Coon Creek Groundwater Chloride Study

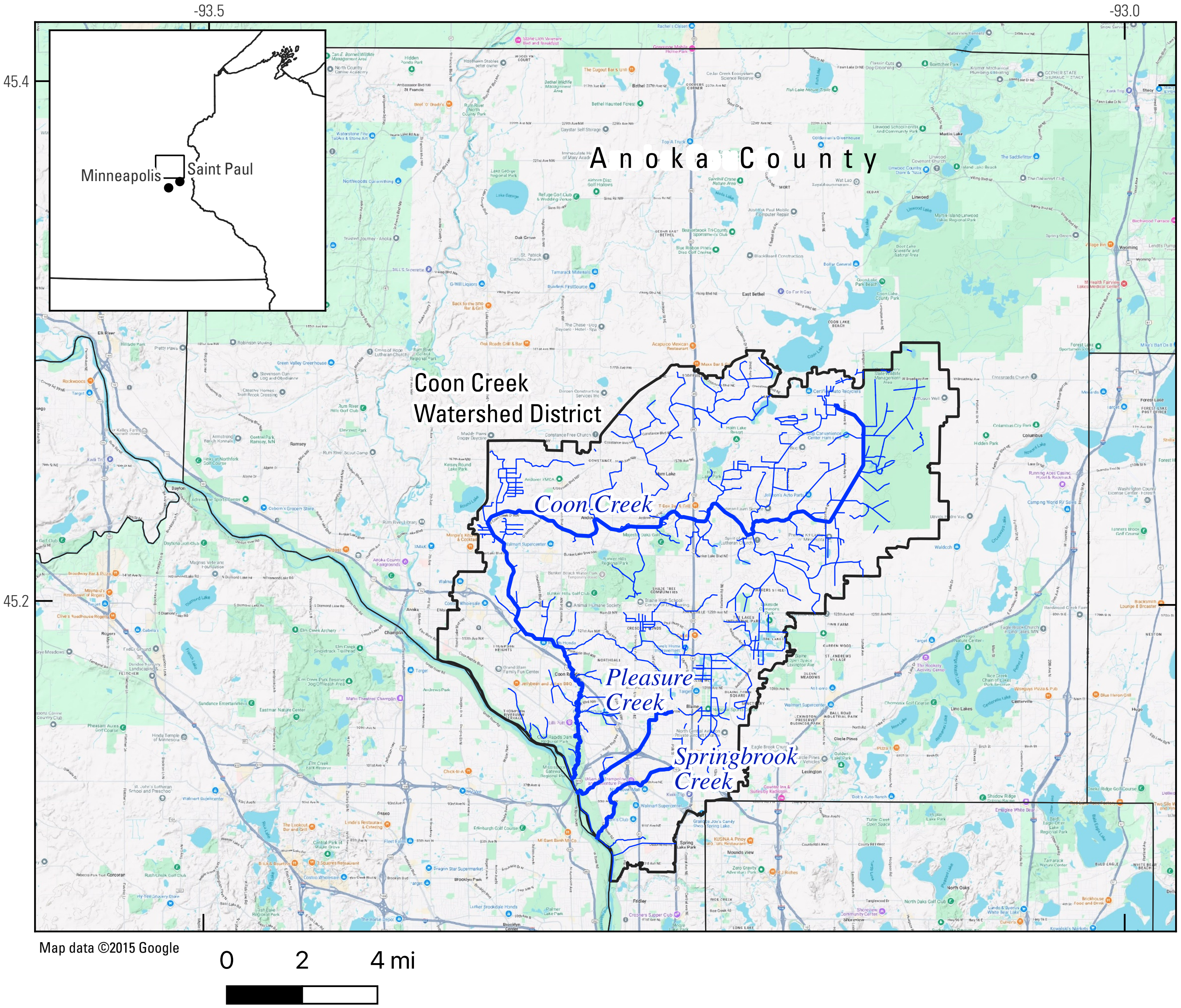
U.S. Geological Survey and
Coon Creek Watershed District (CCWD),
Anoka Co., MN

Andrew Leaf, Andrew Richardet, Allegra Johnson McKee, and Colin Livdahl


Photo credit: Ben Berndt, April, 2016

U.S. Department of the Interior
U.S. Geological Survey

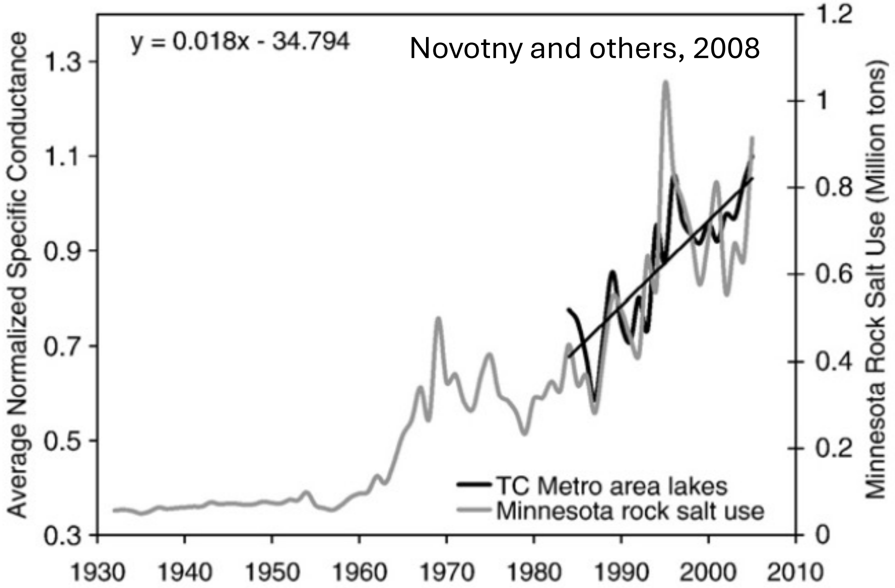
Study Area

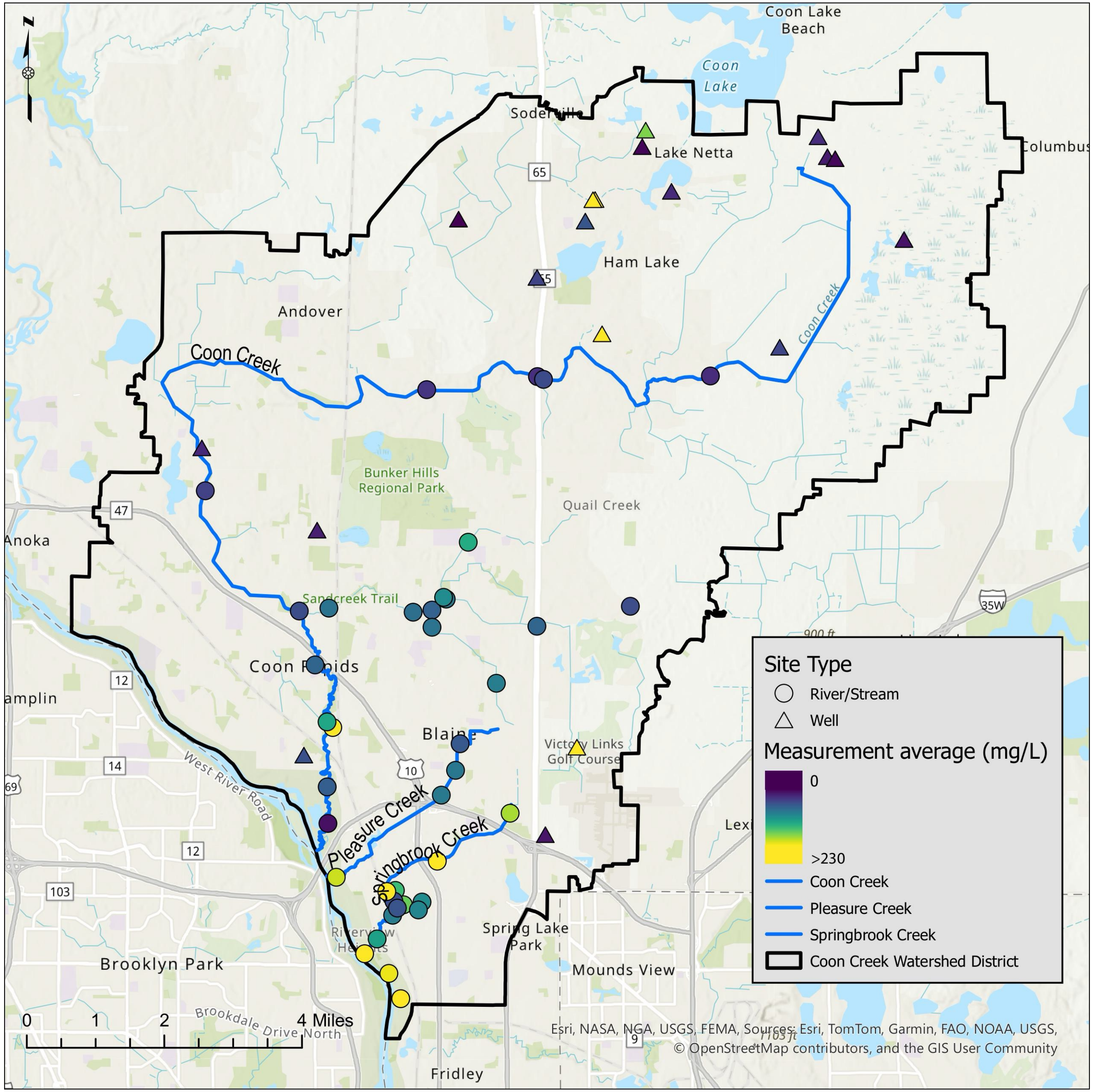


USGS
science for a changing world

Motivation

- Ecological impairment in Springbrook and Pleasure Creeks; elevated chloride throughout CCWD streams
- Natural background <10 mg/L
- Elevated chloride during low-flow periods indicates groundwater transport
- MN chronic surface water standard of 230 mg/L (Minnesota Pollution Control Agency, 2023)





