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

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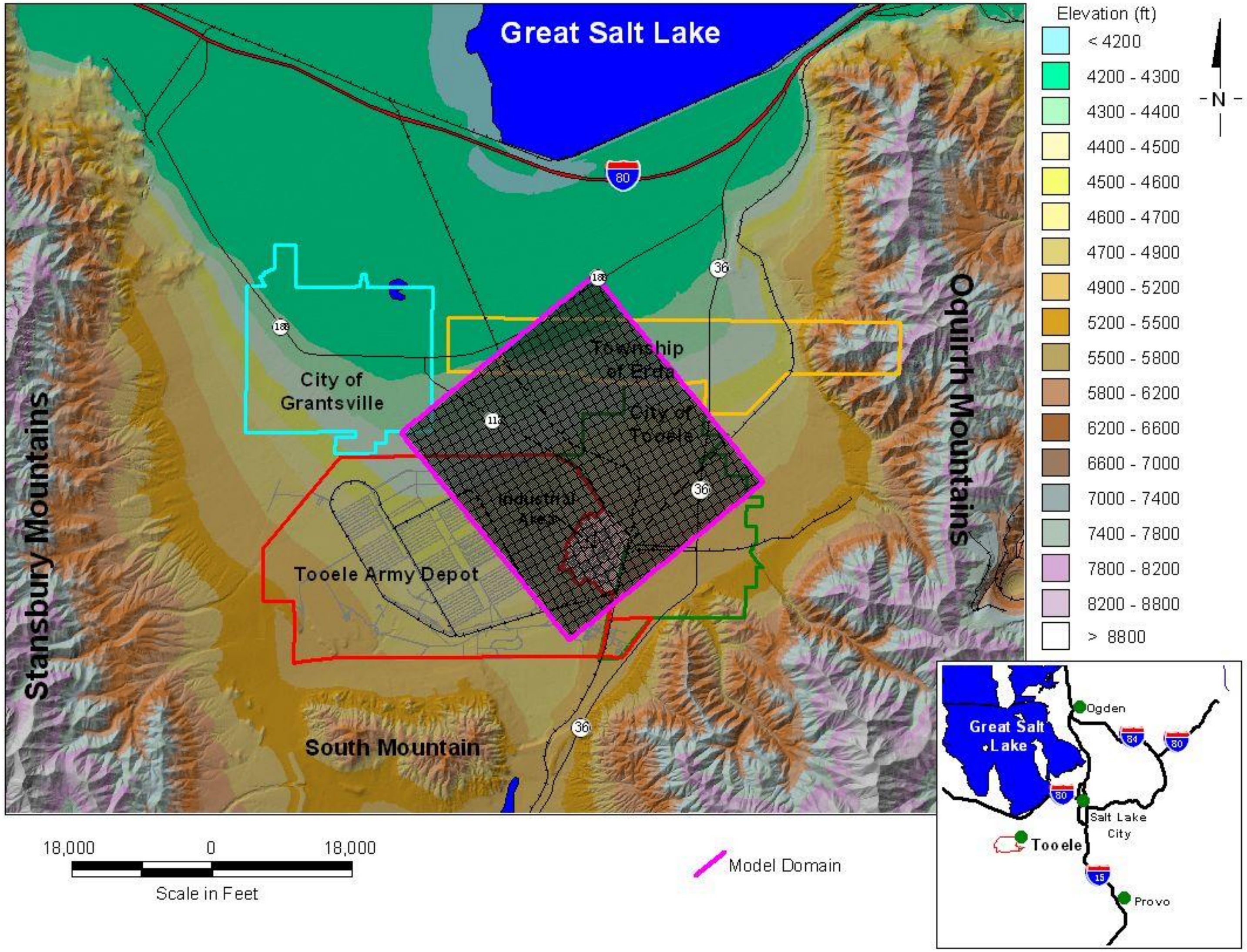
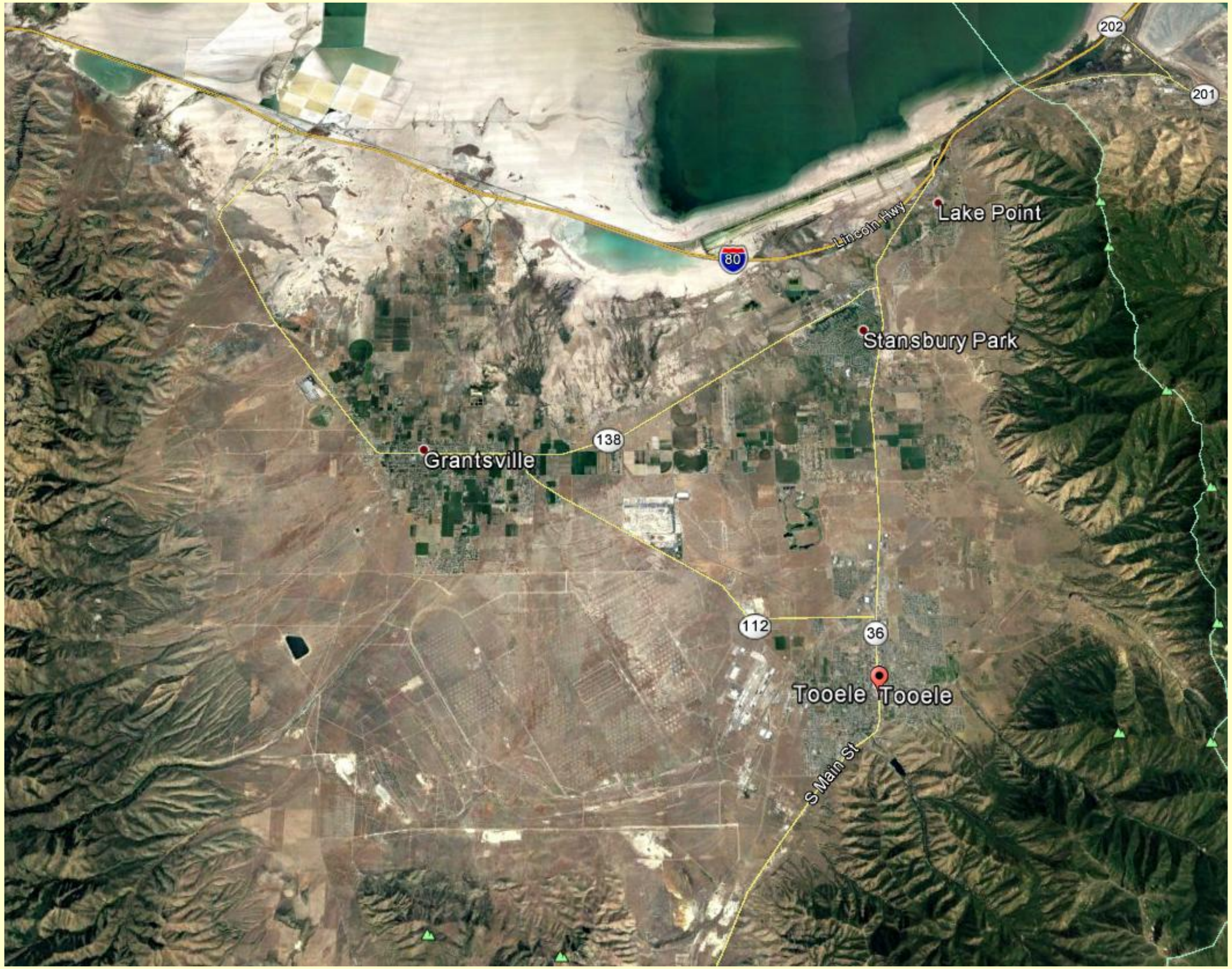

Great Salt Lake
City of Grantsville
Township of Erda
City of Tooele
Industrial Area
Tooele Army Depot
Stansbury Mountains
Oquirrh Mountains
South Mountain
Elevation (ft)
< 4200
4200 - 4300
4300 - 4400
4400 - 4500
4500 - 4600
4600 - 4700
4700 - 4900
4900 - 5200
5200 - 5500
5500 - 5800
5800 - 6200
6200 - 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



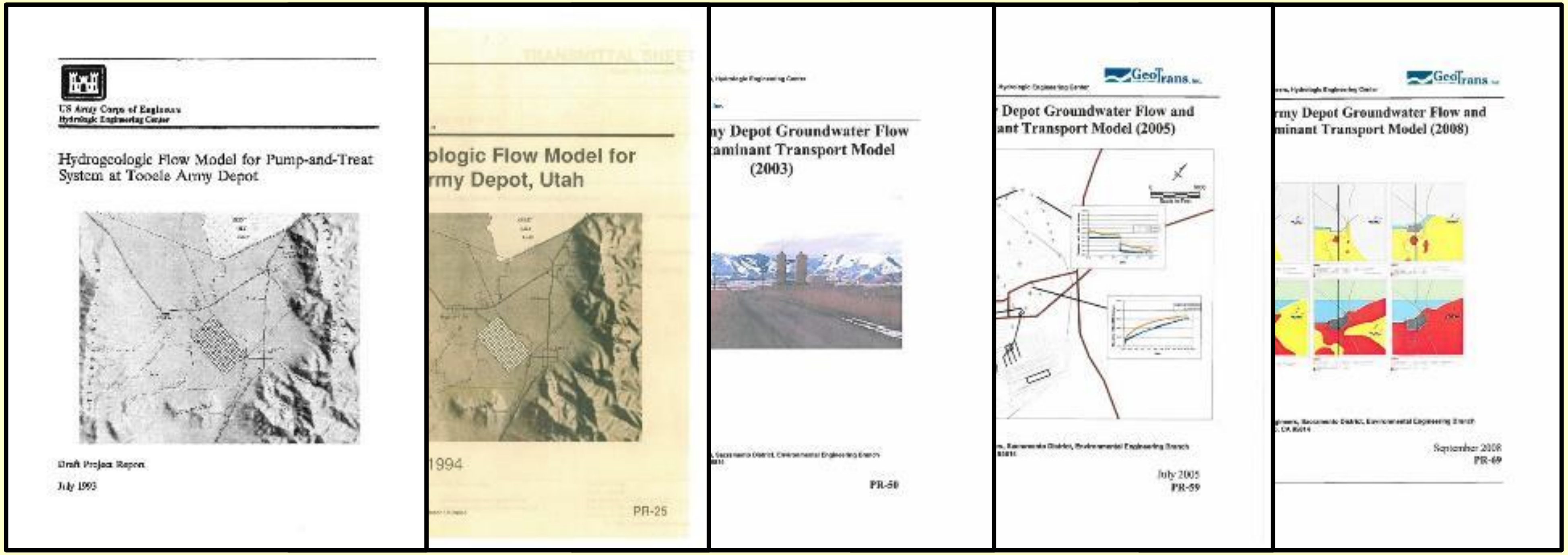
Tooele Army Depot

- 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


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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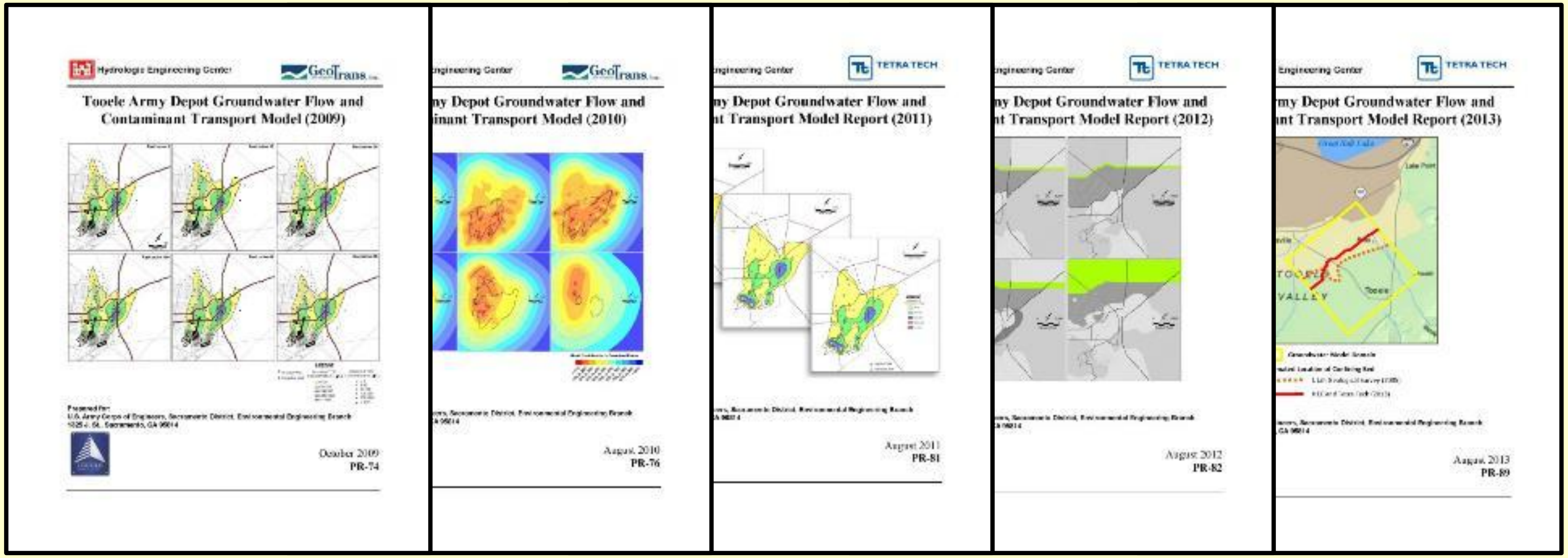
September 2008
PR-69


