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 (^{2}H, ^{18}O) 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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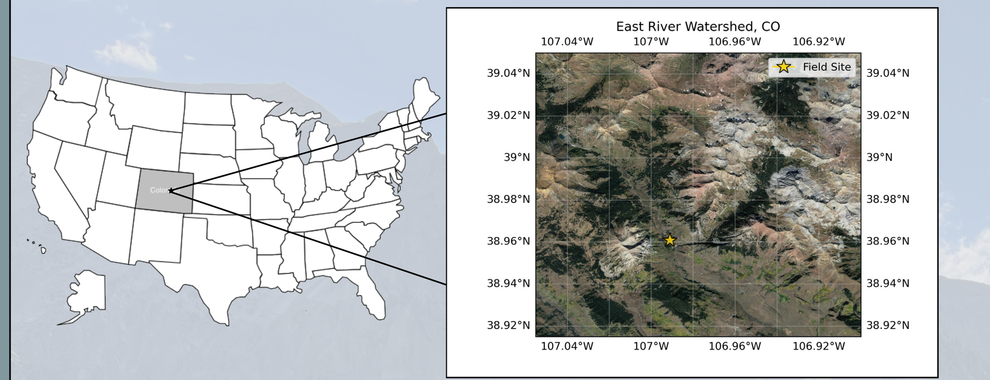
Background

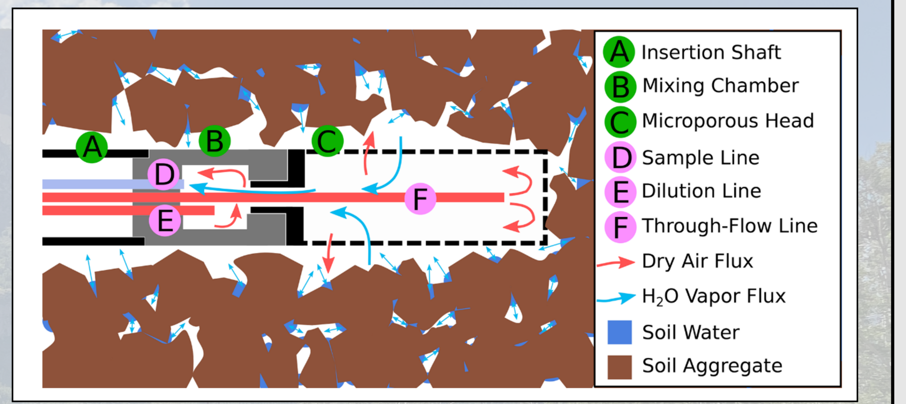


- In the coming years, climate models forecast mountainous watersheds to undergo a reduction in snowpack, early season melt, and increases in evapotranspiration.
- As a result, dry soil conditions will stress vegetation at elevations of 1,850 to 2,900 meters above sea level.
- We investigate infiltration patterns and root water uptake in response to drying within the East River catchment in Colorado.
- This study highlights the benefits of coupling inovative high frequency tracer data and commonly used hydrometric data to better constrain parameters used in numerical modeling.

Research Objective & Methods

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

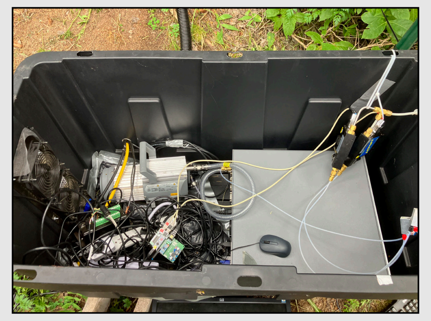
Instrumentation: Pressure head and sap flow sensors, vapor probes (24), daily measurements of concentration recorded using an in situ vapor analyzer.



Vapor probe schematic *Seeger & Weiler, 2021*

- We collected soil cores, measured matric potential, sap flow, and monitored tree xylem and soil for stable isotopes of water (^2H, ^{18}O) along two profiles to 90 cm depth (three Engelmann spruce and three aspen trees).
- 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 across the 128 day period.

