Unraveling groundwater contributions to evapotranspiration in a mountain headwaters: Using eddy covariance to constrain water and energy fluxes in the East River Catchment

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January 4, 2021

Abstract

Despite the importance of headwater catchments for western United States' water supply, these regions are often poorly understood, particularly with respect to quantitative understanding of evapotranspiration (ET) fluxes. Heterogeneity of land cover, physiography, and atmospheric patterns in these high-elevation regions lead to difficulty in developing spatially-distributed characterization of ET. As the largest terrestrial water flux behind precipitation, ET represents a significant fraction of the water budget for any watershed. Likewise, groundwater is the largest available freshwater store and has been shown to play a large role in the water balance, even in headwater systems. Using an eddy covariance tower in the East River Catchment, a Colorado River headwaters basin, this study estimates water and energy fluxes in high-elevation, complex systems to better constrain ET estimates and calculate overall water and energy budgets, including losses from groundwater. The eddy covariance method is used to estimate ET from years 2017 through 2019 at a saturated, riparian end-member site. Owing to complexities in near surface atmospheric structure such as stable boundary layers over snowpack and shallow terrain driven flow from surrounding landscape features, energy flux and ET estimates were limited to the warm season when energy closure residuals from the eddy-covariance system were reliably less than 30 %, a threshold commonly used in eddy covariance energy flux estimation. The resulting ET estimations are useful for constraining water budget estimates at this energy-limited site, which uses groundwater for up to 84 % of ET in the summer months. We also compared East River ET magnitudes and seasonality to two other flux towers (Niwot Ridge, CO and Valles Caldera, NM), located in the Rocky Mountains. This data is useful for constraining ET estimates in similar end-member locations across the East River Catchment. Our results show that groundwater-fed ET is a significant component of the water balance and groundwater may supply riparian ET even during low-snow years.

