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Design and Calibration of a Nitrate Decision Support Tool for Groundwater Wells in Wisconsin, USA

Paul Juckem[1], Nicholas Corson-Dosch[1], Laura Schachter[1], Christopher Green[2], Kelsie Ferin[3], Eric Booth[3], Christopher Kucharik[3], Brian Austin[4], Leon Kauffman[5]

[1]U.S. Geological Survey, Upper Midwest Water Science Center; [2]U.S. Geological Survey, Water Resources Mission Area; [3]University of Wisconsin - Madison, Dept. of Plant and Agroecosystem Sciences; [4]Wisconsin Dept. of Natural Resources, Bureau of Drinking Water and Groundwater; [5]U.S. Geological Survey, New Jersey Water Science Center

pfjuckem@usgs.gov

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1. Abstract

Problem:
Nitrate is the most wide-spread pollutant in groundwater across Wisconsin. High nitrate concentrations pose risks to infants and fetal development, and are linked to some forms of cancer.

Innovation:
A "reduced-complexity" decision support tool for resource managers to assess how *much* nitrate leaching needs to be reduced to meet a goal, and how *long* before changes will be observed in well water. Graphical results of quantified uncertainty facilitate understanding of processes & trade-offs.

Scenarios:
Six scenarios to forecast how leaching reductions could drive future concentrations. Scenarios focus on goals (concentration and duration) and the requirements to meet them (leaching reductions).

