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

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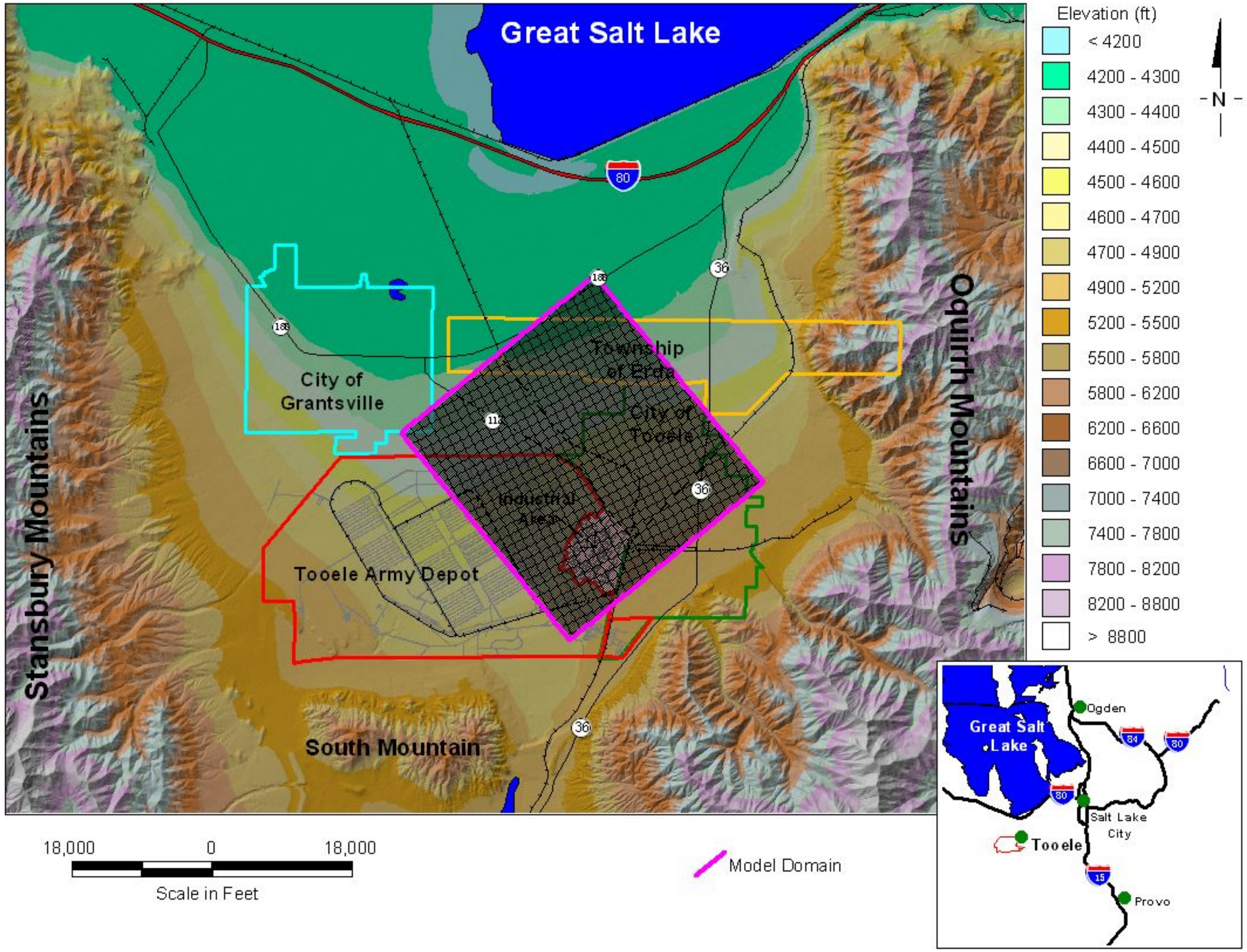
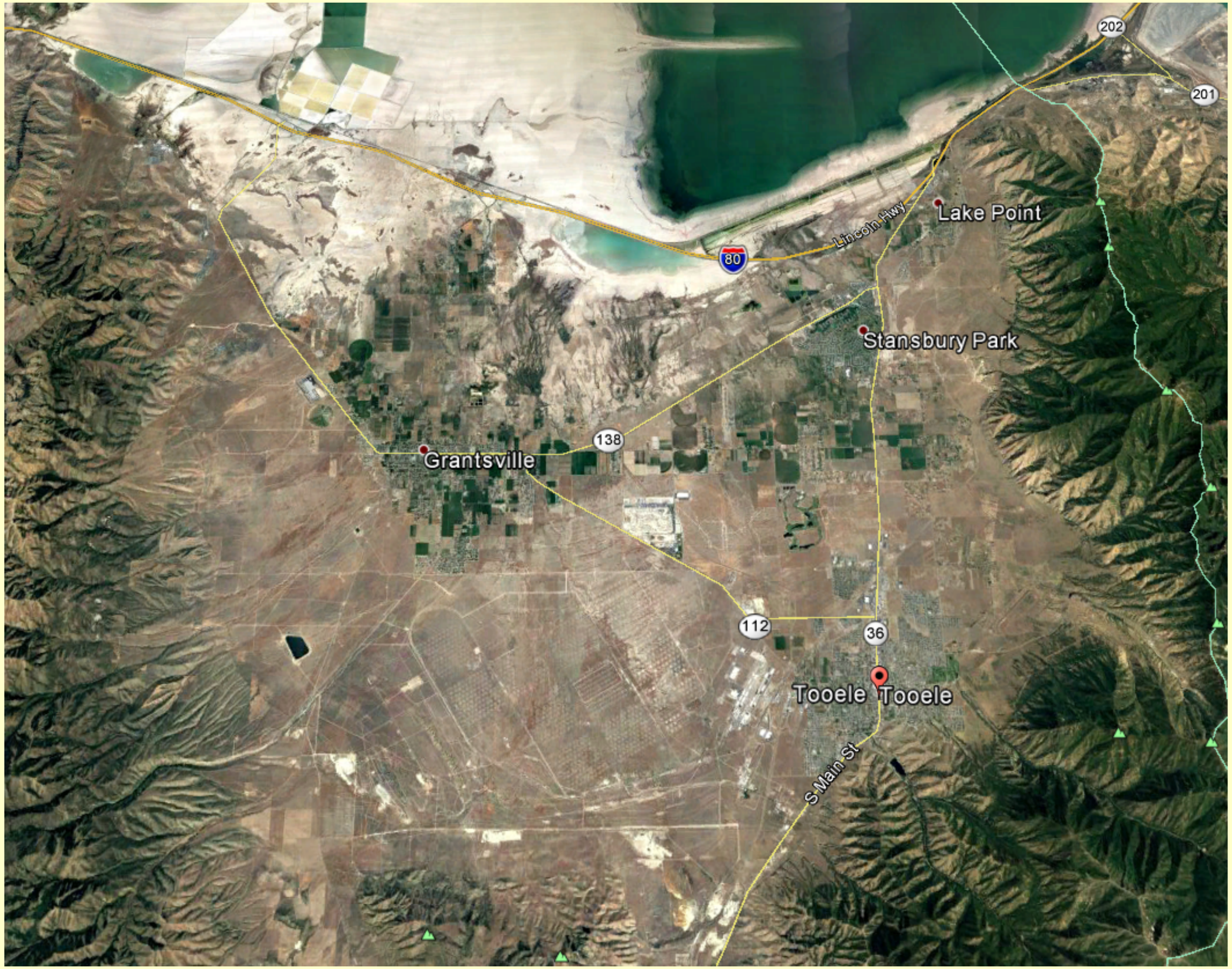
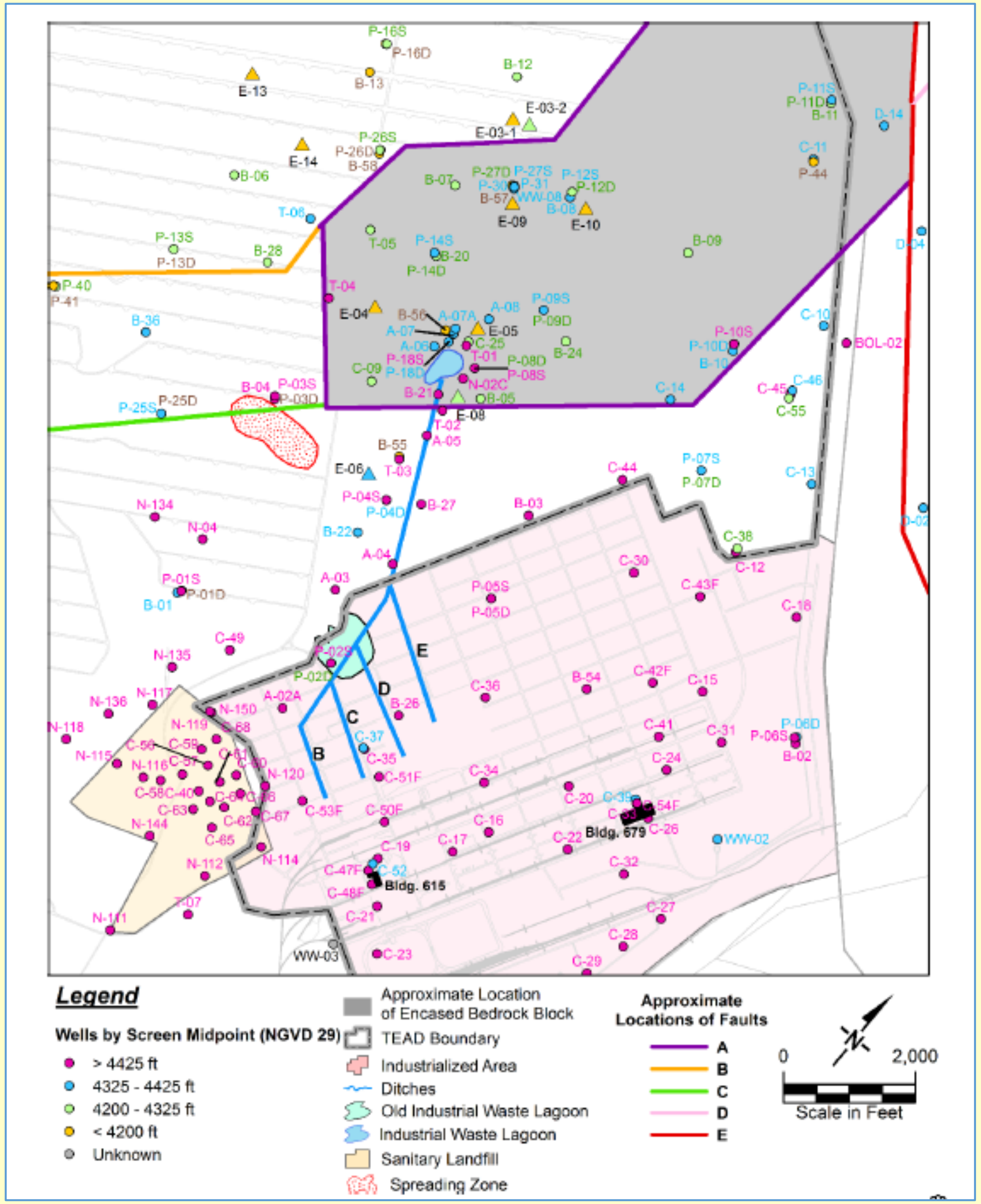


Great Salt Lake
Stansbury Mountains
Oquirrh Mountains
City of Grantsville
Township of Erda
City of Tooele
Industrial Area
Tooele Army Depot
South Mountain
Elevation (ft)
< 4200
4200 - 4300
4300 - 4400
4400 - 4500
4500 - 4600
4600 - 4700
4700 - 4900
4900 - 5200
5200 - 5500
5500 - 5800
5800 - 6200
6200 - 6600
6600 - 7000
7000 - 7400
7400 - 7800
7800 - 8200
8200 - 8800
> 8800
N
18,000 0 18,000
Scale in Feet
Model Domain
Great Salt Lake
Ogden
Salt Lake City
Tooele
Provo

Tooele Valley, Utah





Map of Industrial Area and Source Locations

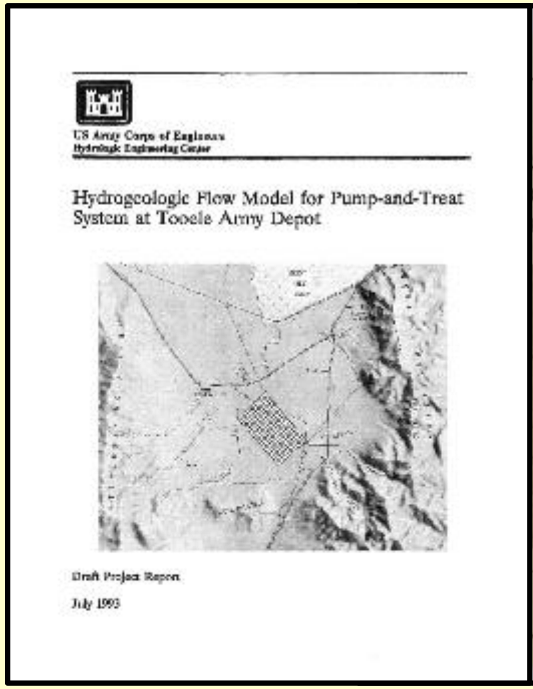
Tooele Army Depot

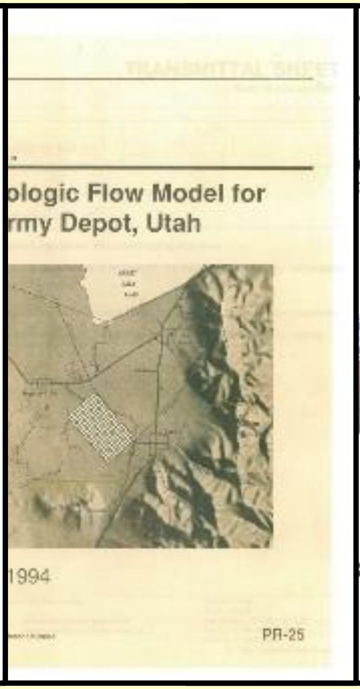
- Groundwater contamination since beginning of depot activities
  - 1942- WWII servicing of military vehicles
  - Primarily TCE
  - Multiple source areas (ditches, lagoons, sumps, landfill)
  - 4 mile long plume(s) extends offsite
- Remedial activities include:
  - Excavation and capping
  - 5400 gpm pump and treat (1994-2004)
    - *Largest in Department of Defense*
  - Air stripping
  - 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


