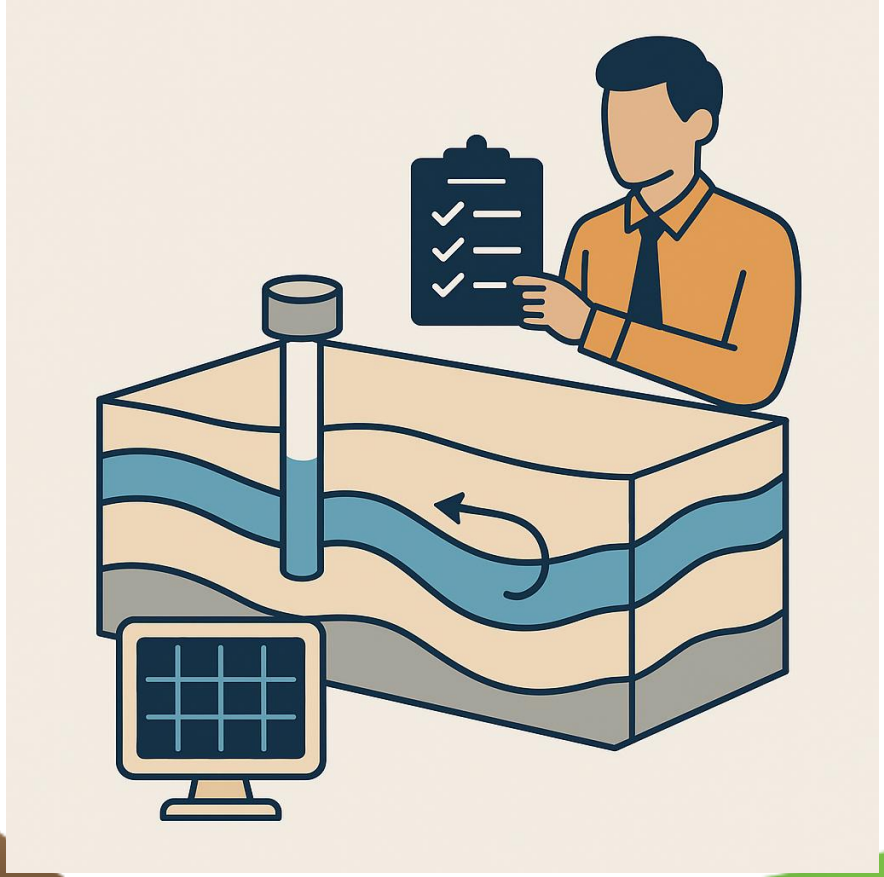

Model Emulation for Decision Support

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Collaborators: Jeremy White, Tyler Hatch, Rui Hugman, Michelle Pedrazas

INTERA

Model Emulation (Surrogate Models)

A **model emulator** is a simplified, fast-running, linear approximation of a full numerical model that replicates its behavior

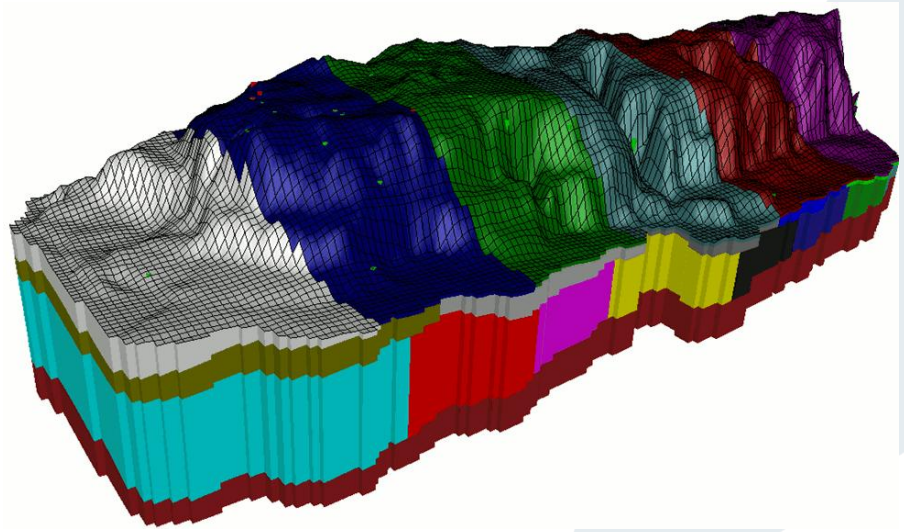
Fast: Run complex scenarios in seconds without launching the full model.

