

From Calibrated Models to Uncertain Futures: Communicating Forecast Uncertainty Around Sustainability Thresholds

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How Models Are Used Alongside Sustainability Thresholds

Establishing the basic relationship before adding uncertainty

① Thresholds are defined from historical observations

Under SGMA, minimum thresholds (MTs) are single numeric values. They are established based on past groundwater levels, local conditions, and management judgment.

② Models are used to explore future conditions

Calibrated groundwater models extend what we know about the past into uncertain future scenarios — different climate forcings, different management responses.

③ Future model outputs are inherently non-unique

A calibrated model matches the past. It does not uniquely determine the future. Parameter uncertainty and forcing uncertainty produce a range of plausible outcomes.

Pajaro Valley Hydrologic Model

Coastal conjunctive-use basin

Why this basin



- ▶ **Coastal, conjunctive-use basin — sole-source aquifer**
 - Agricultural pumping, municipal demand, recycled water delivery
 - Artificial storage and recovery (ASR), managed aquifer recharge (MAR)
 - Surface diversions and Coastal Distribution System (CDS)
- ▶ **Groundwater levels managed to limit coastal intrusion pressure**
 - Intrusion pressure represented using equivalent freshwater-head boundary
- ▶ **Represents all of these processes in one integrated framework**

What Was Added to the Calibrated Model

Building on an existing framework — no additional forward model runs required

Starting point	Model configuration and scenarios
The existing calibrated MF-OWHM model for Pajaro Valley. Calibration dataset: 22,600+ historical groundwater-level observations. Calibration using PEST++.	Seawater intrusion pressure represented using an equivalent freshwater-head formulation at the coastal boundary within MF-OWHM. Downscaled GCMs representing three future climate projections (dry, average, wet) are used to develop model forecasts of key sustainability metrics.
Uncertainty method: FOSM via PEST++	What it produces
First-Order Second Moment (FOSM) analysis. Uses the Jacobian matrix already computed during calibration. Propagates parameter uncertainty forward into each forecast.	A distribution around each forecast value: posterior mean, standard deviation, upper and lower bounds. No Monte Carlo sampling. No additional forward runs.

The model and its calibration are unchanged. FOSM adds a layer of explicit accounting for what cannot be perfectly constrained.

Where Forecast Variability Comes From

Two distinct sources — both present even with a well-calibrated model

Climate forcing

The model is run under three distinct climate scenarios — dry, average, and wet — derived from different General Circulation Models (GCMs) under RCP 8.5.

Each scenario produces a different trajectory of precipitation, temperature, and recharge over the forecast horizon.

The spread between scenarios reflects genuine uncertainty about which future climate will materialize — not model error.

