NEVADA DIVISION OF
ENVIRONMENTAL PROTECTION

STATE OF NEVADA
Department of Conservation & Natural Resources
Brian Sandoval, Governor
Bradley Crowell, Director
Greg Lovato, Administrator

March 7, 2017

Jay A. Steinberg
Nevada Environmental Response Trust
35 East Wacker Drive, Suite 1550
Chicago, IL 60601

Re: **Tronox LLC (TRX) Facility**
Nevada Environmental Response Trust (Trust) Property
NDEP Facility ID #H-000539
Nevada Division of Environmental Protection (NDEP) Response to: *PHASE 5 TRANSIENT GROUNDWATER FLOW MODEL*

Dated: November 15, 2016

Dear Mr. Steinberg,

The NDEP has received and reviewed the Trust's above-identified Deliverable and provides comments in Attachment A. An annotated response-to-comments letter should be submitted by **05/07/2017** based on them found in Attachment A. The Trust should make sure that those comments will be addressed in next Deliverable on Phase 6 model.

Please contact the undersigned with any questions at wdong@ndep.nv.gov or 702-486-2850 x252.

Sincerely,

Dong

Weiquan Dong, P.E.
Bureau of Industrial Site Cleanup
NDEP-Las Vegas City Office

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Attachment A

Essential Corrections

1. The flow model must be able to simulate vertical gradients properly for contaminant transport modeling purposes. Measured and simulated vertical hydraulic gradients were calculated at selected locations where multilevel head data were measured. The locations of these sites are shown in Figure 1. Table 1 shows the measured and simulated vertical hydraulic gradients at these locations. Measured vertical gradients are generally upward which is consistent with the overall conceptual model. Five of the seven locations showed significant deviations between the simulated and measured magnitude by an order-of-magnitude or more. At site 1 the measured gradient was downward and the model simulated upward flow but with a magnitude near zero. The conclusion is that the model is able to generally match the vertical flow direction, but the magnitude of the vertical gradient tends to be under-predicted. The under-prediction is more pronounced at greater depths which may indicate that the model requires smaller vertical hydraulic conductivities in the deeper sediments or an explicit representation of a low permeable unit at depth. In summary, additional calibration is needed to properly simulate vertical gradients.
2. More effort is needed on the steady-state calibration. Steady-state calibration creates a balance between the boundary fluxes and hydraulic conductivity. It appears that there is a conceptual problem (or imbalance) in the lower model layers as evidenced by the large head residuals. The logic behind the comment is given in the following bullets:
    a. According to the Phase 5 modeling report the hydraulic conductivity field is largely dependent on the Phase 4 steady-state calibration. Reviewing the observed versus simulated groundwater level plot in the Phase 4 report (Figure 12 in the Phase 4 report and Figure 2 herein) there is evidence that the calibration was poorer in the lower layers (see red outline in Figure 2). The Phase 4 model relied on 2015 measured water levels so there were only a limited number in the lower layers so it did not appear to be a big problem.
    b. In the Phase 5 transient model a larger groundwater level dataset was used because the model covered a longer period (2000-2015). The calibration problems become more pronounced in the lower layers (Figure 17b in the Phase 5 report and Figure 3 herein) as shown in the points in the red outline of Figure 3. In general, the model is under-predicting hydraulic heads in the lower layers by as much as 70 feet.
    c. Inspection of the spatial distribution of the Phase 5 model head residuals (Figure 4) at early time (2000) in layer 1 suggests that calibration is quite good in the shallow aquifer. The magnitude of the residuals is small (few feet) and do not have any spatial bias.
    d. The calibration gets significantly worse in the lower model layers. Figure 5 shows the Phase 5 model residuals at early time (2000-2001) in layers 3-5. The residuals are larger and indicate under-prediction on the east side and a few over-predictions on the west side.
    e. In summary, the steady-state model calibration should be redone to reduce residuals in lower model layers. The goal should be residuals on the order of 10 feet in all layers.
3. The southernmost general head boundary conditions may need to be revisited as detailed below:

   a. It is not clear why the southern boundary condition was changed from a specified flow to general head between Phase 4 and 5. Generally specified flow up-gradient boundary conditions provide a more robust steady-state calibration as the assumed inflow must balance with the specified hydraulic conductivity. It can be difficult to specify the boundary fluxes with varying hydraulic conductivities and to properly simulate vertical gradients, but it may be worth revisiting to improve the lower layer calibration problems. At a minimum the report should state why the change was made from specified flow to general head boundaries and potential implications for the calibration.
   b. The southern general head boundary conditions are only applied to cells within the alluvium and UMCf-cg units. At first glance it seems reasonable to apply the general head boundary to coarse-grained units, but the hydraulic conductivity of the UMCf-fg is nearly the same as the UMCf-cg (0.72 versus 1.2 ft/day for UMCF-fg and UMCf-cg, respectively). Essentially there is a disconnect between the geologic conceptualization and hydraulic parameters used to define the coarse and fine-grained Muddy Creek deposits. The best solution would be to include boundary conditions to all geologic units. Otherwise, the Ramboll Environ should explain why this was not done.
   c. Section 5.4.1, 2nd paragraph, last sentence: Ramboll Environ states that the boundary fluxes were adjusted to achieve agreement between the simulated and conceptual water budget. General head boundaries require a head and conductance as input, so flux cannot be adjusted directly. Was the conductance adjusted during calibration? Reword this statement to clarify.
   d. It is not clear how the vertical gradients calculated in Appendix E-3 were applied to the southern general head boundary. Table 2 shows the heads applied to two cells along the southern boundary for each of the model layers. Gradients are both upward and downward in various layers but the linkage to Appendix E-3 is not clear. Were the vertical gradients averaged over time and then extrapolated to the boundary condition cells? This process and associated general head boundary conditions may be the cause of the poor calibration in the deeper portions of the model. Ramboll Environ need to provide more detail on how the vertical gradients were applied and discuss any implications of using relatively noisy head data as a basis for boundary conditions.
4. Ramboll Environ's transport modeling approach will be highly dependent on the temporal history of advective and diffusive transport to and from the UMCf. Ramboll Environ proposed using one-dimensional Hydrus results to help guide the MT3D dual-domain modeling. Though the Hydrus results are helpful to understand the processes that control contaminant migration to the UMCf, they will not be easily transferable to the MT3D modeling because of scale and abstraction issues. Appendix B describes a simplified modeling analysis to determine the efficacy of using MT3D's dual porosity approach without simulating the historical plume development. The results suggest that a current estimate of the immobile domain concentration can be used to initiate predictive modeling into the future. In the Phase 6 model Ramboll Environ should note the time period that will be simulated by the contaminant transport model. In other words, will they attempt to recreate the plume evolution or start with current conditions and simulate into the future.
5. Ramboll Environ is suggesting that density effects due to high TDS fluid may not be important for contaminant transport calculations. Generally, TDS concentrations greater than 10,000 mg/L

require density-dependent simulations. A review of the TDS concentrations in the second quarter of 2015 indicates that concentrations are as high as 78,000 mg/L is isolated areas and fairly large areas are in excess of 10,000 mg/L. Given these concentrations, it would be important to at least investigate the importance of density dependent solutions. This could be done with a simpler abstraction model to help quantify the effects. Ramboll Environ should include language in the report that a density-dependent model will at least be tested or otherwise provide a more detailed argument as to why a density-dependent model is not needed.

