Effects of Soil Characteristics on Evapotranspiration-Driven Water Table Decline and Recovery in a Forested Floodplain

DEPARTMENT OF GEOLOGY

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Introduction

The objective of this study is to examine relationships among vegetation, hydrology, soil characteristics and their influences on water table depth in a temperate forest floodplain. Evapotranspiration (ET) and precipitation (PPT) are the largest terms in the water balance, however, water table responses are also affected by soil properties and vegetation, including parameters such as soil bulk density, organic matter content, capillary fringe height, and soil texture. A simple water balance equation is used to explain the change in groundwater storage: Δ storage = PPT – ET. In this study, vegetation and soil characteristics were measured at two sites (floodplain and terrace) in a forest.

Hypotheses

- In Maryland, groundwater minima are driven by evapotranspiration in excess of precipitation, which removes groundwater storage creating groundwater minima in early autumn.
- Soil characteristics (bulk density, organic matter) are influenced near the surface by biota (roots and organisms), which results in a vertical change in soil properties with depth.
- The capillary fringe height primarily reflects effective matrix pore size, which can be estimated by grain size, and will remain constant as the groundwater table declines.

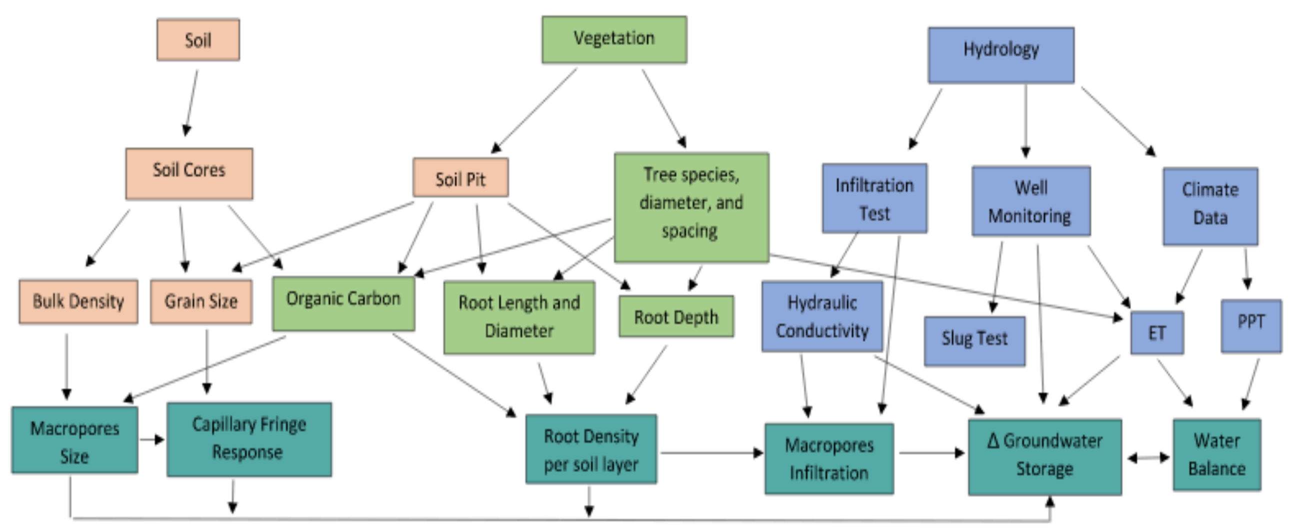

Fig. 1 A ecohydrological interaction flow chart displays the complex interconnection among soil, vegetation, and hydrology aspects and their relations to groundwater storage.

Study Site and Methods

The study site is located along the Little Paint Branch (LPB) floodplain in College Park, Maryland. This site receives about 110 mm of precipitation annually, distributed throughout the year The following data were measured at the study site: Tree density and size (Table I), soil cores for bulk density, grain size, moisture content, and organic matter content analyses. Field hydrological measurements included monitoring of groundwater levels and infiltration measurements (Fig. 2).