Accessible: Allows non-modelers (e.g., planners, regulators) to test policy or operational scenarios.

INTERA

Linear Approximation with Response Matrix

- A **response matrix** quantifies how model outputs respond to changes in parameters
  - "Model of a model"
- Each entry is a **sensitivity**: how much a specific observation changes per unit change in a parameter
- Generated automatically by **PEST++** during model calibration (jacobian matrix)
- Forms the **core of the emulator** — enabling fast prediction of outputs **without rerunning** the full model



PEST++

$$\begin{bmatrix} \frac{\partial o_1}{\partial p_1} & \frac{\partial o_1}{\partial p_2} & \frac{\partial o_1}{\partial p_n} \\ \vdots & \vdots & \vdots \\ \frac{\partial o_2}{\partial p_1} & \frac{\partial o_2}{\partial p_2} & \frac{\partial o_n}{\partial p_n} \\ \vdots & \vdots & \vdots \end{bmatrix}$$

INTERA

Emulator Workflow

- Assign decision variables → Knobs to turn in the emulator
  - Waste water treatment plant discharges
  - Pumping rates and locations
  - MAR and ASR projects
  - Climate change effects (precipitation, inflows/outflows, etc.)

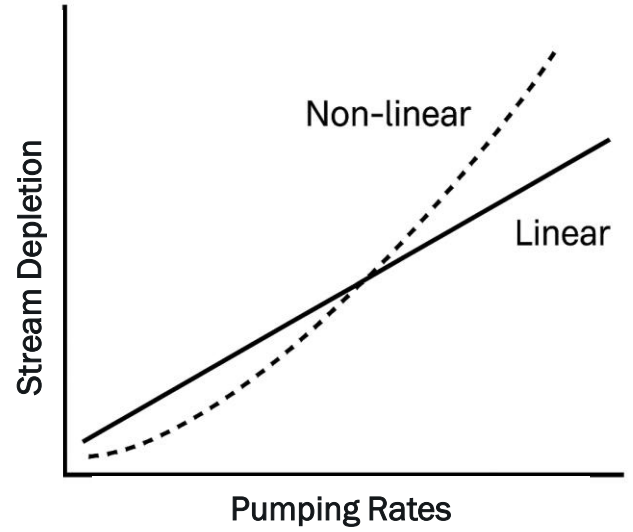
- Assign model responses of interest
  - Surface water flows
  - Basin water levels
  - Inter-basin flows, change in storage

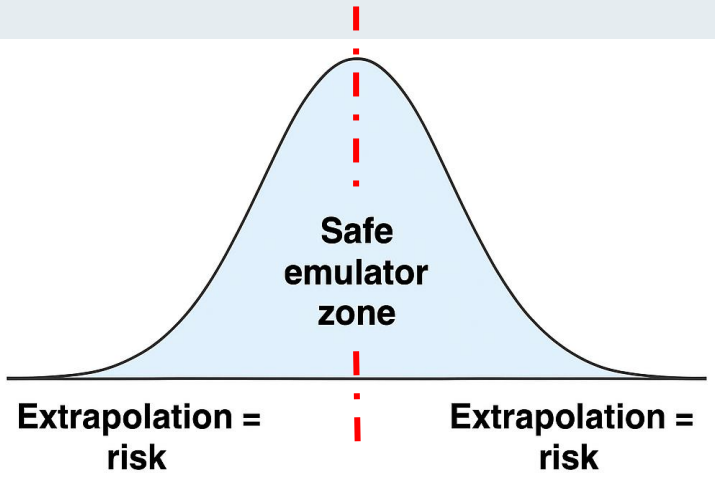
- Use PEST++ to generate response matrix

INTERA

Assumptions and Limitations

- Assumes **linearity** and **super-position**
- Emulator has no understanding of governing **physical laws**
- Best for **relative comparisons** and **pattern evaluation**, not absolute predictions
  - *e.g., "This scenario lowers groundwater elevations by X% relative to baseline"*
- Accuracy is limited to the **range of parameter perturbations** used during calibration