US Army Corps of Engineers
Hydrologic Engineering Center
Hydrogeologic Flow Model for Pump-and-Treat System at Tooele Army Depot
Draft Project Report
July 1993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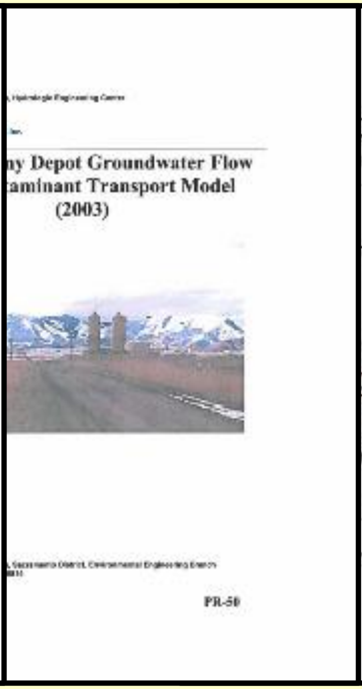
rmy Depot, Utah
1994
PR-25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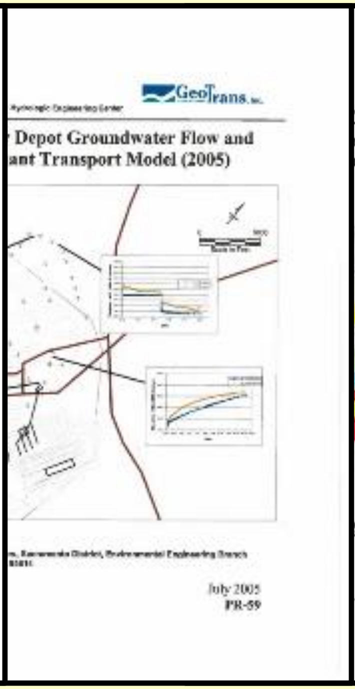
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Depot Groundwater Flow and
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July 2005
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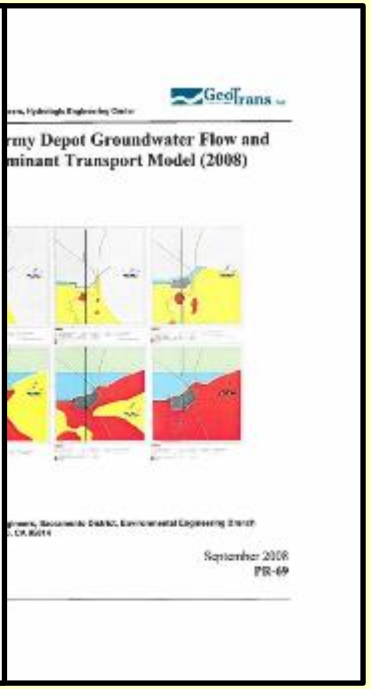
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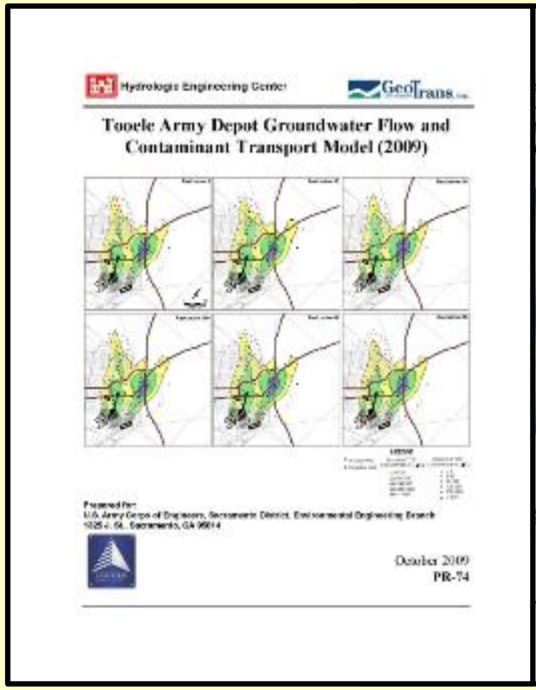
Hydrologic Engineering Center
GeoTrans
Tooele Army Depot Groundwater Flow and
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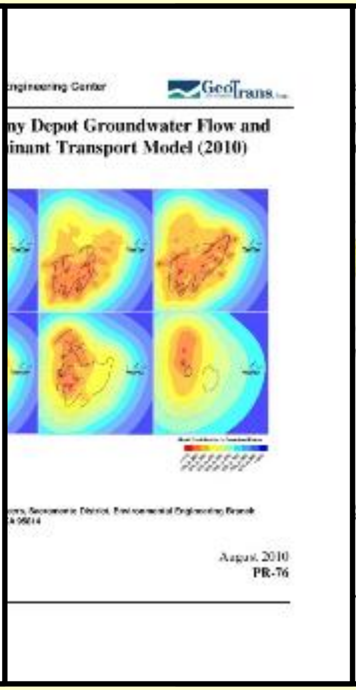
October 2009
PR-74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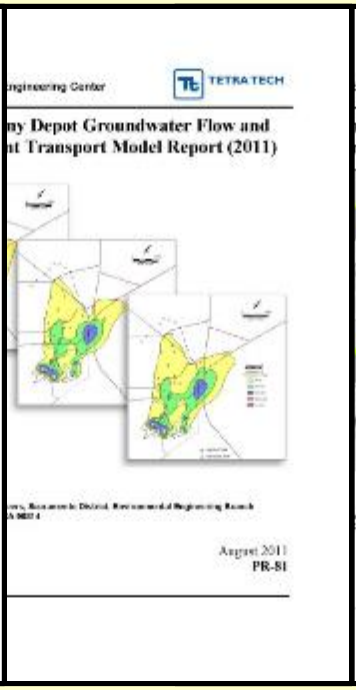
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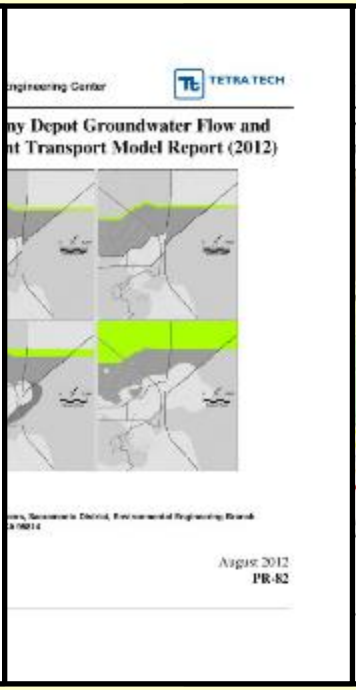
August 2011
PR-81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August 2012
PR-82


Engineering Center
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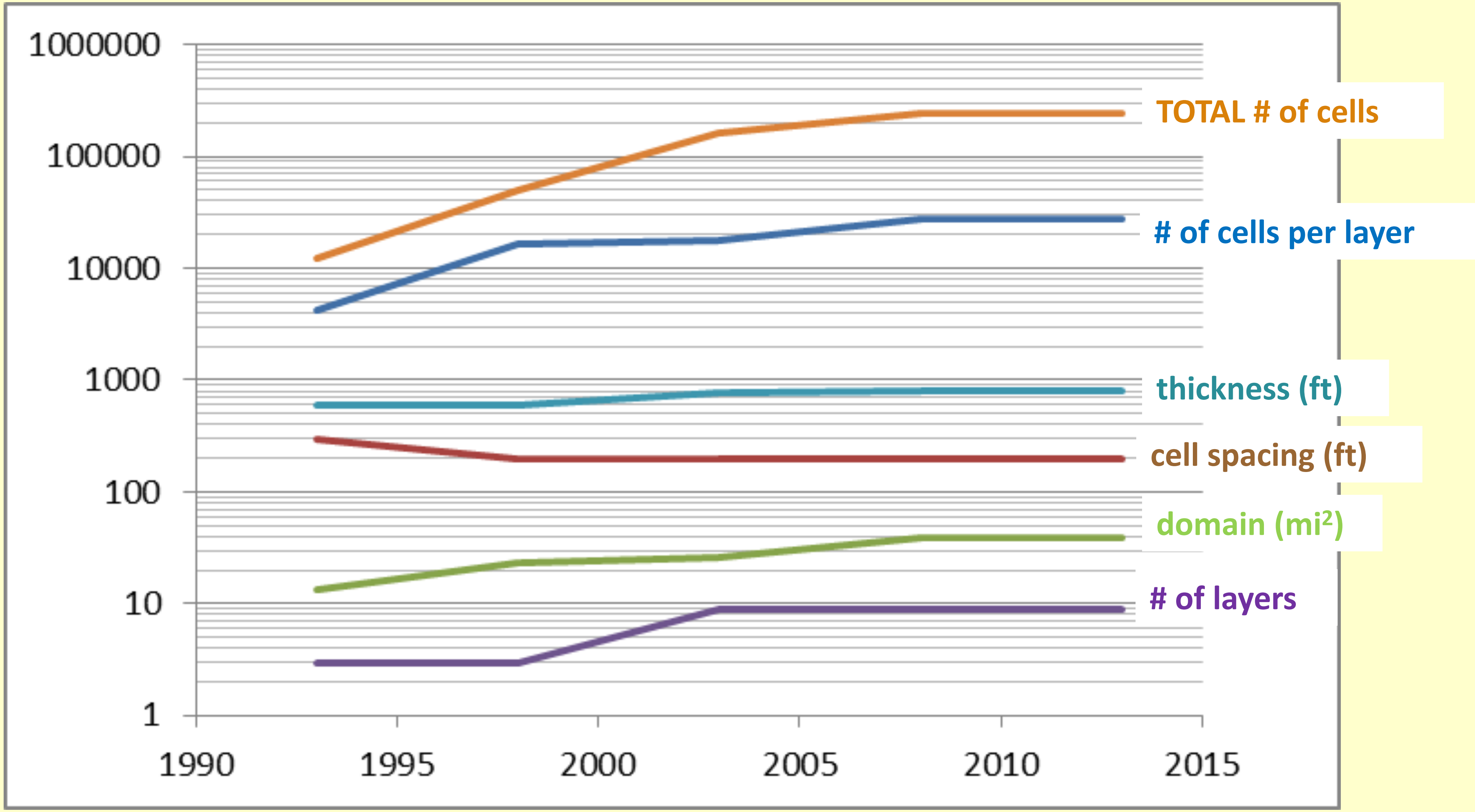
VALLEY
Tooele
August 2013
PR-89

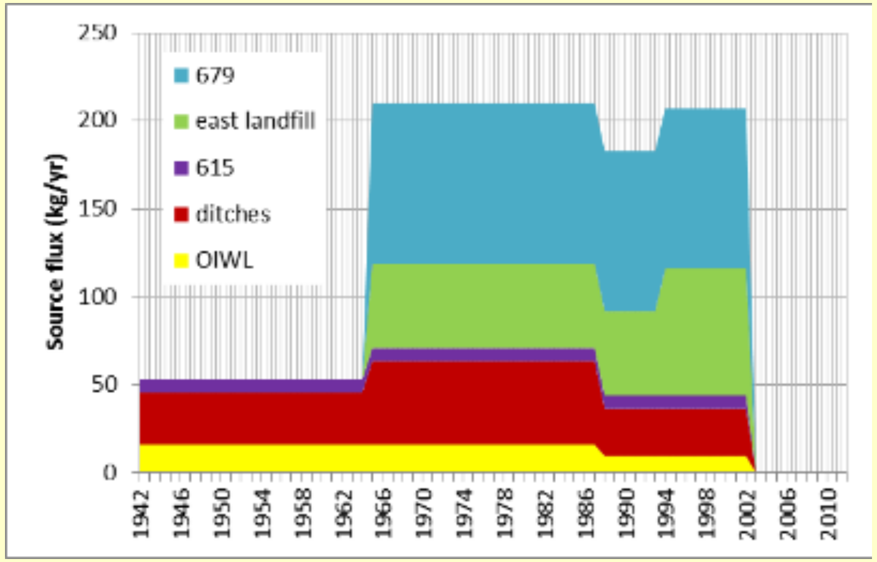
Most Significant Model Changes

- 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

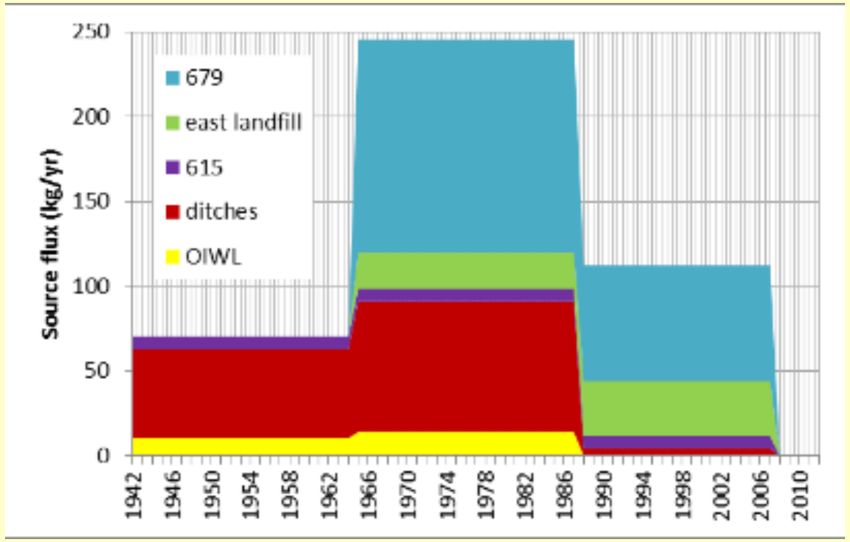
Dimensional Changes Versus Time
(log scale)



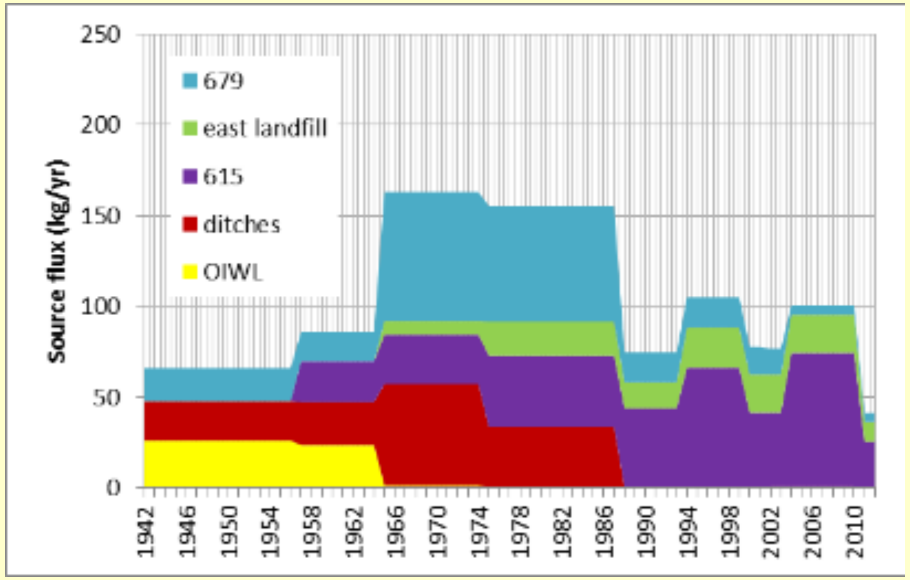
Source Flux By Area: 2003, 2008, 2013 Models



2003



2008



2013

- WWII to Vietnam
- Remediation 1988 – present
- Bldg 615 identified as bigger source in 2013 than previously thought

Uses of Model

- Definition of Sensitive Parameters/Data Gathering
- Conceptual Model Development
  - Mountain Front Recharge to GW
  - Location of low K Confining Bed
- 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