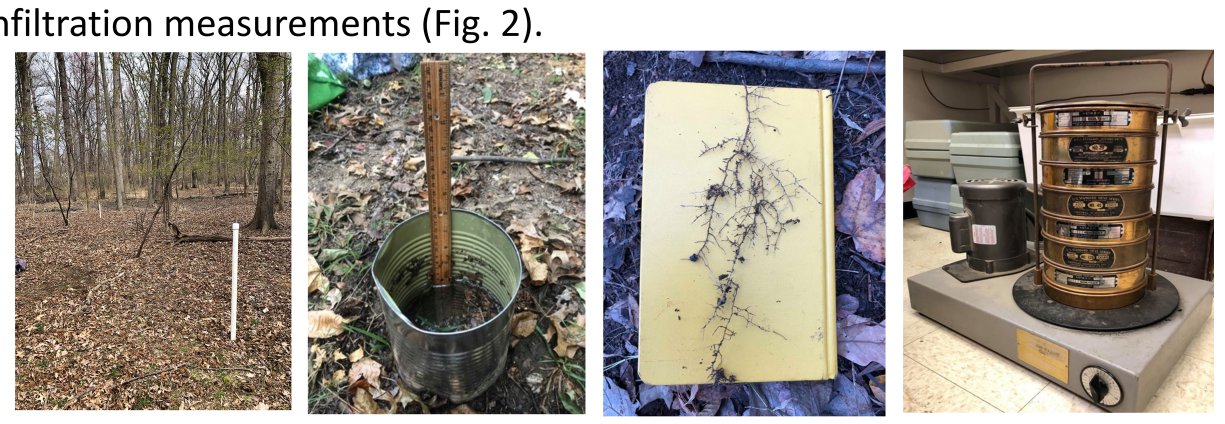

Fig.2: (left) View of the floodplain site with one of the water wells. (left center) Single-ring infiltration ring. (right center) A root from the floodplain site. (right) Mechanical shaker for sieve grain size analysis.

Site	Total Number of Trees	Dominant Species	Total Tree Area (m^2)	Average Diameter (cm)	Tree Density (m^2/m^2)
Hole	15	Red Maple	0.860	14.82	0.00860
Floodplain	32	White Ash, Shadbush	0.425	10.17	0.00425
Terrace	9	Red Maple	0.517	20.46	0.00517

Table I: Size and Density of Trees at the Floodplain and Terrace sites

Results I: Soil Characteristic

At both the floodplain and terrace site: 1) Soil organic matter decrease with depth; 2) Bulk density increase with depth; and 3) Porosity decrease with depth.