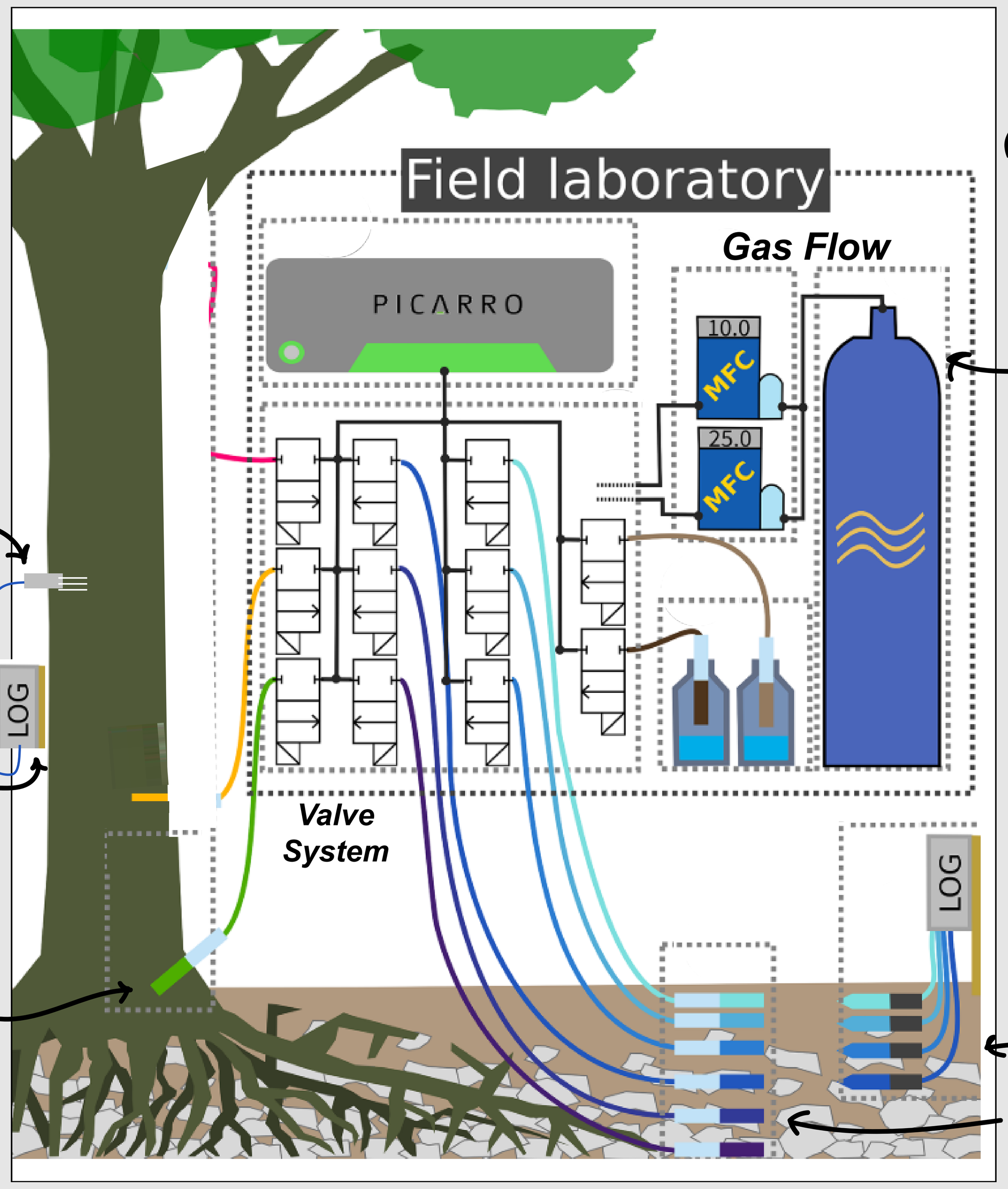
Field Setup



Laser Spectrometer

Sap Flow Sensor

Xylem Water Vapor Probe (6 Trees)



Adapted from Seeger & Weiler, 2021

Standard Waters for Calibration (snow, seawater, Fiji) (Water Vapor Correction and Vapor Liquid)

Dry Gas Supply

Matric Potential Sensors

Soil Water Vapor Probes (2 Profiles)

Vapor probe in a spruce tree.

Conceptual Approach

System Input

↓

True Response (Nature)

↓

Observed Response (Data)

