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Sensitivity Analysis of Groundwater Recharge to Soil Properties in the Central Valley

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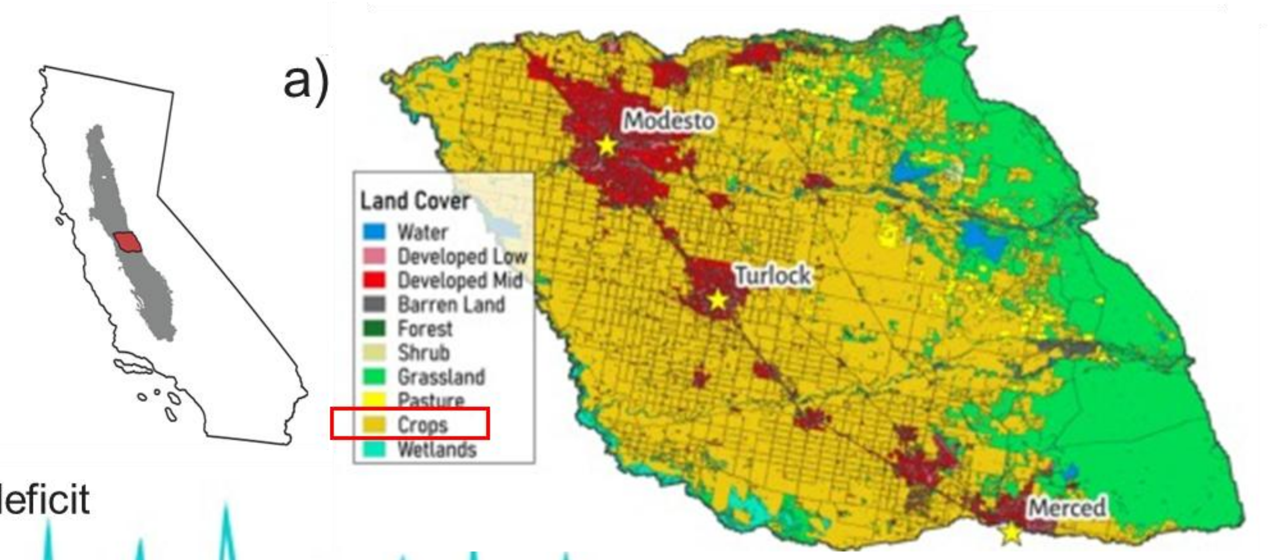
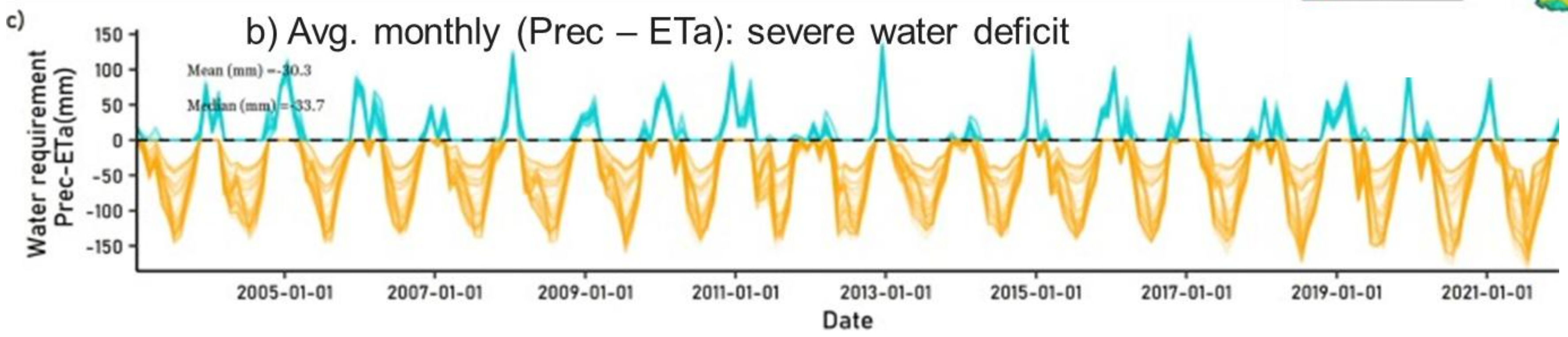
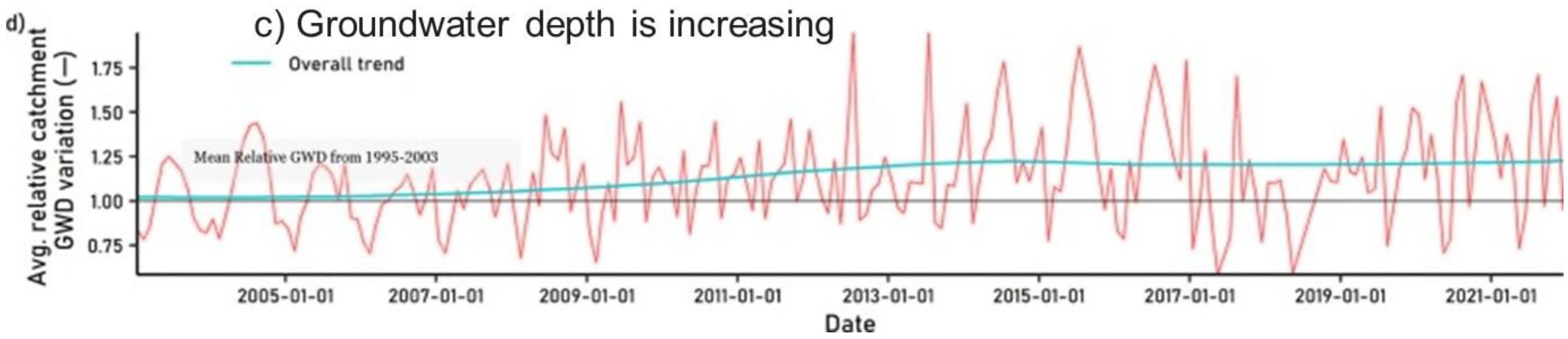
Study area: Modesto-Turlock-Merced subbasins

- ❑ Agricultural region in northeastern San Joaquin Valley.
- ❑ Heavily dependent on groundwater.
- ❑ Suffered by historical overdraft & frequent droughts.
- ❑ Facing serious groundwater sustainability challenges.
- ❑ Need effective Managed Aquifer Recharge (MAR) strategies.