Minor Corrections/Comments

1. The evaporation rate from surface water was estimated as the reference ET for short grass multiplied by 1.05 (Allen et al., 1998), which yielded 78 in/yr. Ramboll Environ should consider subtracting precipitation from this estimate which would reduce the effective evaporation rate.
2. The Nevada Division of Water Resources well log database shows a number of wells drilled within the model domain. It may be worthwhile to see if there are any large capacity wells in the area.
3. Regional recharge rates were evaluated using the PRISM (PRISM Climate Group, 2017) precipitation model and an independent empirical recharge model that relates PRISM precipitation to groundwater recharge (Epstein et al., 2010). Ramboll Environ should at a minimum elaborate on the uncertainty associated with empirically derived recharge estimates and perhaps also refer to the Epstein et al., 2010 method results as an independent estimate of recharge (See Appendix A for more detail explanations about this comments).
4. Section 4.2, 2nd paragraph, 2nd to last sentence: What is meant by a vertical to lateral anisotropy ratio of 0.3 in this context. Ramboll Environ may want to note that this has nothing to do with anisotropy in hydraulic conductivity.
5. The geometric mean of the measured vertical hydraulic conductivity of the UMCf is 1.0×10^{-3} ft/day while the values used in the model are 7×10^{-2} and 1×10^{-1} ft/day for the UMCf-fg and UMCf-cg, respectively. The vertical conductivity used in the model is large relative to the measured values. Ramboll Environ should at least comment on the fact that the modeled value of vertical hydraulic conductivity is near the upper end of the measurements.
6. The stream package is being used with the ICALC parameter being negative such that stream stage is not being calculated based on flow. This has implications for solute transport modeling because solute mass flux into and out of the Las Vegas Wash cannot be simulated unless the fluid water balance is being calculated (i.e. ICALC > 0). The high resolution grid is such that the width of the Las Vegas Wash is larger than a model cell and calculation of stream stage is not support for parallel reaches in a single stream. The inability to simulate the fluid mass balance in the Las Vegas Wash will not allow one to simulate solute concentrations the Las Vegas Wash. This could be important if modeled concentrations in the Wash itself are needed to predict Lake Mead concentrations. The inability to simulate concentrations in the Las Vegas Wash should not have a significant impact on simulated solute migration in the aquifer. Ramboll Environ should discuss the implications of this limitation on future solute transport modeling.

References

PRISM Climate Group, 2017. Oregon State University, http://prism.oregonstate.edu, Copyright © 2016.

Epstein, B.J., G.M. Pohll, J. Huntington, and R.W.H. Carroll, 2010. Development and Uncertainty Analysis of an Empirical Recharge Prediction Model for Nevada's Desert Basins, Nevada Water Resources Association Journal.

Ramboll Environ, 2016. Phase 5 Transient Groundwater Flow Model – Nevada Environmental Response Trust Site Henderson, Nevada, 171p.

Tables

Table 1. Measured and simulated vertical gradients. Bold values represent significant deviations between simulated and measured magnitude and/or direction.

Site	Year	Depth (ft)	Measured Gradient		Simulated Gradient	
			Magnitude	Direction	Magnitude	Direction
1	2010	100	0.045	Down	**-0.001**	**Up**
1	2015	100	0.014	Down	0.005	Down
2	2015	50	-0.004	Up	**-0.062**	Up
2	2015	200	-0.355	Up	**-0.008**	Up
3	2010	300	-0.014	Up	-0.005	Up
4	2015	50	-0.191	Up	**-0.027**	Up
4	2015	200	-0.200	Up	**-0.004**	Up

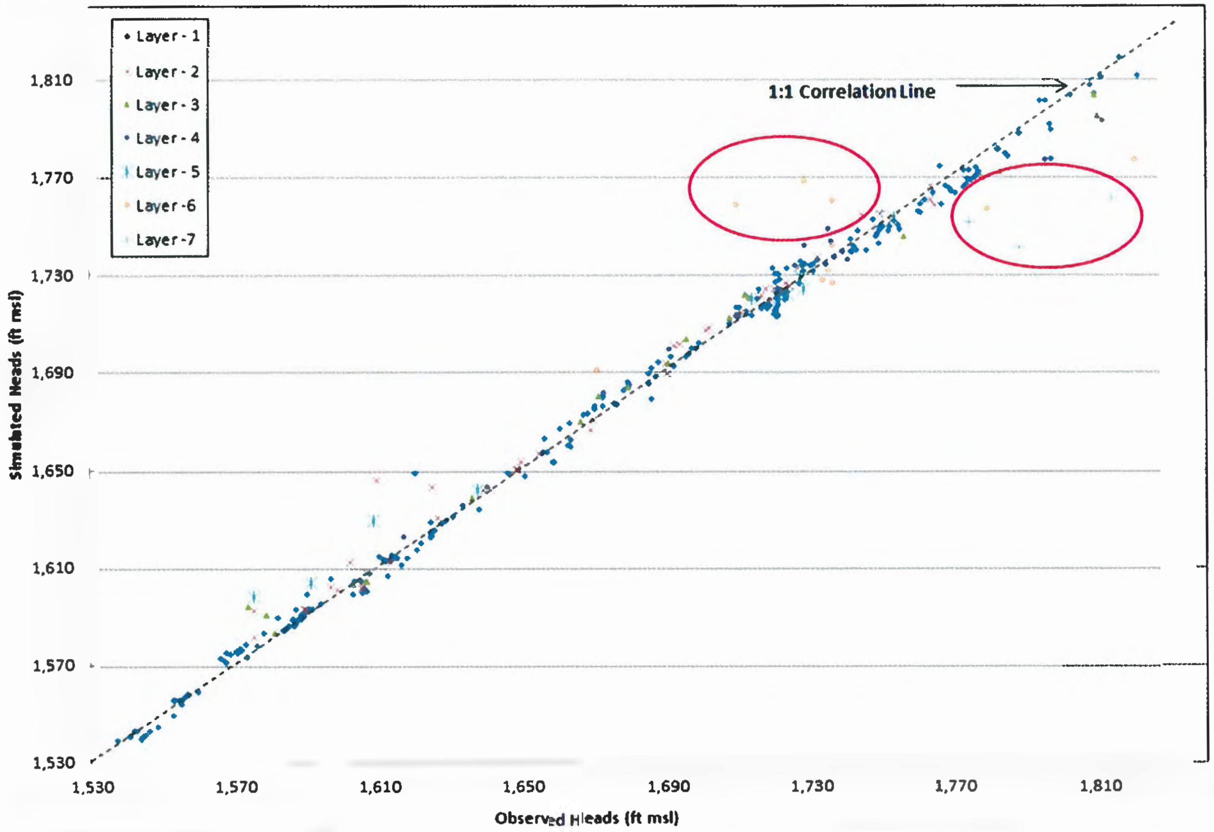
Table 2. Specified head values at selected general head boundary cells in the southern portion of the model.

