Groundwater Flow Model Report Overview

USGS Groundwater Modeling Team, Upper Midwest Water Science Center

April 20, 2023 RAB Meeting

Photo Credit: https://www.devilslakewisconsin.com/wisconsin-parks-trails-natural-areas/sauk-prairie-recreation-area/#jp-carousel-1881

USGS

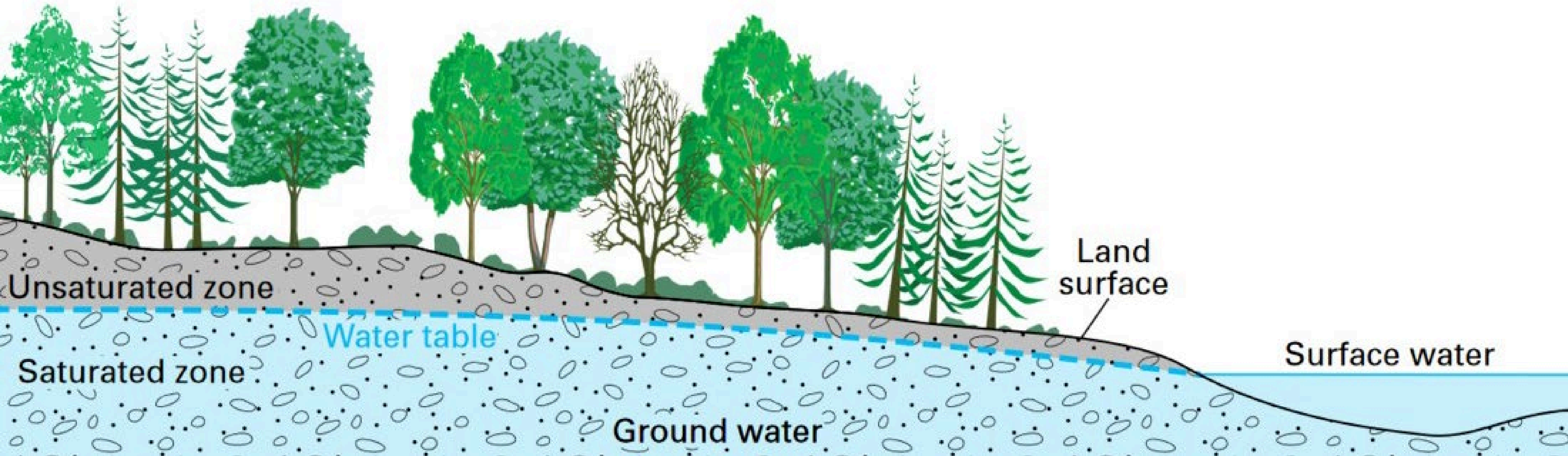
USGS Groundwater Flow Model Report

- USGS publication that details how the groundwater flow model was developed
- Accompanied by a data release with all model files available online
- Characterizes the groundwater flow system at Badger
  - Where is groundwater moving?
  - How does groundwater interact with the Wisconsin River?
  - How does the flow of groundwater control plume movement?
- This is the foundation of the groundwater transport model (in progress).

Photo credit: https://www.nopcommerce.com/en/coming-soon-page

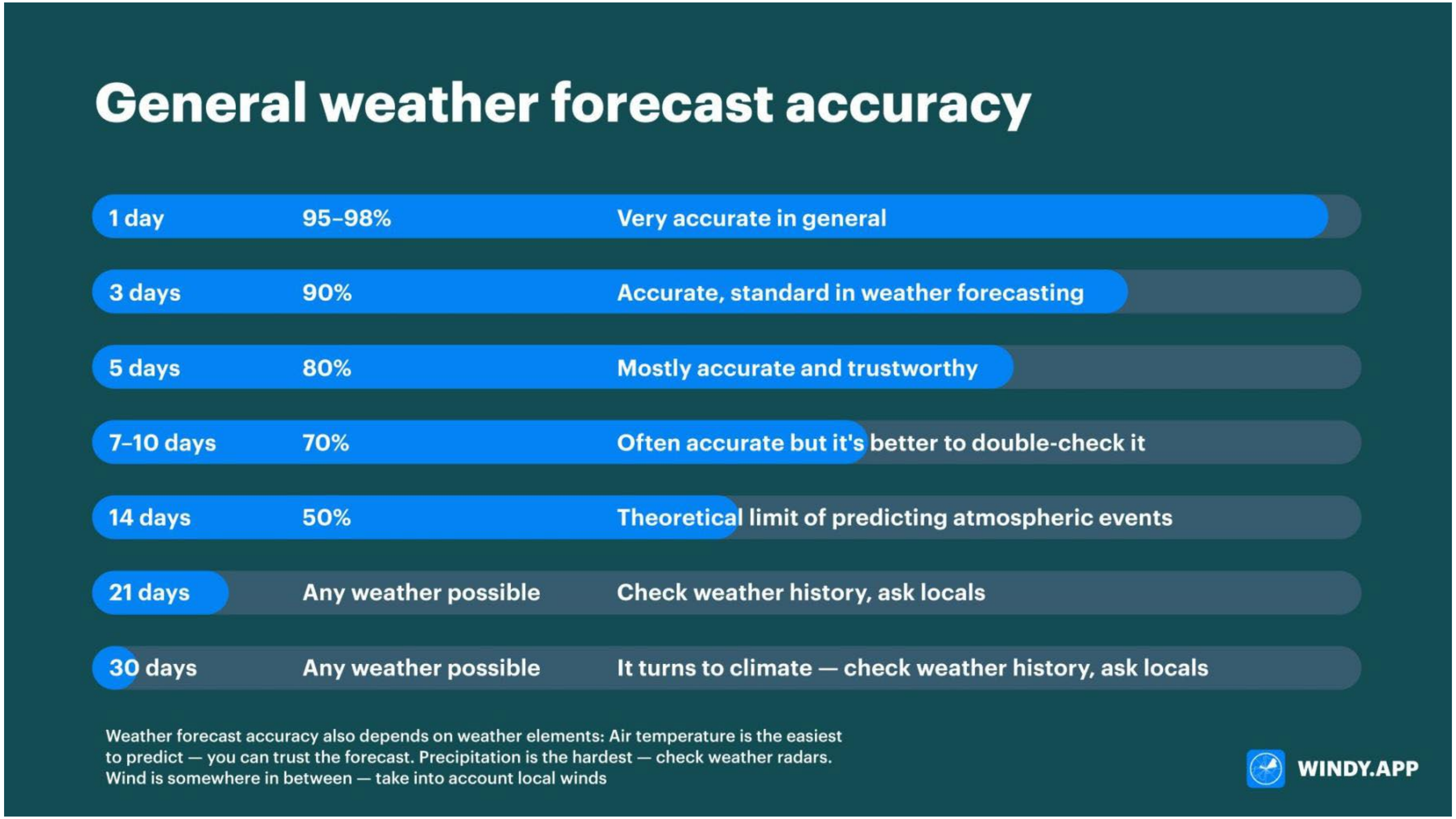
What is a groundwater flow model (technically)?

- A bunch of math equations to calculate how water is moving underground.



Just like models used to predict the weather a groundwater model won't be right all the time / everywhere.

Photo Credit: https://archive.nytimes.com/cityroom.blogs.nytimes.com/2009/12/11/complaint-box-weather-forecasts/



...but models can be accurate enough that we often use them to help us plan for things like:

"Should bring a rain jacket today?"

"If I leave at 3pm will I avoid driving in a snowstorm?"

Forecast Accuracy Photo: https://windy.app/blog/weather-forecast-10-days-3-days.html

What is a groundwater flow model (actually)?

