Numerically Modeling Infiltration and Root Water Uptake in a Montane Forest using High Frequency Stable Isotope Field Measurements

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Abstract

In the coming years, climate models forecast mountainous watersheds to undergo a reduction in snowpack, early season melt, and increases in evapotranspiration. As a result, dry soil conditions will stress vegetation at elevations of 1,850 to 2,900 meters above sea level. In this study we investigate infiltration patterns and root water uptake in response to drying within the East River catchment in Colorado. Our group collected soil cores, measured matric potential and sap flow, and monitored tree xylem and soil for stable isotopes of water (²H, ¹⁸O) along two profiles to 90 cm depth—with three Engelmann spruce and three aspen trees instrumented, respectively. Field isotope dynamics were analyzed on a daily basis between mid-July and late October using an in situ cavity ring-down spectrometer. The numerical model HYDRUS-1D was trained and calibrated with pressure head and isotope data, simulating the response to late summer dry spells and monsoonal rainfall for a 128 day period. Lab measured and model derived rates of saturated hydraulic conductivity are consistent for both soil profiles, with a median rate of 1,410 cm d⁻¹. Model simulations reflect the three distinct dry down events from late July to September, each followed by rapid infiltration of rainfall (42, 47, and 68 mm of cumulative precipitation per event). Compared to aspen trees, shallow soil under Engelmann spruce repeatedly dries out beyond the permanent wilting point of -1.5 MPa, likely due to higher rates of canopy interception for spruce.

This study highlights the benefits of coupling tracer data and commonly used hydrometric data to better constrain parameters used in numerical modeling. That said, these efforts aim to help predict and better understand quantification of certain plant water responses during ecosystem changes and future climate conditions.
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Background

- In the coming years, climate models forecast mountainous regions to undergo a reduction in snowpack, early season melt, and increases in extreme precipitation.
- As a result, dry soil conditions will stress vegetation at elevations of 1,850 to 2,900 meters above sea level.
- In the coming years, climate models forecast mountainous forests to undergo a reduction in snowpack, early season melt, and increases in extreme precipitation.
- Dry soils will stress vegetation at elevations of 1,850 to 2,900 meters above sea level.

Research Objective & Methods

- Observe and model water dynamics in soil beneath Englemann spruce and Aspen profiles.

Field Setup

- The numerical model HYDRUS-1D was trained and calibrated with pressure head and isotope data, using an in situ cavity ring-down spectrometer.

Field Evaluations

- Simulated and observed transpiration with sap flow data.

Model Optimization & Goodness of Fit

- Parameters calibrated:
  - $R$: Saturated Water Content
  - $a$: Aspect (° / (Air Entry))
  - $K$: Saturated hydraulic conductivity
  - $D$: Disperivity
  - $I$: Interception

- Simulated pH compared with in-situ pH.
- Observed data plotted as circles.
- Simulated data plotted as curves
- Red: pH concentration in the Aspen soil profile
- Green: pH concentration in Aspen trees
- (KGEiso: 0.24)

- Modeled $h$ (pressure heads, matric potential)
- Observed data plotted as circles
- Modeled data plotted as curves
- Tan: 15 cm (KGE: 0.08)
- Orange: 30 cm (KGE: 0.04)
- Red: 60 cm (KGE: 0.77)
- KGE: 0.32

Next Steps

- Further optimization and sensitivity analysis for best fit at shallow depths.
- Model and compare isotope dynamics for both WY-22 and WY-23
- Calibration Optimization

Results & Conclusions

- Model simulations roughly show the three distinct dry down events from late July to September, each followed by rapid infiltration of rainfall (42.47, and 88 cm of total precipitation per event).
- Compared to Aspen trees, shallow soil under Englemann spruce repeatedly dries out beyond the permanent wilting point of -1.5 MPa (higher rates of canopy interception).
- The numerical model HYDRUS-1D was trained and calibrated with pressure head and isotope data, simulating the response to late summer dry spells and monsoonal rainfall across the 128 day period.

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