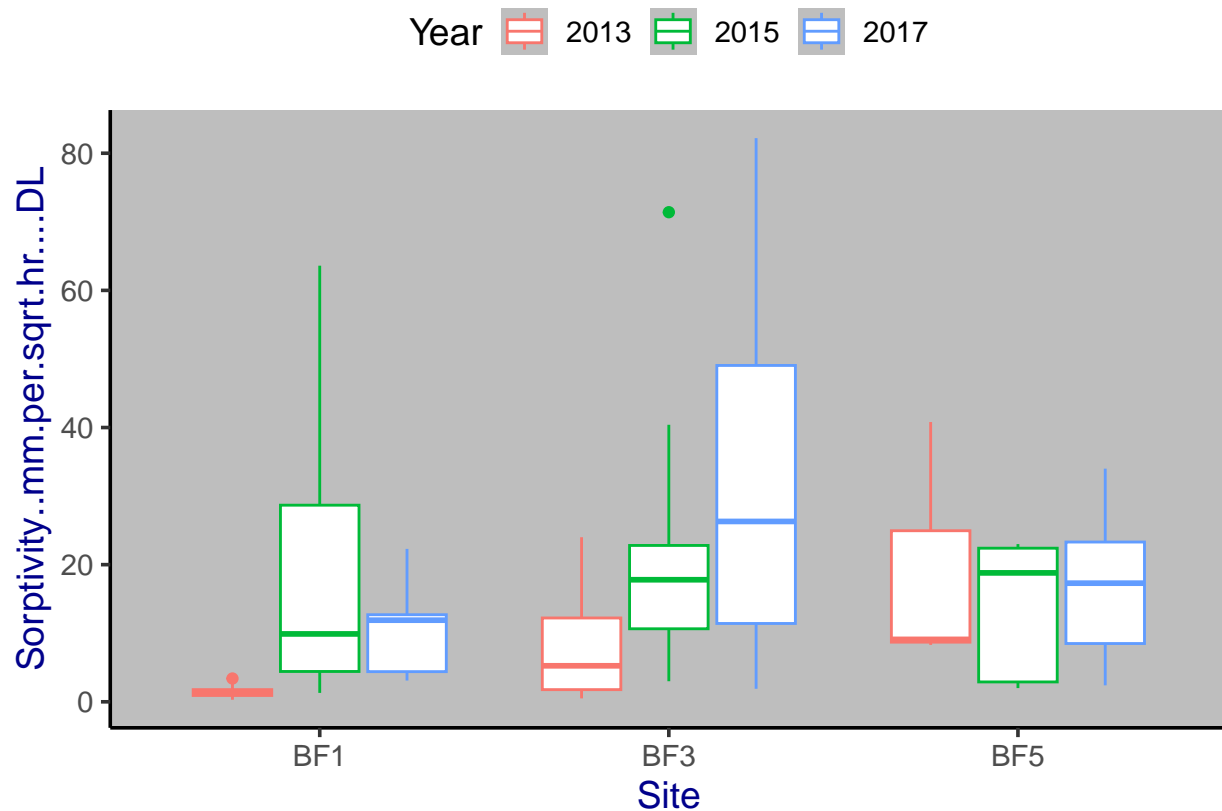
```
## null device
##      1
```

#### 5.1.4 Kfs and sorptivity by site and year

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



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



```
#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
```

```
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
```

```
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"
```

```
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.

