NEVADA DIVISION OF
ENVIRONMENTAL PROTECTION

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

July 22, 2020

Jay A. Steinberg
Nevada Environmental Response Trust
35 East Wacker Drive, Suite 690
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 6 Groundwater Flow and Transport model*

Dated: November 27, 2019

Dear Mr. Steinberg,

The NDEP has received and reviewed the Trust's above-identified Deliverable and provides comments in Attachments 1 and 2. The comments in Attachment 2 were sent to NDEP by the Stakeholders-Metropolitan Water District of Southern California and NDEP concurs with those comments. NDEP asks that the Trust only provides an annotated response-to-comments letter and the actions for next phase model based on the facts of on-going remediation investigations and new data associated those investigations that will be incorporated in next phase model.

Please contact the undersigned with any questions at wdong@ndep.nv.gov or 702-668-3929.

Sincerely,

Dong Weiquan

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

WD:cp

EC:
Jeffrey Kinder, Deputy Administrator NDEP
Frederick Perdomo, Deputy Administrator NDEP
James Dotchin, NDEP BISC Las Vegas
Carlton Parker, NDEP BISC Las Vegas
Allan Delorme, Ramboll Environ
Alison Fong, U.S. Environmental Protection Agency, Region 9
Andrew Barnes, Geosyntec
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John Pekala, Ramboll Environ
John Solvie, Calrk County Water Quasslity
Kelly McIntosh,GEI Consultants
Kirk Stowers, Broadbent & Associates
Kirsten Lockhart, Neptune & Company Inc.
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Nicholas Pogoncheff, PES Environmental, Inc.
Orestes Morfin, CAP
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within 15%. The comparison between simulated and conceptual discharge to the Wash should be clearly stated in the Deliverable. If the actual difference between the conceptual and simulated discharge to the Wash is as presented in Table 3.2 above, this suggests that Phase 6 Model may significantly under predict groundwater discharge to the Wash and that there is room to improve the model calibration in this regard as the simulated groundwater discharge to the wash does not meet the stated calibration objective in section 6.1 of the Deliverable, "to match simulated groundwater discharge to Wash within 15% of conceptual estimates". It is recommended that this potential for improvement be considered in developing the Phase 7 Model.

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8. The vertical gradients may have an important influence on movement of perchlorate from source areas, and the accurate simulation of vertical gradients is critical to the success of the transport model. Therefore, for the Phase 7 Model, it is recommended that bottom boundary condition be further evaluated with respect to upward groundwater flow from depth and that justification be provided for the selection of the bottom boundary condition. In addition, as described in Section 3.2, the match to observed vertical gradients based on actual simulated groundwater elevations shows room for improvement, and revising the bottom boundary condition from no flow to specified flux, for example, may help in this regard in developing the Phase 7 Model.

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13. The results of model calibration are presented and described in Section 6.4 (pp. 40-42) with a focus on comparing model results to the conceptual model using the tolerances stated as the calibration objectives stated in Section 6.1. There are several statements and

conclusions presented here that are difficult to interpret and/or are incomplete, including those listed below. Calibrated model flow rates are summarized in attached Table 1.

a. Simulated pumping rates are not compared to measured rates as stated (and the call to Table 3 appears to be incorrect).
b. The simulated groundwater discharge rate appears to differ from the rate in the conceptual model by 26%, not within 15% as stated.
c. Compared to the Phase 5 model, the Phase 6 model simulates much higher boundary flow rates at the southern boundary and groundwater discharge rates to the wash. This difference, and the important implications that it will have for simulated groundwater velocities and transport distances are not discussed, even if these velocities are a better representation of site conditions. Note that horizontal hydraulic conductivities are also increased in the Phase 6 model, which also can contribute to higher flow rates and velocities.
d. Although simulation of heads has improved in the Phase 6 model, the simulation of vertical hydraulic gradients remains a challenge. The conclusion that Figure 6-5 demonstrates an "acceptable fit except a few outliers" is an incomplete presentation of the results, especially because "acceptable" is not defined. As shown in attached Figure 2, all of the measured vertical gradients in the deep zone, which all direct flow upward, are under-predicted by the model. In addition, gradients at over half of the measurement locations in the middle zone that indicate upward flow, are also under-predicted. Although most simulated gradients in the shallow zone show little bias, all of the observed upward gradients are under-predicted by the model (attached Figure 3). Most of these points are located in the NERT source area and source areas to the west, as shown in attached Figures 4 and 5. In combination with the relative small difference in hydraulic conductivity of the alluvium, UMCf-cg, and UMCf-fg, these vertical gradients may have an important influence on movement of perchlorate from the release sites into the underlying units and their accurate simulation is critical to the success of the transport model.

14. The Phase 6 flow model has reached a level of sophistication and parameterization that automated calibration and parameter estimation is warranted and should be carefully considered for the next modeling phase. An extended analysis of this type will also provide a much more comprehensive description of model sensitivity than is currently provided. Furthermore, results of a sensitivity analysis can be utilized to more effectively evaluate and guide future data collection and analysis efforts.

15. Conceptual Model of Transport. In addition to the process of back-diffusion, the observed upward-directed vertical hydraulic gradients are described as an important mechanism for migration of perchlorate from the UMCf to the overlying alluvium. However, the groundwater flow model under-predicts this important aspect of the conceptual model of transport, so further evaluation and discussion of the interplay between vertical groundwater flow and the back-diffusion processes is needed. This is mentioned as being planned for more detailed description in forthcoming RI reports (Section 7.1, p. 45). These

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14. The Phase 6 flow model has reached a level of sophistication and parameterization that automated calibration and parameter estimation is warranted and should be carefully considered for the next modeling phase. An extended analysis of this type will also provide a much more comprehensive description of model sensitivity than is currently provided. Furthermore, results of a sensitivity analysis can be utilized to more effectively evaluate and guide future data collection and analysis efforts.

15. Conceptual Model of Transport. In addition to the process of back-diffusion, the observed upward-directed vertical hydraulic gradients are described as an important mechanism for migration of perchlorate from the UMCf to the overlying alluvium. However, the groundwater flow model under-predicts this important aspect of the conceptual model of transport, so further evaluation and discussion of the interplay between vertical groundwater flow and the back-diffusion processes is needed. This is mentioned as being planned for more detailed description in forthcoming RI reports (Section 7.1, p. 45). These

processes were briefly addressed in the NDEP comments to the Phase 5 model and should be modeled in more detail as part of the NERT transport modeling process.

16. An evaluation of density-driven flow is presented in Appendix A. There are several aspects of the model used for this evaluation that are not clear and therefore the results do not currently provide a strong case for not including density-driven flow in the NERT model. For example, the configuration of the boundaries is uncertain (Figure A-1, Appendix A). Because they are no-flow, they appear to be boundaries parallel to the mean flow direction (given that this is a 3-D model), thought the assigned heads in the top layer of each boundary suggests that they may be the up- and down-gradient boundaries. If so, then groundwater flow is allowed into the model only in the uppermost layer at the presumed southern boundary, which is an oversimplification of the system. Also, the 50,000 mg/L source is applied only at the top of the alluvium layer and vertical hydraulic gradients are not included.

17. Numerical Model of Transport. The simulation period for the transport model from 2014 through 2018 begins long after perchlorate contamination began at the NERT site and the report does not describe how observed concentrations and their spatial distributions are changing during this simulation period as compared to previous years (Section 8.2, p. 49). For example, is there evidence that the plumes are fairly stable or do they continue to expand? If concentrations are reasonably stable during the simulation period, then the model may be easier to calibrate during this simulation period but may not be adequately calibrated for forecasting future transport when concentrations may be expected to change to a greater degree. To test the model's ability to simulate developing and spreading plumes, the modeling team should consider running a transient transport scenario that incorporates the calibrated transport parameters with a steady-state groundwater flow condition. Using a set of approximations of the initial transport condition, this effort may be useful for comparing to the observed transport history and for identifying whether the model's transport processes are adequately simulating responses under changing transport conditions.

    The dual-domain mass transfer approach for modeling perchlorate transport (Section 8.4.1, p. 49) is an appropriate choice for the NERT transport model.

    Because advection-dominated transport simulations rely heavily on the values of effective porosity (Section 8.4.1, p. 49), it is strongly recommended that these values be measured onsite, rather than derived from specific yield and/or total porosity values. Field tracer tests utilizing single or dual-well configurations are relatively easy to implement and could be performed at numerous wells along the primary flow paths. In addition, implementation of a multi-year natural gradient tracer test where the source concentration is known can provide parameter estimates at the scale of contaminant transport at the NERT site. Analysis of these test results to determine site-specific effective porosity will provide greater confidence in the results of the transport model, particularly for forecasting future transport.