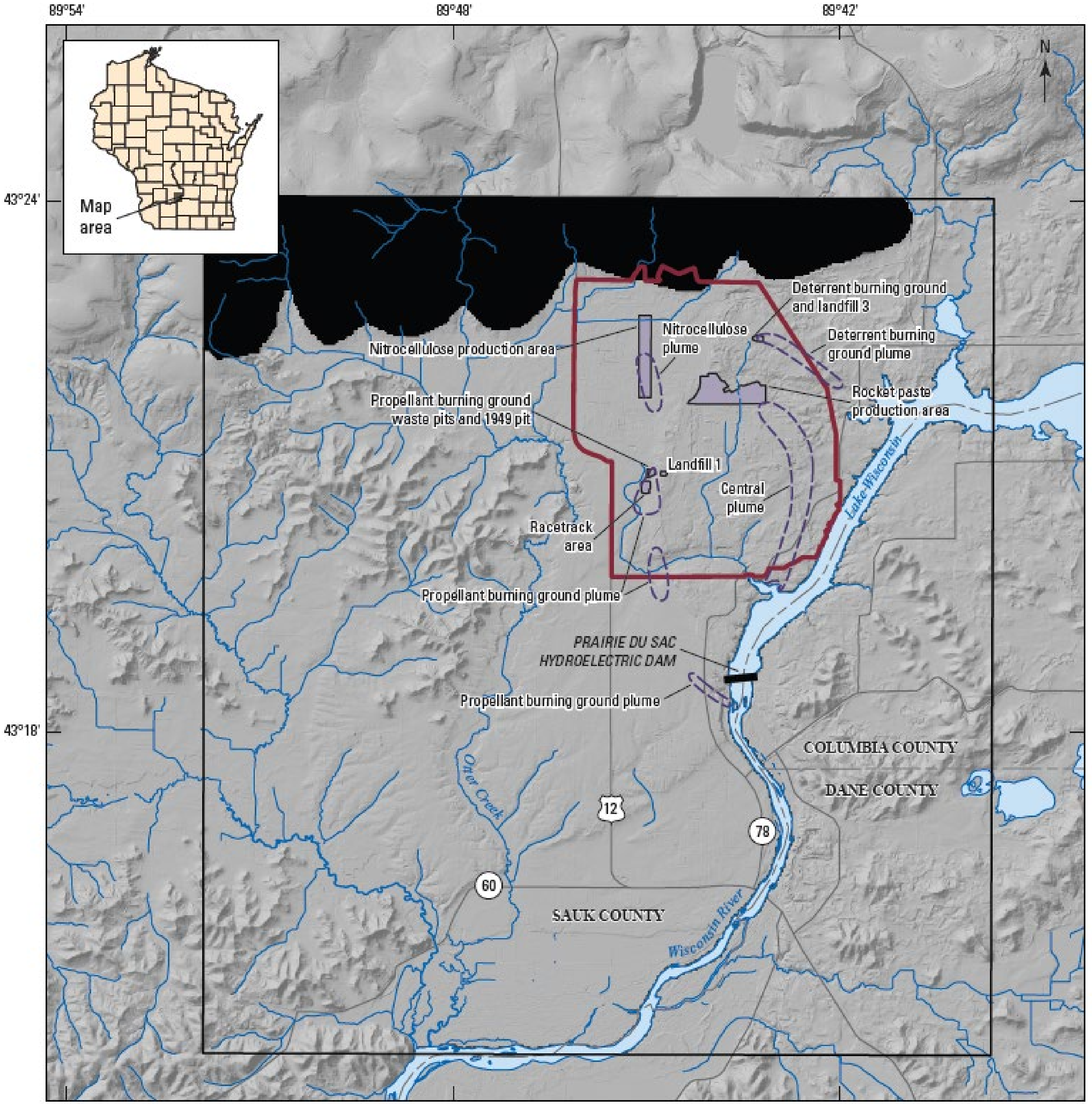
- A tool that is built to help answer a particular question.
  - It's not one-size-fits-all approach
- Can be used with other information to help make informed decisions about a groundwater system under conditions we cannot directly observe or measure.
  - May be other factors that are important to consider in the decision beyond what is modeled.
- Useful but necessarily simplified version of the natural world.
  - Inherently uncertain and best to understand how that may impact the model prediction

Photo Credit: https://twitter.com/HandToolsInst/status/1444041480096600087/photo/1

What is the purpose of the Badger groundwater flow model?

A tool to help guide strategic implementation of remediation efforts at the Badger site including:

1. Assess overall plume footprint at a future date with monitored natural attenuation v. bioremediation.
2. Estimate how long bioremediation may need to run to reach plume reduction targets.
3. Guide the layout of treatment wells for maximum plume reduction.



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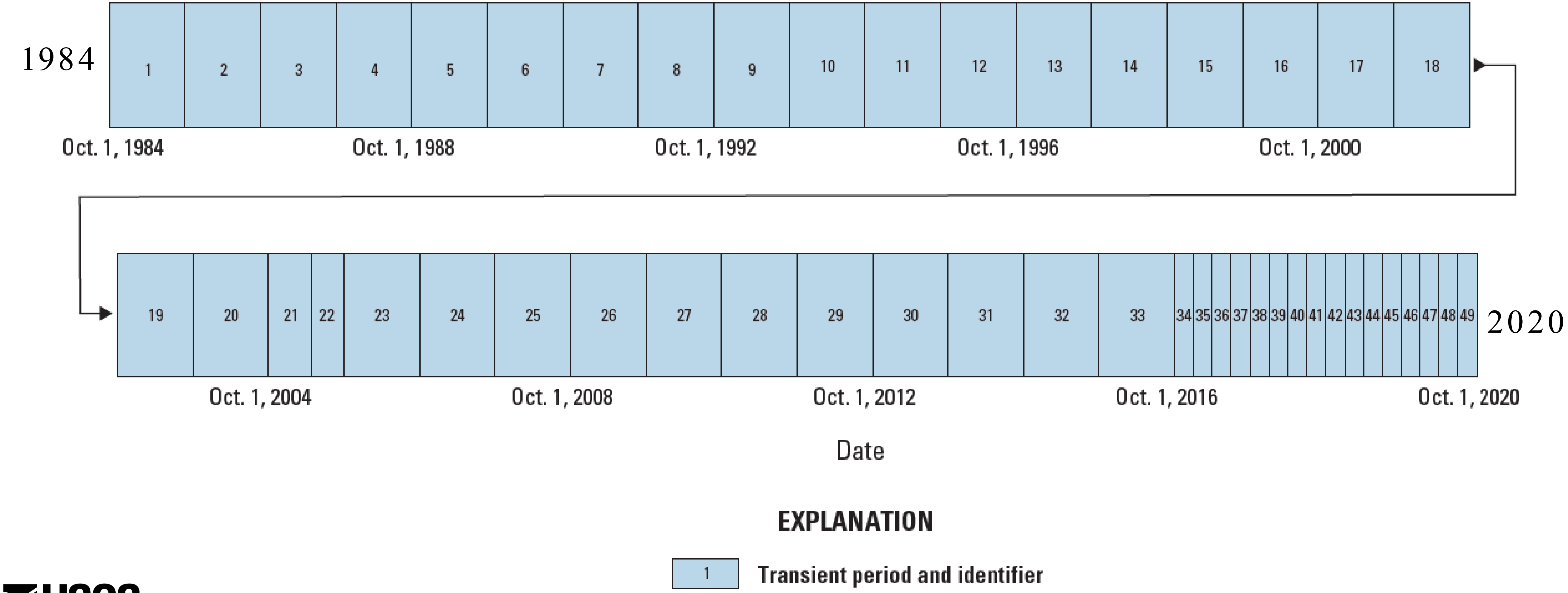
What went into the Badger groundwater flow model?

Photo credit: https://www.devilslakewisconsin.com/wisconsin-parks-trails-natural-areas/sauk-prairie-recreation-area/

1) Decided what time period is covered by the model.

- Based on when we have site data available to calibrate the model.
- Year-long periods for early times when less data.
- Quarterly periods for recent times when more data.



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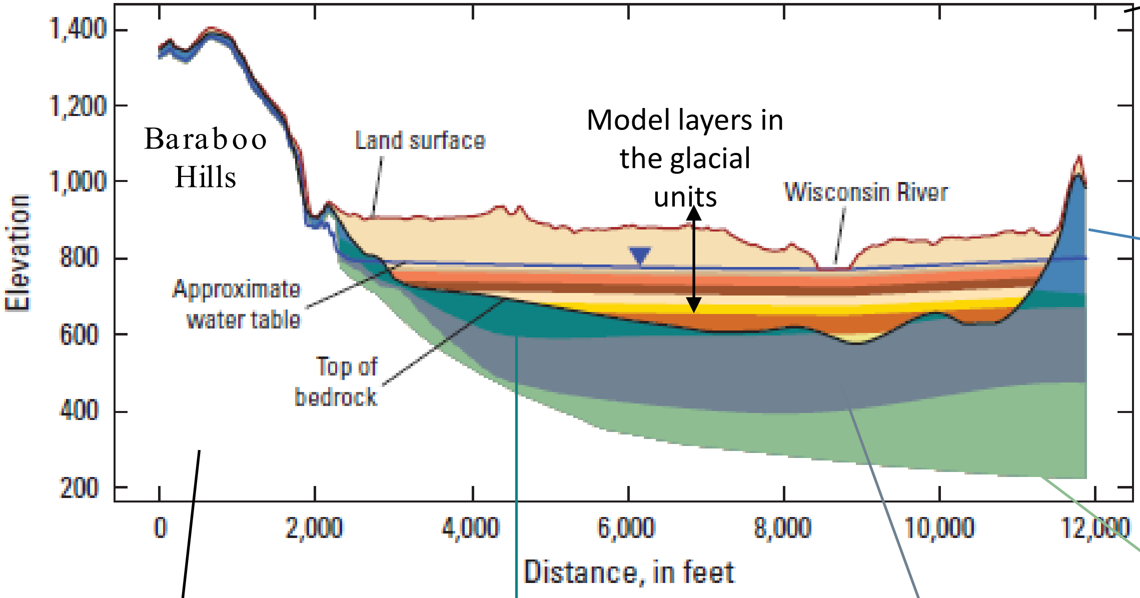
2) Chose a model area and defined a model grid.