Row	Column	Layer	Head (ft)	Notes
261	178	1	1957.8	
261	178	2	1877.1	
261	178	3	n/a	UMCf-fg - No GHB
261	178	4	n/a	UMCf-fg - No GHB
261	178	5	n/a	UMCf-fg - No GHB
261	178	6	1935.6	
261	178	7	1935.6	
282	72	1	2066.9	
282	72	2	2071.9	
282	72	3	2071.9	
282	72	4	1948.6	
282	72	5	1948.6	
282	72	6	1948.6	
282	72	7	n/a	UMCf-fg - No GHB

Figures

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 1. Location of sites where vertical hydraulic gradient was calculated.



RAMBOLL ENVIRON

OBSERVED VERSUS SIMULATED GROUNDWATER ELEVATION
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
12

Drafter: AS Date:09/30/2015 Contract Number: 21-38800C Approved: Revised:

Figure 2. Observed versus simulated groundwater levels from the Phase 4 steady-state model.

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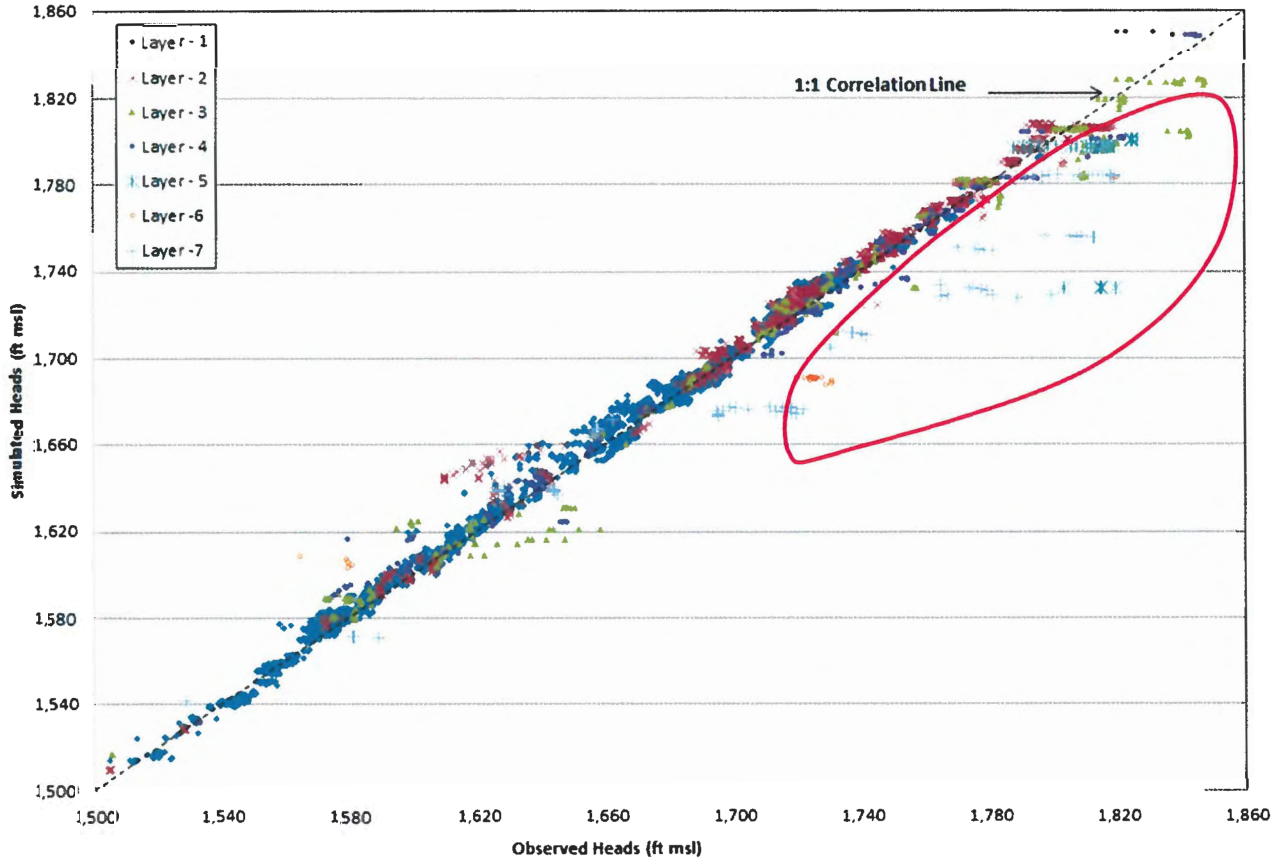