```
#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
```

```
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
```

```
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
```

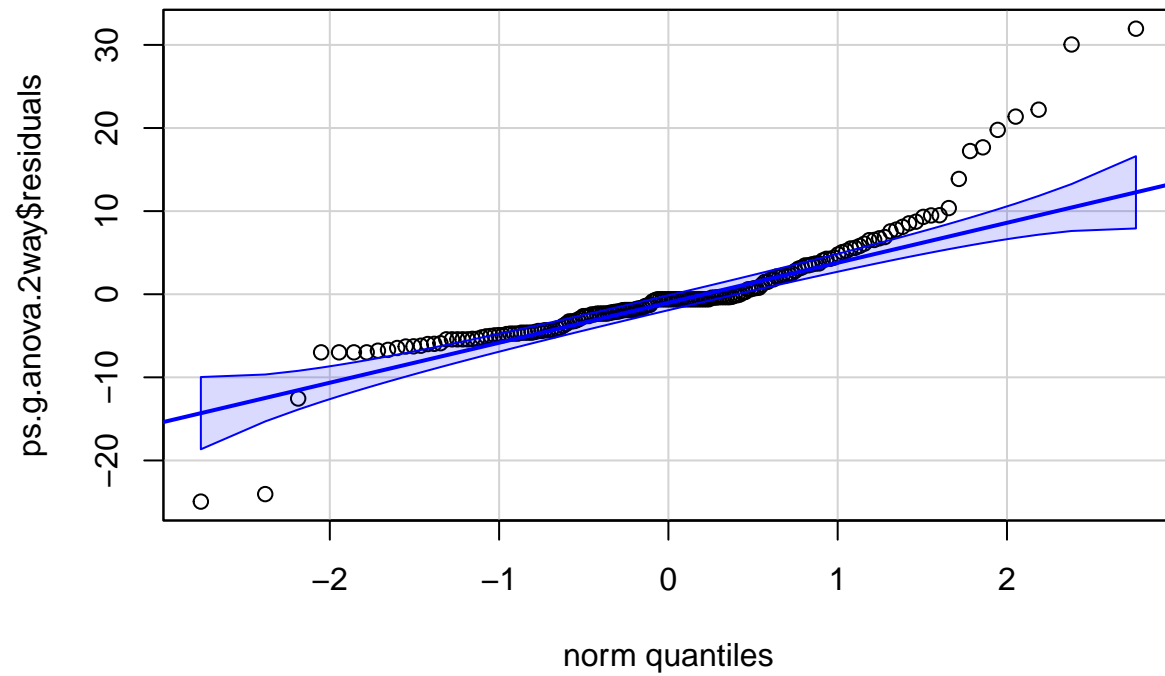
```
## $statistics
##      MSerror Df      Mean      CV
## 88.45726 165 24.44655 38.47239
##
## $parameters
##      test          name.t ntr StudentizedRange alpha
## Tukey ps.sc.interaction    9         4.445476 0.05
##
## $means
##      Silt...Clay....      std  r      se Min Max   Q25   Q50   Q75
## 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"
```

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

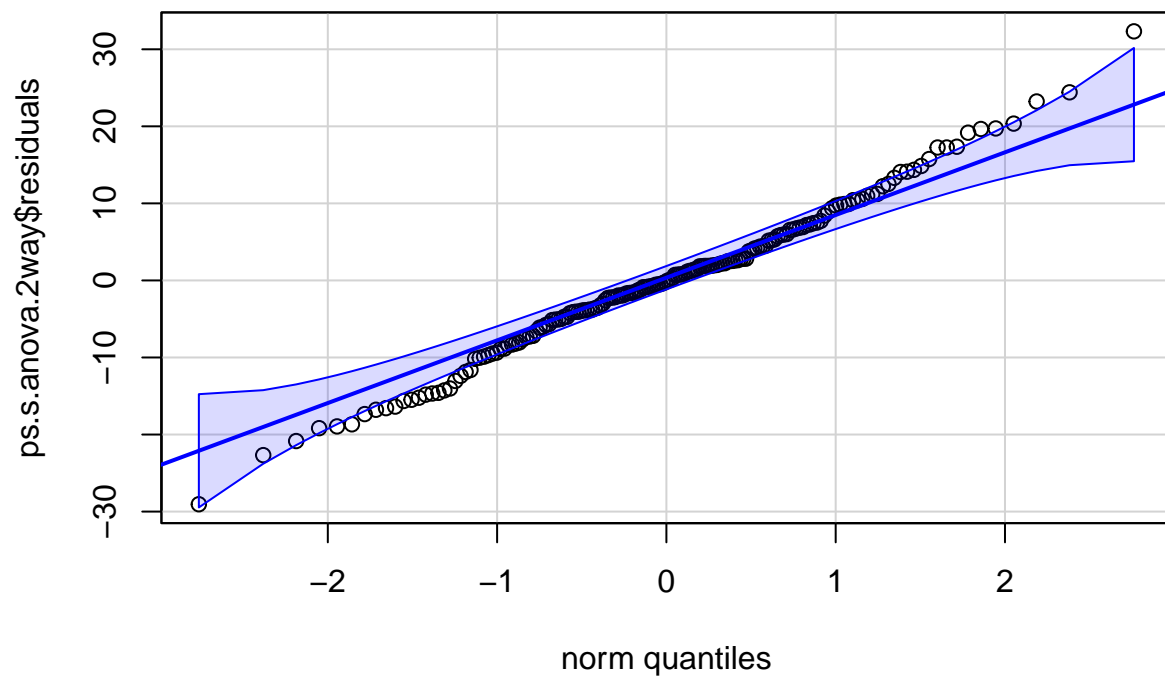
With p-values less than 0.05 across the board, we reject the null hypothesis and conclude that particle size does vary across sites and time.

### 5.2.1 Assumptions

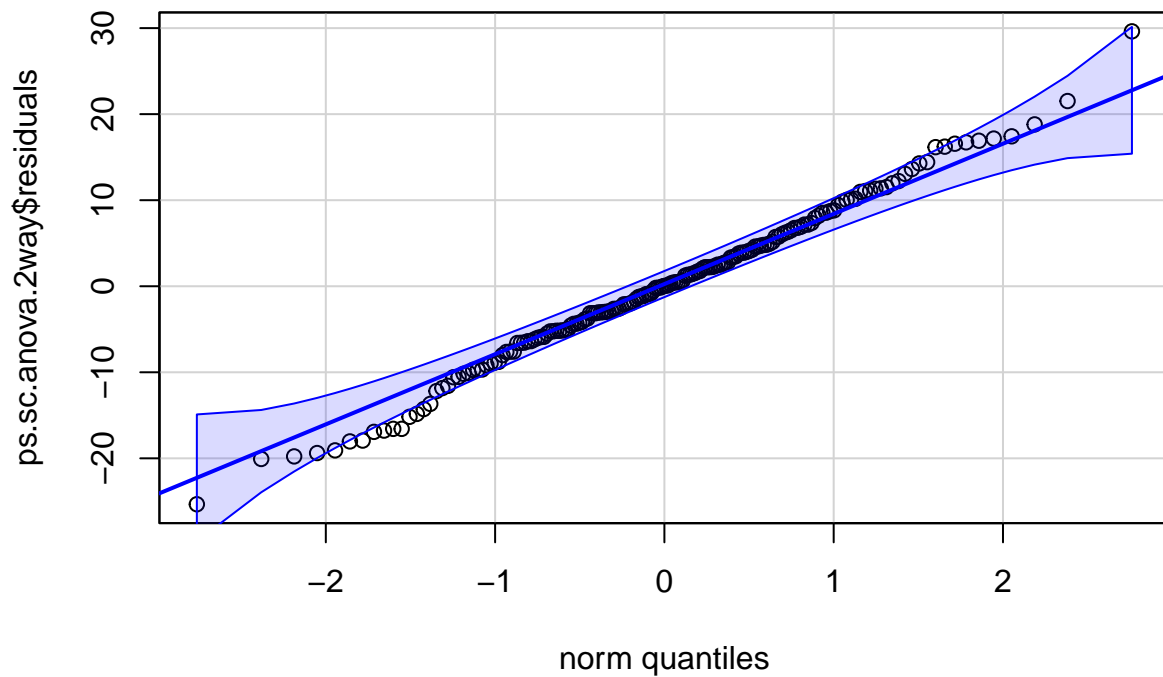
```
#normality  
qqPlot(ps.g.anova.2way$residuals, id = F)
```



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



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



```
#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
```

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

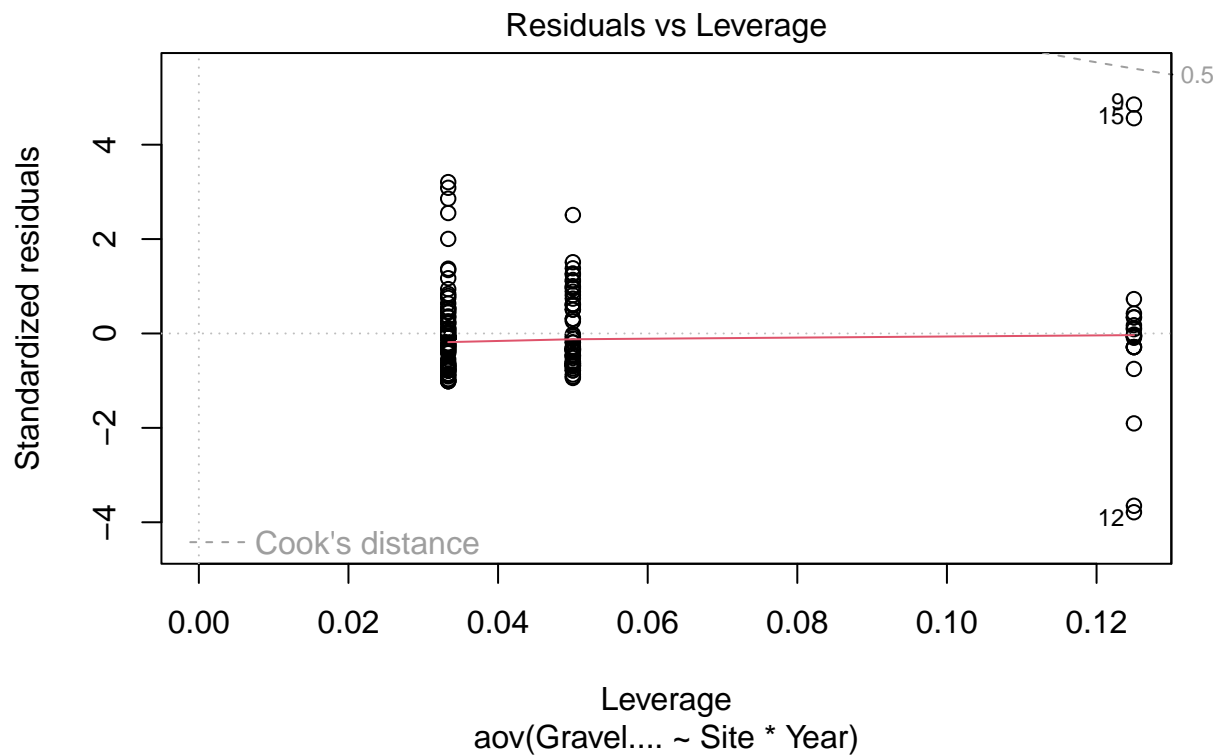
```
## Levene's Test for Homogeneity of Variance (center = median)
##      Df F value    Pr(>F)
## group  8  4.0447 0.0002052 ***
##      165
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