Conceptual Model Development - Mountain Front Recharge

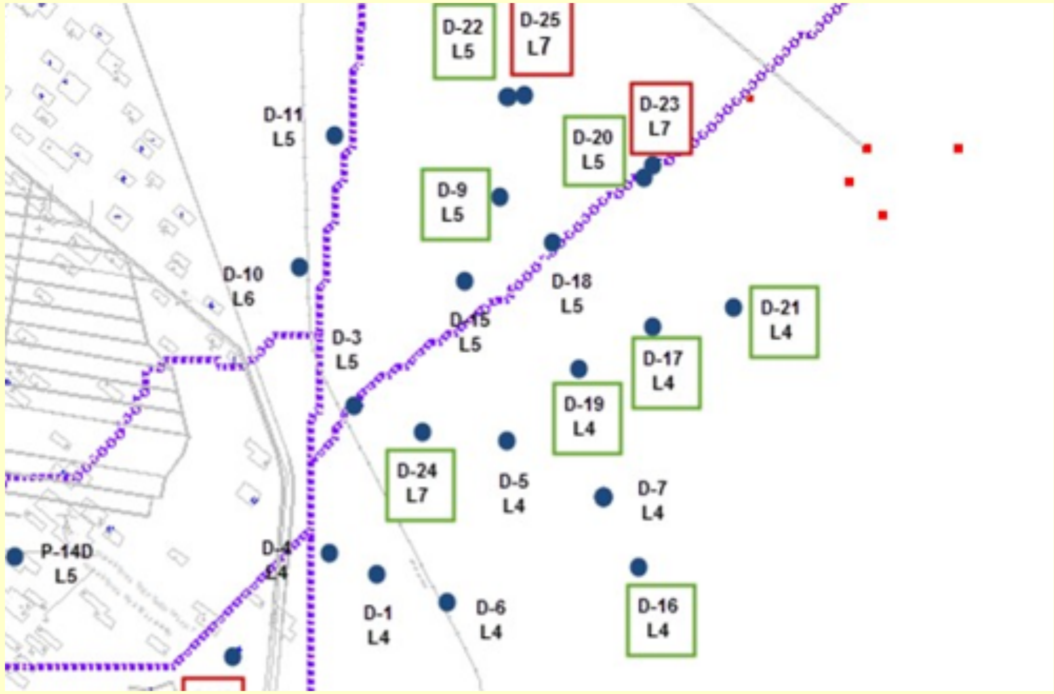
- Based on large snowfall, snowmelt event that occurred between March 26 and April 4, 2016

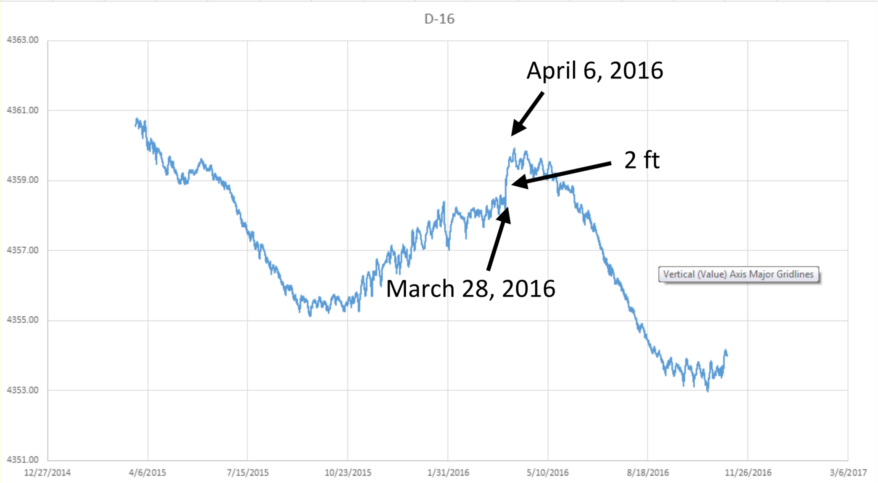
Weather history Tooele march 2016

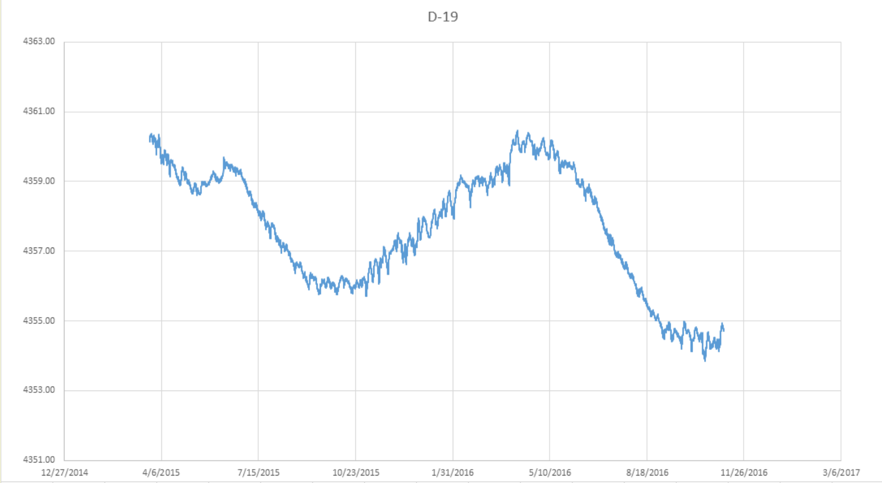
Day	High (°F)	Low (°F)	Precip. (inch)	Snow (inch)	Snow depth (inch)
25 mar 2016	55.0	35.1	0.00	0.00	0.00
26 mar 2016	51.1	28.0	0.46	2.99	0.00
27 mar 2016	57.9	33.1	0.00	0.00	0.00
28 mar 2016	57.9	30.0	0.49	2.99	0.98
29 mar 2016	48.0	30.0	0.30	0.98	0.00
30 mar 2016	45.0	30.0	0.00	0.00	0.00
31 mar 2016	50.0	34.0	T	0.00	0.00
1 apr 2016	52.0	33.1	0.00	0.00	0.00
2 apr 2016	60.1	34.0	0.00	0.00	0.00
3 apr 2016	68.0	42.1	0.00	0.00	0.00
4 apr 2016	71.1	43.0	T	0.00	0.00

Mountain Front Recharge

Upgradient wells near mountain front



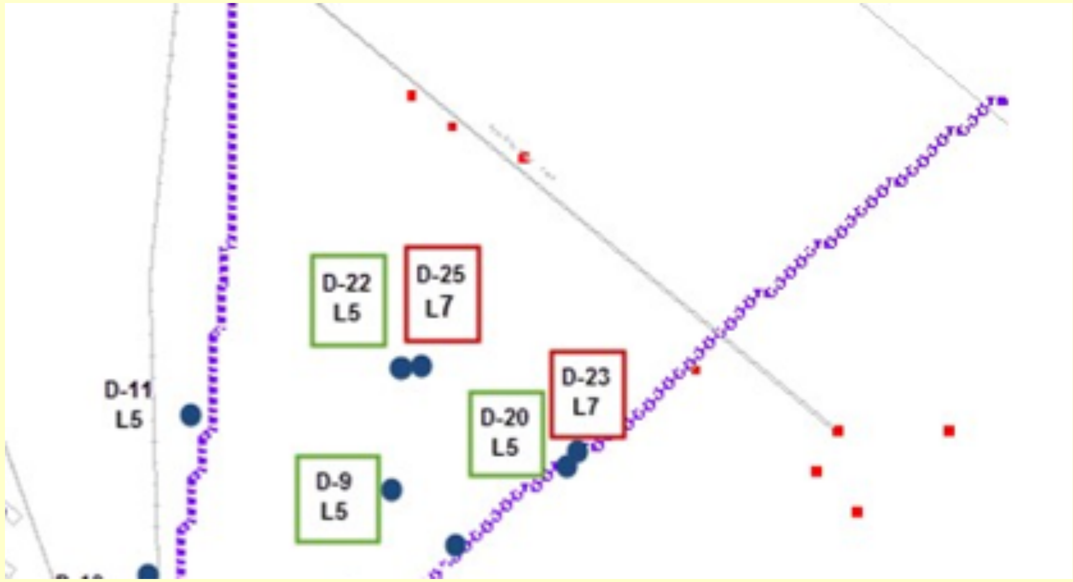


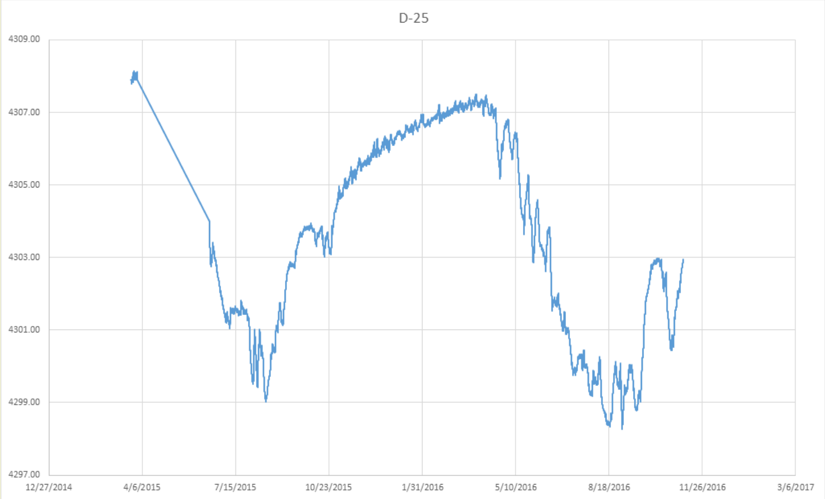


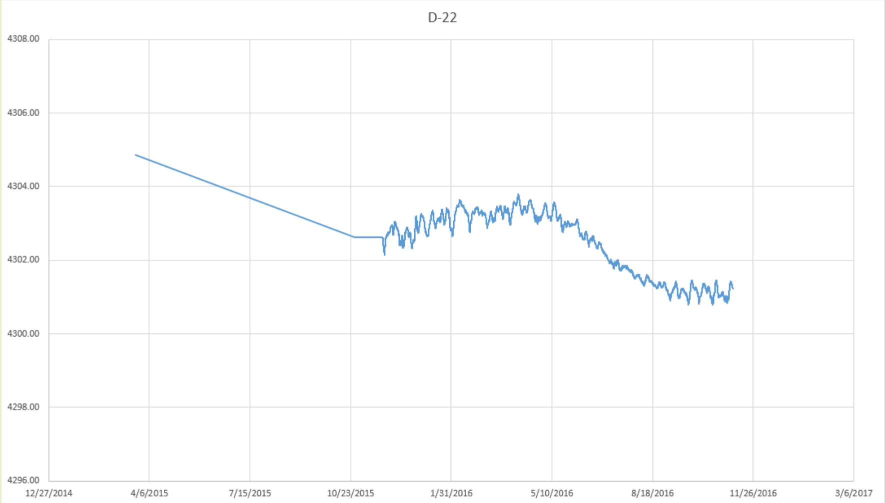
D well measurements 3/25/15 to 11/15/16

Mountain Front Recharge

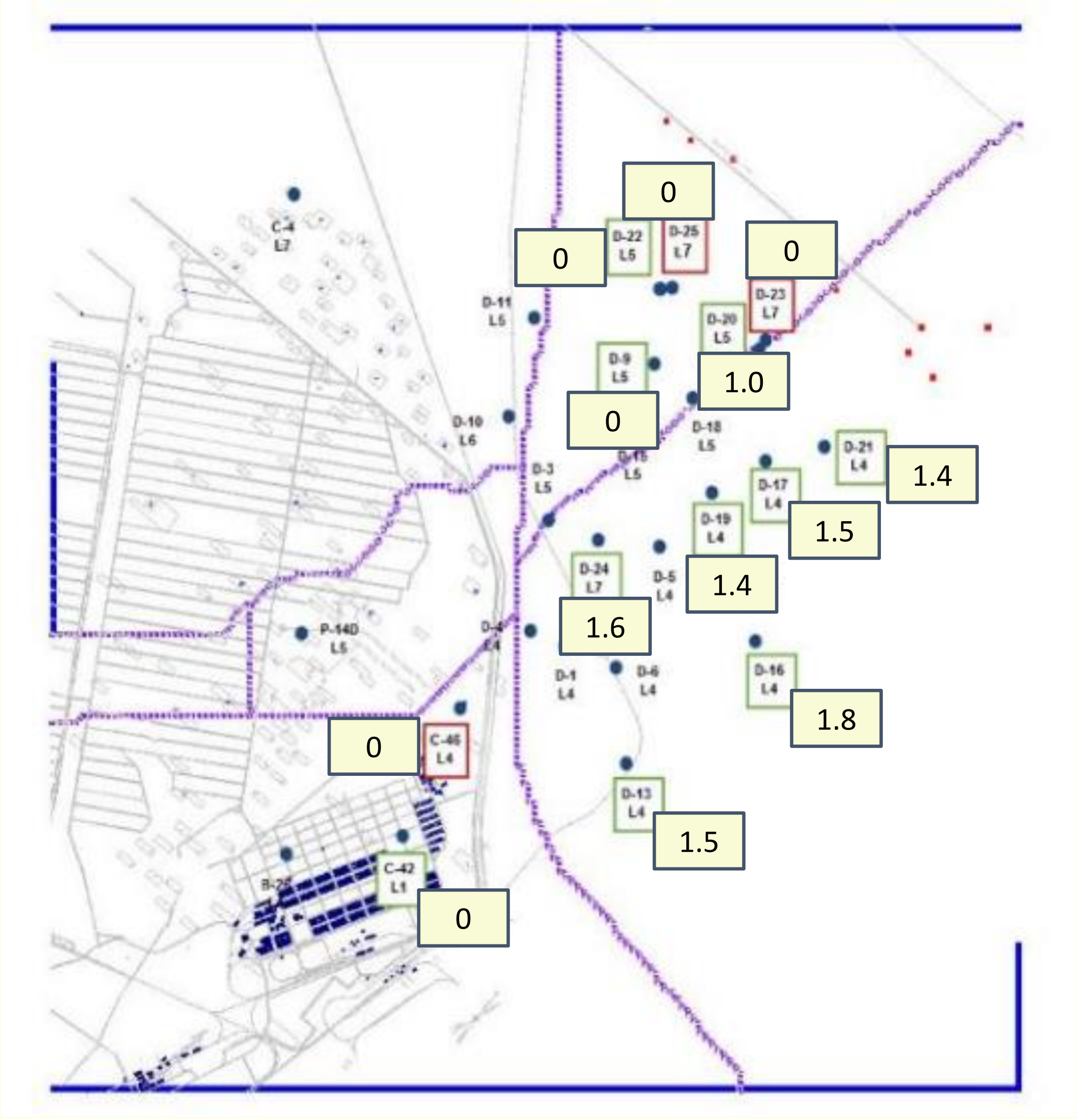
Downgradient wells further away from mountain front (downgradient of fault)