Calibrated parameter uncertainty

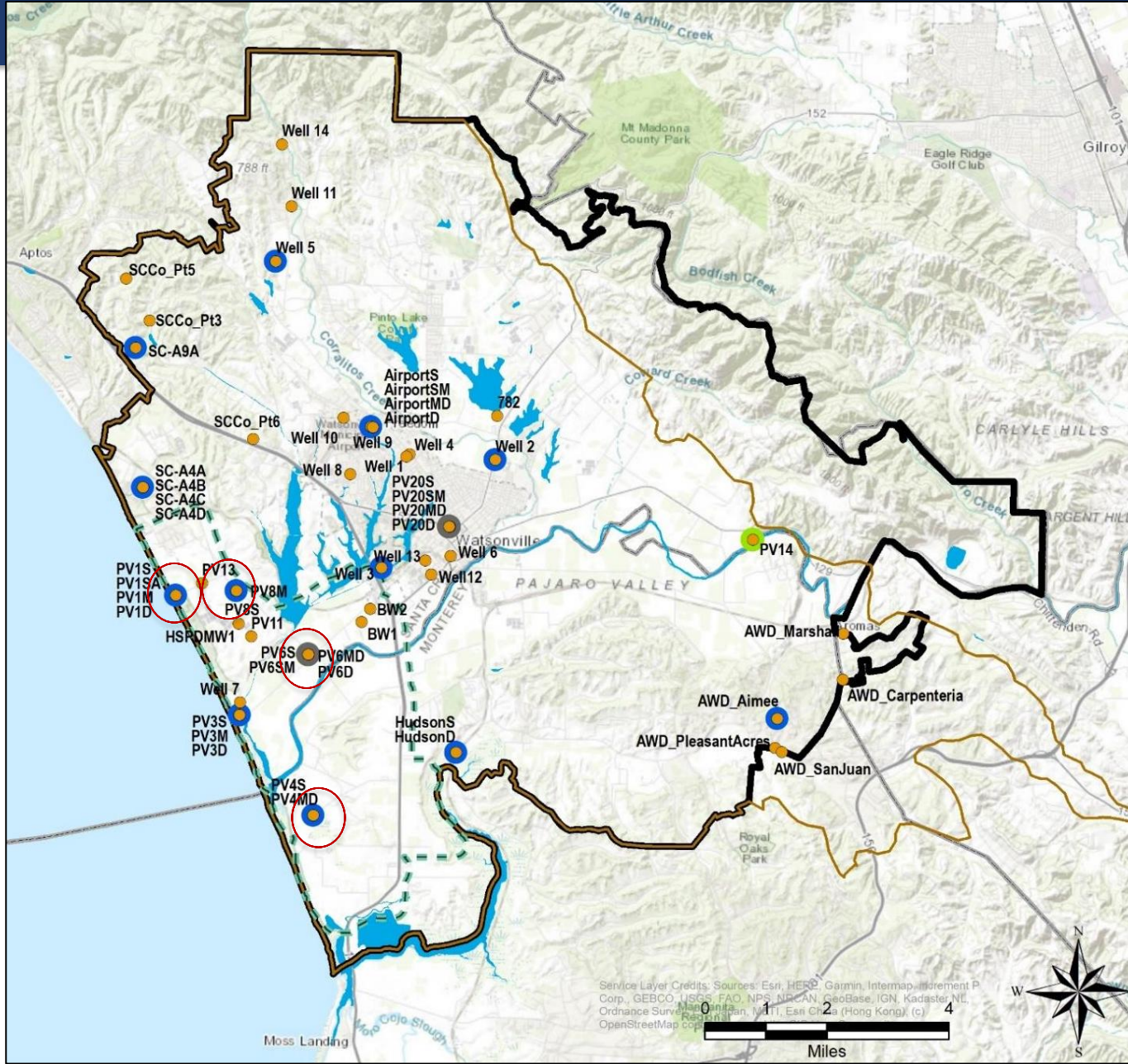
Even with 22,600+ historical observations, the calibrated parameter set is not unique. Many parameter combinations produce equally good fits to the historical record.

FOSM propagates that non-uniqueness forward into each forecast, producing the upper and lower bounds around the median.

A model that calibrates well to the past does not produce a unique future. This is not a limitation of this model specifically — it is a property of all calibrated models.

