FACTORS INFLUENCING RECHARGE TO THE MEMPHIS AQUIFER IN AN URBAN WATERSHED

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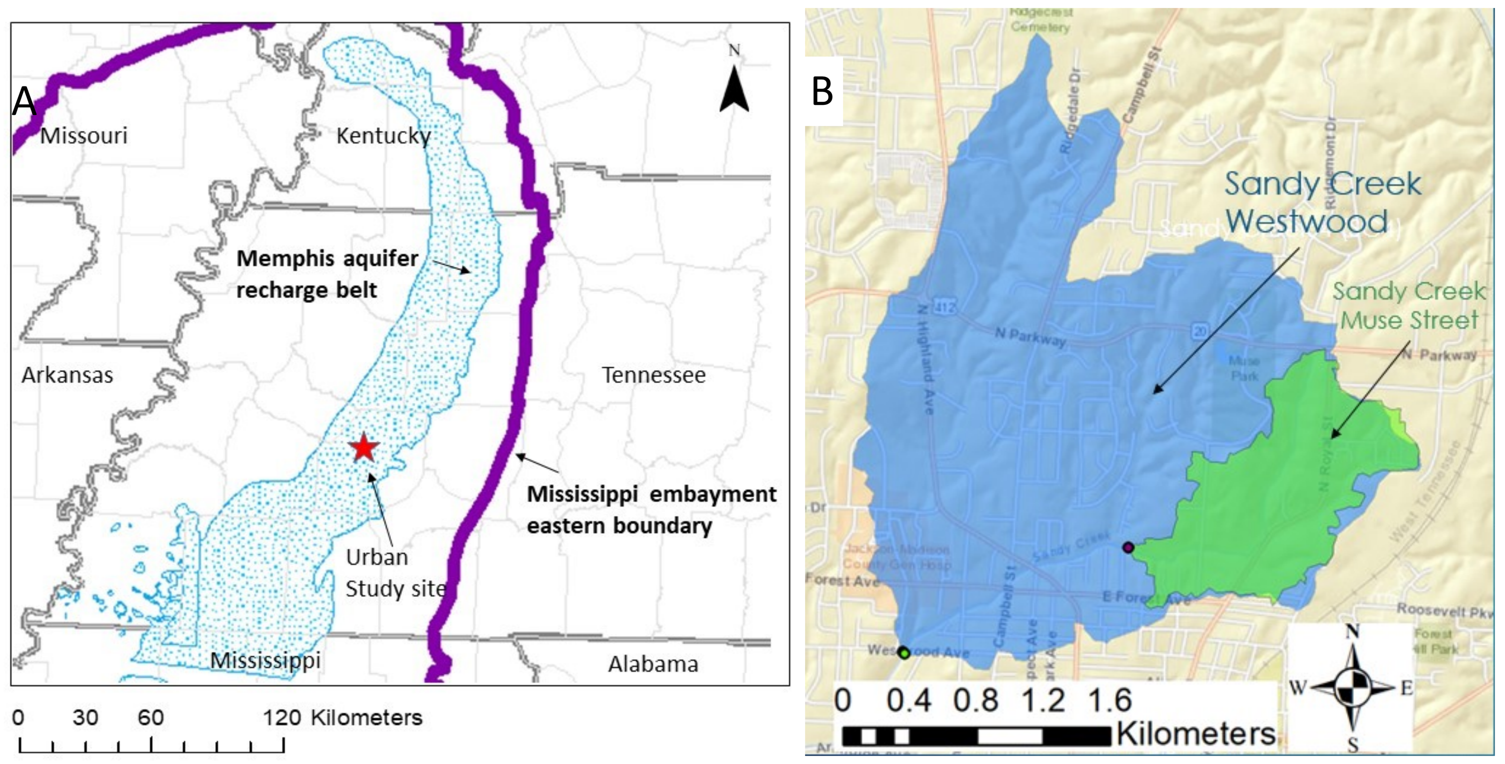
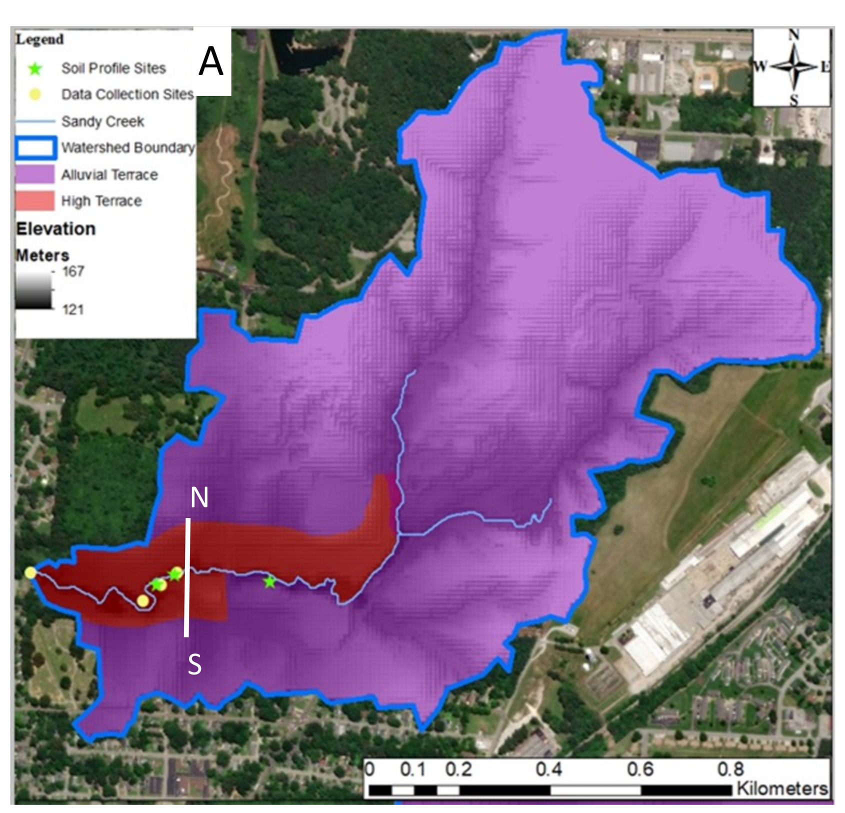