RAMBOLL ENVIRON

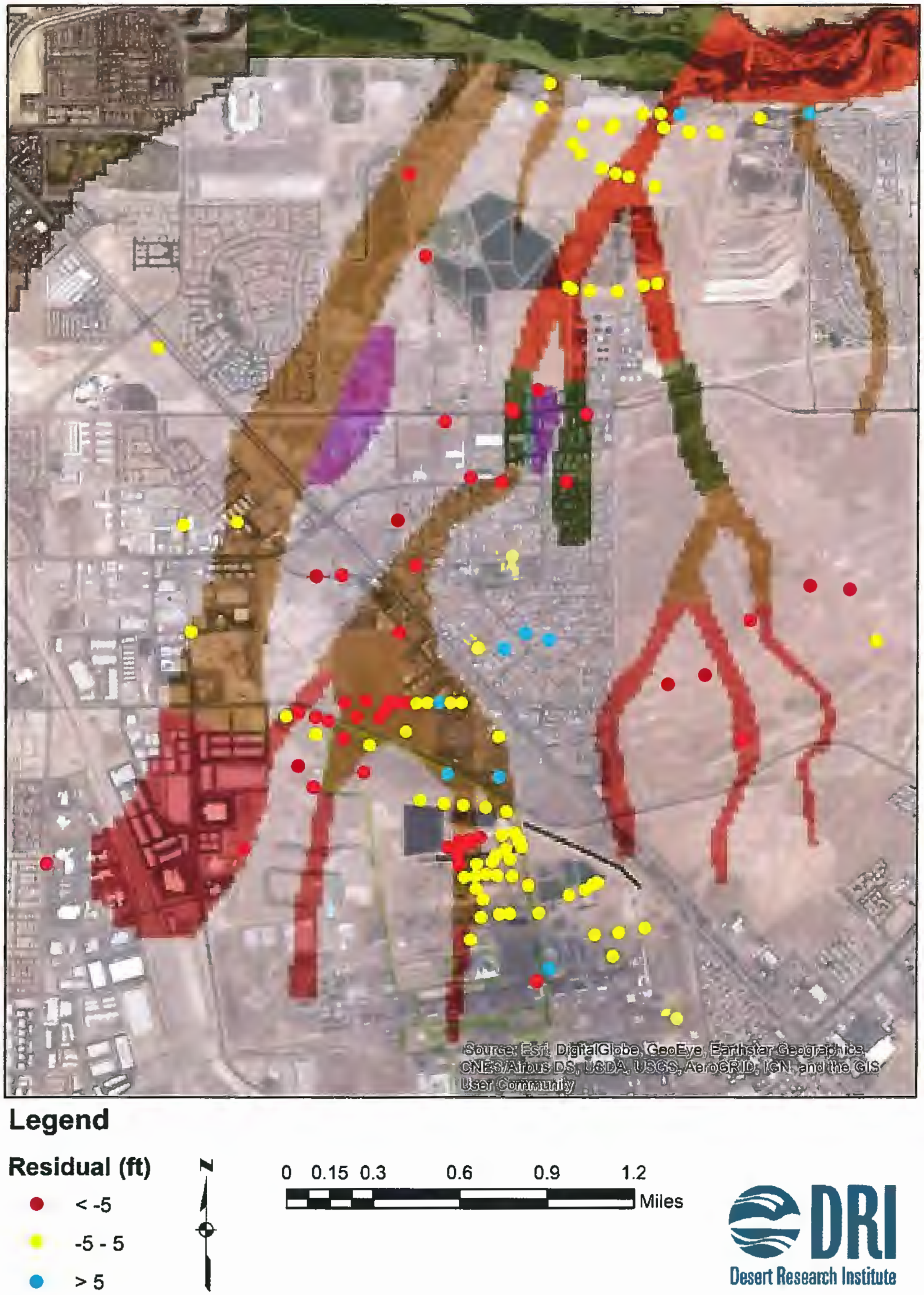
OBSERVED VERSUS SIMULATED GROUNDWATER ELEVATION

Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
17b

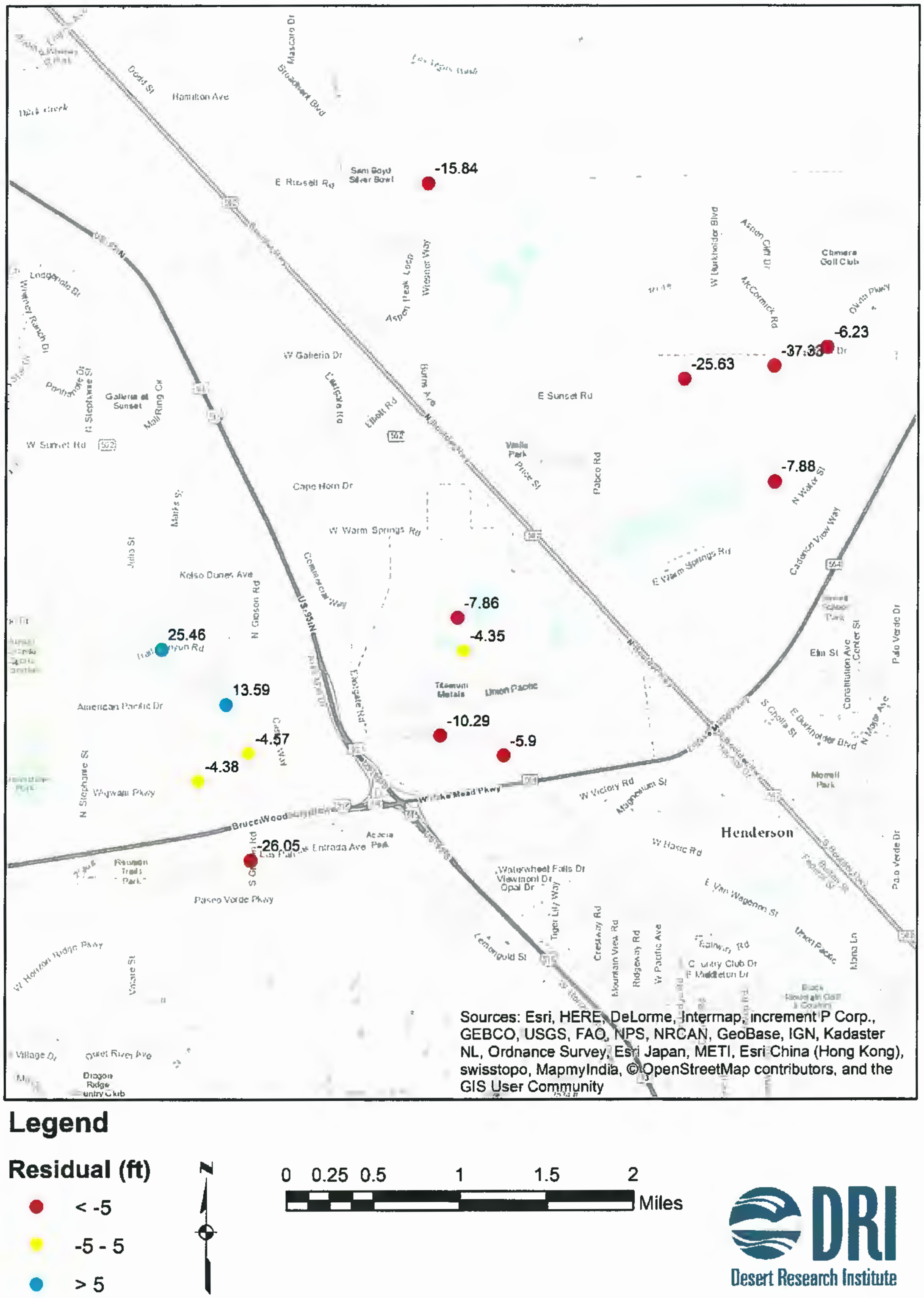
Drafter: AS
Date:10/5/2016
Contract Number: 21-38800C
Approved:
Revised:

Figure 3. Observed versus simulated groundwater levels from the Phase 5 transient model.