Example Use Case: Freyberg Model Dashboard Tool

Dash

https://freyberg-emulator-dash.onrender.com/

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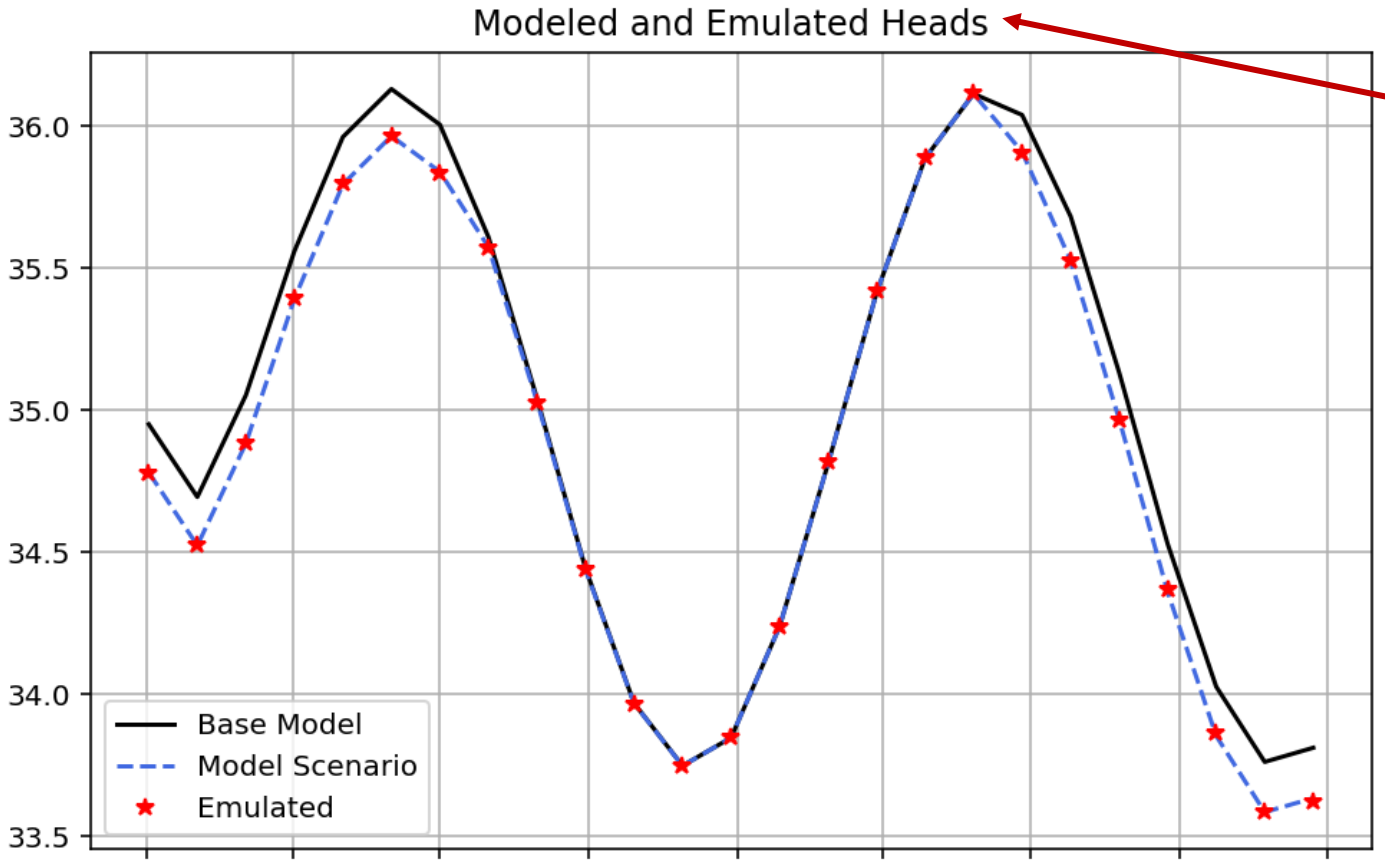
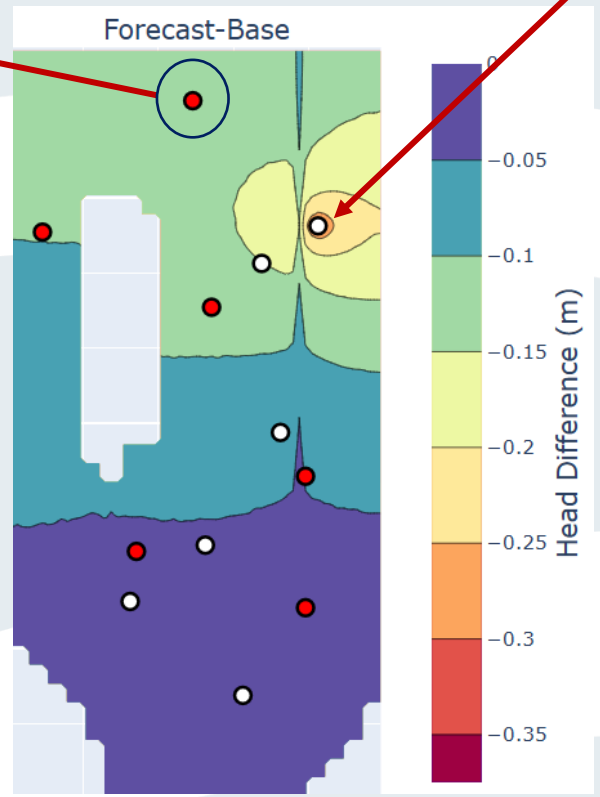
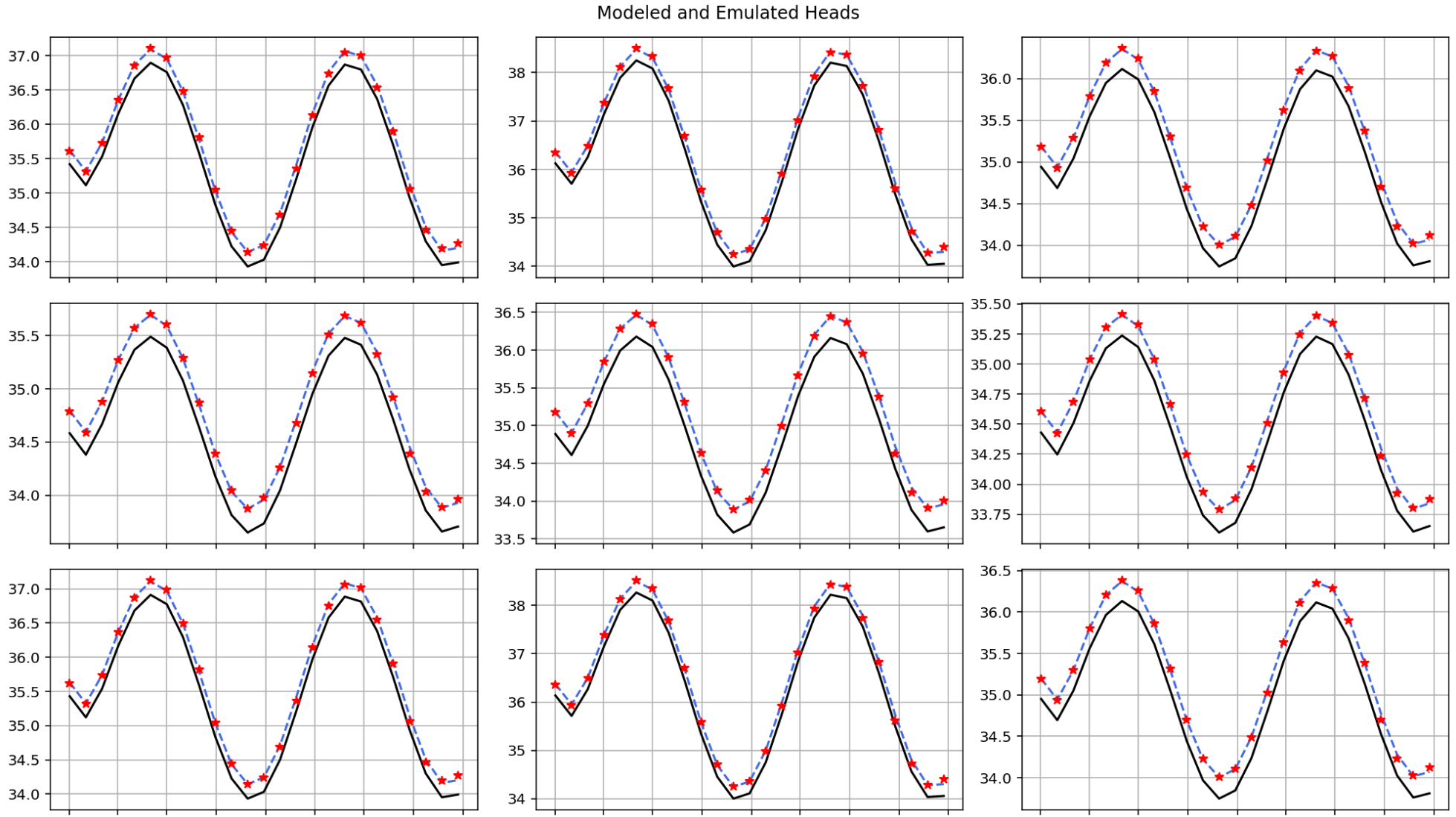
300% pumping, back to base, back to 300% pumping