Figure 1. A. Regional map with study site (red star) shown in comparison to Memphis aquifer recharge area (modified from Brahana and Broshears, 2001) B. Map of the Sandy Creek study area showing the Westwood Avenue and Muse Street sub-basins (from Smith, 2019).

Introduction

The West Tennessee River Basin Authority (WTRBA) previously completed several stream restoration projects throughout West Tennessee since 2010, with the overall goals of decreasing overbank flooding and erosion, and improving stream hydrology. The impacts of stream restoration on recharge to the underlying Memphis aquifer, the major water supply aquifer in the region, are unknown, but needed to better manage groundwater resources in the region. Recent studies in the Jackson, Tennessee area include two investigations of water balance and recharge processes through annual cycles in the Sandy Creek Watershed (Simco, 2018; Smith, 2019). The Sandy Creek watershed areas of interest are Muse Street, 1.26 square kilometers, and Westwood Avenue, 7.11 square kilometers (Figure 1). The Muse Street watershed is a smaller, upstream portion of the larger Westwood Avenue watershed, and is primarily in forest and residential land use (Figure 2).

The current study is utilizing water balance data from the Muse Street watershed over 3 years to evaluate the degree to which weather, soil, and discharge data can be used to predict recharge in watersheds of similar land use, geomorphology, and subsurface geology. Precipitation, evapotranspiration, and discharge are being monitored continuously, whereas soil moisture is being monitored on a monthly basis. Multiple regression models using different sets of variables are being developed to predict monthly and yearly recharge in the watershed.



