Tooele Army Ordnance Depot – Continuous Improvement of a Groundwater Model for Remedy and Decision Making over a 25 Year Period

Jon P Fenske, P.E.
USACE-IWR-Hydrologic Engineering Center
Davis CA

Peter Andersen, P.E.
TetraTech Inc.
Alpharetta GA

James Ross, PhD, P.E.
HydroGeologic Inc.
Hudson OH
Tooele Valley, Utah
Tooele Army Depot

- Groundwater contamination since beginning of depot activities
  - 1942 - WWII servicing of military vehicles
  - Primarily TCE
  - Multiple source areas (ditches, lagoons, sumps, landfill)
  - 4 mile long plume(s) extends offsite

- Remedial activities include:
  - Excavation and capping
  - 5400 gpm pump and treat (1994-2004)
  - Source treatment
  - MNA

- Regulatory requirements
  - Monitoring and continued characterization
  - Annual updates to flow and transport model
Tooele Groundwater Flow and Transport Model

• Unique Case:
  • Groundwater Model Updated Annually over 25 Year Period
  • Consistent Modeling Team for Entire Period

• Applications:
  • Definition of Sensitive Parameters/Data Gathering
  • Conceptual Model Development
  • Support for Shut-Down of Pump and Treat System
    - Implementation of Monitored Natural Attenuation
  • Supporting Evidence for Abiotic Degradation
  • Probabilistic Analysis of Plume Migration Reaching Action Boundaries
Most Significant Model Changes

- 1993 Completion of initial flow model by HEC
  - Evaluation of plume containment by Pump & Treat system
- 1997-2003 Annual Recalibrations
  - Model extent expanded to SW, NE; vertical resolution increased
- 2004 Flow and Transport Model
  - Model extent expanded NE,SE
  - Multiple calibration targets (heads, drawdown, plume migration, etc)
  - Steady state flow, transient transport
- 2007 Transient calibration of water levels from 1942 to present
- 2008 Analysis of uncertainty in model predictions
- 2010 Calibration using parameter estimation (PEST)
- 2016 Evaluation using Ensemble Kalman Filtering (EnKF)
- 2018 Initial implementation of abiotic degradation
Uses of Model

• Definition of Sensitive Parameters/Data Gathering
• **Conceptual Model Development**
• Support for Test Shut-Down (and Permanent Shutdown) of Pump and Treat System
• Implementation of Monitored Natural Attenuation
• **Supporting Evidence for Abiotic Degradation**
• **Planning Lead Time for Potential Remediation**
  • Probabilistic Analysis of Plume Migration Reaching Action Boundaries
• Conceptualization of Mountain Front Recharge
  • Based on large snowfall, snowmelt event that occurred between March 28 and April 6, 2016

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Mountain Front Recharge

Upgradient wells near mountain front

D well measurements 3/25/15 to 11/15/16
Downgradient wells further away from mountain front (downgradient of fault)
* Early April water levels “spike” (ft)
Mountain Front Recharge
The rate and timing of direct mountain front recharge in an arid environment, Silver Island Mountains, Utah

Gregory T. Carling
Brigham Young University - Provo

2007-12-03

Mountain Front Recharge

Note fast GW response to Spring rainfall event in alluvial catchments
Conclusion

• SE wells closer to mountain fronts had greatest early April response in water levels.

• Thus, snowmelt and subsequent increased GW recharge from canyons, streams has direct, larger, and faster than expected influence on water elevations than previously anticipated.

• This is contrary to the previous conceptualization that subsurface recharge to model domain from mountain fronts took months/years
Mountain Front Recharge

Integration on Conceptualization into Numerical Model

The MODFLOW CHD Package adjusted to interpolate greater GW inflows in SP6 – Fall/Winter 2016
Mountain Front Recharge

FY17 Transient Model Calibration – increasing subsurface inflow from canyons resulted in improved calibration
Confining Bed Conceptualization

Based on water levels, response to agricultural pumping

Confining Bed – low K lacustrine deposits
Confining Bed Conceptualization

Burk, et al. (2005) of the Utah Geologic Survey performed a study to delineate areas of recharge and discharge to springs and wetlands in the Tooele Valley.