2. Workflow

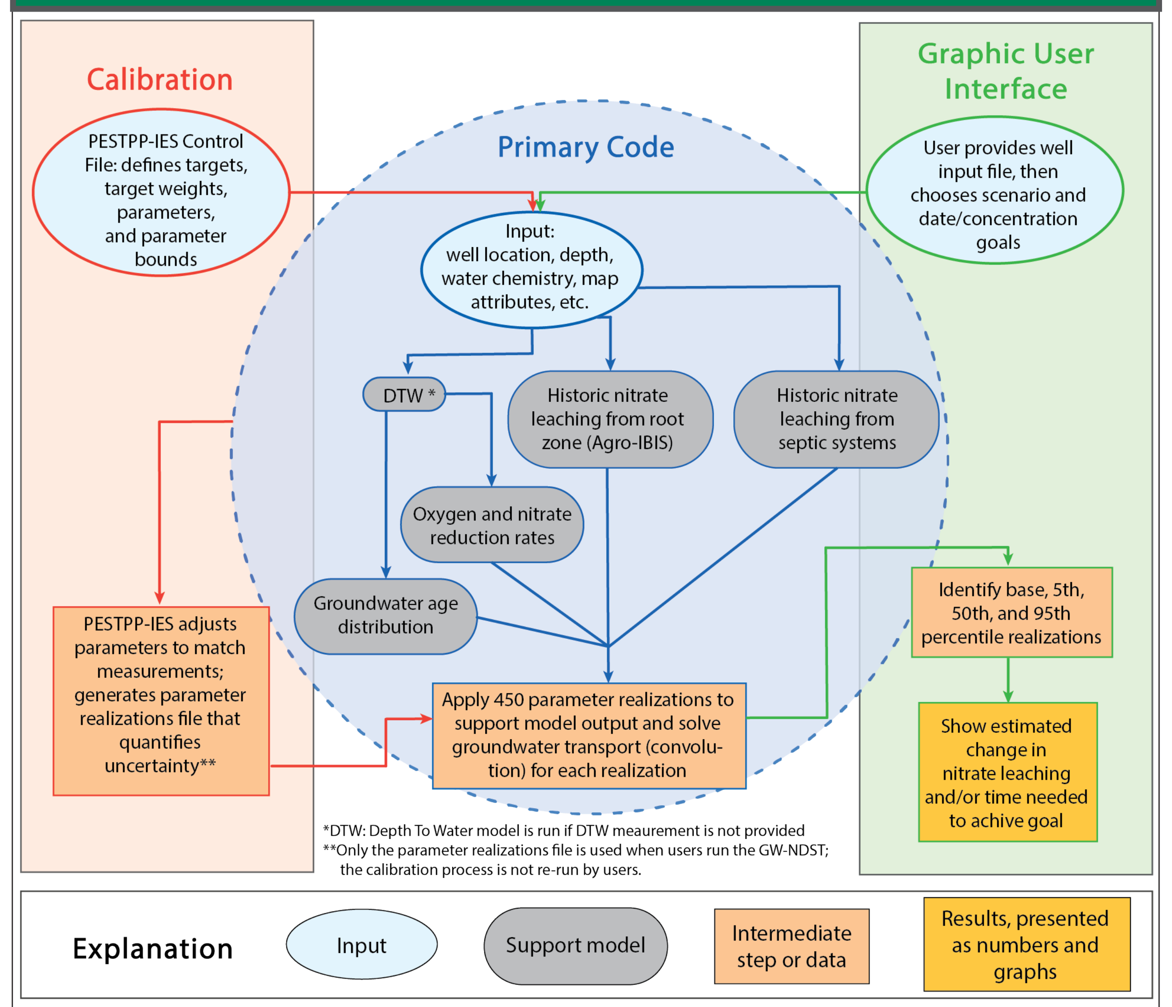

Figure 1. Flow chart of the GW-NDST.