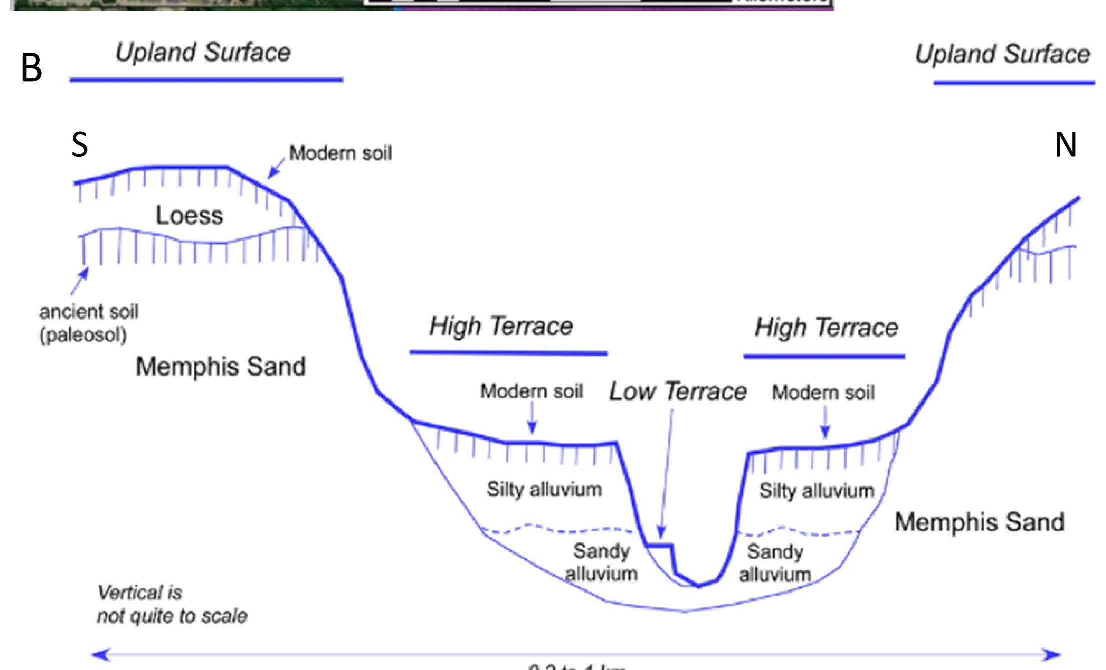


Figure 2. A. map of Sandy Creek Muse Street watershed showing upland surface in purple and high terrace in red (from Simco, 2018). B. Schematic cross-section from north (N) to south (S) across Sandy Creek valley showing landforms and stratigraphy (Smith, 2019). C. Image of Muse Street sandy streambed showing high terrace, on the left, and low terrace, on the right.

Abstract

The Memphis aquifer is a valuable groundwater resource for west Tennessee. To ensure sustainability of this resource, aquifer recharge processes need to be fully understood and quantified. Previous studies of recharge to the Memphis aquifer in rural and urban areas show recharge occurs more efficiently where precipitation or runoff infiltrates into the Memphis Sand or sandy soil exposed at the surface. Hydrologic and meteorological data collected and analyzed over a three-year period are used to determine recharge rates by water balance in the outcrop belt of the Memphis Sand in the Sandy Creek watershed in Jackson, Tennessee. These data help determine the sensitivity of recharge to meteorological and runoff measurements in the watershed and used to develop a predictive relationship. Sandy Creek is an ephemeral urban stream incised into the Memphis Sand with water primarily present during or immediately after precipitation events. Previous studies indicate annual recharge rates of as much as 300 to 900 mm/yr in the Sandy Creek watershed.