Hydrologic Engineering Center
GeoTrans
Tooele Army Depot Groundwater Flow and
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August 2012
PR-82
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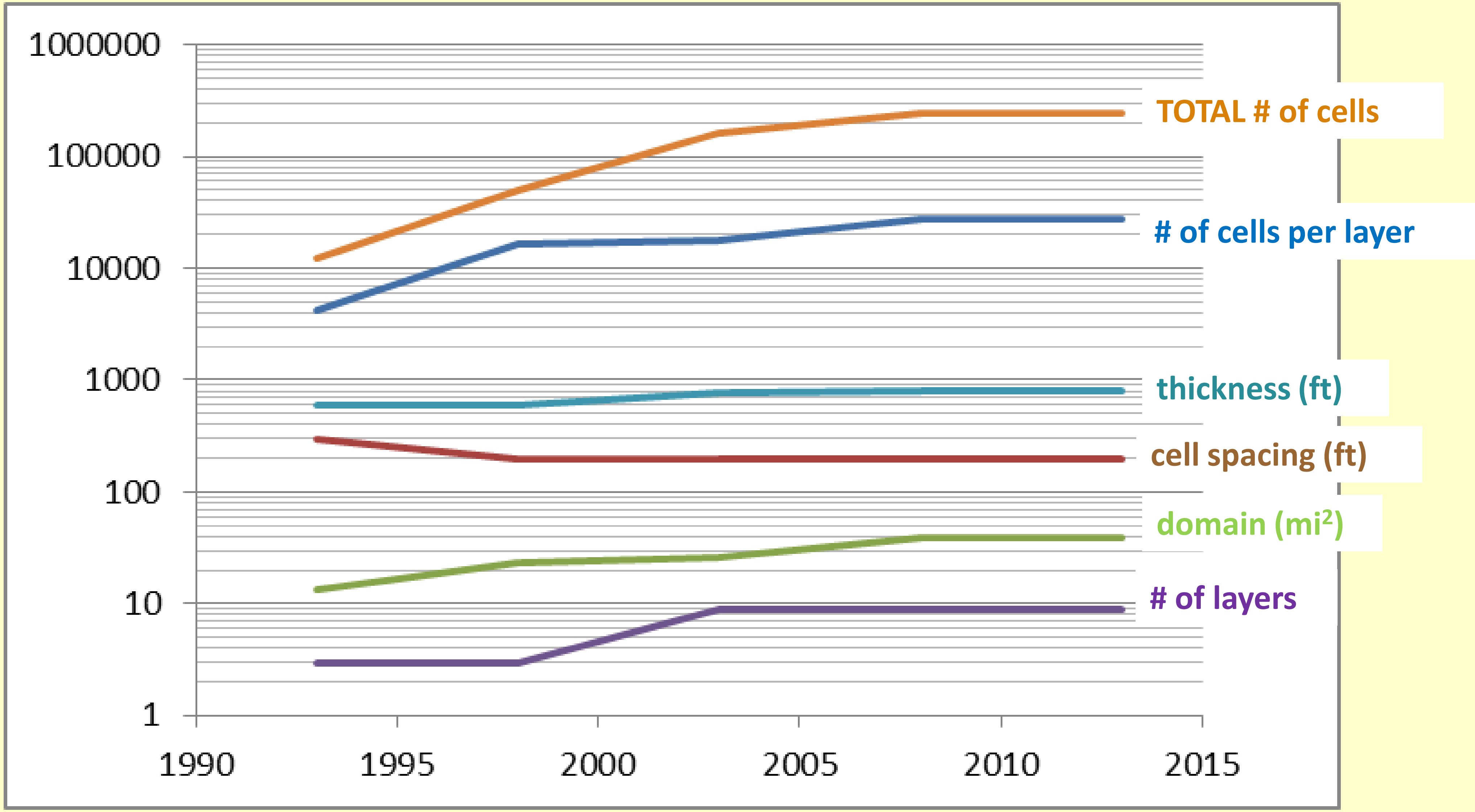
TETRA TECH
rmy Depot Groundwater Flow and
nt Transport Model Report (2013)
August 2013
PR-89

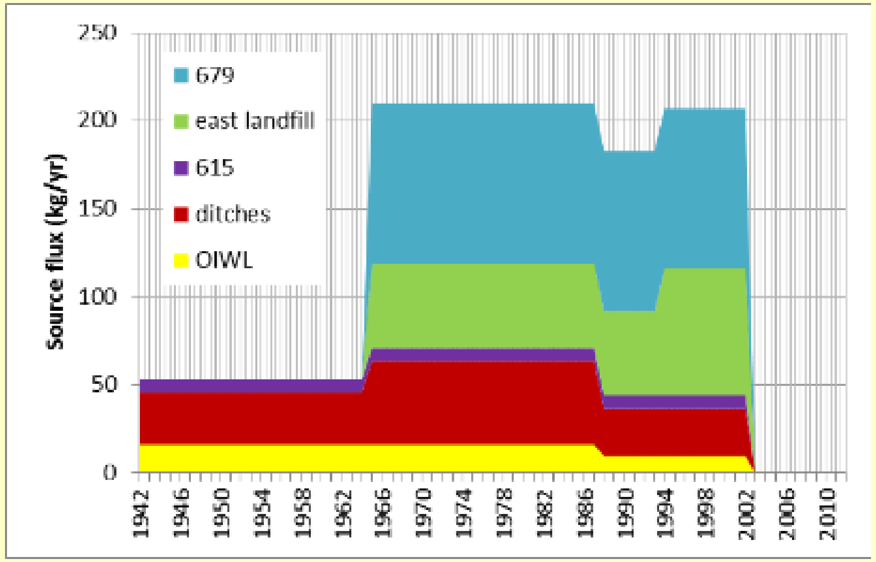
Most Significant Model Changes

- 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

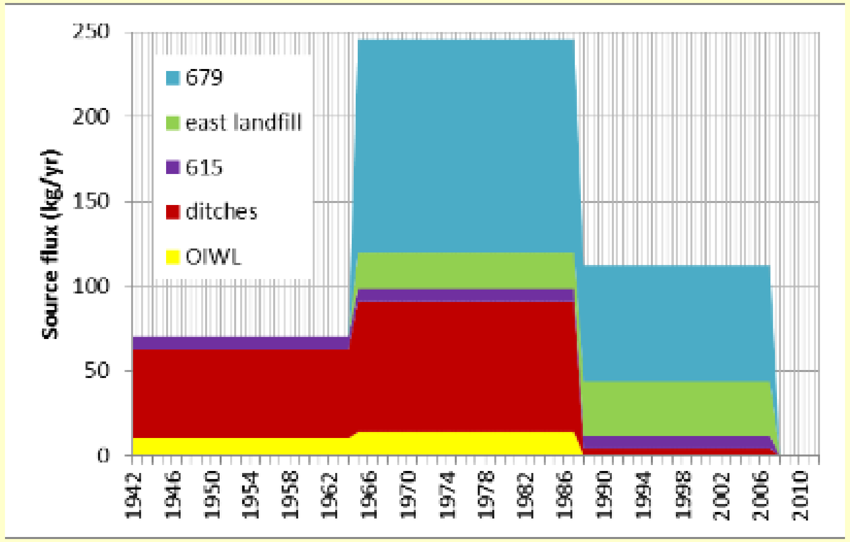
Dimensional Changes Versus Time



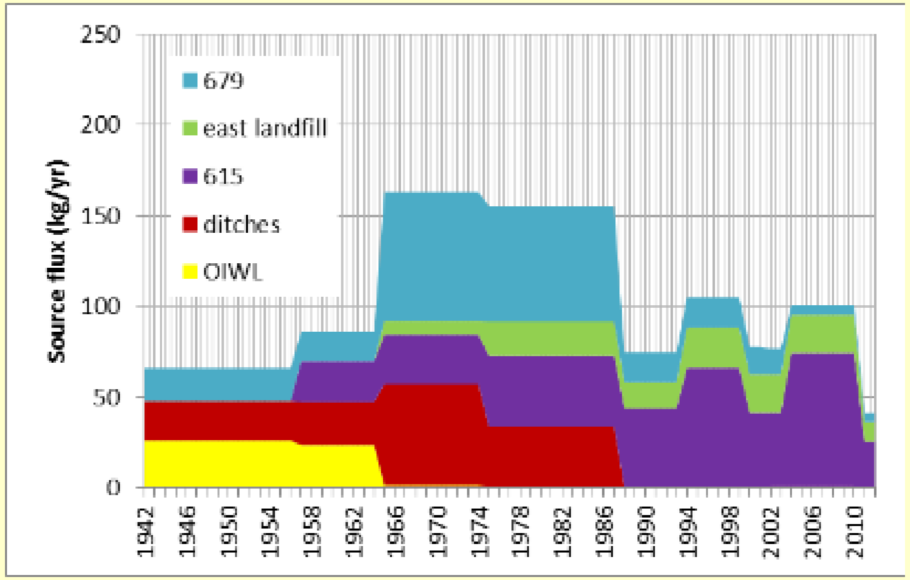
Source Flux By Area: 2003, 2008, 2013 Models



2003



2008



2013

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

Conceptual Model Development

- Conceptualization of Mountain Front Recharge
  - Based on large snowfall, snowmelt event that occurred between March 28 and April 6, 2016

Weather history Tooele march 2016

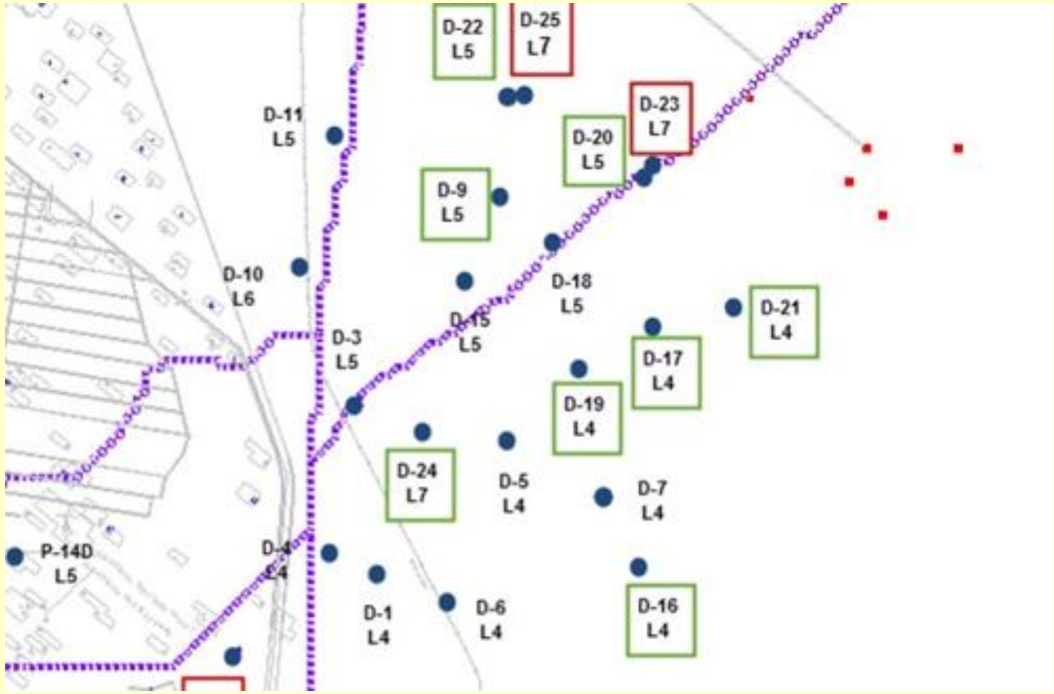
Day	High (°F)	Low (°F)	Precip. (inch)	Snow (inch)	Snow depth (inch)
1 mar 2016	61.0	32.0	0.00	0.00	0.00
2 mar 2016	59.0	39.9	0.00	0.00	0.00
3 mar 2016	70.0	37.9	0.00	0.00	0.00
4 mar 2016	64.9	41.0	0.00	0.00	0.00
5 mar 2016	66.9	42.1	0.00	0.00	0.00
6 mar 2016	66.0	37.9	0.30	T	0.00
7 mar 2016	46.9	30.9	0.40	2.01	0.00
8 mar 2016	48.0	28.9	0.00	0.00	0.00
9 mar 2016	51.1	37.0	0.00	0.00	0.00
10 mar 2016	66.9	36.0	0.00	0.00	0.00
11 mar 2016	66.0	59.0	0.00	0.00	0.00
12 mar 2016	63.0	45.0	T	0.00	0.00
13 mar 2016	62.1	39.0	0.00	0.00	0.00
14 mar 2016	57.0	30.9	0.13	T	0.00
15 mar 2016	46.0	30.0	0.06	T	0.00
16 mar 2016	50.0	28.9	0.00	0.00	0.00
17 mar 2016	54.0	36.0	0.00	0.00	0.00
18 mar 2016	53.1	27.0	0.00	0.00	0.00
19 mar 2016	52.0	28.0	0.00	0.00	0.00
20 mar 2016	62.1	30.9	0.00	0.00	0.00
21 mar 2016	66.9	37.0	0.00	0.00	0.00
22 mar 2016	64.0	30.0	0.48	2.01	0.00
23 mar 2016	51.1	30.9	T	T	0.00
24 mar 2016	55.0	32.0	0.00	0.00	0.00
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