USGS
science for a changing world

Project Goals

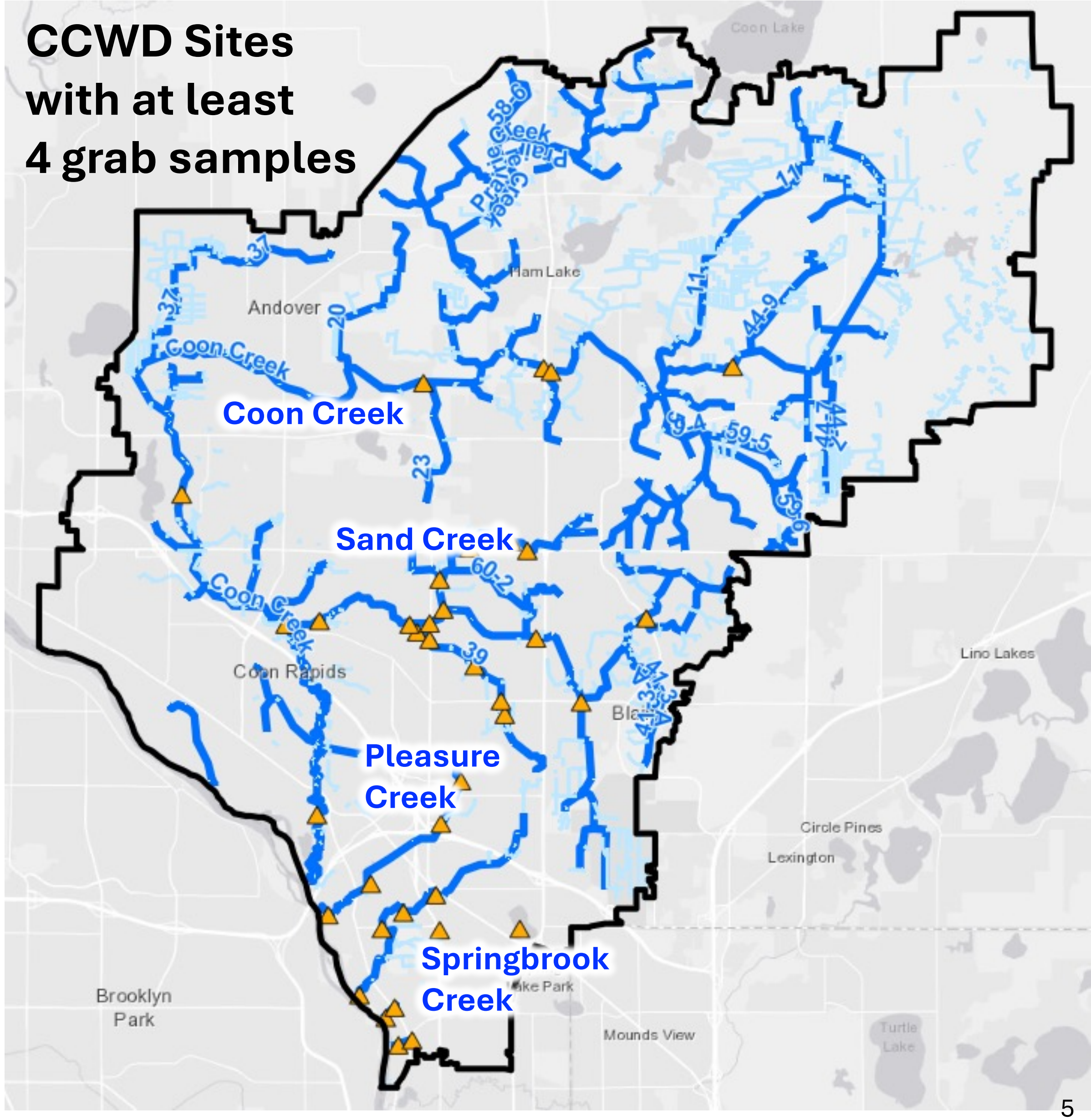
- **PHASE ONE: January 2025 – June 2025**
  - Develop groundwater flow and advective transport model of Coon Creek Watershed District
  - Emphasis on groundwater/surface water interactions, groundwater flow paths and travel times
  - Compile historical and field data
  - **Report findings/preliminary model results (this presentation!)**

- **PHASE TWO: Beginning June 2025**
  - Use model results to inform a groundwater monitoring network in the District
  - Add simulation of chloride mass transport
  - Additional model improvements to reduce uncertainty and answer specific management questions
  - Collect field data in “gap” areas of the model
  - Publish report and data release

USGS science for a changing world

Existing data collected by CCWD

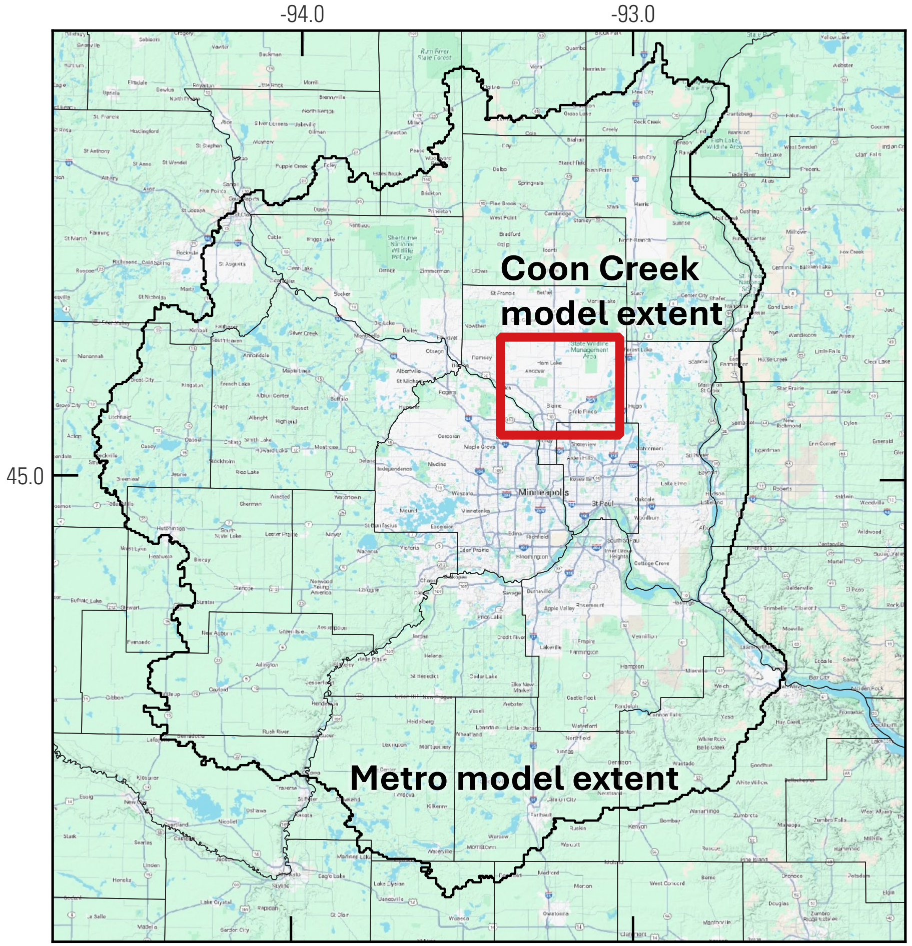
- **Seepage runs**
  - 6-14 sites along each stream; collected during base flow conditions in October 2024, along with chloride grab samples
- **Continuous stream stages and specific conductance measurements**
  - Springbrook and Pleasure Creek outlets (since 2023)
  - Coon Creek outlet + 2 upstream sites (proposed for 2025 or later)
  - Sand Creek outlet + 1 upstream site (proposed for 2025 or later)
- **Misc. chloride measurements**
  - 529 samples taken during base flow conditions
  - Select long-term sites have 4-6 samples/year for 1-13 years from 2005 to 2024
- **~4,000 surveyed streambed elevations**