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

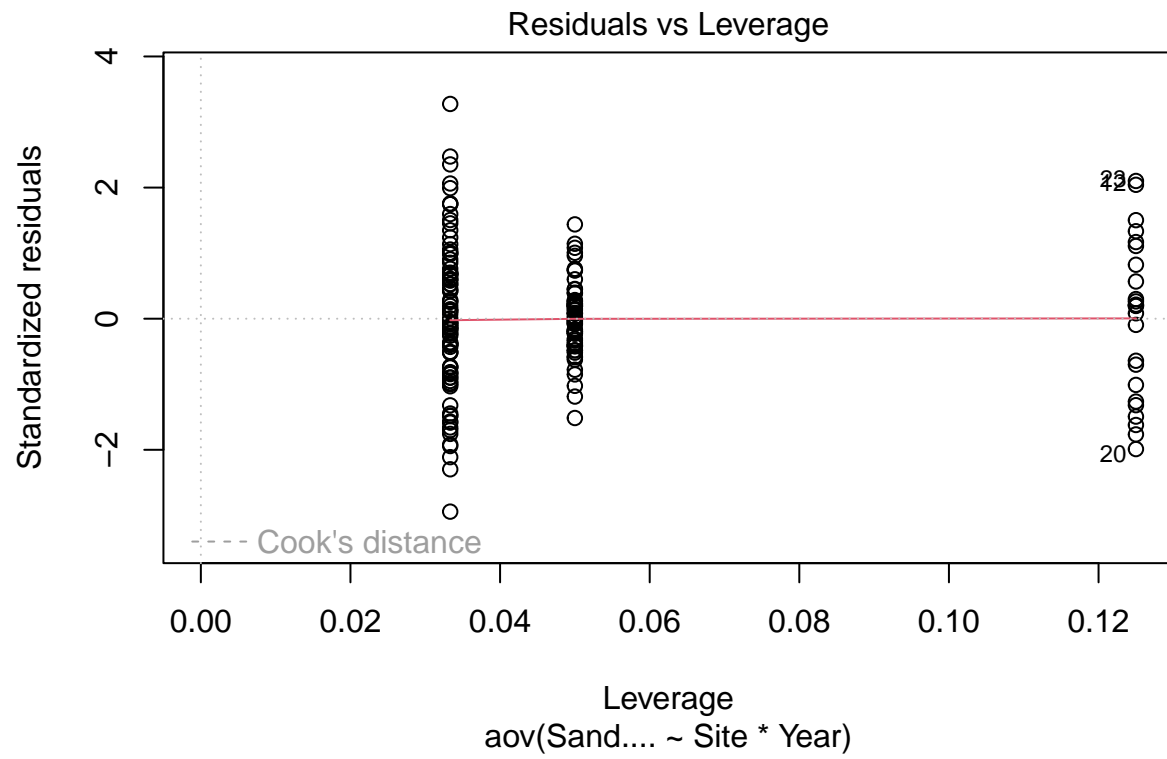
```
## Levene's Test for Homogeneity of Variance (center = median)
##      Df F value    Pr(>F)
## group  8  6.1011 7.027e-07 ***
##      165
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

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

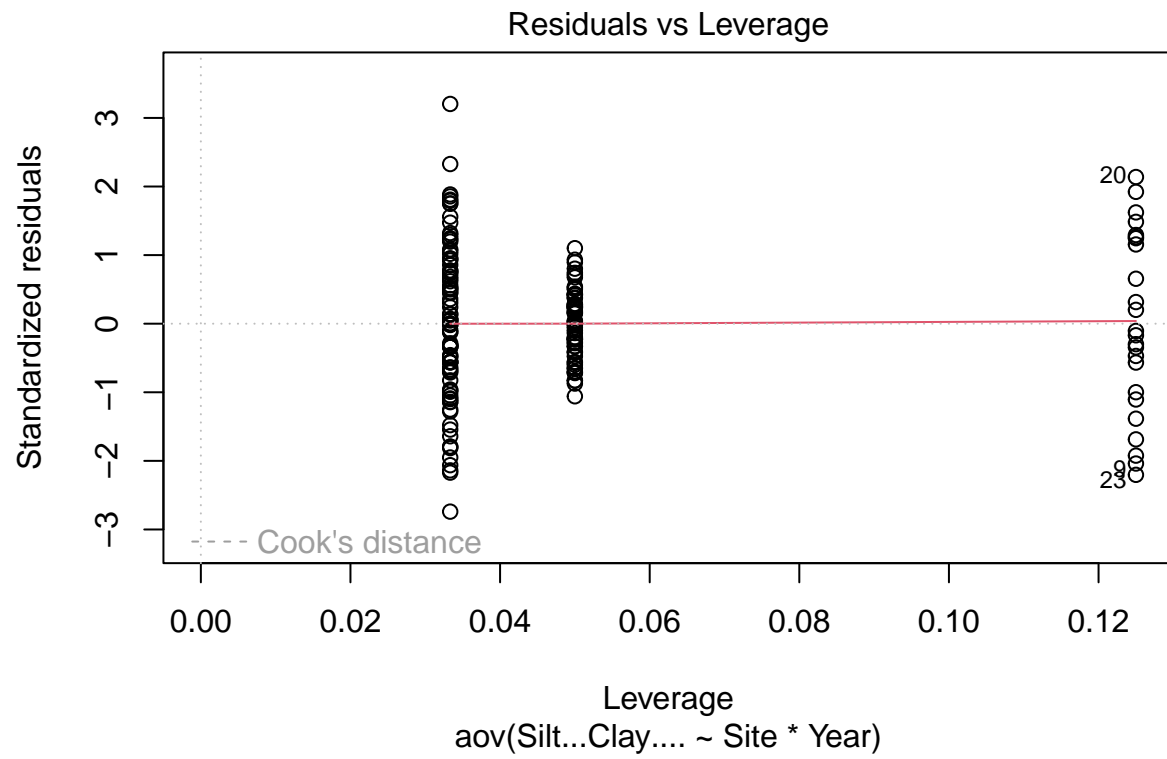