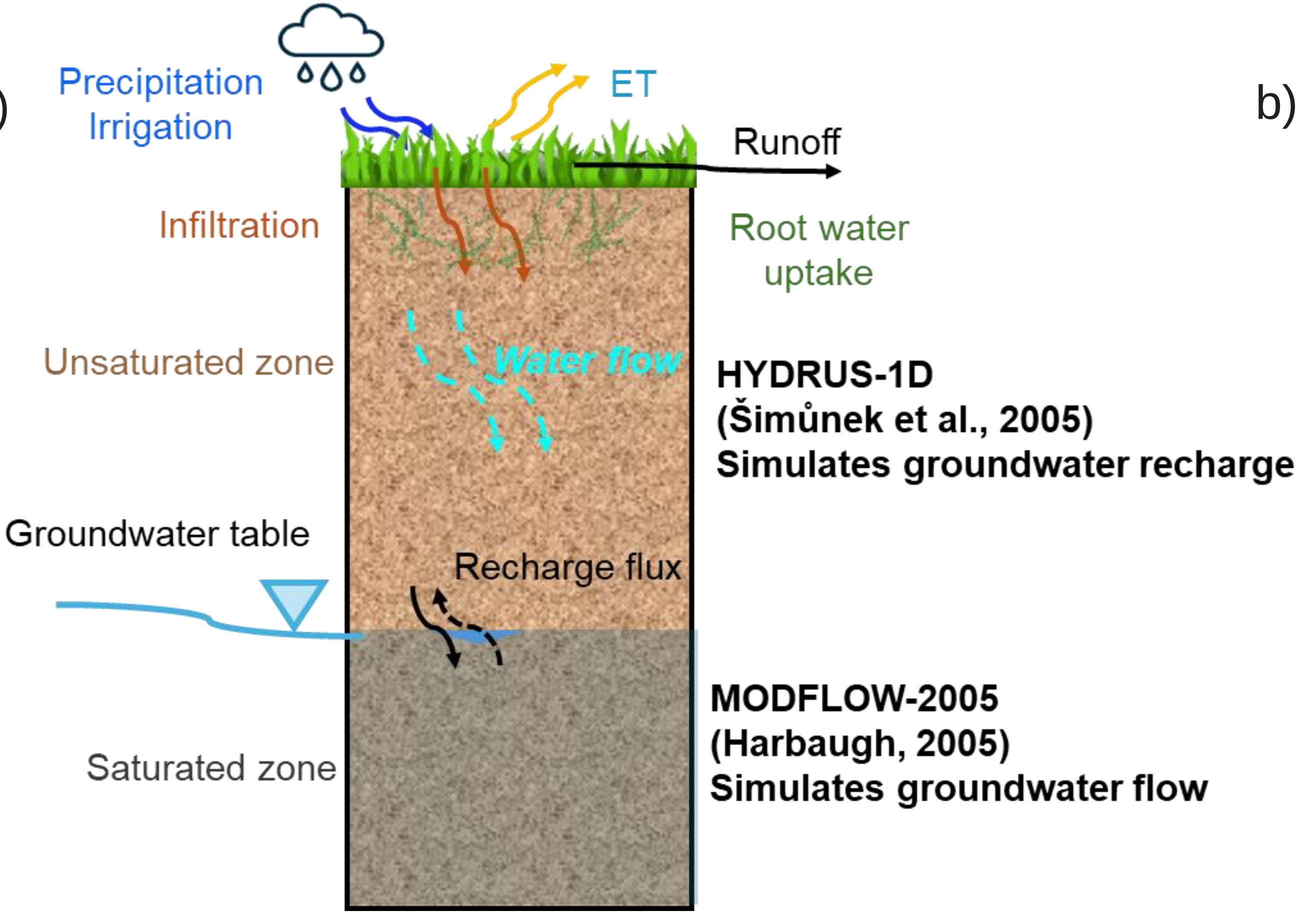


(Source: Casillas-Trasvina et al., 2025, JH)

An integrated hydrologic model was developed for this region:

- MODTUR groundwater flow model (HYDRUS–MODFLOW, 300 m x 300 m) (Casillas-Trasvina et al., 2025, JH).
- To understand recharge processes and groundwater dynamics.
- To guide effective groundwater sustainability practices.

a)



