Sagehen Groundwater Data Processing

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Load and Summarize Data

1. Upload data (.csv file)
2. Examine the following properties:

- length and frequency of the time series
- completeness of each time series
- descriptive statistics
  - basics: mean, CV, ACF for each variable
  - normality: histogram, qqplot, skewness, kurtosis

```
# Load libraries
library(dplyr)
library(astsa)
library(lubridate)
library(moments) # for skewness and kurtosis testing

# Setup directories and filepaths
home_dir='/Volumes/SANDISK_SSD_G40/GoogleDrive/GitHub/'
repository_dir = paste(home_dir,'sagehen_meadows/', sep='')
groundwater_filepath = paste(repository_dir,'data/field_observations/groundwater/biweekly_manual/groundw
observation_filepath = paste(repository_dir,'data/field_observations/groundwater/biweekly_manual/groundw

# Load groundwater data
groundwater <- read.csv(groundwater_filepath)

# Manage dates and times
groundwater$timestamp <- ymd_hms(groundwater$timestamp)

# Check timestamp formatting
str(groundwater$timestamp)
```

```
##  POSIXct[1:1116], format: "2018-06-01 07:45:00" "2018-06-18 08:32:00" "2018-06-30 08:55:00" ...
```

```
# Create columns for date and isoweek (starts on Monday)
groundwater <- groundwater %>% mutate(
  date = as.Date(timestamp),
  year = year(timestamp),
  isoweek = isoweek(date),
  day_of_year = yday(date))

# summarize the full times series
summary(groundwater)
```

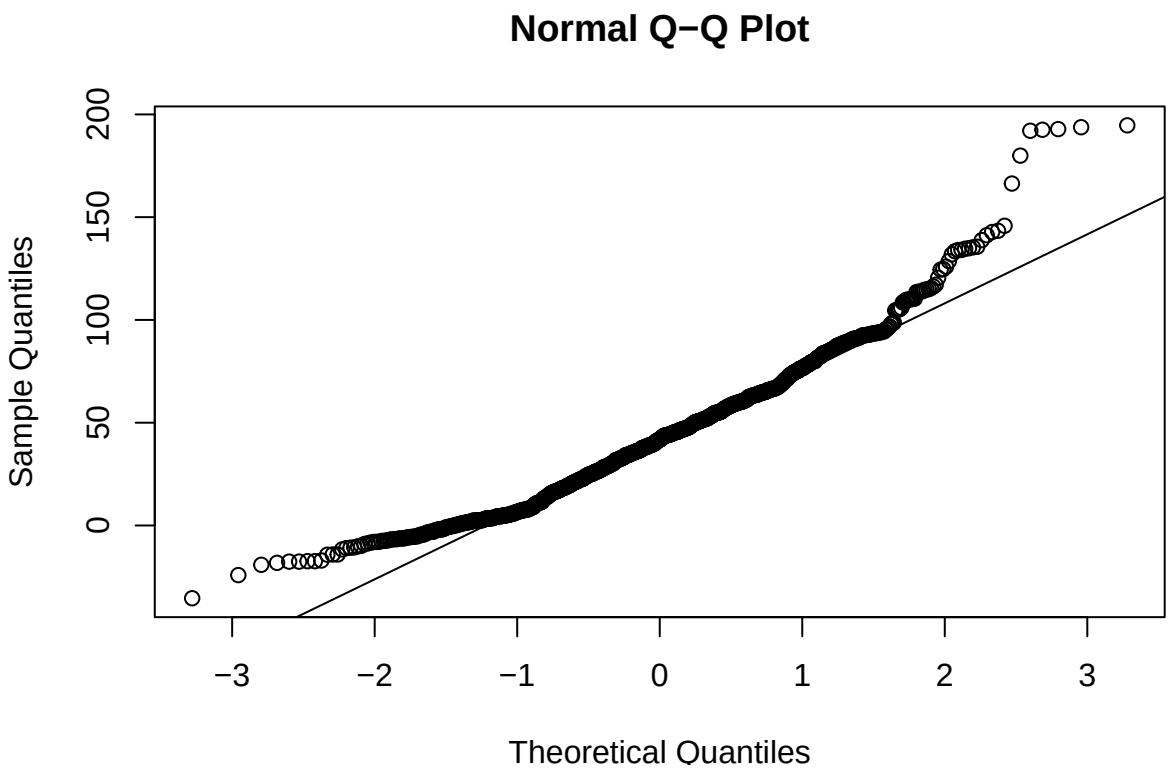
```
##    well_id            timestamp                     ground_to_water_cm
```

```
##  Length:1116        Min.   :2018-05-31 08:30:00.00   Min.   :-35.41
##  Class :character   1st Qu.:2018-10-14 08:55:45.00   1st Qu.: 18.30
##  Mode  :character   Median :2019-09-21 07:50:30.00   Median : 41.86
##                     Mean   :2020-03-02 18:05:30.48   Mean   : 43.85
##                     3rd Qu.:2021-07-20 06:53:30.00   3rd Qu.: 63.59
##                     Max.   :2021-11-14 10:14:00.00   Max.   :194.67
##                                                      NA's   :151
##       date                 year         isoweek       day_of_year
##  Min.   :2018-05-31   Min.   :2018   Min.   :20.00   Min.   :140.0
##  1st Qu.:2018-10-14   1st Qu.:2018   1st Qu.:26.00   1st Qu.:185.0
##  Median :2019-09-21   Median :2019   Median :31.00   Median :217.0
##  Mean   :2020-03-02   Mean   :2020   Mean   :31.94   Mean   :222.2
##  3rd Qu.:2021-07-20   3rd Qu.:2021   3rd Qu.:38.00   3rd Qu.:264.0
##  Max.   :2021-11-14   Max.   :2021   Max.   :46.00   Max.   :322.0
##
```