The study also delineated location of a fine grained confining bed resulting from lake recession.
Confining Bed Conceptualization

A conclusion of their analysis was the existence of a sloping confining layer near the same location as in the Tooele groundwater flow model. Studies were completely independent of each other.
Confining Bed Conceptualization
Confining Bed Conceptualization

Figure 7. Wetland unit 14, which includes wet-meadow environment. The photo was taken in August after most of the pond had dried up.
Confining Bed Conceptualization
Supporting Evidence for Degradation

Modeled TCE Plume in 1986
Supporting Evidence for Degradation

Modeled TCE Plume in 1997
Supporting Evidence for Degradation

Modeled TCE Plume in 2009
Supporting Evidence for Degradation

Kriged Measured Plume (late 2017)

Modeled Plume (late 2017)
note: accurate match with flow gradient resulted in over simulation of transport
Supporting Evidence for Degradation

- Over-simulation of historical and future plume movement at the plume edge suggests that the model is not accounting for physical and/or chemical processes
- Separate sensitivity analysis indicated that simulated TCE degradation could improve the model match to observed plume migration
- These results support the presence of degradation in some areas of the aquifer
- Simulation of this process has potential to improve the calibration of the model and provide grounded predictions more consistent with recently observed trends in concentration
Supporting Physical Evidence for Degradation

• Magnetic susceptibility in core samples at TEAD-N suggest abiotic degradation of TCE
• First line of evidence for TCE degradation
• Measurements of magnetic susceptibility provide broad ranges of degradation
  • Zero degradation to 1.2 yr\(^{-1}\)
  • Infinite to 7 month half lives
• Defined to be spatially variable via hydrogeologic zonation
Supporting Evidence for Degradation

- Pilot test results
- 289 year to 204,000 year half-lives
- Consider lower half-lives next year
Planning Lead Time for Potential Remediation

• How long are TCE concentrations likely to remain below 5 µg/L along the GWMA or 1-mile buffer boundary?

• Initialize predictive plume to reflect both modeled and observed TCE concentrations
  • Minimize uncertainty related to initial conditions

• Employ Monte Carlo analysis
  • Inject stochasticity into calibrated model parameters
  • Mean: Calibrated value
  • 95% confidence interval: ± 20% of mean
  • Randomly sample values from stochastic model parameters (frequency based on probability)
  • Models created by parameter sampling should all represent plausible versions of reality
  • Results should still reflect intended uncertainty while still maintaining relatively high calibration quality
Planning Lead Time for Potential Remediation

5-Year Prediction

Approx. 1600 ft

Approx. 1900 ft
Planning Lead Time for Potential Remediation

1-Mile Buffer Boundary

[Graph showing cumulative likelihood of maximum boundary concentration over time]
Planning Lead Time for Potential Remediation

GWMA Boundary

Main Plume

NEB Plume
High likelihood of TCE concentrations remaining below MCL along
- 1-mile boundary within 10 years (70% likelihood)
- Main Plume GWMA boundary within 6 years (62%)
- NEB Plume GWMA boundary within 12 years (73%)

Predictions deemed to be conservative
- Simulated conditions produce over-simulation of plume extent (e.g., wells B-42, C-04, D-09, D-11, D-22)
- Rate of concentration increase also over-simulated at many of these wells
- 5-year predictions show faster plume movement in some areas than observed over last 5 years
FY18 Modeling Conclusions

• The calibrated model matches water levels and water level differences well throughout the model domain

• Improved the match to interior and boundary plume concentrations
  • Likely due to simulated degradation

• However, magnitude of simulated degradation can/should be increased in certain areas of the aquifer

• Like the 2017 model, calibrated 2018 model generally:
  • Under-estimates interior plume concentrations
  • Over-estimates concentrations along leading edge

• This over-simulation extends to the predictive model, whose results should be viewed as conservative

• Conceptual Model is critical
Questions/Comments?