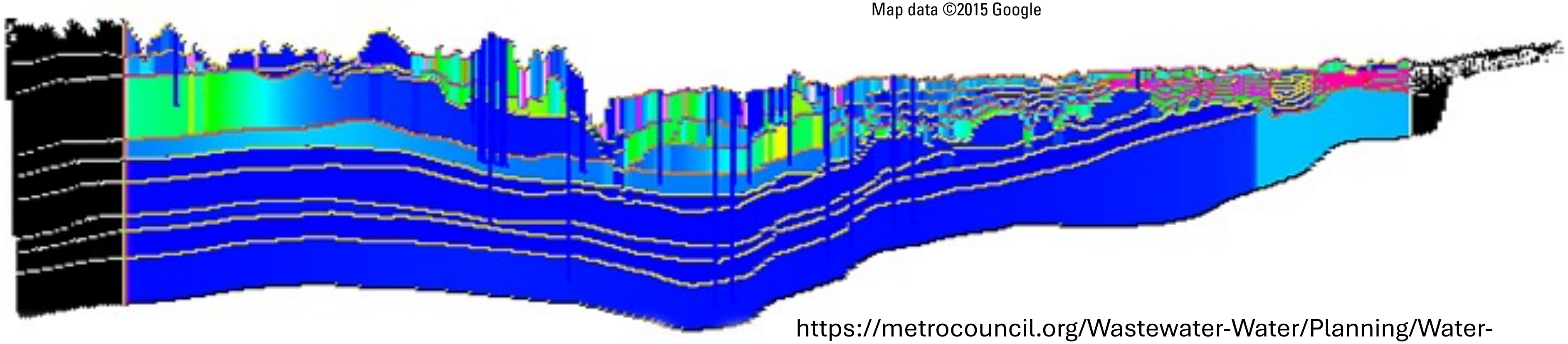
USGS
science for a changing world

Previous modeling work

- **Metro Model 3: Twin Cities Area Groundwater Flow Model (MM3)**
  - MM1 was published in 1990s, MM3 published in 2014 (by Metropolitan Council in cooperation with Barr Engineering Co)
  - MODFLOW-NWT
  - Uniform grid cells (500m x 500m),
  - Represents entire hydro stratigraphy with 9 layers; Quaternary consolidated into 1 layer in many places
    - "Quasi-3D" layering scheme not ideal for advective transport simulation
    - Horizontal discretization too coarse for representing small creeks



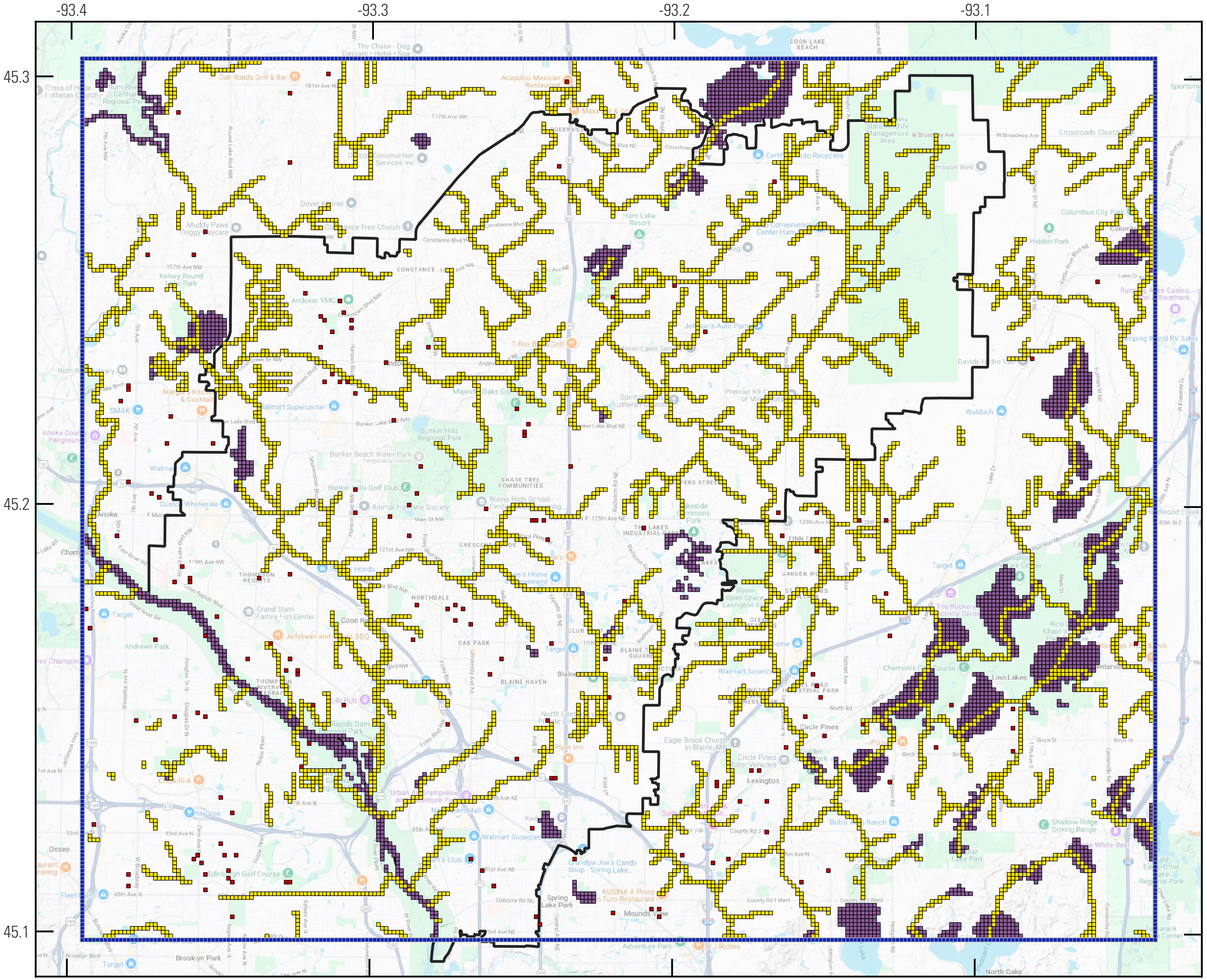
Map data ©2015 Google



https://metrocouncil.org/Wastewater-Water/Planning/Water-Supply-Planning/Planners/Metro-Model-3.aspx

Model construction

- MODFLOW 6 (Langevin and others, 2025)
- Steady-state, 100-meter cells, 12 layers
- Model simulates groundwater divides between Coon, Springbrook and Pleasure Creeks, and surrounding sinks (Rum & Mississippi Rivers, Lino Lakes & Rice Creek, etc.)
- Perimeter boundaries developed from Metro Model flow solution
- Surface water developed from NHDPlus High Resolution dataset (Buto and Anderson, 2020)
  - Streams represented with Streamflow Routing Package (head-dependent flux boundary with stream water balance; simulated stages)
  - Mississippi River and most lakes > 12 acres simulated with River Package (head-dependent flux boundary with specified stages)
- 2016–2021 water use data from the MNDNR Water permitting and reporting system (MNDNR, 2025)
- Groundwater recharge from statewide Soil Water Balance estimates (Smith and Westenbroek, 2015)