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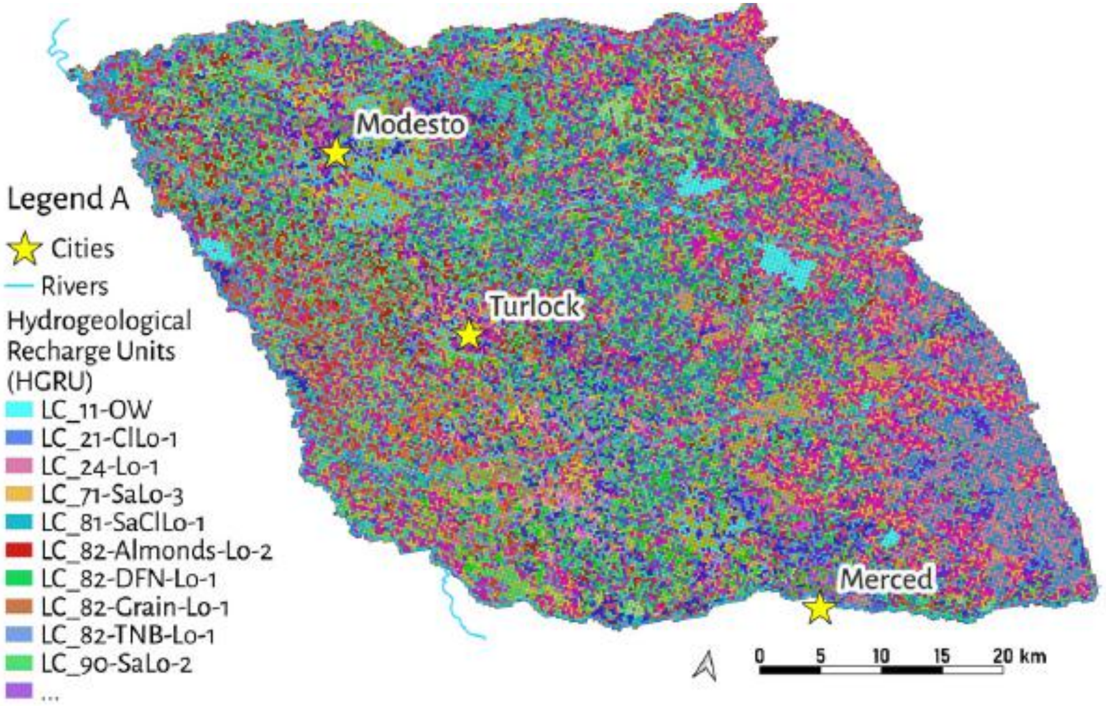
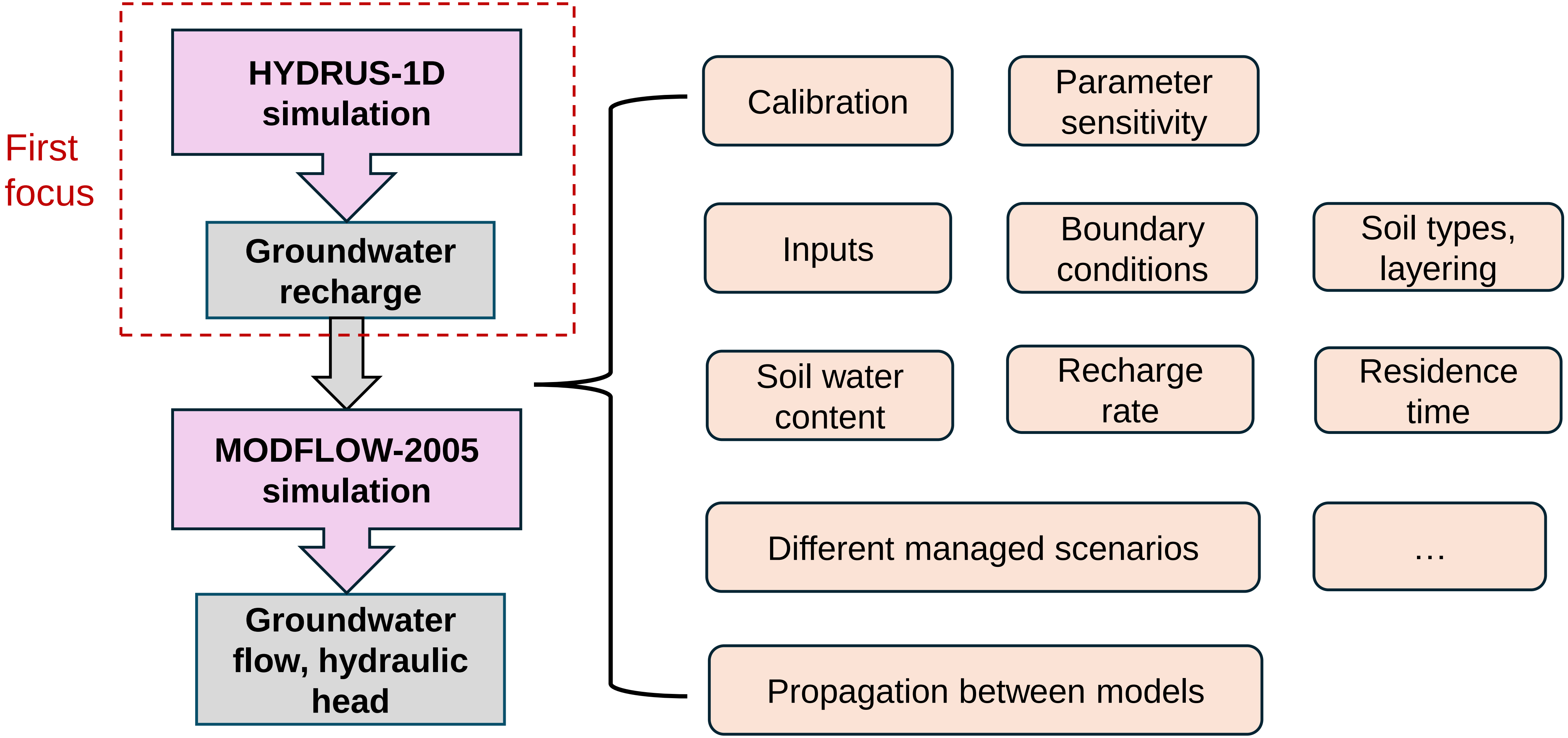


(Source: Casillas-Trasvina et al., 2025, JH)

86 hydrogeological recharge units (HGRU): developed from spatial combination of land cover classes, dominant soil series, crop types and a series of lithological borehole logs.

However, question comes:

How much uncertainty is inherent in this externally coupled model?