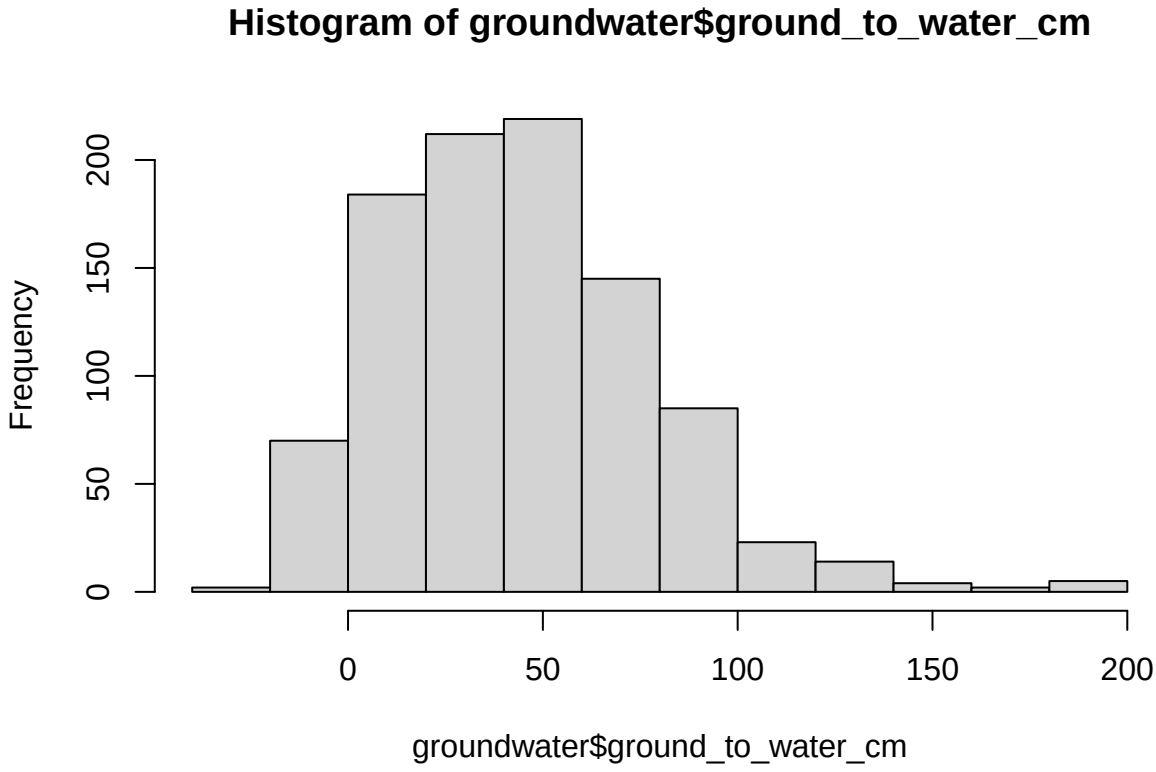
```r
# use z-score? test if data is normally distributed

# shapiro-wilk test; data is likely non-normal if p-value < 0.05
shapiro.test(groundwater$ground_to_water_cm)
```

```
##
##  Shapiro-Wilk normality test
##
## data:  groundwater$ground_to_water_cm
## W = 0.96037, p-value = 1.653e-15
```

```r
# results: p << 0.05, data is non-normal

# Q-Q plots; data is normal if falls on a straight line
qqnorm(groundwater$ground_to_water_cm)
qqline(groundwater$ground_to_water_cm)
```




```
# results: mostly normal but some outliers

# Histogram; check for bell-shaped curve
hist(groundwater$ground_to_water_cm)
```



```r
# Skewness; test if near 0 (symmetric), >0 (positive skew), <0 (neg skew)
skewness(groundwater$ground_to_water_cm, na.rm = TRUE)
```

```
## [1] 0.8304517
```

```r
# result: 0.83; positive skewed, >0.5 so moderately skewed

# Kurtosis; test for heavy tails (if ~3 normal, if >3 heavy tails + sharp peak, if <3 light tails, flat
kurtosis(groundwater$ground_to_water_cm, na.rm = TRUE)
```

```
## [1] 4.468805
```

```r
# result 4.5; heavy tail and sharp peak

# YES, USE Z-SCORE!
# ---TODO: Add ground_to_water_zscore column

# summarize the span of full time series by date
groundwater %>% summarize(
  start_date = min(date, na.rm=TRUE),
  stop_date = max(date, na.rm=TRUE),
  timespan = difftime(stop_date, start_date, units="days"),
  unique_dates_count = n_distinct(date)
)
```

```
##   start_date  stop_date  timespan unique_dates_count
## 1 2018-05-31 2021-11-14 1263 days                 53
```

```r
# summarize the weekly data
groundwater_weekly_summary <- groundwater %>%
  group_by(isoweek) %>%
  summarize(
      n_week = n()  # Number of entries in each week
  )
groundwater_weekly_summary
```

```
## # A tibble: 24 x 2
##    isoweek n_week
##      <dbl>  <int>
##  1      20     27
##  2      22     84
##  3      23     17
##  4      24     51
##  5      25     55
##  6      26     58
##  7      27     72
##  8      28      3
##  9      29     85
## 10      30     83
## # i 14 more rows
```

```r
# summarize spacing of the full time series
unique_observations <- groundwater %>%
  select(-well_id, -ground_to_water_cm, -timestamp) %>%
  distinct(date, .keep_all=TRUE) %>%
  group_by(year) %>%
  arrange(date) %>%
```

```
  mutate(day_diff = as.numeric(difftime(lead(date), date, units="days")))

unique_observations
```

```