Map data ©2015 Google

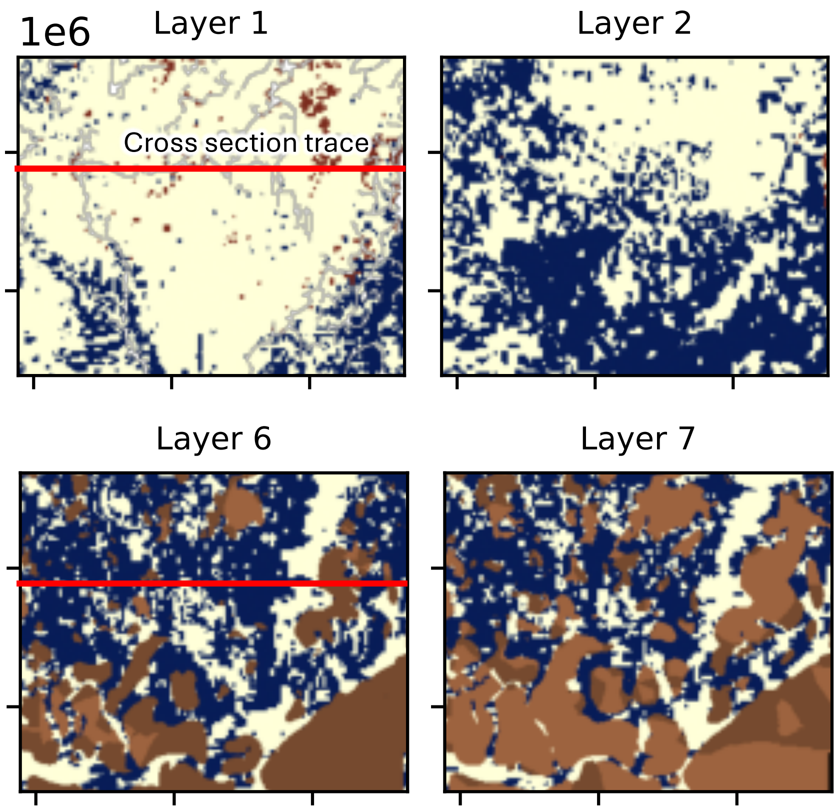
0 1 2 mi

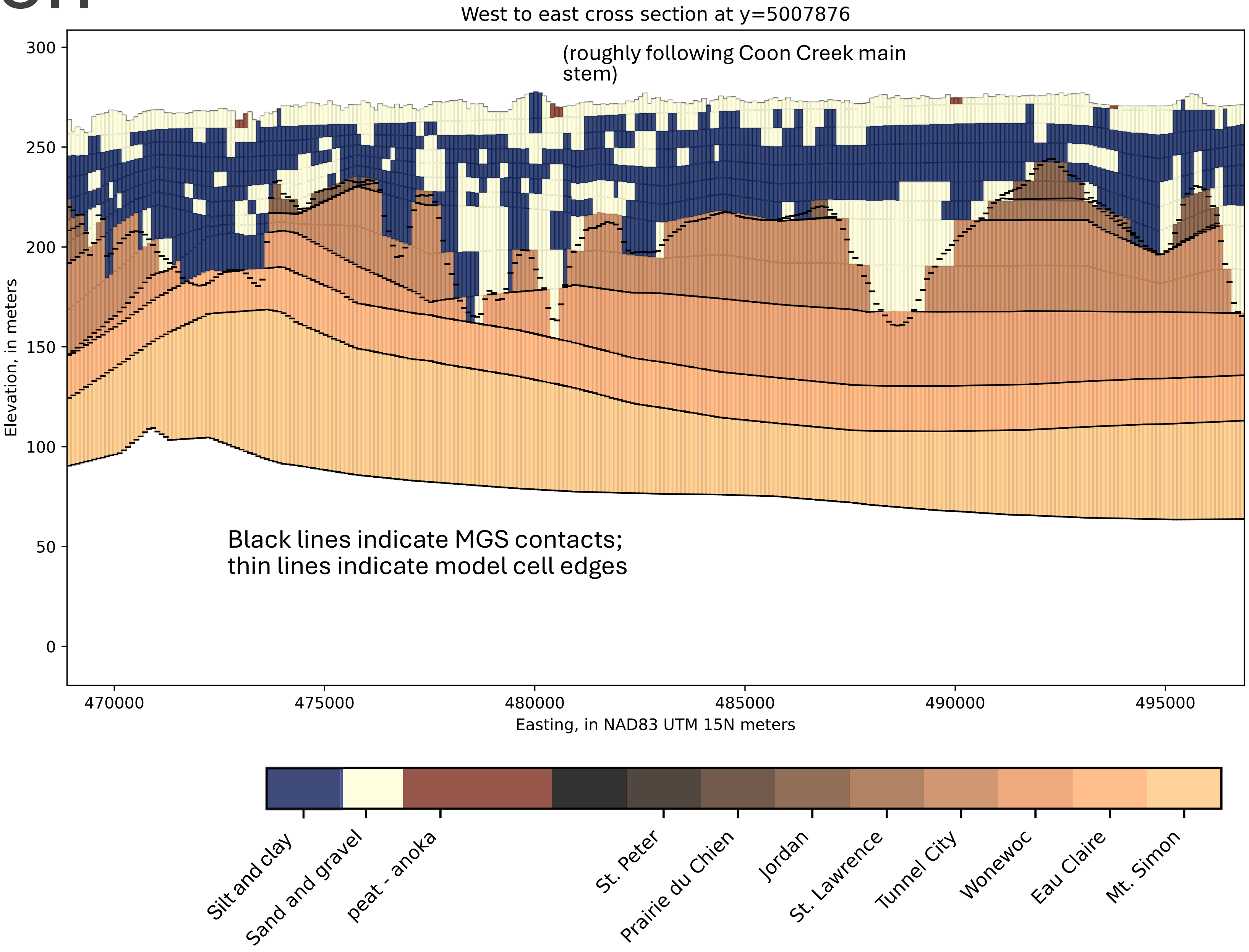
EXPLANATION

- Streamflow Routing (SFR) Package cells
- River Package cells
- Multi-Aquifer Well Package cells
- Specified Head boundary cells
- Coon Creek Watershed District

Model construction

- Model layering developed from Minnesota Geological Survey (MGS) county atlas data (Berg, 2016)
- Voxel-based layers above Eau Claire top; zones based on MGS Quaternary lithology data for Twin Cities (unpublished data)
- Quaternary = recent surficial deposits, especially from the last glacial period





This information is preliminary or provisional and is subject to revision. Not for Citation or Distribution

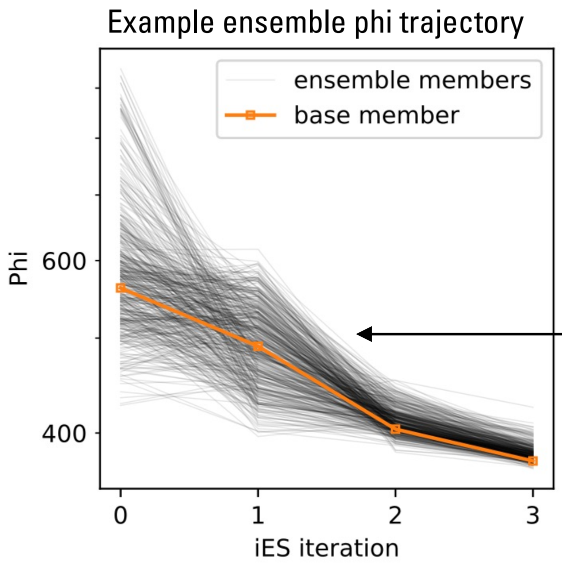
Model history matching

- Often called “calibration”; processes of refining model inputs (parameter estimation) by matching field observations
- Ensemble of plausible models considered to represent uncertainty
- Observations:
  - CCWD seepage runs (base flows)
  - County Well Index groundwater levels (heads)
  - Land surface elevations[1]
  - Well pumping rates[2]

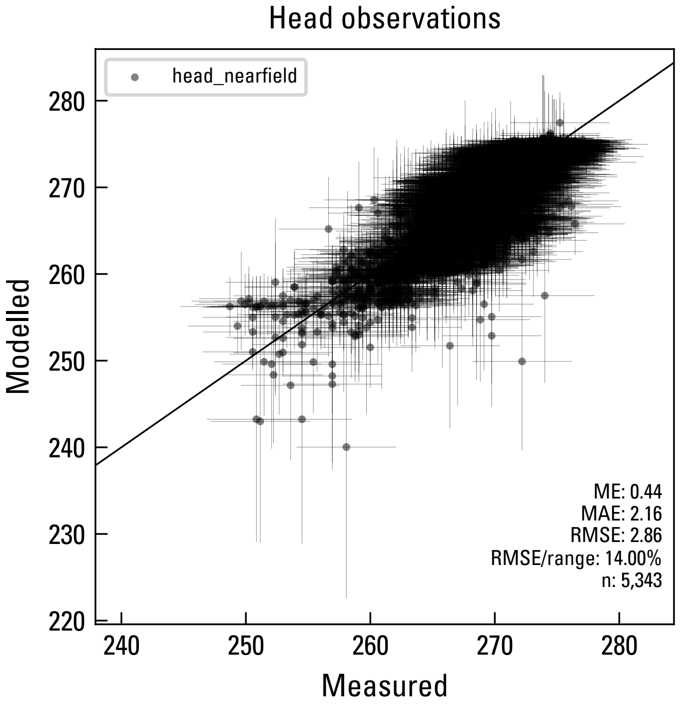
phi: Quantifies mis-fit between model outputs an equivalent field observations (the sum of squared, weighted residuals)

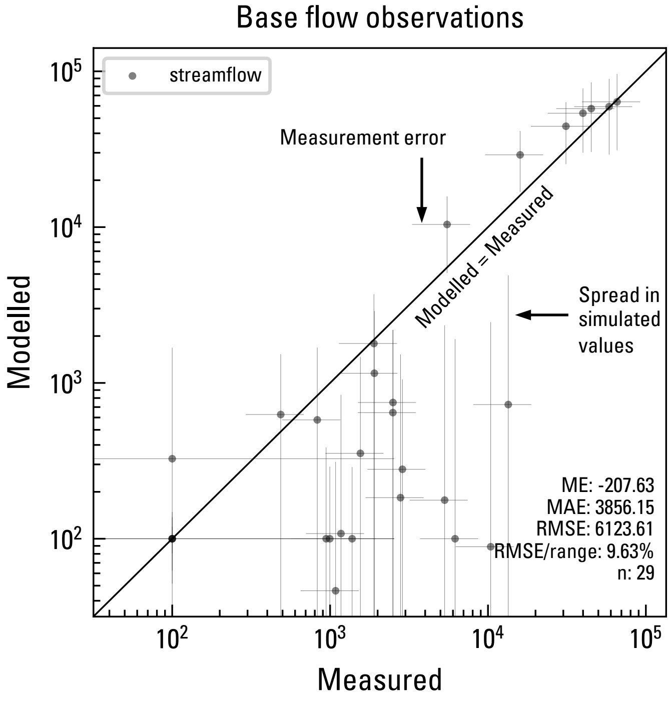
ME: Mean error; MAE: Mean absolute error; RMSE: Root mean squared error.

