Simulating the Performance of a Dry Stack Tailings Design for Water Control Permitting

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ABSTRACT

Dewatering tailings to below saturation prior to placement in a permanent storage facility, referred to as "dry stacking", offers significant advantages over conventional slurried tailings storage, especially in arid environments. These include significantly reduced water requirements, a much smaller environmental footprint, and reduced long-term water management costs. Even with these clear benefits, dewatered tailings have not previously been permitted in the state of Nevada. In order to demonstrate to the regulators that the proposed tailings design is feasible and to lay out a clear path for evaluating the performance of the facility design, a series of models and presentations were developed.

The modeling results provided clear evidence that the facility design and phased stacking plan would produce unsaturated tailings, limiting the potential flow of water into the subsurface and impacts to groundwater. A sensitivity analysis of the modeling was conducted to evaluate the parameters used and the possible facility performance under less than ideal conditions. The sensitivity modeling suggested that flux into the foundation layer is most affected by the water content of the placed tailings. Geochemical modeling was also conducted, incorporating results from the Meteoric Water Mobility Procedure results of site specific tailings samples. The geochemical modeling predicted that the geochemistry of the interstitial fluids in the tailings would be of generally good quality and below state standards.

The facility's Water Pollution Control Permit was issued in August 2013, conditionally approving the placement of dewatered, unsaturated tailings in the facility. The project has agreed to construct and monitor a field test cell over a minimum of a one-year period. Additional project work is currently underway to monitor water contents in the initial operating cells of the tailings storage facility. Both of these seek to validate the modeling results and demonstrate the efficacy of the tailings storage facility design.

Keywords: Modeling, dewatered tailings, geochemistry, permitting

INTRODUCTION

Dewatered tailings, also known as dry stack tailings (DST), are better suited for the arid southwest than traditional slurried tailings disposal due to the reduced water requirements, environmental footprint, long-term water management, and seepage. Additionally, concurrent reclamation can be completed on DST facilities because of the increased trafficability of the material compared to slurried tailings. Despite these clear benefits, as a DST facility had not previously been constructed or permitted in the state of Nevada, additional steps were necessary to permit such a facility with the Nevada Department of Environmental Protection (NDEP).

Prior to developing the predictive models to support the permitting of the DST facility, a presentation was provided for the regulators to help educate them on the operational design and function. This approach had previously been proven successful for permitting a DST facility in Arizona. The initial presentation was conducted in late 2011, and included the general concepts of dry stacking (including the water content of unsaturated "dry" tailings, the conveyance process, stacking plans, stability of DST, seepage mechanisms, and trafficability) and a path forward for additional site-specific field investigations, laboratory analyses, and modeling that could be used to verify the proposed design concept.

A second presentation was held in early 2012. The time between the presentations allowed the regulatory officials to digest the original information and develop specific follow-up questions about the project. The second presentation focused on the specific design proposed for the project and results of the predictive modeling. This second meeting also focused on presentation of a proposed alternative lining concept. For this project, an alternate liner system consisting of 0.45 meters (m) (18 inches [in]) of compacted tailings with a maximum permeability of $4x10^{-4}$ centimeters per second (cm/s) was proposed. These presentations and the predictive modeling laid the groundwork for open communication, which allowed for approval of the water pollution control permit application. The remainder of this paper focuses on the predictive modeling that was used to support these presentations and ultimately the permit application.

CONCEPTUAL MODEL

The predictive modeling was developed to supplement the engineering design report for the DST facility. Figure 1 shows the conceptual model of a DST facility. The conceptual model for a DST facility is similar to other mining facilities. The conceptual model shown in Figure 1 illustrates the system water balance components which consist of precipitation, evaporation, runoff, infiltration, and seepage. The tailings material will also contain some solution when it is placed in the facility (interstitial water), adding to the initial water balance of the facility. The gravimetric water content of the tailings at placement is expected to range from 15% to 17%, equivalent to a volumetric water content of 26%.

MODELING TECHNIQUE AND INPUTS

VADOSE/W (GEO-SLOPE, 2007a), a two-dimensional variably saturated flow model that is part of the Geo-Studio suite of programs, was used to simulate the flow of water through the tailings mass in the DST facility. To determine the quality of the water that could potentially seep from the base of the facility into the foundation soils, fate and transport modeling was completed using a combination of particle tracking and geochemical modeling.

The objectives of the infiltration and seepage analyses were to assess:

- The performance of the proposed closure cover configuration;
- The rate of infiltration into the tailings mass;
- The rate of seepage to the drains; and
- The rate of seepage from the DST to the foundation soils.

The objective of the fate and transport analysis was to:

- Predict the geochemical quality of the seepage from the base of the DST facility;
- Evaluate the potential for seepage into the foundation soils; and
- Evaluate the potential for any seepage to impact the regional groundwater system.