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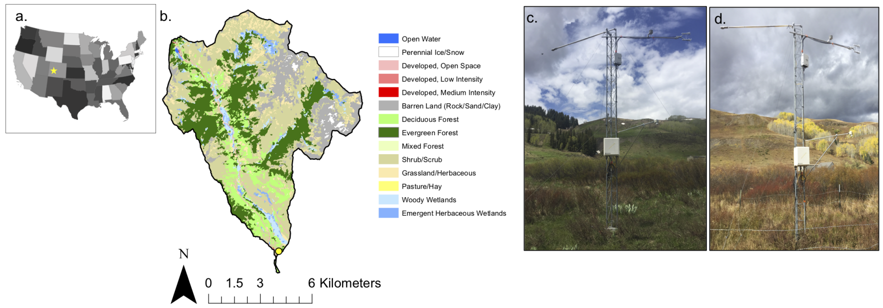
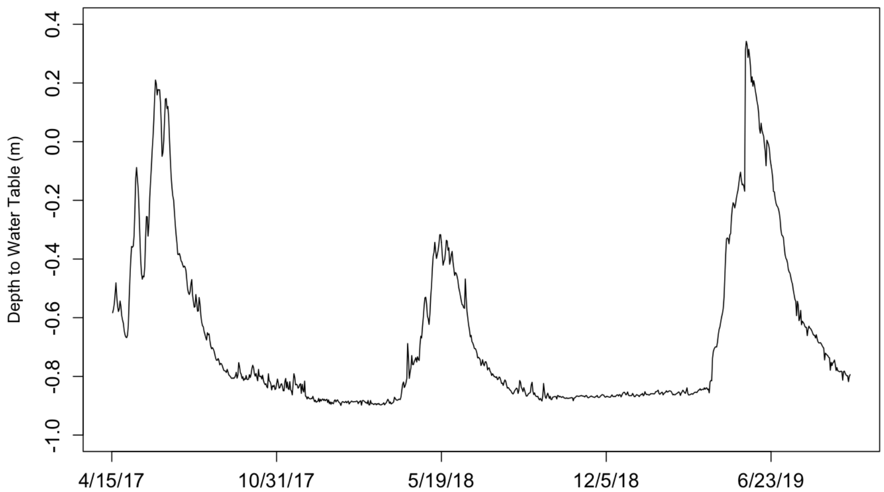
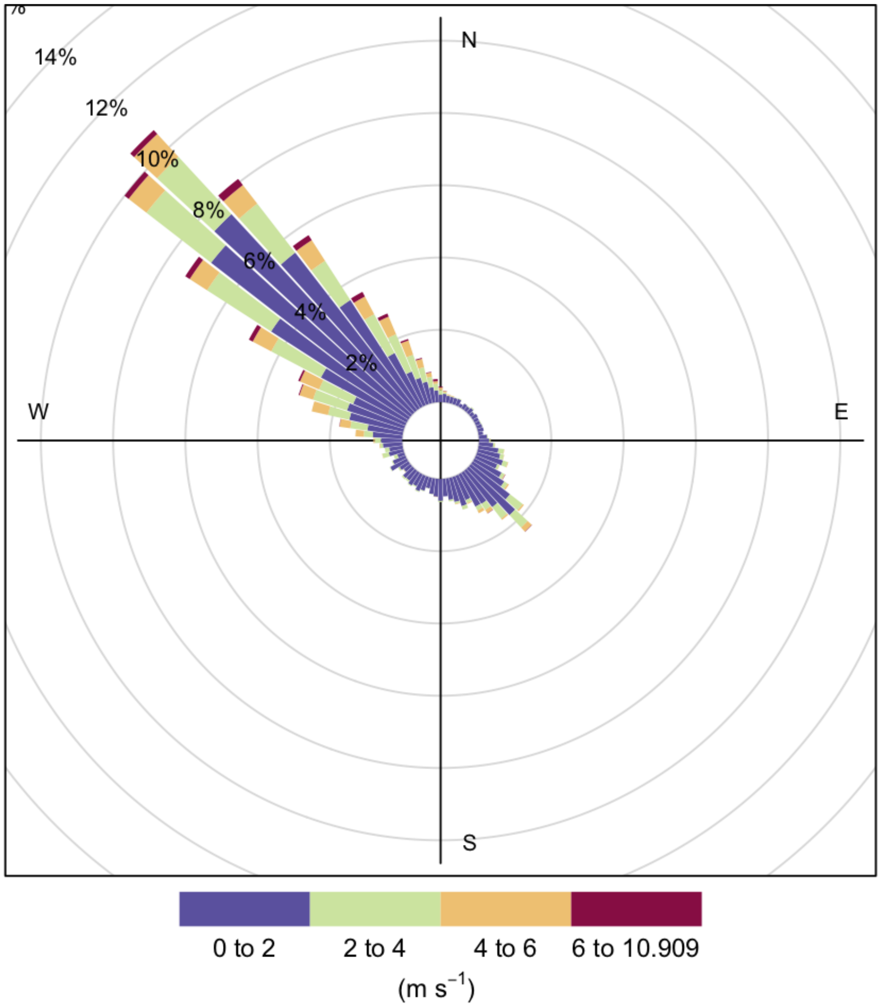
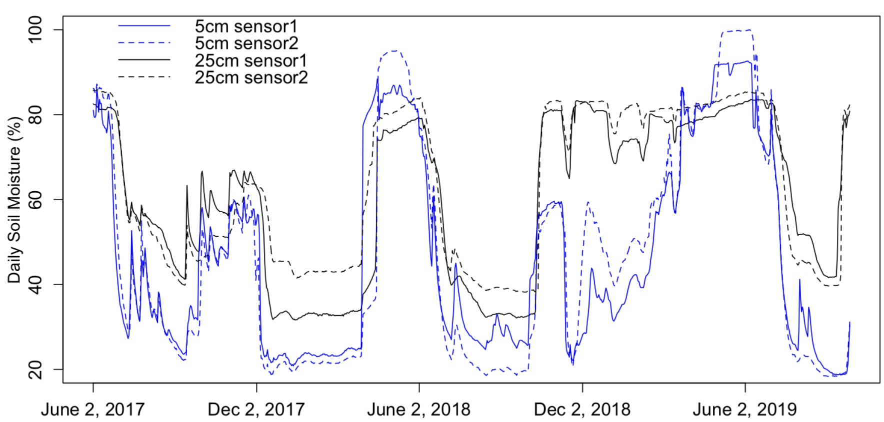
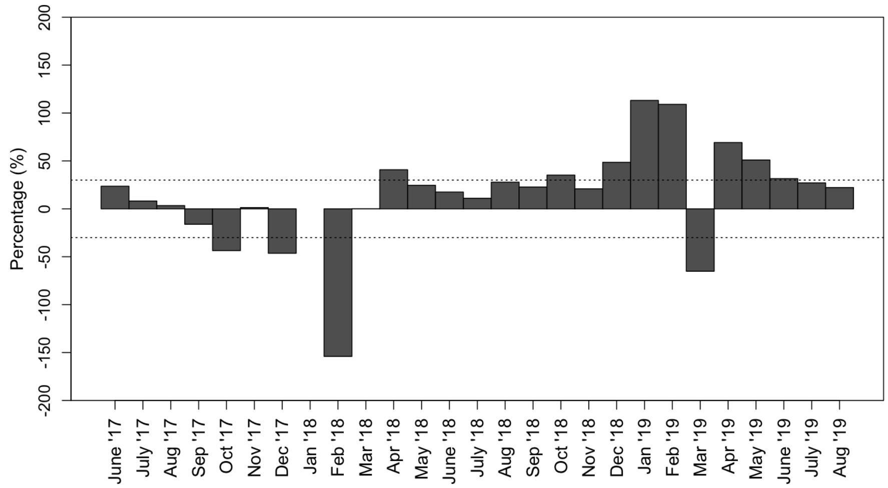
`UnravelingGroundwater.pdf` available at https://authorea.com/users/345910/articles/502335-unraveling-groundwater-contributions-to-evapotranspiration-in-a-mountain-headwaters-using-eddy-covariance-to-constrain-water-and-energy-fluxes-in-the-east-river-catchment