- Divided the model area into a grid of small boxes that represent real locations on a map.
- At each box the model has various properties defined that govern how groundwater moves through that area.

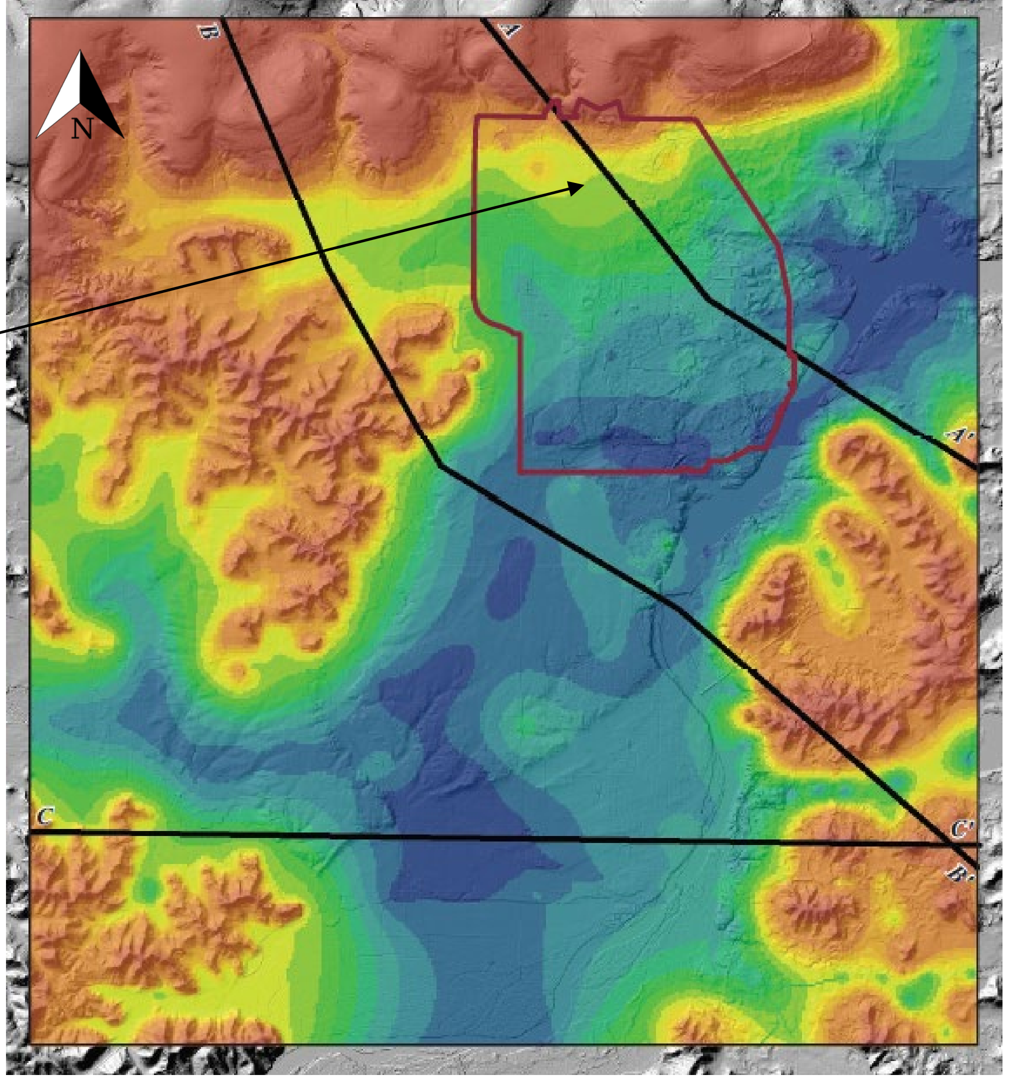
Photo credit: Parfrey's Glen, Meg Haserodt

Bedrock Geology

Cross-section from Northwest to Southeast



General upper bedrock for units above the Wonewoc



Baraboo Quartzite

Wonewoc Sandstone

Eau Claire

Mt. Simon Sandstone

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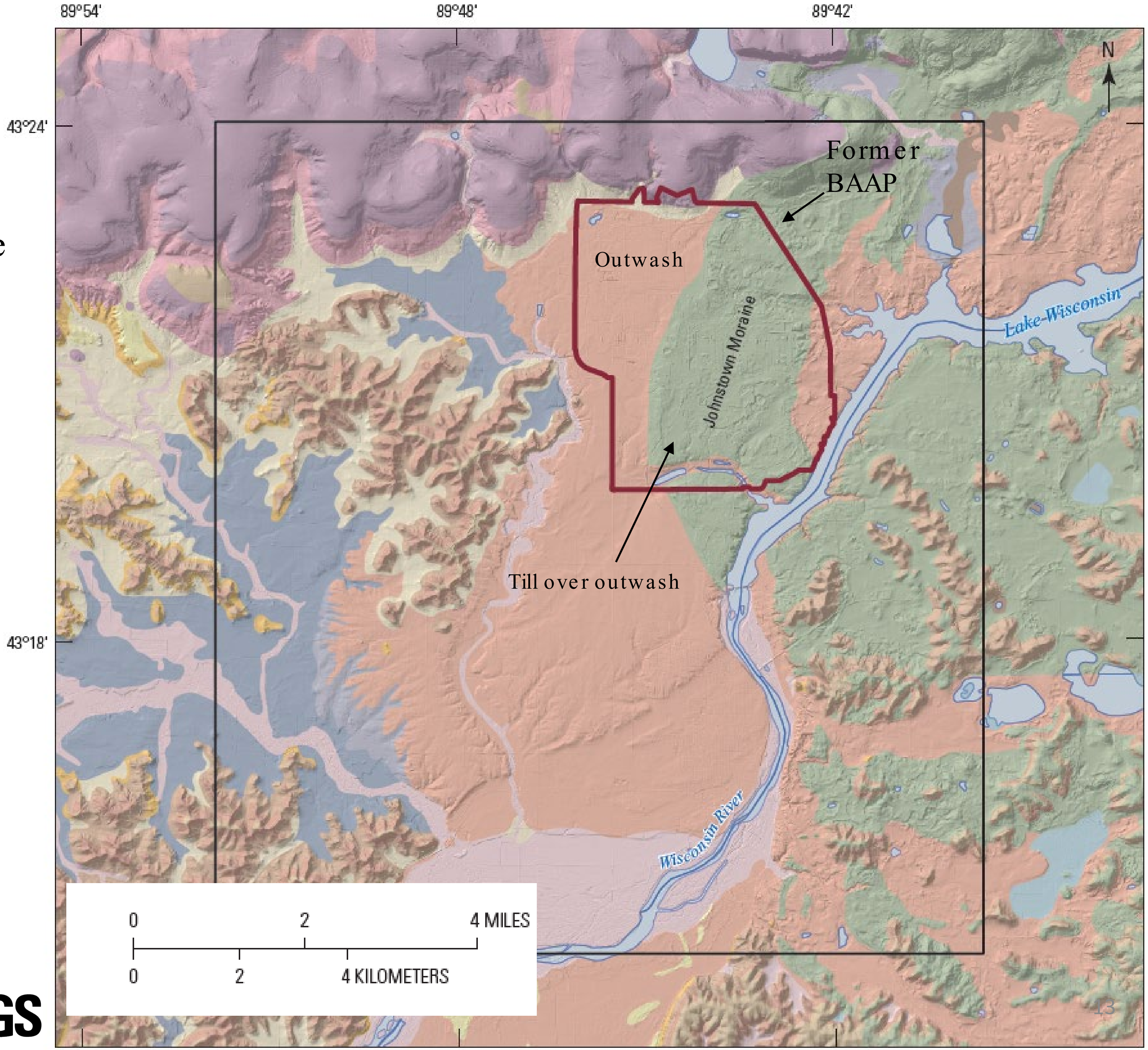
Photo Credits:
Baraboo Quartzite: http://pages.uwc.edu/keith.montgomery/baraboo/quartz.htm,
Wonewoc: https://confluence.journalism.wisc.edu/tag/drinking-water/,
Eau Claire:
http://www.aipgwisconsin.org/PDF/Zambito%20et%20al%202017%20Sand%20Resources%20of%20West-central%20WI.pdf,
Mt. Simon: http://aerialgeologist.blogspot.com/2013/02/old-rocks-cold-rocks-mid-winter-outcrop.html