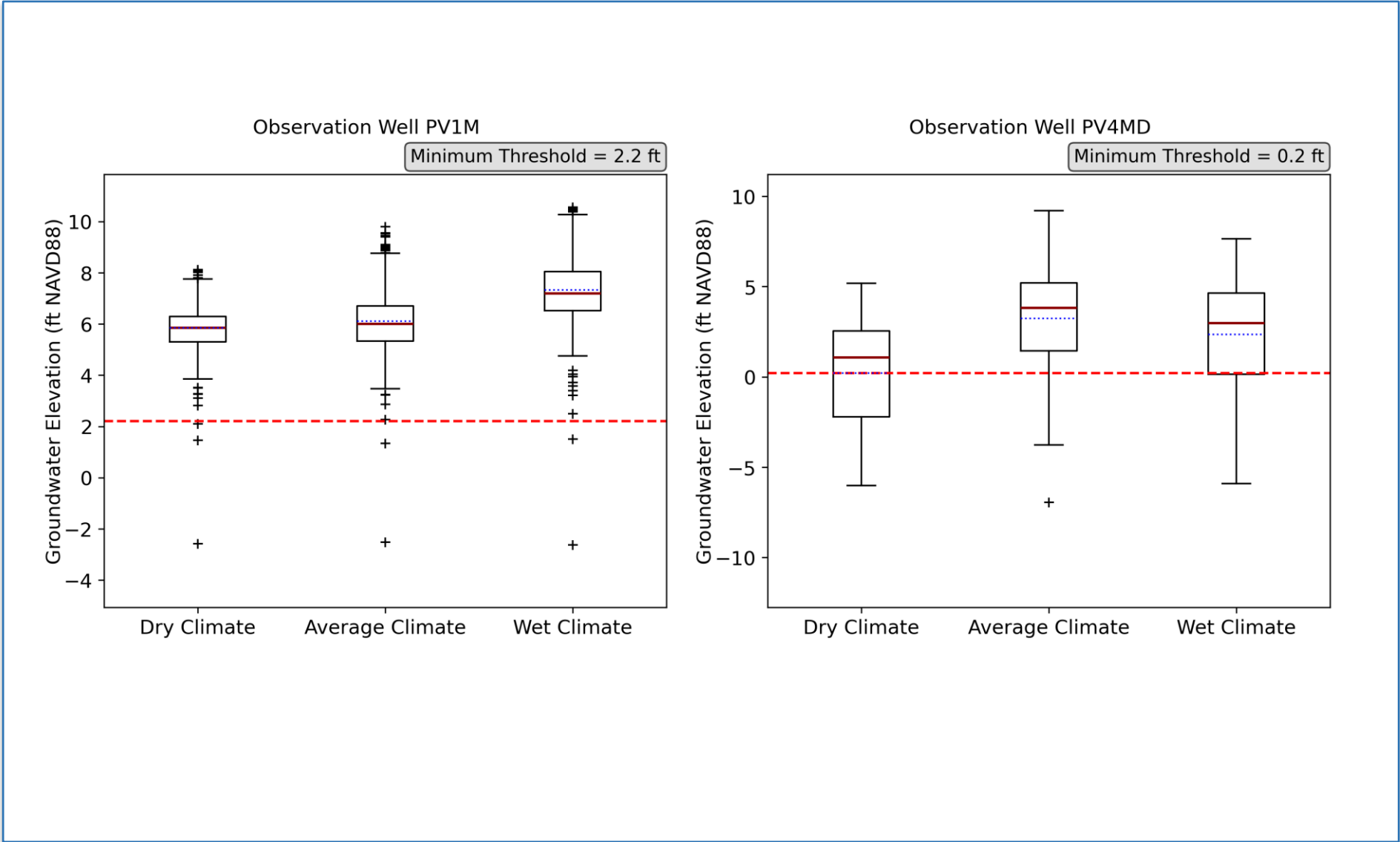
Both sources of variability are present simultaneously. Neither can be reduced by additional calibration of the existing model.