18. Assumptions about the initial perchlorate concentrations in the mobile and immobile phases (Section 8.4.3, p. 51) are also critical to the success of the transport model and warrant further discussion and justification using local-scale models. Assigning equal concentrations to the mobile and immobile phases in the first year assumes that equilibrium conditions exist between the two phases. However, the concentrations in the immobile zone are then adjusted manually during calibration. There is no discussion of whether the immobile concentrations chosen during calibration are reasonable or consistent with the conceptual transport model.

    Values for other transport parameters are presented in Section 8.4.4 (p. 51). however, no context is given for the choices of mass transfer coefficient. NDEP suggests that NERT analyze all tracer studies and NMR logging data conducted at the NERT site to derive porosity values for the mobile and immobile phases of the dual-porosity formulation and use the results for next phase of transport modeling. If the existing tracer studies are insufficient to characterize the dual-porosity parameters, then NDEP suggests that a multi-year natural gradient tracer test where the source concentration is known can provide parameter estimates at the scale of contaminant transport at the NERT site.

19. The contaminant transport model calibration to observed perchlorate concentrations is based on weighted simulated concentrations and not actual simulated concentrations. Like the groundwater flow model calibration target residual statistics (see Section 3.1), the contaminant transport model calibration target residual statistics presented in Table 11 of the Deliverable are based on weighted residuals and not actual residuals. Actual transport calibration residuals, weighted transport calibration residuals, and weighted simulated concentrations are calculated in the same fashion as in Equations 1, 2, and 3, above, except actual simulated and observed concentrations replace the actual simulated and observed groundwater elevations. The contaminant transport model calibration results as presented in the Deliverable are based on weighted residuals and weighted simulated perchlorate concentrations, which is not an industry standard practice. Presenting the contaminant transport model calibration results in terms of the weighted residuals and weighted simulated perchlorate concentrations makes the Phase 6 Model appear better calibrated than it really is. When the contaminant transport model calibration results are presented in terms of actual residuals and actual simulated perchlorate concentrations, there appears to be room for improvement in the contaminant transport model calibration. It is recommended that actual residuals and actual simulated perchlorate concentrations be applied in developing the Phase 7 Model, which would increase confidence in its application in evaluating alternative remedial designs.

    Given the use of weighted simulated concentrations identified for technical clarification 4 above, it is unclear whether the contaminant transport model calibration to observed mass discharge to the Wash is based on weighted simulated concentrations or actual simulated concentrations. Model calibration to observed mass loading to the Wash from groundwater discharge is significant for demonstrating the reliability of the Phase 6 Model to simulate the impact of potential remedial designs. However, the Deliverable is unclear on the method used to calculate perchlorate mass loading to the Wash. Given that weighted simulated concentrations, not actual simulated concentrations, were presented in the Deliverable, it raises the concern that weighted simulated concentrations may have been applied to calculate the simulated mass loading to the Wash and other potential discharge locations.

20. For the eastern model domain boundary, the Deliverable states that "The simulated groundwater perchlorate discharge leaving the model domain at the eastern boundary is approximately 2-3 lbs/d during the model simulation period (Table 13). This has been estimate based on the total simulated flow in the outflow boundary at the east model boundary (Figures 5-11 and 5-12) and the average simulated perchlorate concentrations in wells WMW3.5N and WMW3.5S".

    The above statement from the Deliverable confirms that the weighted simulated concentrations were used to estimate the mass loading to the eastern model boundary and further implies that weighted simulated concentrations may have been used throughout (and in particular for the mass discharge to the Wash). Therefore, it is recommended that clarification be provided such that the reader can clearly understand the method applied to calculate the simulated mass loading from groundwater discharge to the Wash. Where it is reported that weighted simulated concentrations were applied to calculate mass discharge, such as for the eastern model boundary, the calculated mass loading should be based on the actual simulated concentrations at the model boundary cell and the simulated groundwater flux that discharges to that model boundary cell.

21. Calibration of the Transport Model. The transport model is manually calibrated using observed mass removal rates at the extraction wells and the estimated perchlorate mass loading to the wash as calibration targets (Section 9.1, p. 53). The parameters adjusted during calibration are mass transfer rate and the concentrations in the immobile zone for shallow layers.

    Although the mass balance and model goodness-of-fit statistics suggest that the model is performing well (Section 9.1, p. 53) during the simulation period, a more detailed analysis is required to demonstrate that the model is capably simulating the transient transport processes that will provide the framework for accurately forecasting future transport of perchlorate and other contaminants of concern. As with the flow model, automatic calibration and parameter estimation seems warranted given the great deal of concentration data available, but few measurements of other transport parameters. Results of a sensitivity analysis can guide future data collection efforts and improvements to the model.

    Presenting the results of observed verses simulated perchlorate concentrations for all layers combined (Section 9.1, Figure 9-1 for example) obscures the results for individual layers and times. A more complete analysis of these results is needed. In addition to breaking out results by layer, area, and time, presentation of how the model is matching temporal changes in concentrations at specific locations is necessary. An analysis of this type will be needed in order to demonstrate that the model is a reliable tool for forecasting concentrations in the future and at locations beyond the current limits of contamination.

22. Section 2 of the Deliverable should include a description of the general setting consistent with that recommended in ASTM Standard D5718. Conveying an understanding of the general hydrogeologic setting will aid the reader in understanding the subsequent development of the Site-specific conceptual site model. Specifically, regional groundwater elevations and regional/Site-specific topography should be presented and discussed as they form the basis for the selection of model boundary conditions. Including regional groundwater flow directions could support the flow directions presented Figure 2-1 of the Deliverable thereby supporting the location of the specified no-flow and inflow boundaries around the periphery of the model domain.

23. In Section 3 of the Deliverable, the conceptual site model should include discussion of hydrologic boundaries (ASTM Standard D5718). While a detail description is provided for the groundwater sinks/sources, discussion of hydrologic boundaries corresponding to the Phase 6 Model no-flow boundaries is absent. Description and justification for the no-flow boundary conditions specified along the west model domain boundary, east model domain boundary and the bottom of the model domain would increase the reader's confidence in the selection of these boundary conditions assigned in the Phase 6 Model.

24. Section 3.1.4. Groundwater discharge to the Wash is estimated by dividing the perchlorate mass discharge by the average groundwater perchlorate concentrations in each reach. In reviewing Figure 2-2 of the Deliverable, it appears that there are only groundwater/groundwater concentration monitoring locations on the south side of the Wash and that there are no monitoring locations on the north side of the Wash. Additional clarification would be beneficial in helping the reader understand how groundwater flow from the north was included in the estimate of groundwater discharge to the Wash.

25. Section 3.1.5. The result of the transducer analysis indicates that the Wash is a losing stream in Reach 3. This appears to contradict the analysis of groundwater discharge to Reach 3 from the perchlorate mass loading analysis, which indicates that Reach 3 gained a relatively small volume of water. It is suggested that the potential contradiction between the transducer and perchlorate mass loading analyses be further explored and that further justification be provided for identifying Reach 3 as a gaining stream versus a losing stream.

26. Section 3.2 of the Deliverable, paragraph 5 states that "flow data above 500 cfs" are considered outliers. Section 2 of the Deliverable states that precipitation occurs in storms of high intensity and short duration that often lead to floods. Short duration storms of high intensity may provide a plausible explanation for flows in excess of 500 cfs. Providing rationale to support the exclusion of flow data above 500 cfs would help the reader to better understand this decision. In general, the NDEP does not allow elimination of outliers without robust justification.

27. Section 3.6, Page 26, Paragraph 5. The Deliverable states that "An outflow of 25,000 cfd has been assumed from the eastern boundary near the Wash. This value was selected because it produces a balance between the inflow and outflows in the basin water balance for the steady-state stress period of 2014 (Table 2d)". This statement should be expanded on to provide a physical justification for the eastern boundary outflow. The justification provided appears to be that it improves the water balance, but if there is no physical basis for this outflow, then requiring it to improve the water balance is not defensible and suggests that something is inaccurate, or not understood, with either the conceptual site model or model construction.