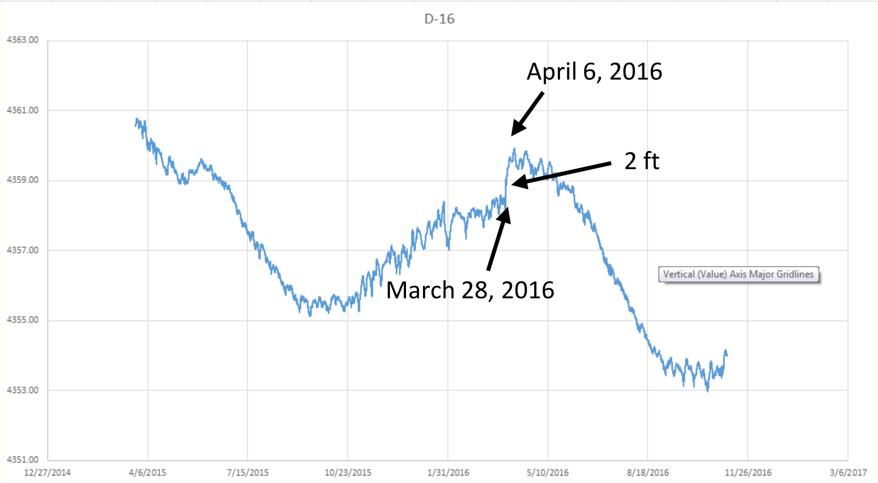
Weather history Tooele april 2016

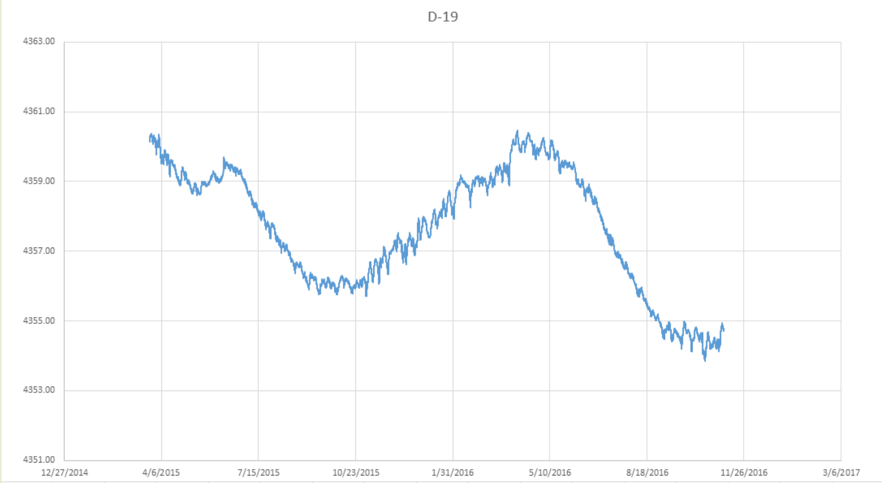
Day	High (°F)	Low (°F)	Precip. (inch)	Snow (inch)	Snow depth (inch)
1 apr 2016	52.0	33.1	0.00	0.00	0.00
2 apr 2016	60.1	34.0	0.00	0.00	0.00
3 apr 2016	68.0	42.1	0.00	0.00	0.00
4 apr 2016	71.1	43.0	T	0.00	0.00
5 apr 2016	59.0	36.0	0.00	0.00	0.00
6 apr 2016	57.9	35.1	0.00	0.00	0.00
7 apr 2016	64.0	41.0	0.00	0.00	0.00
8 apr 2016	72.0	44.1	0.00	0.00	0.00
9 apr 2016	71.1	54.0	0.00	0.00	0.00
10 apr 2016	69.1	50.0	T	0.00	0.00
11 apr 2016	66.9	42.1	0.00	0.00	0.00
12 apr 2016	72.0	43.0	0.00	0.00	0.00
13 apr 2016	68.0	48.9	0.02	0.00	0.00
14 apr 2016	57.9	35.1	0.36	0.00	0.00
15 apr 2016	54.0	30.9	0.02	T	0.00
16 apr 2016	52.0	34.0	0.00	0.00	0.00
17 apr 2016	55.0	33.1	0.00	0.00	0.00
18 apr 2016	55.0	35.1	0.00	0.00	0.00
19 apr 2016	63.0	39.9	0.00	0.00	0.00
20 apr 2016	71.1	43.0	0.00	0.00	0.00
21 apr 2016	80.1	46.9	0.00	0.00	0.00
22 apr 2016	78.1	57.9	0.00	0.00	0.00
23 apr 2016	75.0	39.9	0.10	0.00	0.00
24 apr 2016	59.0	39.0	0.22	0.00	0.00
25 apr 2016	62.1	39.9	0.11	0.00	0.00
26 apr 2016	54.0	37.0	1.03	0.00	0.00
27 apr 2016	55.0	37.9	0.20	0.00	0.00
28 apr 2016	50.0	39.9	0.24	0.00	0.00
29 apr 2016	54.0	37.0	0.04	0.00	0.00
30 apr 2016	55.9	39.0	0.05	0.00	0.00

Mountain Front Recharge

Upgradient wells near mountain front



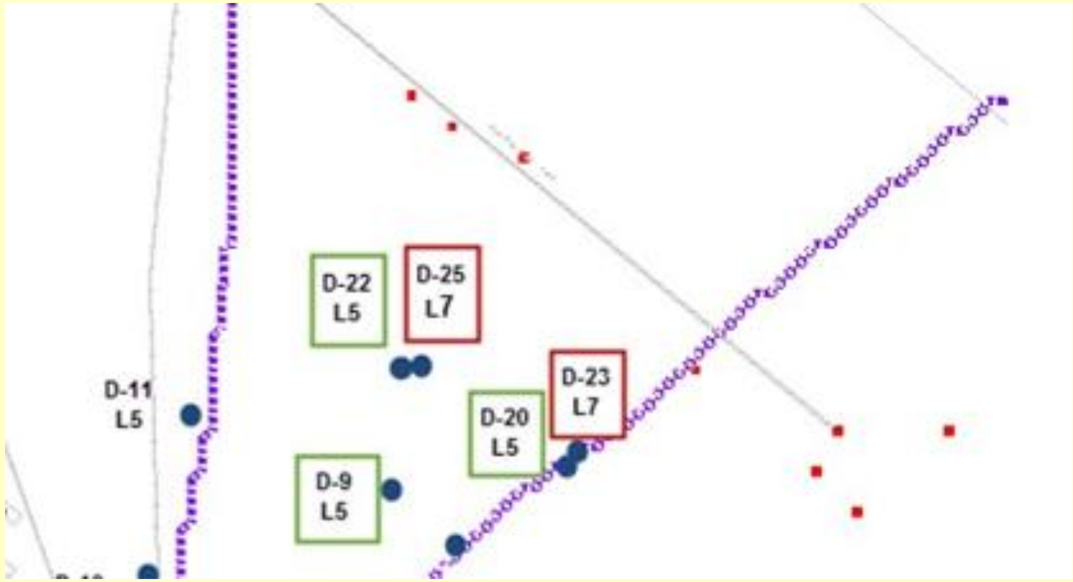


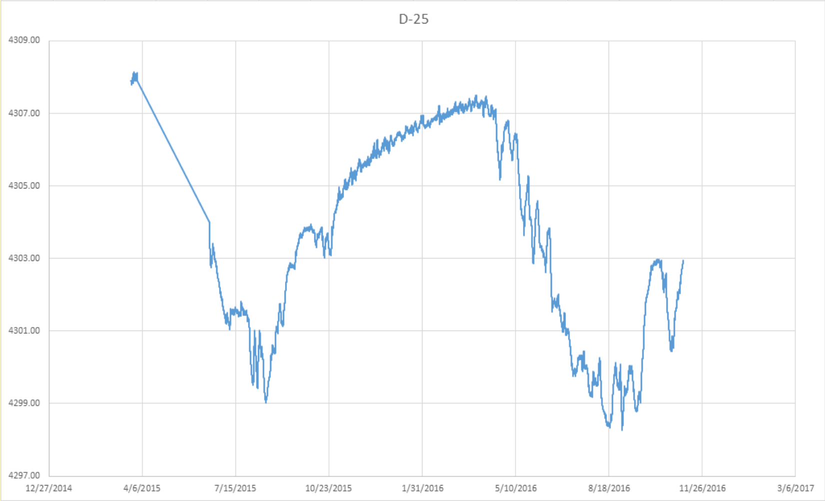


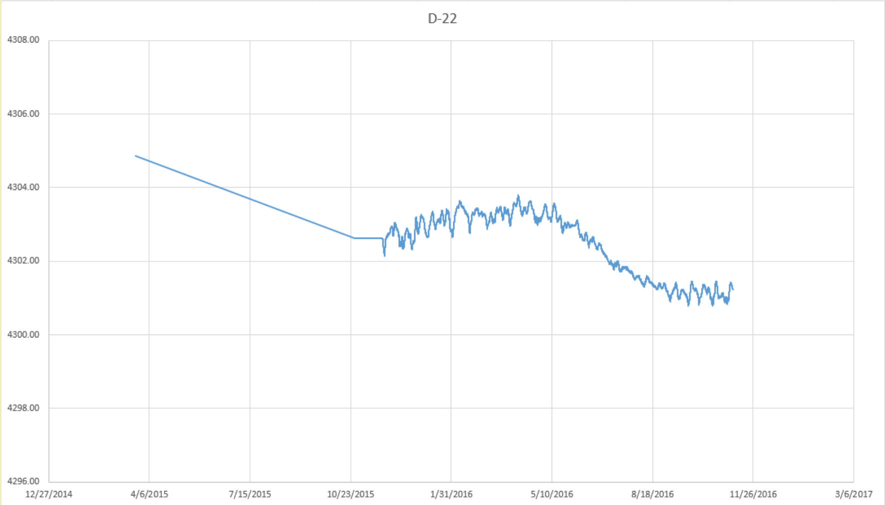
D well measurements 3/25/15 to 11/15/16

Mountain Front Recharge

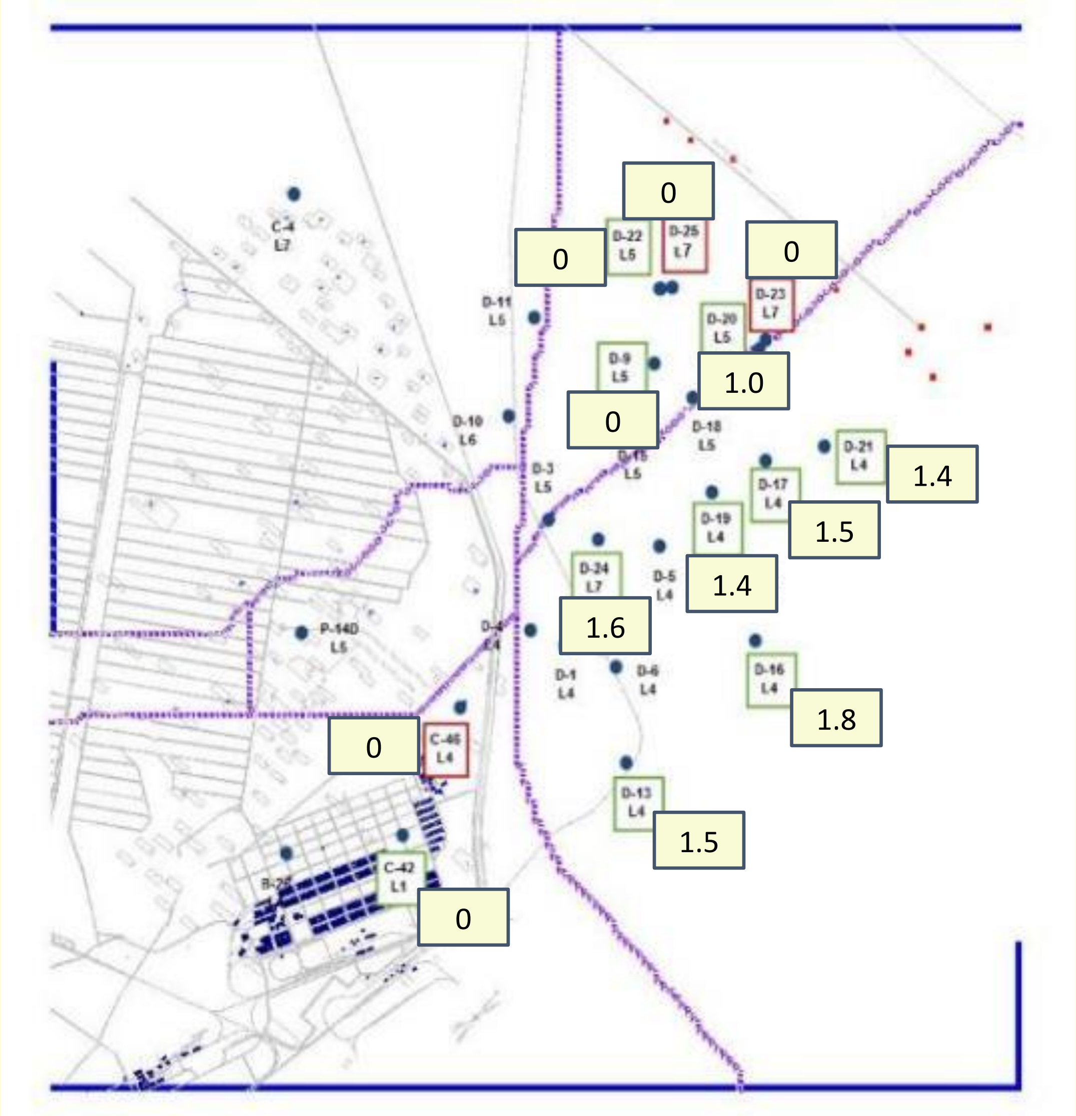
Downgradient wells further away from mountain front (downgradient of fault)





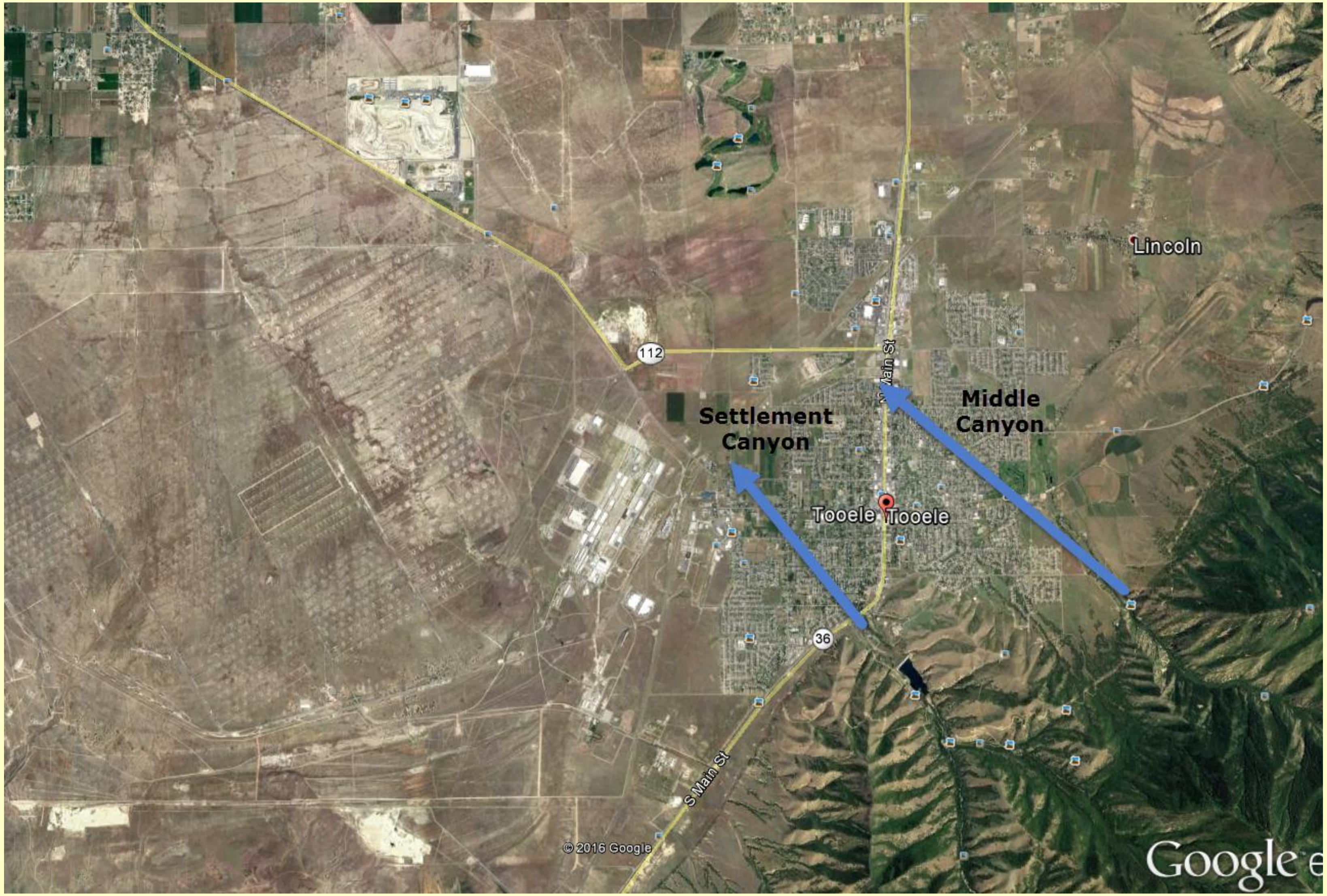


Mountain Front Recharge



* Early April water levels “spike” (ft)

