Coupling Field Data and a Flow Model to Characterize the Role of Groundwater in a Montane, Semi-Arid, Headwater Catchment, Gordon Gulch, Colorado

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Abstract

Groundwater is critical in sustaining streamflow, especially in mountain catchments, because of its ability to supply baseflow in the absence of precipitation. In water-limited arid and semi-arid mountain environments, the need to characterize groundwater recharge and discharge has grown in tandem with demands to effectively manage current and future water resources. However, studying groundwater is challenging in complex terrain due to limited field measurements. Nearly a decade of monitoring data collection at Gordon Gulch in the Colorado Front Range provides a unique opportunity to study such an environment. The field data is used to parameterize and calibrate a groundwater flow model (MODFLOW-NWT). Model results reveal spatial and temporal patterns in groundwater recharge and discharge to the stream. Groundwater is recharged primarily by one to two recharge events each year, driven by spring snowmelt and rain. The majority of groundwater recharge occurs in upper Gordon Gulch and is stored in saprolite and weathered bedrock. Groundwater is discharged to the stream via long, deep flowpaths sourced from upper Gordon Gulch and short, shallow flowpaths from soil and saprolite in lower Gordon Gulch. Using Gordon Gulch as a case study, this model and data analysis contribute to a larger effort to understand and constrain the mechanisms driving groundwater recharge and groundwater-stream exchanges in semi-arid, montane environments.

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Introduction

We use multi-year hydrologic records in Gordon Gulch to understand groundwater recharge within a montane environment

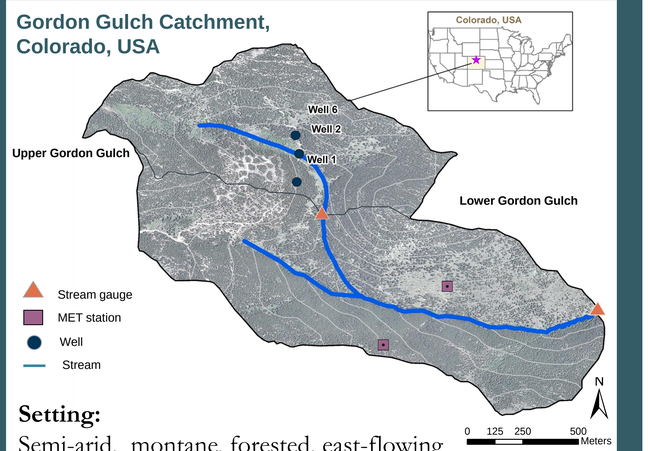
Groundwater is critical in sustaining streamflow, especially in headwater catchments, because of its ability to supply baseflow in the absence of precipitation. In water-limited arid and semi-arid mountain environments, the need to characterize groundwater recharge and discharge has grown in tandem with demands to effectively manage current and future water resources. However, studying groundwater in complex terrain is challenging due to limited field measurements. Nearly a decade of monitoring data collection at Gordon Gulch in the Colorado Front Range provides a unique opportunity to study such an environment.

Questions

In a semi-arid, montane, headwater catchment:

1. When and where is groundwater recharged?
2. When and where does groundwater contribute to streamflow?

Study Area



Setting:
Semi-arid, montane, forested, east-flowing catchment with intermittent snow, at ~2600 m in the Colorado Front Range

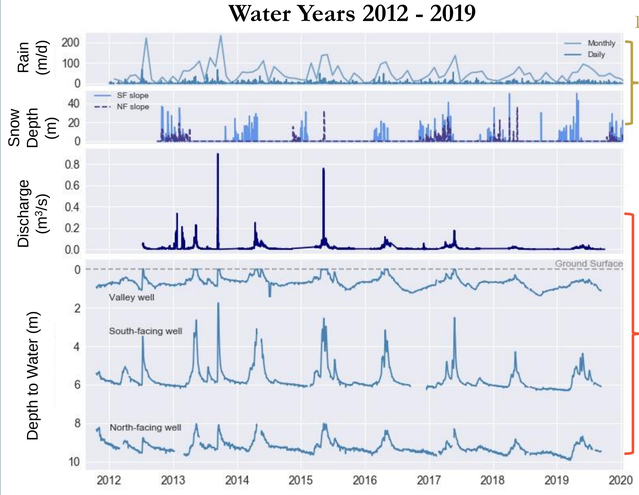
Geology:
A thin (0.4 m) soil is underlain by weathered rock extending 8-12 m depth, and biotite gneiss bedrock (Anderson et al. 2021)

Area (km²)	Elevation (m)	Mean Annual Precipitation (mm)	Mean Annual Temperature (°C)
2.6	2,450 - 2,750	580	6.5

Coupling Data and a Groundwater Flow Model

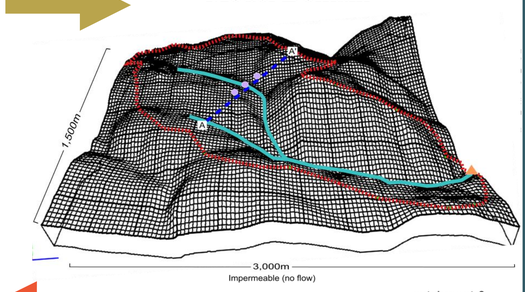
- Gordon Gulch has been actively monitored by the Boulder Creek Critical Zone Observatory (BcCZO) since 2011
- Data was used in the development and calibration of a groundwater flow model, using MODFLOW-NWT