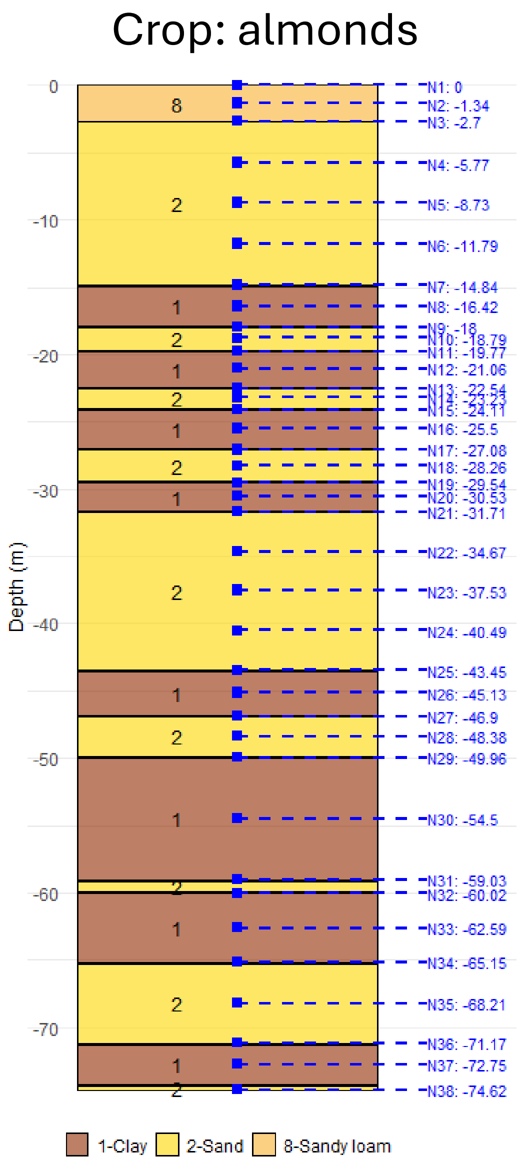
Overall Aim

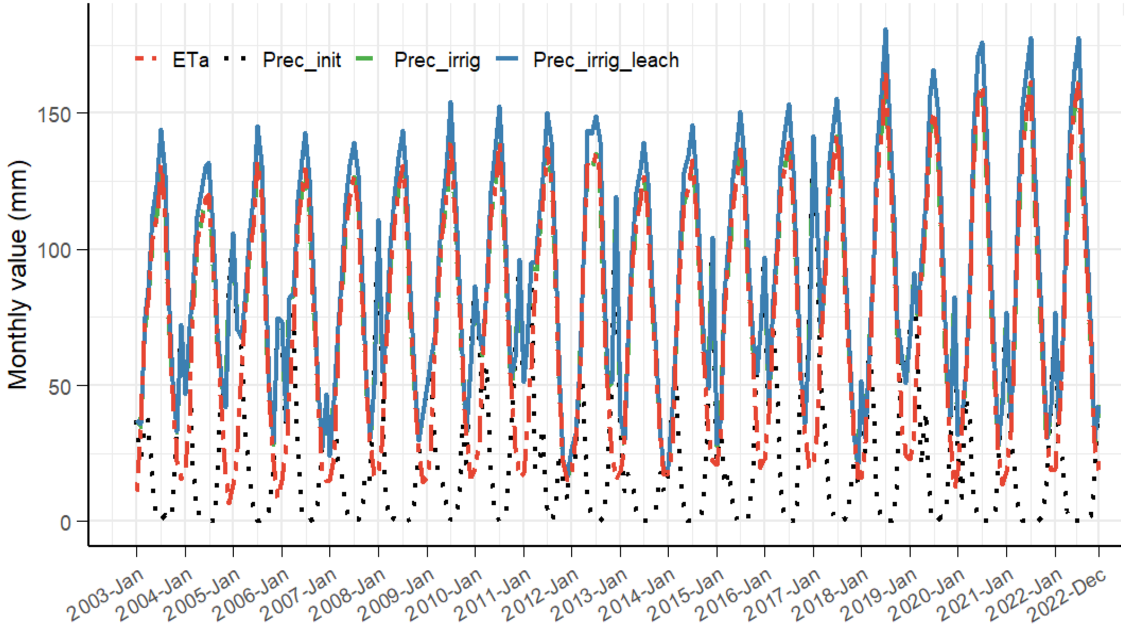
To improve the reliability, robustness, and efficiency of groundwater recharge simulations in the vadose zone by exploring the uncertainty associated with the HYDRUS 1D modeling for the Modesto-Turlock-Merced subbasins.

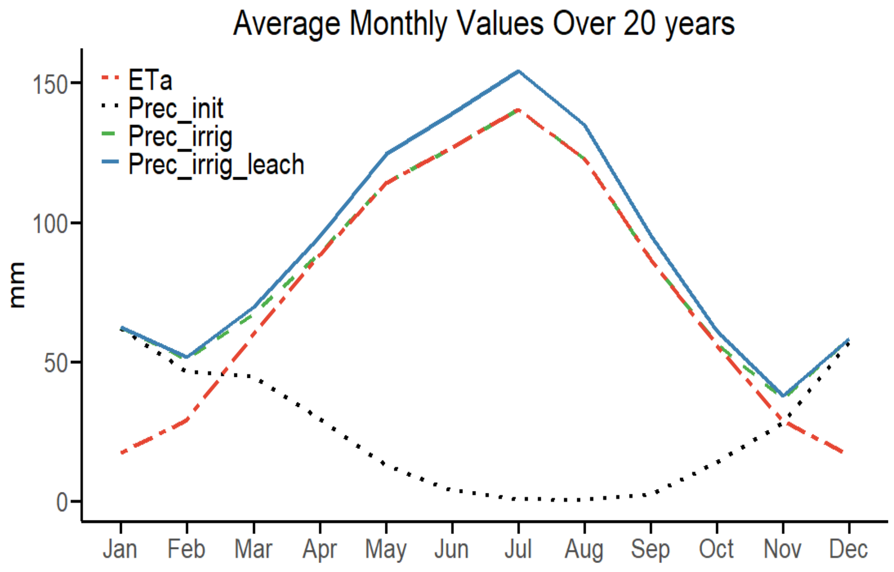
Specific Tasks

- ❑ Evaluate how vertical heterogeneity, different soil texture, and upper boundary conditions influence unsaturated water movement.
- ❑ Quantify parameter sensitivity for different components in groundwater recharge processes.
- ❑ Assess the spatio-temporal variability of vertical transit time to identify optimal time required for effective aquifer recharge.

Select a representative HGRU







Effects from

- ❑ Vertical distribution
- ❑ Different soil texture
- ❑ Boundary perturbations
- ❑ Soil hydraulic parameters

(global sensitivity analysis)