28. Section 5.2, Paragraph 1. The Report states that "the simulation period of 2014-2018 was selected because of the availability of concentration data for calibration". While a more robust groundwater sampling network was present from 2014-2018, that does not preclude the usefulness of both groundwater elevation and concentration data collected prior to 2014 in the calibration of the Phase 6 Model. Demonstrating that the Phase 6 Model can replicate the groundwater flow conditions observed from 2000 onwards would increase confidence in the model calibration. Furthermore, expanding the simulation period to 18 years would bring the calibration period closer in length to the timeframe that likely will be considered for remedial design (i.e., 10s of years to potentially 100 years). Concentration data prior to 2014 should, at a minimum, should have been incorporated to inform the initial condition applied in the Phase 6 Model. Where warranted, the transport calibration should include all available concentration data to increase confidence in the ability of the Phase 6 Model to simulate long-term perchlorate migration and the subsequent performance of alternatives remedial designs.

29. Section 5.3.4, Page 33, Paragraph 5. For the Frenchman Mountain Fault, it is stated that "Ramboll is not aware of specific information regarding the hydraulic properties of the fault. For modeling purposes, this fault has been assumed to slightly impede groundwater flow in the units beneath the alluvium. The width of the fault zone has been assumed to be 10 ft with a conductivity of 0.065 ft/d (which accounts for 10% of the conductivity of Horse Spring Formation"). Fault zones can have similar hydraulic properties to the surrounding geology, be a preferential flow path (i.e., higher conductivity), or be an impedance to flow (i.e., lower conductivity). Justification should be provided to support the assumption that the Frenchman Mountain Fault impedes groundwater flow. Alternatively, a sensitivity analysis could be conducted to assess the potential impact of the Frenchman Mountain Fault on groundwater flow and contaminant transport.

30. Section 5.4.1, Page 33, Paragraph 1. The Deliverable states that "These inflows were simulated using specified flux boundary conditions (WEL package). In the Phase 5 Model, a general head boundary (GHB) condition was used to simulate lateral boundary flows". Typically, the groundwater elevation at a model boundary is better defined and has less associated uncertainty than the groundwater inflow at that model boundary. The decision to switch from a general head boundary to an inflow boundary should be further justified. If groundwater elevation data is available to define the groundwater elevations along the

model domain boundary, a general head boundary may be more defensible than a specified inflow boundary. As identified in Section 3.6 of the Deliverable, for the conceptual water balance there is considerable uncertainty associated with the groundwater inflow along the model domain boundaries.

31. Section 5.4.1, Page 34, Paragraph 1. The Deliverable states that "The boundary conditions with higher fluxes were applied in places where the UMCf-cg unit is present. The boundary inflows through the UMCf-fg are expected to be minimal due to the lower hydraulic conductivity of the finer-grained unit. Hence, the southern boundary fluxes in Layer 3 through 10 where the UMCf-fg is present are assigned a smaller inflow". The modification made to the southern boundary condition (and all other flux boundaries where cell size and hydraulic conductivity vary) appears to have been done in an arbitrary fashion (i.e., the specification of flux in each model cell representing a given inflow boundary does not directly calculated to correspond to the hydraulic conductivity value assigned to that cell and the dimensions of that cell). The total flux assigned across each model domain boundary should be subdivided into model cell specific fluxes on the basis of the cell area facing the active model domain and the hydraulic conductivity of that model cell.

32. Section 5.4.3 Paragraph 1. An extinction depth of 15 ft is specified for the evapotranspiration rate. Typical values for extinction depth for bare soil or grass range from approximately 1.5 to 8 ft for a sand to a sandy loam (Shah et al., 2007). Justification for the specified extinction depth should be provided.

33. Section 6.1 Paragraph 1. The report states that "The model was calibrated using a combination of automatic calibration and a trial-and-error approach". The automated calibration methods that were applied should be discussed. If automated calibration methods were not applied, NDEP further recommends that automated calibration methods be implemented to improve confidence that a unique model calibration has been achieved. In addition to improving the confidence in the uniqueness of the model calibration, automated methods also provide a robust means to conduct model sensitivity and uncertainty analyses.

34. Section 6.2, Page 38, Paragraph 5. The report states that "In order to address the quality of available data, weights were applied to targets. A simple weighting scheme was used based on the statistical principle that the accuracy of the mean is proportional to the square root of the number of samples. Weights of each quarter target were set to one-half the square root of the number of quarters with one or more head measurements for that location and quarter. The maximum value of the weights is set to be 1 for wells with frequent data".

35. The above-mentioned weighting scheme does not address the quality of the measured data, rather it is based on the quantity of data in a given quarter. While it is recognized that the confidence interval around the mean value changes proportional to the square root of the number of samples, the decision to multiply the square root of the number of samples by 0.5 is arbitrary. Furthermore, where the water level does not change significantly

throughout the quarter, a single sample may be representative of mean quarterly value. In this case, the selection of the weighting scheme should ideally stem from an evaluation of the data quality and whether or not given data points are representative of aquifer conditions in a given quarter. Where this determination cannot be made, it is recommended that all data points be given a weight of one, with the potential exception of where the type of data differs (i.e., groundwater elevation measurement versus a flow measurement).

36. Section 6.3 Paragraph 1. The report states "For Layer 10, the conductivity values were updated for better calibration of artesian wells as shown on Figure 5-10". Figure 5-10 presents model boundary conditions in Layer 2. The correct figure should be referenced and/or included.

37. Section 6.3, Page 40, Paragraph 2. The report states that "The vertical conductivity values were modified throughout the model domain to improve the calibration at the head targets. The vertical conductivity value of the alluvium was decreased from 0.6 ft/d in the Phase 5 Model to 0.4 ft/d. Like the previous model versions, the vertical conductivity in the rest of the geologic units (paleochannels, Las Vegas Wash sediments, UMCf-fg, xMCf, and UMCf-cg) was defined by multiplying the hydraulic conductivity by a vertical-to-horizontal anisotropy ratio of 0.1"

38. The anisotropic ratios specified in the Phase 6 Model appear to differ from those stated above and in Table 4 of the Deliverable. For example, the anisotropy ratio of 10,000 is specified in the Phase 6 Model for hydraulic conductivity Zone 52. Other hydraulic conductivity zones specified in the model also have anisotropy ratios ranging from 100 to 1,000. The text, tables and model files should be updated such that the anisotropy and conductivity values match. Where anisotropic ratios fall outside typically observed ranges, such that anisotropy values identified above or those where the anisotropy ratio is less than one as in the UMCf/Horse Springs, a justification should be provided to explain the assigned anisotropy values.

39. Section 6.3 Paragraph 3. The report states "The calibrated conductance applied for each stream segment is given in Figure 5-21". It appears that Figure 5-13 should be referenced as there is no Figure 5-21 included in the Deliverable.

40. Section 6.4, Page 42, Paragraph 2. The simulated streamflow was compared to that measured at USGS gage stations for five locations (i.e., Duck Creek Confluence Gage Station, Pabco Road Gage Station, Bostic Gage Station, Homestead Gage Station, and Three Kids Gage Station). The model simulated streamflow compares reasonably well with the 1-year rolling average of the observed streamflow at the USGS gage stations, as shown on Deliverable Figures 6-9 through 6-13. However, Deliverable Figures 3-1 through 3-7 show that there is temporal variation in the flow rates observed in the Wash and that the 1-year moving average may significantly dampen or flatten the observed temporal variations. Therefore, it is recommended that the quarterly simulated streamflow at each gage station be compared to a quarterly (3 month) moving average.

41. Section 6.4, Page 43, Paragraph 5. It is stated that "the model is further evaluated by comparing the observed versus simulated heads for Q2-2018 as presented on Figure 6-18". However, no analysis or evaluation of the comparison between observed versus simulated heads for Q2-2018 is provided. Matching observed groundwater flow directions is a critical component of model calibration. Any groundwater flow model should be evaluated by, in addition to other metrics, a comparison of simulated versus observed groundwater flow directions (Joseph et al., 2016). The evaluation of groundwater flow directions is critical as the observed groundwater flow directions will impact the direction of contaminant migration and attempting to match the groundwater heads alone does not also ensure match to groundwater flow directions. Therefore, it is recommended that figures showing observed versus simulated groundwater elevations be presented for each water bearing zone for each simulated quarter and that the match between observed and simulated groundwater flow directions be discussed. This additional analysis will increase the transparency of the Deliverable and improve confidence in the Phase 6 Model and its future application.