Time series data from Gordon Gulch for Water Years 2012 - 2019



Data used for model inputs

Model Domain

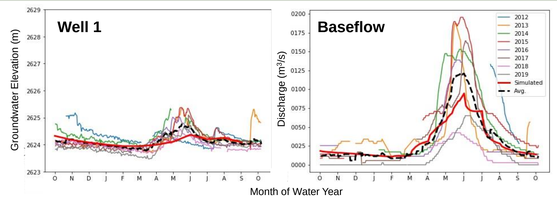


Model outputs compared to data

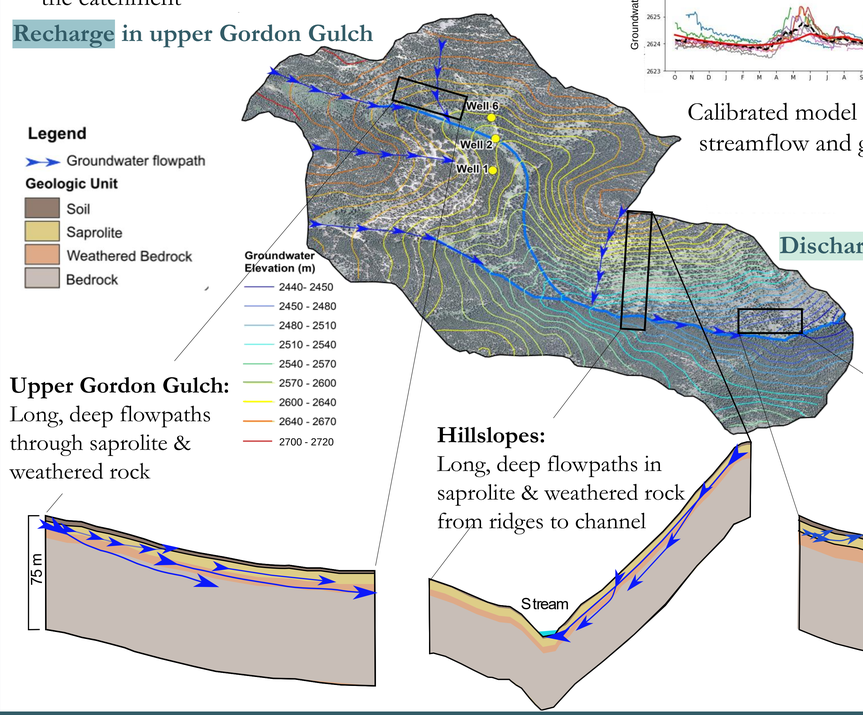
Model Results

- Groundwater elevation follows topography
- Groundwater flowpaths differ spatially throughout the catchment

Recharge in upper Gordon Gulch



Calibrated model to baseflow estimated from streamflow and groundwater levels at wells



Discharge in lower Gordon Gulch

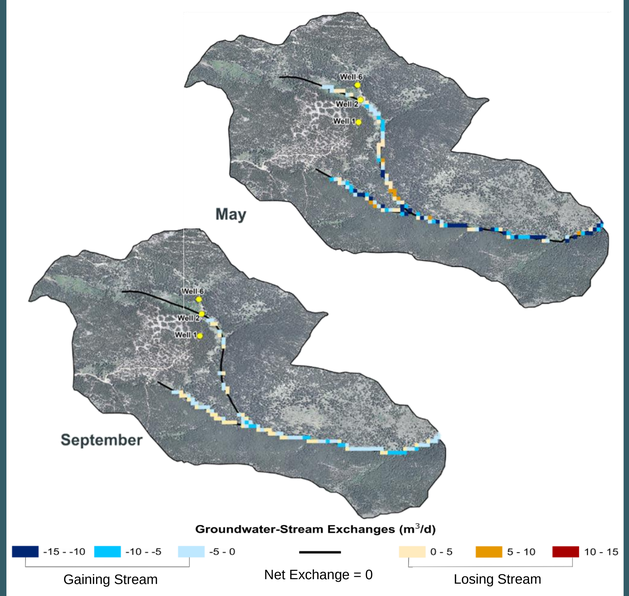
Upper Gordon Gulch:
Long, deep flowpaths through saprolite & weathered rock

Hillslopes:
Long, deep flowpaths in saprolite & weathered rock from ridges to channel

Lower Gordon Gulch:
Short, shallow, emergent flowpaths in saprolite

Discussion & Conclusions

Seasonal Modeled Groundwater – Surface Water Exchanges



1. Groundwater recharge depends on snowmelt and rain:
   - 1 – 2 recharge events each water year, driven by spring snowmelt and summer rainstorms
   - 50% of total annual recharge occurs during spring snowmelt (April and May)
   - Groundwater is recharged in upper Gordon Gulch

2. Overall, the stream is a gaining system
   - 16 to 34% of total annual streamflow comes from groundwater
   - The highest rates of groundwater discharge to the stream occur in the spring.
   - Groundwater is discharged to the stream in lower Gordon Gulch
   - Both long and deep flowpaths and short and shallow flowpaths sustain streamflow

References & Acknowledgements

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Anderson, SP, Kelly, PJ, Hoffman, N, Barnhart, K, Befus, K, and Ouimet, W (2021): Is this steady state? Weathering and critical zone architecture in Gordon Gulch, Colorado Front Range. *In* Hydrogeology, Chemical Weathering, and Soil Formation, AGU Geophysical Monograph 257, ed. by AG Hunt, M Egli, and B Faybishenko, John Wiley & Sons, Inc., p. 231-252, doi: 10.1002/9781119563952.ch13