[1]To ensure that the models considered don’t simulate unrealistic groundwater mounding in non-wetland areas
[2]To help ensure that realistic aquifer properties are simulated (that can support the reported pumping rates being simulated in the model).



Each gray line represents the fit of an individual model (realization)



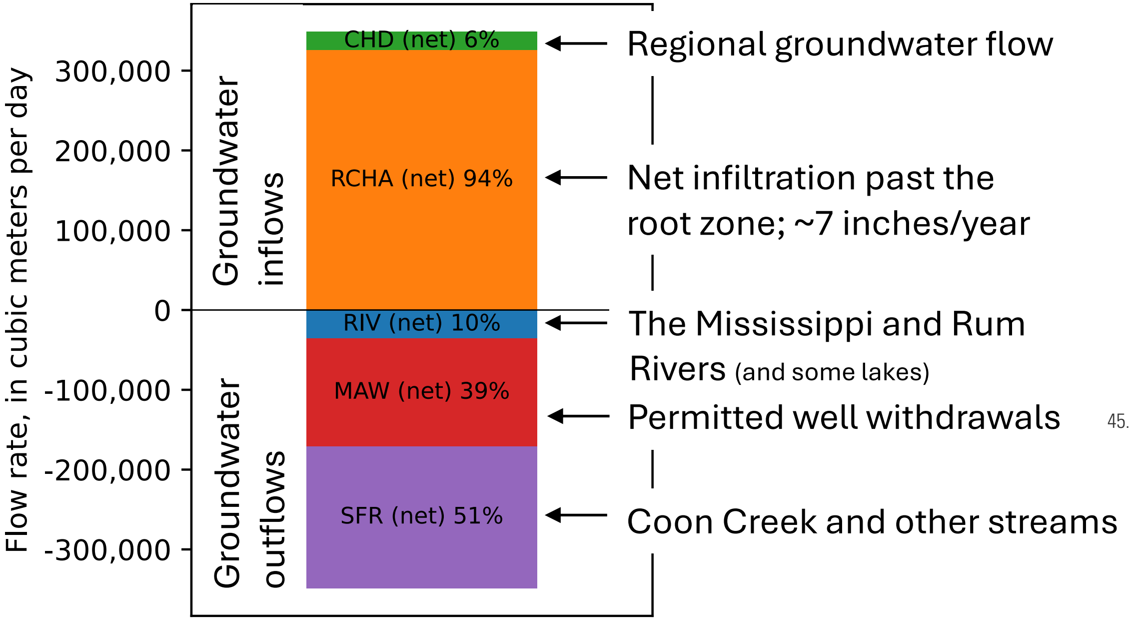


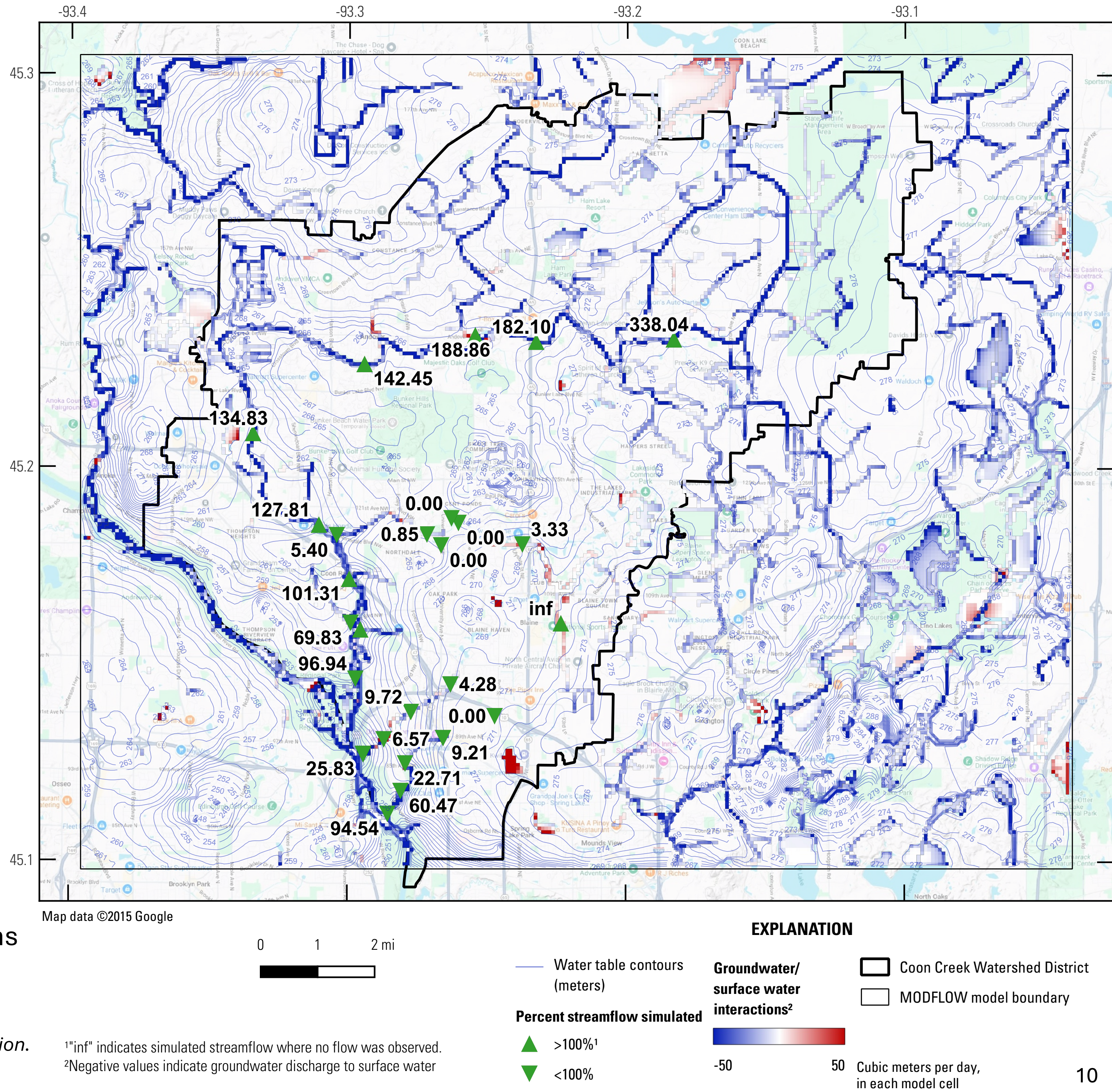
This information is preliminary or provisional and is subject to revision. Not for Citation or Distribution

Groundwater Flow results

- Coon Creek base flows and regional groundwater flow mostly well-simulated
- Sand, Springbrook and Pleasure Creeks consistently *under*simulated (flow in these probably supported by aquitards that are not adequately represented in the model)

MODFLOW Water Budget Summary (net fluxes)