5. Example Applications

No forecasted change in leaching rates through 2060

Immediately reduce leaching to meet goal concentration of 10mg-N/L by 2060

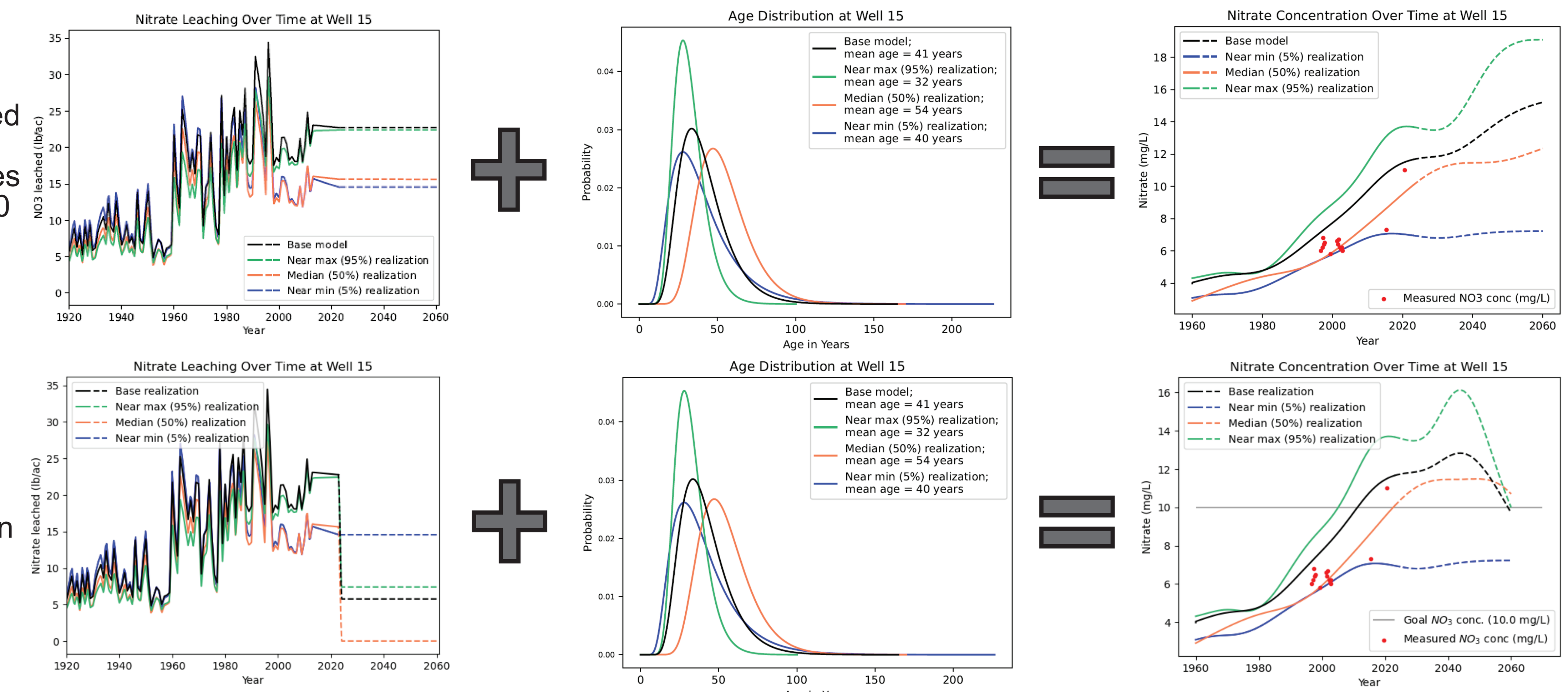

Figure 6. Example results for an example well using two forecasting scenarios. Example 1 (top) represents constant leaching from 2023 through 2060. Example 2 (bottom) is an optimization of the leaching rates needed to match a goal concentration of 10 mg-N/L in 2060. The groundwater age distribution (middle graph) is the same for both scenarios (same well).

Forecast Nitrate Concentrations in Wells:

How *much* leaching reduction is needed to meet a concentration goal?

How *long* before the goal is realized?

3. Parameters and Uncertainty

Parameter estimation performed by calibrating to 34,255 nitrate targets using the Iterative Ensemble Smoother (IES) technique implemented in PESTPP-IES

- 11 spatially variable parameters (support-model output multipliers):
  - 3 groundwater lag time parameters
  - 5 nitrate leaching parameters
  - 3 denitrification rate parameters
- 450 parameter realizations quantify uncertainty:
  - "base" and median realizations illustrate central tendencies
  - 5th and 95th percentile realizations illustrate forecasted range
- Parameter bounds informed by prior studies
- Most sensitive parameters are leaching and groundwater lag time