Preliminary results indicate recharge to the Memphis aquifer based on an October to September water year ranges from 430 mm/yr in 2016-17 to 810 mm/yr in 2017-18. Preliminary investigation shows correlations between recharge and precipitation (total and intensity), evapotranspiration, stream discharge, and soil moisture content. Relationships between the variables will be evaluated on a monthly and yearly basis using the available data. A multiple regression model will be fit to the data to estimate groundwater recharge in areas with similar land use, surface soil exposure, and climate conditions.

Methods

Water balance is calculated based on the equation below assuming nominal annual change in soil moisture (October—September water year).

Inflows	Outflows	ΔStorage
Precipitation –	(Evapotranspiration + Discharge) =	Ground water Recharge

Data for water balance is obtained from facilities installed in the Muse Street watershed (Figure 2), with some supporting data from the Westwood watershed (Figure 1):

- A Decagon EM50 Microclimate Monitoring System is located on the high terrace to collect precipitation, temperature, wind speed, wind direction, relative humidity, atmospheric pressure, and solar radiation.
  - Measurements taken at 15 minute intervals
- Two Decagon GS1 Ruggedized Soil Moisture Sensors were installed at 1.0 and 1.5 meter depths below the surface on the low terrace with measurements taken at 15 minute intervals.
- Troxler 4300 soil moisture gauge collected readings at 0.3 m increments on the high and low terrace to depth of 3 meters on a monthly basis.
- Solinst pressure transducer was installed in the stream bed at the terminus of the watershed with measurements taken every 15 minutes.
- Groundwater level measurements are taken on a monthly basis.
- Evapotranspiration was calculated using a modified Penman-Monteith equation from data collected at the weather station.
- Discharge was calculated using the pressure transducer, stream cross-section and survey, and the Manning equation.
- Used RStudio program to evaluated statistical analysis of data programmed in R-coding.