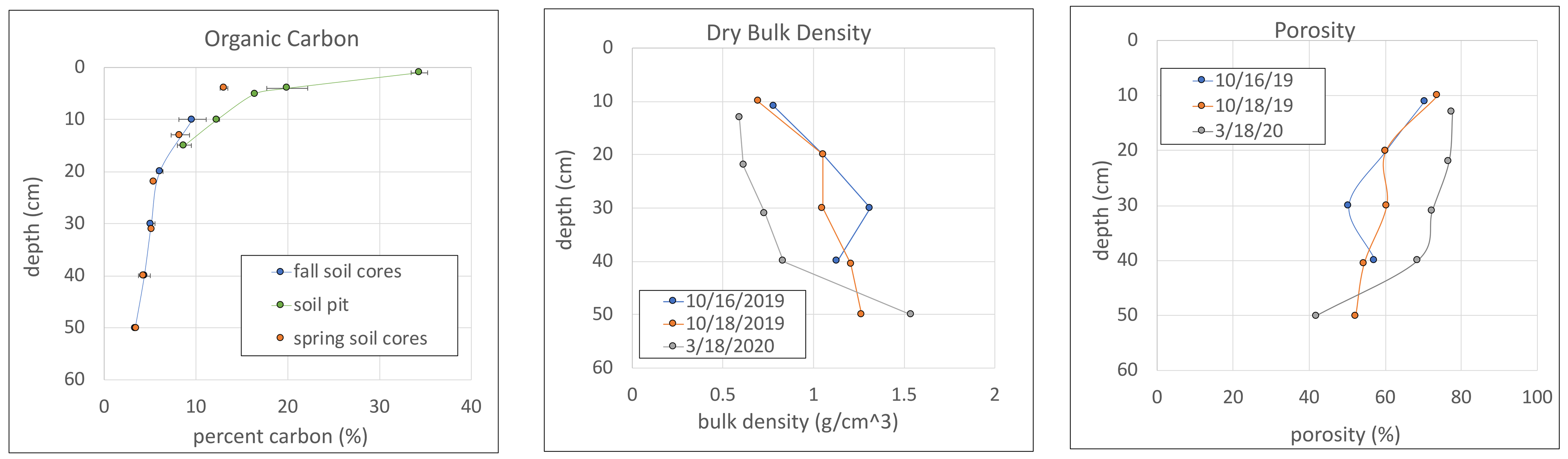

Fig 3: Soil characteristics at the floodplain site. From left to right: organic matter content, bulk density, and porosity

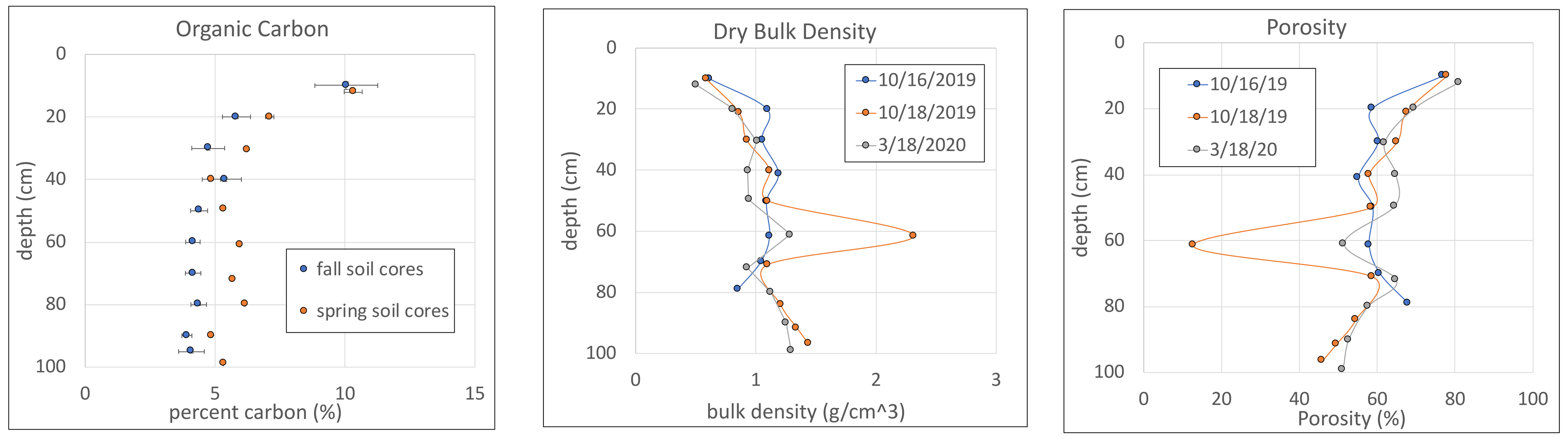

Fig. 4: Soil characteristic at the terrace site. From left to right: organic matter content, bulk density and porosity.