Glacial Geology

1. Outwash – tends to be more coarse

2. Till – mix of grain sizes often with lots of finer-grained materials



Outwash Image: https://en.wikipedia.org/wiki/Outwash_fan
Till image: https://en.wikipedia.org/wiki/Till

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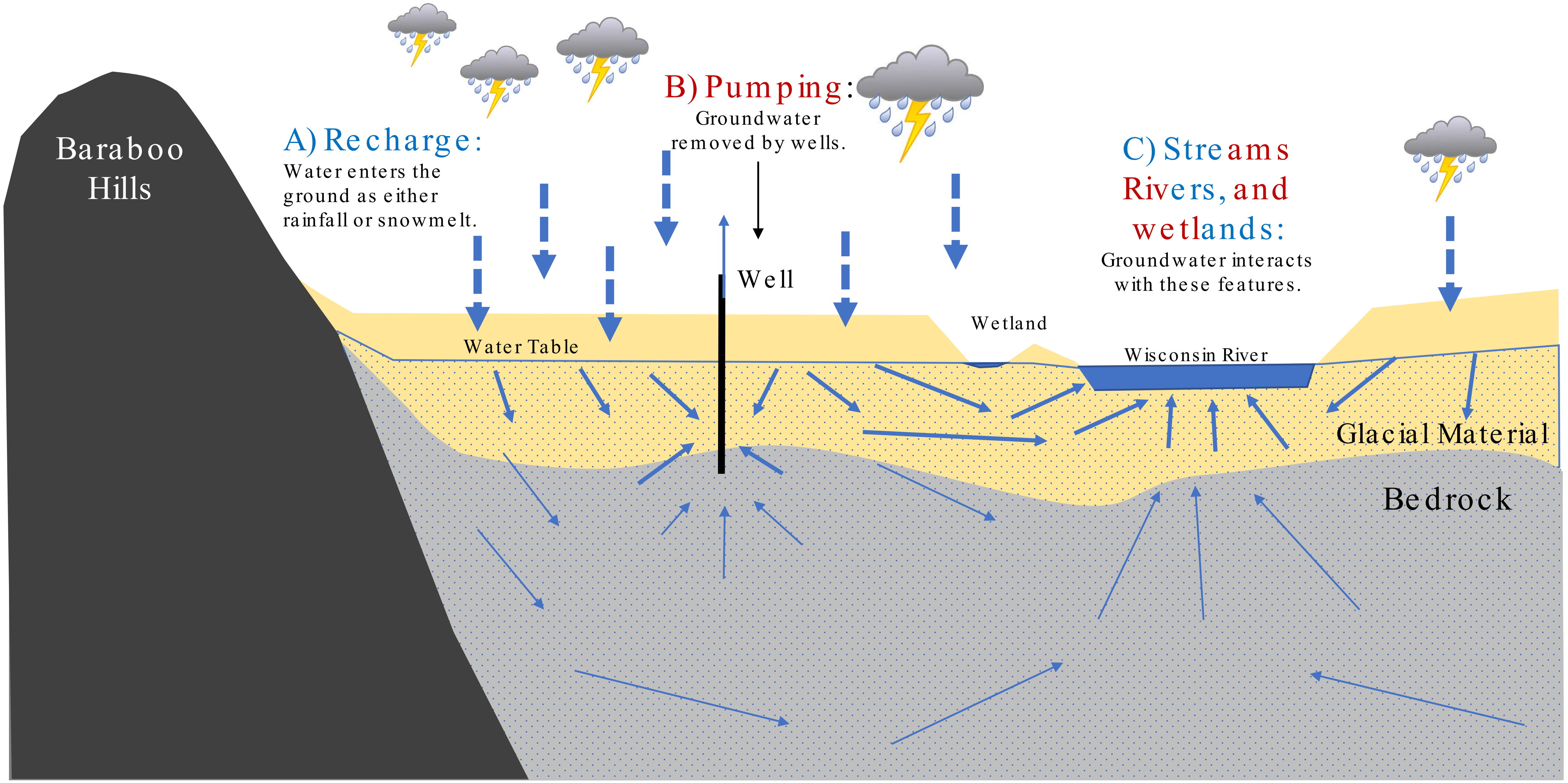
4) Defined how water can enter/ leave the groundwater system.



Vertical scale has been greatly exaggerated to illustrate the flow system.

Red = Removes groundwater   Blue = Adds to groundwater

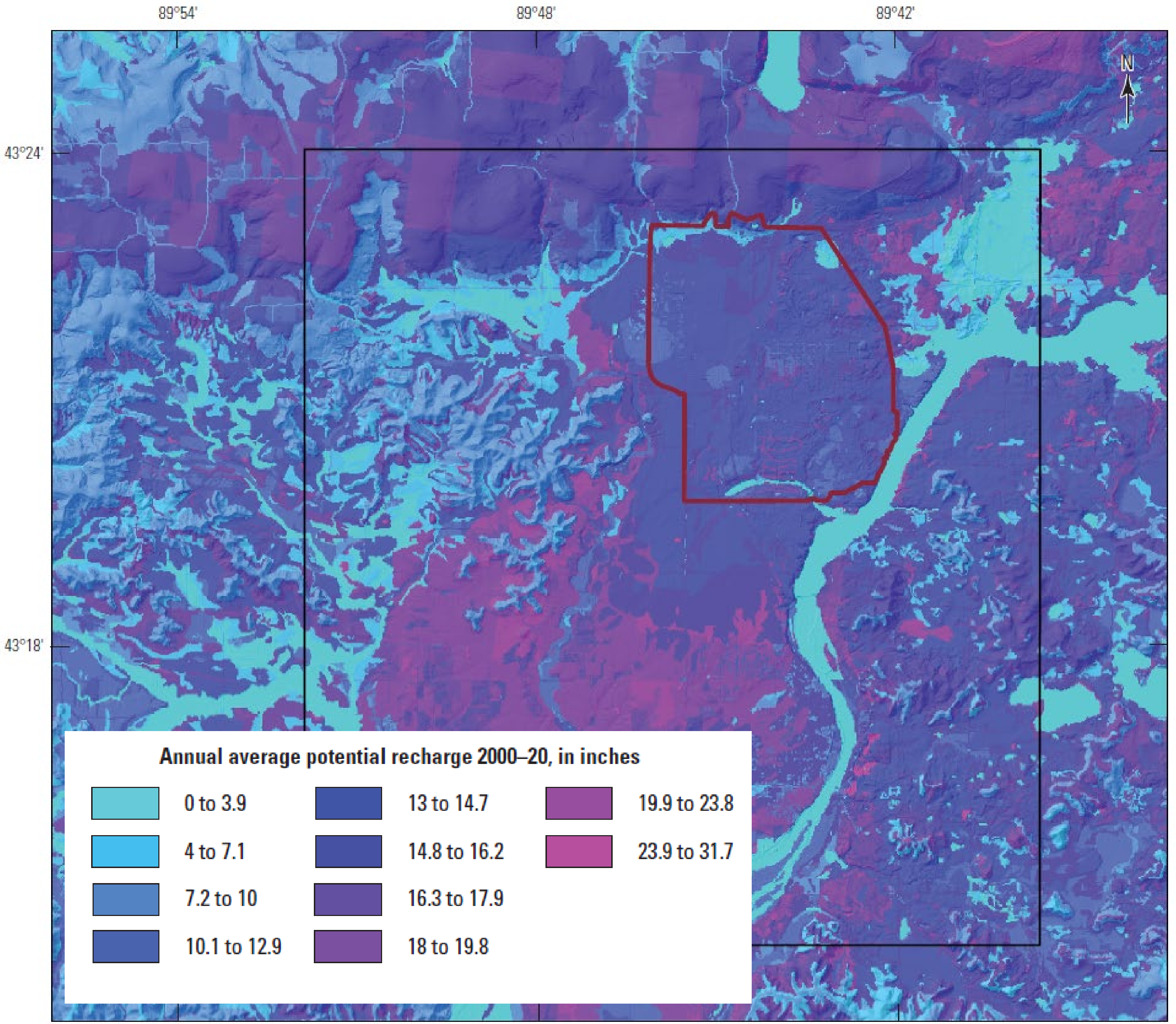
4A) Groundwater Recharge

Recharge: precipitation that soaks into the ground and moves down to the top of the groundwater surface (water table).