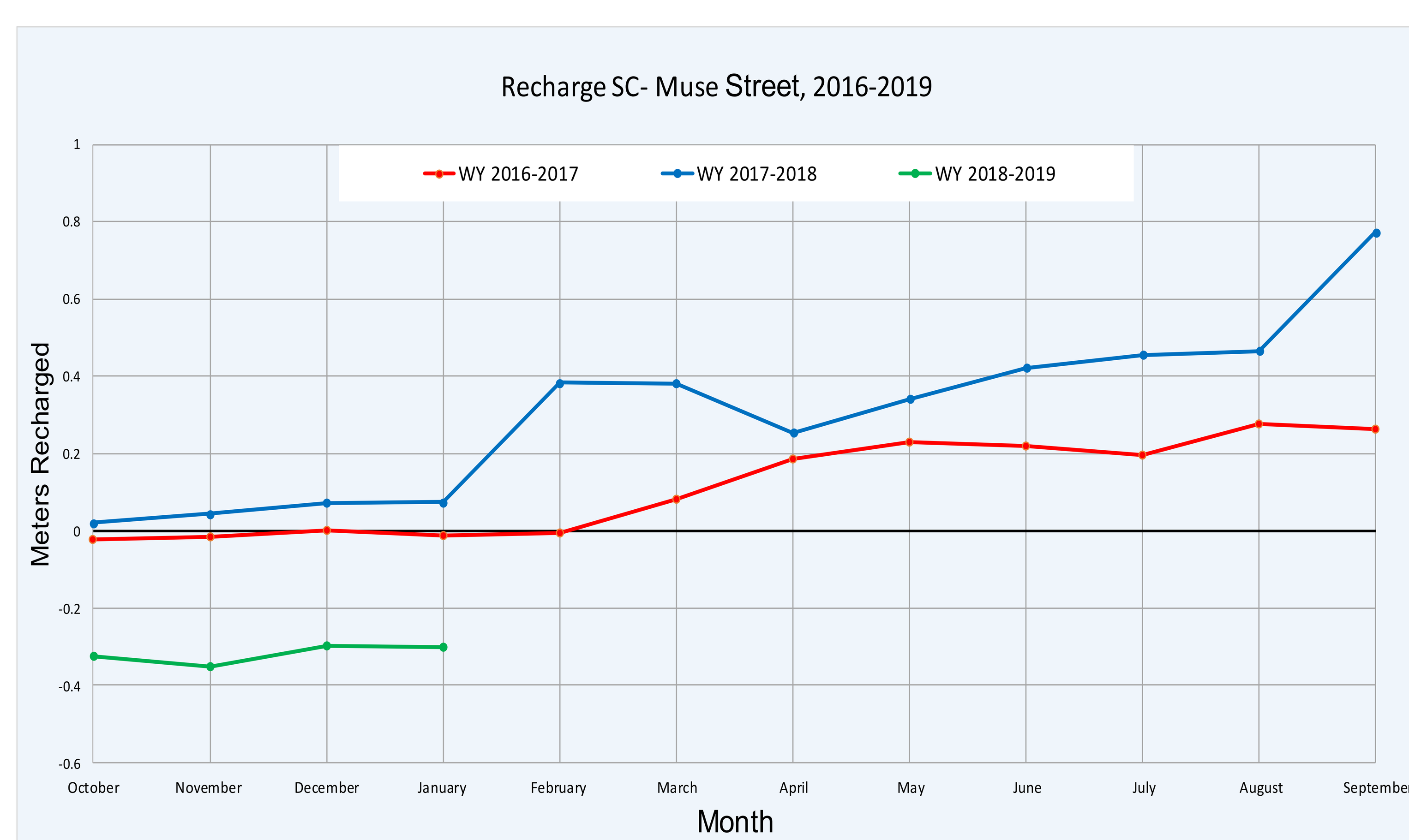


Figure 3: Monthly recharge for Sandy Creek—Muse Street for consecutive years.