42. Section 6.5 & Section 9.2. A more robust sensitive analysis would increase confidence in the uniqueness of the calibrated model. The sensitivity analysis presented in the Deliverable is a simple bracketing approach where selected parameters or groups of parameters are perturbed by a factor of ±0.25 from the calibrated/assigned parameter value. Hydraulic conductivity values, surface recharge rates, streambed conductance, storage parameters, southern and western boundary inflows and evapotranspiration rates were perturbed by a factor of ±0.25 from the calibrated/assigned parameter value to evaluate the sensitivity of the flow calibration (i.e., head residual statistic, discharge to wash and simulated vs. actual pumping). Dispersivity, mass transfer rate and porosity were perturbed by a factor of ±0.25 from the calibrated/assigned parameter value to evaluate the sensitivity of the transport calibration (i.e., concentration calibrations statistics, mass loading to the Wash and mass removed from extraction systems).

    To increase the robustness and defensibility of the model sensitivity analysis it recommended that each parameter be evaluated over a reasonable wider range of values. Typically the range in parameter values considered during the sensitivity analysis should correspond to the range of measured or literature values that were considered during model calibration. Some parameter values should be varied geometrically while others should be varied arithmetically across the parameter range (ASTM D5611). Where parameters that were adjusted independently during model calibration are grouped together, a justification for that grouping should be provided.

    Perturbation by a factor of ±0.25 generally is insufficient to explore the full parameter range. Newman (2018) recommends a common starting point as perturbation by a factor of ±0.50 for parameters that show little variation (i.e., porosity) and that a greater variation should be applied for parameters that vary over orders of magnitude (i.e., hydraulic conductivity). Typically multiple parameter perturbations (6-10) are applied to each calibrated parameter to explore the potential range of sensitivity in model results to that parameter value, as recommended by ASTM D5611. For each input parameter that was varied, the Deliverable should present a graph showing the changes in residuals or residual statistics and the computed outputs with respect to the changes in the model input.

Consistent with ASTM D5611, the type of sensitivity of the model results to each parameter should be identified. To identify the type of sensitivity, the transport sensitivity analysis should be expanded to include parameters considered in the flow calibration sensitivity analysis (i.e., recharge, hydraulic conductivity, etc.). This is critical, as there may be parameters to which the flow solution is insensitive, yet that parameter has a significant impact on the transport calibration and subsequently the evaluation of remedial design alternatives and cleanup timeframes.

In addition to the above comments, if warranted, the robustness of the Phase 6 Model sensitivity and uncertainty analysis can be further improved through the application of automated tools such as PEST/SVD Assist with Null-Space Monte Carlo analysis and PEST with its iterative ensemble smoother. These automated tools provide a robust means to generate an ensemble of calibrated models that are applied to evaluate a range of uncertainty in model predictions and to develop confidence intervals for model predictions.

43. Section 7.1 and 7.2. Section 7.1 of the Deliverable describes that "perchlorate mass that accumulated in the UMCf would migrate upwards into the alluvium via back diffusion and upward flow". Section 7.2 of the Deliverable further states that "Diffusion is the transport of chemicals due to concentration differences between regions (e.g., the alluvium and UMCf). Accurate simulation of diffusion typically requires a very fine discretization, which is not feasible for regional-scale models. An alternative approach is the dual-domain mass transfer method, which offers a practical solution to modeling perchlorate fate and transport for a geologically complex system like NERT study area, where small-scale preferential flow pathways cannot be fully and explicitly represented by the spatial discretization of the numerical regional model. Hence, for the current model, the dual porosity, mass transfer approach is used to represent back diffusion from low conductivity UMCf".

    The advantage of a dual-domain approach is the ability to represent heterogeneity on the sub-model grid scale. The dual-domain approach implemented in the Phase 6 Model (through MT3D-USGS) is a dual porosity approach where a mobile domain and an immobile domain are represented. Advection and dispersion occur in the mobile domain, but not in the immobile domain. The mass exchange between the mobile and immobile domain is governed by the concentration difference between the two domains multiplied by a mass transfer coefficient. As the mass transfer rate increases, the exchange between the mobile and immobile domains becomes increasingly fast and the dual-domain model functions more and more like a single-domain model whose porosity approaches the total porosity of the porous media. As the mass transfer rate approaches zero, the dual-domain model also becomes equivalent to a single-domain model, but the porosity of the single-domain model approaches the porosity of the mobile domain (Zheng and Wang, 1999).

Since advection and dispersion are not simulated in the immobile phase, the dual-domain approach does not represent preferential flow paths. Mass transfer only occurs between the mobile and immobile phase within a given model cell. It does not represent immobile phase mass transfer across adjacent cells. The alluvium and UMCf are explicitly represented in the Phase 6 Model by individual model cells, and dual domain approach is not representing back diffusion from the UMCf to the alluvium, it is representing back diffusion separately within the alluvium and UMCf. Therefore, the mathematical representation of the dual-domain approach implemented in MT3D-USGS is inconsistent with the rationale provided in the Deliverable for the selection of the dual-domain approach. That is not to say that the dual-domain approach implemented in MT3D-USGS is not applicable to the Site, but rather that the justification provided should clearly state that dual-domain approach is selected to represent diffusion between dead-end pore space and the mobile pore space or effective porosity (for water/solute to flow through) within a single model cell and corresponding geologic unit (i.e., mass transfer occurs between a mobile and immobile alluvium domain and a mobile and immobile UMCf domain, but not between alluvium and the lower permeability UMCf). The application of the dual-domain approach should be evaluated on the basis of heterogeneity observed within a given geologic unit, not on the basis of diffusion between different geologic units that are explicitly represented in the Phase 6 Model. It is further noted that should a dual domain approach be selected, it will introduced additional uncertainty in the simulation of perchlorate transport unless the effective porosity for mobile, immobile porosity for immobile, total porosity, initial mobile and immobile concentrations, and mass-transfer coefficient are well characterized.

Although the dual-domain approach is more commonly applied to transport problems in heterogeneous fractured rock settings where most advection occurs in fractures with diffusion into the matrix, the approach is also applied in settings where diffusion may occur into fine-grained sediments along preferential groundwater flow paths. The Phase 6 conceptual model of transport at the NERT study area is described by the latter mechanism. Advection is simulated in "small-scale preferential pathways" in both the alluvium and UMCf units (Ramboll, 2019), and it should be noted that the hydraulic conductivity values of the two units differ by only about 1.5 orders of magnitude (Table 4 [Ramboll, 2109]). It follows that diffusion and back-diffusion be simulated in both units, though the mass transfer coefficients used in the model are very similar (Table 10 [Ramboll, 2019]). The process of back-diffusion may have more to do with back-diffusion from fine-grained sediments in the UMCf followed by advective transport from the UMCf to the alluvium in response to upward hydraulic gradients.

In summary, it is recommended that further consideration be given to the applicability of the dual porosity approach applied in the Phase 6 Model. If selected for the Phase 7 Model, appropriate rationale should be provided to justify the application of the dual porosity approach, consistent with the numerical implementation of the approach in MT3D-USGS. Further consideration also should be given to define transport parameters specific to the dual porosity approach. Where field tests are unavailable to confirm transport parameters, a detailed sensitivity and uncertainty analysis is recommended to assess the potential impact of parameter uncertainty on model calibration and the application of the model to assist in evaluating remedial designs.

44. Section 8.4.3. Part 1: It was noted that the initial mobile domain perchlorate concentrations assigned in the Phase 6 Model digital files potentially demonstrate some interpolation error relative to the initial perchlorate concentrations presented on Figures 8-3, 8-4 and 8-5 of the Deliverable. The figures reproduced show the initial mobile domain perchlorate concentrations from Phase 6 Model digital files as shown on Figures 13, 14, and 15 for model layers 1, 2, and 3, respectively. Figures 12, 14, and 15 demonstrate that there is likely error in the interpolated perchlorate concentrations outside of the plume area that is well defined by the Site monitoring network. This has resulted in concentrations of near 1 mg/L being assigned along portions of the Phase 6 Model boundaries in layer 1 and 2. While this likely does not have a significant impact to the model calibration the initial condition, the initial perchlorate concentration should be updated such that additional perchlorate mass is not introduced at the model boundaries unless supported by observed data.

    Part 2: The initial concentrations in both the mobile and immobile zones are two of the key parameters of the dual porosity approach applied for the perchlorate fate and transport simulations. The initial concentrations define the amount of perchlorate mass in the system, which will have a significant controlling influence the evaluation of remedial time frames. The mass transfer coefficient is also a key parameter it controls how quickly mass moves between the mobile and immobile domains and thus has a significant influence on the duration for which the immobile zone will act as a source of perchlorate mass.