Soil Water Balance Model to estimate recharge

Inputs:

- Climate data (temperature, rainfall)
- Soil characteristics
- Land use



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4B/ C) Pumping / streams, rivers, and wetlands

- Allow the model to interact with these features
- Placement in the model is based on actual locations

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Wetlands, lakes, and ponds

Focused recharge from ravines coming off the Baraboo Hills

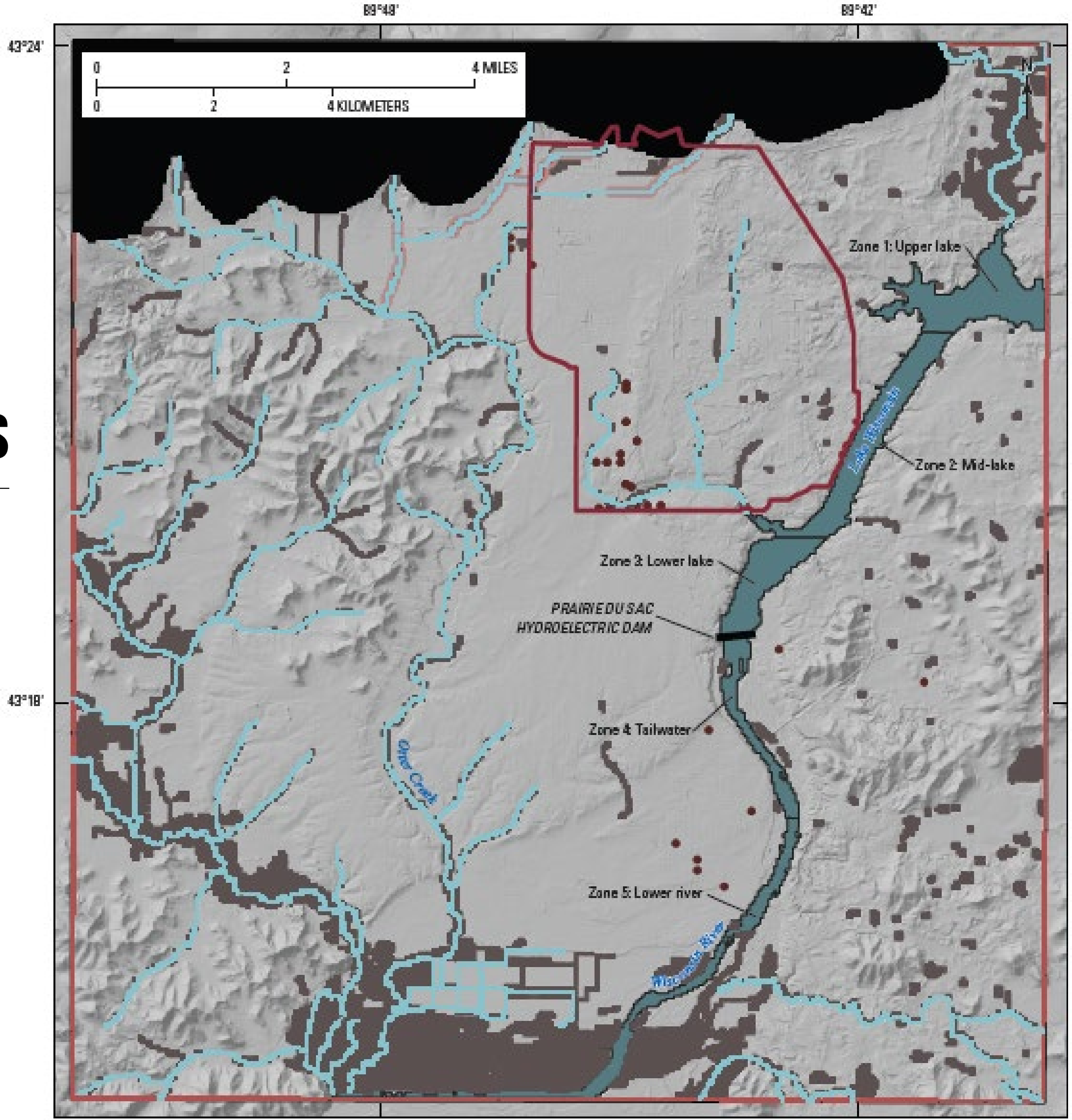
Edge boundary inputs representing regional groundwater flow

Wisconsin River

Streams

Inactive cells where Baraboo Quartzite is at the land surface in the Baraboo Hills

High capacity pumping well (typically irrigation, municipal water supply, site treatment pumping system



How do we know if the model predictions are anywhere close to reality?

Photo credit: https://www.devilslakewisconsin.com/wisconsin-parks-trails-natural-areas/sauk-prairie-recreation-area/#jp-carousel-1877

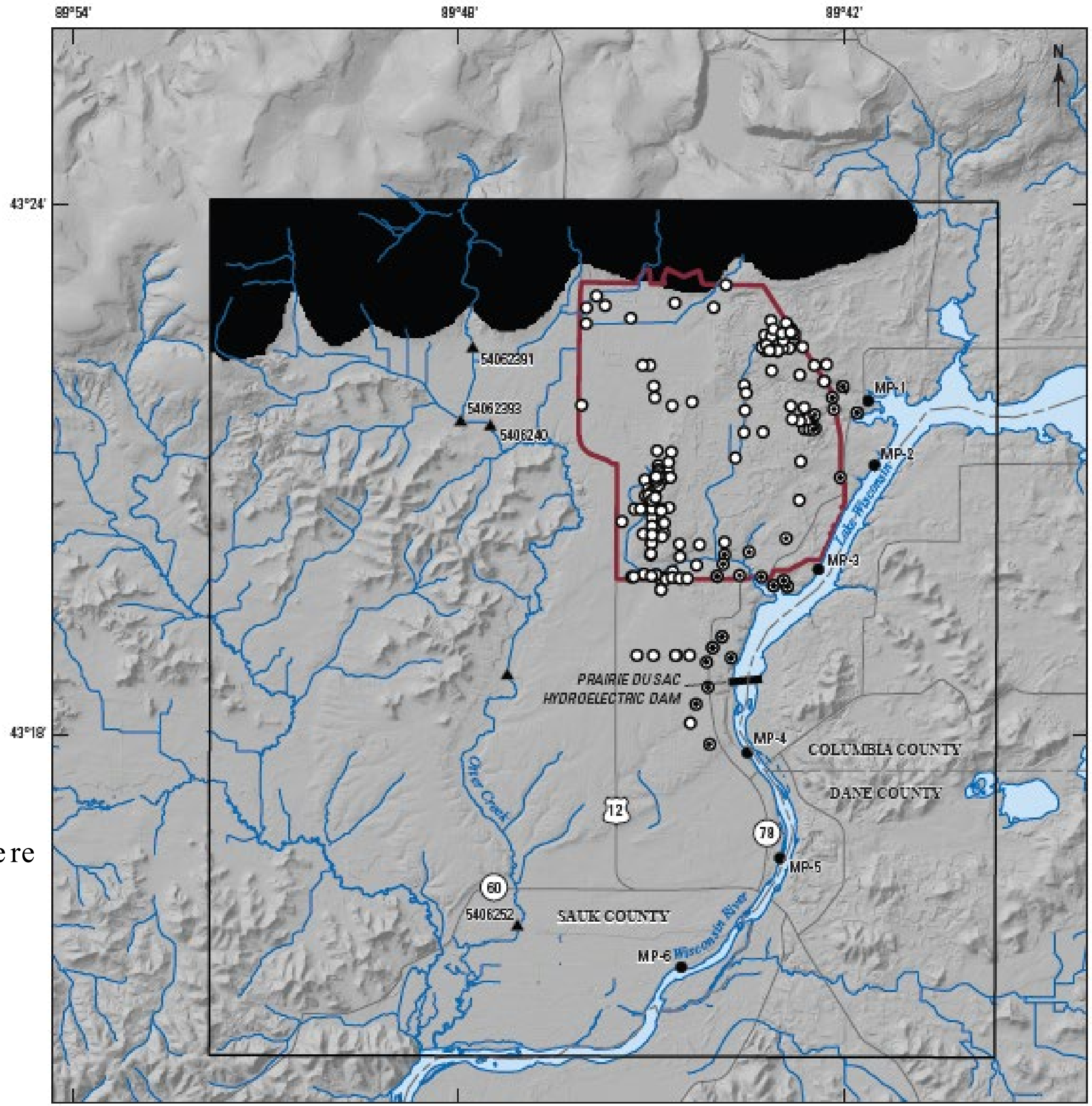
Used a process called model calibration

- Compared the model outputs to past measurements from wells and streams
- Changed model parameters to better fit the observed values
- Examples below of some of the calibration data

Well data used in different ways to assess groundwater elevations and flow direction across the site.