Mountain Front Recharge

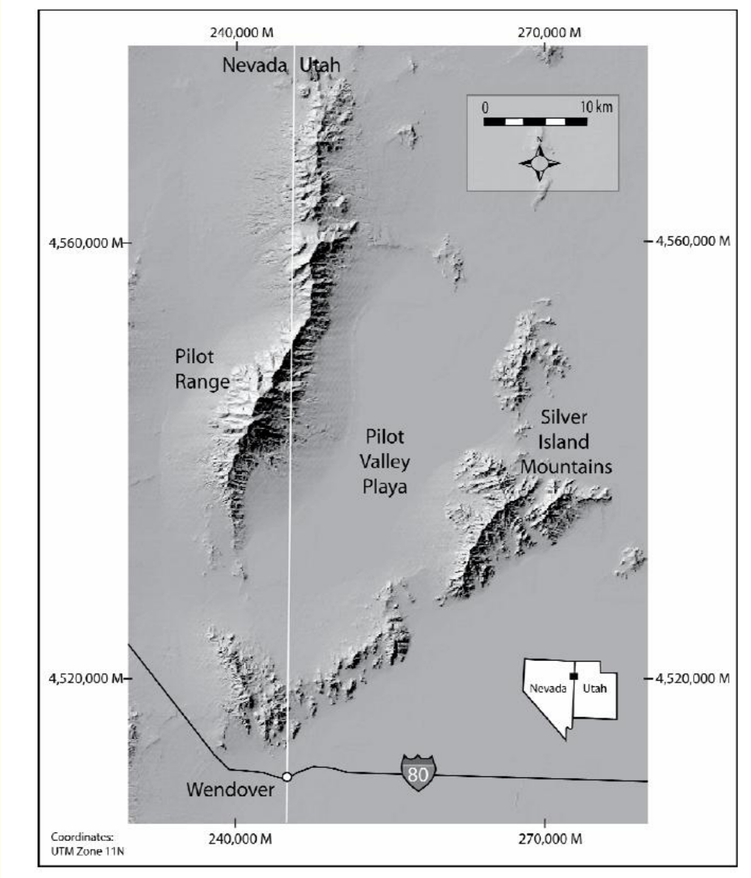


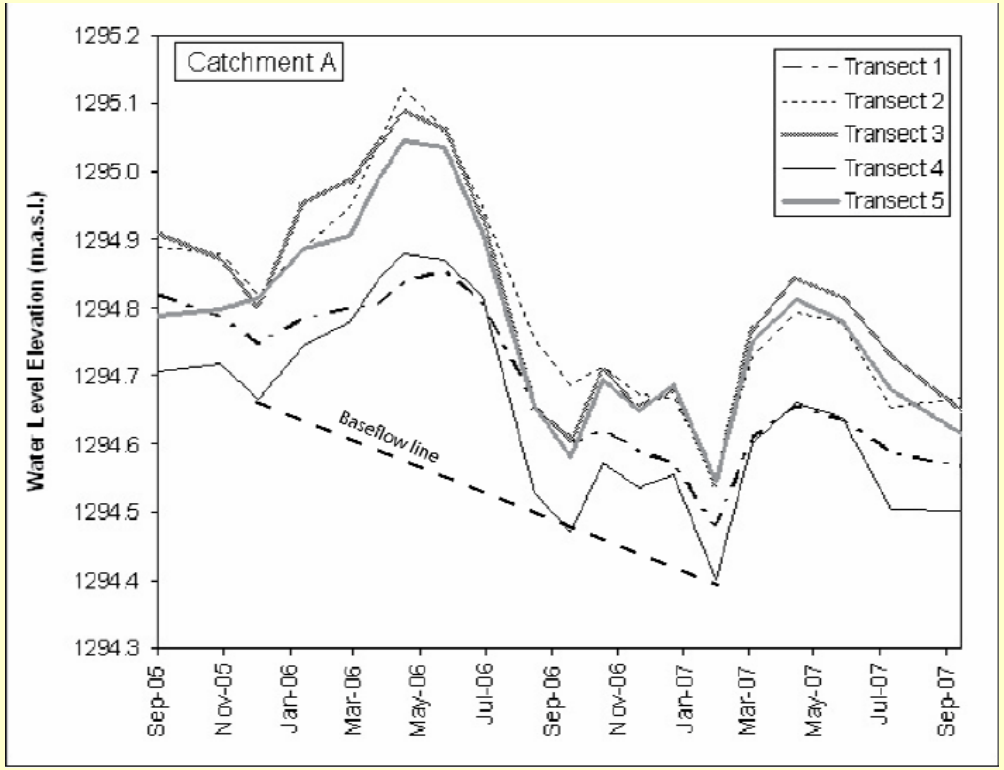
Mountain Front Recharge

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





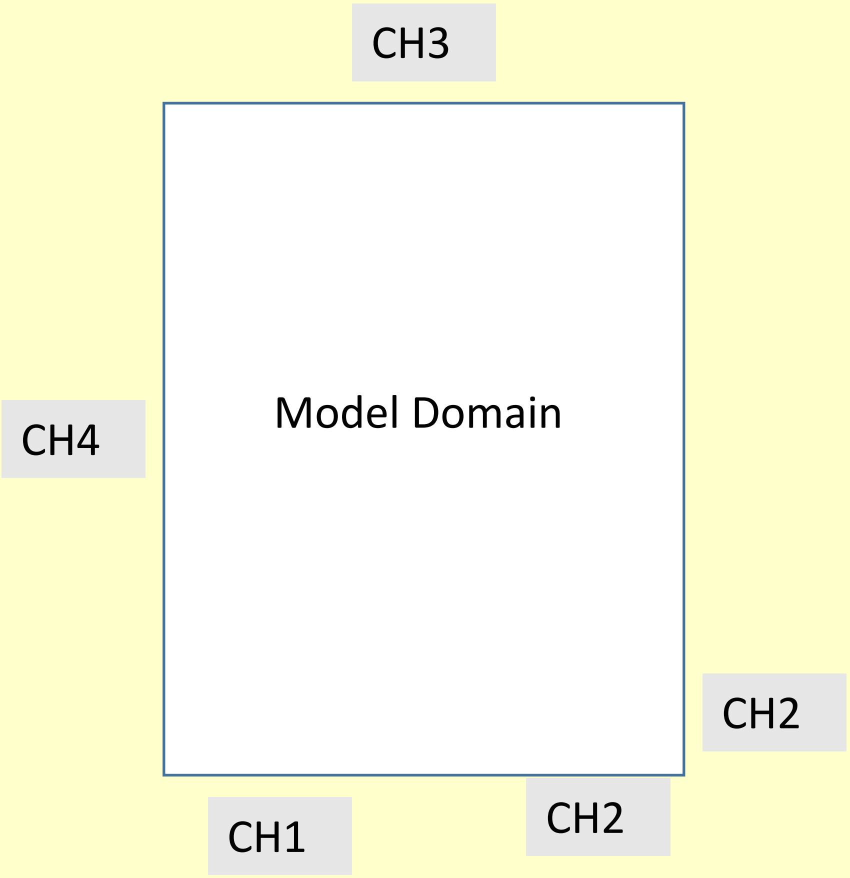
Note fast GW response to Spring rainfall event in alluvial catchments

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 on Conceptualization into Numerical Model



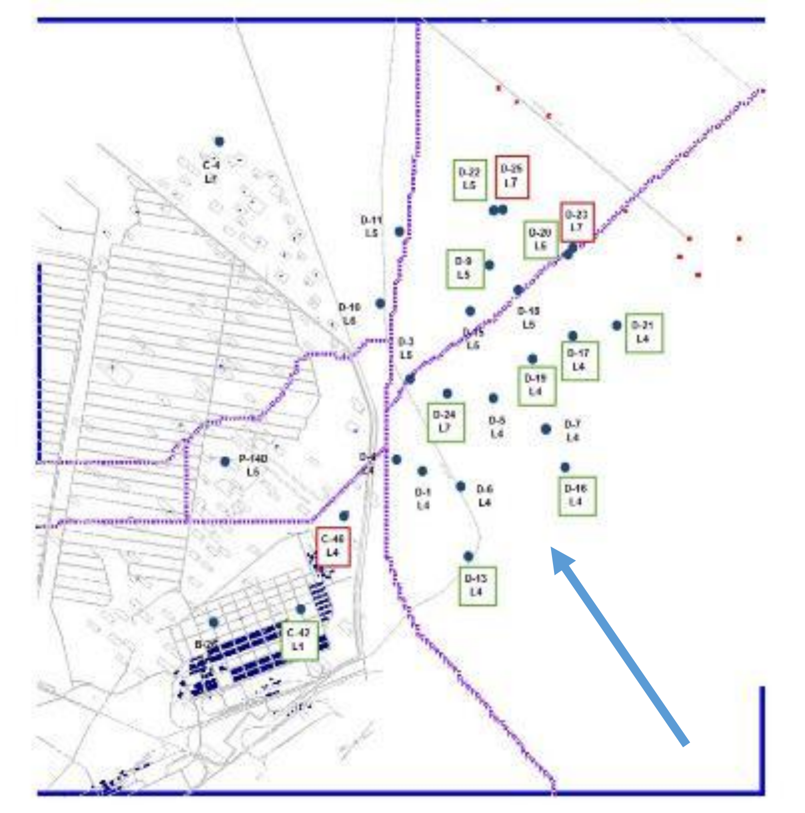
	CH1	CH2	CH3	CH4
SP1	477	364	277	305
SP2	476	363	276	304
SP3	475.5	362.5	275.5	303.5
SP4	474.5	361.5	275.5	302.5
SP5	473.5	360.5	275.5	301.5
SP6	476	363	276	304
SP7	474.5	361.5	275.5	302.5
SP8	472.5	359.5	274.5	300.5

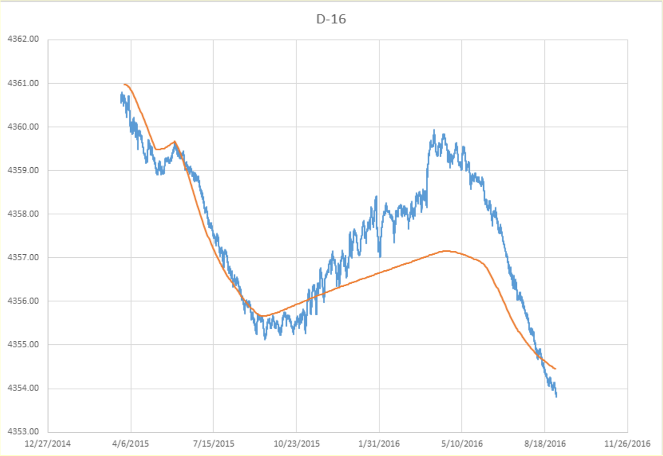
	CH1	CH2	CH3	CH4
SP1	477	364	277	305
SP2	476	363	276	304
SP3	475.5	362.5	275.5	303.5
SP4	474.5	361.5	275.5	302.5
SP5	473.5	360.5	275.5	301.5
SP6	476	**367**	276	304
SP7	474.5	361.5	275.5	302.5
SP8	472.5	359.5	274.5	300.5

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

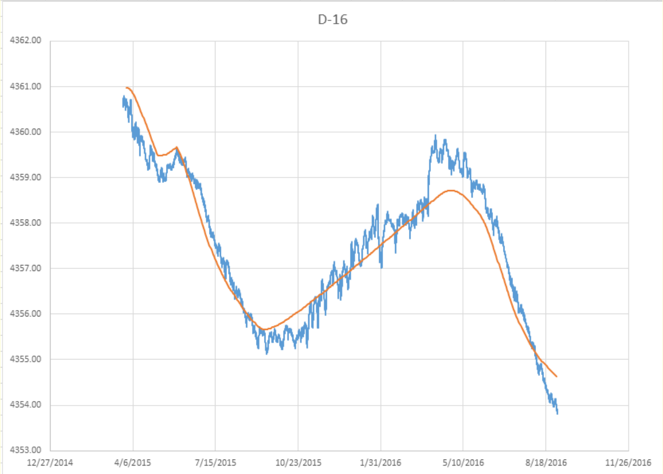
Mountain Front Recharge

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



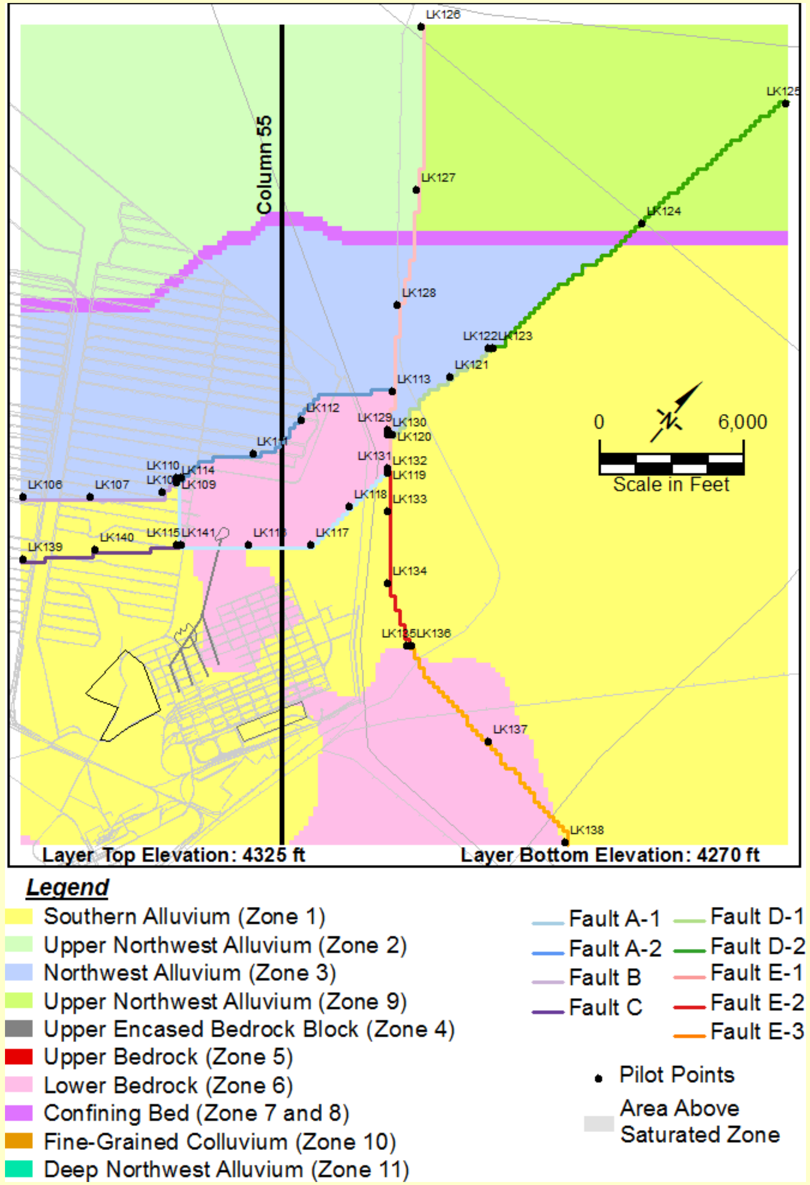


Initial



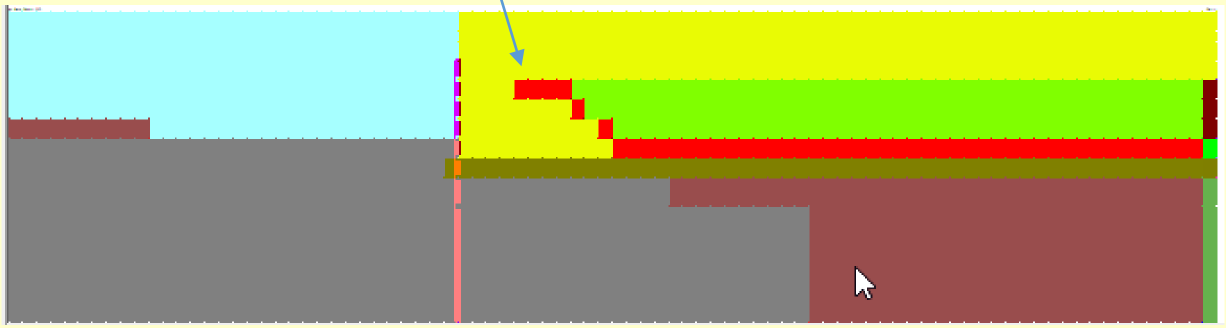
Increased CH2

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.