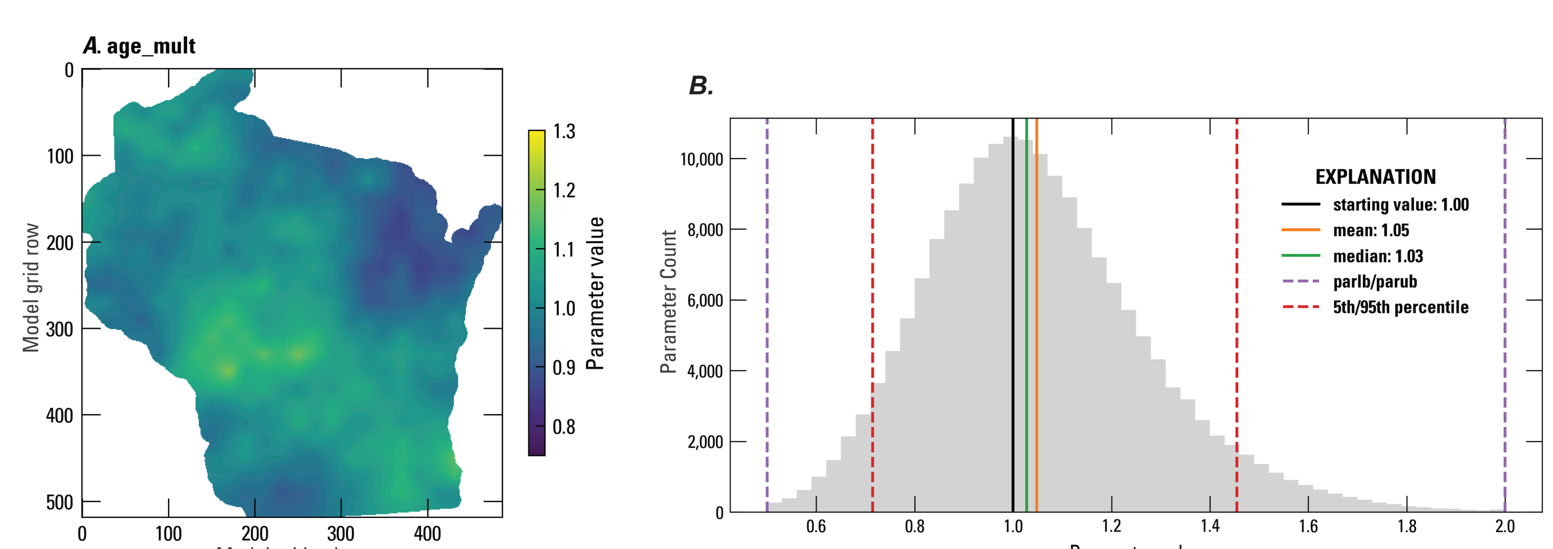

Figure 2. Range of "age_mult" parameter values shown (A) across Wisconsin for the "base" realization, and (B) as a histogram for all locations across Wisconsin for all 450 realizations.

4. Calibration

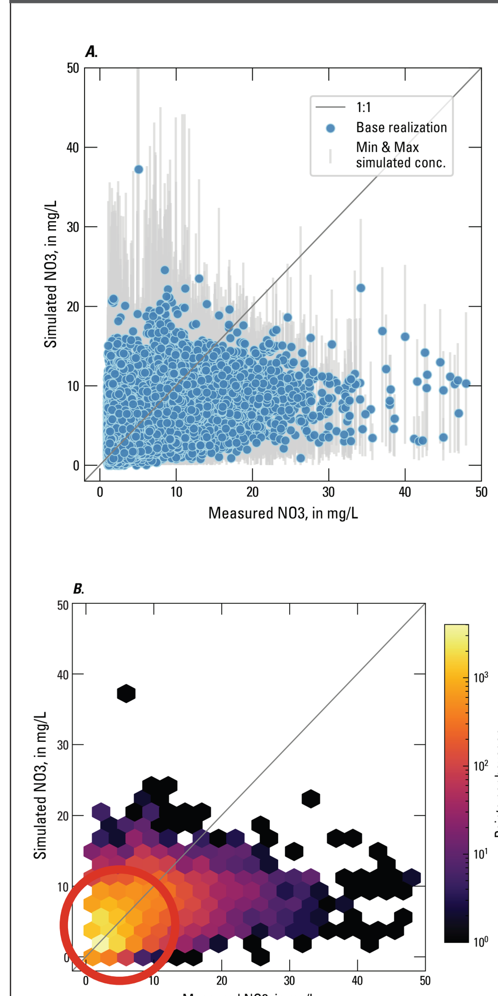

Figure 3. Measured versus simulated nitrate concentrations (A) for the base realization, with min/max ranges from all realizations as vertical lines, and (B) as a hexbin plot, with warm colors representing greater numbers of values.

- Greater weight to high concentration targets
- >78% of targets within simulated uncertainty range
- Limited match to >20 mg-N/L targets due to low-resolution leaching model input