a.
b.
c.
d.
Open Water
Perennial Ice/Snow
Developed, Open Space
Developed, Low Intensity
Developed, Medium Intensity
Barren Land (Rock/Sand/Clay)
Deciduous Forest
Evergreen Forest
Mixed Forest
Shrub/Scrub
Grassland/Herbaceous
Pasture/Hay
Woody Wetlands
Emergent Herbaceous Wetlands
N
0 1.5 3 6 Kilometers


Depth to Water Table (m)
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
4/15/17
10/31/17
5/19/18
12/5/18
6/23/19


%
14%
12%
10%
8%
6%
4%
2%
N
W
E
S
0 to 2
2 to 4
4 to 6
6 to 10.909
(m s^{-1})


5cm sensor1
5cm sensor2
25cm sensor1
25cm sensor2
Daily Soil Moisture (%)
20
40
60
80
100
June 2, 2017
Dec 2, 2017
June 2, 2018
Dec 2, 2018
June 2, 2019


Percentage (%)
200
150
100
50
0
-50
-100
-150
-200
June '17
July '17
Aug '17
Sep '17
Oct '17
Nov '17
Dec '17
Jan '18
Feb '18
Mar '18
Apr '18
May '18
June '18
July '18
Aug '18
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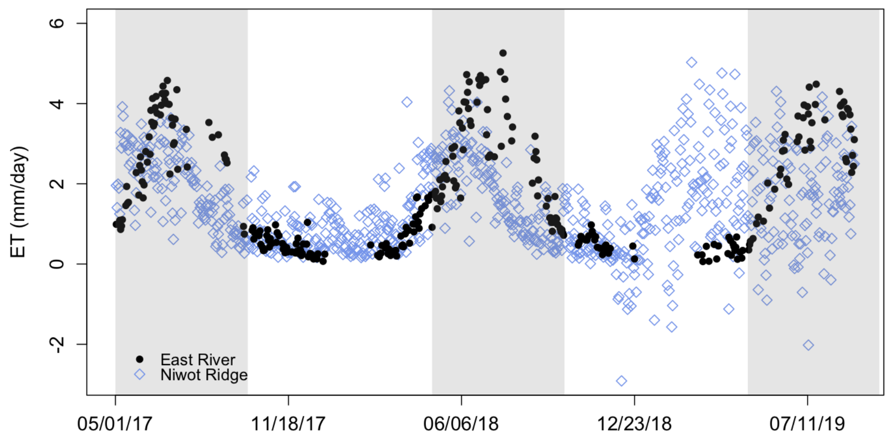
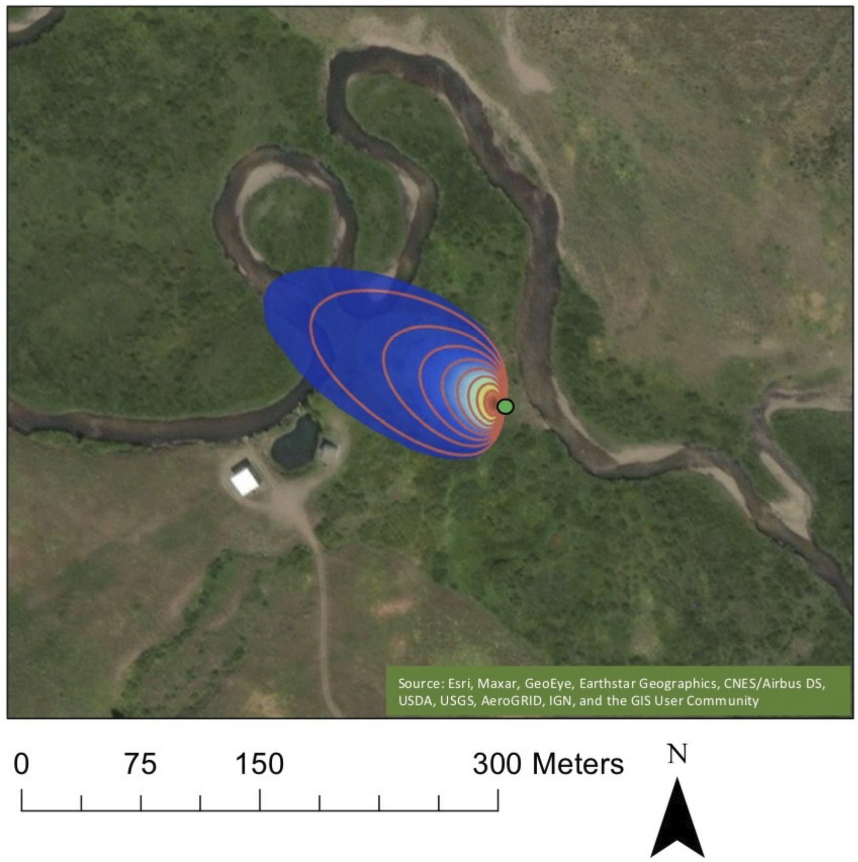
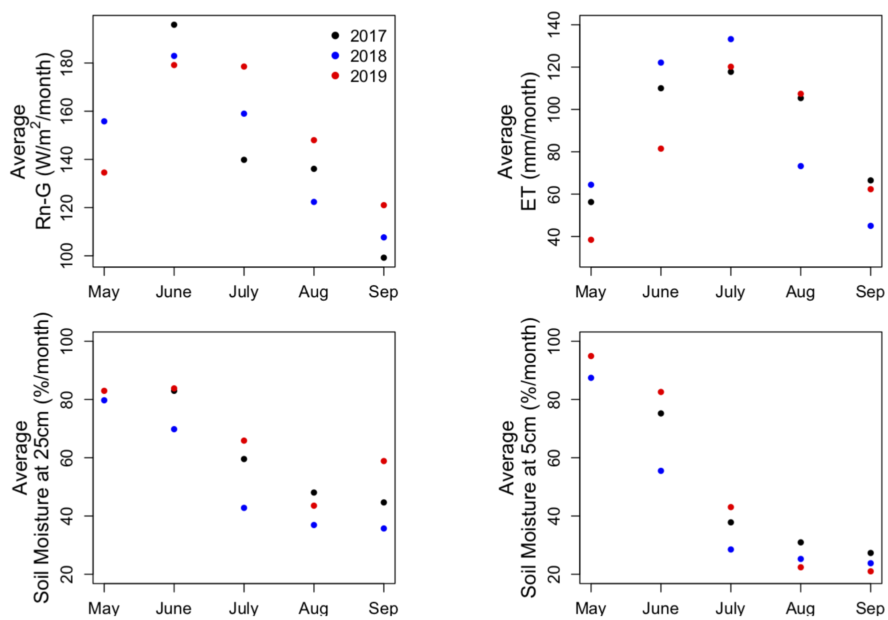
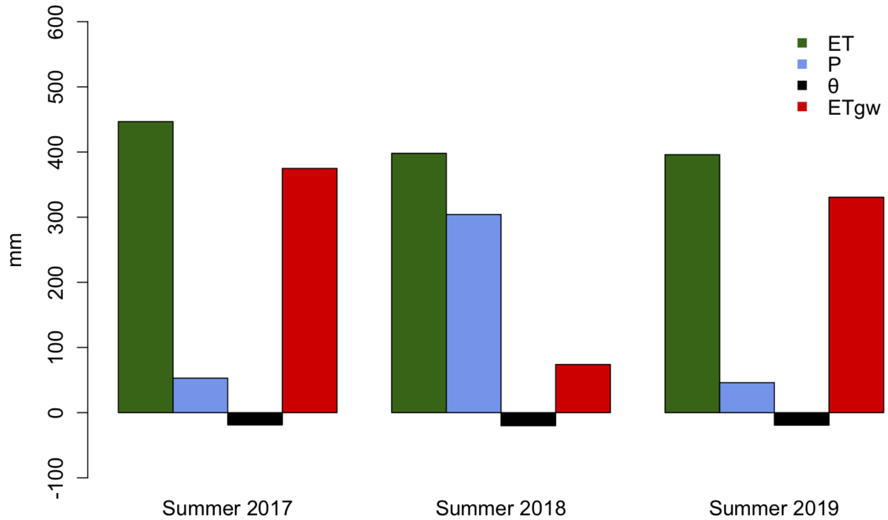
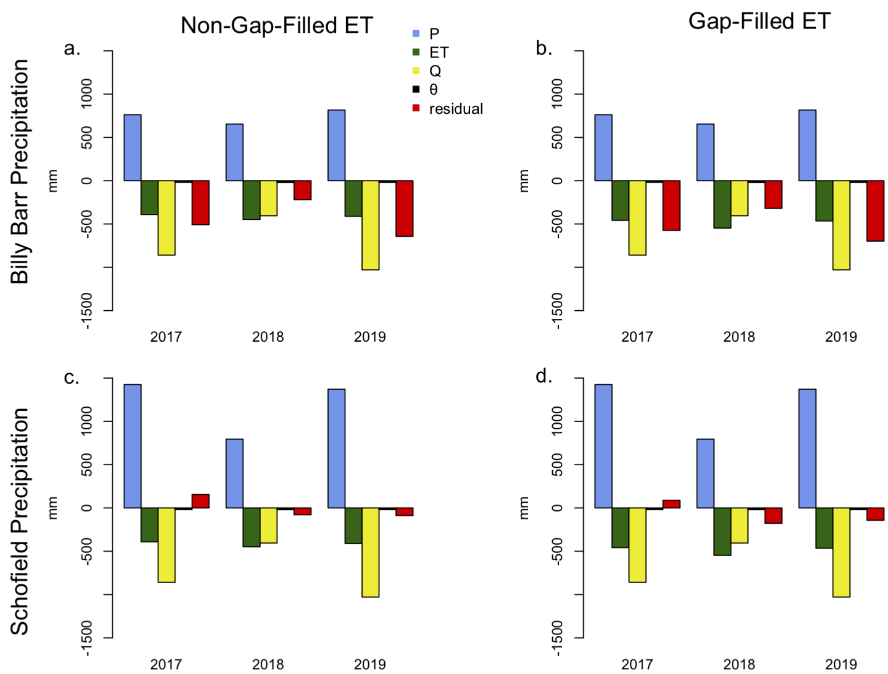
May '19
June '19
July '19
Aug '19