## # A tibble: 53 x 5
## # Groups:   year [3]
##    date        year isoweek day_of_year day_diff
##    <date>     <dbl>   <dbl>       <dbl>    <dbl>
##  1 2018-05-31  2018      22         151        1
##  2 2018-06-01  2018      22         152       17
##  3 2018-06-18  2018      25         169        1
##  4 2018-06-19  2018      25         170       11
##  5 2018-06-30  2018      26         181        1
##  6 2018-07-01  2018      26         182       15
##  7 2018-07-16  2018      29         197        1
##  8 2018-07-17  2018      29         198        8
##  9 2018-07-25  2018      30         206        2
## 10 2018-07-27  2018      30         208       14
## # i 43 more rows
```

```
#write.csv(unique_observations, observation_filepath)

unique_observations %>% summarize(
  max_days = max(day_diff, na.rm=TRUE),
  mean_days = mean(day_diff, na.rm=TRUE)
)
```

```
## # A tibble: 3 x 3
##    year max_days mean_days
##   <dbl>    <dbl>     <dbl>
## 1  2018       35     10.1
## 2  2019       19      7.05
## 3  2021       39     13.7
```

```
# filter measurements, only before 11a
am_time_limit <- 10
groundwater_filter_by_time <- groundwater %>%
  filter(hour(timestamp) < am_time_limit)

# number of rows lost from this filter
nrow(groundwater) - nrow(groundwater_filter_by_time)
```

```
## [1] 193
```

```
# filter for duplicate entries (same well, same week)
groundwater_filter_duplicates <- groundwater_filter_by_time %>%
  group_by(well_id, isoweek) %>%
  distinct(well_id, isoweek, .keep_all = TRUE) %>%
  ungroup()

# compare and validate results
summary(groundwater)
```

```
##    well_id            timestamp                      ground_to_water_cm
##  Length:1116        Min.   :2018-05-31 08:30:00.00   Min.   :-35.41
##  Class :character   1st Qu.:2018-10-14 08:55:45.00   1st Qu.: 18.30
```

```
##  Mode  :character   Median :2019-09-21 07:50:30.00   Median : 41.86
##                     Mean   :2020-03-02 18:05:30.48   Mean   : 43.85
##                     3rd Qu.:2021-07-20 06:53:30.00   3rd Qu.: 63.59
##                     Max.   :2021-11-14 10:14:00.00   Max.   :194.67
##                                                      NA's   :151
##       date                 year         isoweek       day_of_year
##  Min.   :2018-05-31   Min.   :2018   Min.   :20.00   Min.   :140.0
##  1st Qu.:2018-10-14   1st Qu.:2018   1st Qu.:26.00   1st Qu.:185.0
##  Median :2019-09-21   Median :2019   Median :31.00   Median :217.0
##  Mean   :2020-03-02   Mean   :2020   Mean   :31.94   Mean   :222.2
##  3rd Qu.:2021-07-20   3rd Qu.:2021   3rd Qu.:38.00   3rd Qu.:264.0
##  Max.   :2021-11-14   Max.   :2021   Max.   :46.00   Max.   :322.0
##
```

```
summary(groundwater_filter_by_time)
```

```
