Using a Numerical Model to Assess Groundwater Remediation Effectiveness at a Former Manufactured Gas Plant Site

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Introduction

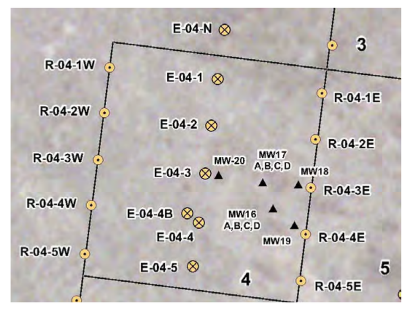
Groundwater remediation purpose and goal

- address elevated levels of ammonia, arsenic, and phenolics within the GRZ (Groundwater Remediation Zone) in the lowermost 5 feet of the 30-foot sand aquifer
- goal of 80 percent reduction in ammonia, arsenic, and total phenolics mass at the base of the aquifer

Detailed monitoring of one treatment cell, Cell 4, was completed to:

- observe and document behavior of a representative cell and
- provide data to validate cell performance

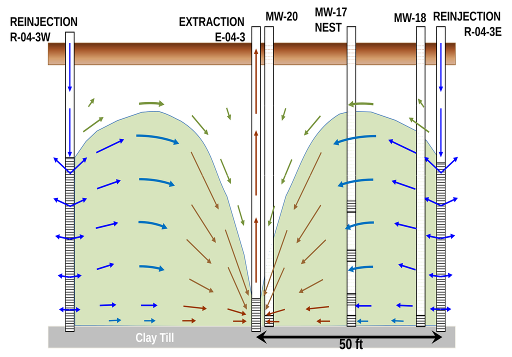
Numerical modeling of groundwater flow and ammonia fate and transport to assess remediation effectiveness



Monitored cell (Cell 4) layout

Groundwater remediation system

- cell-based extract ⟶ treat ⟶ re-inject
- typical cell ~110 feet long by 100 feet wide
  - one line of either five or six extraction (E) wells bracketed by two lines of five reinjection (R) wells each, for a total of 10 R wells per cell.
  - typical well spacing was approximately 22 feet between in-line wells and 50 feet between E and R well lines
- flush groundwater from reinjection (R) to extraction (E) wells
  - promote faster contaminant removal and biodegradation
- monitoring wells along flow transect in Cell 4
  - deep and nested



Cell 4 cross section

operation flow rates:
E ~ 0.25 – 3 gpm per well
R ~ 0.5 – 1.3 gpm per well

Modeling motivation

Enhance understanding of subsurface processes

- monitoring data provide only a snapshot of spatially and temporally distributed processes and may result from multiple processes
- *given that ammonia mass extracted exceeds initial mass, how can we relate mass extracted at wells to mass reduction in the aquifer?*
- *at what point in cell operations is the mass reduction remediation goal achieved?*

Conceptual model testing

- *what gives rise to tails on ammonia concentration and mass extracted time-series data?*

Explicit representation of system complexity

- incorporate system complexity to a greater degree than what can be unambiguously discerned from monitoring data

Cost savings

- modeling can be a cost-effective alternative to extensive data collection
- legacy model already in existence
  - previous use as design/investigation tool

Model construction

Numerical codes

- MODFLOW (groundwater flow)
- MT3DMS (contaminant fate and transport)

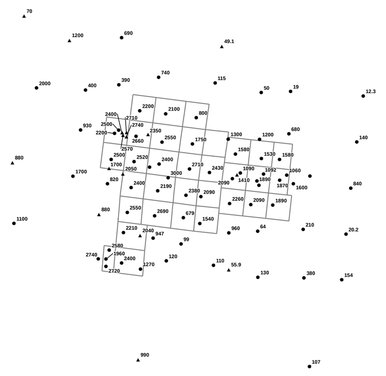
Three-dimensional

- 8 layers 1~10 ft thick (thinner near base of aquifer)
- grid spacing 6 ft by 6 ft in GRZ

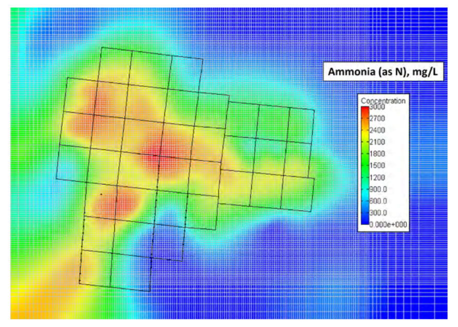
Aquifer hydraulic properties

- hydraulic conductivity values and distribution based on site data (slug tests) and well performance