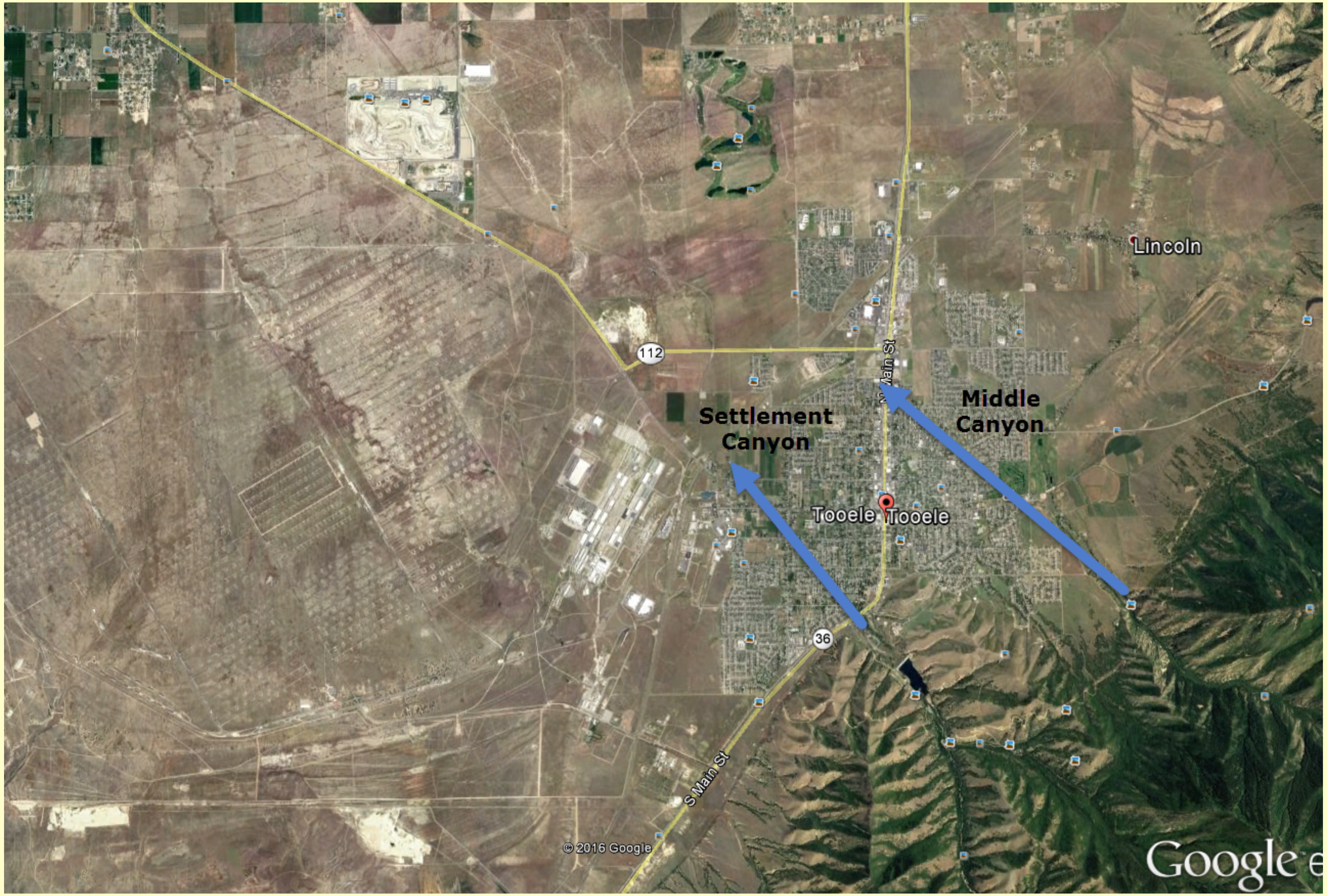


Mountain Front Recharge



* Early April water levels “spike” (ft)

Mountain Front Recharge

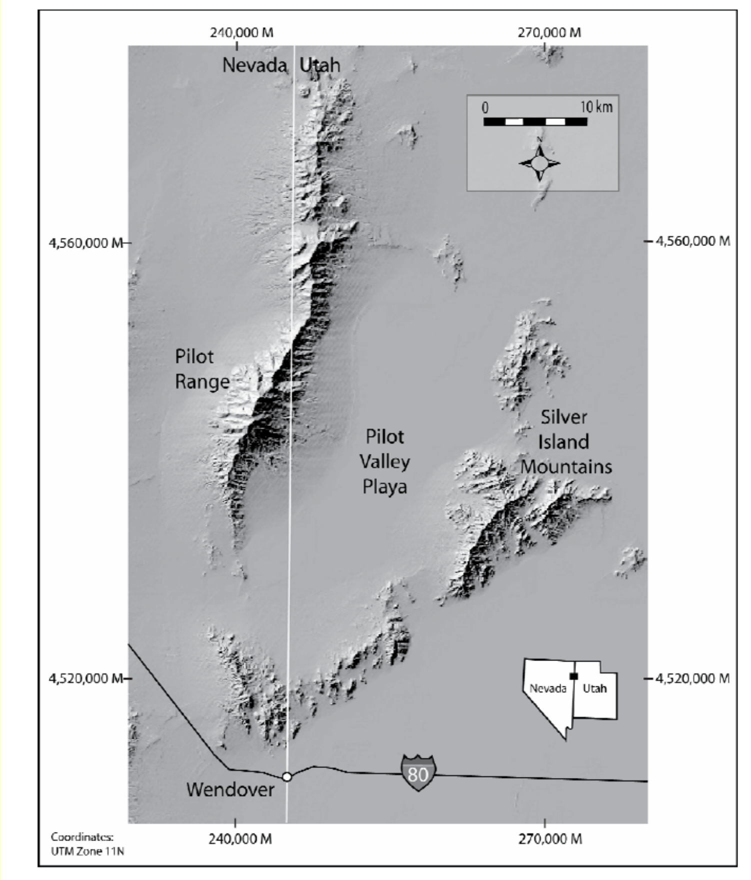


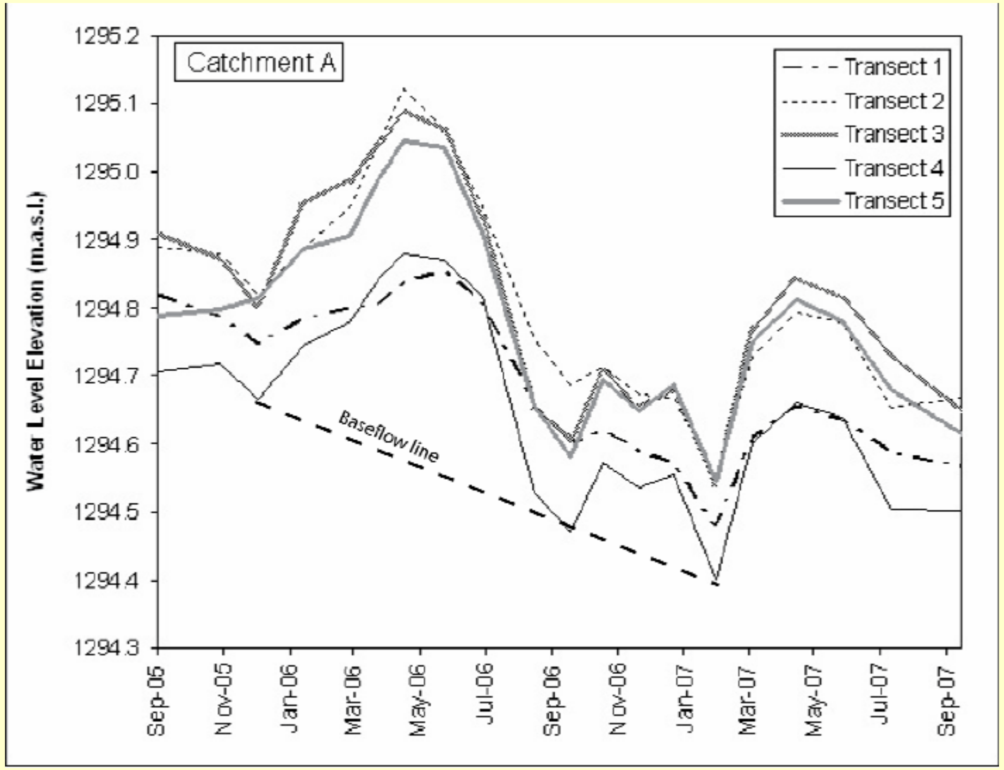
Mountain Front Recharge

2007-12-03

The rate and timing of direct mountain front recharge in an arid environment, Silver Island Mountains, Utah

Gregory T. Carling
Brigham Young University - Provo





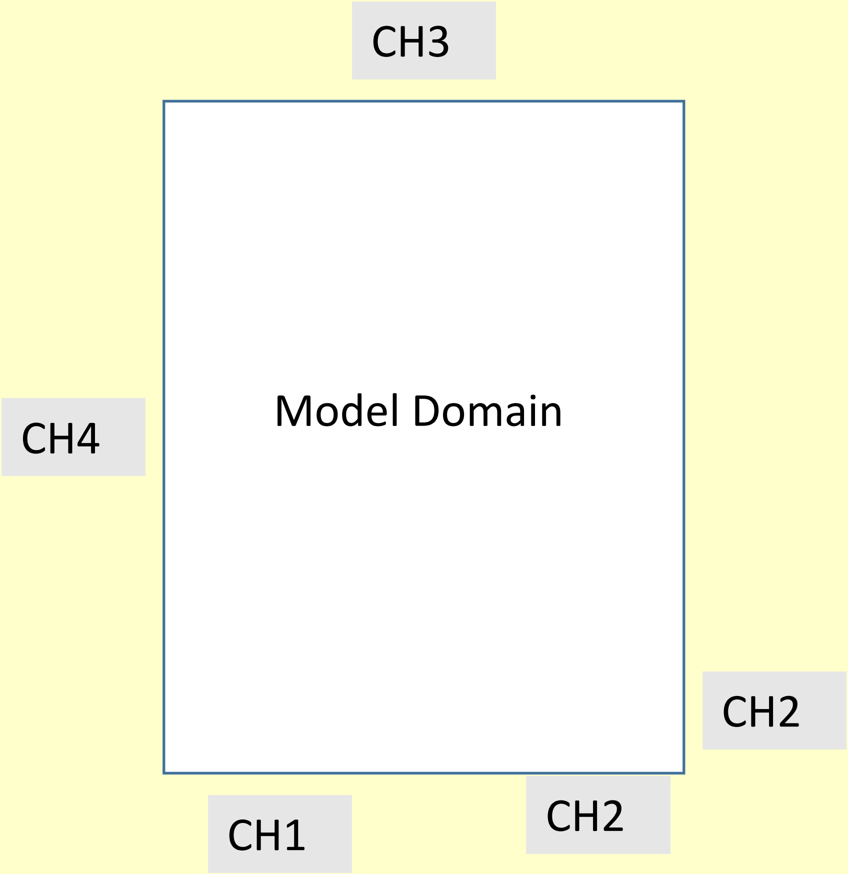
Note fast GW response to Spring rainfall event in alluvial catchments

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 of Conceptualization into Numerical Model



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

	CH1	CH2	CH3	CH4
SP1	477	364	277	305
SP2	476	363	276	304
SP3	475.5	362.5	275.5	303.5
SP4	474.5	361.5	275.5	302.5
SP5	473.5	360.5	275.5	301.5
SP6	476	363	276	304
SP7	474.5	361.5	275.5	302.5
SP8	472.5	359.5	274.5	300.5

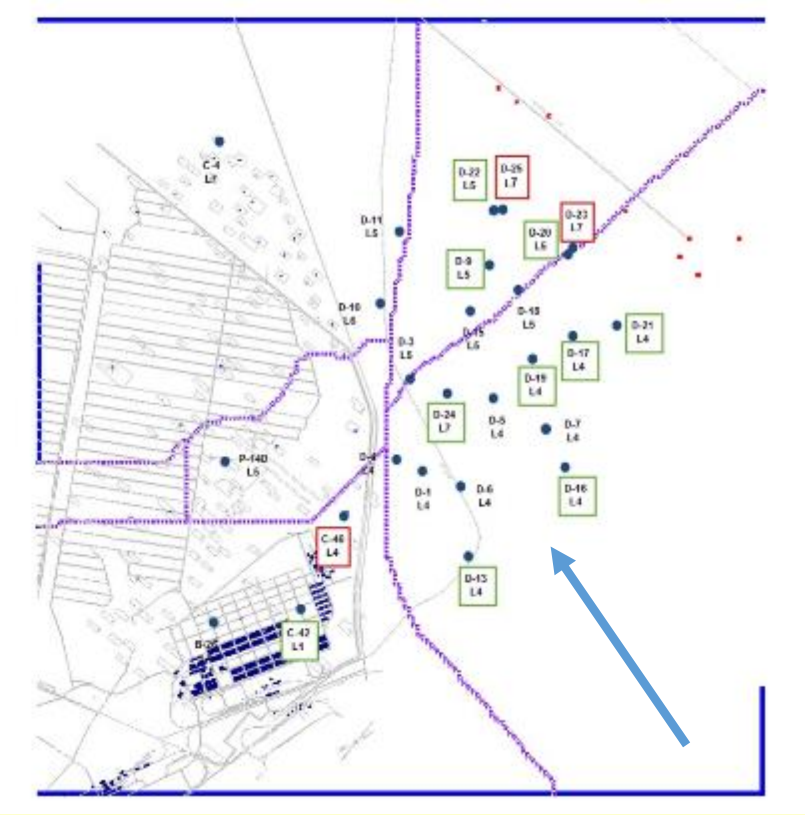
Initial

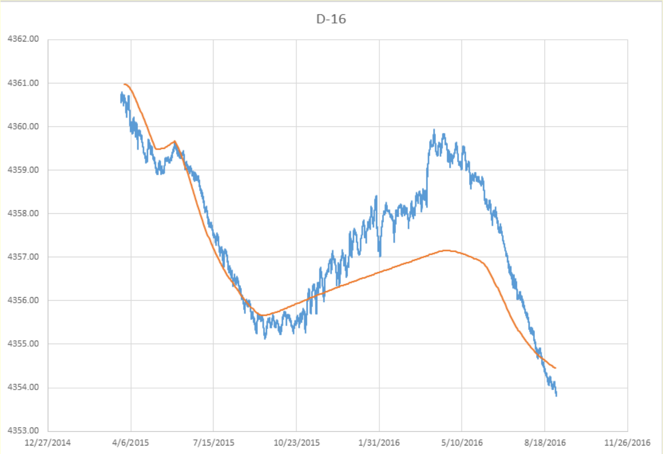
	CH1	CH2	CH3	CH4
SP1	477	364	277	305
SP2	476	363	276	304
SP3	475.5	362.5	275.5	303.5
SP4	474.5	361.5	275.5	302.5
SP5	473.5	360.5	275.5	301.5
SP6	476	**367**	276	304
SP7	474.5	361.5	275.5	302.5
SP8	472.5	359.5	274.5	300.5