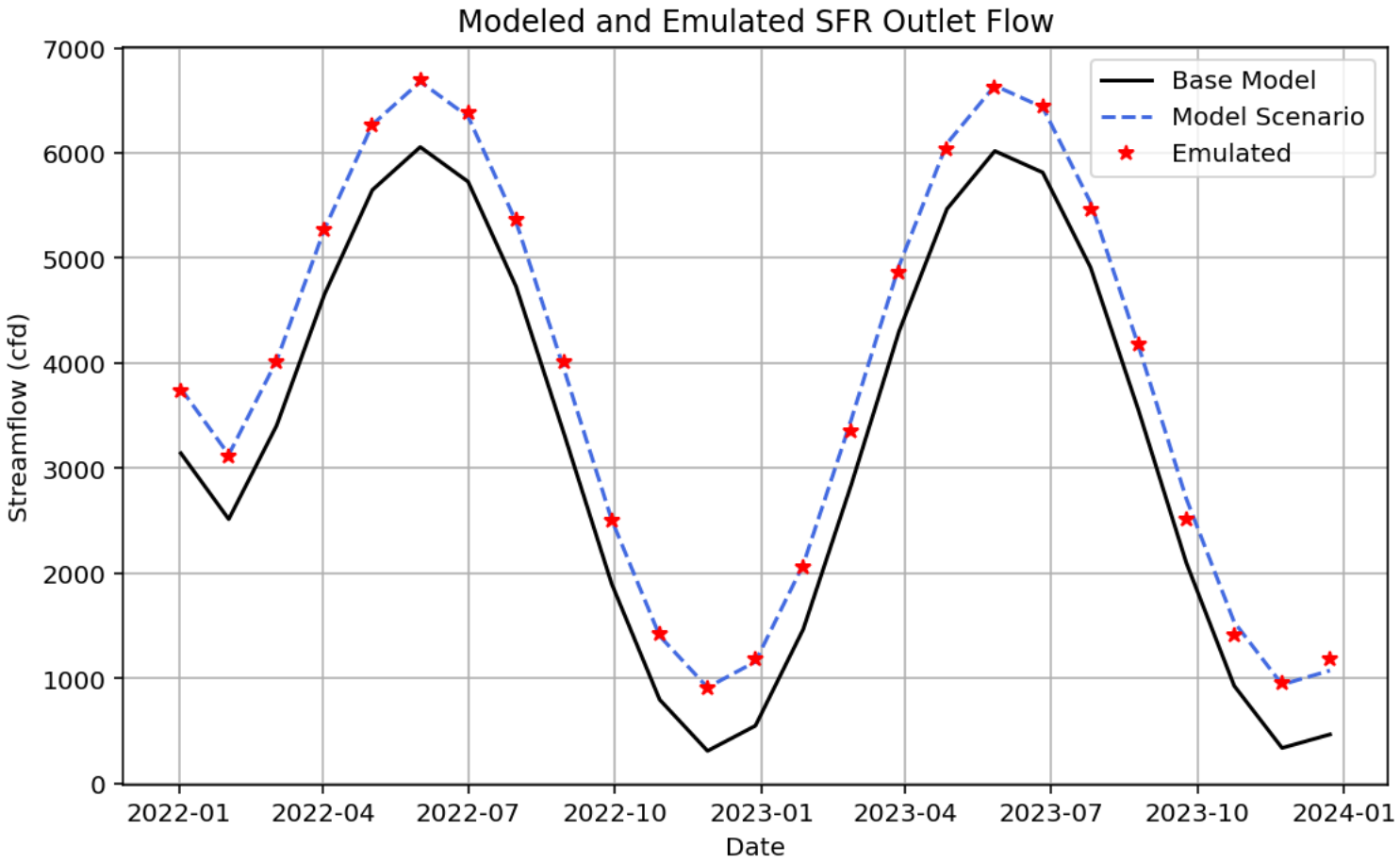
- 300% Increase in pumping

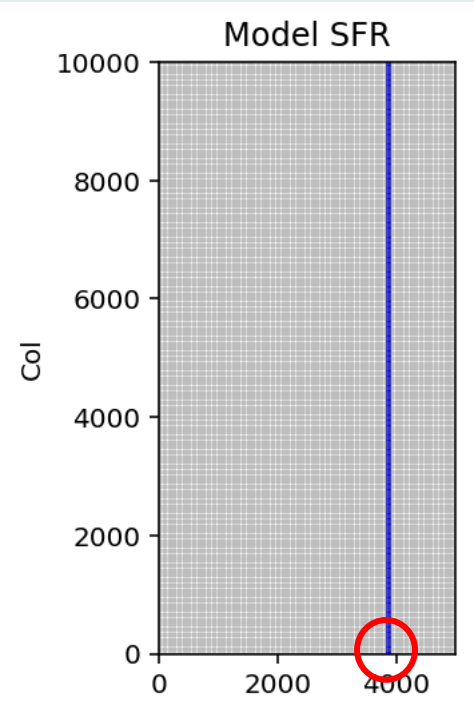


90% Pumping Decrease at all Wells

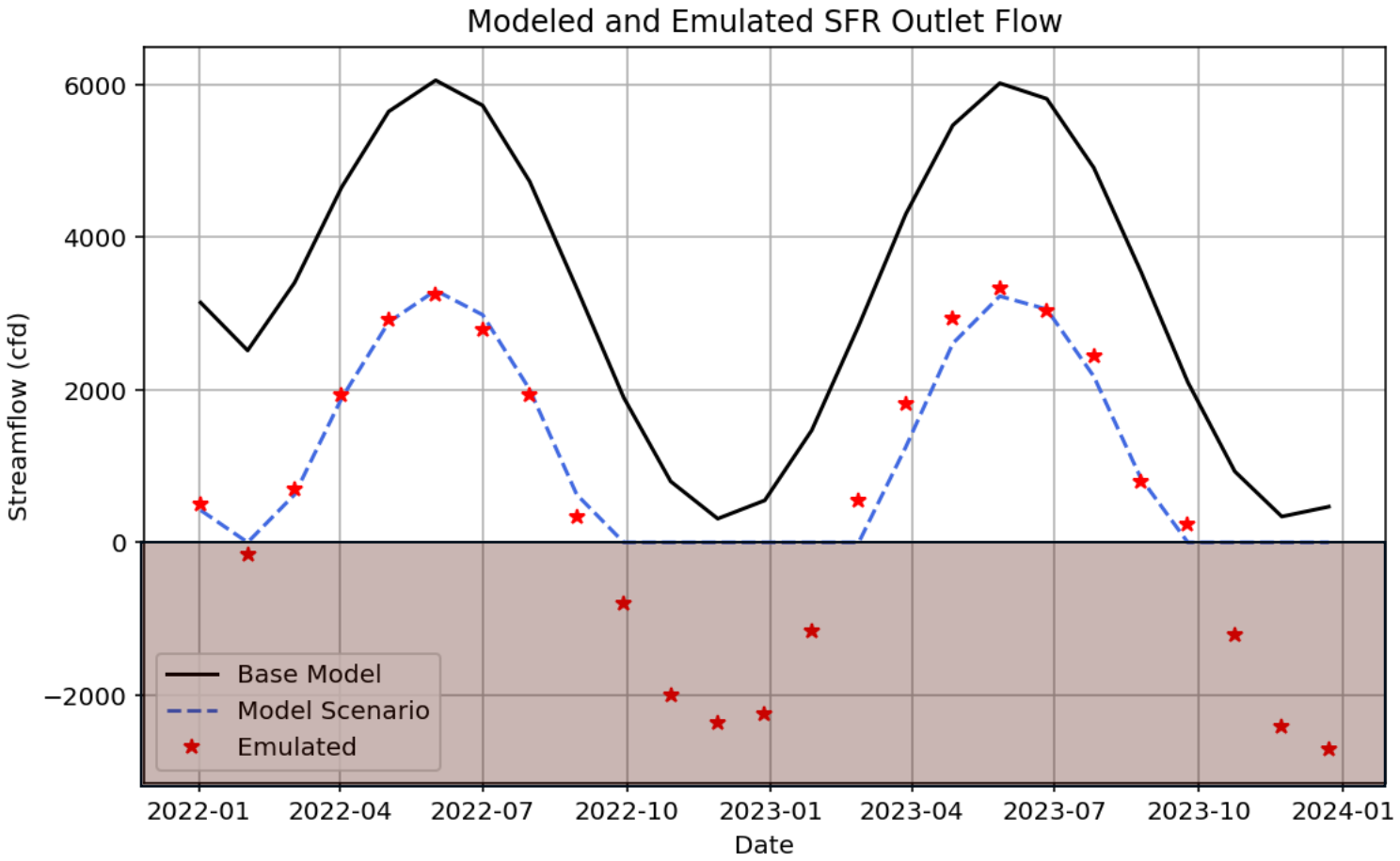


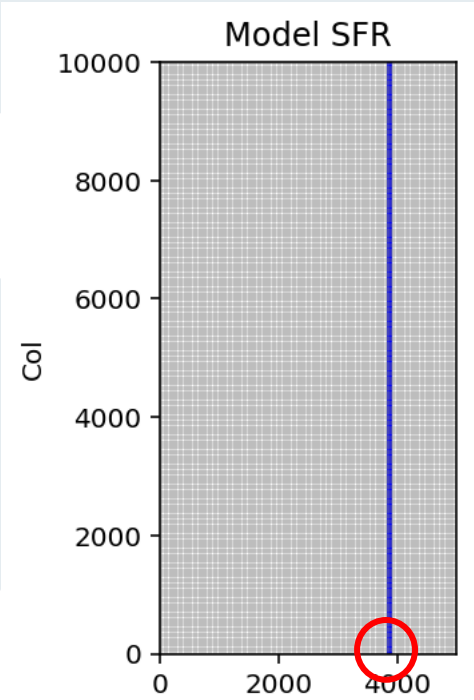
SFR Flows: All Pumping 10%