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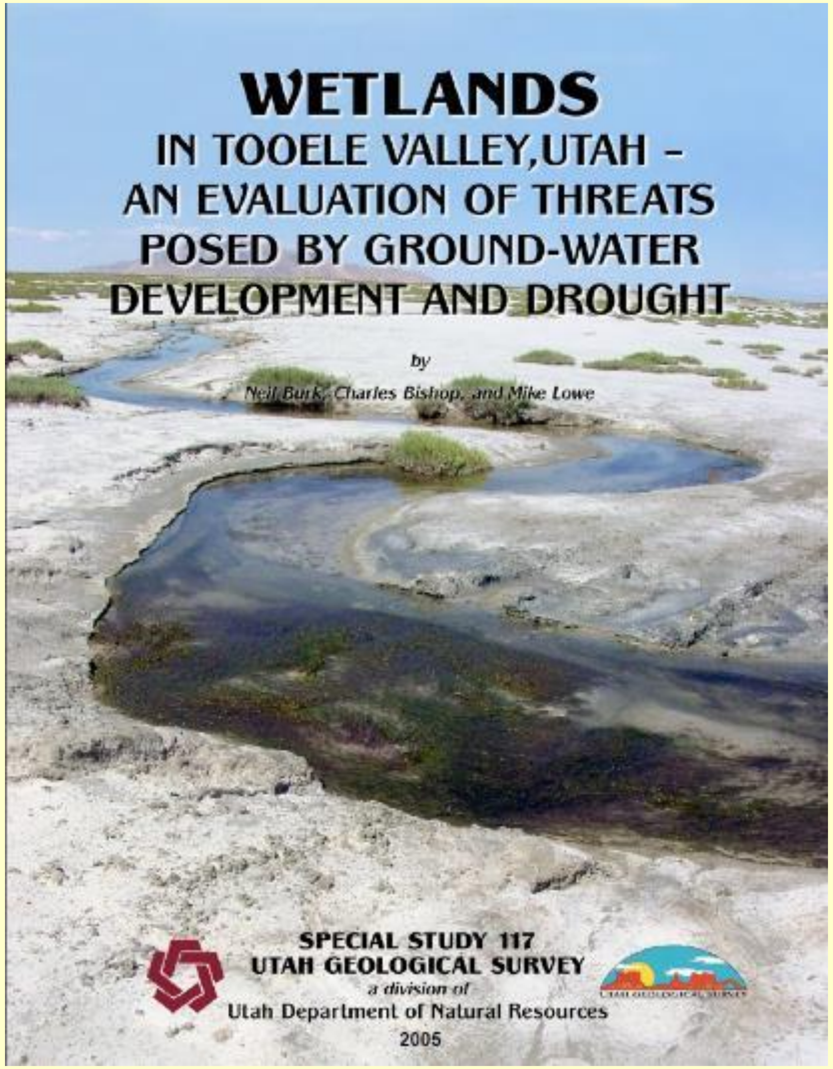


Confining Bed Conceptualization

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.

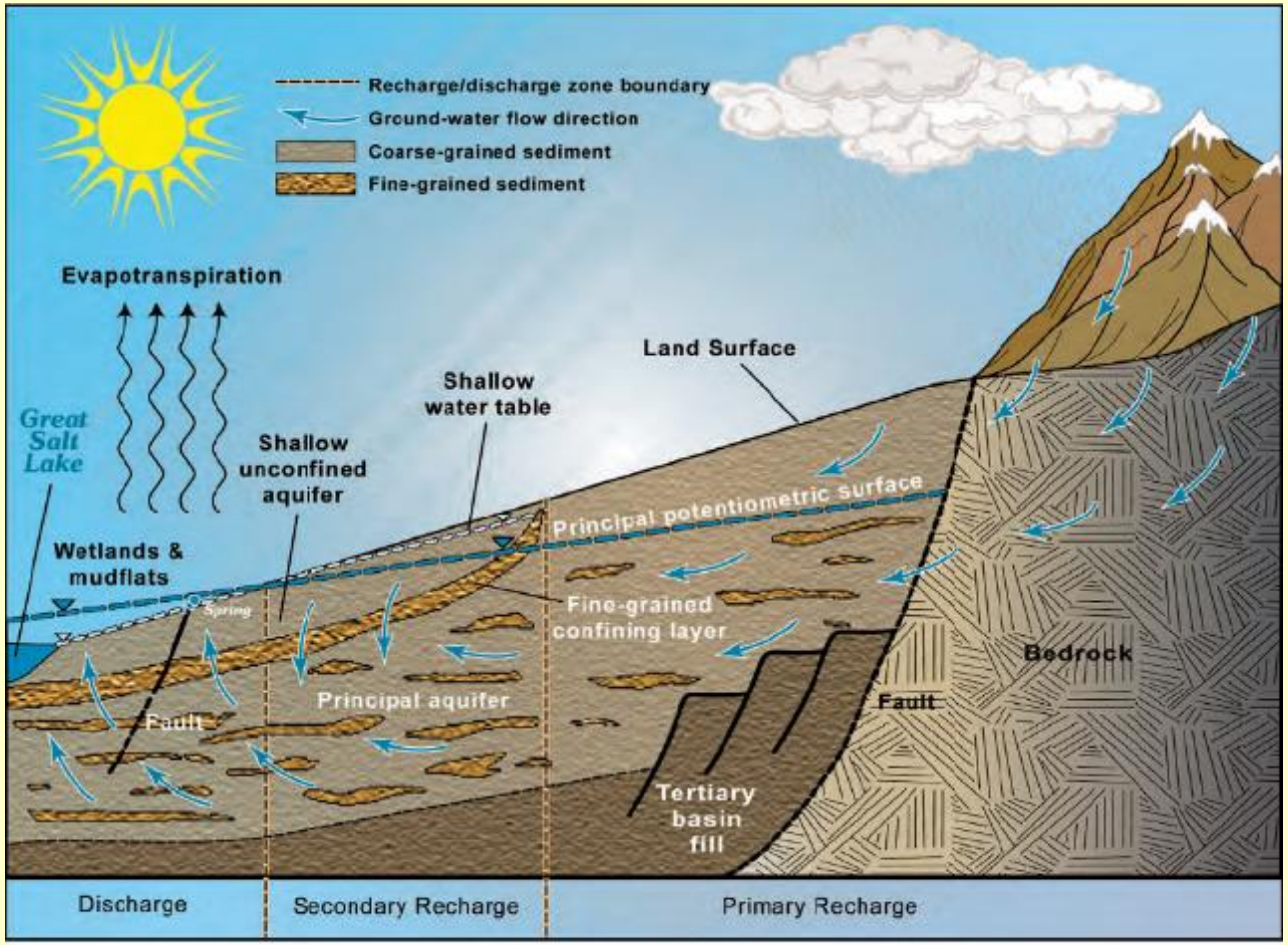
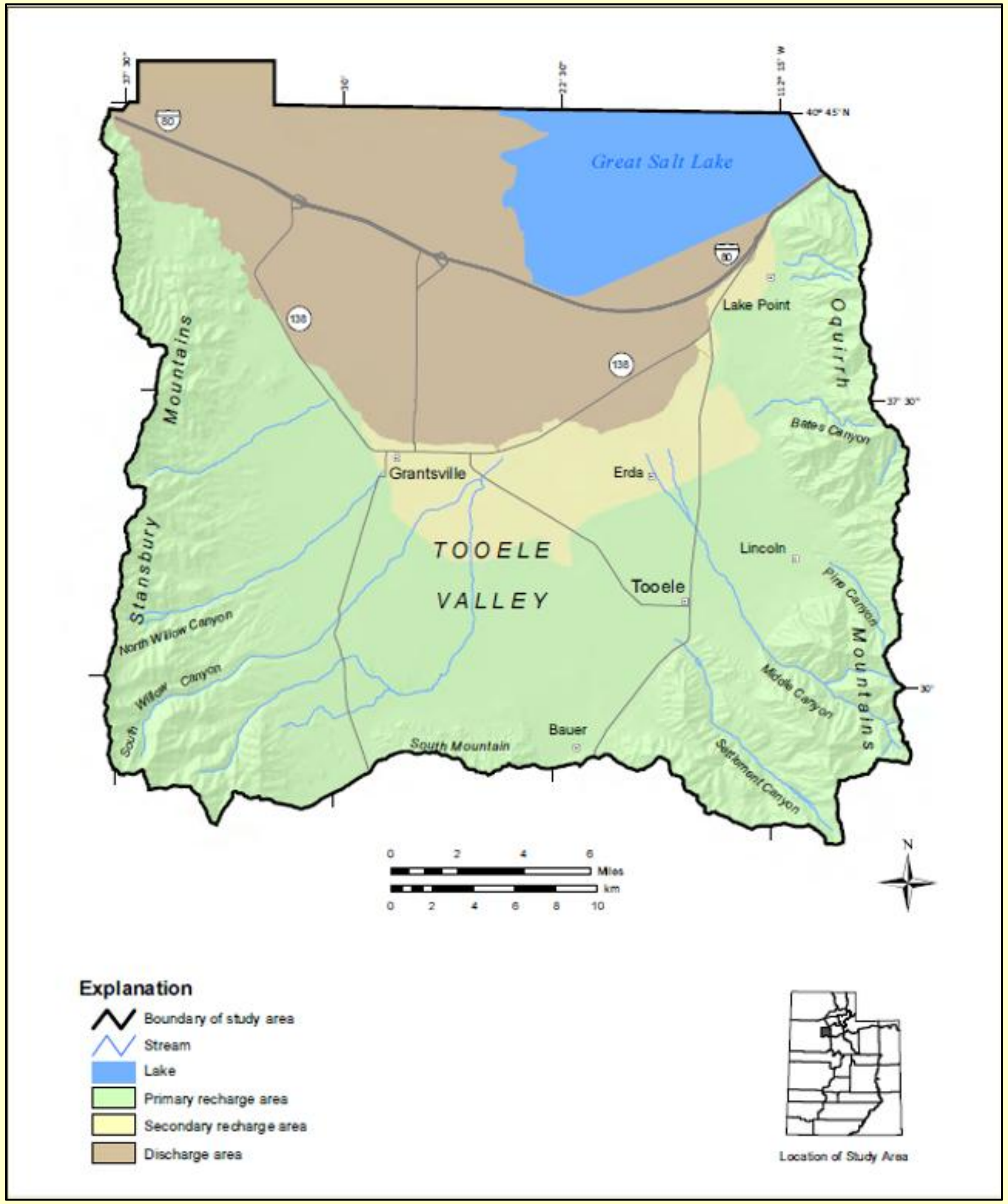


Figure 10. Schematic diagram of Tooele Valley ground-water flow system.