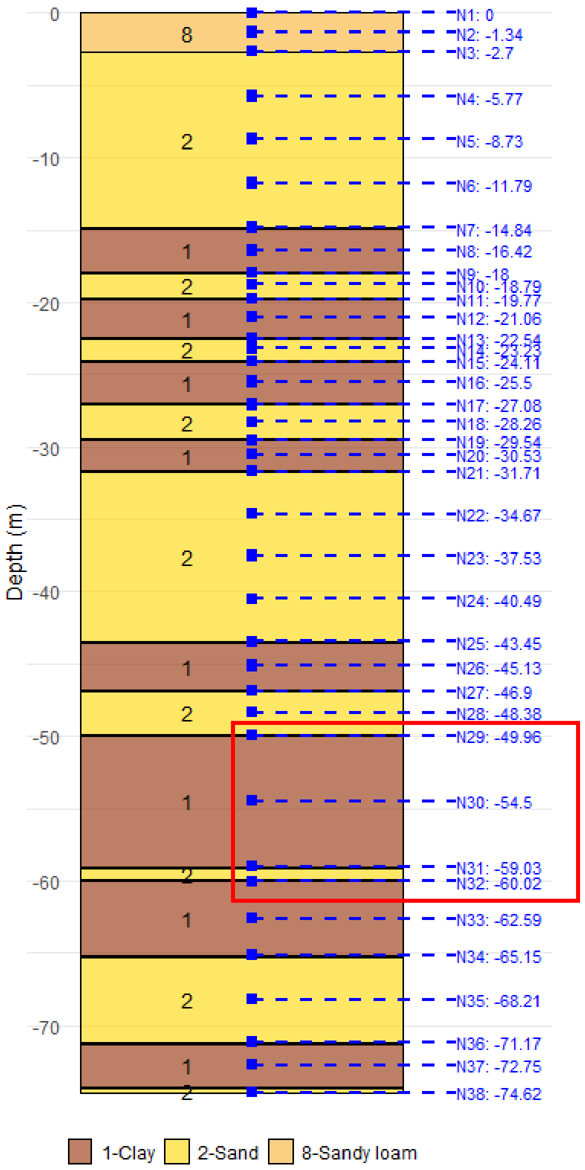
On

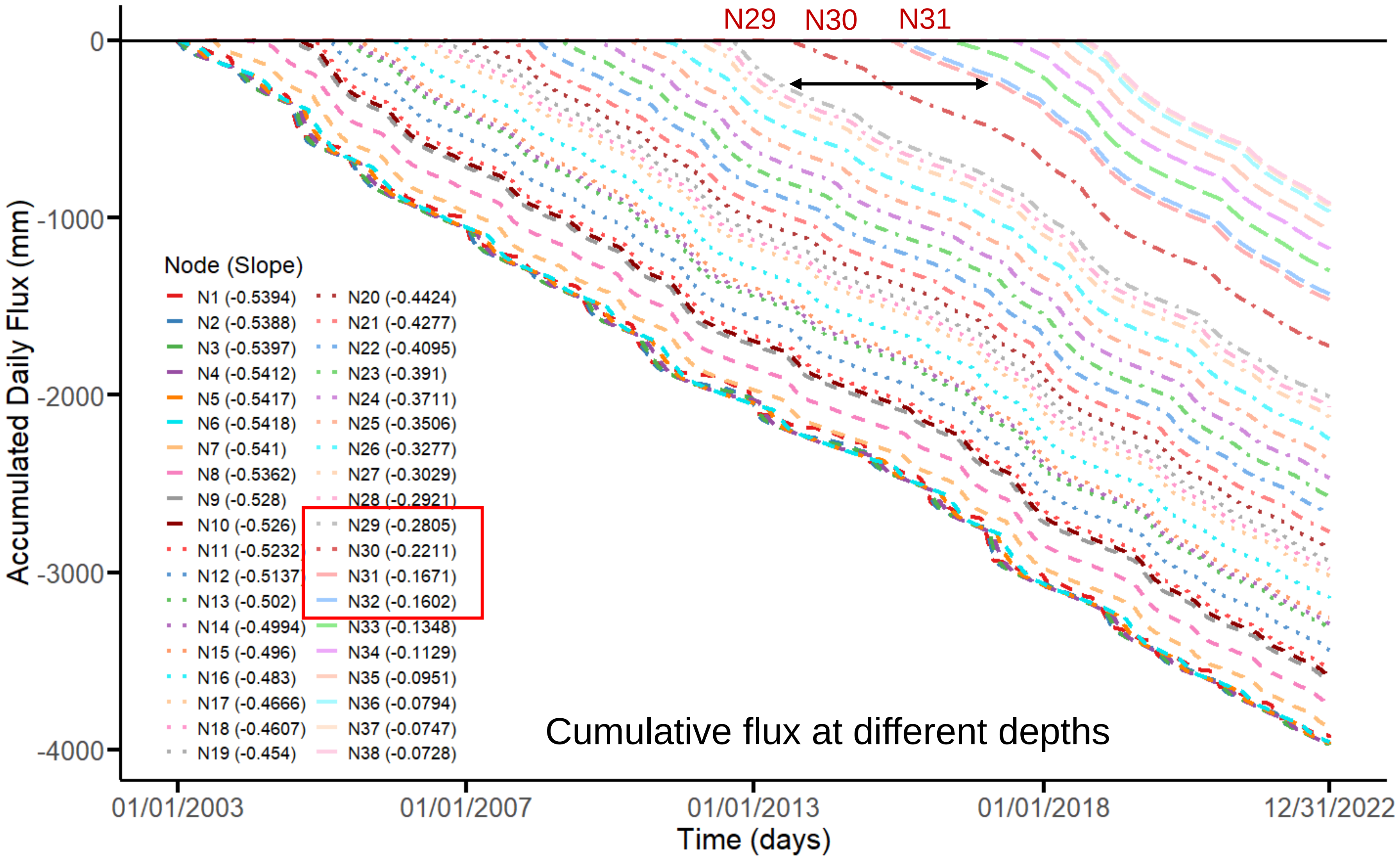
At varying depths

- ❑ Recharge rate
- ❑ Soil water content
- ❑ vertical transit time

➢ (1) At varying depths

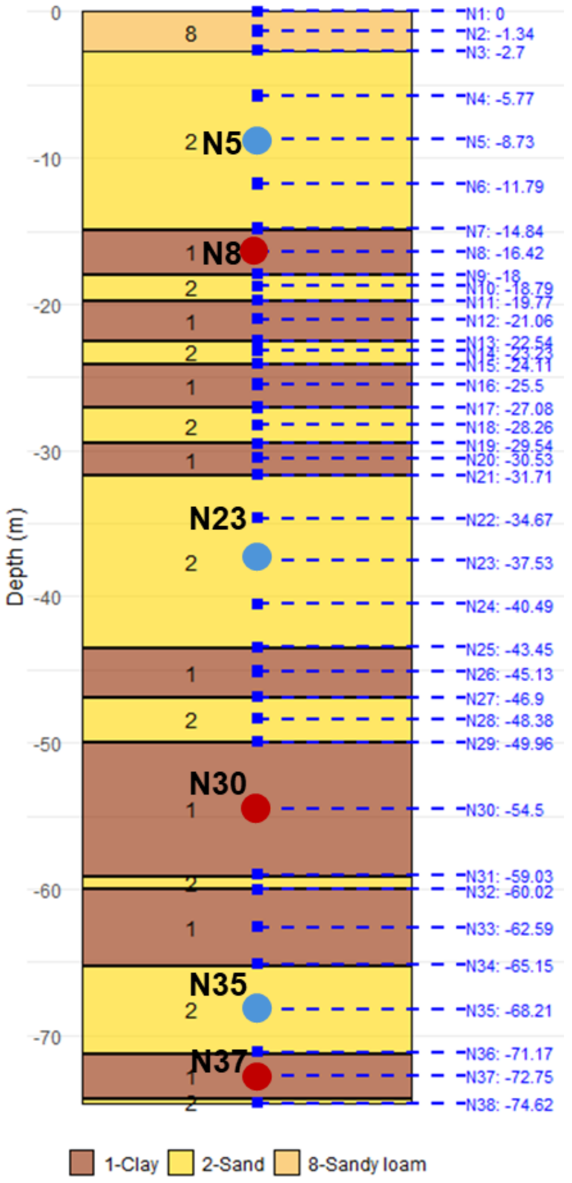
- ❑ Notable time lags of water flux accumulation.
- ❑ Thick clay plays a critical role.