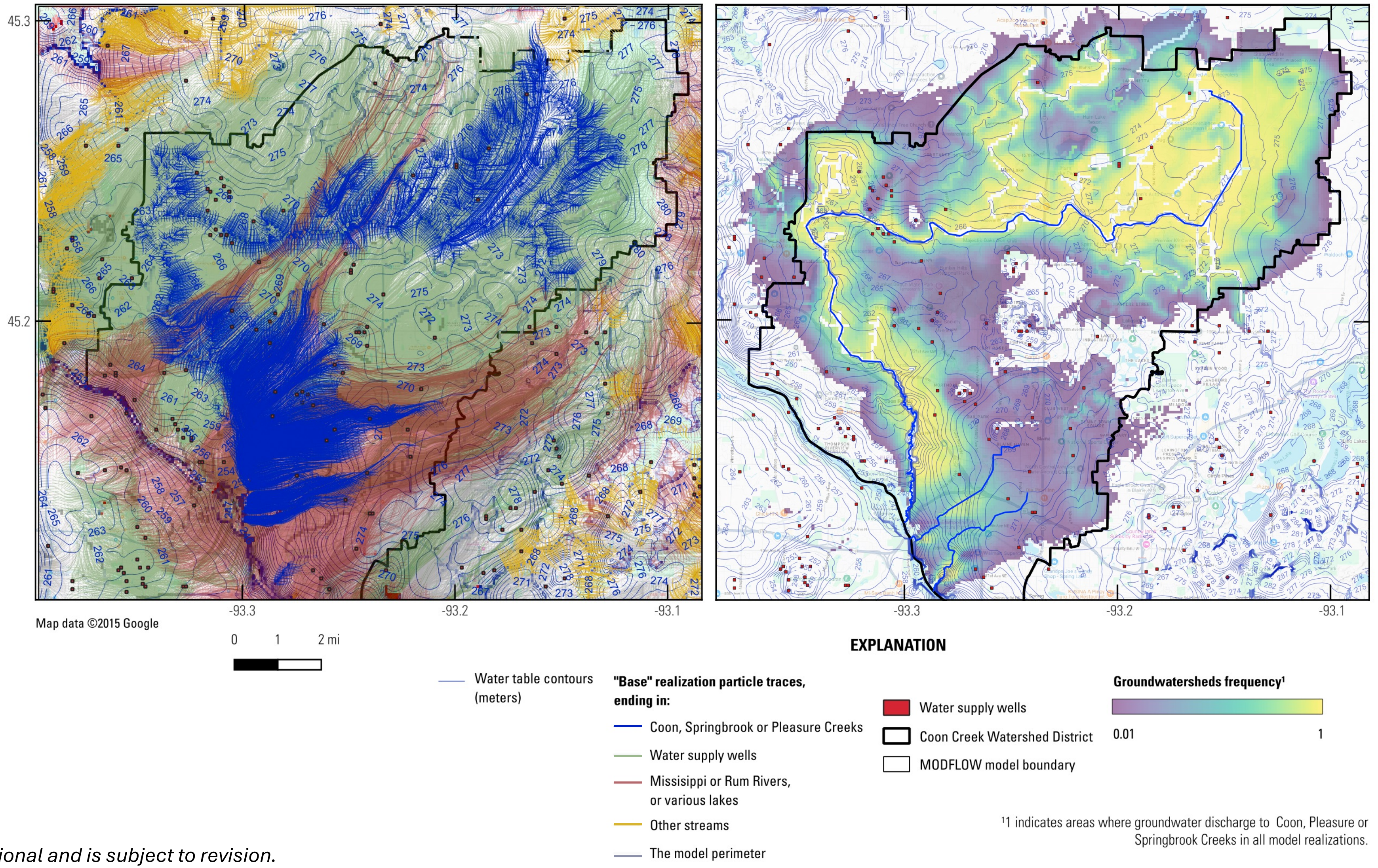




Particle tracking

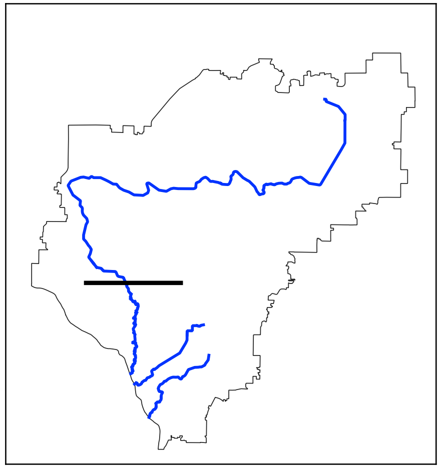
- Hypothetical ‘particles’ are tracked through the groundwater flow solution
- 1 particle released in each (100m^2) model cell, at the water table; tracked forward until it discharges
- Starting locations of particles discharging to a surface water body define it’s “groundwatershed”
- With an ensemble of possible models, we can look at the likelihood of an area being within the groundwatershed

***A.* Particle traces for the (single) ‘base’ model** ***B.* Groundwatershed extents estimated by the ensemble**

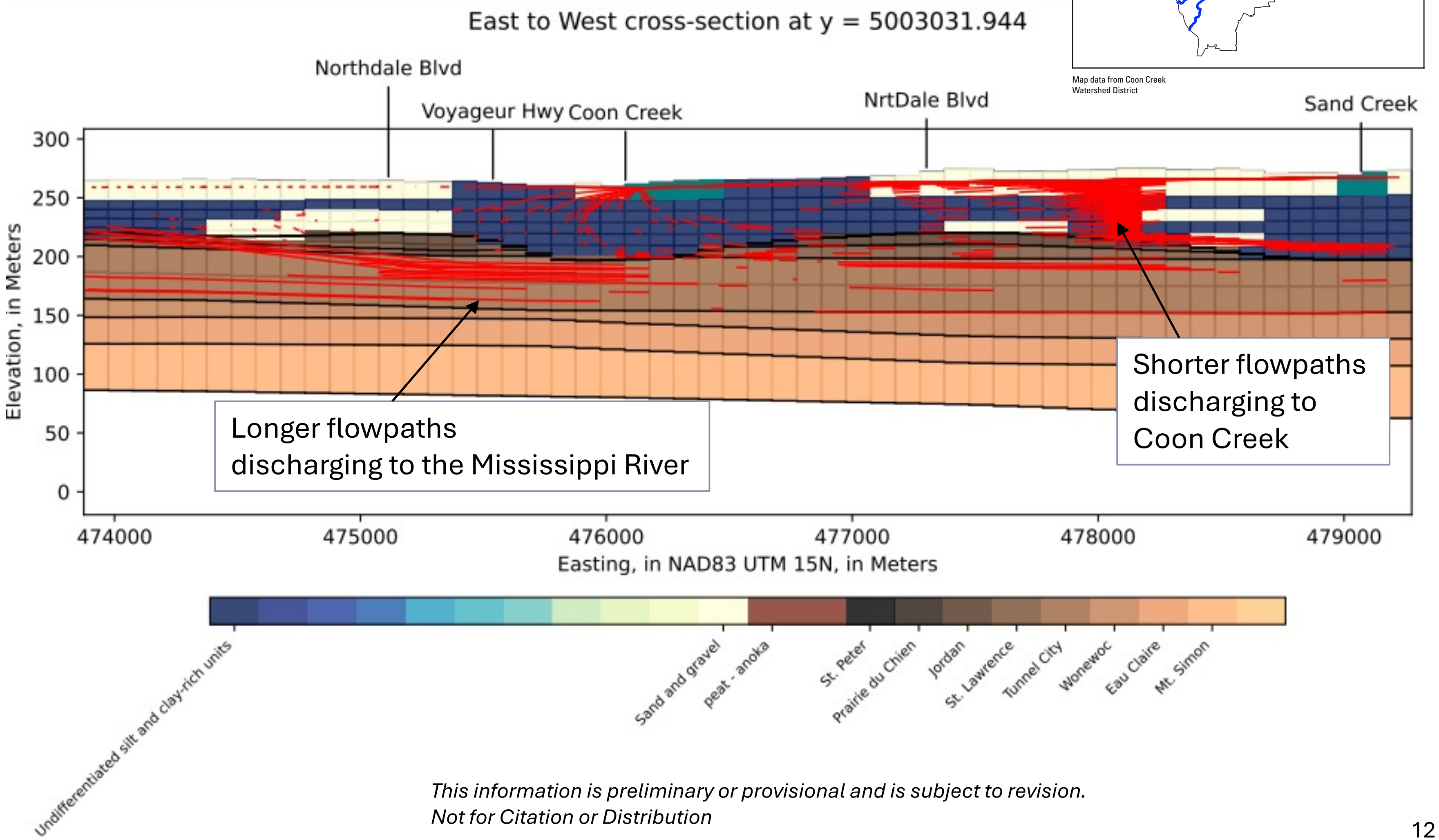


Particle tracking

- Particle tracking can also be used to look at the vertical extent of groundwater flowpaths
- The example illustration on the right shows selected particle traces along a cross section perpendicular to Coon Creek
- Ensemble results indicate that more than ~90% of groundwater discharging to Coon Creek is sourced exclusively from Quaternary deposits
- Generally, groundwater discharge to the creeks comes from a depth of less than 40 meters; with median depths of around 10-20 meters.
- The sources of water to Springbrook and Pleasure Creeks are uncertain but likely also dominated by the Quaternary