ET (mm/day)
6
4
2
0
-2
East River
Niwot Ridge
05/01/17
11/18/17
06/06/18
12/23/18
07/11/19


Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
0
75
150
300 Meters
N


Average Rn-G (W/m2/month)
100
120
140
160
180
2017
2018
2019
Average ET (mm/month)
40
60
80
100
120
140
Average Soil Moisture at 25cm (%/month)
Average Soil Moisture at 5cm (%/month)
20
40
60
80
100
May
June
July
Aug
Sep


ET
P
θ
ETgw
mm
600
500
400
300
200
100
0
-100
Summer 2017
Summer 2018
Summer 2019


Non-Gap-Filled ET
Gap-Filled ET
P
ET
Q
θ
residual
a.
b.
c.
d.
Billy Barr Precipitation
Schofield Precipitation
mm
1000
500
0
-500
-1500
2017
2018
2019

Meteorological Variable	Sensor	Make/Model	Sampling Frequency
Wind Speed	3-dimensional sonic anemometer	Campbell Scientific IRGASON	10 Hz
Air Temperature	sonic anemometer	Campbell Scientific IRGASON	10 Hz
Barometric Pressure	sonic anemometer	Campbell Scientific IRGASON	10 Hz
Water Vapor Concentration	infra-red gas analyzer	Campbell Scientific IRGASON	10 Hz
CO_2 Gas Concentration	infra-red gas analyzer	Campbell Scientific IRGASON	10 Hz
Incoming/Outgoing Shortwave/Longwave Radiation	ingoing/outgoing pyranometer incoming/outgoing pyrgeometer	Kipp and Zonen CNR-4	15 minutes
Soil Heat Flux	heat flux plate	Huskeflux self-calibrating soil heat flux plate	15 minutes
Soil Temperature	soil thermistor	Steven's Hydra-Probe	15 minutes
Soil Moisture	soil dielectric probe	Steven's Hydra-Probe	15 minutes
Soil Electrical Conductivity	soil electrical conductivity probe	Steven's Hydra-Probe	15 minutes
Surface Infra-red Skin Temperature	infra-red radiometer	Apogee SI-111 Infra-red radiometer	15 minutes
	data logging/control system	Campbell Scientific CR3000	

Sampling Frequency	10Hz
Sensor Orientation	315 degrees (from North)
Measurement Height	5.9 meters
Canopy Height	2 meters
Displacement Height	Diagnosed online
Roughness Length	Diagnosed online
Site Elevation	2862 meters ASL
Wind Coordinate Rotation	Planar-fit method (Wilczak, Oncley, & Stage, 2001)
Spectral Correction (low pass filter correction)	Massman (2001)
Density Corrections	WPL method (Webb, Pearman, & Leuning, 1990)

	2017	2018	2019
Latent Heat (W/m^2)	105.24	92.65	95.55
Summer ET (mm)	334.48	294.49	303.69
Annual ET (mm)	457.94†	547.12	465.54
Rn-G (W/m^2)	157.26	154.75	168.55
Air Temperature (K)	286.59	286.41	285.56
Dew Point Depression	11.42	12.13	12.04
Annual Precipitation (mm) from Billy Barr Station	1037.5	790.13	1115.61

	2017	2018	2019
ER Summer Evapotranspiration (mm)	334.48	294.49	303.69
VC Summer Evapotranspiration (mm)	398.47	381.44	453.63
NR Summer Evapotranspiration (mm)	230.53	218.31	151.63
ER Annual Evapotranspiration (mm/year)	457.94†	547.12	465.54
VC Annual Evapotranspiration (mm/year)	731.35	849.79	855.64
NR Annual Evapotranspiration (mm/year)	320.02	464.10	499.64
ER Temperature (K)	286.59	286.41	285.56
VC Temperature (K)	289.98	290.86	290.29
NR Temperature (K)	285.42	286.39	284.25
ER Precipitation (mm, cumulative)	1037.5	790.13	1115.61
VC Precipitation (mm, cumulative)	539.56	299.51	545.69
NR Precipitation (mm, cumulative)	979.52	745.57	848.10

	2017	2018	2019
Billy Barr	-507.98	-220.05	-643.08
Billy Barr and ET Gap-filled	-574.11	-318.52	-697.87
Schofield	155.13	-79.10	-87.60
Schofield and ET Gap-filled	89.00	-177.55	-142.39