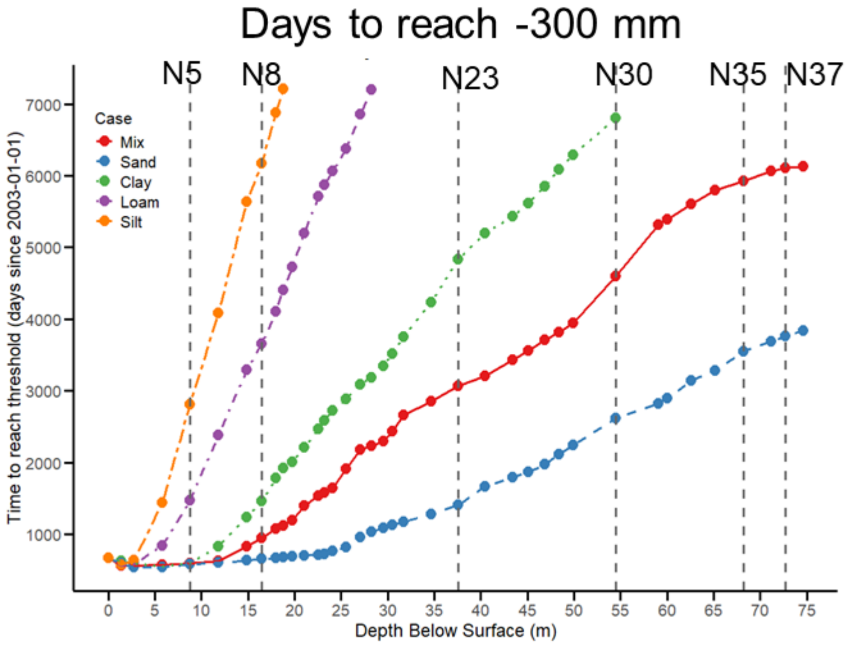


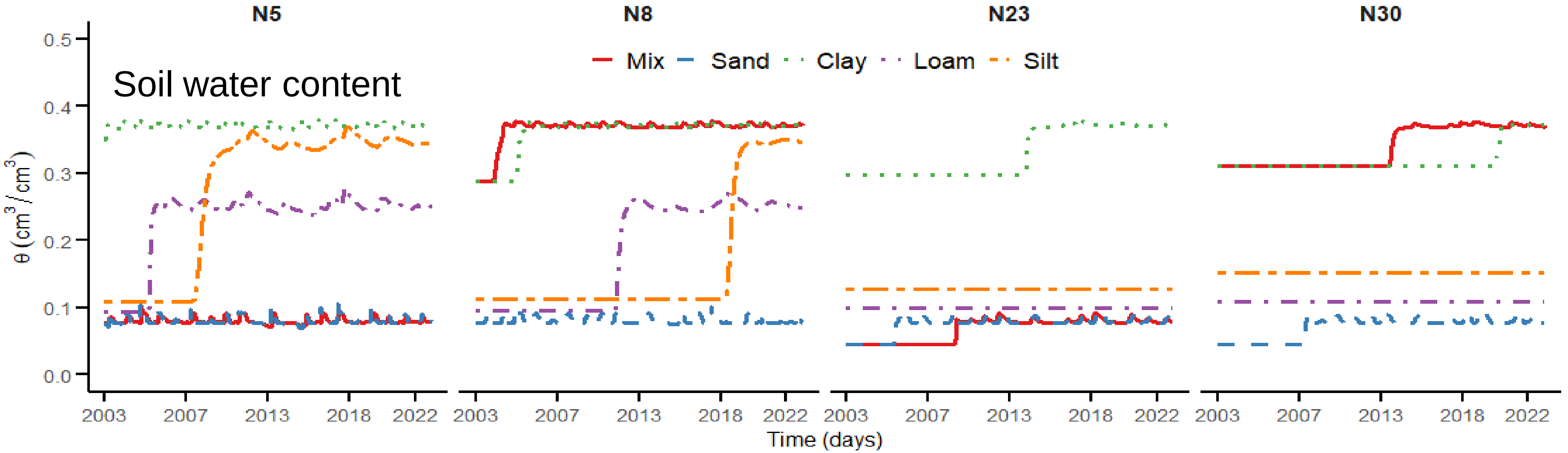


Cumulative flux at different depths

➢ (2) With different soil texture



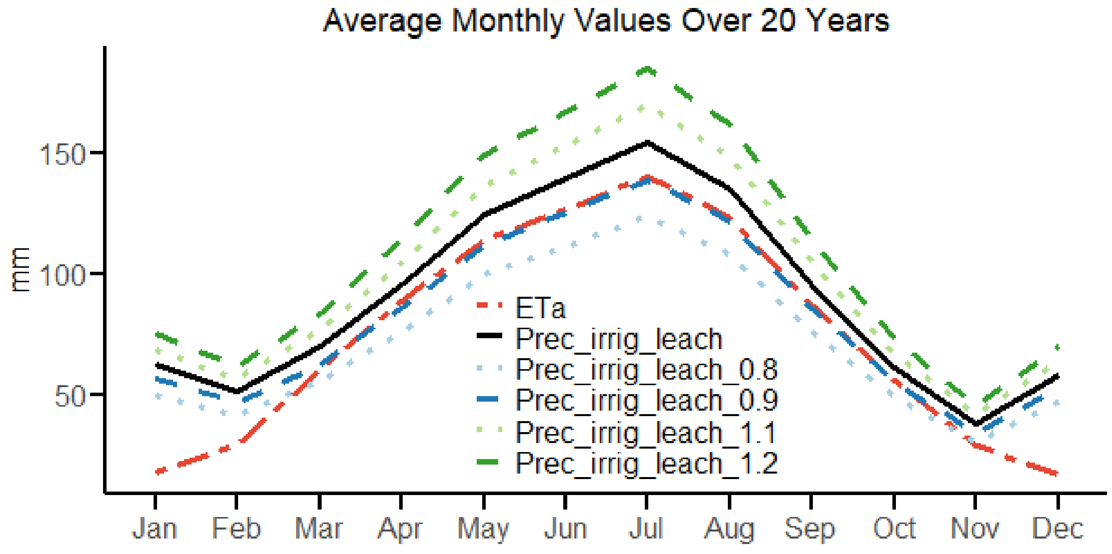


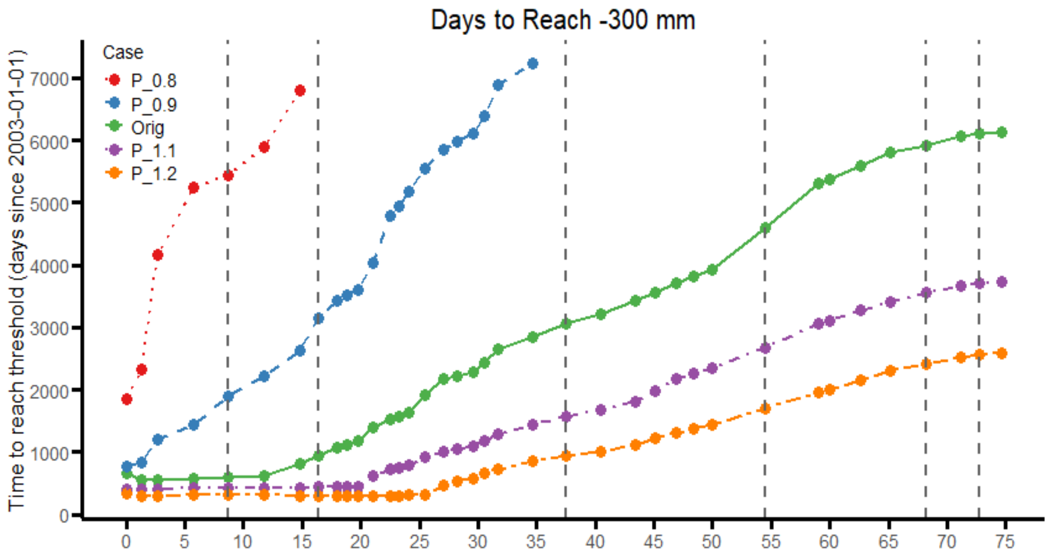


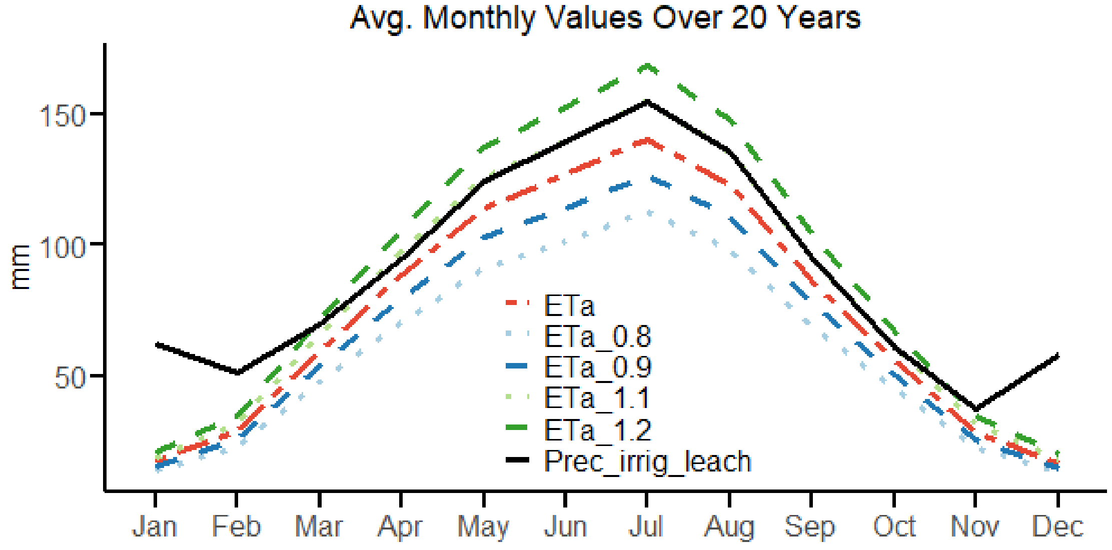
- ❑ Soil texture strongly controls infiltration rate and vertical transit time.