##    well_id            timestamp                     ground_to_water_cm
##  Length:923         Min.   :2018-05-31 08:30:00.00   Min.   :-19.12
##  Class :character   1st Qu.:2018-09-29 08:25:00.00   1st Qu.: 19.30
##  Mode  :character   Median :2019-09-03 07:55:00.00   Median : 41.97
##                     Mean   :2020-02-26 00:58:58.04   Mean   : 44.37
##                     3rd Qu.:2021-07-05 08:14:00.00   3rd Qu.: 63.71
##                     Max.   :2021-11-14 09:59:00.00   Max.   :194.67
##                                                      NA's   :133
##       date                 year         isoweek      day_of_year
##  Min.   :2018-05-31   Min.   :2018   Min.   :20.0   Min.   :140.0
##  1st Qu.:2018-09-29   1st Qu.:2018   1st Qu.:26.0   1st Qu.:182.0
##  Median :2019-09-03   Median :2019   Median :30.0   Median :207.0
##  Mean   :2020-02-25   Mean   :2020   Mean   :30.9   Mean   :214.8
##  3rd Qu.:2021-07-05   3rd Qu.:2021   3rd Qu.:36.0   3rd Qu.:251.0
##  Max.   :2021-11-14   Max.   :2021   Max.   :45.0   Max.   :318.0
##
```

```
summary(groundwater_filter_duplicates)
```

```
##    well_id            timestamp                     ground_to_water_cm
##  Length:688         Min.   :2018-05-31 08:30:00.00   Min.   :-19.12
##  Class :character   1st Qu.:2018-08-10 08:31:30.00   1st Qu.: 17.84
##  Mode  :character   Median :2019-08-04 07:59:00.00   Median : 39.80
##                     Mean   :2019-12-02 23:25:09.50   Mean   : 42.73
##                     3rd Qu.:2021-06-20 07:12:30.00   3rd Qu.: 63.38
##                     Max.   :2021-11-14 09:59:00.00   Max.   :193.76
##                                                      NA's   :109
##       date                 year         isoweek       day_of_year
##  Min.   :2018-05-31   Min.   :2018   Min.   :20.00   Min.   :140.0
##  1st Qu.:2018-08-10   1st Qu.:2018   1st Qu.:26.00   1st Qu.:181.0
##  Median :2019-08-04   Median :2019   Median :30.00   Median :208.0
##  Mean   :2019-12-02   Mean   :2019   Mean   :31.02   Mean   :215.8
##  3rd Qu.:2021-06-20   3rd Qu.:2021   3rd Qu.:36.00   3rd Qu.:251.0
##  Max.   :2021-11-14   Max.   :2021   Max.   :45.00   Max.   :318.0
##
```

```
# test completeness of full time series
# ---TODO: create a ground_to_water_greater_than column for NO WATER readings
#          to capture the depth of the well; this is more info than nothing.
```

```r
# completeness in terms of entries with NA
# ---NOTE: expect 153 NA entries due to NO WATER readings

groundwater %>%
  summarize(
    na_sum = sum(is.na(ground_to_water_cm)),
    na_percent = 100 * sum(is.na(ground_to_water_cm)) / n())
```

```
##   na_sum na_percent
## 1    151   13.53047
```

```r
# basic descriptive statistics across all groundwater readings: mean, CV, ACF
groundwater %>%
  summarize(
    mean_value = mean(ground_to_water_cm, na.rm = TRUE),
    sd_value = sd(ground_to_water_cm, na.rm = TRUE),
    var_value = var(ground_to_water_cm, na.rm = TRUE),
    cv_value = 100 * sd_value / mean_value
  )
```

```
##   mean_value sd_value var_value cv_value
## 1   43.84532 34.49195  1189.695 78.66735
```