MP-6 Small wells installed in river bed to understand where groundwater is moving into or out of the Wisconsin River.

5406252 Locations where streamflow was collected.



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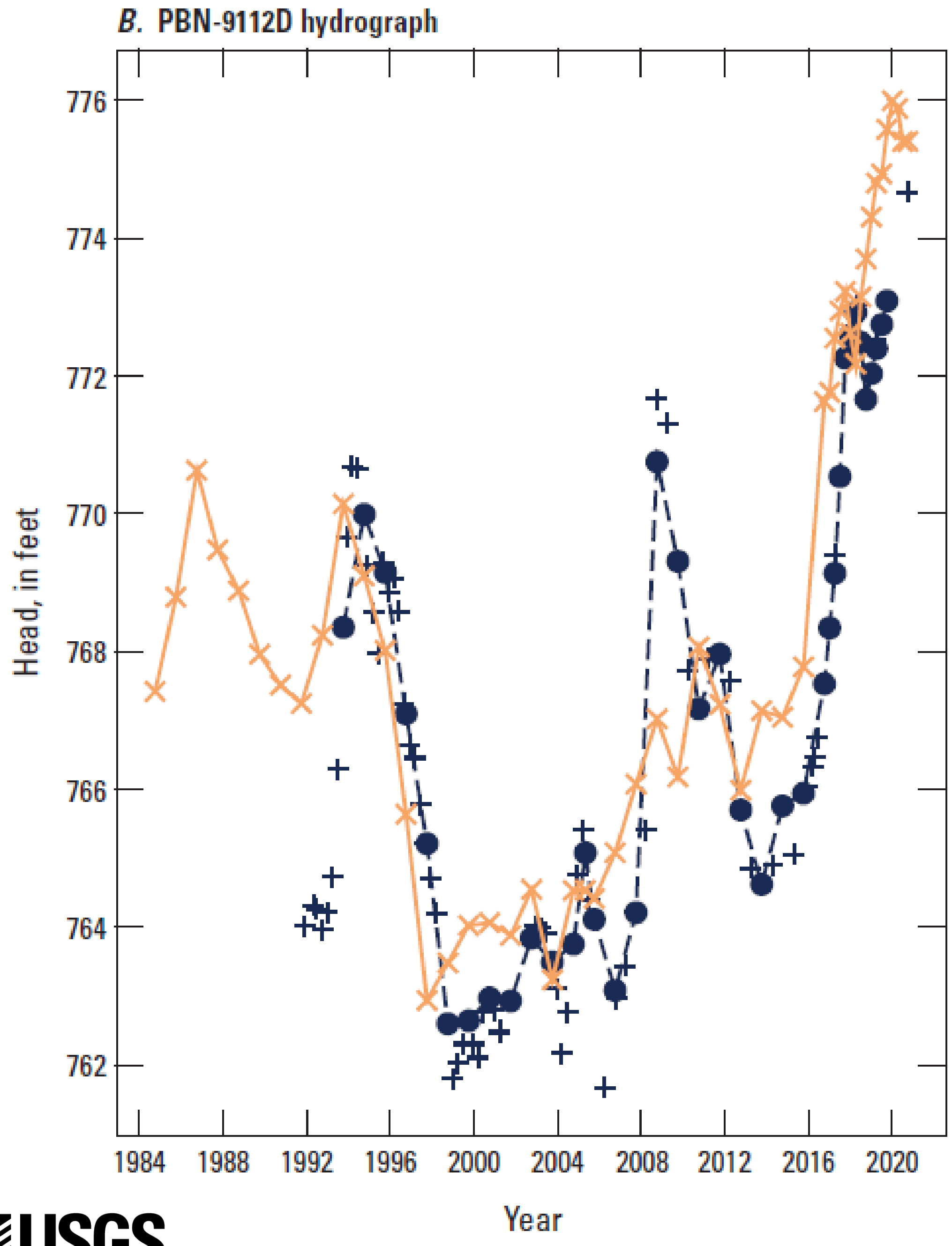


Also considered how well the model could match a history of observations at a well.

- Many points observed over time reflect changing weather and site conditions.
- Can be more difficult to match than a single point.
- Gives confidence in the models usefulness over a range of weather conditions (wet and dry years)
- Different performance at different wells; emphasized better fits for wells closer to the plumes