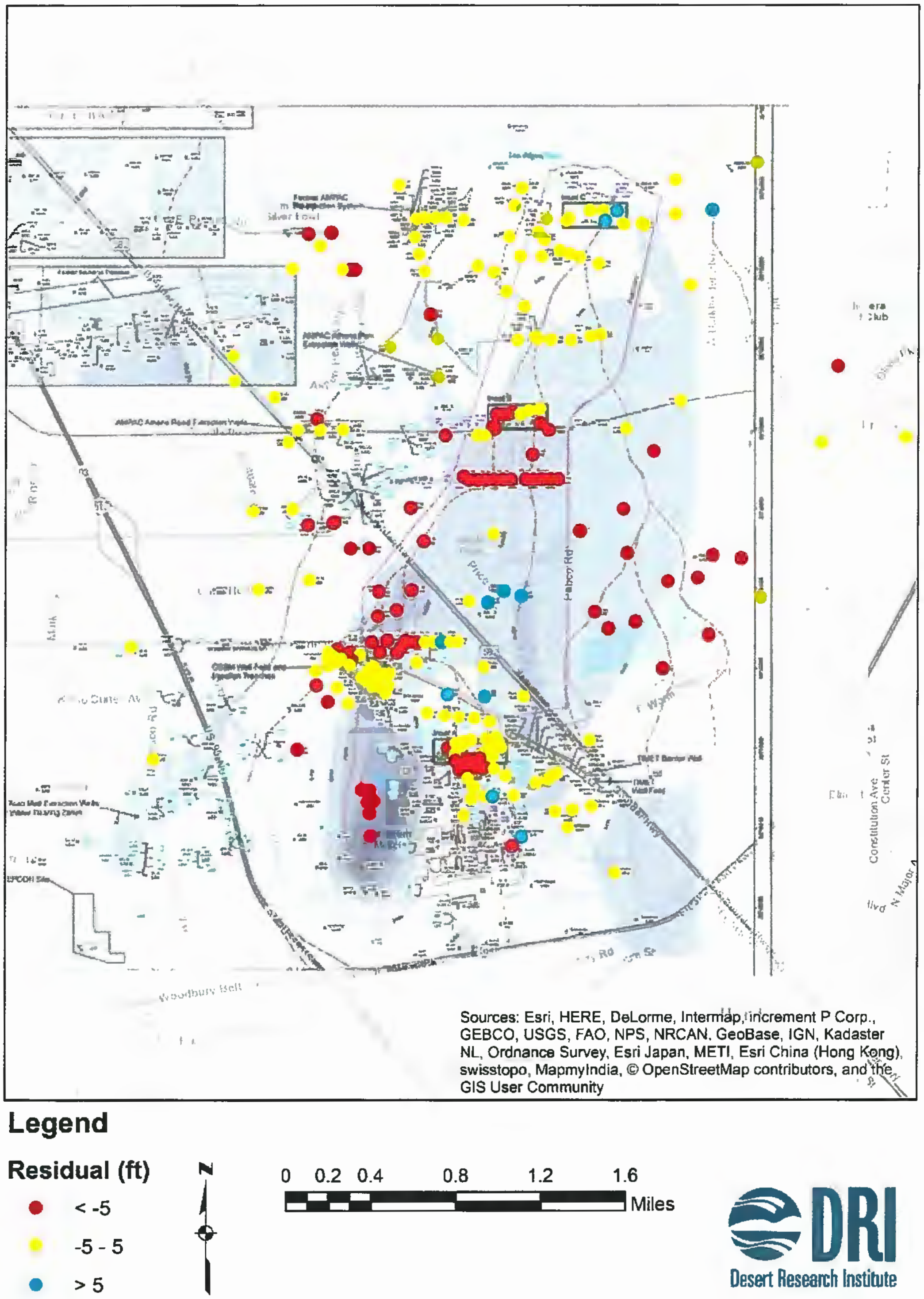
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 4. Early time (2000) from the NERT groundwater flow model in layer 1. Overlaid are the paleochannels. Positive residuals indicate that the model is under-predicting relative to the measured head value.



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 5. Early time (2000) from the NERT groundwater flow model in layers 3-5. Positive residuals indicate that the model is under-predicting relative to the measured head value. The number next to the measurement point represents the residual in feet.



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

DRI
Desert Research Institute

Figure 6. Early time (prior to 2005) residuals from the NERT groundwater flow model in layers 1. Also shown is a 2015 TDS isoconcentration map. Positive residuals indicate that the model is under-predicting relative to the measured head value. The number next to the measurement point represents the residual in feet.

Appendix A – Recharge Analysis

Groundwater recharge rates were evaluated at the regional scale to verify the conceptual water balance for the NERT model. The PRISM precipitation map (PRISM Climate Group, 2017) was used evaluate the spatial distribution of average annual precipitation. An independent empirical recharge model that relates PRISM precipitation to groundwater recharge (Epstein et al., 2010) was used to quantify recharge rates for each of the watershed areas identified in the modeling report (south, north, and west).

Figure A-1 shows the average annual precipitation as calculated by the PRISM model in relation to the three watershed areas. The eastern side of the valley generally has annual precipitation rates less than six inches. Precipitation increases on the west with annual rates in excess of 16 inches in the higher elevations.

The Epstein et al., 2010 method is similar to the Maxey-Eakin (1949) method in that it uses a simple additive linear model to estimate the quantity of water recharging an aquifer at the basin scale. These models lump many physical processes into one set of coefficients. Mathematically, the empirical model of Epstein et al. (2010) uses four annual precipitation zones (0 – 10, 10 – 20, 20 – 30, and greater than 30 inches). For each zone precipitation volume (rate times area) is multiplied by an empirically derived recharge coefficient to estimate groundwater recharge. Therefore, the recharge coefficients represent the fraction of precipitation that becomes recharge. The recharge coefficients are 0.019, 0.049, 0.195, and 0.629 for 0 – 10, 10 – 20, 20 – 30, and greater than 30 inches precipitation zones, respectively.

The Epstein et al., 2010 method also provides uncertainty estimates. These are typically presented as 95 percent confidence bounds, but other confidence intervals can be produced.

In a comparison of the Epstein et al., 2010 with Maxey-Eakin (1949), the Maxey-Eakin (1949) was found to produce the lowest error for basins with low-expected recharge, but the mean behavior of the Epstein et al., 2010 model was capable of explaining the highest percentage of recharge variability.