45. To improve confidence in the assigned initial concentrations, the history of perchlorate sources at the Site and the evolution of the perchlorate plume to its assigned initial condition should be discussed. If perchlorate concentrations have remained relatively stable, then it may be reasonable to assign equal concentrations to both the mobile and immobile domains. However, if the perchlorate concentrations in the mobile domain are decreasing more rapidly, then this could be used as a line of evidence to support higher initial concentrations in the immobile domain.

    Regarding the adjustment of initial concentrations during calibration, the Deliverable states that "Immobile concentrations under the Wash gravels in Layer 2 were increased to three times the mobile concentration during calibration. The UMCf-cg underneath the NERT site is expected to have higher mass in the immobile zone. Hence in Layer the concentrations in the immobile zone in the UMCf-cg were increased to seven times the mobile concentrations. Immobile concentrations within the paleo channels were adjusted during model calibration and were set to 1.5 times the mobile concentrations in Layer. The concentration in the immobile domain were also adjusted in Layer 7 near the AMEW extraction wells for calibrating mass removal rates."

Adding mass to the immobile phase might not be the correct rationale to achieve the increased mass removal needed for calibration. The needed additional mass may be present in the mobile domain but located between monitoring locations that has simply not been detected. It cannot be expected that the monitoring network will capture all mass present in a subsurface system. Perhaps the increased mass could be achieved by refining the initial concentration in the mobile phase and it is recommended that this be explored before concluding that the additional mass is only in the immobile phase.

46. Section 8.4.4, Paragraph 3. The formula presented by Xu and Eckstein (1995) should be updated to the corrected formula presented in the comment to Xu and Eckstein (1995) by Al-Suwaiyan (1995) . It is recognized that the corrected formula will result in similar estimated longitudinal dispersivity value and is not expected to significantly impact the Phase 6 Model results.

    Section 8.4.4, Paragraph 4. Provide justification for assigning a longitudinal dispersivity value of 60 ft versus the longitudinal dispersivity value of 64 ft calculated using the formula presented by Xu and Eckstein (1995).

47. Figure 2-1 presents arrows depicting the groundwater flow directions at the model domain boundary conditions. Regional groundwater elevation contours should be presented to justify the groundwater flow directions.

48. Figures 5-1 to 5-8 Spatial distributions of hydraulic conductivity for model layers do not reflect the heterogeneity of the model domain. NDEP suggests that hydraulic conductivity interpolation (e.g. ordinary kriging and conditional geostatistical simulation based on fractional Brownian motion) of existing data with help from NMR data may be a way to improve observed contaminant plumes in next phase model.

49. Figure 5-13. The streambed hydraulic conductivity values presented in Figure 5-13 do not appear to match streambed hydraulic conductivity specified in the Phase 6 Model files in the western end Las Vegas Wash. This apparent discrepancy should be resolved.

50. Figure 6-18: Figure 6-18 presents the simulated versus observed potentiometric surface map for second quarter 2018. In general, there is reasonable agreement between the observed and simulated potentiometric surfaces; however, there are some areas where improvements could be made. Specifically, on the east side of the of the NERT off-Site RI Study area, the inflection in the observed potentiometric surface indicates that there is an area of higher transmissivity that is not well represented in the Phase 6 Model. It is also noted that in the south end of the NERT Property Boundary, the observed potentiometric surface demonstrates a northerly flow direction, whereas the simulated potentiometric surface demonstrates a northwest flow direction. Perhaps the match to observed flow directions can be improved in those areas for the Phase 7 Model.

51. Appendix A. The equation of state (EOS) defining the relationship between perchlorate concentration and specific gravity is not stated. The accurate determination of the EOS is critical to the simulation of density-dependent flow using SEAWAT (Langevin et al., 2008). The EOS should be stated in Appendix A and rationale should be provided for the development of the EOS.

52. Additional Minor Secondary Clarifications:

    a) Section 1.0, Page 1, Second Paragraph, line 9 – "Nevada Department of Environmental Pollution" should be "Nevada Division of Environmental Protection"
    b) Section 1.1, Page 1, Second Paragraph, Line 4 – "dat.a." should be "data"
    c) Section 6 – Simulated groundwater elevations presented in Deliverable do not match those in the Phase 6 Model digital files. While the difference is small (typically <0.1 ft), the Deliverable and/or Phase 6 Model digital files should be updated such that both reflect correspond to the same version of the Model.
    d) Section 8.4.3 - The modifications to the initial immobile concentrations as described in the Deliverable do not appear to reflect to the totality of the changes made to the initial immobile condition as contained in the Phase 6 Model digital files. The Deliverable should include additional explanation to fully present the initial condition assigned in the immobile domain.
    e) Section 9 – Simulated concentration values presented in Deliverable do not match those in the Phase 6 Model digital files. While the difference is typically small, the Deliverable and/or Phase 6 Model digital files should be updated such that both reflect correspond to the same version of the Phase 6 Model.

53. References

Al-Suwaiyan, M., 1996. "Discussion of 'Use of Weighted Least-Squares Method in Evaluation of the Relationship Between Dispersivity and Field Scale' by M.Xu and Y. Eckstein", Groundwater 34 (4): 578.

ASTM Standard D5611, 2016. Standard Guide for Conducting a Sensitivity Analysis for a Ground-Water Flow Model Application, ASTM International, West Conshohocken, PA.

ASTM Standard D5718, 2000. Standard Guide for Documenting a Ground-Water Flow Model Application, ASTM International, West Conshohocken, PA.

Brooks, L.E., Masbruch, M.D., Sweetkind, D.S., and ButoSteady, S.G., 2014. State Numerical Groundwater Flow Model of the Great Basin Carbonate and Alluvial Aquifer System. Scientific Investigations Report 2014–5213.

Donovan, D.J. and Katzer, T., 2000. Hydrologic implications of greater ground-water recharge to Las Vegas Valley, Nevada. Journal of the American Water Resources Association, 36(5):1133-1148.

Epstein, B. J., Pohll, G. M., Huntington, J., and Carroll, R. W. H., 2010. Development and Uncertainty Analysis of an Empirical Recharge Prediction Model for Nevada's Desert Basins. Journal of the Nevada Water Resources Association, 5(1):1-22.

Joseph, T., D. McManus, M. Nordberg, H. Shannon, and S. Springhorn, 2016. Best Management Practices for the Sustainable Management of Groundwater, Modeling BMP, California Department of Water Resources.

Langevin, C.D., D.T. Thorne, Jr., A.M. Dausman, M.C. Sukop, and W. Guo, 2008. SEAWAT Version 4: A Computer Program for Simulation of Multi Species Solute and Heat Transport, Techniques and Methods Book 6, Chapter A22, U.S. Department of the Interior, U.S. Geological Survey, Reston, Virginia.

Morgan, D.S., M.D. Dettinger, 1996. Groundwater conditions in Las Vegas Valley, Clark County, Nevada, Part 2, Hydrogeology and Simulation of Ground-Water Flow. United States Geological Survey Water-Supply Paper 2320-B.

Nevada Division of Environmental Protection (NDEP), 2017. NDEP Response to: Phase 5 Transient Groundwater Flow Model, Response to Comments, Nevada Environmental Response Trust, Henderson, Nevada, dated May 3, 2017.

Newman, C.P., 2018, Guidance for Hydrogeologic Groundwater Flow Modeling at Mine Sites. In Price, R.A. and R. J. W. Douglas (ed.). Nevada Division of Environmental Protection, Bureau of Mining Regulation and Reclamation.

Ramboll, 2016. Phase 5 Transient Groundwater Flow Model – Nevada Environmental Response Trust Site Henderson, Nevada. Prepared by Ramboll Environ, Emeryville, California.

Ramboll, 2019. Phase 6 Groundwater Flow and Transport Model – Nevada Environmental Response Trust Site Henderson, Nevada. Prepared by Ramboll US Corporation, Emeryville, California.

Shah, N., Nachabe, M., and M. Ross, 2007. Extinction Depth and Evapotranspiration from Groundwater Water under Selected Land Covers, Ground Water, Vol. 45, No. 3, May-June 2007 (pp 329-338).

Thiros, S.A., L.M. Bexfield, D.W. Anning, and J.M. Huntington, 2010. Conceptual Understanding and Groundwater Quality of Selected Basin-Fill Aquifer in the Southwestern United States, U.S. Geological Professional Paper 1781, 288 p.