- ❑ Recharge timing at depth is not only a function of water input but also of the soil's ability to store vs transmit water vertically.

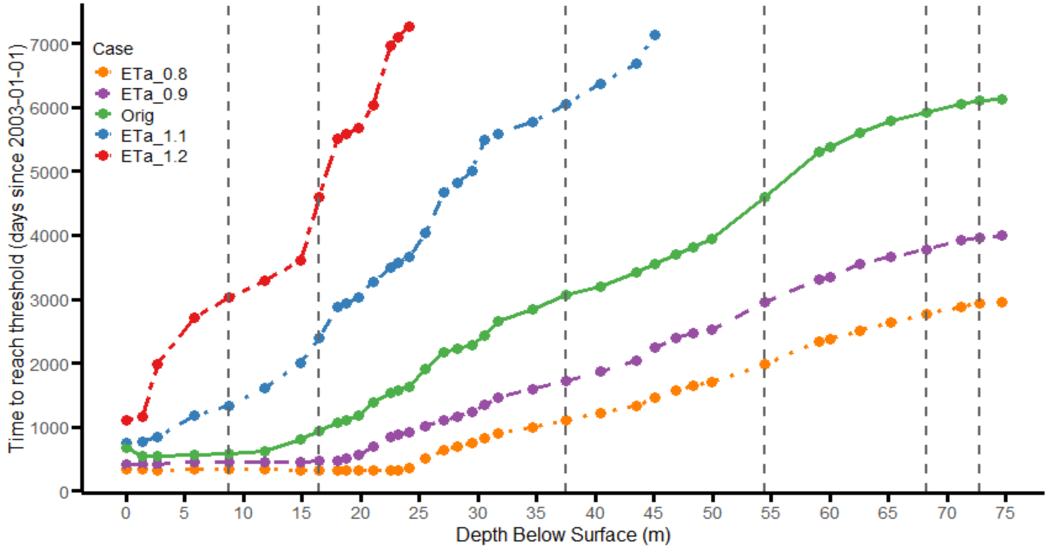
➢ (3) Upper boundary perturbations

- ❑ Decreased P or increased ET could prolong **transit time**.
- ❑ Shallower layers are less sensitive to increased P or decreased ET.