↓

Model

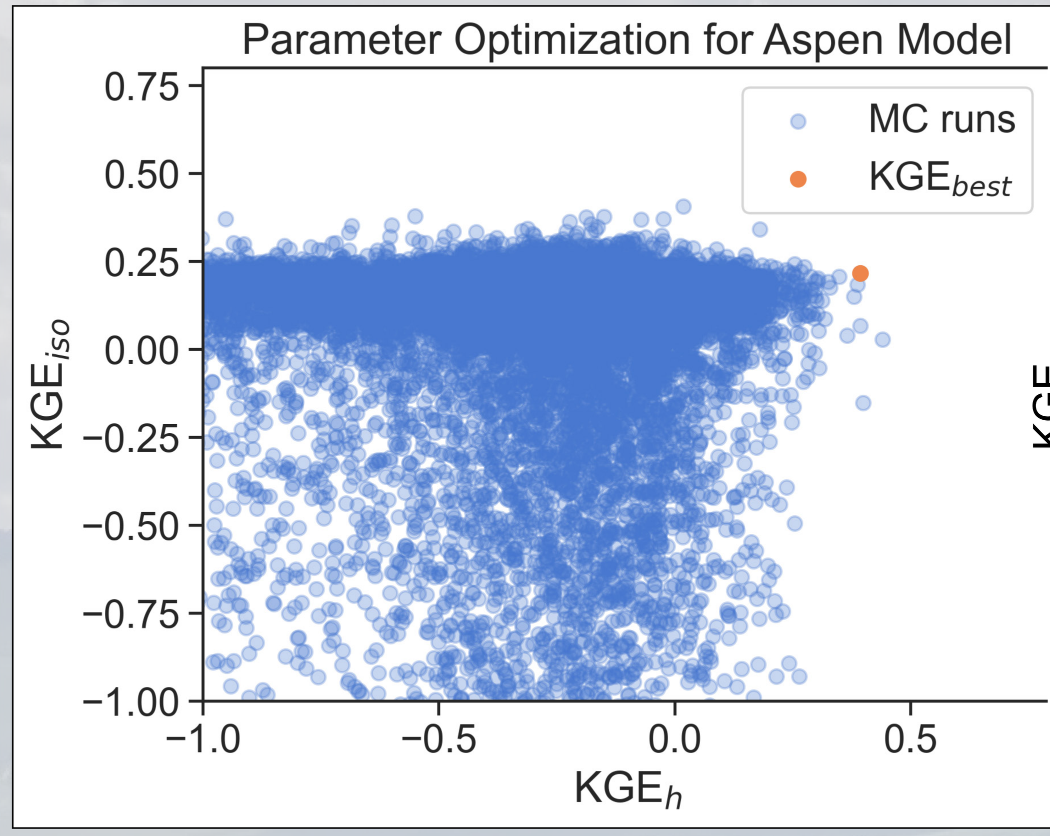
Calibration ***Optimization***

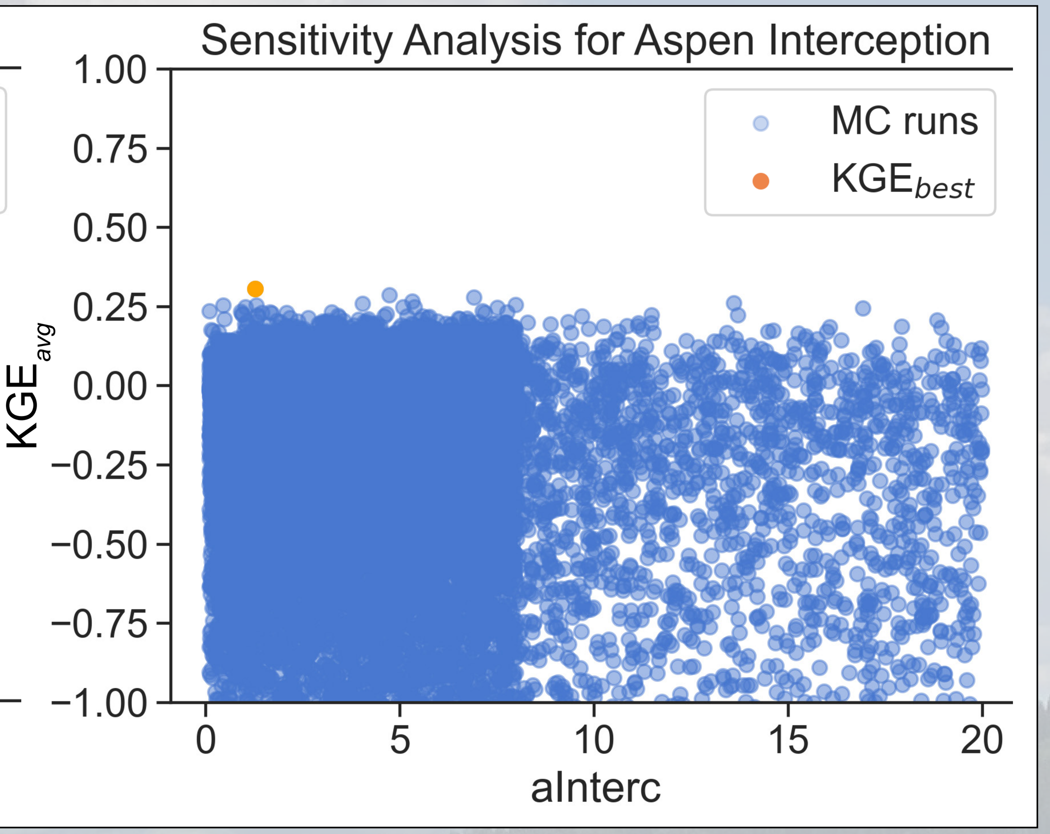
Simulated Response

↓

Predictive Response

Model Optimization & Goodness of Fit



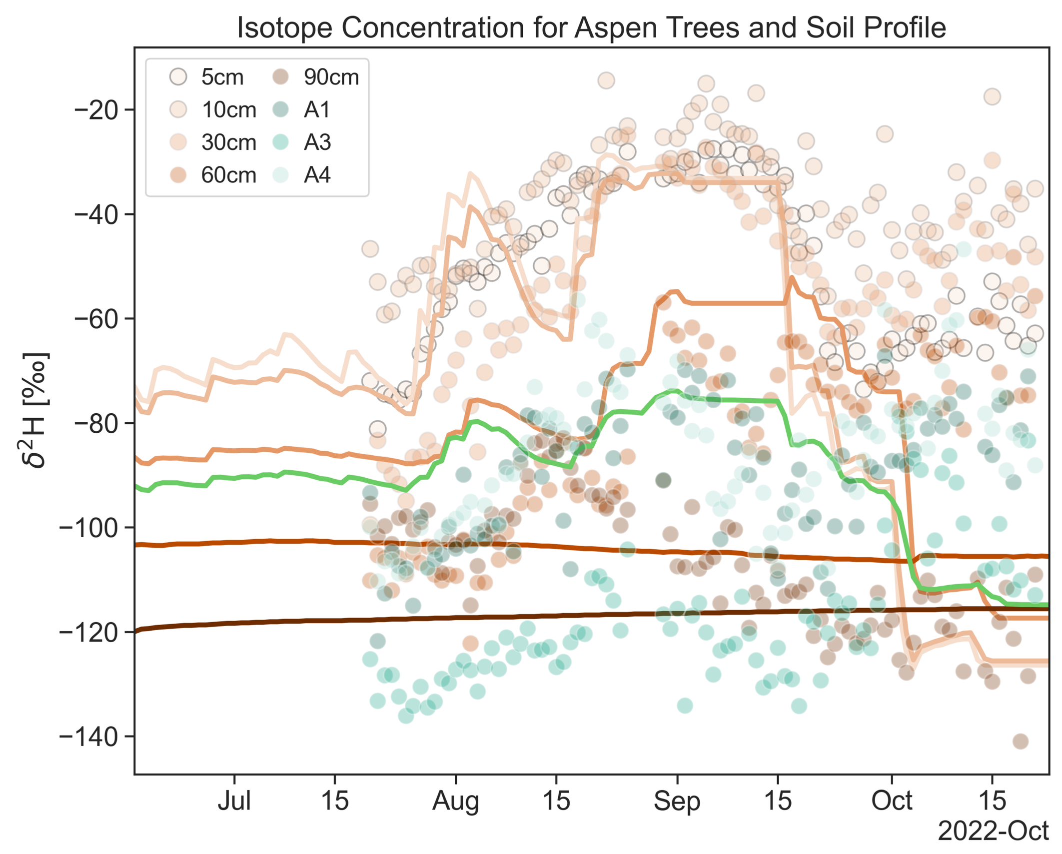


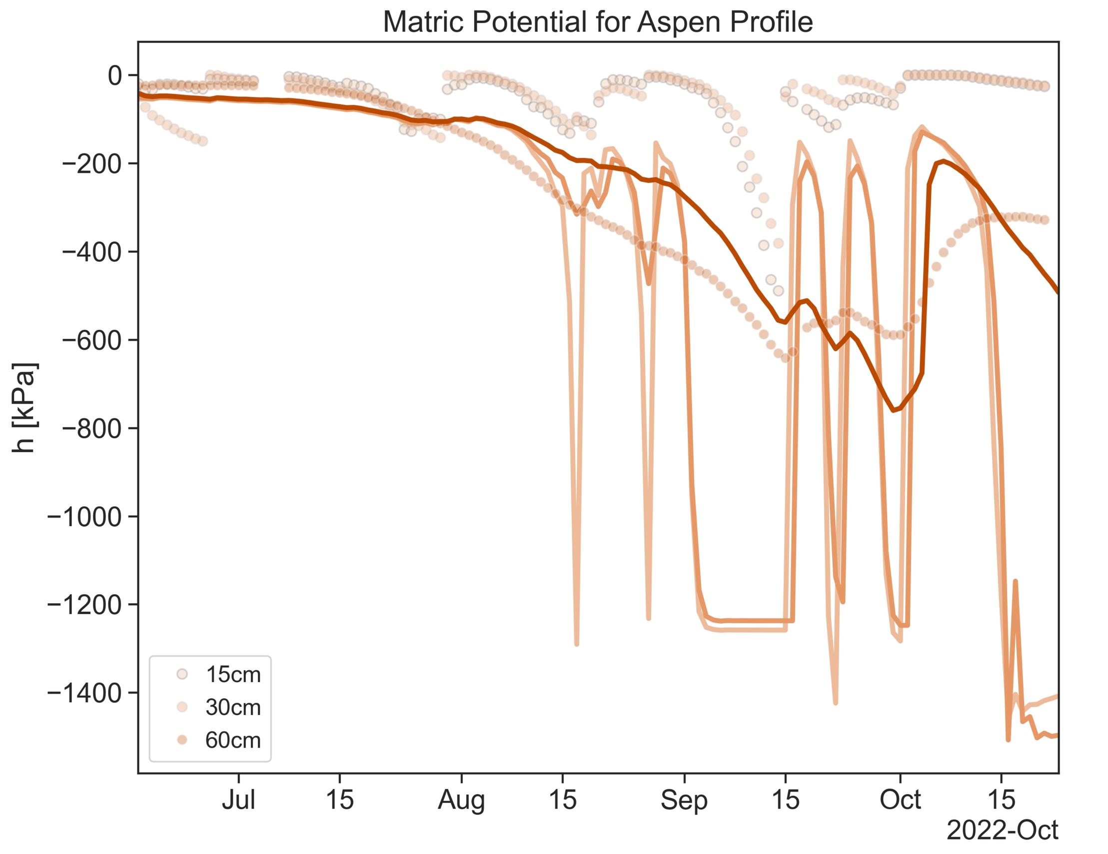
- Plots showing Aspen model runs for parameter optimization and sensitivity analysis for interception parameter (30,000 runs).
- A *multi-objective approach* and *Monte Carlo analysis* was used to identify a best parameter set for the model.
- The Kling-Gupta Efficiency (KGE) was utilized as a goodness of fit metric, with a range of $-inf$ (poorest fit) to 1 (best possible fit).
- ***KGE_{iso}: Goodness of fit for the of stable isotope time series.***