```
#outliers
plot(ps.g.anova.2way, which = 5)
```



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



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

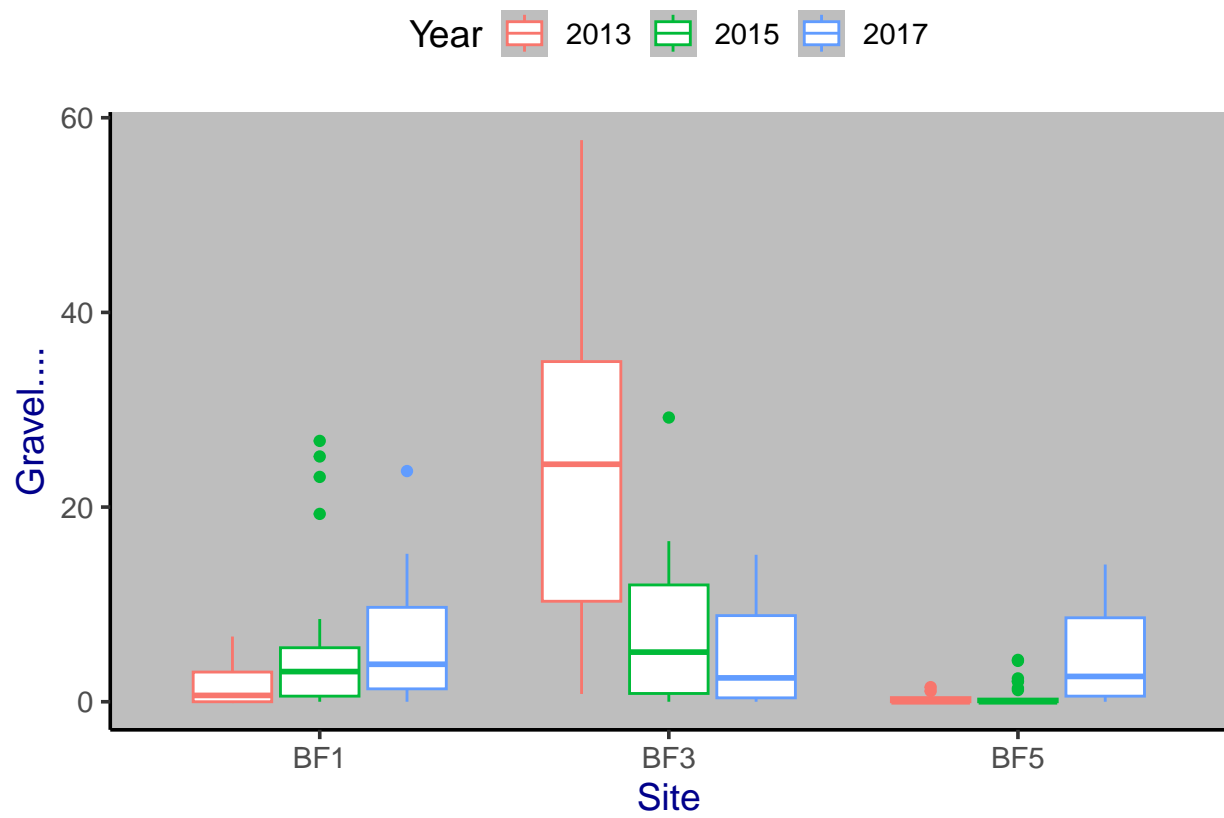


### 5.2.3 Residuals

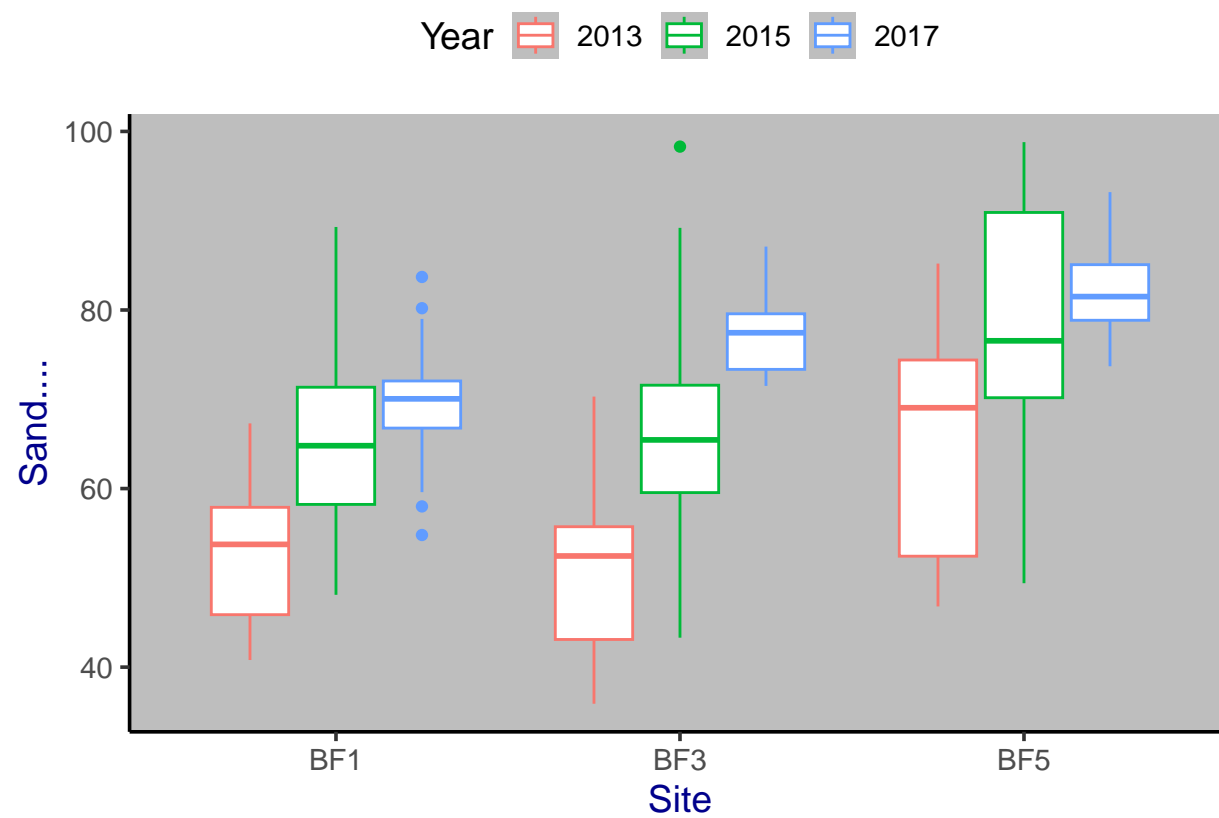
## 5.2.4 Plots

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

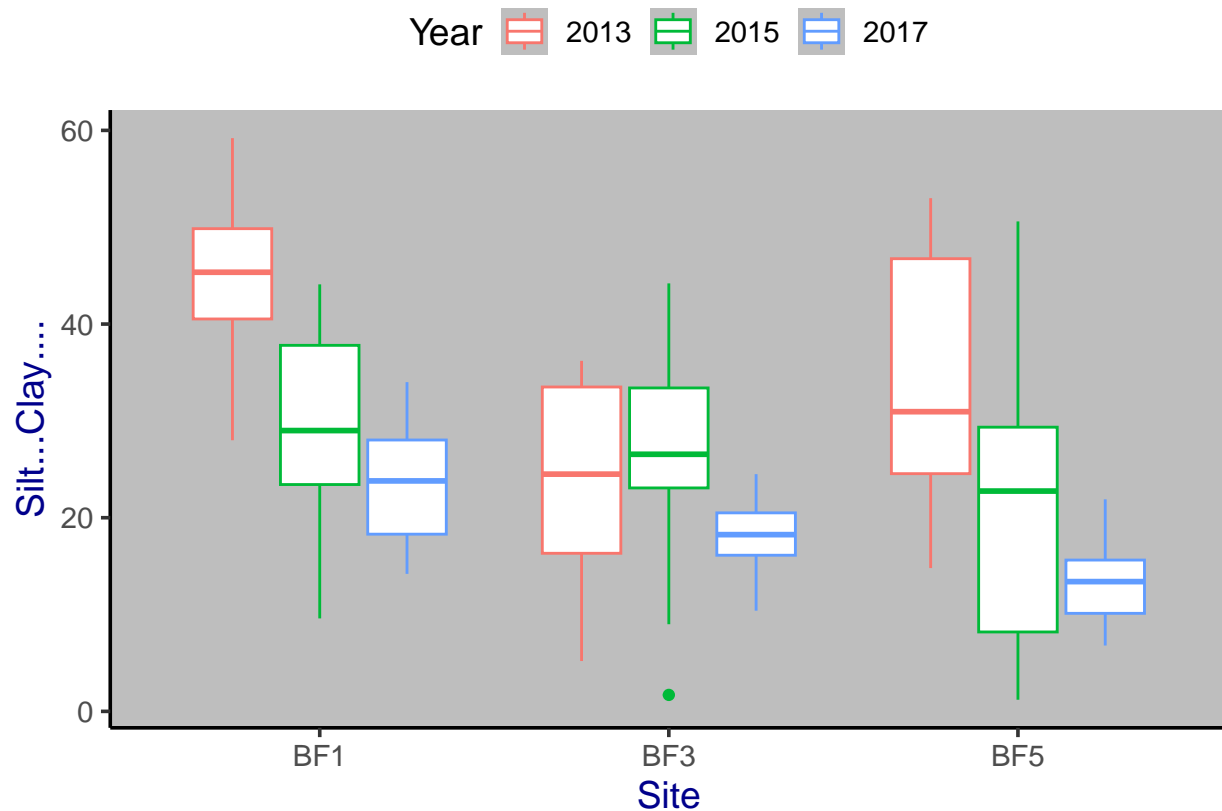