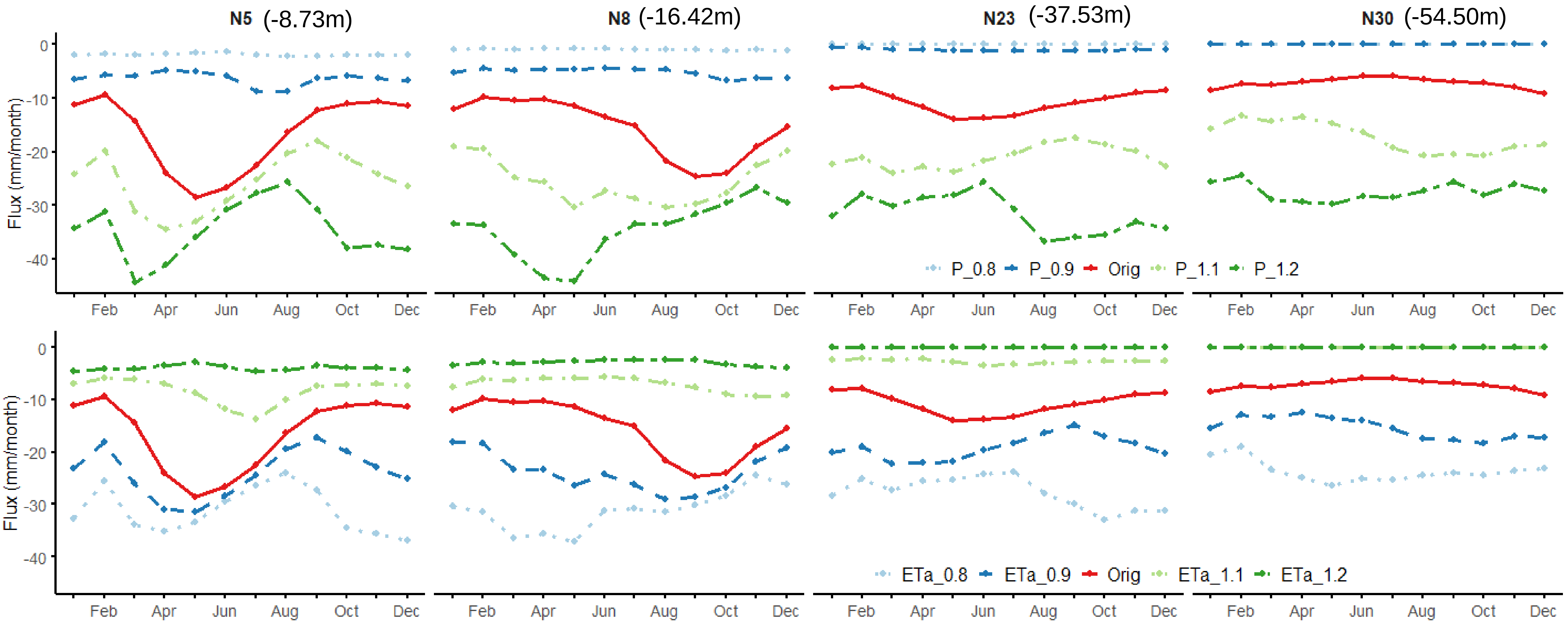






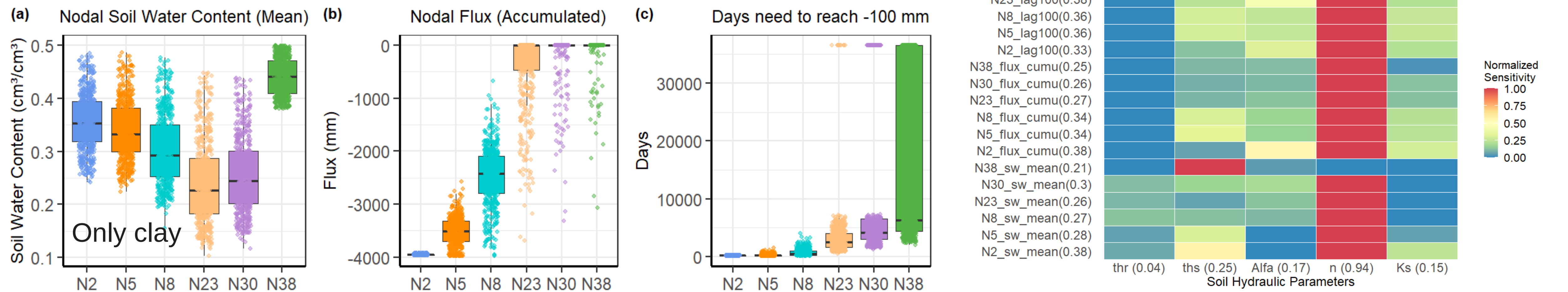
Seasonal response → When and where is MAR most effective?

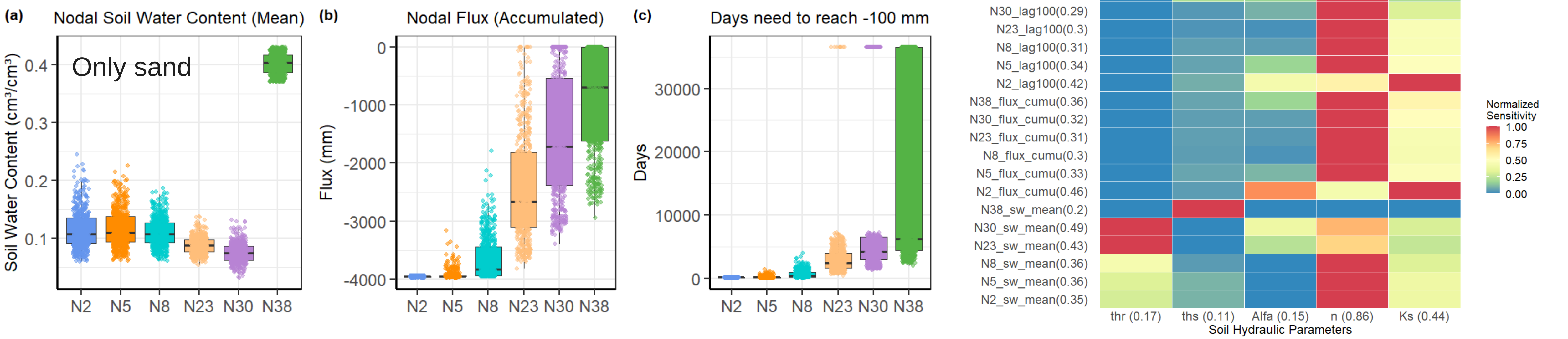
- **Monthly water flux** from shallower to deeper depths: similar seasonal pattern; smaller magnitude; delayed peaks.
- Surface inputs are attenuated as water percolates through the subsurface, where soil water retention, possible lateral flow, and delays dampen the response.



➢ (4) Parameters Sensitivity (Homogeneous profile)

- ❑ The most sensitive parameters: “n” and “Ks”.
- ❑ “Ks” shows higher sensitivity in sandy profile than in clay profile.





Key findings from preliminary investigation in vadose zone:

- ❑ Water flux patterns and vertical transit times are heavily influenced by soil layering and soil texture.
- ❑ Thick clay plays a dominant role in water movements due to its high water retention capacity.
- ❑ Decreased P or increased ET could prolong vertical transit time, with shallower layers less sensitive to increased P or decreased ET.
- ❑ Water fluxes at deeper layers show dampened and delayed responses to boundary perturbations.
- ❑ The van Genuchten parameters “n” and “Ks” are the most sensitive across most simulation outputs.

Next steps:

- ❑ Extend analysis to more soil types and boundary perturbation scenarios.
- ❑ Validate the robustness and reliability of sensitivity results.
- ❑ Identify optimal timing for MAR strategies under different scenarios.
- ❑ Upscale analysis to the entire Modesto-Turlock–Merced subbasins.

Comments and Suggestions are Welcome and Appreciated!

Thank you!

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Casillas-Trasvina, A., Meles, M., Cui, W., Hatch, T., Bradford, S., Harter, T., 2025. Integrated Hydrologic Modeling of Groundwater Flow Dynamics and Recharge in the San Joaquin Valley. *Journal of Hydrology*.

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