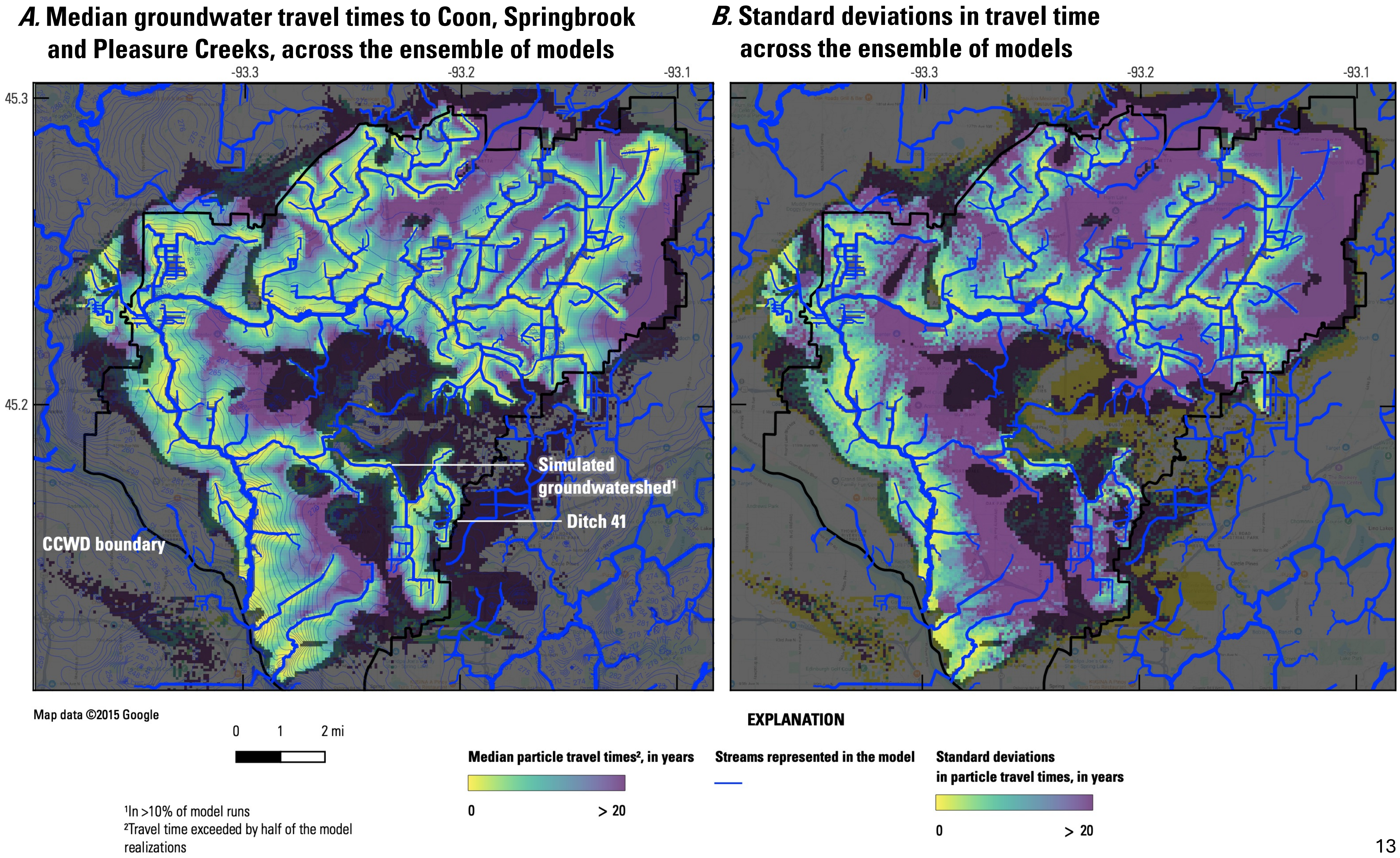
Map data from Coon Creek Watershed District



This information is preliminary or provisional and is subject to revision.
Not for Citation or Distribution

Particle tracking

- Particle tracking can also be used to estimate the ages of discharging groundwater



This information is preliminary or provisional and is subject to revision.
Not for Citation or Distribution

USGS
science for a changing world

Key Model limitations

This model is a first step for understanding groundwater chloride in CCWD but has some important limitations that will be addressed in phase 2:

- **The lateral extent of the groundwatershed around Springbrook, Pleasure and Sand Creeks may be underrepresented**
  - Currently, the simulated water table is too deep to reproduce observed in-stream base flows[1]
  - In reality, fine-grained Quaternary till and lacustrine deposits may be "holding up" the water table in these areas (by providing resistance to flow to the Mississippi River or deeper high-capacity wells)[2]
  - Additional fieldwork and refinement of the model vertical discretization and representation of Quaternary units may help resolve this issue

- **Contributing areas for some ditches are not included**
  - NHDPlus provided an easy starting point for the model but does not include all mapped ditches, such as the headwater areas of Ditch 41 (slide 13)
  - Groundwater contributing areas for many missing ditches are currently not included in the simulated groundwatershed
  - Incorporating CCWD's hydrography into the model should resolve this

- **Observation data informing the model inputs is incomplete and may be biased**
  - The October 2024 seepage run may not represent long-term average base flow (due to seasonal variation, use of weirs at Carlos Avery, or potentially, sod irrigation). Next step: look at all miscellaneous base flow measurements and develop estimates of long-term averages.
  - Static CWI levels may be biased (taken in non-equilibrium conditions after drilling, or due to longer-term trends). Next step: identify and prioritize wells with multiple or high-quality measurements.

- **Particle tracking (simulation of advective transport) does not consider:**
  - Source concentrations
  - Dispersion (spreading) of the solute along a flowpath
  - Differences in flow rates/volumes (i.e. loading) among different flowpaths

- **In any case, the model is a simplified representation of reality, and may not capture the actual range of possible outcomes, even in an ensemble context.**

[1]See % simulated flows on slide 10.
[2]See for example Berg, 2016, plate 9.

Implications of model limitations

- The edges of the groundwatershed shown on slide 11 are uncertain, but probably include areas adjacent to ditches with perennial flow
- Travel times and the groundwatershed extent may shift somewhat as the model is improved
- Travel times are increasingly uncertain with distance from the creeks and their tributaries
- Currently, the model can give a sense of contributing areas and approximate groundwater travel times
- The current model can't predict specific chloride concentrations or connect loading on the landscape to concentrations downstream

[1]See % simulated flows on slide 10.
[2]See for example Berg, 2016, plate 9.

Preliminary Findings

- Permitted high-capacity well pumping consumes approx. 40% of groundwater originating within the study area
- Groundwater flow to the creeks, and partitioning of flow to high-capacity wells is probably controlled by fine-grained layers within the Quaternary deposits
- >90% of groundwater discharging to Coon Creek is sourced exclusively from Quaternary deposits, Springbrook and Pleasure Creeks uncertain but likely similar
- Groundwater discharge to the creeks comes from a depth of less than 40 meters; with median depths of around 10-20 meters.
- The median age of groundwater discharge to Coon Creek and its tributaries is probably less than 20 years; possibly less than 10 years
  - In general, groundwater age decreases with stream order (with headwaters having the youngest water; Abrams and others, 2013)
- Median ages of groundwater discharge to Pleasure and Springbrook creeks are likely younger than Coon Creek
- More work is needed to build confidence in model predictions of flow paths
- Simulation of mass transport is needed to predict chloride concentrations and connect loading to concentrations near the creeks

Looking ahead: PHASE TWO

- Add mass transport and loading history to
  - Establish where chloride reduction will lead to improvements in water quality
  - Set reasonable expectations for when changes may be observed
  - Evaluate potential chloride reduction strategies
- Model improvements to build confidence (reduce uncertainty) in model predictions of flowpaths to Sand, Springbrook and Pleasure Creeks and high-capacity wells:
  - Improve model representation of Quaternary hydrostratigraphy
  - Incorporate all mapped ditches
  - Improve observation data used to estimate model inputs
  - Sample groundwater chloride concentrations near streams and source areas; include these data in history matching
- Design and install well network for long-term monitoring of water quality and groundwater levels in the surficial aquifer
- Publish a peer-reviewed, citable report and model archive

References

Abrams, D., Haitjema, H., and Kauffman, L. (2013). On modeling weak sinks in MODPATH. Groundwater 51 (4), 597–602.

Berg, J.A., 2016, Geologic atlas of Anoka County, Minnesota (Part B): Minnesota Department of Natural Resources, County Atlas Series C-27, report and plates 7-9.

Buto, S.G., and Anderson, R.D., 2020, NHDPlus High Resolution (NHDPlus HR)—A Hydrography Framework for the Nation: Fact Sheet 2020–3033, accessed June 9, 2025, at https://doi.org/10.3133/fs20203033.

Metropolitan Council, 2014, Metro Model 3—Twin Cities Area Groundwater Flow Model hydrogeologic property grids: accessed May 2025 at https://metrocouncil.org/Wastewater-Water/Planning/Water-Supply-Planning/Planners/Metro-Model-3.aspx.

Minnesota Pollution Control Agency, 2023, Minnesota rules, chapter 7050—Waters of the state: Minnesota Office of the Revisor of Statutes, accessed May 20, 2025, at https://www.revisor.mn.gov/rules/7050.