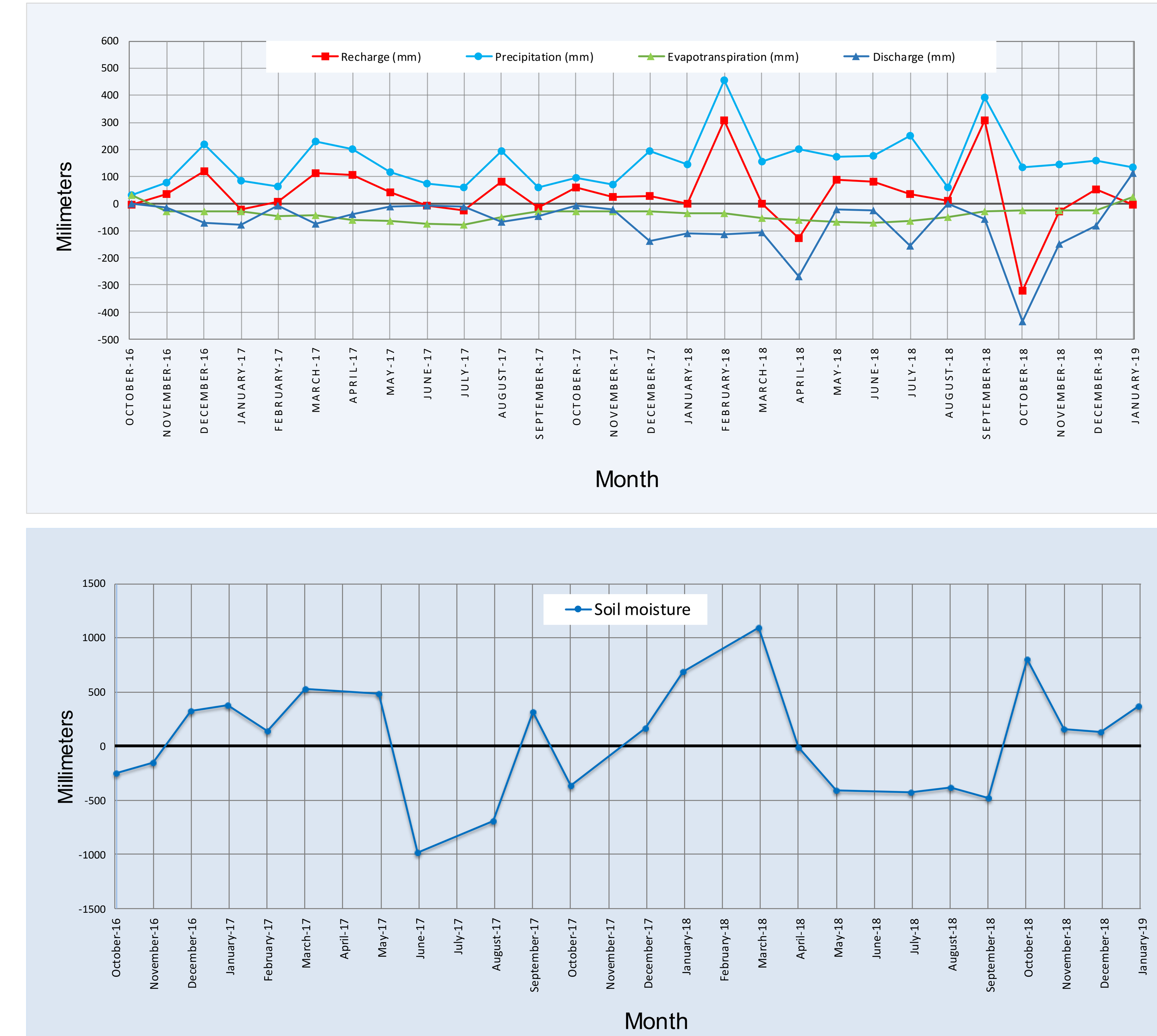


Figure 4: Water Budget data that is being used to form predictive multiple regression model (top) and soil moisture data measured by neutron probe at the high terrace site.

Data with only precipitation and discharge

```
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -49.36992    7.00316   -7.05  3.5e-07 ***
p             1.00801    0.03733   27.00  < 2e-16 ***
d             0.95111    0.03825   24.86  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
' ' 1

Residual standard error: 17.72 on 23 degrees of freedom
Multiple R-squared:  0.9793,  Adjusted R-squared:  0.9775
F-statistic:   544 on 2 and 23 DF,  p-value: < 2.2e-16
```

Data with only precipitation and evapotranspiration

```
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -107.1888    61.6567  -1.738  0.09550 .
p              0.7924     0.1920   4.127  0.00041 ***
et            -0.3564     1.0613  -0.336  0.74007
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '

Residual standard error: 93.36 on 23 degrees of freedom
Multiple R-squared:  0.4256,  Adjusted R-squared:  0.3757
F-statistic: 8.523 on 2 and 23 DF,  p-value: 0.0017
```

Figure 5. Linear regression with R-value of 0.9793 with only precipitation and discharge (left) and linear regression with R-value of 0.4256 with only precipitation and evapotranspiration (right)

Discussion

- Water budget data collected from October 2016 to September 2019 is being evaluated.
- Precipitation shows yearly increases since 2016:
  - 2017 had 1412 (mm) of precipitation and 2018 has 2451 (mm) of precipitation
- RStudio statistical program is being used to write a linear regression model
  - regression models demonstrate the importance of precipitation and discharge to overall recharge
  - evapotranspiration plays less significant role in linear model
  - predicting discharge variable proven to be the most difficult
  - soil moisture data shows significant amounts of storage with higher than average precipitation
- Soil moisture storage decreases annually in the summer months on the high terrace.
  - data is plotted separately from water due to data being collected over 3-meter thickness to determine change in soil over watershed area.
- Soil moisture was originally assumed to be negligible due to an annual drying pattern however increased yearly precipitation doubled from 2017 to 2018.
  - data will be added to the linear model to evaluate possible changes to overall groundwater recharge
- Predictive model will be validated using water budget data collected from Westwood Avenue watershed site

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