SGMA Groundwater-Level Representative Monitoring Locations



Groundwater-Level Forecast Distributions

Posterior uncertainty bounds — selected monitoring wells, 3 climate scenarios

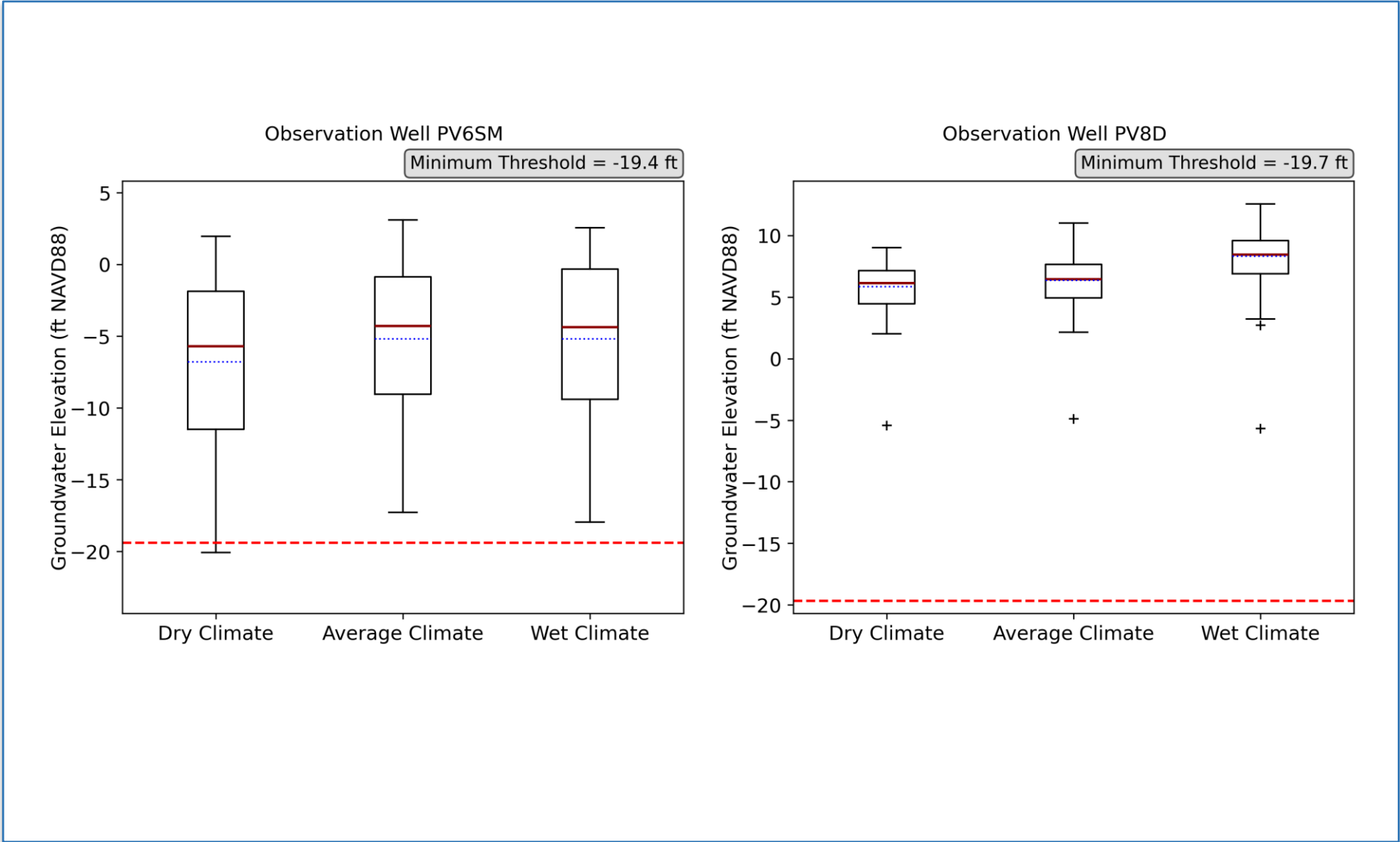


READING THE BOX

- Red dashed line
Minimum sustainability threshold
- Box top/bottom
Interquartile range (25th–75th percentile)
- Whiskers
95% of the forecast distribution
- Three boxes
Dry / Average / Wet climate scenario

Groundwater-Level Forecast Distributions

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Using Forecast Uncertainty to inform Sustainability Thresholds

What forecast distributions tell us

- ▶ **A single forecast value cannot describe future conditions.**
- ▶ **The width of the distribution indicates how sensitive a forecast is to uncertainty at a given location.**
- ▶ **Differences between climate scenarios illustrate variability in future conditions.**
- ▶ **Comparing forecast distributions to minimum thresholds provides context for interpreting future uncertainty.**
- ▶ **Expressing forecasts as distributions, rather than single values, supports clear communication of variability and the ongoing need for adaptive management.**

An aerial photograph showing a landscape with a mix of urban and agricultural areas. On the left, a city with dense housing and some industrial buildings is visible. A multi-lane highway runs diagonally from the bottom left towards the center. To the right of the highway, there are large, rectangular agricultural fields in various shades of green and brown, indicating different crops or stages of cultivation. A dark, winding line of trees or a small waterway separates the fields from the city. In the upper right, a tall, thin structure, possibly a tower or antenna, stands out against the sky. The overall scene suggests a transition zone between urban development and rural agriculture.

Questions?