Final

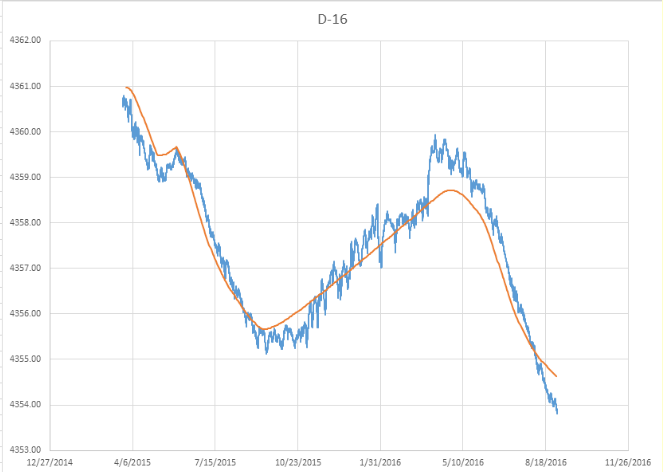
Mountain Front Recharge

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



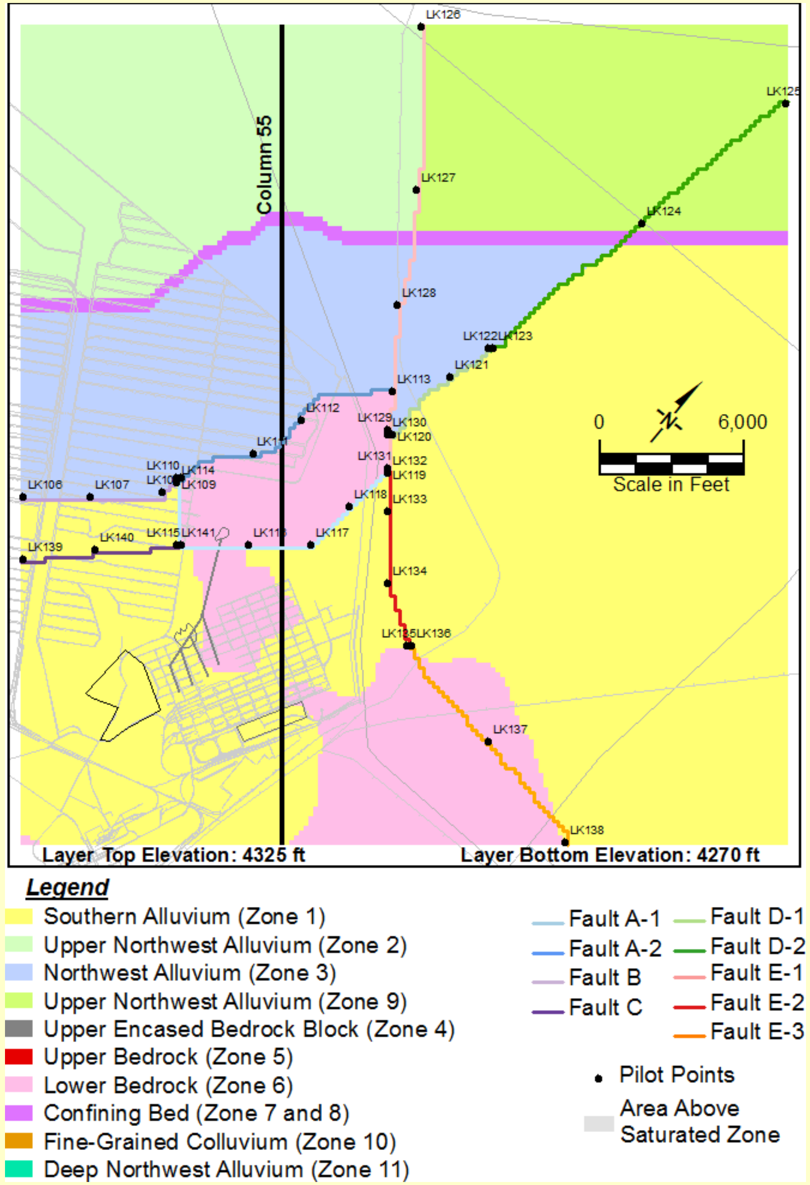


Initial



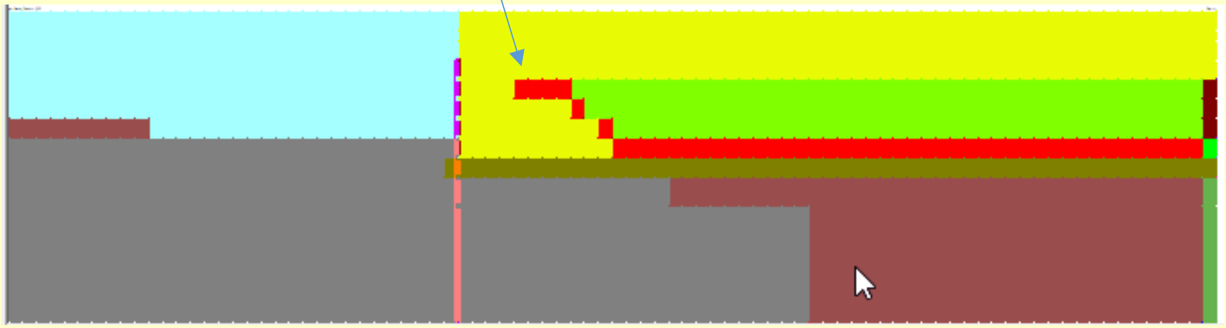
Increased CH2

Conceptual Model Development – Confining Bed



Hydrogeologic approach based on water levels, response to agricultural pumping

Confining Bed – low K lacustrine deposits

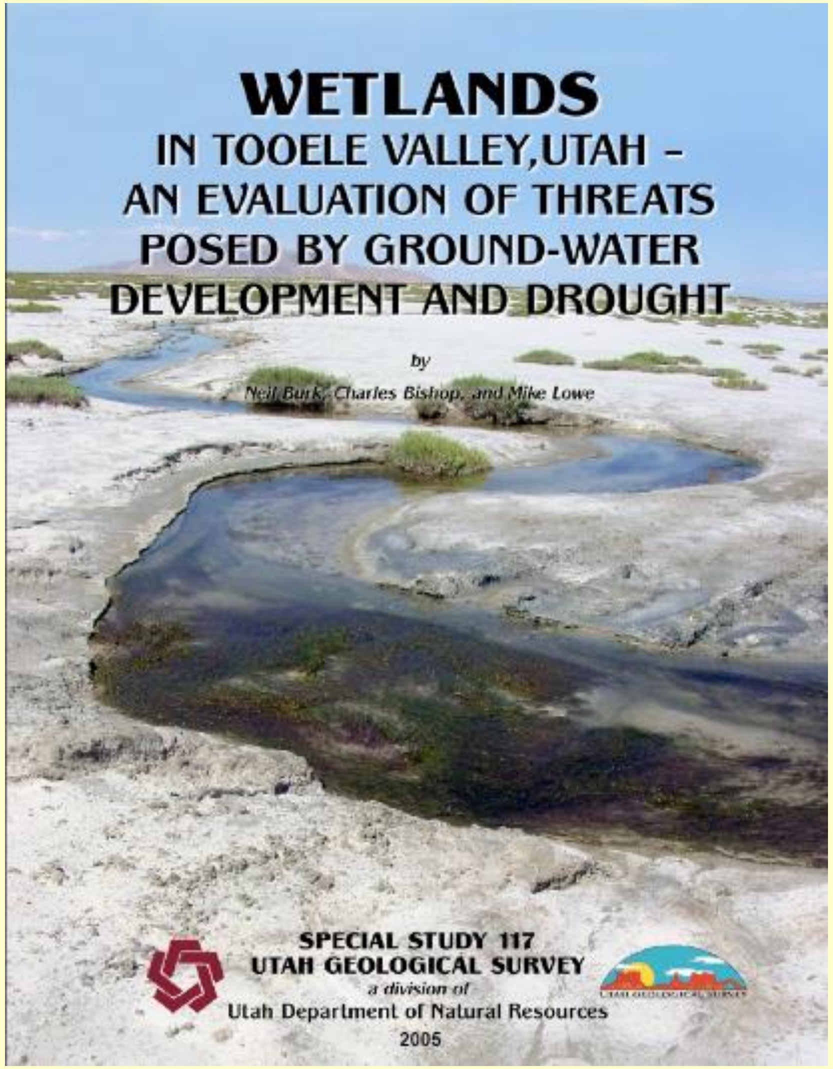


Confining Bed Conceptualization

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.

Water balance survey.

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 and based on different approaches/data.**

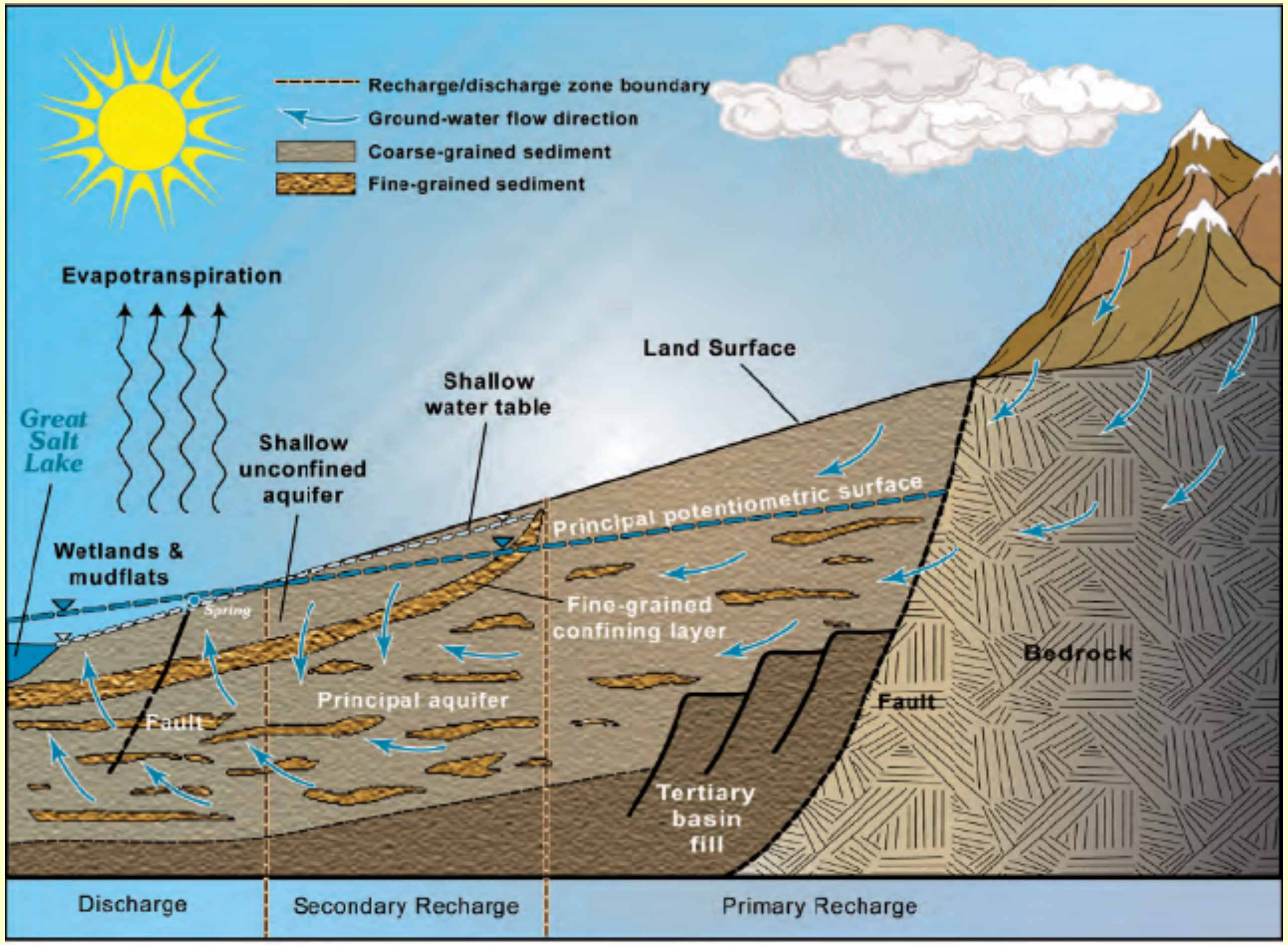
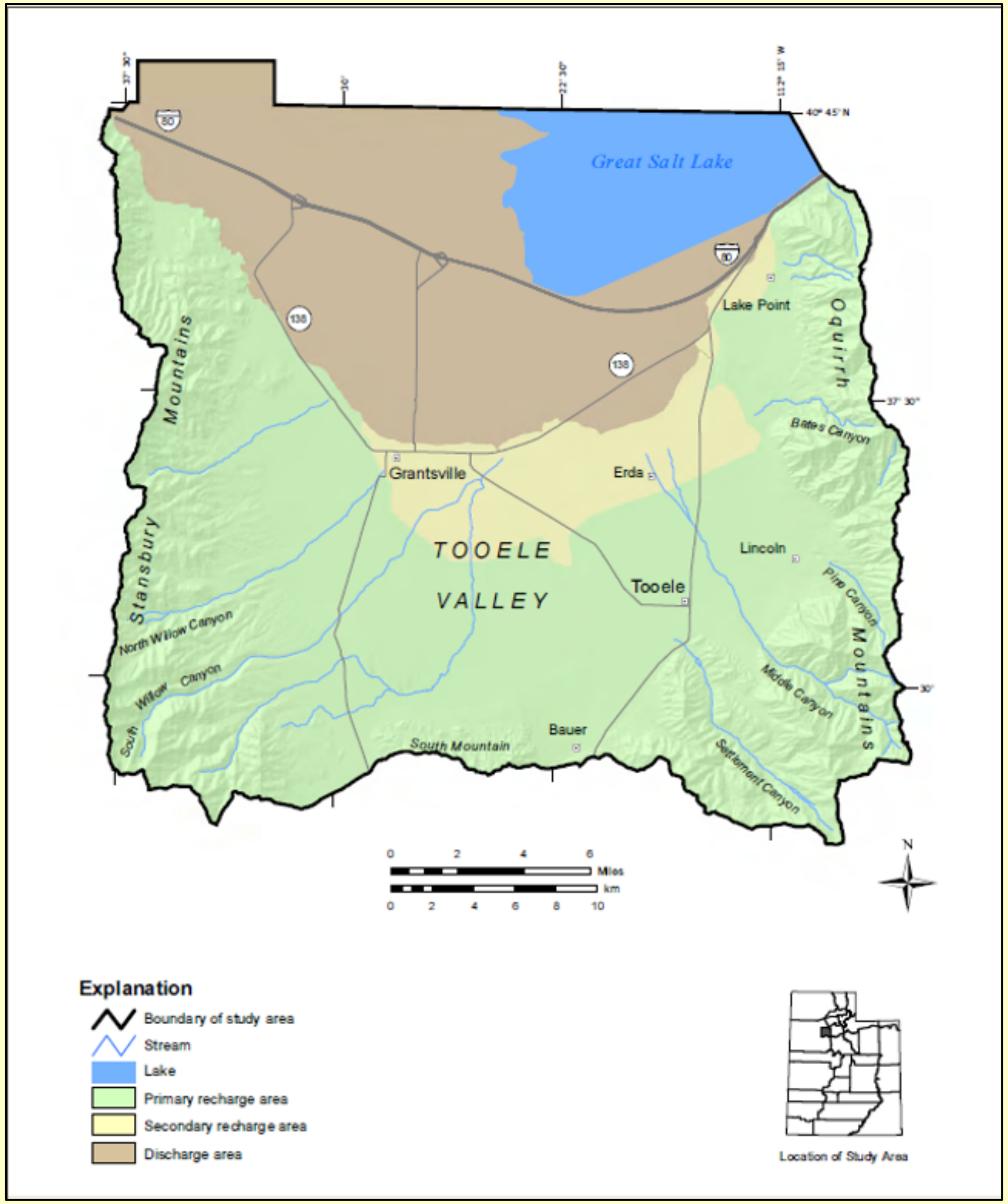


Figure 10. Schematic diagram of Tooele Valley ground-water flow system.