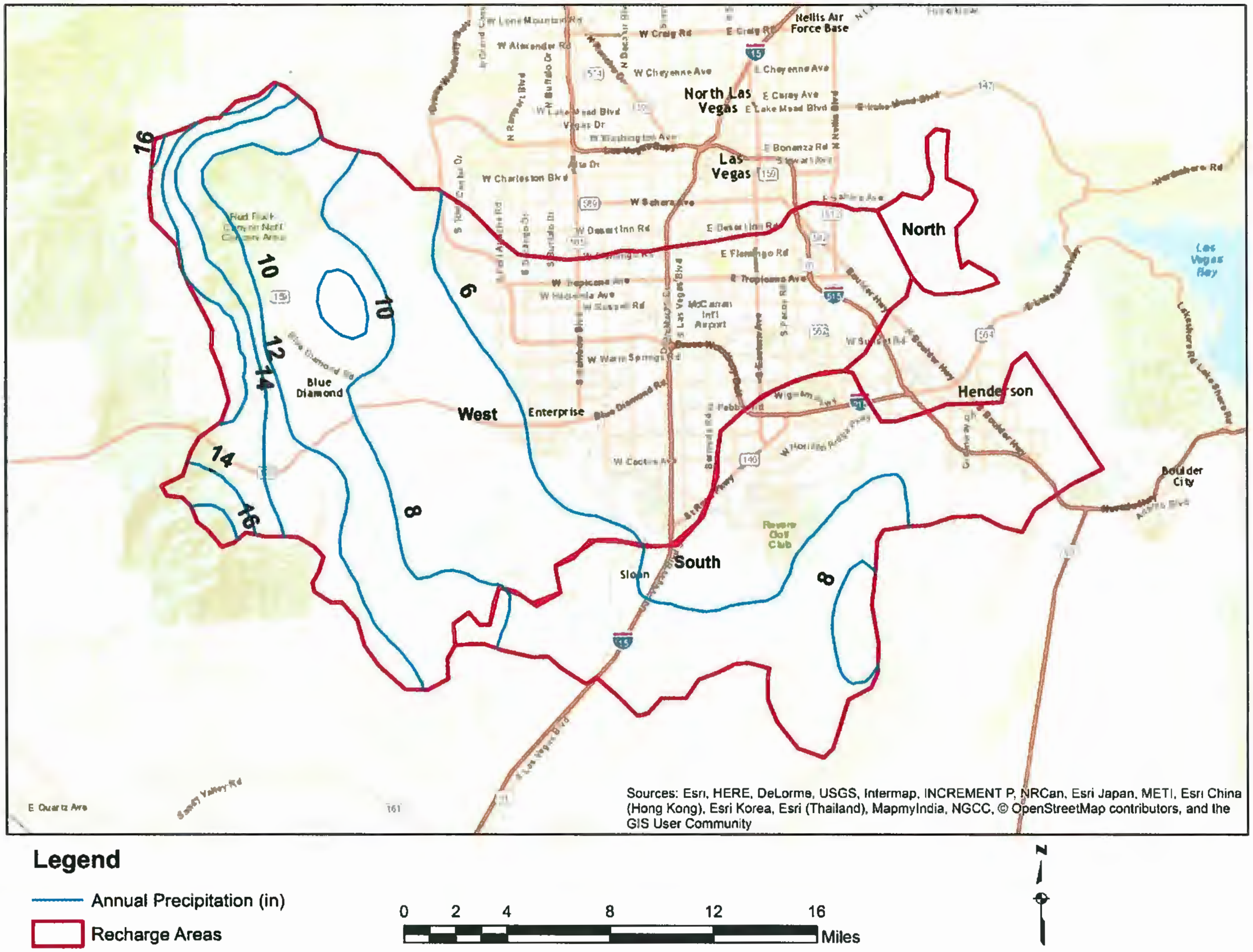
The Epstein et al., 2010 recharge estimates are generally similar to the Donovan and Katzer, 2000 method used to develop the NERT model estimates (see Table 1). The Epstein et al., 2010 method resulted in 61 acre-ft/yr versus 12 acre-ft/yr for Donovan and Katzer, 2000 in the northern watershed. Similarly, the Epstein et al., 2010 estimate was larger for the southern zone (1,182 versus 419 acre-ft/yr). In the western zone the Epstein et al., 2010 method yielded 4,060 acre-ft/yr while the Donovan and Katzer, 2000 method was 3,519 acre-ft/yr.

Although the resulting recharge estimates were different, a more important conclusion is that there is considerable uncertainty in the recharge rates. In the northern area recharge rates can vary between 0 – 129 acre-ft/yr. In the south, uncertainty is quite large with a range of 0 – 5,644 acre-ft/yr. Likewise, uncertainty in the western area is large with a range of 1,882 - 6,653 acre-ft/yr. These results would indicate that there is a rather large range over which recharge rates could be varied to achieve an acceptable groundwater model calibration.

Table A-1. Calculated recharge rates for the three watershed areas using the Epstein et al., 2010 method and associated 95 percent uncertainty bounds. The results are compared to the boundary fluxes used in the NERT model (i.e. modeled recharge column).

Zone	**Area (acres)**	**Recharge (acre-ft/yr)**	**Epstein Lower**	**Upper**	**Modeled Recharge (acre-ft/yr)**
North	8,136	61	0	129	12
South	119,924	1,182	0	5,644	419
West	226,967	4,060	1,882	6,653	3,519
Total:	**355,027**	**5,303**	**1,882**	**12,426**	**3,950**

Figure A-1. Recharge areas and average annual precipitation (PRISM Climate Group, 2017).



Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community

Appendix B – Transport Analysis

A simple two-dimensional cross-sectional model was constructed to better understand the efficacy of using MT3D's dual porosity approach for the NERT Site. The model geometry generally represents the NERT Site as shown in Figure B-1. The upper layer represents the alluvial aquifer (Qal) with high hydraulic conductivity (100 m/day) and the lower layer represents the Muddy Creek formation (UMCf) with a hydraulic conductivity of 1 m/day. The flow system is defined by an up-gradient specified head boundary across all layers and another in the uppermost layer to represent a discharge point at the Las Vegas Wash using a regional gradient of 0.02. The simplified flow system is solved in MODFLOW and the fluxes are used in MT3D to simulate long-term contaminant migration.

The purpose of the simplified simulation is to determine if the initial condition in the immobile domain could be estimated rather than performing a long-term historical simulation to develop the diffusive migration from the alluvial aquifer into the UMCf.

Three simulations are developed including:

1. No immobile domain.
2. Immobile domain included with full historical simulation to allow the development of the contaminant in the immobile domain.
3. Immobile domain included but with a simplified initial condition in the immobile domain and upper zone (Qal) already flushed out.

Transport parameters for all three simulations include:

- Effective porosity of 0.1 and 0.4 for the Qal and UMCf, respectively.
- Longitudinal dispersivity of 100 m
- No sorption or decay.
- Immobile porosity of 0.4.
- Mobile/immobile mass transfer coefficient is 10^{-5} day^{-1}.

The initial conditions for Simulation 1 is:

- 1000 mg/L in Qal (mobile)
- 1 mg/L in UMCf (mobile)
- 0 mg/L everywhere (immobile)

The initial conditions for Simulation 2 is:

- 1000 mg/L in Qal (mobile)
- 1 mg/L in UMCf (mobile)
- 0 mg/L everywhere (immobile)

The initial conditions for Simulation 3 is:

- 1 mg/L in Qal (mobile)
- 1 mg/L in UMCf (mobile)
- 0 mg/L in Qal (immobile)
- 20 mg/L UMCf (immobile) – The approximates the peak concentration in the central portion of the UMCf for the immobile domain as determined in Simulation #2.