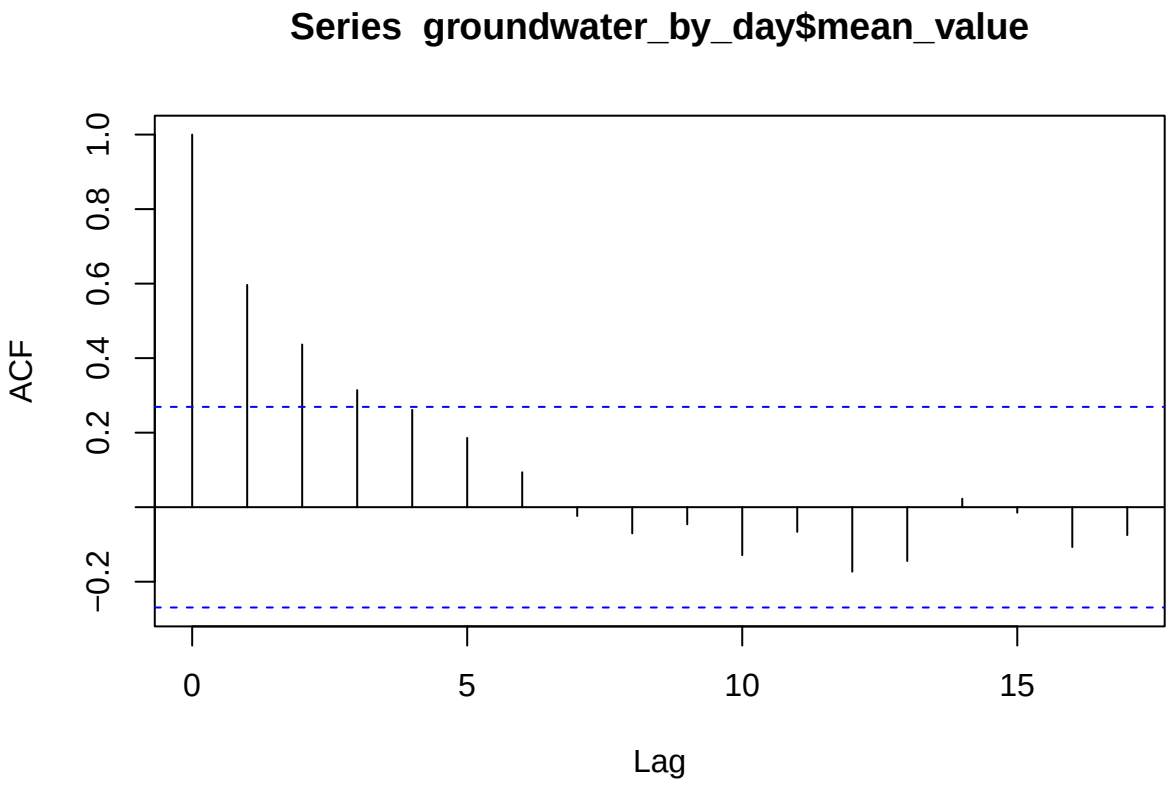
```r
groundwater_by_day <- groundwater %>%
  group_by(date) %>%
  summarise(
    mean_value = mean(ground_to_water_cm, na.rm = TRUE),
    sd_value = sd(ground_to_water_cm, na.rm = TRUE),
    var_value = var(ground_to_water_cm, na.rm = TRUE)
  )

# basic descriptive statistics by groupings: mean, CV, ACF for each variable
groundwater_by_well <- groundwater %>%
  group_by(well_id) %>%
  summarise(
    mean_value = mean(ground_to_water_cm, na.rm = TRUE),
    sd_value = sd(ground_to_water_cm, na.rm = TRUE),
    var_value = var(ground_to_water_cm, na.rm = TRUE)
  )
groundwater_by_well
```

```
## # A tibble: 54 x 4
##    well_id  mean_value sd_value var_value
##    <chr>         <dbl>    <dbl>     <dbl>
##  1 EEF-1          28.8    31.7     1003.
##  2 EER-1          34.1    10.8      117.
##  3 EET-1          59.9    32.8     1076.
##  4 EET-2         101.     41.2     1699.
##  5 EET-XB4S       31.6    20.0      400.
##  6 EFF-XA1N       40.1    11.3      127.
##  7 EFF-XA2N       27.0    11.6      134.
##  8 EFF-XB7S       30.5    36.8     1357.
##  9 EFR-XB1S       45.2     4.96      24.6
## 10 EFR-XB2N       28.7    11.3      127.
## # i 44 more rows
```

```r
groundwater_by_well_year <- groundwater %>%
  mutate(year = year(timestamp)) %>%
  group_by(well_id, year) %>%
  summarise(
    mean_value = mean(ground_to_water_cm, na.rm = TRUE),
    sd_value = sd(ground_to_water_cm, na.rm = TRUE),
    var_value = var(ground_to_water_cm, na.rm = TRUE),
    .groups = "keep"
  )
groundwater_by_well_year
```

```
## # A tibble: 141 x 5
## # Groups:   well_id, year [141]
##    well_id  year mean_value sd_value var_value
##    <chr>   <dbl>      <dbl>    <dbl>     <dbl>
##  1 EEF-1    2018       6.21     7.70      59.3
##  2 EEF-1    2019      19.2     21.6      465.
##  3 EEF-1    2021      61.0     29.8      888.
##  4 EER-1    2018      34.5      8.50      72.3
##  5 EER-1    2019      27.6     12.4      155.
##  6 EER-1    2021      39.1      8.76      76.7
##  7 EET-1    2018      65.4     31.7     1007.
##  8 EET-1    2019      57.0     41.7     1736.
##  9 EET-1    2021      56.4     31.1      968.
## 10 EET-2    2019     107.      20.4      418.
## # i 131 more rows
```