```
print(ps.s.anova.plot)
```



```
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<sub>a</sub>: 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
```

```
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 location does significantly influence bulk density at this depth.

```
#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
```

# 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
```

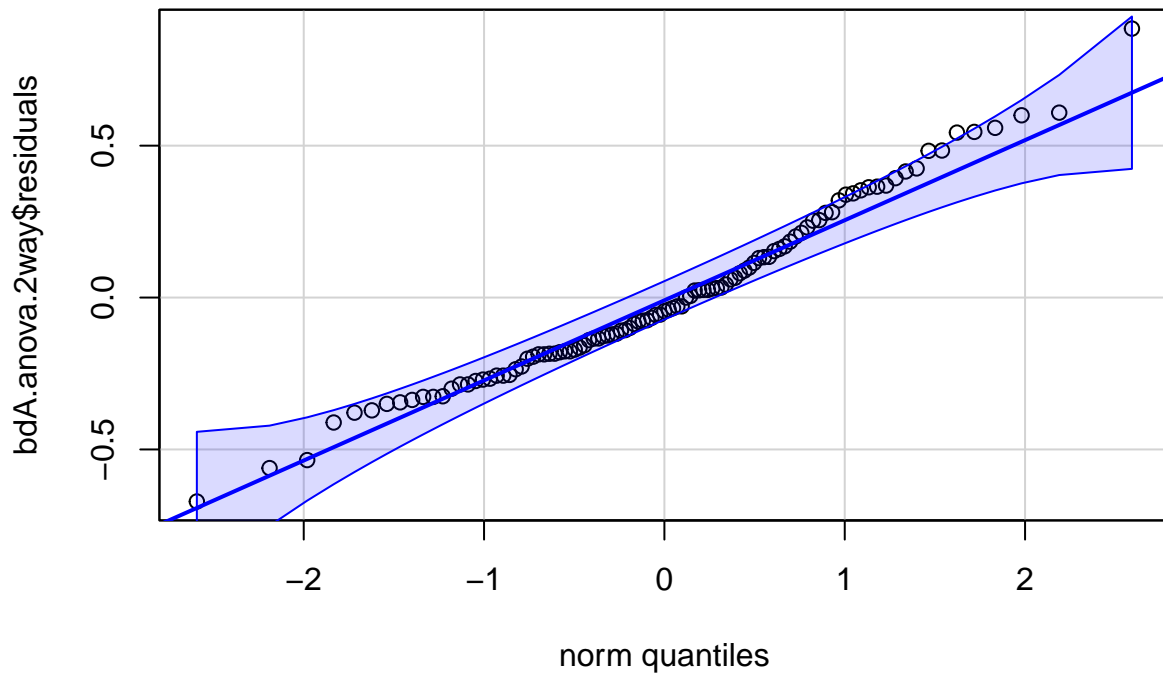


```
## BF5:2017-BF5:2015 -0.029666667 -0.25704405 1.977107e-01 0.9999741
## BF3:2017-BF1:2017 -0.002000000 -0.25107945 2.470794e-01 1.0000000
## BF5:2017-BF1:2017 -0.287000000 -0.53607945 -3.792055e-02 0.0119241
## BF5:2017-BF3:2017 -0.285000000 -0.53407945 -3.592055e-02 0.0129280
```

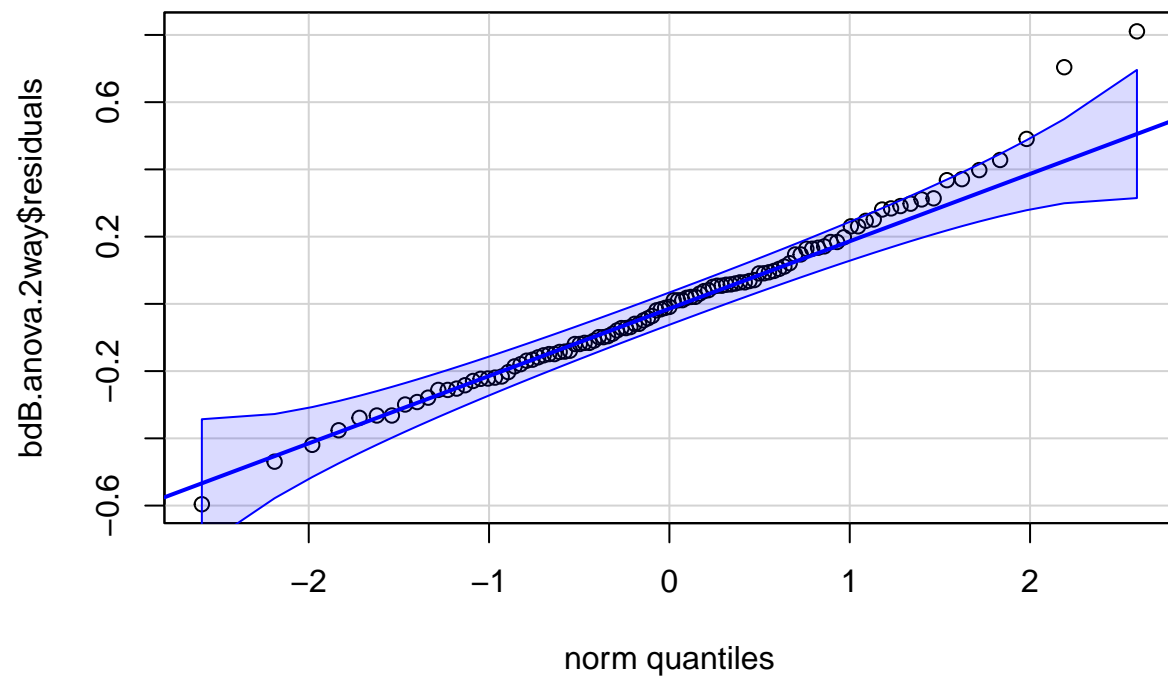
With a p-value of less than 0.05, we reject the null hypothesis and conclude that site location does significantly influence bulk density at this depth.

### 5.3.2 Assumptions

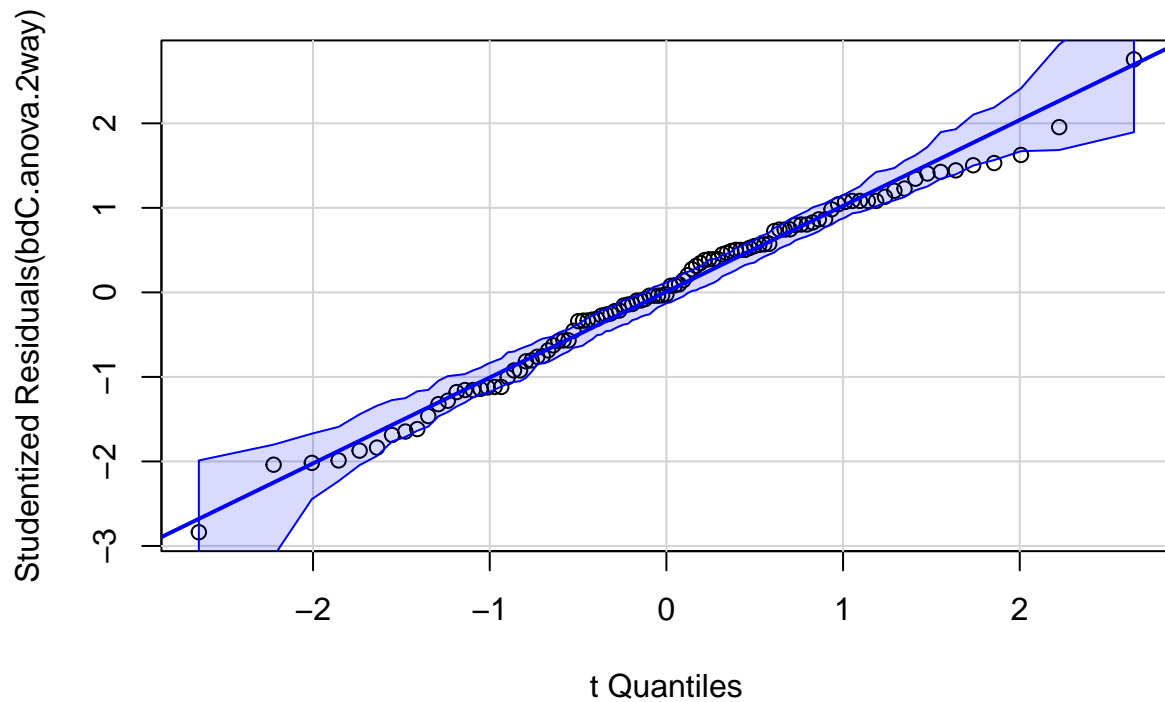
```
#normality
qqPlot(bdA.anova.2way$residuals, id = F)
```