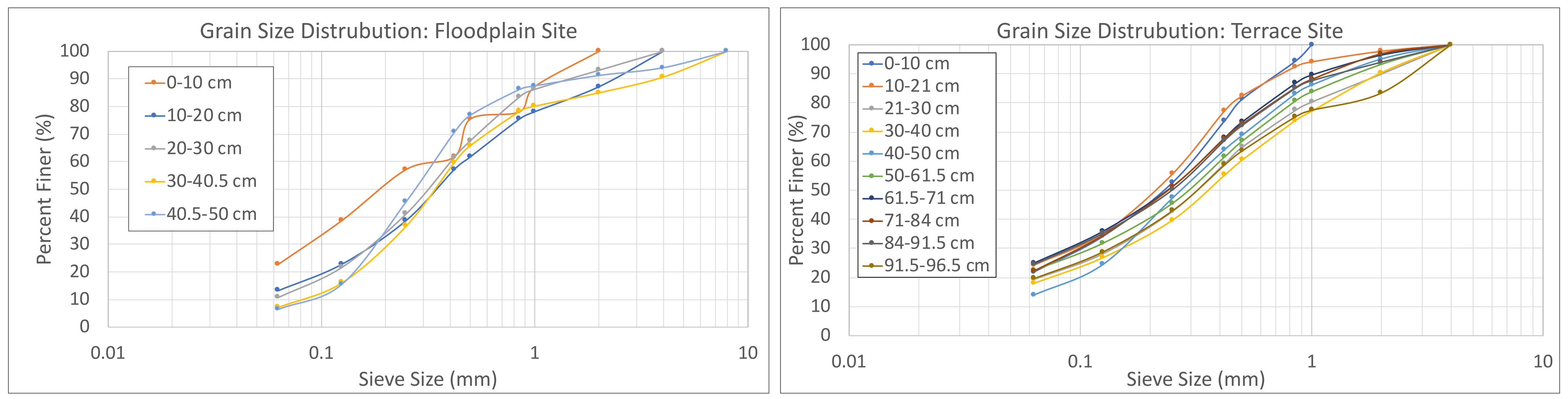

Fig. 5: Grain Size Analysis: Floodplain site (left), Terrace site (right)

Soil Characteristics. Percent organic matter and porosity decreased with soil depth. Bulk density increased with depth. Particle size distributions were similar for different intervals and sites (fig. 5).. Both median, D_{50} , and large, D_{90} , grain sizes were used to calculate the expected rise of the capillary fringe.

Capillary fringe calculations based on these grain sizes indicate that the capillary fringe should extend to the surface. This doesn't match the field measurements, which indicate lower rises after storm events The low capillary fringe rise is likely due to removal of water from the capillary fringe by ET and macropores in the soil. Macropores are indicated by low bulk density values.

Capillary fringe Rise equation, Bear (1972):

$$R = \frac{2\gamma cos}{\Theta\rho g h_c}$$

where R is pore radius; γ is the surface tension of water which is 72.9 N/m; θ is the wetting angle which is ~1 for mineral soils; ρ is water density which is 1000 kg/m^3; g is gravity which is 9.814 m/s^2; h_c is the capillary rise height (Bear 1972)

Depth (cm)	Sieve Analysis Error (%)	D_{50} (mm)	Capillary Fringe Rise for D_{50} (m)	D_{90} (mm)	Capillary Fringe Rise for D_{90} (m)
0-10	2.27	0.19	156.38	1.2	24.76
10-20	0.79	0.27	110.05	2.5	11.89
20-30	0.18	0.32	92.85	1.5	19.81
30-40.5	0.23	0.34	87.39	3.9	7.62
40.5-50	0.80	0.35	84.89	1.6	18.57
Mean		0.29	106.31	2.14	16.53
Standard Deviation		0.07	29.66	1.10	6.78

Depth (cm)	Sieve Analysis Error (%)	D_{50} (mm)	Capillary Fringe Rise for D_{90} (m)	D_{90} (mm)	Capillary Fringe Rise for D_{90} (m)
0-10	4.39	0.24	123.80	0.71	41.85
10-21	0.66	0.22	135.06	0.73	40.70
21-30	0.61	0.33	90.04	2	14.86
30-40	0.69	0.36	82.54	2	14.86
40-50	0.85	0.27	110.05	1.5	19.81
50-61.5	0.52	0.29	102.46	1.7	17.48
61.5-71	0.85	0.25	118.85	1	29.71
71-84	0.81	0.25	118.85	1.2	24.76
84-91.5	0.52	0.25	118.85	1.5	19.81
91.5-96.5	0.96	0.33	90.04	2.7	11.00
Mean		0.28	109.05	1.50	23.48
Standard Deviation		0.05	17.17	0.63	10.76