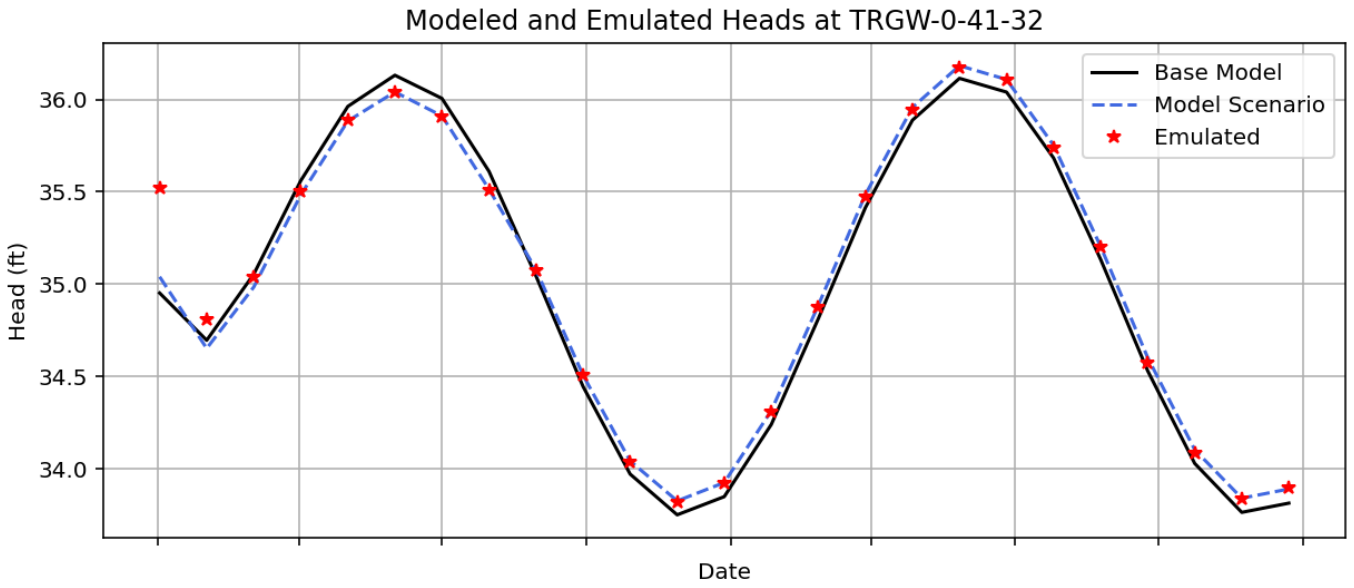


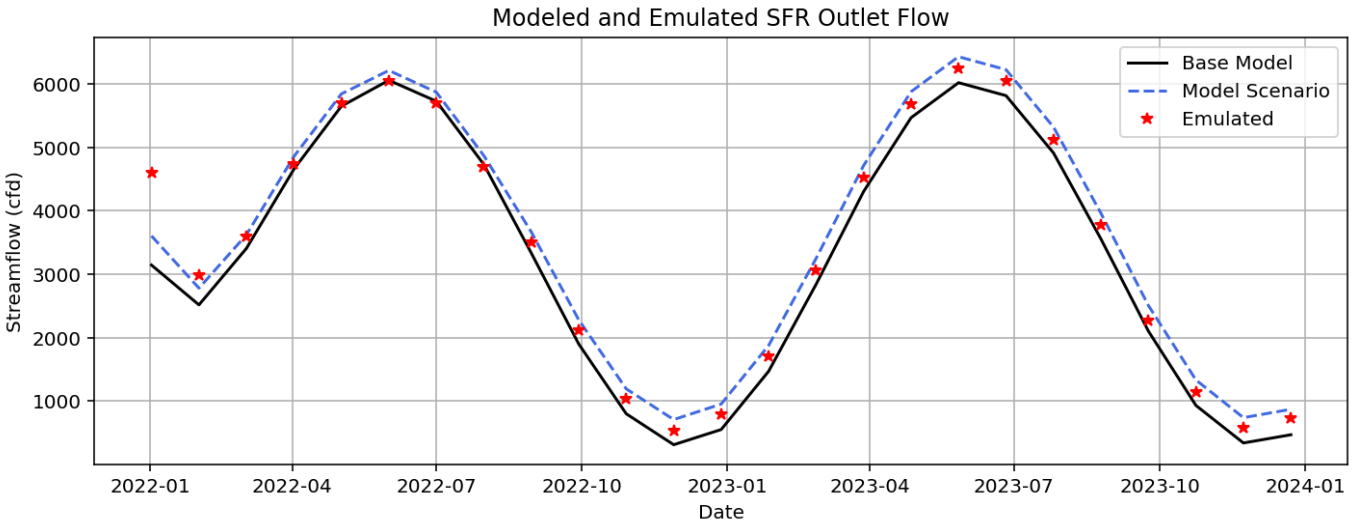
SFR Flows: All Pumping 500%





Representing Superposition:





- Well 1 pumping at 50% for SP 1-5
- Well 2 pumping at 300% for SP 2-8
- Pumping at Well 3 and Well 4 set to 0% for the entire simulation period
- WTP inflows increased by 25%
- Antecedent Recharge Increased by 35%

INTERA

Conclusions

- Model emulation provides a fast, lightweight alternative to running full numerical models.
- When paired with a user-friendly interface, it becomes a powerful tool for scenario planning by water managers, planners, and stakeholders.
- While not a replacement for the full model, emulators can offer accurate relative insights.
- Emulator accuracy is quantifiable — and model-specific limitations should be identified and clearly communicated during development.

INTERA