Langevin, C.D., Hughes, J.D., Provost, A.M., Russcher, M.J., Niswonger, R.G., Panday, Sorab, Merrick, Damian, Morway, E.D., Reno, M.J., Bonelli, W.P., Boyce, S.E., and Banta, E.R., 2025, MODFLOW 6 Modular Hydrologic Model version 6.6.2: U.S. Geological Survey Software Release, 12 May 2025, https://doi.org/10.5066/P1DXFBUR

Minnesota Department of Natural Resources (MNDNR), 2025, MPARS: accessed February 3, 2025, at, https://www.dnr.state.mn.us/mpars/index.html.

Novotny, E.V., Murphy, D., and Stefan, H.G., 2008, Increase of urban lake salinity by road deicing salt: Science of The Total Environment, v. 406, no. 1–2, p. 131–144. https://doi.org/10.1016/j.scitotenv.2008.07.037

Smith, E.A., and Westenbroek, S.M., 2015, Potential groundwater recharge for the State of Minnesota using the Soil-Water-Balance model, 1996–2010: U.S. Geological Survey Scientific Investigations Report 2015–5038, 85 p., http://dx.doi.org/10.3133/sir20155038

Stefan, H., Novotny, E., Sander, A., and Mohseni, O., 2008, Study of Environmental Effects of De-Icing Salt on Water Quality in the Twin Cities Metropolitan Area, Minnesota: Minnesota Department of Transportation 2008–42, accessed May 20, 2025, at https://www.lrrb.org/pdf/200842.pdf.

Comparison of model hydrostratigraphy to the Anoka County Atlas

- Low vertical hydraulic conductivities in fine-grained glacial till and lacustrine deposits produce vertical hydraulic head gradients and resistance to downward flow that maintains a shallow water table
- Vertical head gradients are further exaggerated by pumping from deeper high capacity wells

Quaternary aquitards

Grouped by texture ranging from highest to lowest sand content indicating relative hydraulic conductivity.

Hydrogeologic unit code	Percent sand
cr, ce, rt, lc (sandy)	> 60%
nu	> 40% and ≤ 50%
xt, pt	> 30% and ≤ 40%
lc	≤ 30%

Tritium age

Darker color in small vertical rectangle (well screen symbol) indicates tritium age of water sampled in well. Lighter color indicates interpreted age of water in aquifer.

Cold War era: water entered the ground during the peak period of atmospheric tritium concentration during nuclear bomb testing, 1958–1959 and 1961–1972 (greater than 15 tritium units [TU]).

Recent: water entered the ground since about 1953 (8 to 15 TU).

Mixed: water is a mixture of recent and vintage waters (greater than 1 TU to less than 8 TU).

Vintage: water entered the ground before 1953 (less than or equal to 1 TU).

Well not sampled for tritium.

Symbols and labels

41.1 If shown, chloride concentration equals or exceeds 5 parts per million. (* indicates naturally elevated values)

13.4 If shown, arsenic concentration equals or exceeds 10 parts per billion.

3000 If shown, groundwater residence time in years as estimated by carbon-14 (^{14}C) isotope analysis.

General groundwater flow direction

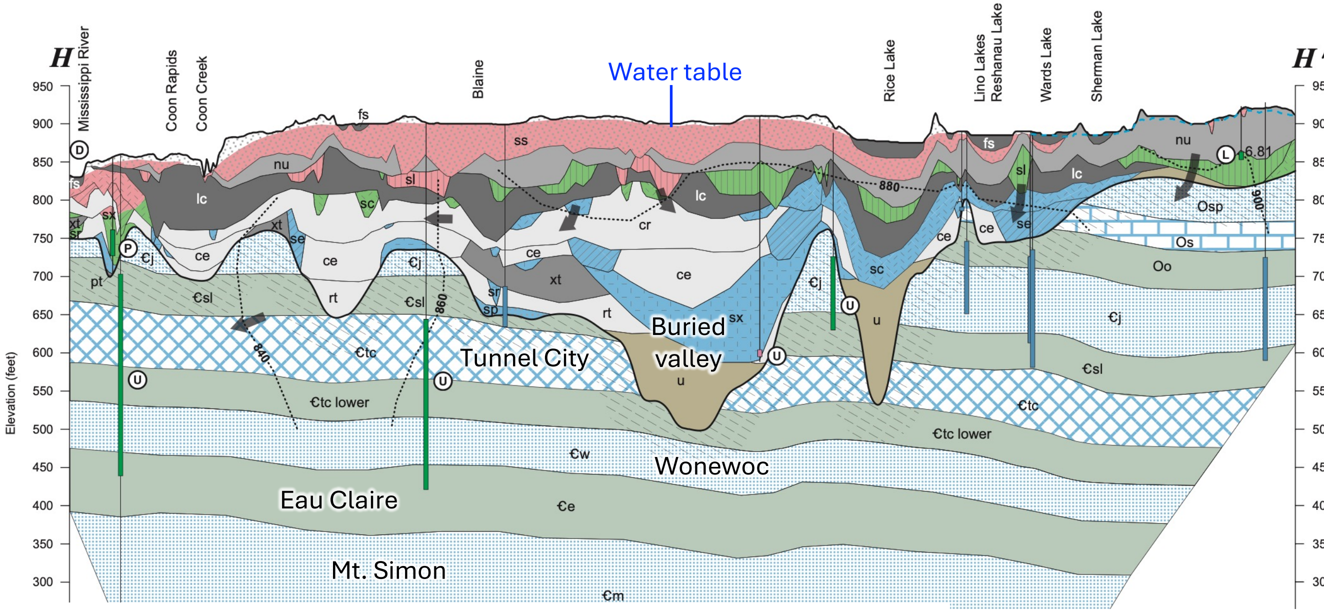
···· 900 ···· Approximate equipotential contour; contour interval 20 feet

Geologic contact

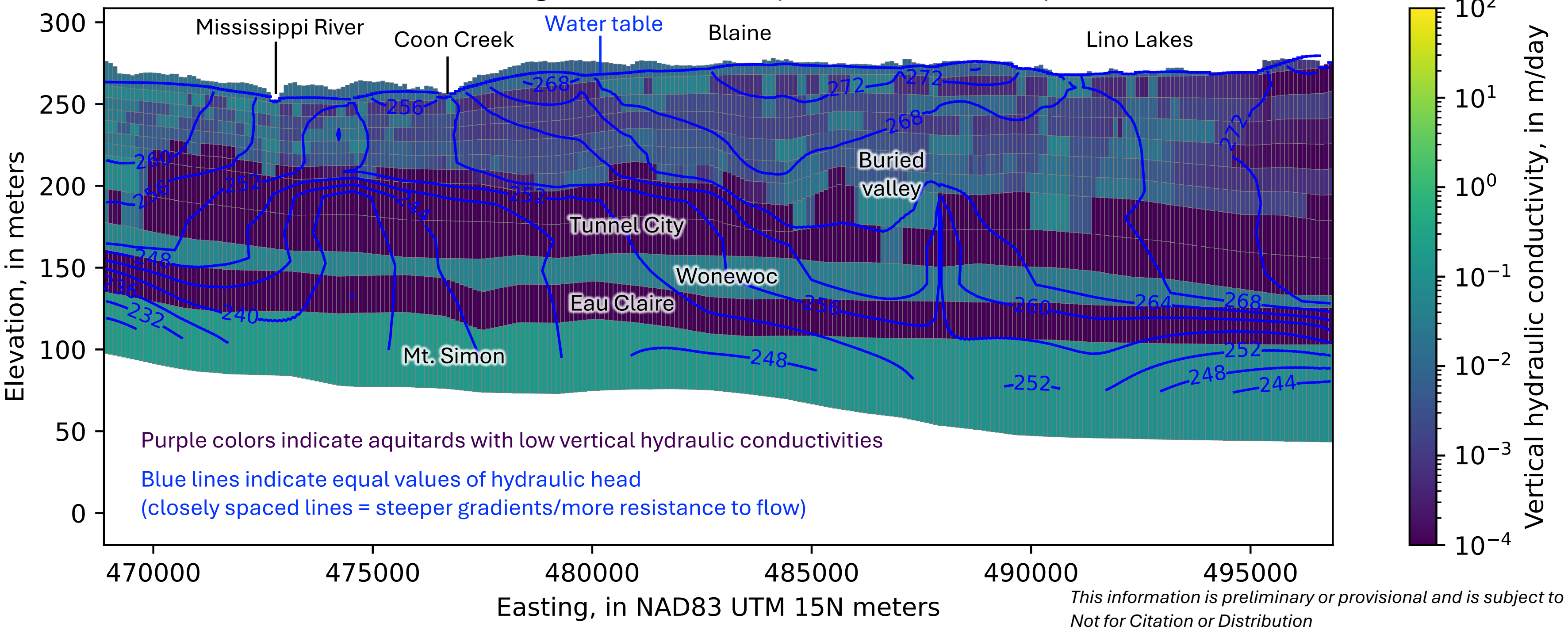
Land or bedrock surface

Water table

West-East cross section from Berg, 2016, plate 9 (~5,000,000 m north)



West-East cross section along model row 160 (5,000,825 m north)



This information is preliminary or provisional and is subject to revision. Not for Citation or Distribution