Simulated breakthrough curves for the mobile domain at the Las Vegas Wash are shown in Figure B-2. Without mass transfer to an immobile domain in Simulation #1 breakthrough is more rapid and concentrations decrease rapidly at late time. When mass transfer to an immobile domain is included in Simulation #2 the early time (first 40 years) behavior is nearly identical to Simulation #1, but a long tail exists in the late-time breakthrough. This behavior is consistent with the concentrations measured at Northshore Road. Figure B-3 shows the simulated immobile domain concentrations in the central portion of the UMCf (see Figure B-1). As expected, the immobile domain concentrations increase rapidly over the first five years due to diffusion. Though the peak concentration at this location is nearly 15 mg/L, peak concentrations vary throughout the transect with higher peak concentrations occurring down gradient.

In Simulation #3 it is assumed that a majority of the contaminant mass has discharged to the Las Vegas Wash and the remaining mass is held in the immobile zone within the UMCf. This simulation tries to mimic the late time behavior seen in Simulation #2 by estimating the initial condition in the immobile zone. After approximately 50 years Simulation #3 is able to match the down-gradient concentrations reasonably well.

The conclusion from the analysis is that late time breakthrough behavior can be simulated reasonably well without simulating the full historical development of the plume in the mobile and immobile domains. Some fidelity is lost with this simplification, but given the large uncertainty in the pre-2000 flow field at the NERT site, this approach may be more appropriate.