```
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
```

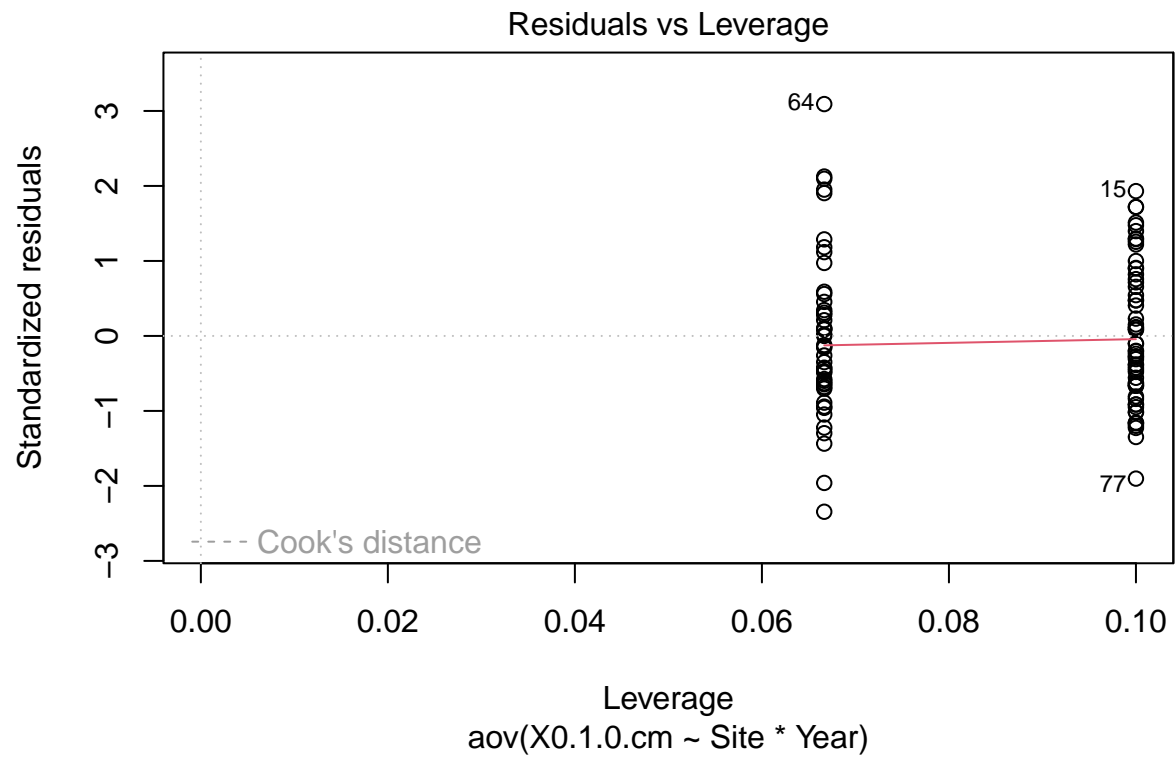
```
leveneTest(bdB.anova.2way)
```

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

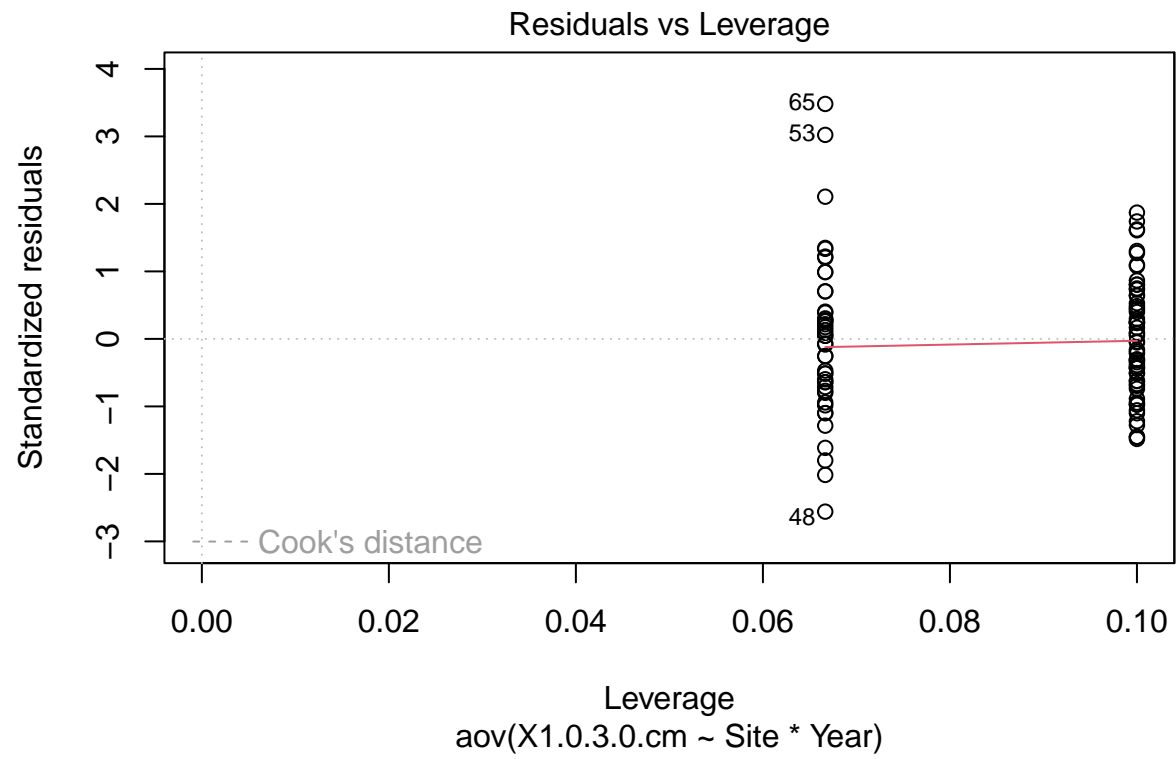
```
leveneTest(bdC.anova.2way)
```

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