Initial ammonia concentrations



Field data



Model representation

Model calibration

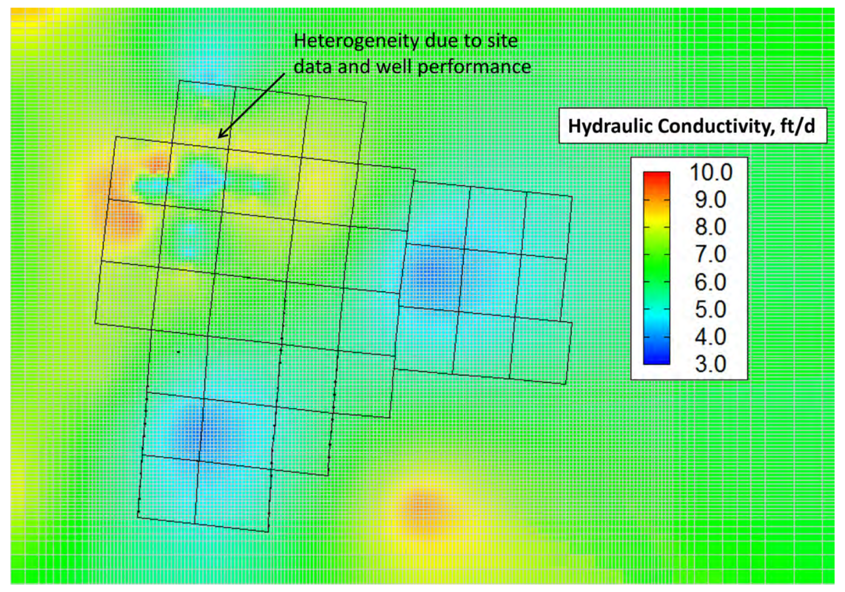
- used the automated parameter estimation code PEST to adjust parameter values to optimize fit to observations from monitored cell (Cell 4)
- simulated full treatment cell operations
  - flow rates from totalized volumes measured during cell operations

Observations

- well water levels
- Cell 4 monitoring data
  - ammonia concentration and mass extracted

Adjustable parameters

- hydraulic conductivity
  - strong control on timing of concentration breakthrough



- transport parameters

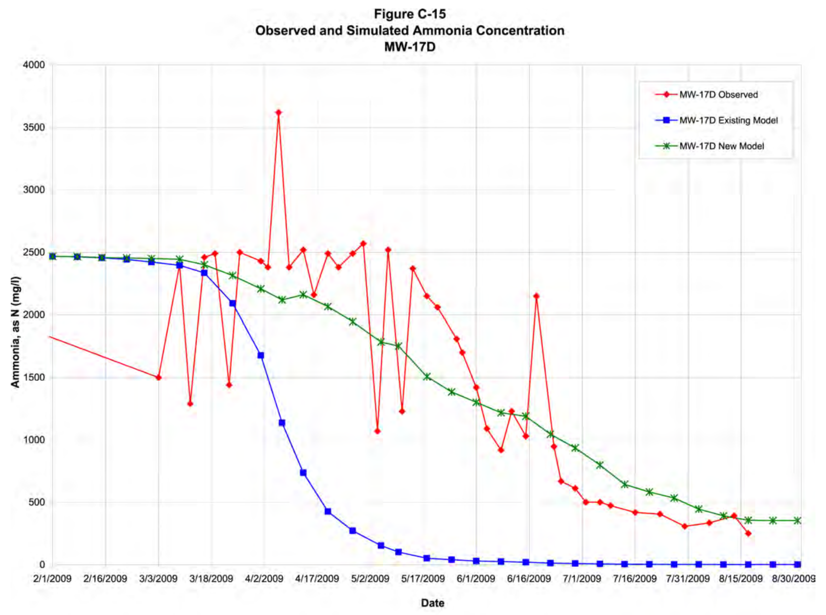
Ammonia transport conceptual model testing

- ammonia initially conceptualized as conservative (no sorption, no production) species
- "tails" on concentration time series and mass extraction in excess of initial dissolved-phase cell mass suggest ammonia partitioning by some physical or chemical mechanism
- attempts to reproduce tails by introducing heterogeneity in hydraulic parameters were unsuccessful
- simulation of ammonia as a non-conservative species (following a Langmuir sorption isotherm) allowed replication of the concentration tails and mass extraction in excess of initial mass