Confining Bed Conceptualization



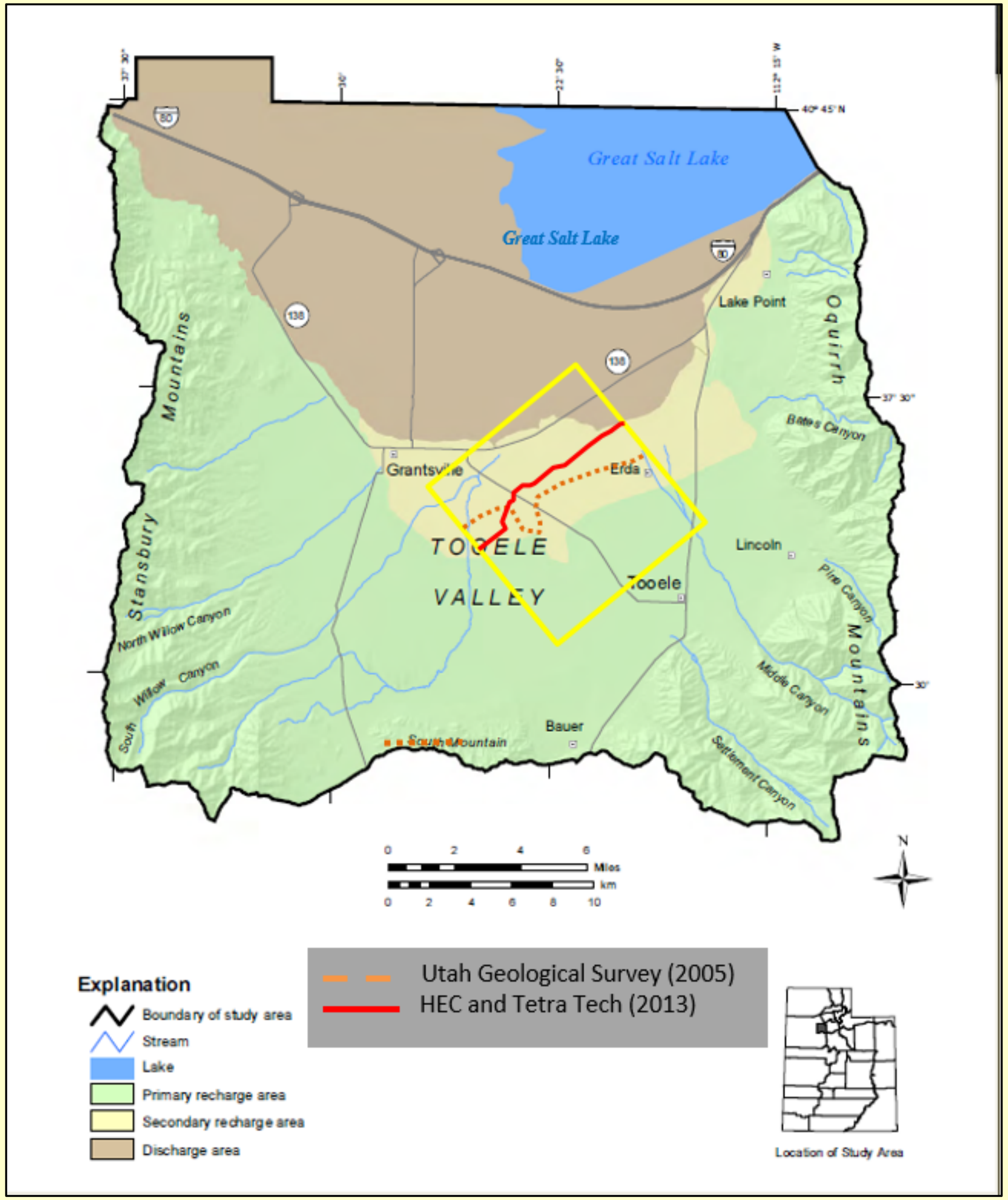
Burk et al., (2005)

Confining Bed Conceptualization

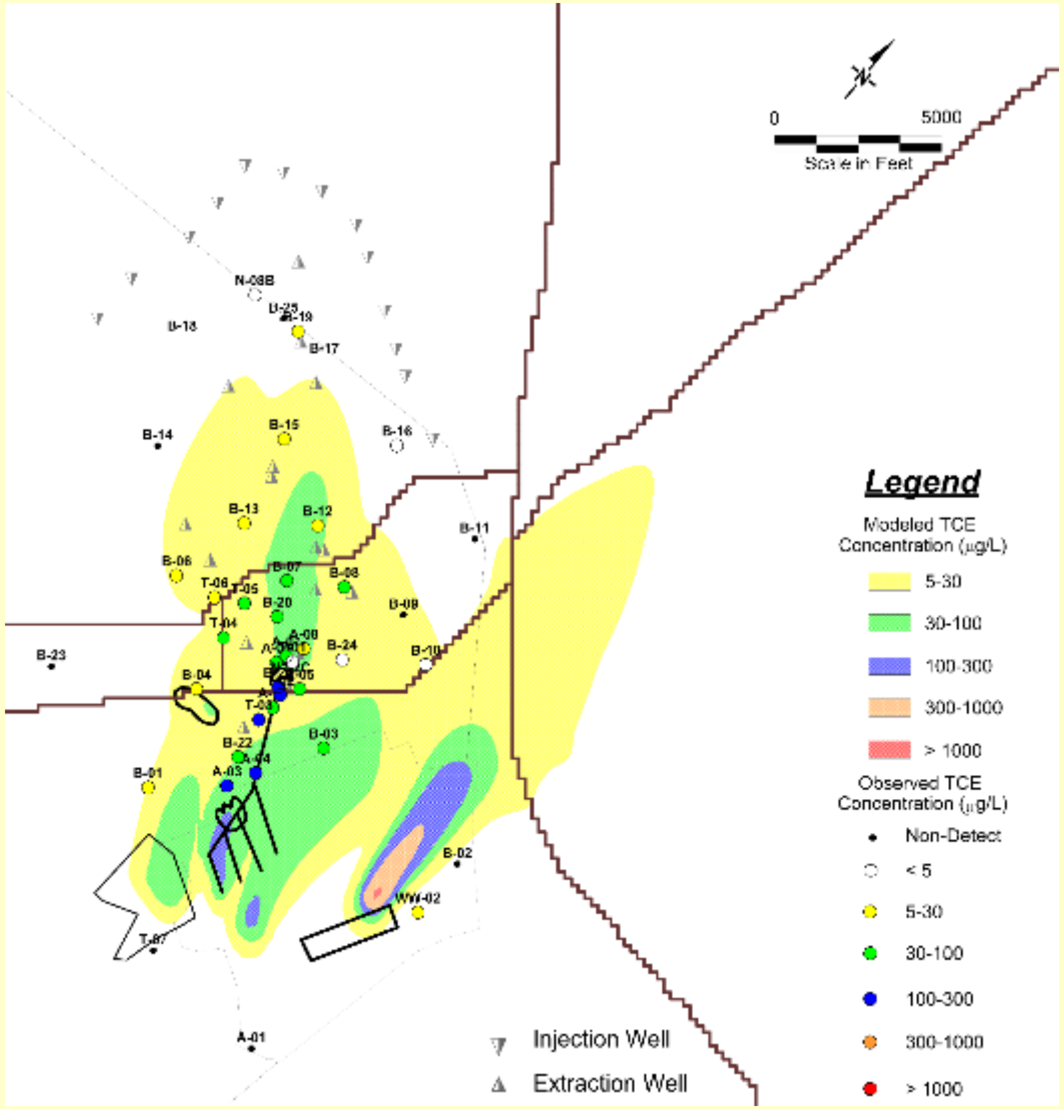
Figure 7. *Wetland unit 14, which includes wet-meadow environment. The photo was taken in August after most of the pond had dried up.*

Burk et al., (2005)