- ***KGE_h: Goodness of fit for the of pressure head time series.***

Parameters Calibrated

θ_s : Saturated Water Content
α : Aspect ≈ [1 / (Air Entry)]
n : Pore-size distribution
K_s: Saturated hydraulic conductivity
D_L: Dispersivity
I : Interception

Simulating Infiltration and Uptake Dynamics



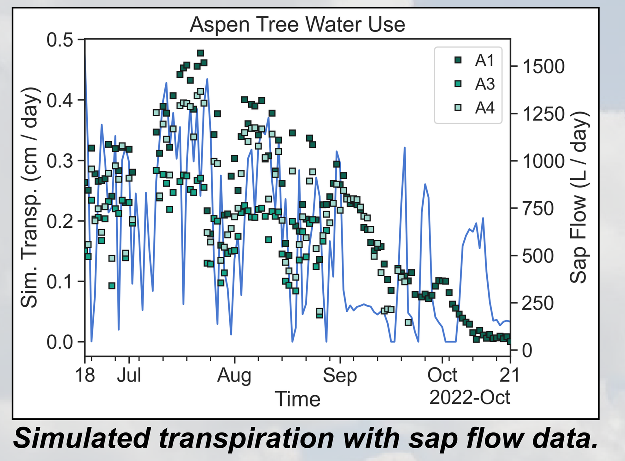


- ***Simulated ∂^2H compared with in-situ ∂^2H.***
- Observations plotted as circles.
- Simulations plotted as curves
- **Red:** ∂^2H concentration in the Aspen soil profile
- **Green:** ∂^2H concentration in Aspen trees
- (***KGE_{iso}: 0.24***)

- ***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_h: 0.32.***

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 68 mm of total precipitation per event).
- Compared to Aspen trees, shallow soil under Engelmann spruce repeatedly dries out beyond the permanent wilting point of -1.5 MPa (higher rates of canopy interception).



Simulated transpiration with sap flow data.

- That said, these efforts aim to help predict and better understand quantification of certain plant water responses during ecosystem changes and future climate conditions (i.e. less frequent monsoonal rains and even fewer high magnitude rain events).

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
- Simulate infiltration and uptake under high ET and low P conditions.

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