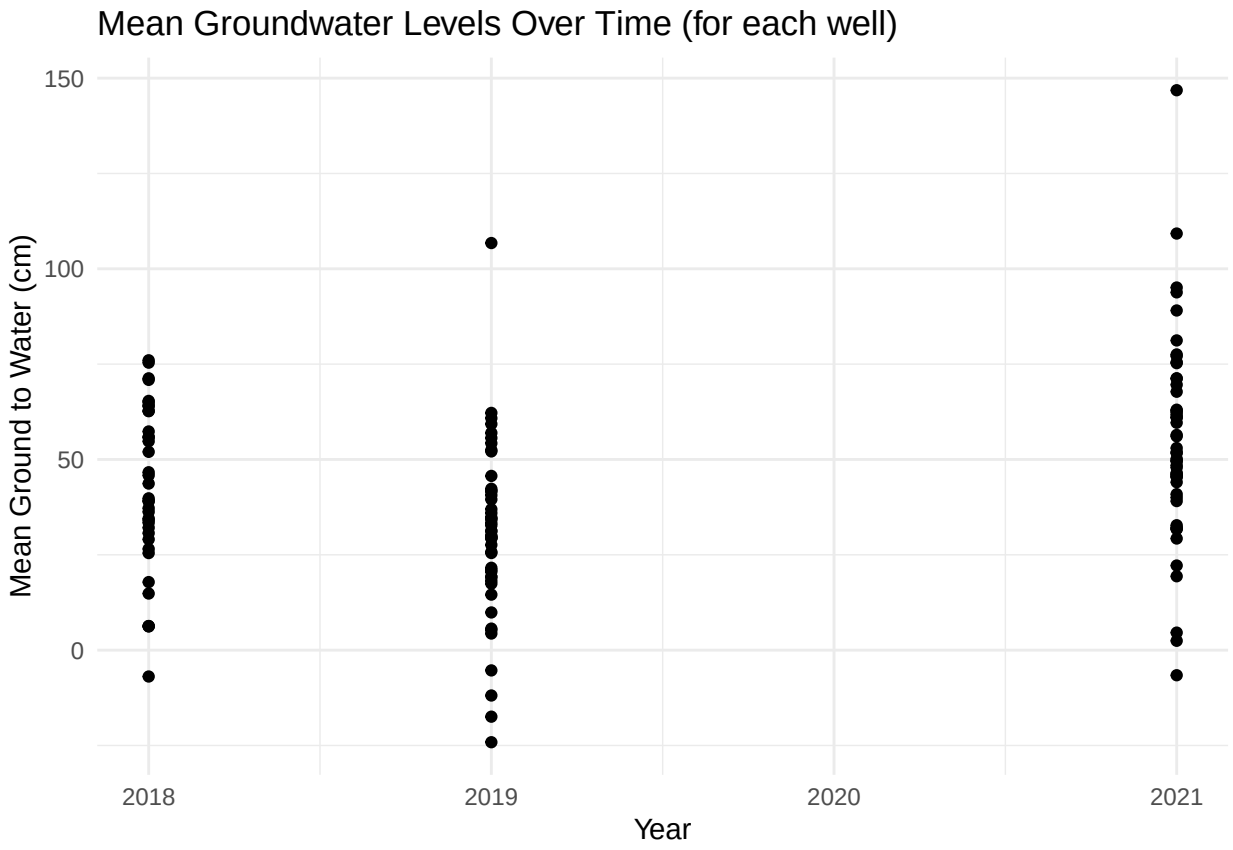
```r
# Trying to get acf, but not sure if this summarized data means anything
acf(groundwater_by_day$mean_value)
```



```
# TODO Next step summary statistics
# ------wells in each meadow group: kiln, east, low
# ------wells from each plant functional type: sedge, willow, mixed herbaceous, pine
# ------wells from each hydrogeomorphic zone: riparian, terrace, fan

# TODO: Next time series to consider
# ------discharge (at one point)
# ------daily precipitation (at one point)
# ------sunlight, aka PAR (at one point)
# ------max, mean daily temperature (at each meadow)
```