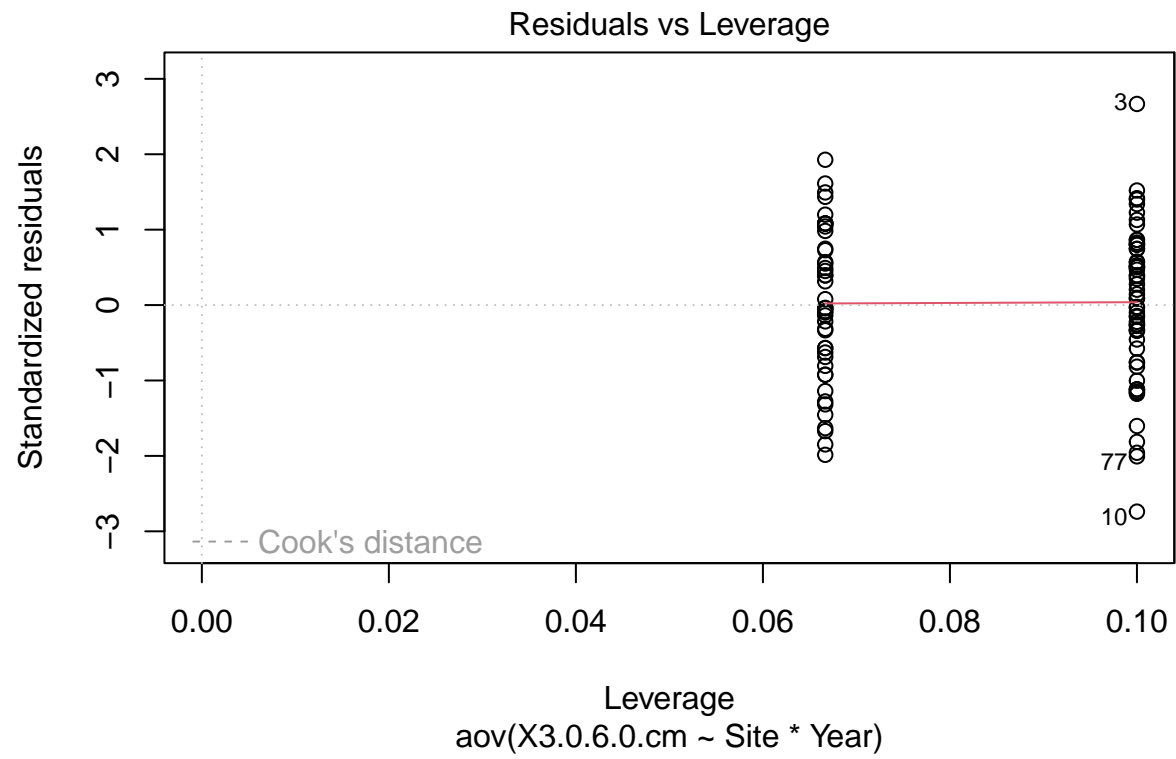
```
#outliers
plot(bdA.anova.2way, which = 5)
```



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



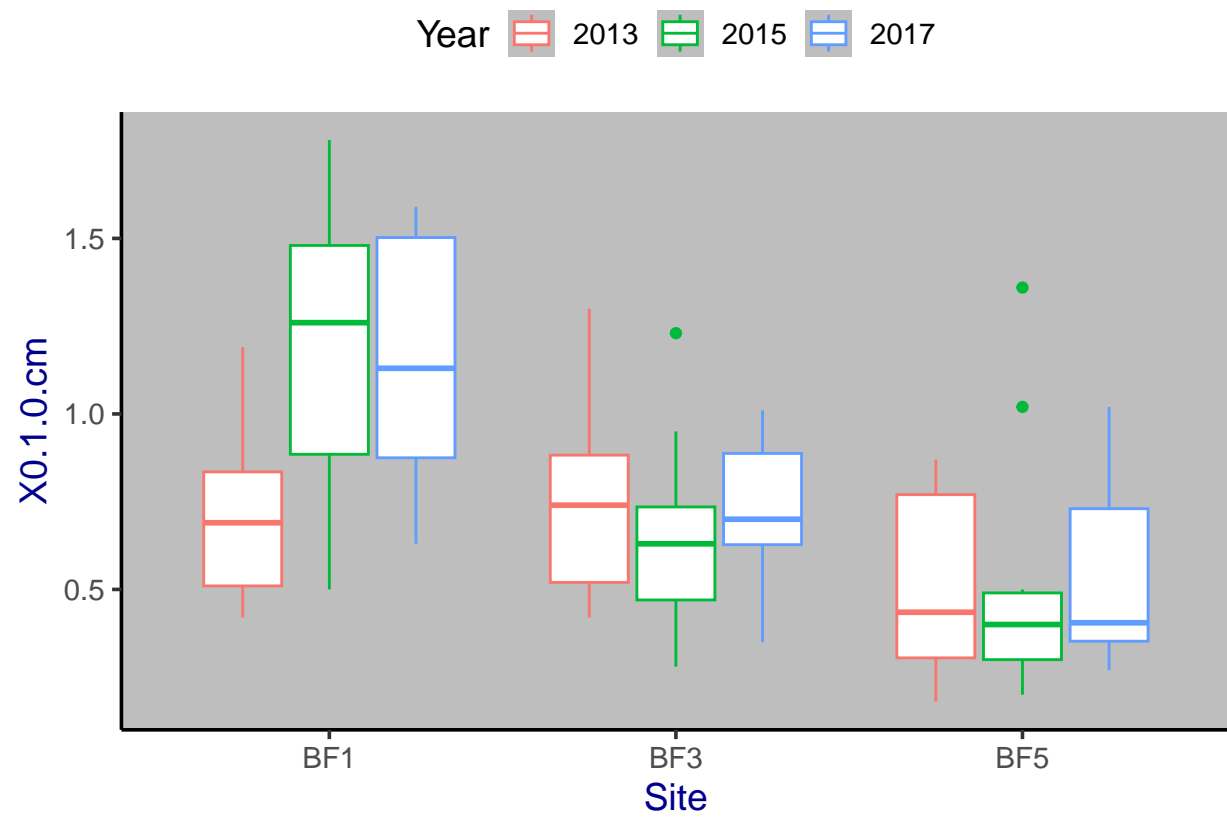
```
plot(bdC.anova.2way, which = 5)
```



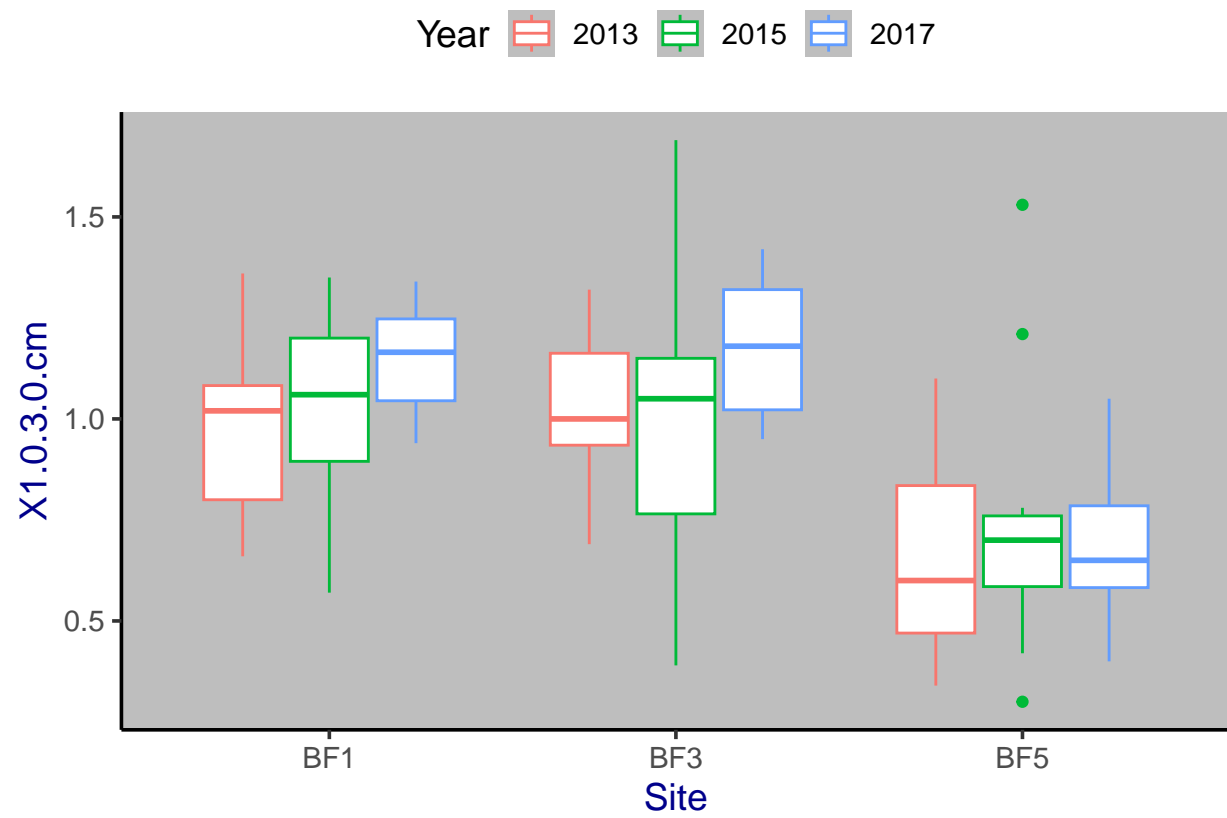