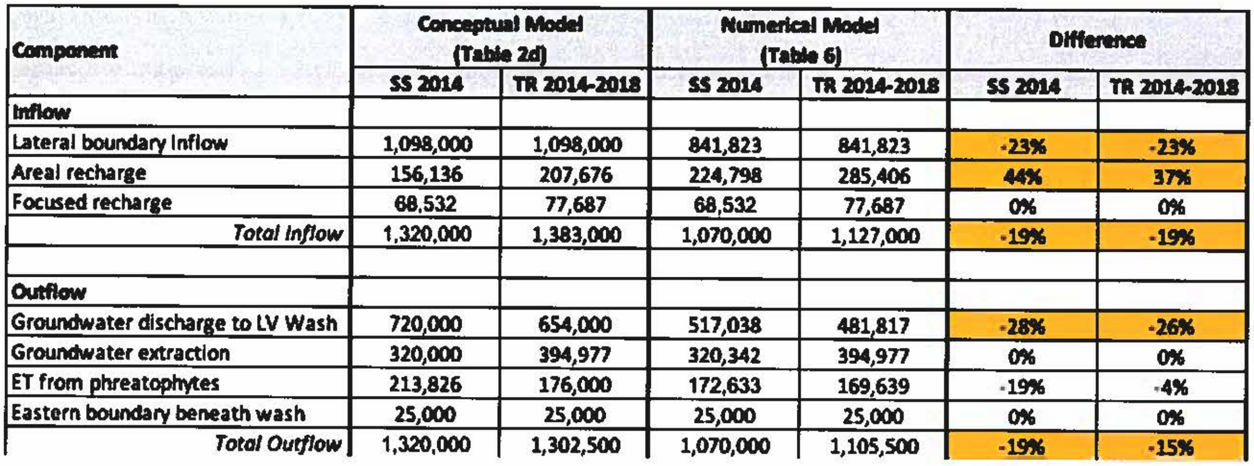
Watermark Numerical Computing, 2016. PEST, Model Independent Parameter Estimation User Manual Part I: PEST, SENSAN and Global Optimizers, 6th Edition, Watermark Numerical Computing, Brisbane, Australia, April.

Xu, M. and Y. Eckstein, 1995. Use of Weighted Least-Squares Method in Evaluation of the Relationship Between Dispersivity and Scale, Groundwater, 33(6), pp. 905 - 908.

Zheng, C. and P.P. Wang, 1999. MT3DMS: A Modular Three-Dimensional Multispecies Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems; Documentation and User's Guide, U.S. Army Corps of Engineers, Washington, DC, Contract Report SERDP 99 1, December.

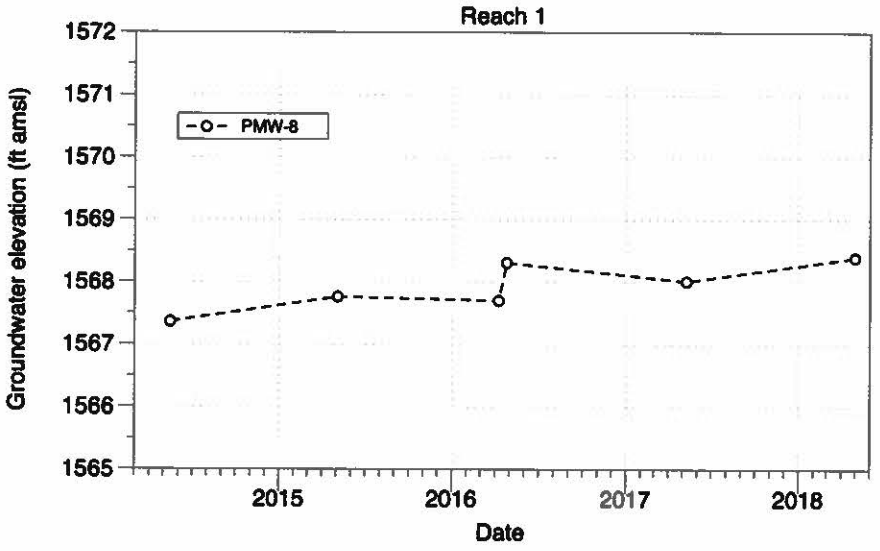
Table

Table 1. Summary of components of groundwater flow in the Phase 5 and Phase 6 models.



Component	Conceptual Model (Table 2d)		Numerical Model (Table 6)		Difference	
	SS 2014	TR 2014-2018	SS 2014	TR 2014-2018	SS 2014	TR 2014-2018
Inflow						
Lateral boundary inflow	1,098,000	1,098,000	841,823	841,823	-23%	-23%
Areal recharge	156,136	207,676	224,798	285,406	44%	37%
Focused recharge	68,532	77,687	68,532	77,687	0%	0%
Total Inflow	1,320,000	1,383,000	1,070,000	1,127,000	-19%	-19%
Outflow						
Groundwater discharge to LV Wash	720,000	654,000	517,038	481,817	-28%	-26%
Groundwater extraction	320,000	394,977	320,342	394,977	0%	0%
ET from phreatophytes	213,826	176,000	172,633	169,639	-19%	-4%
Eastern boundary beneath wash	25,000	25,000	25,000	25,000	0%	0%
Total Outflow	1,320,000	1,302,500	1,070,000	1,105,500	-19%	-15%

Figures



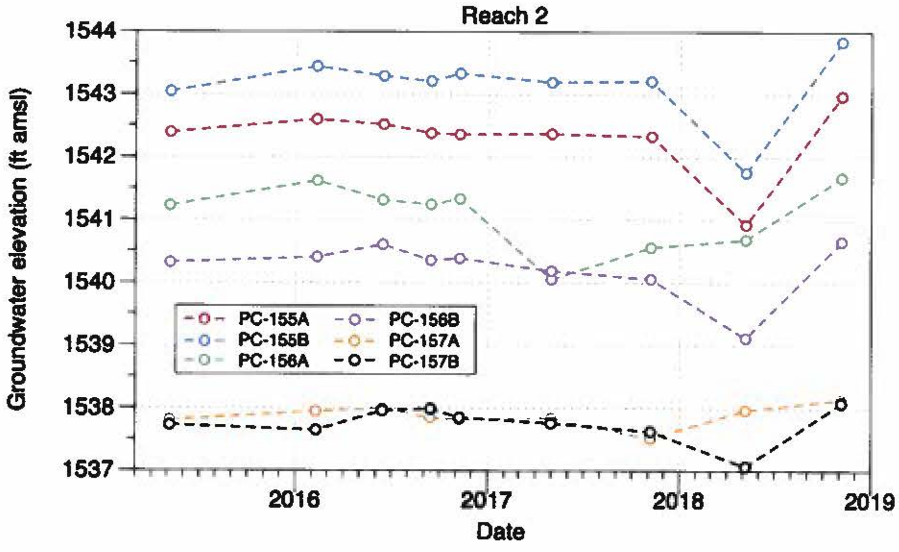


Figure 1. Groundwater levels in wells adjacent to Reaches 1 and 2 of the Las Vegas Wash. Data from Appendix E (Ramboll, 2019). Water level data for wells adjacent to other reaches of the wash are not included in Appendix E.

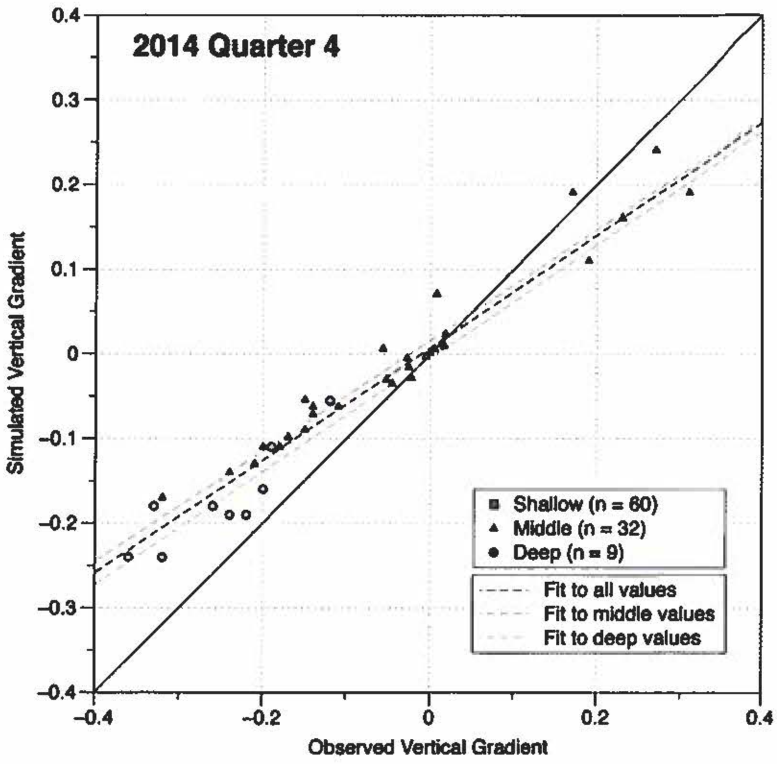


Figure 2. Observed and simulated vertical hydraulic gradients in the middle and deep zones of the flow model in Quarter 4 of 2014.