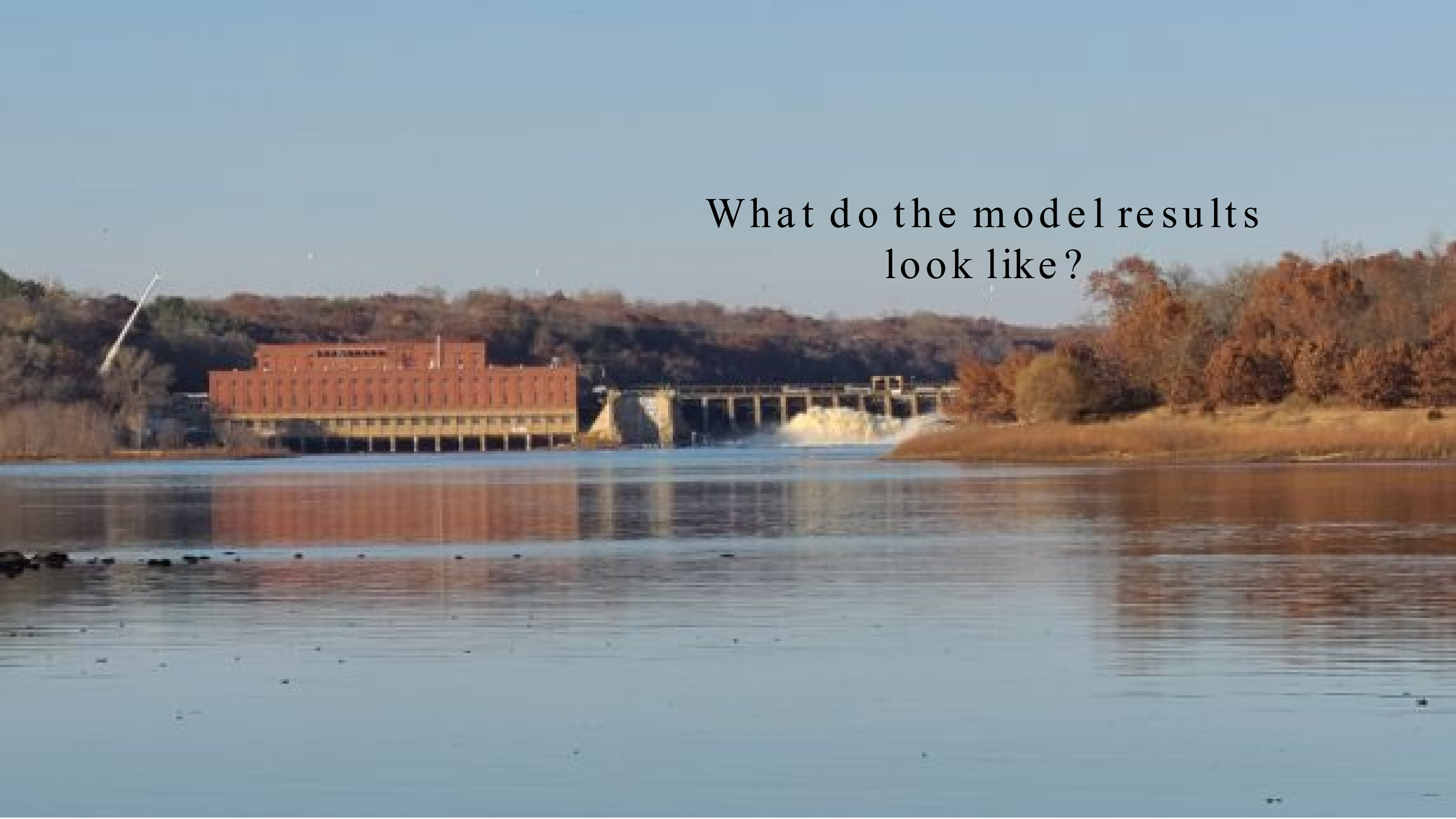
EXPLANATION

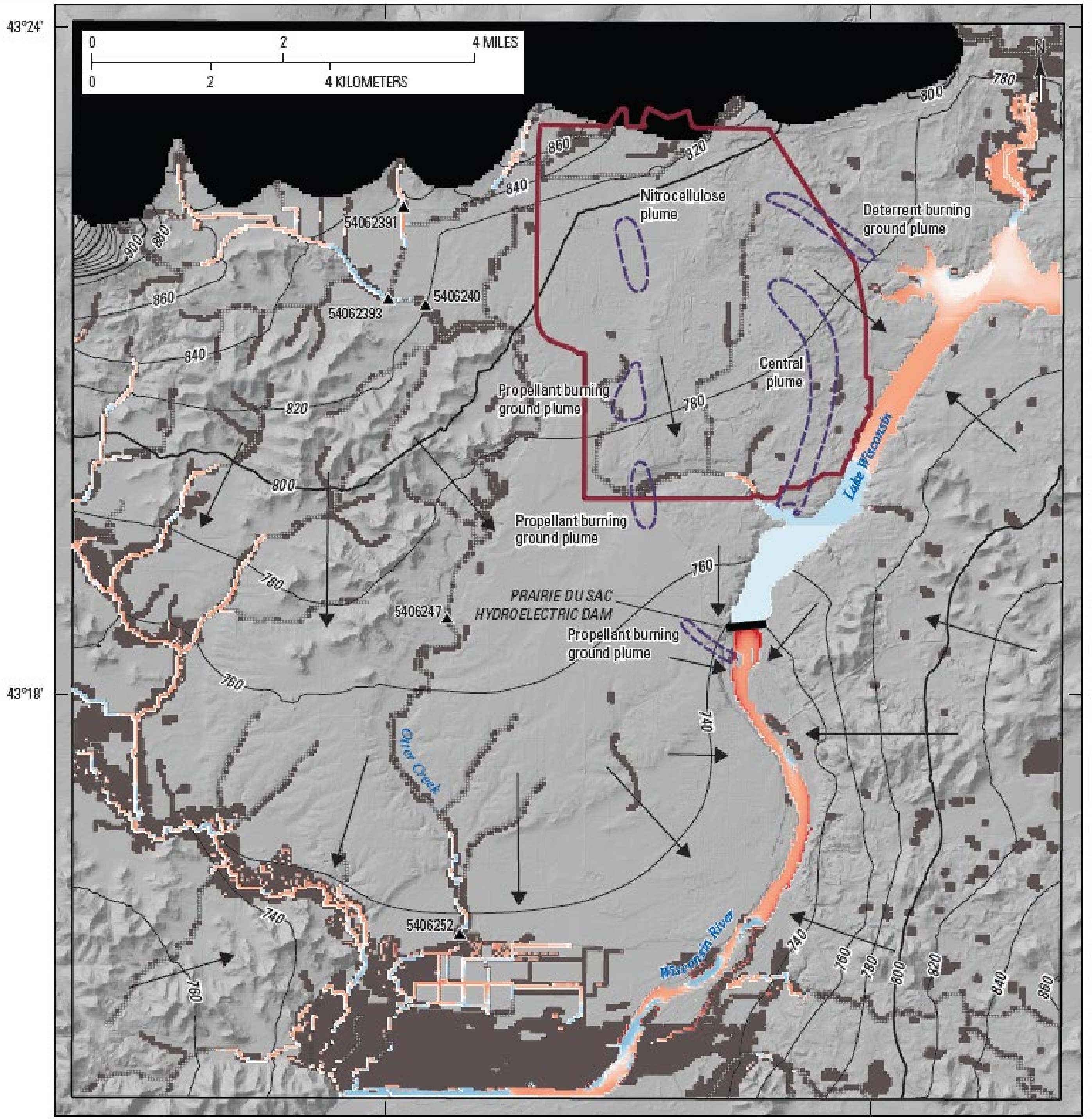
Interpolated for change observation

Simulated

Observed hydrograph

What do the model results look like?





Where does the model have groundwater moving at Badger?

800 — 100-foot contour of water table elevation, with elevation label

740 — 20-foot contour of water table elevation, with elevation label

→ Direction of groundwater flow

Groundwater interactions with Wisconsin River

Groundwater entering the Wisconsin River

Wisconsin River water entering the aquifer

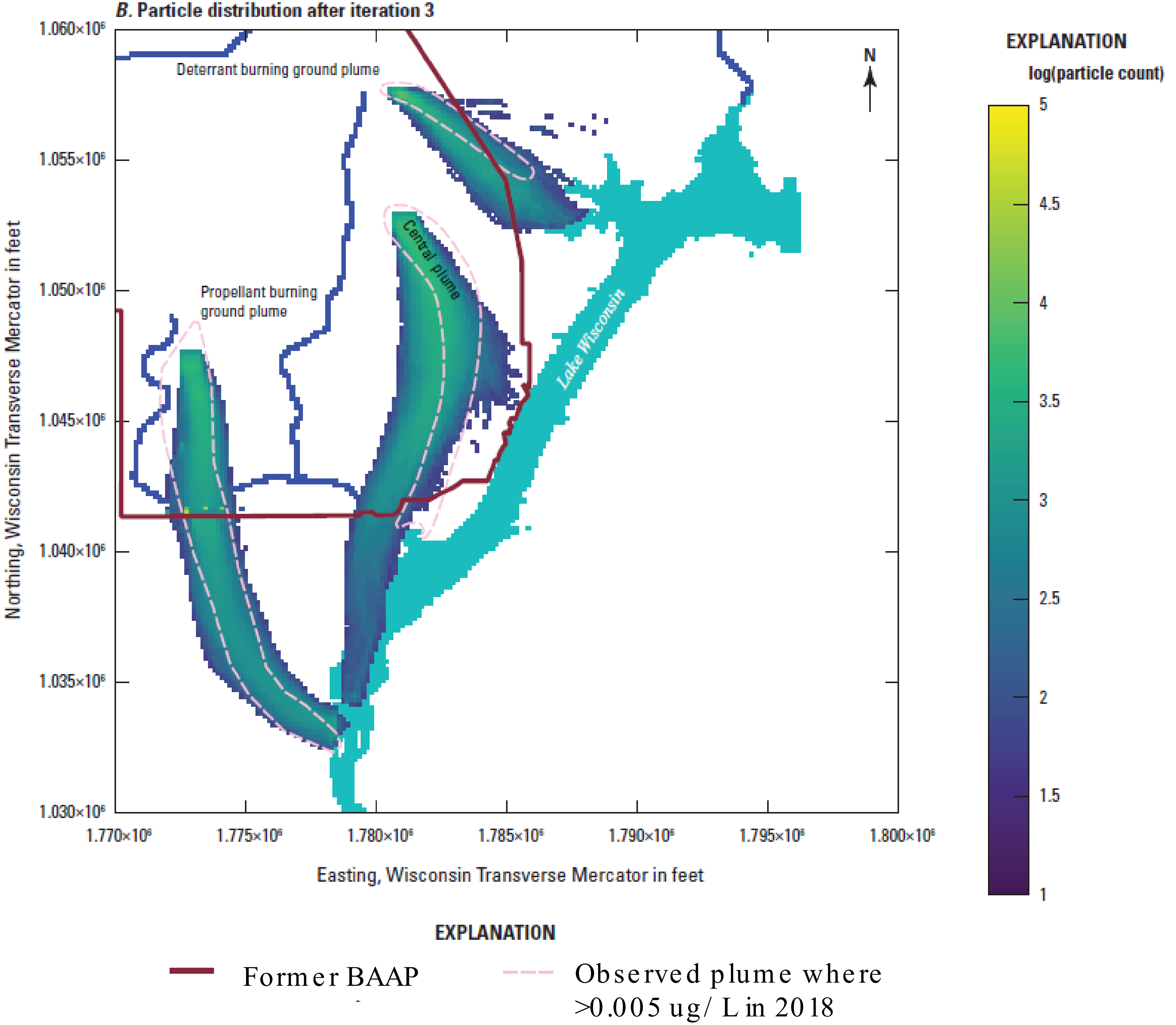
Darker colors indicate higher amounts of water moving.

Does what we not know matter?

Photo credit: https://www.devilslakewisconsin.com/wisconsin-parks-trails-natural-areas/sauk-prairie-recreation-area/#jp-carousel-1867

Compared flow model results to plume shape.

- Put imaginary particles in the source areas that can then move with the groundwater in the model.
- Got resulting particle paths.
- Ran 200+versions of the model that each have slightly different model parameters (let us explore the uncertainty in the model predictions). These are the paths from all those runs.
- Particle paths do not equal concentration.
- They do indicate how well the plume shape can be described by the groundwater flow.