Plots

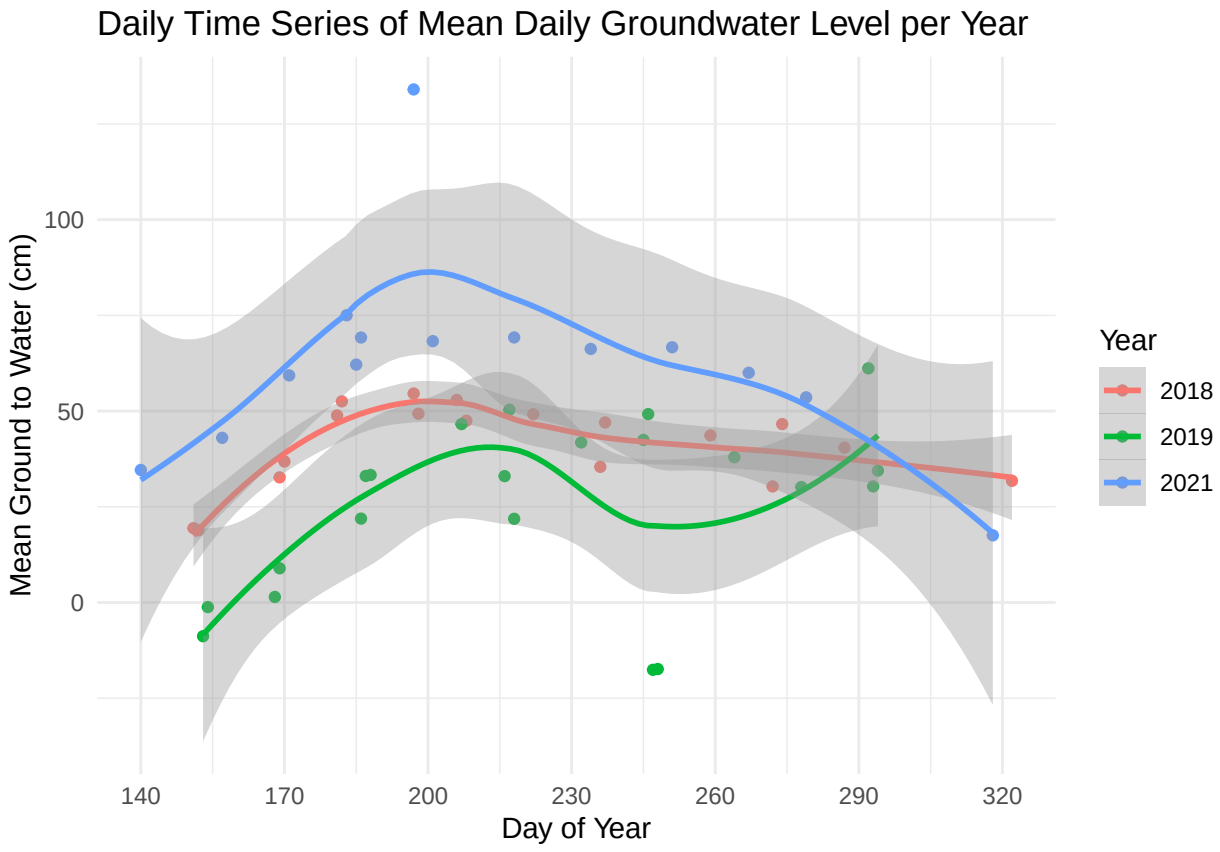
```
# Load libraries
library(ggplot2)
library(tidyr)

# Plot (1): the mean annual groundwater level for all wells for each year
ggplot(groundwater_by_well_year, aes(x = year, y = mean_value, group = well_id)) +
  geom_point() +  # Optional: add points at each data point
  labs(title = "Mean Groundwater Levels Over Time (for each well)",
       x = "Year", y = "Mean Ground to Water (cm)") +
  theme_minimal()
```




```
# Plot (2): year-over-year daily time series of mean groundwater level

# ---Setup dataframe with new columns for year and day_of_year
```

```r
groundwater_by_day <- groundwater_by_day %>%
  mutate(
    year = year(date),                # Extract the year from Date
    day_of_year = yday(date)          # Extract the day of year (1-365/366)
  )

# ---Add NA values for days with no measurement (or mean_value)
complete_groundwater_by_day <- groundwater_by_day %>%
  group_by(year) %>%
  complete(day_of_year =
           min(groundwater_by_day$day_of_year):max(groundwater_by_day$day_of_year),
           fill = list(mean_value = NA))  # Fill missing days with NA

# ---Plot it!
ggplot(complete_groundwater_by_day, aes(x = day_of_year, y = mean_value, color = factor(year), group = y
  geom_point() +
  geom_smooth() +
  theme_bw() +
  labs(title = "Daily Time Series of Mean Daily Groundwater Level per Year",
       x = "Day of Year",
       y = "Mean Ground to Water (cm)",
       color = "Year") +
  scale_x_continuous(breaks = seq(min(groundwater_by_day$day_of_year),
                                  max(groundwater_by_day$day_of_year), by = 30)) +  # Customize x-axis
  theme_minimal()
```

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



Research Questions and Hypotheses

1. How does meadow groundwater vary by season and climate as influenced by elevation, hydrogeomorphic zones, and evapotranspiration rates of plant functional types?

- Hypothesis: I expect evapotranspiration to drive daily and seasonal groundwater levels with sensitivity to meteorology and day length.

2. What controls plant functional type phenology?

- Hypothesis: peak productivity and senescence will correlate to groundwater levels as governed by meteorology but moderated by hydrogeomorphic zones and elevation.

3. Does topography or subsurface character influence groundwater reliability?

- Hypothesis: I expect that groundwater reliability will correlate to topographic convergence or subsurface boundaries (i.e. differing conductivity).