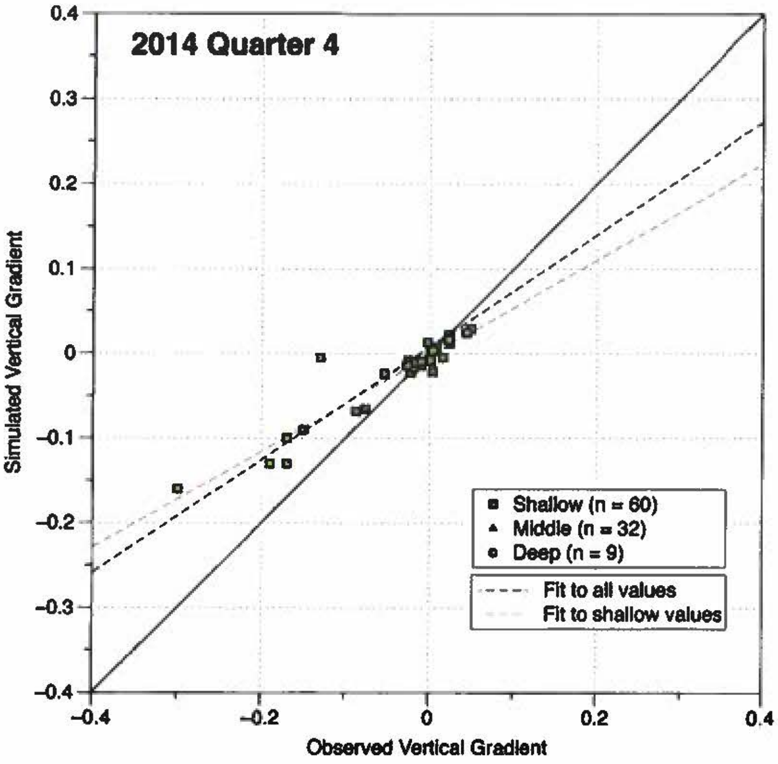


Figure 3. Observed and simulated vertical hydraulic gradients in the shallow zone of the flow model in Quarter 4 of 2014.

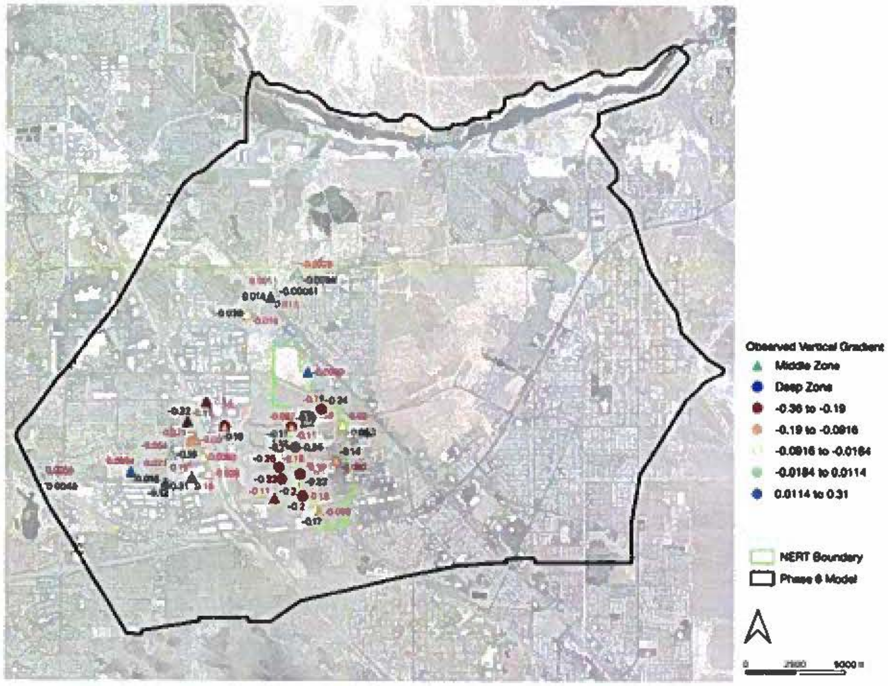


Figure 4. Observed vertical hydraulic gradients in the middle and deep zones. Observed values are identified by black labels and model-simulated values are identified by red labels.

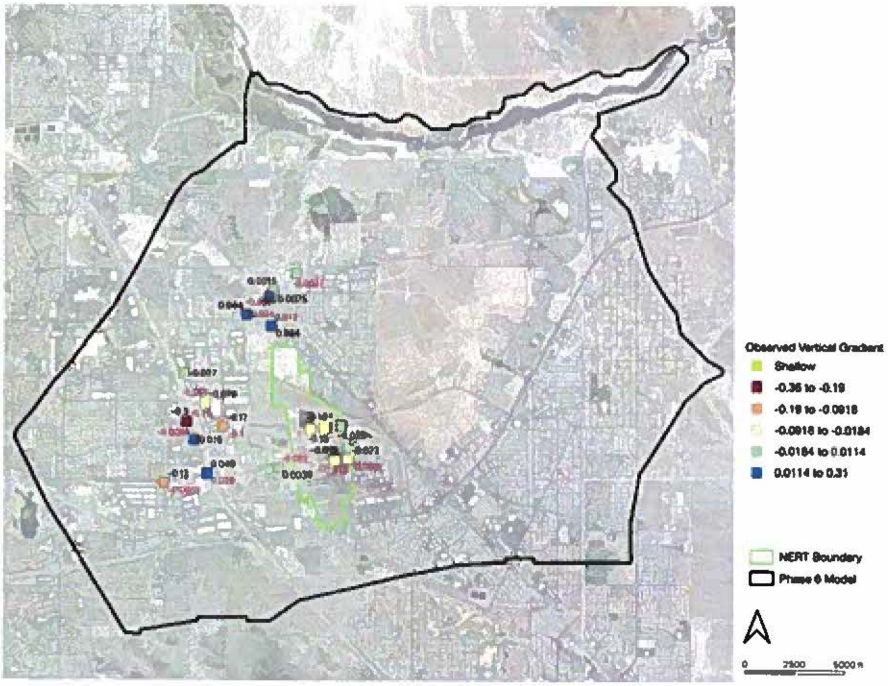


Figure 5. Observed vertical hydraulic gradients in the shallow zone. Observed values are identified by black labels and model-simulated values are identified by red labels.

Attachment 2

Metropolitan's Comments on NERT Phase 6 Groundwater Flow and Transport Model
June 15, 2020

The following comments provide the results of our review of the Phase 6 Groundwater Flow and Transport Model report and associated model files dated November 27, 2019 that has been prepared for the Nevada Environmental Response Trust Site of Henderson, Nevada. The model will be an integral tool to understanding the transport of perchlorate and other contaminants of concern at the site and the remediation of these contaminants. The intent of our model comments provided below is to point out issues with the model that we believe, if appropriately addressed in future versions of the model, will improve the model's reliability for the models intended purposes as identified in Section 1.1 Model Objectives, of the subject report.

MODFLOW Comments

Regional vs. Local Model Calibration

While the groundwater flow model is well-calibrated from a regional perspective, the model has not been demonstrated to effectively predict groundwater conditions at a site-specific scale. Localized model calibration will be necessary for this model to effectively predict the effects of site-specific treatment alternatives. Examples of localized model performance issues in the vicinity of Las Vegas Wash are given below.

Response to Weir Dewatering

Target wells in the vicinity of the Seep Well Field do not appear to respond appropriately to applied stresses representing the weir dewatering that occurred between the 1st and 3rd quarters of 2018. While actual water levels in the vicinity of the Seep Well Field did not change substantially during weir dewatering, the model simulated a drop in water levels of 7 to 10 feet in certain wells (e.g. PC-83, PC-86, PC-87, SWFTS-MW-3, and SWFTS-MW-4).