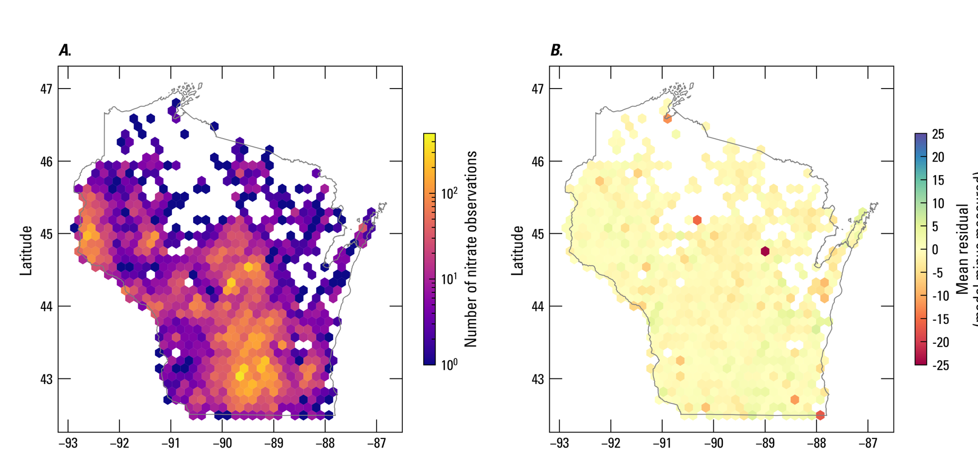

Figure 4. Maps of (A) the number of nitrate concentration measurements per hexbin area used to calibrate the GW-NDST, and (B) the mean residual for each hexbin.

- Minimal spatial clustering of residuals due to spatial parameter calibration

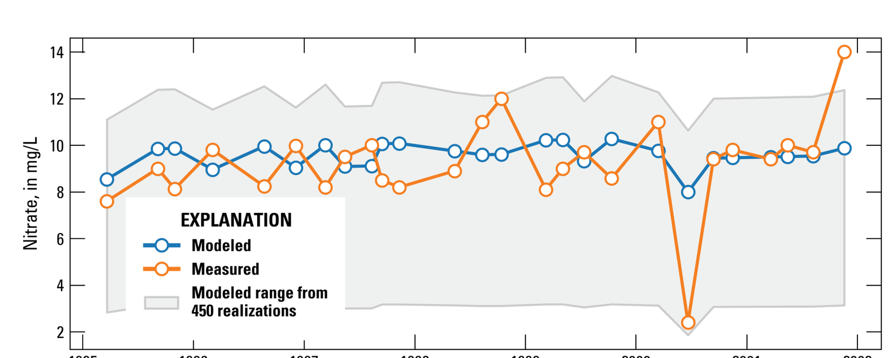

Figure 5. Time-series of modeled (base realization) versus measured concentrations for an example well.

- High-frequency variability is limited by resolution of leaching model input (fertilization) & lag time distribution

6. Take-home

- Groundwater lag time is critical for understanding effects of "legacy nitrate" and future management on well concentrations
- Faced with uncertainty -- make changes that move in the right direction

7. Enhancements

- Identify *where* is well water coming from
  - MODFLOW/MODPATH for age
  - Contributing areas to ID priority management
  - Speed recovery by identifying and targeting "young nitrate areas" to apply greatest leaching reductions
- Nutrient transport to streams and rivers
- Online user interface

Support model references:
- Green, Ransom, Nolan, Liao, and Harter, 2021. Machine learning predictions of mean ages of shallow well samples in the great lakes basin, USA. Jour. of Hydrol., 126908. https://doi.org/10.1016/j.jhydrol.2021.126908
- Kucharik and Brye, 2003. Integrated Blosphere Simulator (IBIS) yield and nitrate loss predictions for Wisconsin maize receiving varied amounts of nitrogen fertilizer. Jour. of Env. Quality 32: 247-68. https://doi.org/10.2134/jeq2003.2470
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GW-NDST resources:
- Juckem, Corson-Dosch, Schachter, Green, Ferin, Booth, Kucharik, Austin, Kauffman, *2024*. Design and calibration of a Nitrate Decision Support Tool for groundwater wells in Wisconsin, USA. Environmental Modeling and Software, https://doi.org/10.1016/j.envsoft.2024.105999
- Schachter, L.A., Juckem, P.F., Corson-Dosch, N.T., and Green, C.T., 2024, A Groundwater Nitrate Decision Support Tool (GW-NDST) for the State of Wisconsin: U.S. Geological Survey Software Release, https://doi.org/10.5066/P1IFJYEB