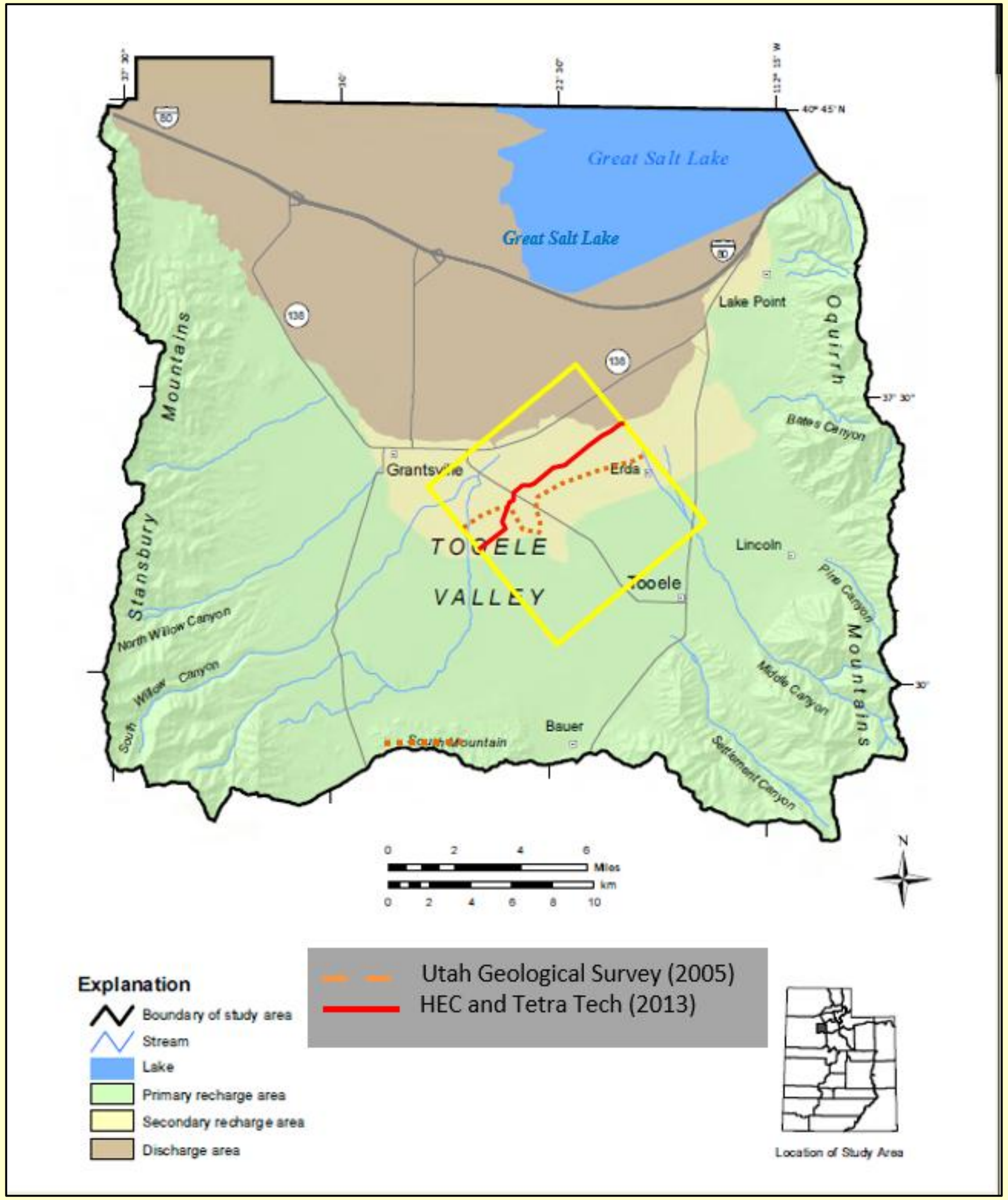
Confining Bed Conceptualization



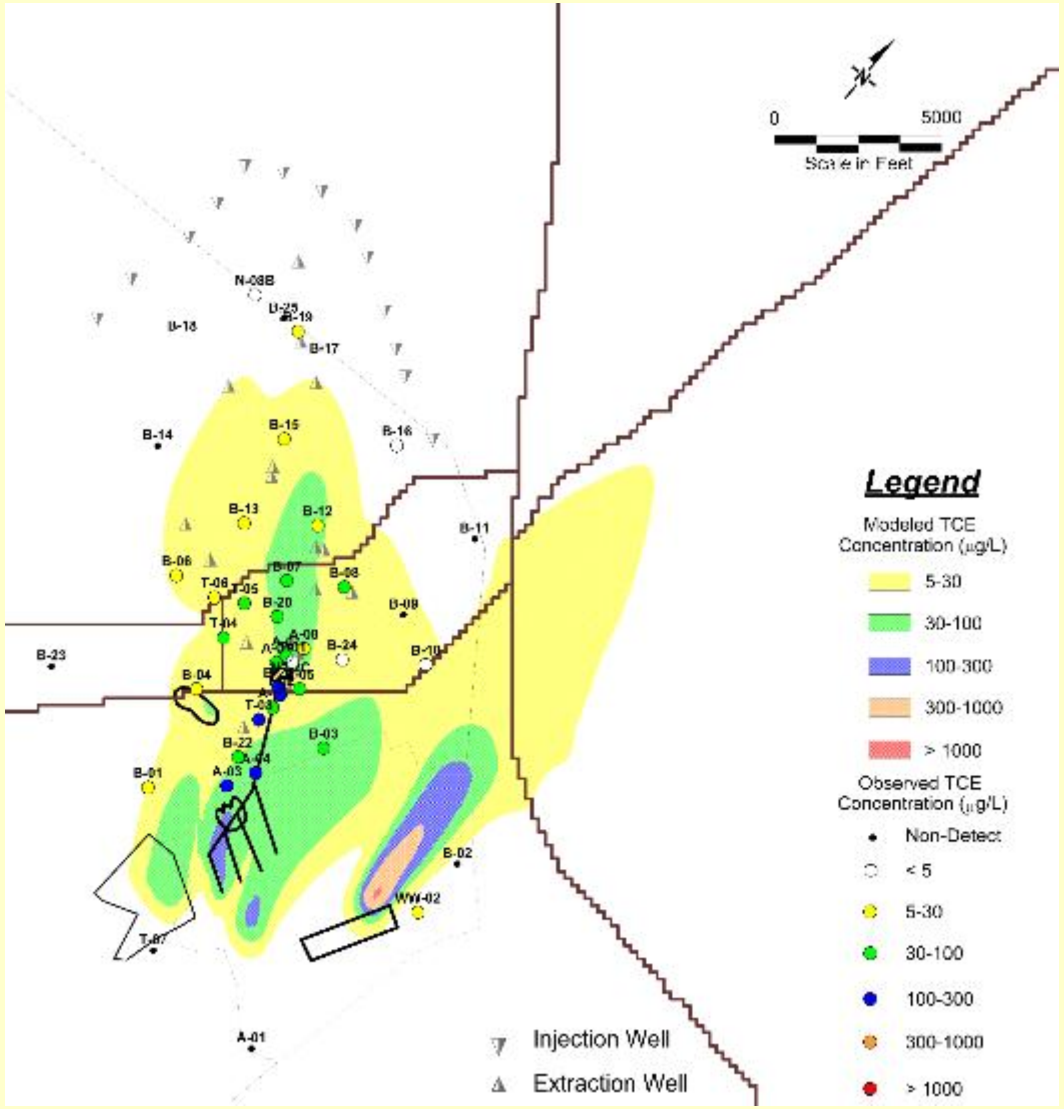
Confining Bed Conceptualization

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

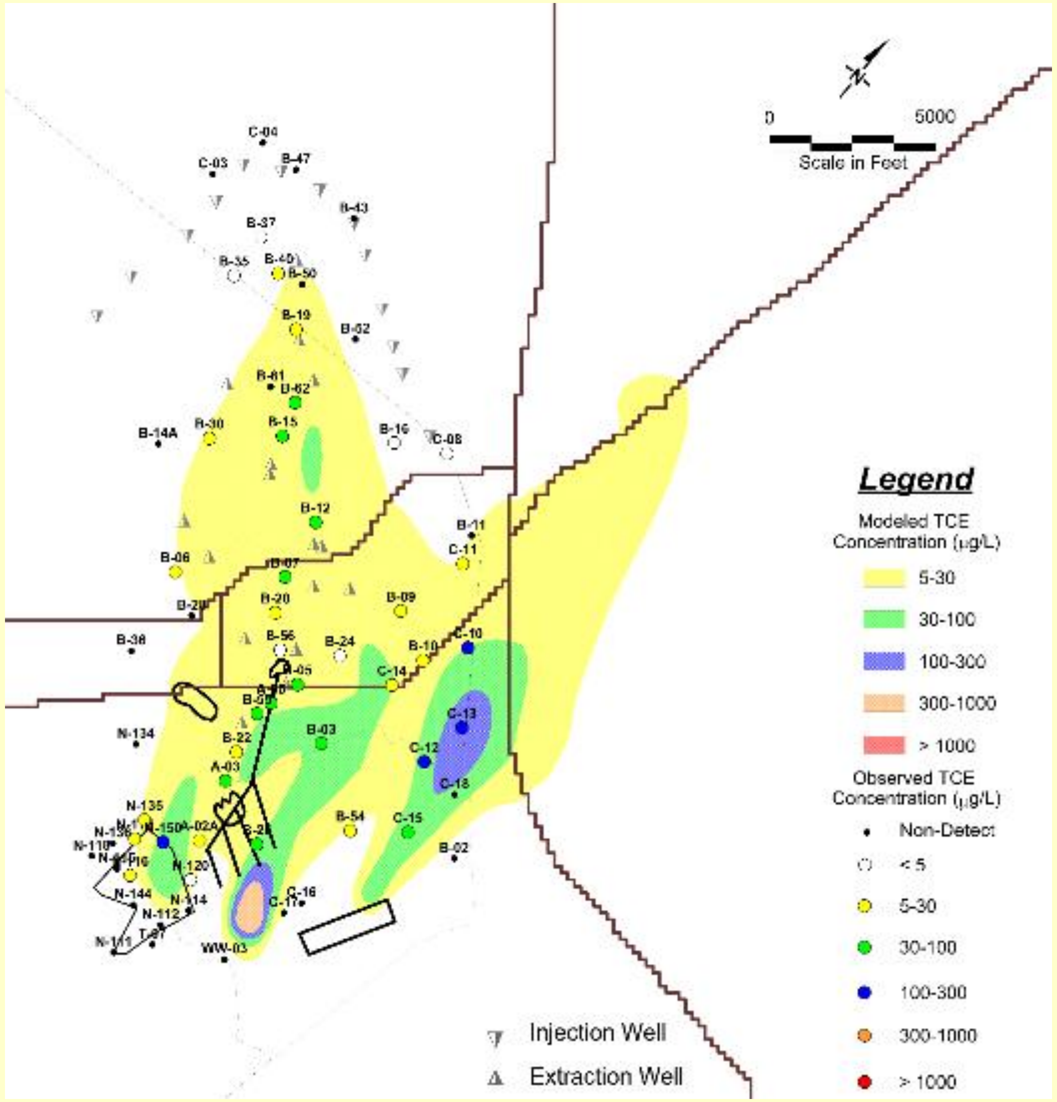


Supporting Evidence for Degradation



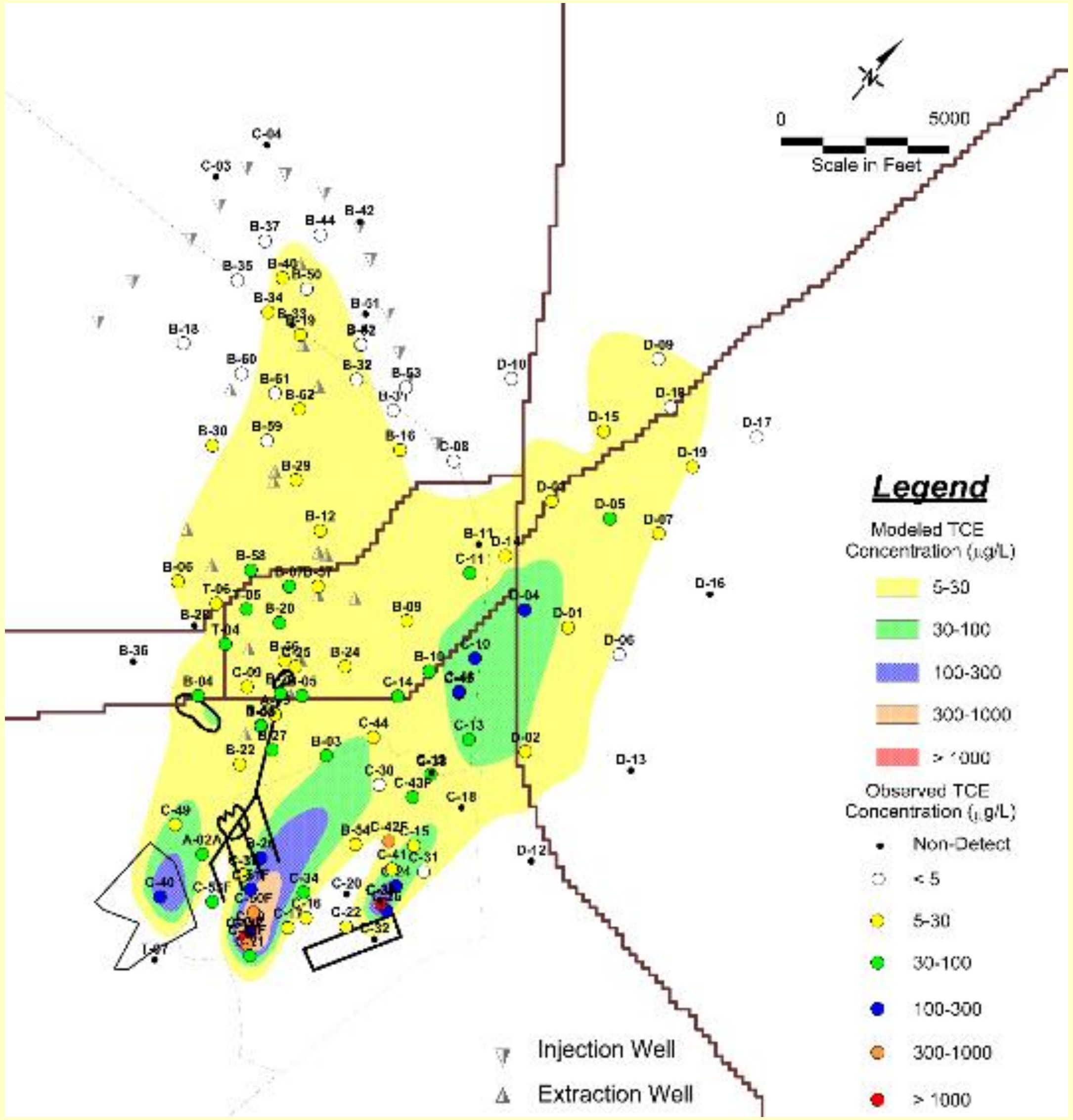
Modeled TCE Plume in 1986

Supporting Evidence for Degradation



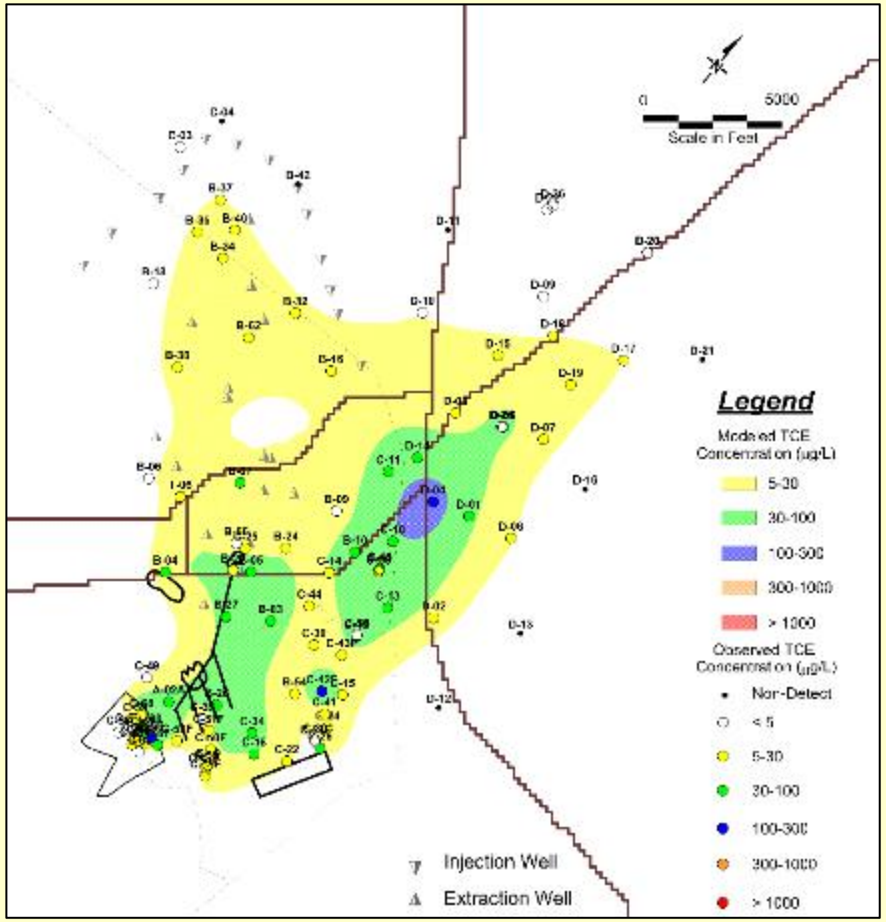
Modeled TCE Plume in 1997

Supporting Evidence for Degradation

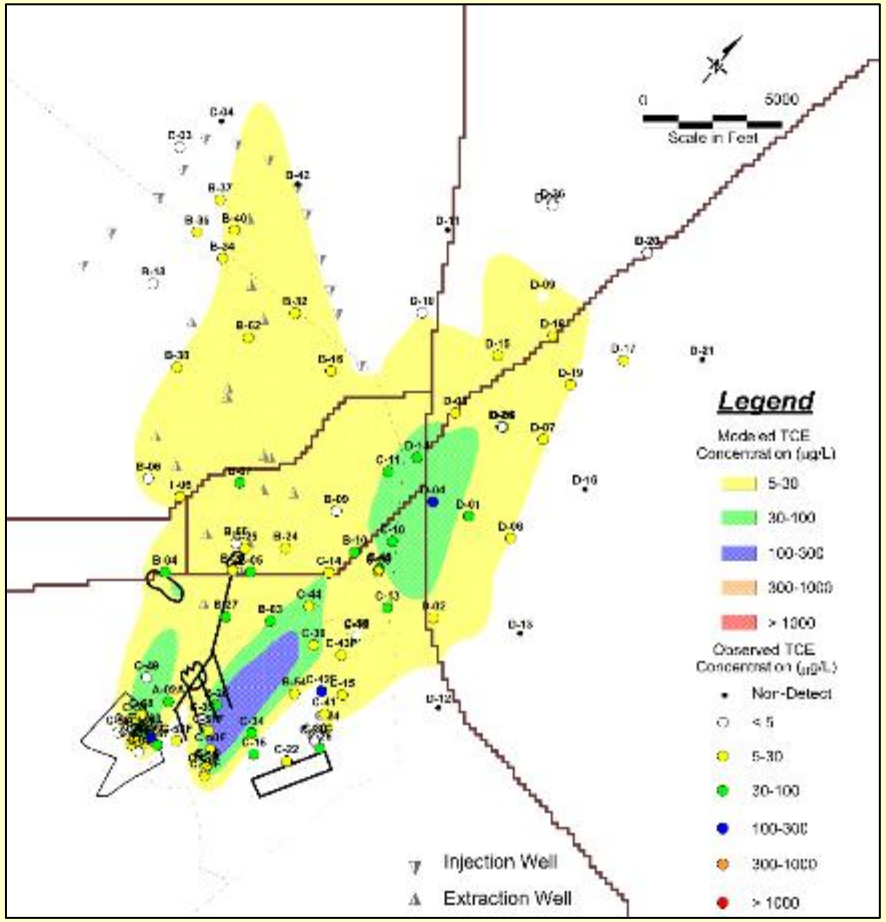