Simplification of Hydraulic Conductivity Zones

While simplification of parameter zones is necessary at the regional scale to achieve model calibration, localized discretization of hydraulic conductivity values may be necessary to effectively simulate local groundwater movement. For example, a paleochannel was reported to exist to the east of the Seep Well Field during the Bioremediation Treatability Study performed in that area. The hydraulic conductivity values measured near the paleochannel at that location were as high as 300 ft/d, whereas in the model the hydraulic conductivity in that area is only 45 feet/d. Modeling of such local site features will likely be necessary to accurately predict the impact of site-specific treatment options.

Sharply Contrasting Hydraulic Conductivity Zones

The model contains sharp contrasts between paleochannel, wash area, and alluvium hydraulic conductivity zones. Based on the cross sections shown in the Seep Well Field Area Bioremediation Study, the changes are more likely to be gradational than sharp, however. While the paleochannels are likely to cause preferential flow to occur, the sharp contrasts may cause more channelization of the flow within the model than actually occurs in these areas.

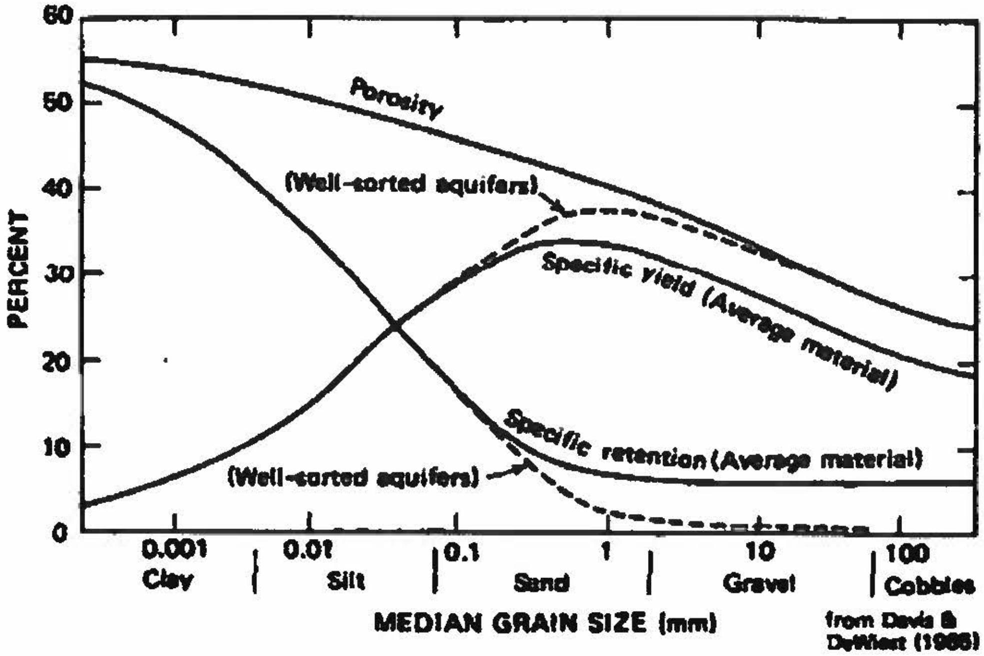
MT3D Comments

Use of Calibration as a Sole Means of Justifying Parameter Values

While the model appears to be well-calibrated to conditions occurring for the 5 years from 2014 through 2018, the model producers tend to over-rely on calibration results to justify model parameter values with little theoretical or observational basis for selection. This results in the use of some slightly unrealistic aquifer properties to achieve calibration, especially in the transport model. While the model may reproduce results observed from 2014 to 2018 well, future concentrations may be poorly predicted more than a few years into the future, especially if flow conditions change (e.g. if changes are made to remediation system operations). Comments regarding specific transport parameters are included below.

Porosity/Specific Yield Values

In a dual domain transport model, the mobile porosity is equal to the specific yield, and the immobile porosity is equal to the specific retention. An unnaturally high specific retention/unnaturally low specific yield is used for the Layer 1 sand and gravel units in this model (alluvium, paleochannels, wash gravels). While a total porosity of 0.37 is reasonable, a specific retention of 0.27 versus a specific yield of 0.10 is unrealistic for a sand or sand and gravel aquifer. Specific retention should be less than the specific yield in a coarse-grained aquifer unit (see graph below from Davis and Dewiest, 1966).



from Davis & DeWiest (1966)

While a total porosity of 0.54 may be reasonable for a fine-grained aquifer consisting predominantly of clay, such a total porosity is not realistic for an aquifer unit that contains substantial quantities of coarse-grained materials, such as the UMCf-cg. As stated above for Layer 1 aquifer units, specific retention (immobile domain porosity) should be relatively low in a coarse-grained unit. Driscoll (1986) gives the following representative values for porosity and specific yield:

Sediment Type	Porosity (%)	Specific Yield (%)
Clay	45-55	1-10
Silt	35-50	Not given
Sand	25-40	10-30
Gravel	25-40	15-30
Sand and Gravel Mixes	10-35	15-25

Conversely, an unrealistically high specific yield is used in the fine-grained aquifer units (e.g. UMCf-fg). Specific yield (mobile porosity) for a fine-grained unit should be lower than coarse-grained units. A reasonable specific yield for a clay unit would be 0.10 or less. Instead, the model has higher specific yields for fine-grained units and lower specific yields for coarse-grained units (opposite of the natural progression of specific yields).

Diffusion Coefficient

The first paragraph of page 52 appears to indicate that diffusion coefficient was adjusted based on the geologic material present (presence of fine-grained material). Diffusion coefficient is a physical value that is specific to a given ion (at a given temperature). It does not change based on aquifer material. According to the CRC Handbook of Chemistry and Physics (94th Edition, 2013), the diffusion coefficient for perchlorate at 25°C is 1.67×10^{-3} ft^2/d. The diffusion coefficient for perchlorate used in the model (1.53×10^{-3} ft^2/d) is an appropriate value because of the ion and groundwater temperature, not because fine-grained materials are present.

Initial Perchlorate Concentrations

Initial perchlorate concentrations in the immobile zone appear to be determined solely by calibration and do not appear to be tied to any physical measurement of soil perchlorate concentrations. Ramboll completed an estimate of total perchlorate mass for the remedial investigation study area (Attachment A of the 2019 Remedial Performance Report). The model report should discuss how the estimated total mass in that study compares to the total mass applied to the model.

Mass Transfer Coefficient

Mass transfer coefficient appears to be determined solely by calibration and is not tied to any theoretical or observed value. This value may be incorrect if one or more of the previously discussed parameters is incorrect.

Observed Versus Simulated Perchlorate Concentrations

While the text indicates that the model overall slightly overpredicts perchlorate concentrations based on an overall target residual of -0.57 mg/L, Figure 9-1 appears to show the opposite occurring. Far more targets in Figure 9-1 appear to be below the 1:1 line than above, indicating a systematic underprediction of perchlorate concentrations (modeled concentrations less than observed values).

The calibration statistics may be misleading because the number of targets below 1,000 mg/L far exceeds the number of targets above 1,000 mg/L, but the regression calculations are weighted toward the higher concentration targets (i.e. residuals are calculated based on absolute distance from the regression curve, so low concentrations will automatically have a shorter absolute distance from the regression curve, giving them little weight in the regression calculation). By residual percentage, many of the lower concentration targets are actually not well calibrated. While the calibration favors the higher concentration areas of the model, the lower concentration zones within the model are areas of intended future use of the model (measuring perchlorate mass transfer into Las Vegas Wash, analyzing treatment alternatives near the wash). The authors should use log-transformed concentration values to analyze calibration statistics or use statistical analyses that account for a logarithmic concentration distribution.

References:

Davis, S. N. and DeWiest, R. J. M., 1966. Hydrogeology. John Wiley and Sons, New York.

Driscoll, F.G., 1986. Groundwater and Wells, Second Edition. Johnson Screens, St. Paul, Minnesota.

Gibb, J.P., Barcelona, M.J., Ritchey, J.D., and LeFaivre, M.H., 1984. Effective Porosity of Geologic Materials, First Annual Report. Illinois State Water Survey, Champaign, Illinois.

Haynes, W.M., ed. 2013. CRC Handbook of Chemistry and Physics, 94th Edition. CRC Press, Boca Raton, Florida.