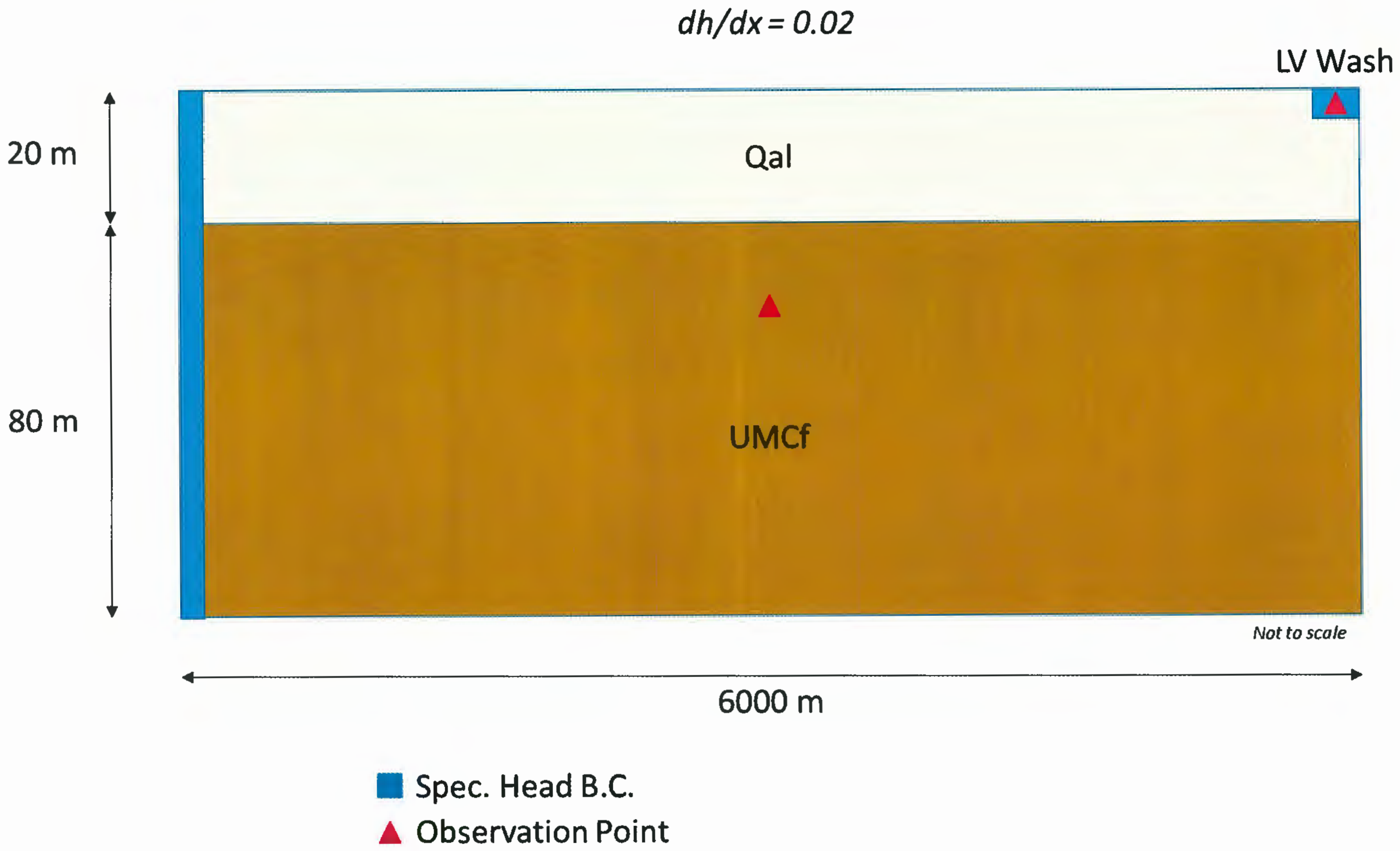


Figure B-1. Conceptual diagram of the aquifer

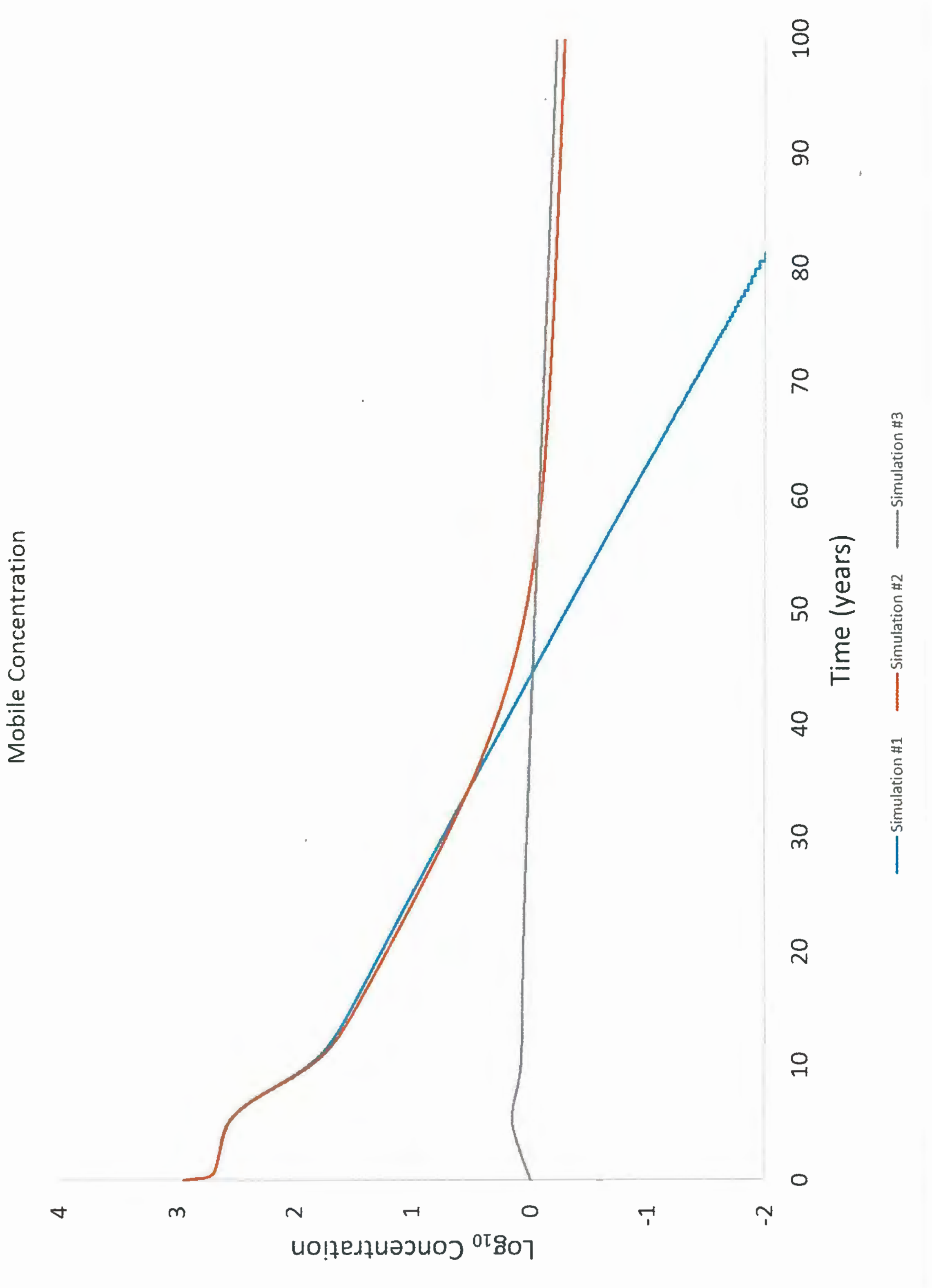


Figure B-2. Simulated breakthrough curve at the Las Vegas Wash in the mobile domain for the three simulations.

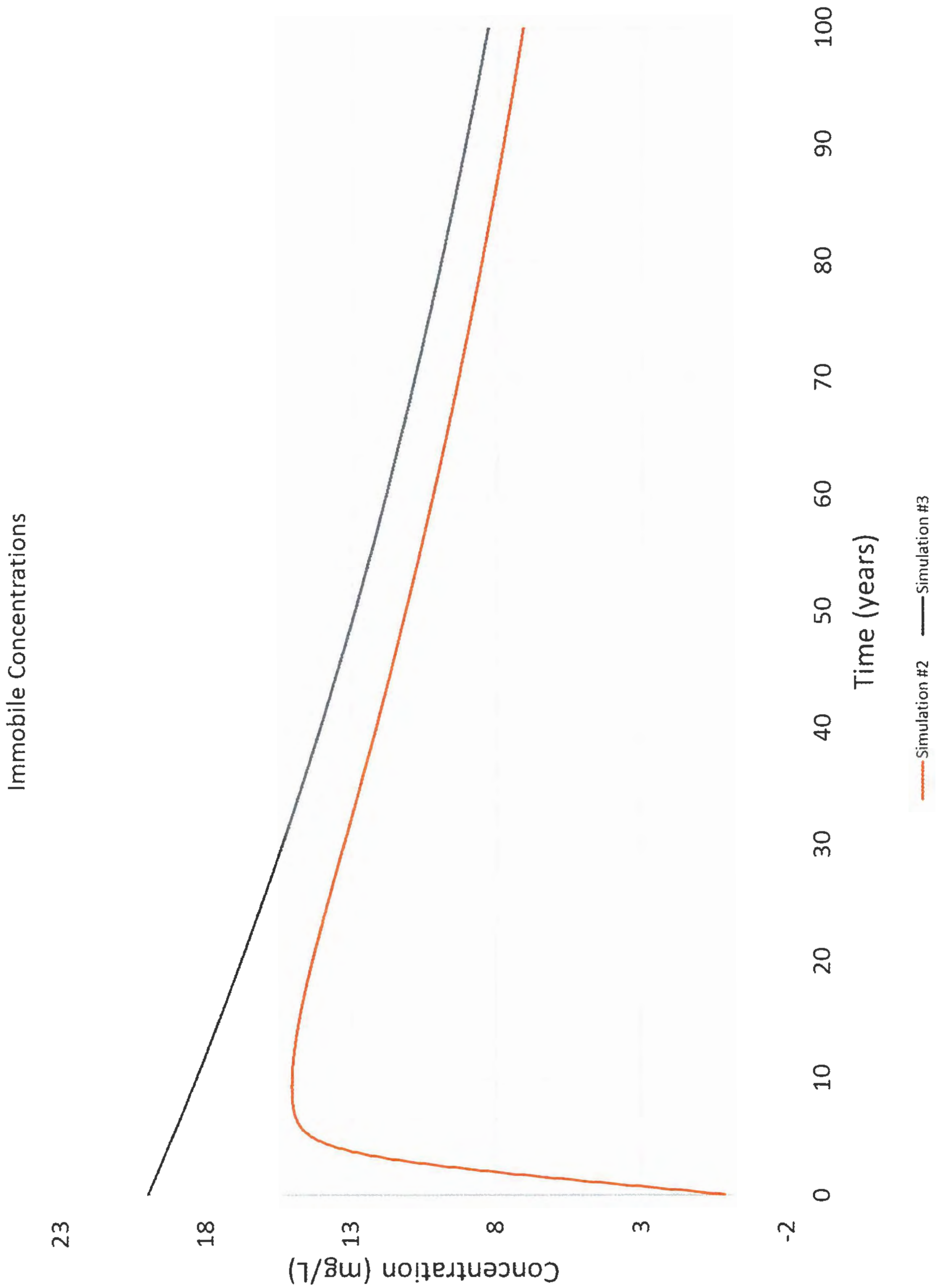


Figure B-3. Simulated concentrations in the central portion of the UMCf for immobile domain for Simulations 2 and 3.