Where are we currently with transport?

Input information

- Groundwater flow model results
- Aquifer properties
- Historical contamination data

Transport model

- Integrates flow and transport information
- Simulate fate of contamination
- Subject to assumptions and simplifications

Calibration*

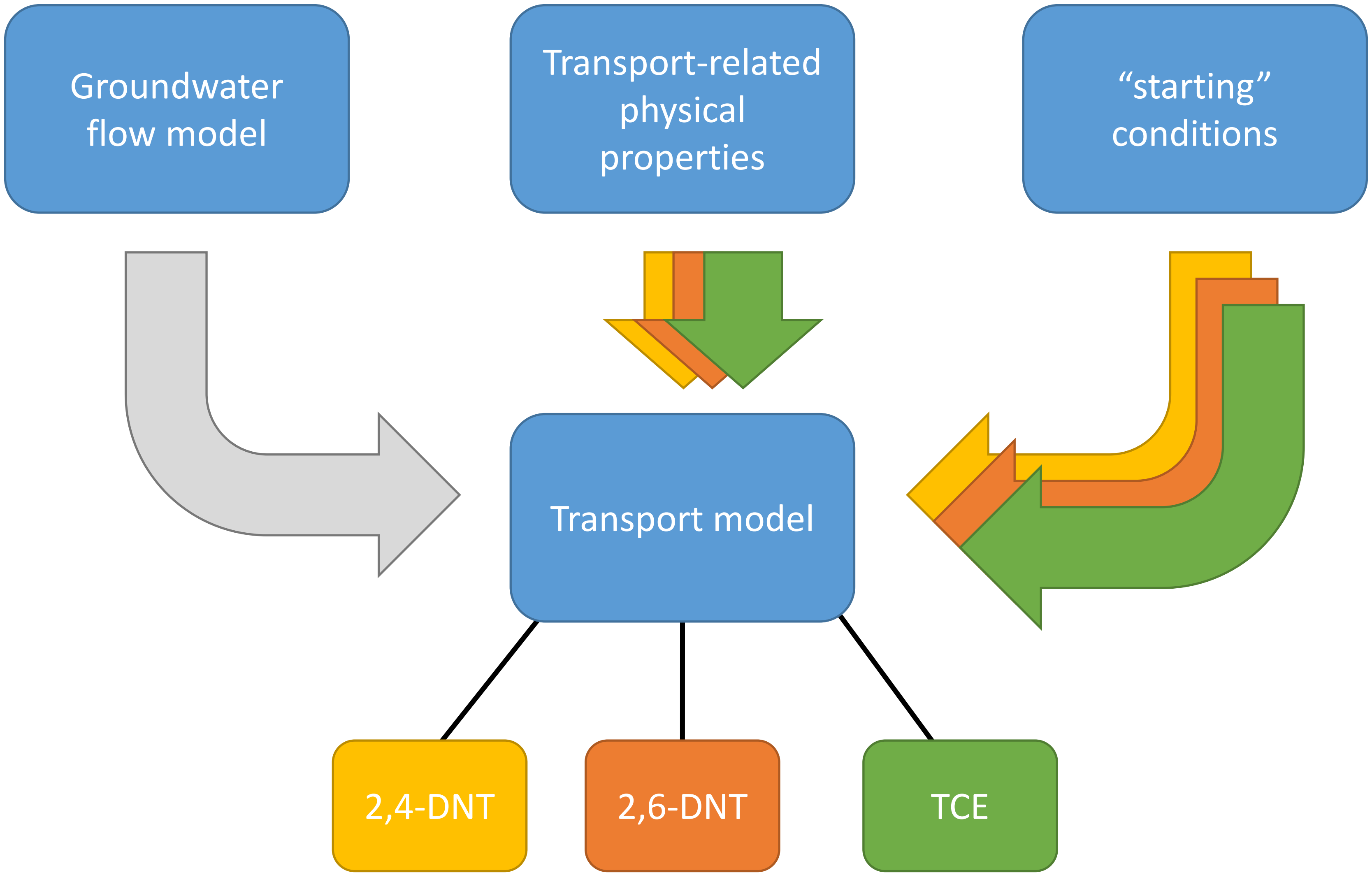
- Improves the model’s ability to simulate reality
- Quantifies model uncertainty

Predictions

- Use calibrated model to make predictions
- Range of likely outcomes, given uncertainty

*We are here

Transport modeling workflow



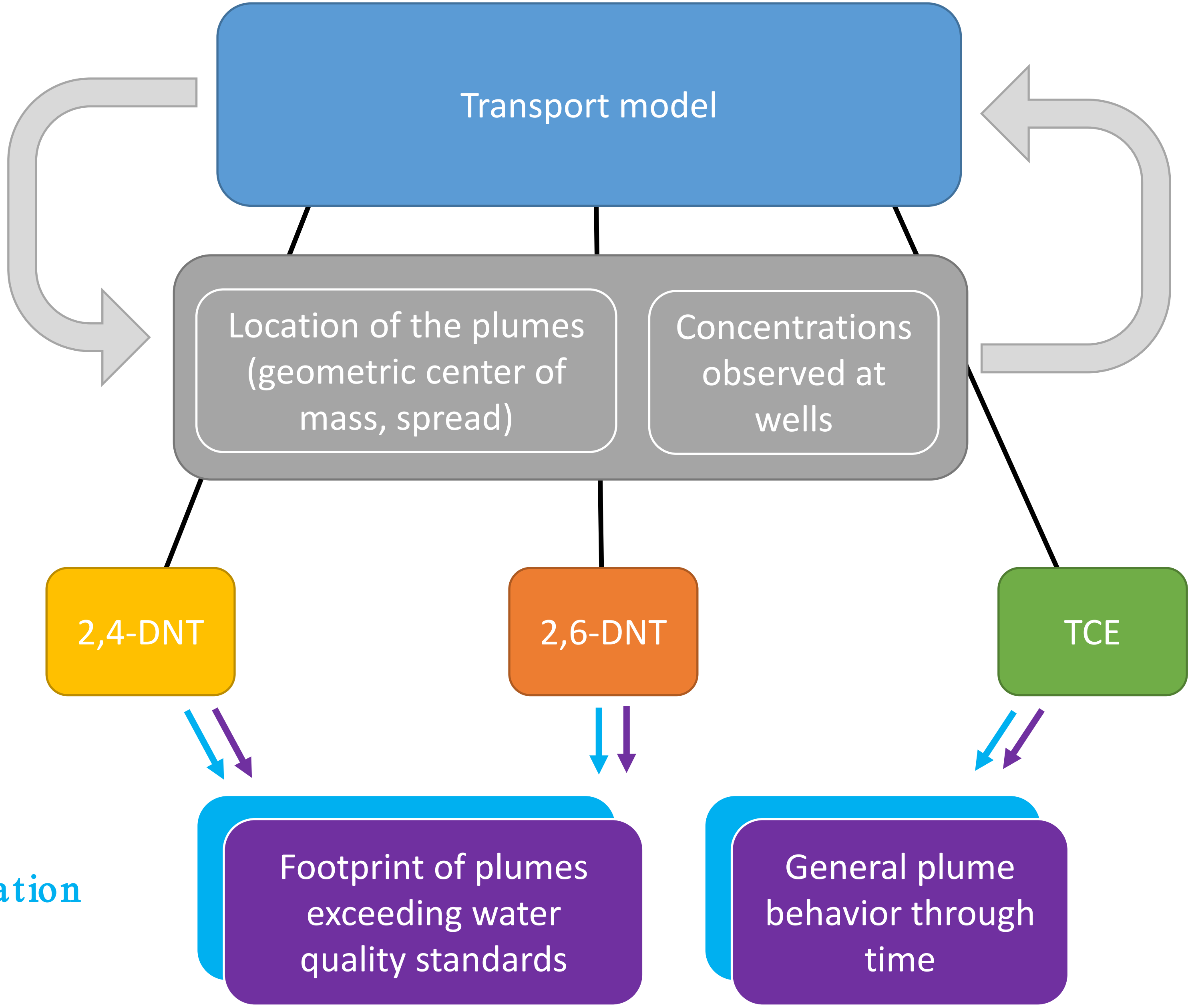
Transport modeling workflow

Model

Calibration: Compare with observed data

Predictions

Forecasting behavior under **natural attenuation** and **bioremediation**



2024: Run bioremediation scenarios and write up transport model report.

2023: Refining the transport model.

Where are we headed?

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Questions?