Calibration results

Concentration in Cell 4 monitoring well

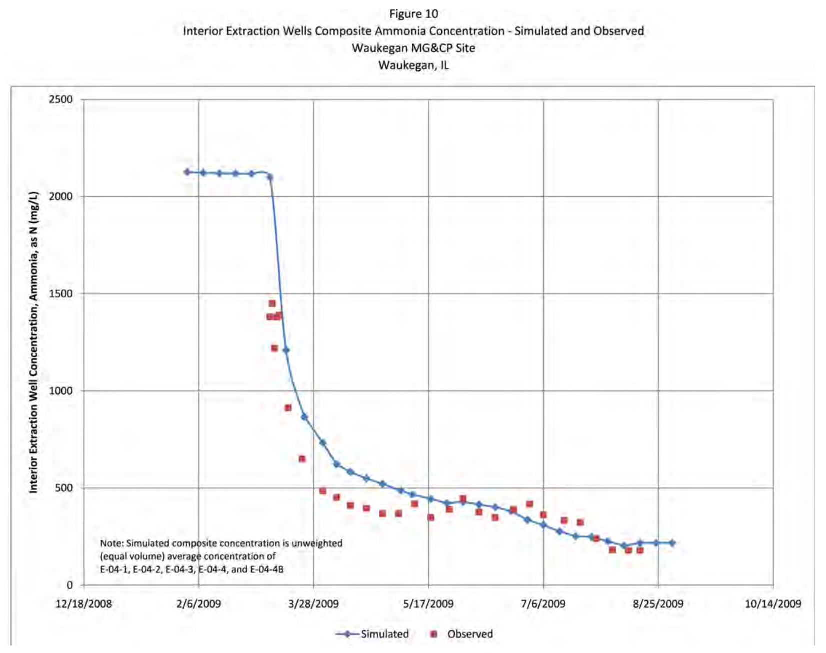
- confirmation that model is accurately simulating ammonia transport processes within Cell 4



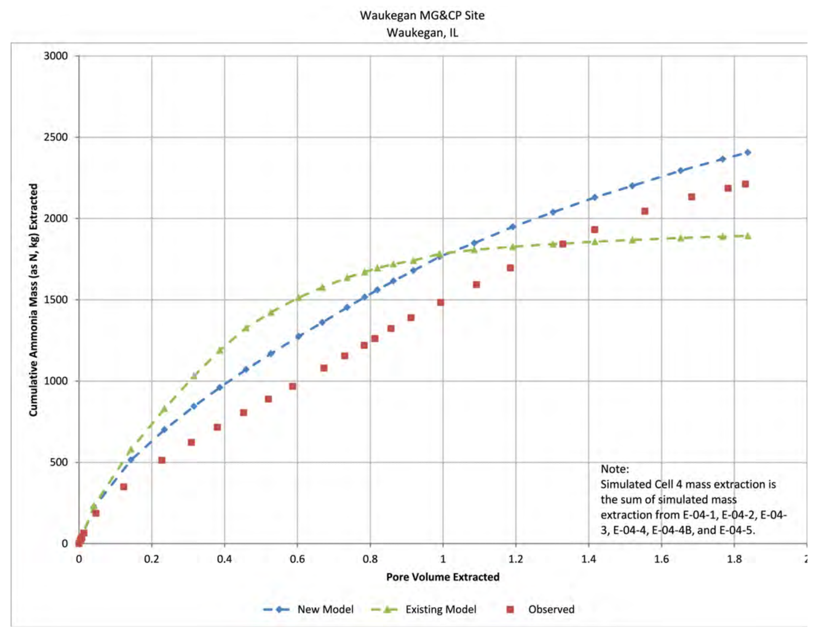
Extraction well concentration and mass extracted

- model accurately reproduces remediation parameters measured for all treatment cells