Confining Bed Conceptualization

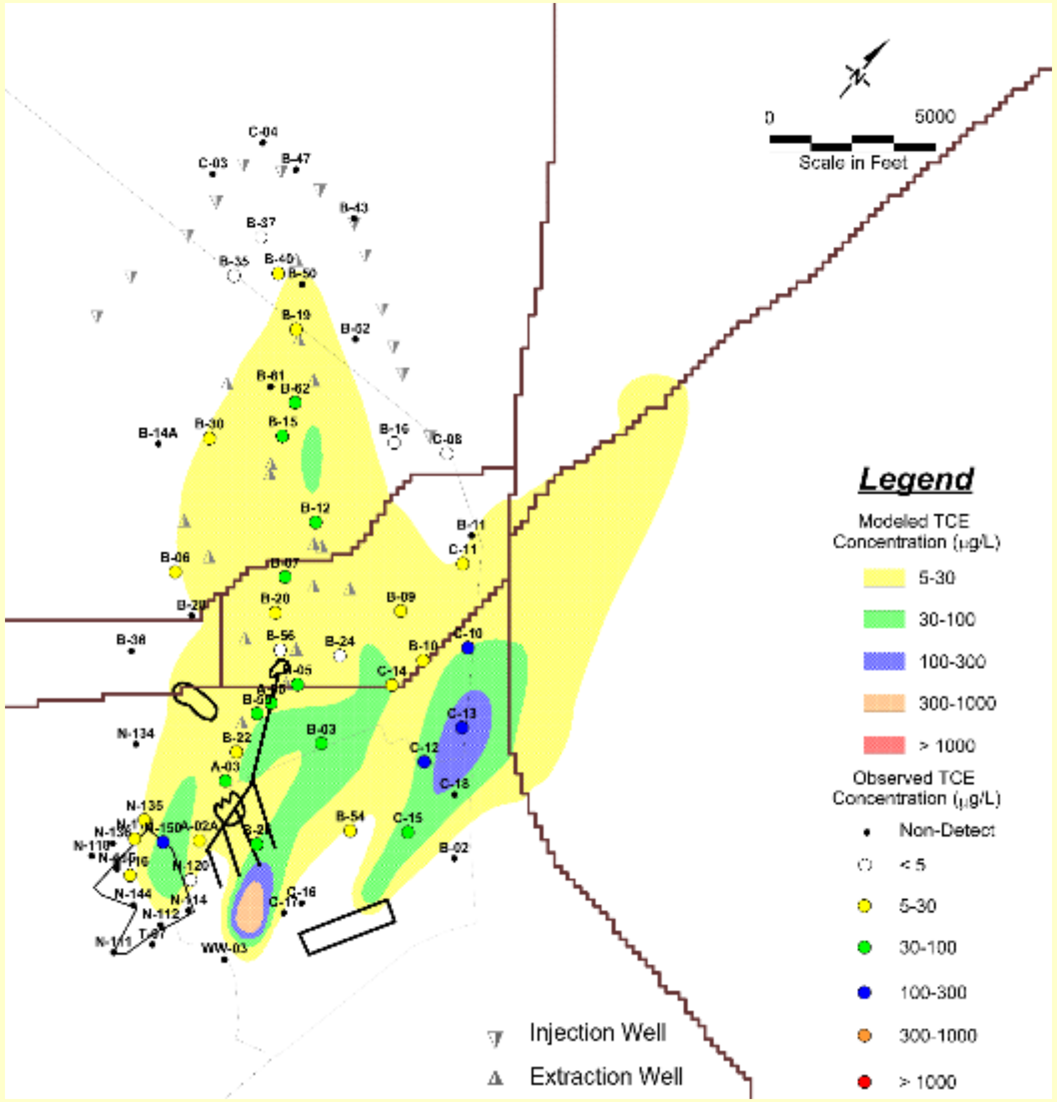


Supporting Evidence for Degradation



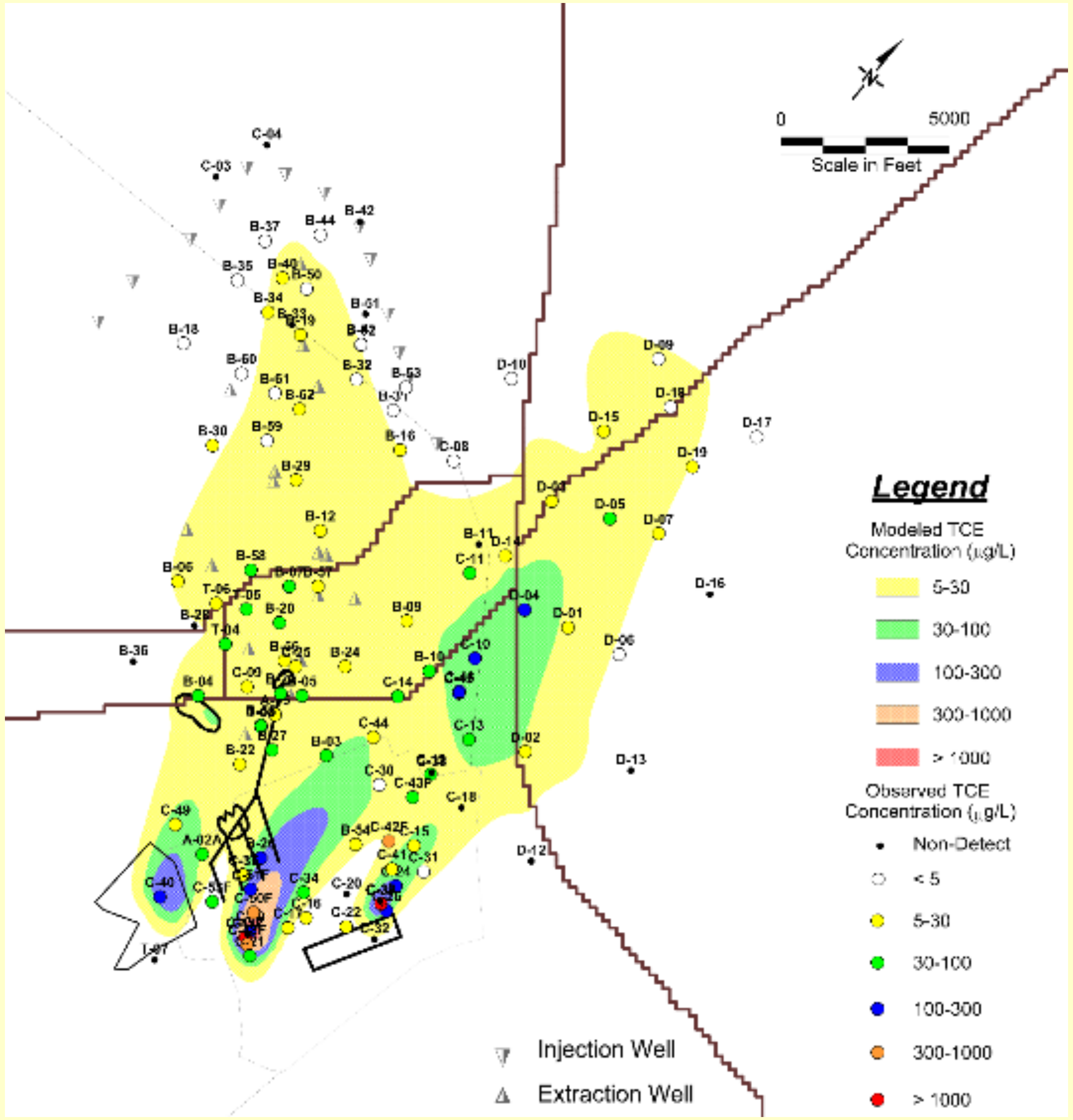
Modeled TCE Plume in 1986

Supporting Evidence for Degradation



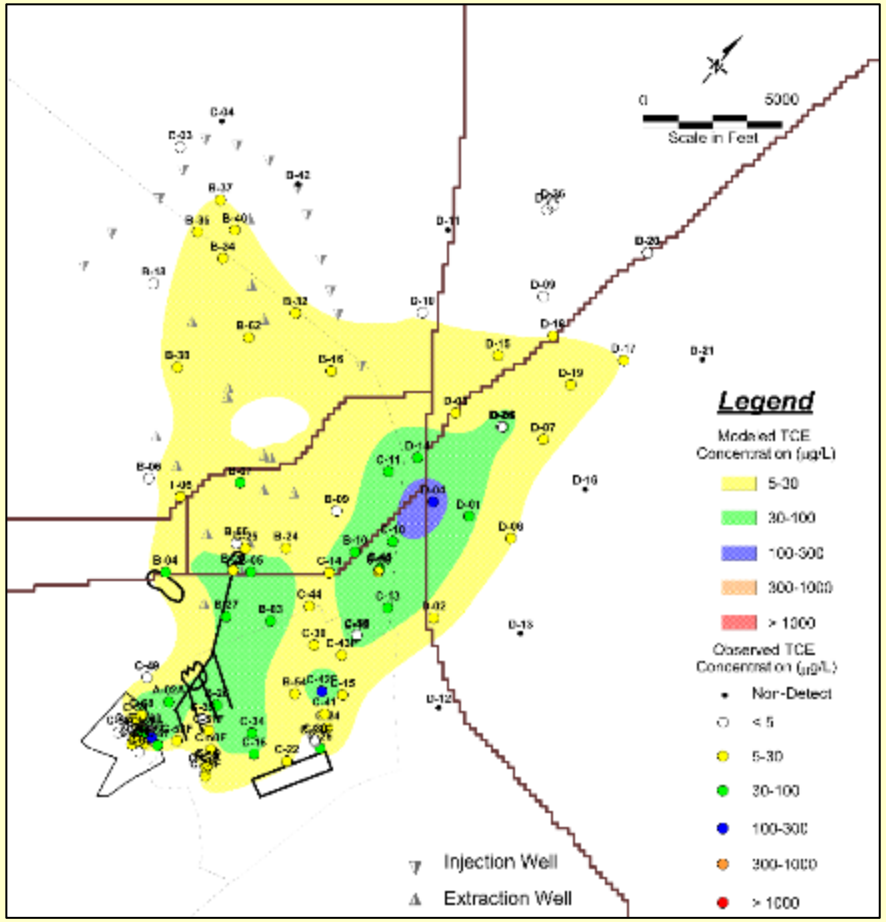
Modeled TCE Plume in 1997

Supporting Evidence for Degradation

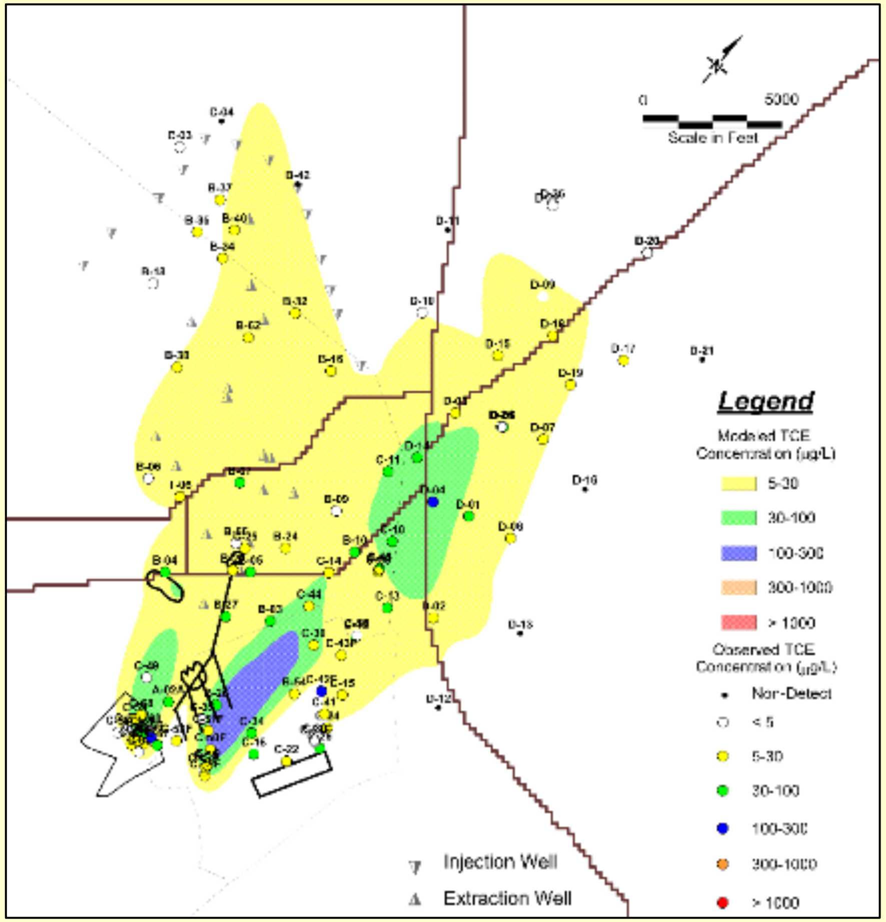


Modeled TCE Plume in 2009

Supporting Evidence for Degradation



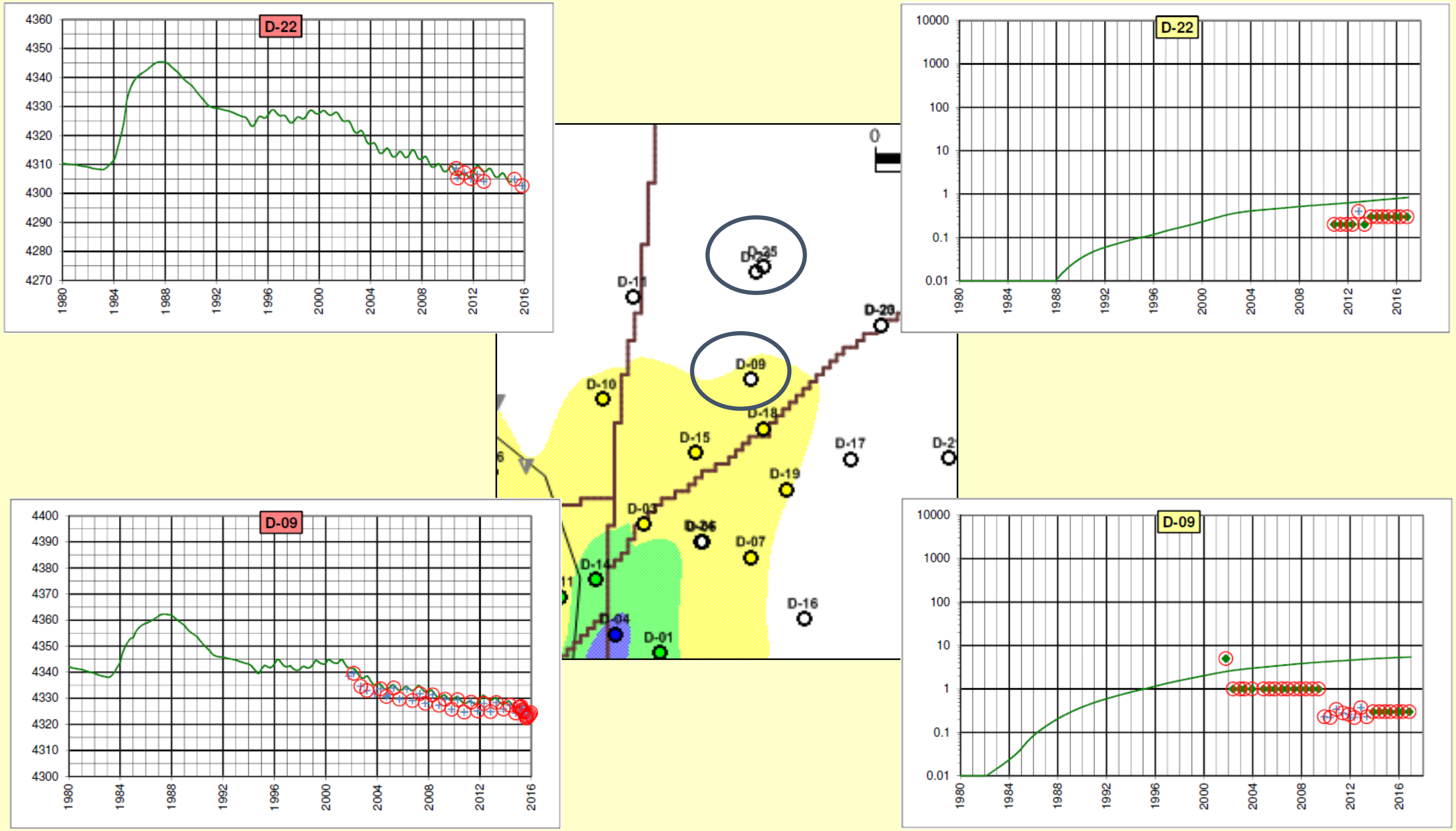
Kriged Measured Plume (late 2017)



Modeled Plume (late 2017)

Supporting Evidence for Degradation

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
- **Supports need for investigation of physical field evidence**

Supporting Physical Evidence for Degradation

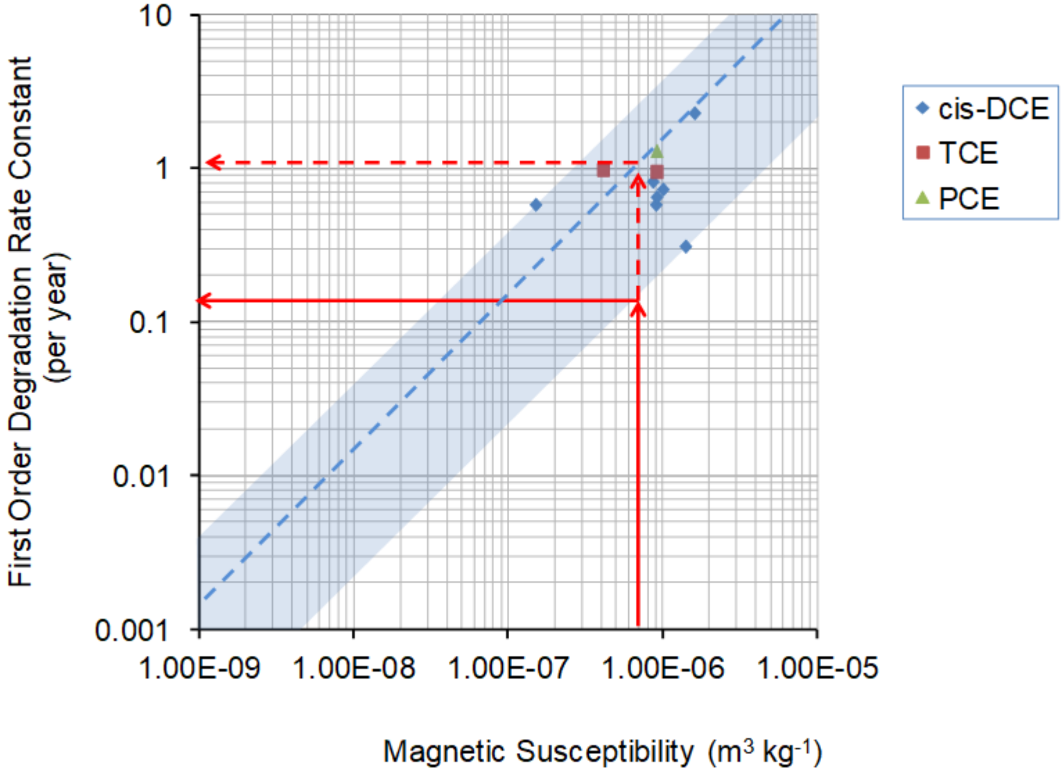


Figure 2. Rate constant for abiotic degradation of TCE on magnetite, as predicted from magnetic susceptibility.

EPA (2009)

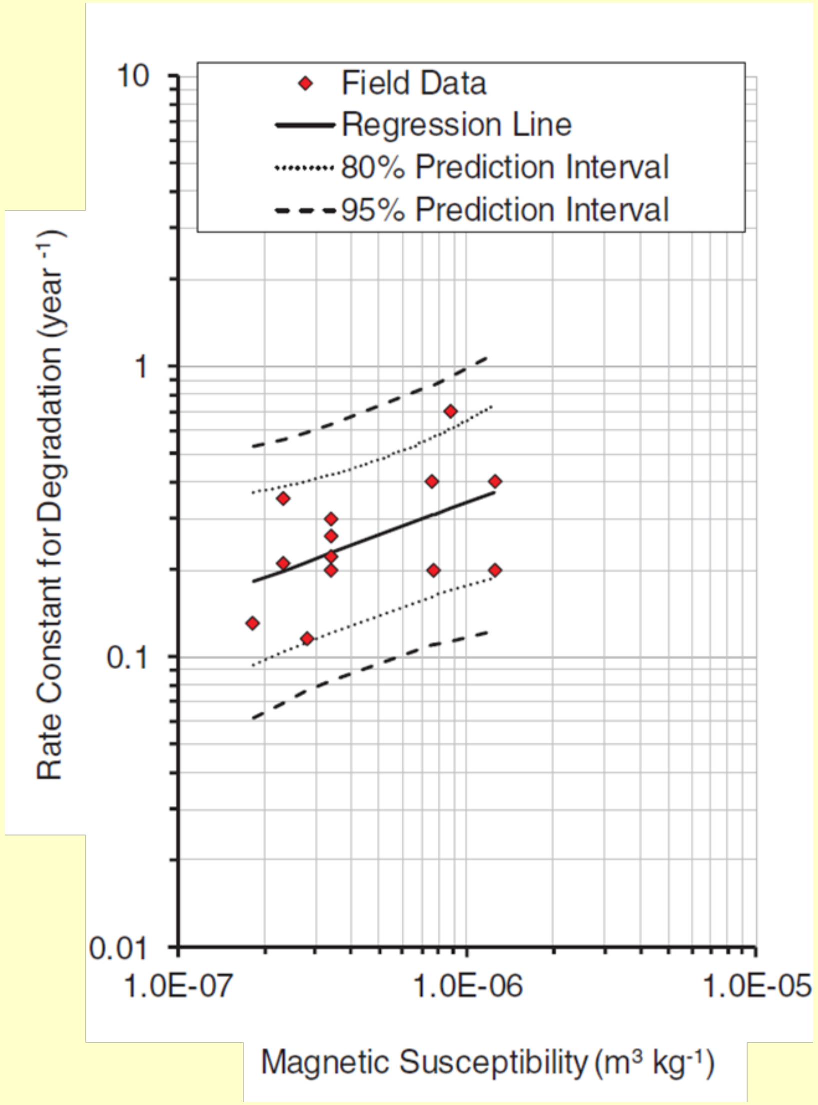
Sediment sample from Tooele Army Depot

Figure 3. Magnetite extracted from core sample AS-8 310-315 with a magnet.