### 5.3.3 Residuals

#### 5.3.4 Plots

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

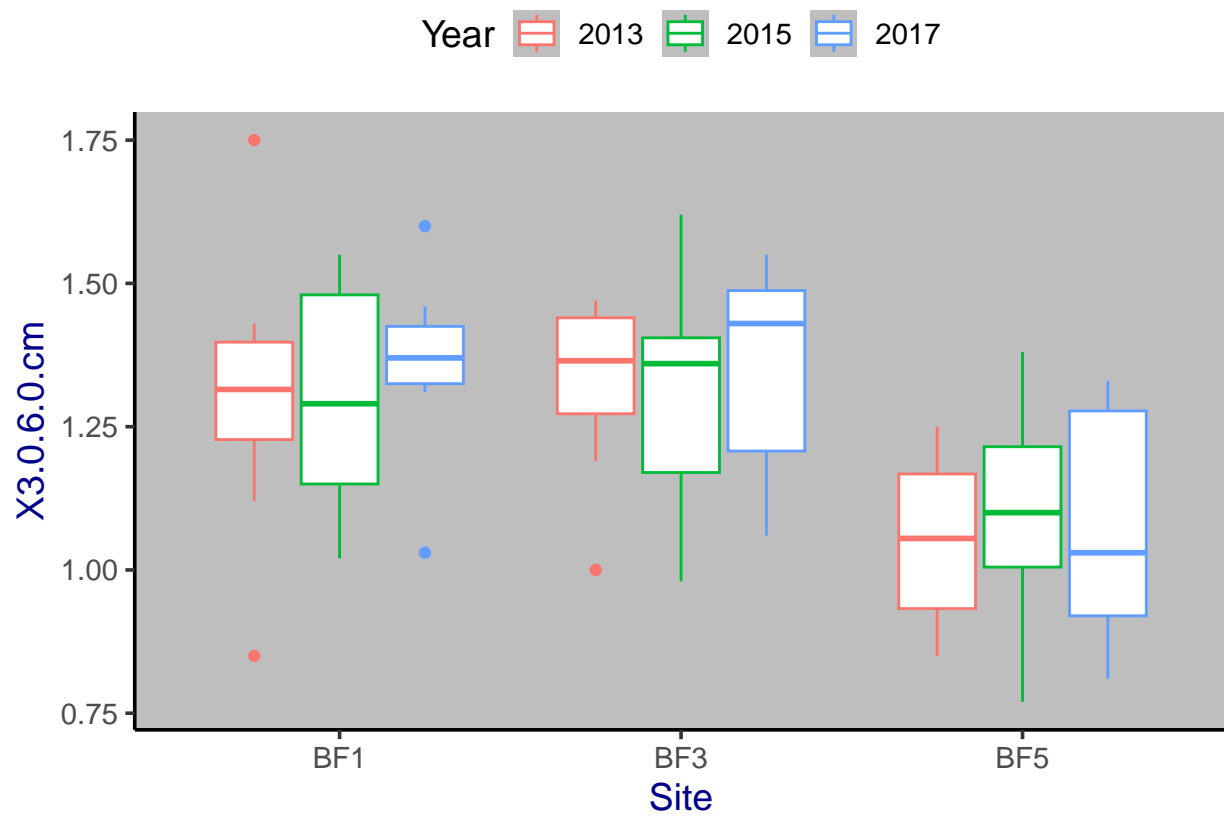


```
print(bdB.anova.plot)
```



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





## 6. Summary and Conclusions

## 7. References

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