Composite extraction well ammonia concentration

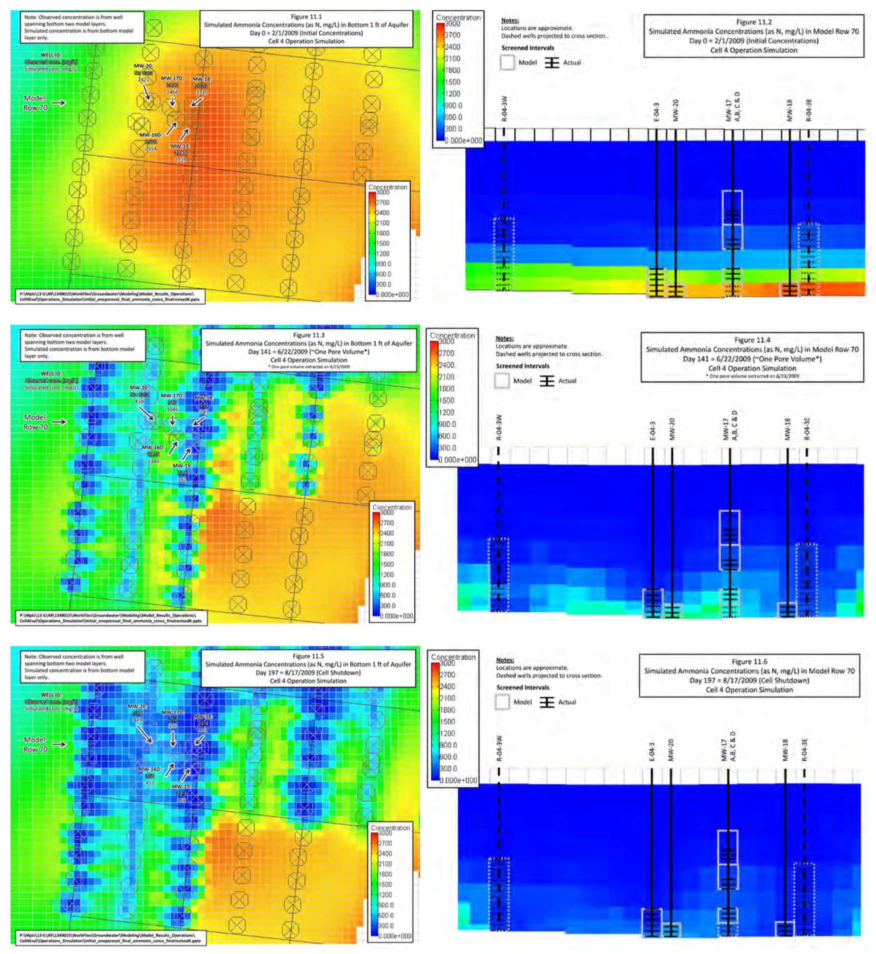


Ammonia mass extracted

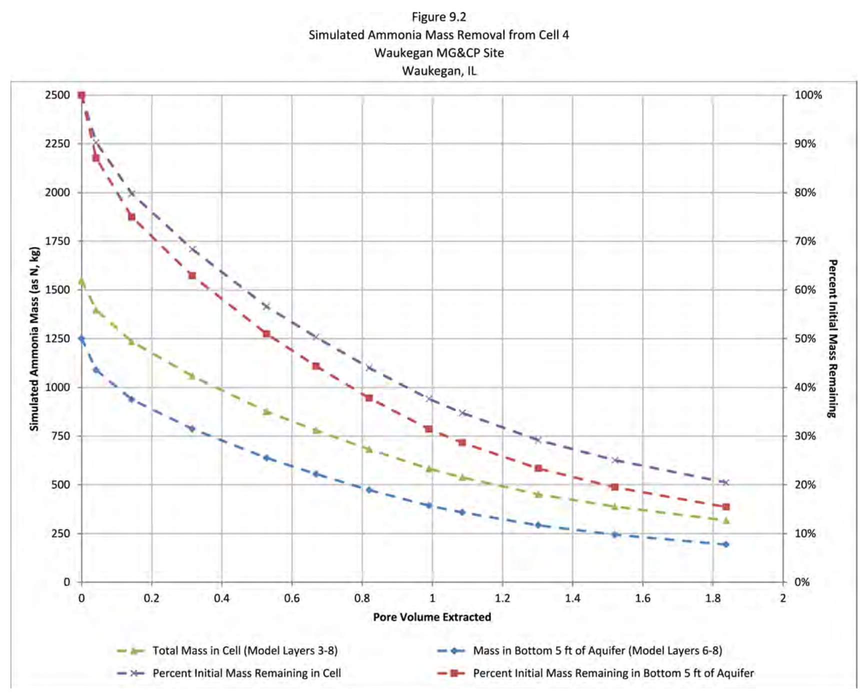


Remediation effectiveness

Ammonia concentration reduction



Ammonia mass reduction



Conclusions

- model results were a vital component to demonstrate the overall effectiveness of the treatment cells to reduce contaminant mass
- considerable insight into the system was obtained during model calibration and conceptual model testing
- numerical models provide information that cannot be obtained from monitoring data