Table II: Tables containing the error from the sieve grain size analysis, D_{50},D_{90} and the calculated capillary fringe rise for floodplain (left) and terrace site (right)

Results II: Hydrological

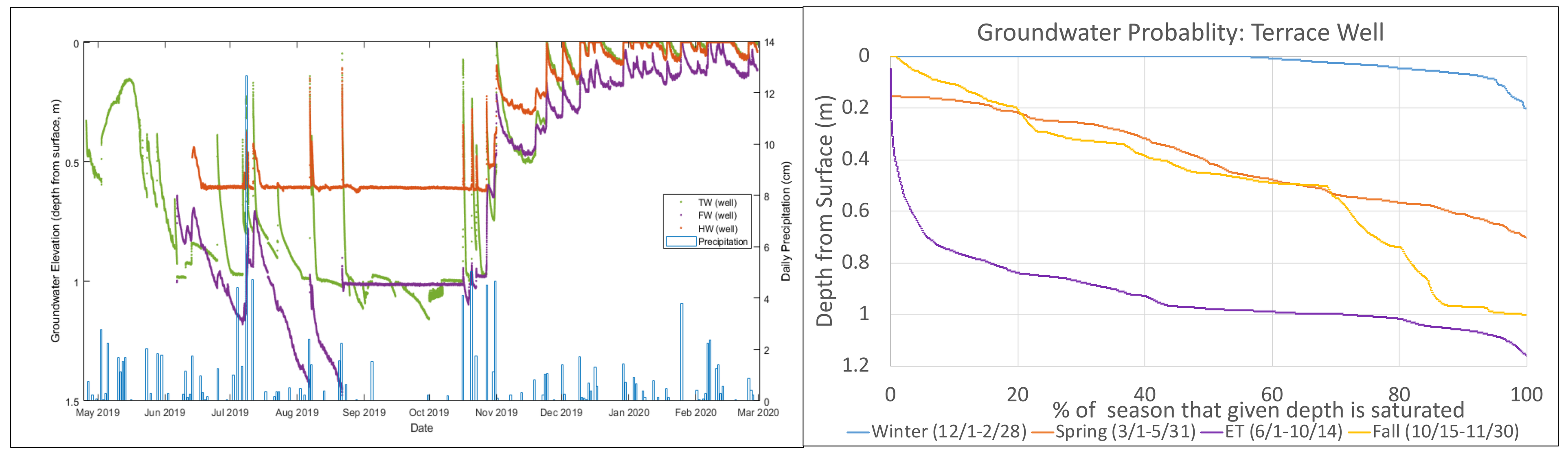

Fig. 6: (left) The groundwater well data time series data, (right) Groundwater probability distributions for 4 seasons. (figure credit: Haley Talbot-Wendlandt)

Groundwater monitoring data indicate near surface water tables during winter periods ,declining water tables in spring and rising water tables in fall. The minimum groundwater table was between July to October for all sites. Also, the well data shows the capillary fringe response, which is the rapid response to precipitation events. The Terrace site groundwater probability curve provides the percent of the time the groundwater level will be at or above the indicated value.. During the summer, the water table retains similar values as it drops to a minimum. This suggests the water table has dropped below the rooting depth of the vegetation.

Modeling Evapotranspiration and Groundwater Storage.