Modeled TCE Plume in 2009

Supporting Evidence for Degradation



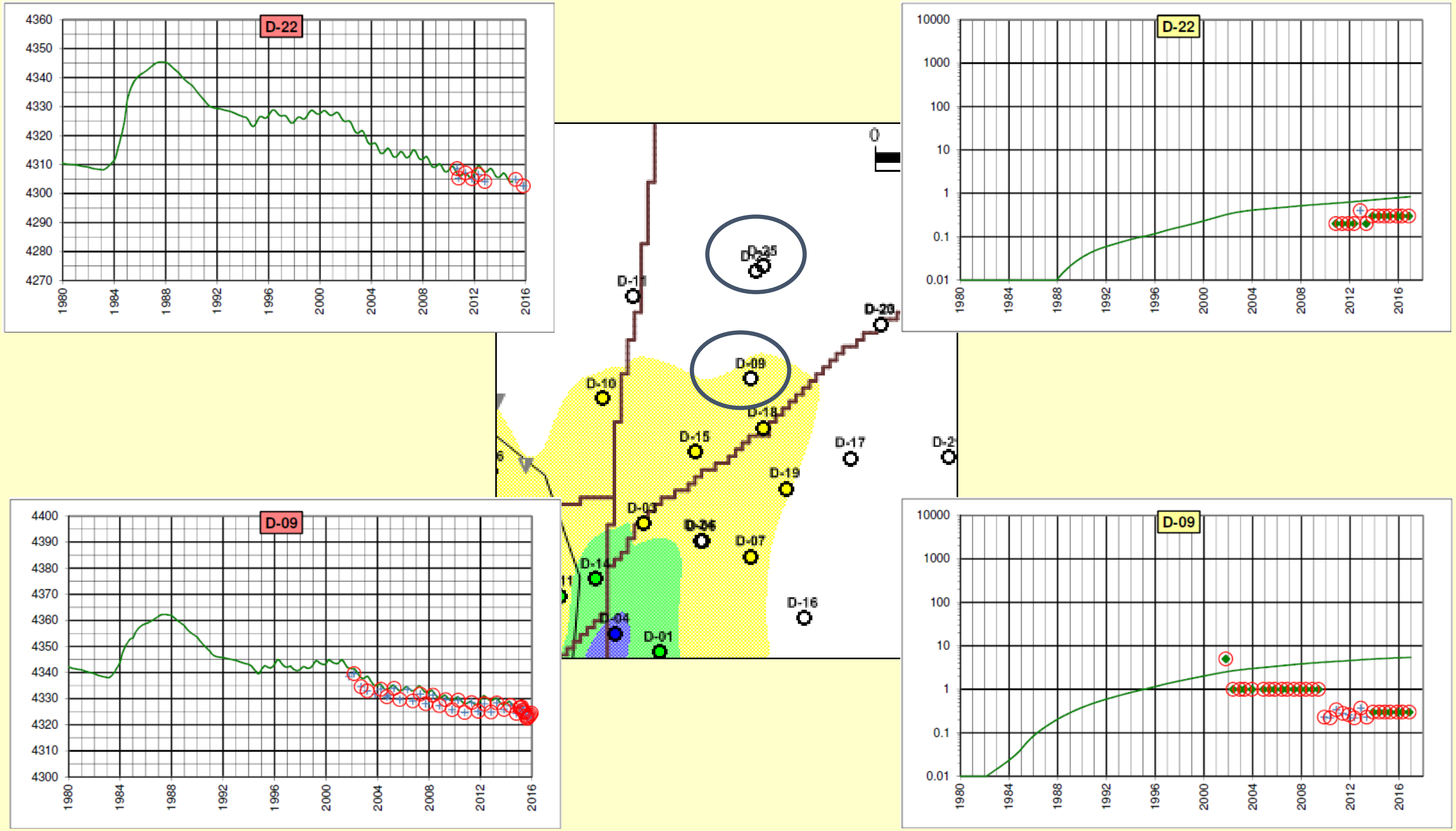
Kriged Measured Plume (late 2017)



Modeled Plume (late 2017)

Supporting Evidence for Degradation

note: accurate match with flow gradient resulted in over simulation of transport

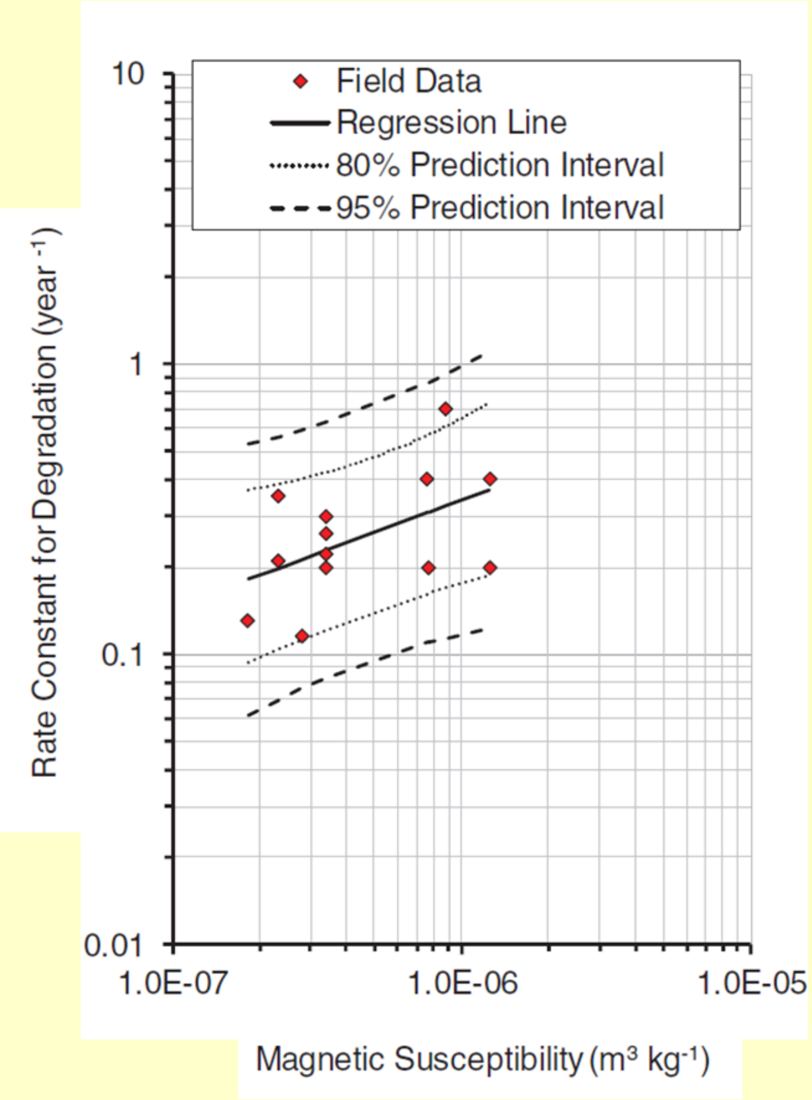


Supporting Evidence for Degradation

- 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

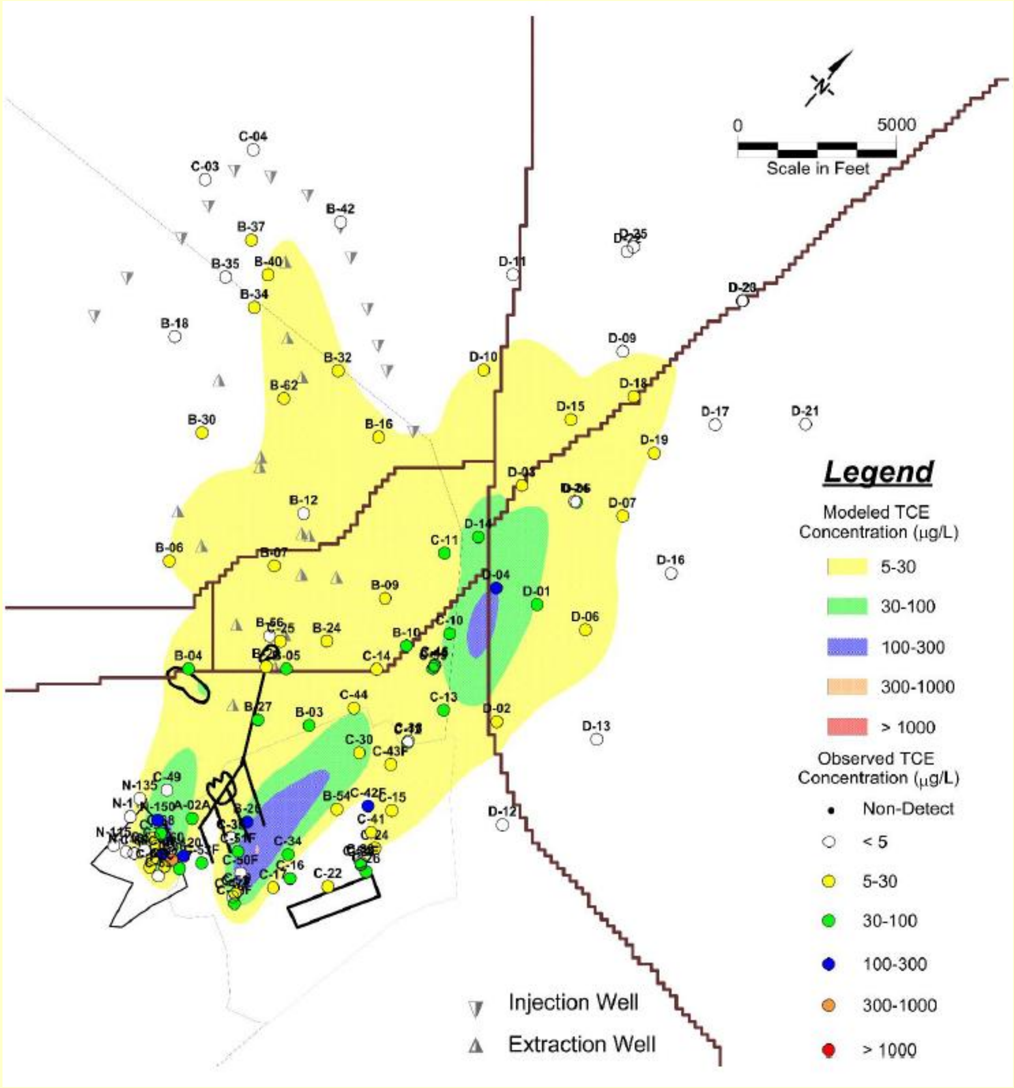
Supporting Physical Evidence for Degradation