Savannah River National Laboratory (2018)

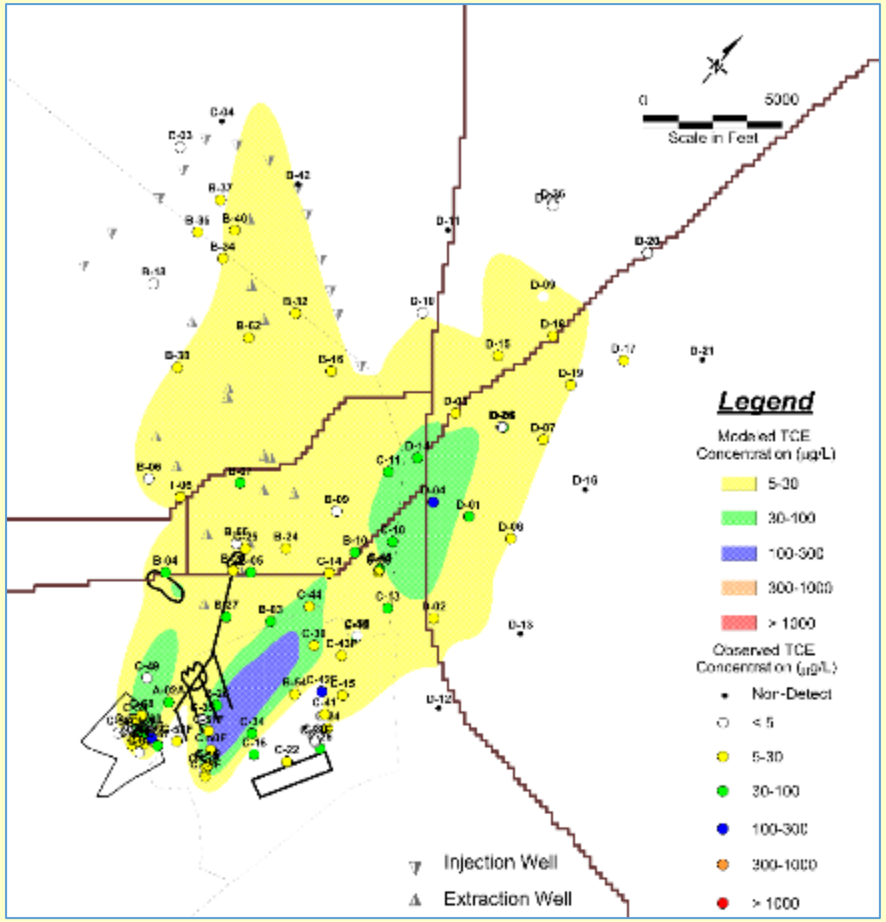
Supporting Physical Evidence for Degradation

- 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 <u>broad</u> ranges of degradation
- Defined to be spatially variable via hydrogeologic zonation

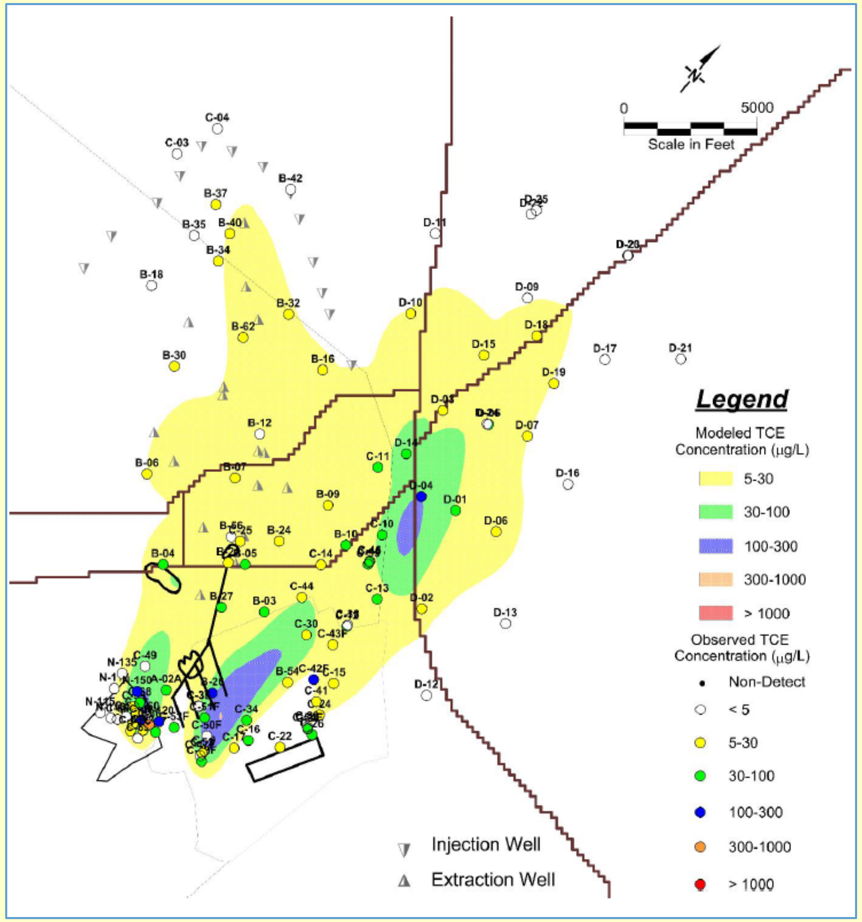


John Wilson (2018)

Supporting Evidence for Degradation



Modeled 2017 plume w/o degradation



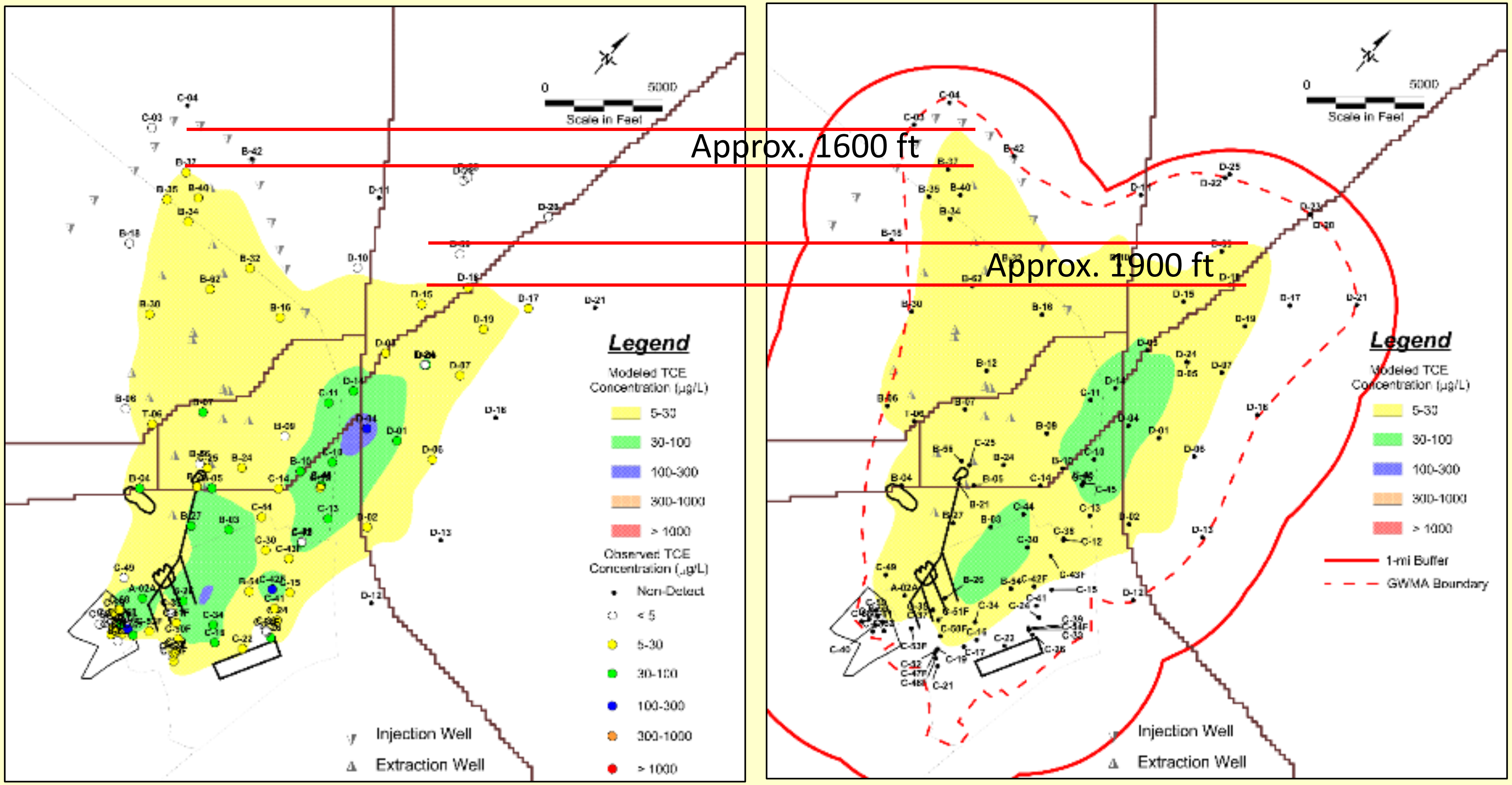
Updated modeled 2017 plume with degradation at extent of plume boundaries

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

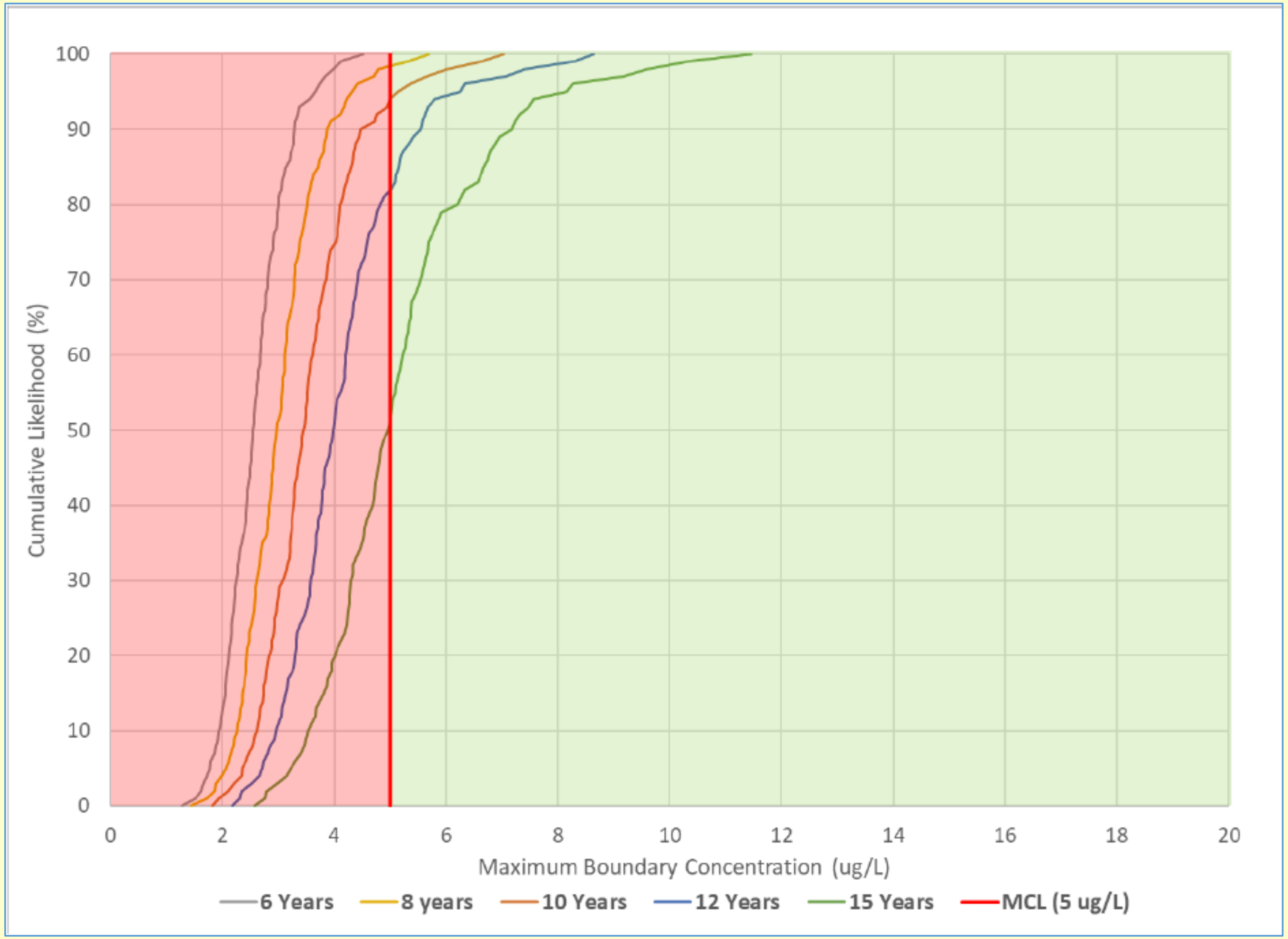
5-Year Prediction



Aggregate starting plume combining Kriged and Modeled TCE plumes

Planning Lead Time for Potential Remediation

1-Mile Buffer Boundary



- High likelihood of TCE concentrations remaining **below** MCL along
  - 1-mile boundary within 6 years (100% likelihood)
  - 1-mile boundary within 12 years (82% likelihood)

Conclusions

- The Tooele model has been continuously developed and refined on an annual basis over a 25 year period.
- The groundwater flow and transport modeling team has been largely consistent throughout the past 25 years.
- This has allowed for:
  - Multiple field investigations based on model findings
  - The increased complexity and expanse of the model as data warrants
  - Validation of the model based on studies independent from the modeling effort
  - Developing supporting evidence for abiotic degradation
  - Planning lead time for potential remediation in the future

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

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Questions/Comments?