The Hargreaves-Samani (HS) Equation for calculating daily reference evapotranspiration (ET_0):

$$ET_{0,HS} = HC * R_a * (T_{max} - T_{min})^{HE}\left(\frac{T_{max}+T_{min}}{2} + 17.8\right)$$

where $ET_{0,HS}$ is the reference evapotranspiration by the HS equation (mm/day); HC is an empirical coefficient (HC=0.0023); R_a is the extraterrestrial radiation (mm/day); HE is an empirical exponent (HE=0.5); T_{max} is the daily maximum air temperature (°C); and T_{min} is the daily minimum air temperature (°C) (Revazzani et al. 2012).

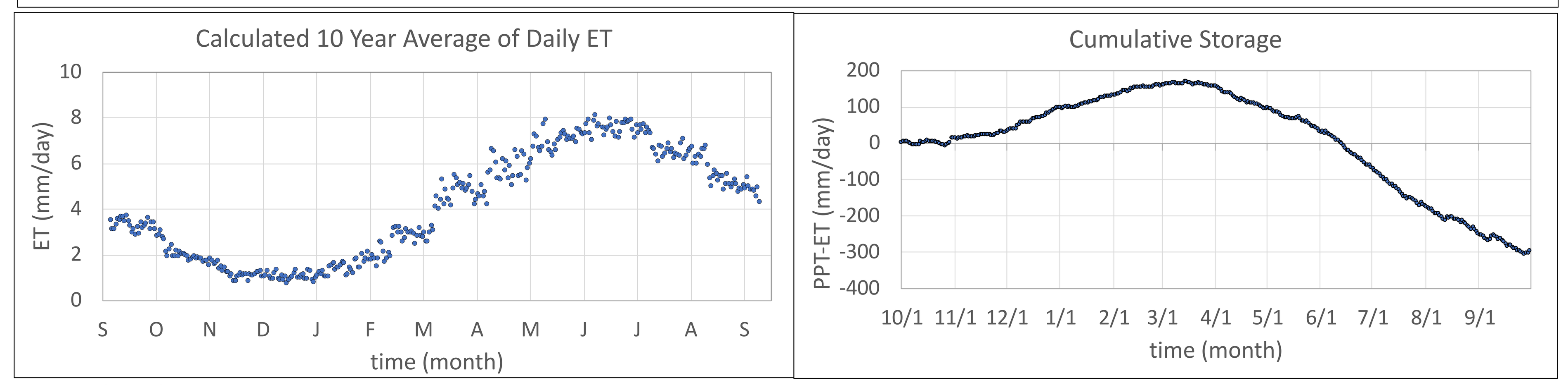

Fig. 7: (Left) The daily ET was calculated from Hargreaves-Samani Equation using the maximum and minimum temperature data obtained from PRISM climate group. Calculations for the period 2009 – 2010 were averaged to obtain 10-year average of daily ET for Little Paint Branch Floodplain . (Right) the cumulative change in groundwater storage for LPB floodplain. The groundwater table is at its maximum in Mid-March then it begins to decline. The storage maximum and minimum timing match water table observations.

Conclusion

- The organic carbon was highest at the surface and deceases with depth, which is consistent with leaf matter and roots in the near surface soils. Initial examination of the roots indicates high density of roots in the upper 20-30 cm of the floodplain soils. The grain size distributions are relatively similar for the different horizons in the soil and do not show systematic changes with depth. The bulk density increases with depth intervals at both sites, reaching values consistent with mineral soils with these grain sizes at depth. This suggests that the surface soil horizons have more or larger macropores, which is also indicated by the higher values of porosity in the surface soils. These data support the soil characteristics hypothesis.
- The height of the potential capillary fringe calculated from the median (D_{50})and large (D_{90}) grain sizes both suggest that the capillary fringe should be near the surface, but field data indicate much lower capillary fringe response values, indicating macropores or water removal by roots. The hypothesis that matrix grain size creates the height of the capillary fringe response is not supported.
- Groundwater well data displays the water table declining during the summer months and recovering during the fall/winter months. Calculation of PPT-ET (from observed precipitation and an ET equation) generates a pattern of changes in groundwater storage with similar minimum and maximum, which translates to the groundwater recharging during the winter and depleting during the summer. Data support the hypothesis

References

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