- 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

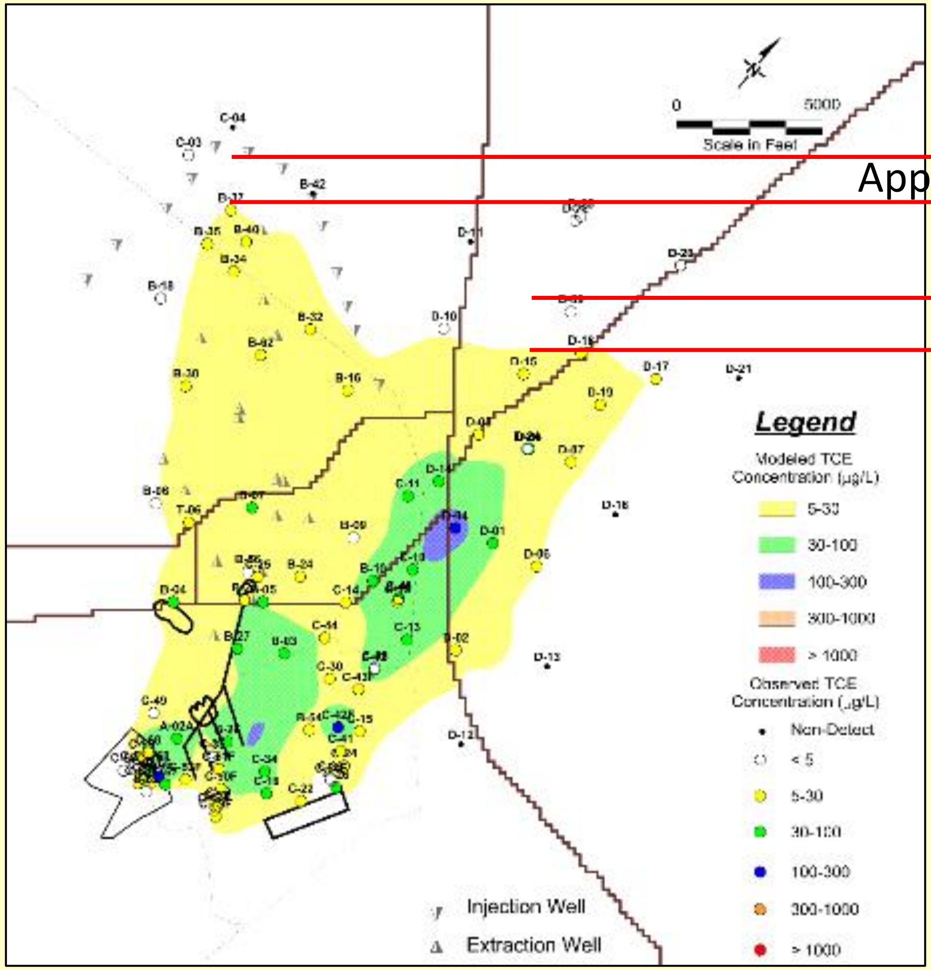


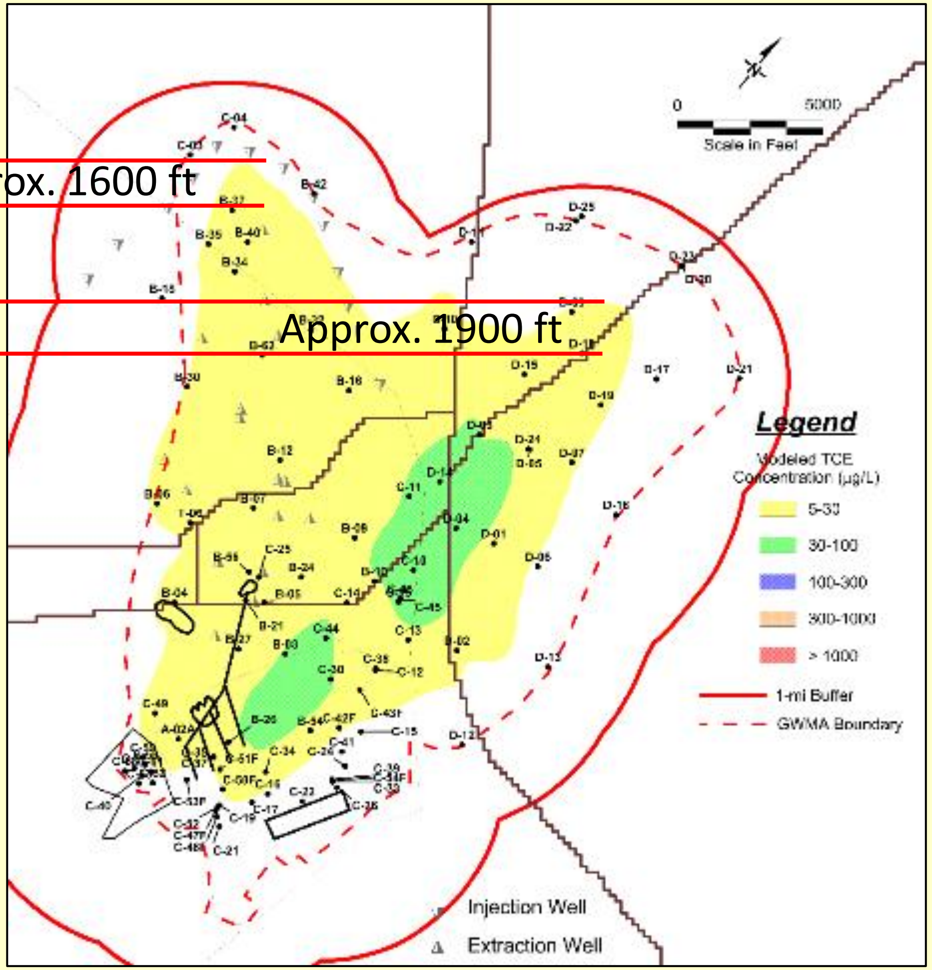
Planning Lead Time for Potential Remediation

- 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 <u>and</u> 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



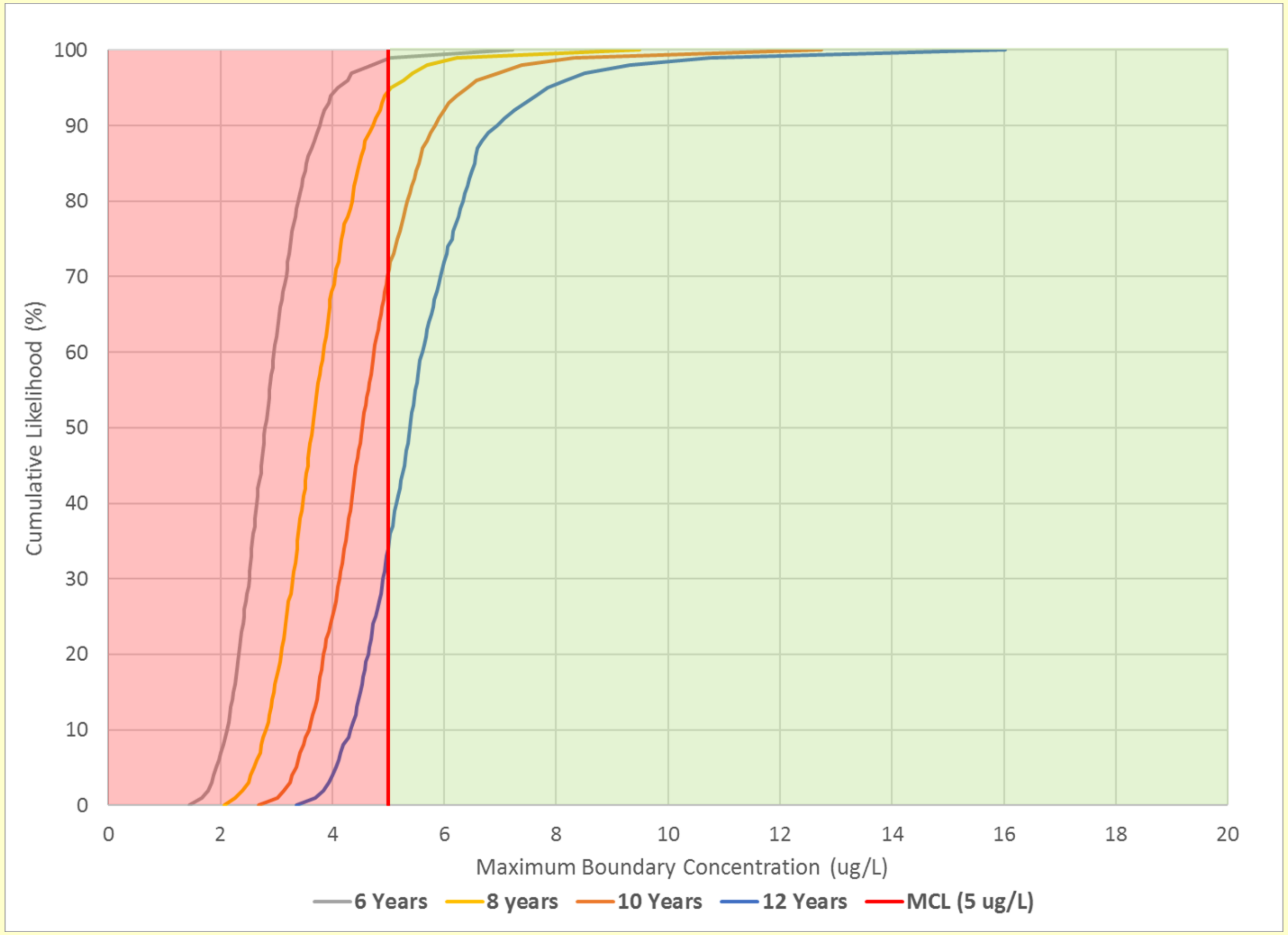


Approx. 1600 ft

Approx. 1900 ft

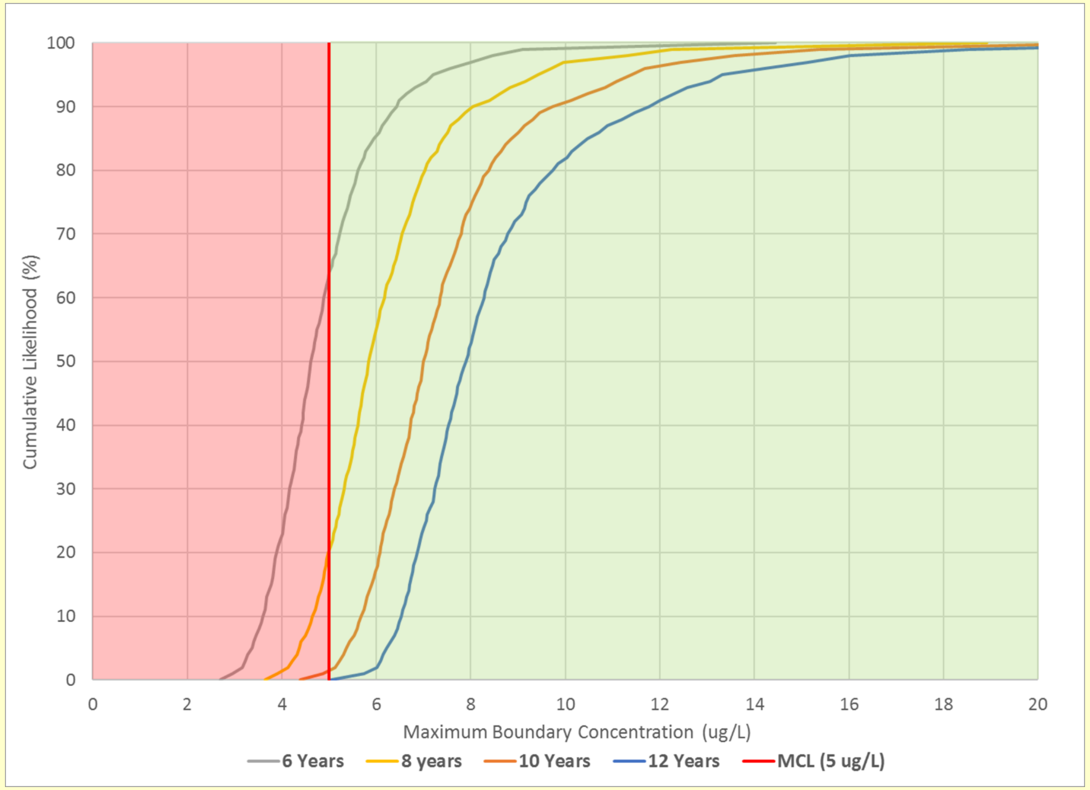
Planning Lead Time for Potential Remediation

1-Mile Buffer Boundary

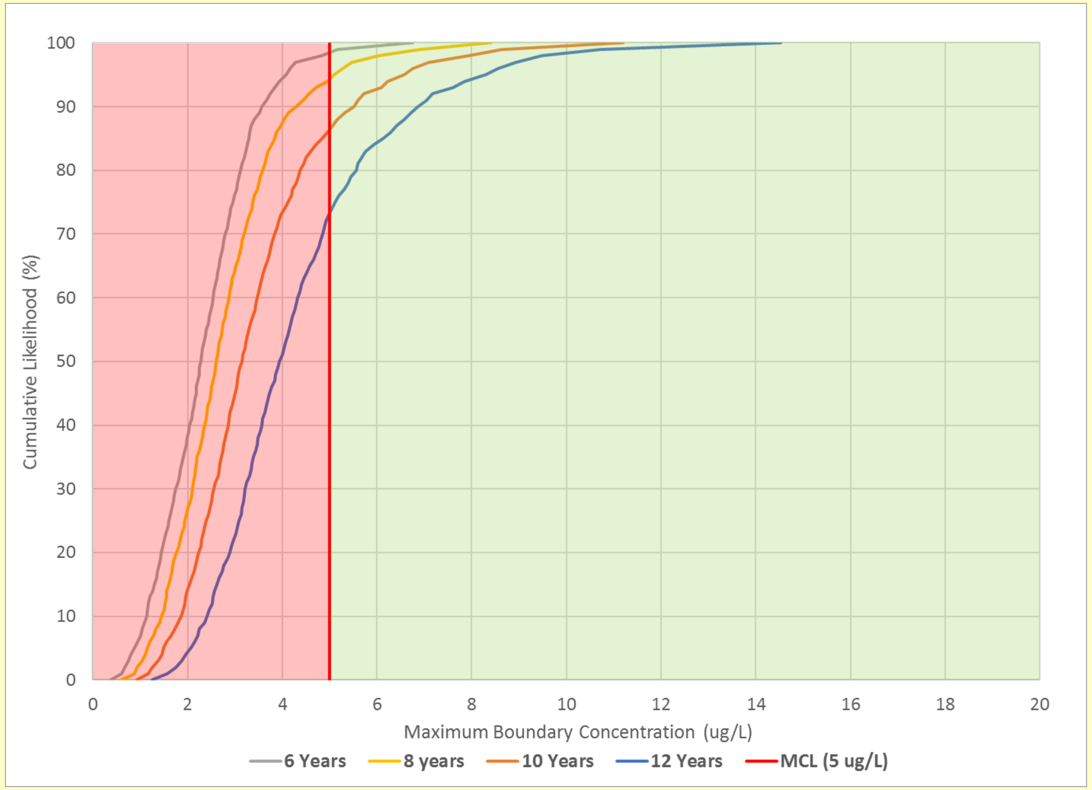


Planning Lead Time for Potential Remediation

GWMA Boundary



Main Plume



NEB Plume

Planning Lead Time for Potential Remediation

- 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?