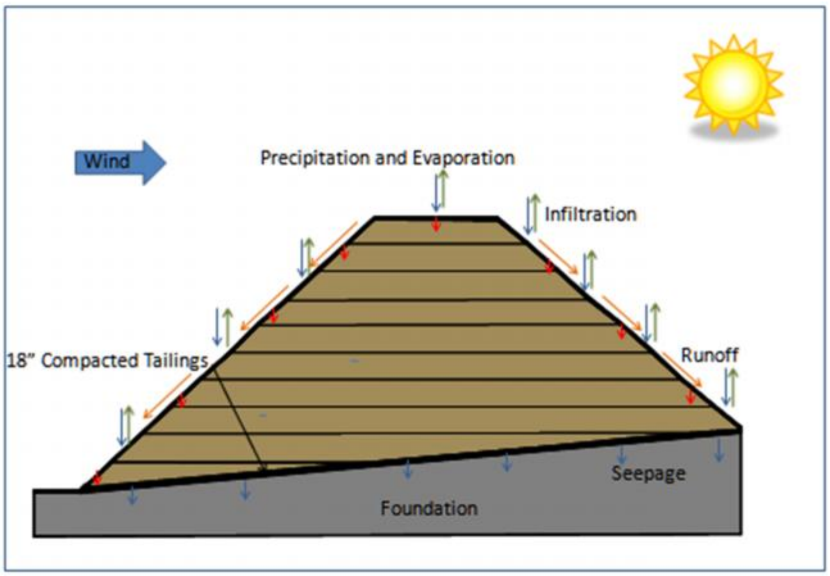

Figure 1 Conceptual Flow Model DST Facility

Climate

The Project is located in low barren hills above a dry alluvial valley. The climate is arid with hot summers and relatively mild winters, allowing nearby mining operations to work year round. Vegetation in the immediate project area is sparse low brush with local grasses suitable for limited cattle grazing. The alluvial Mason Valley to the west, hydrogeologically separate and different from the project area, contains numerous agricultural fields, primarily alfalfa, onions, vegetables, and pasture lands. These fields are watered by irrigation canals from the nearby Walker River and groundwater wells.

Daily climate data were used for the analyses. Actual daily precipitation and minimum and maximum temperatures were obtained from a meteorological station in Yerington, Nevada (WRCC Station 269229). The relative humidity and wind speed were obtained from Fallon Naval Air Station, Nevada (TuTiempo Station 724885[KNFL]). A data set spanning from 1914 through 2010 was assembled. The average annual precipitation is 12.2 cm (4.81 in) and the median precipitation is

11.7 cm (4.61 in) for the years included in the data set. A year matching the median precipitation, 1970, was chosen for use in the modeling to represent the typical conditions. The 75th percentile precipitation for the data set is 14.8 cm (5.83 in), occurring in 1918. This year was modeled to represent above average precipitation conditions. The daily measured precipitation for 1970 (median precipitation) and 1918 (above average precipitation) was applied over the models in 24-hour time periods distributed according to a sinusoidal function that peaks at noon (normal distribution).

Material Properties

Table 1 summarizes the material parameters used in the VADOSE/W (GEO-SLOPE, 2007a) models for the DST facility. The material properties used in the VADOSE/W (GEO-SLOPE, 2007a) models were based on the design properties of the facility, laboratory and field testing of actual Project materials, and literature values where no site specific data was available.

Table 1 Material Properties

Material Type	Porosity	Dry Density# (g/cm^3)	Saturated Hydraulic Conductivity (cm/s)	Initial Volumetric Water Content# (%)	Thermal Properties
Soil Cover	0.40*	1.92	5.0×10^{-4}*	10	silt
Capillary Break	0.34*	1.92	7.2×10^{-3}*	10	sand
Tailings	0.39^	1.60	3.1×10^{-3}^	26	sand
Compacted Tailings Layer	0.42^	1.92	1.8×10^{-5}^	26	silt
Foundation Soil	0.29^	1.92	8.7×10^{-4}^	6 - 8	sand

* Literature values

\# Assumed values

^ Laboratory testing of site specific material

Facility Design

The configuration of the DST facility includes a 0.45 m (18 in) thick layer of compacted tailings placed directly on the foundation soils. The compacted layer of tailings will act as the liner unit to limit the flux of water into the underlying foundation soils. Over the compacted tailings layer, a network of gravel drains will be placed that will be used to collect and convey the solution draindown from the tailings into lined ditches and ponds. The gravel drains will be piped such that the draindown solution will be removed from the drainage network to an adjacent lined pond, where it will be managed. The DST will be placed over the compacted tailings and drainage network in 9 m (30 foot [ft]) lifts using mobile conveyors. Equipment traffic will be limited on the tailings surface as to avoid development of compacted zones, to minimize the changes to the material properties after stacking, and to limit the development of preferential flow paths. The stacking plan has been designed such that after the placement of each lift of tailings material, the tailings mass will be allowed to drain for an average duration of one year prior to the placement of the next lift. This will maximize the amount of solution that will be able to freely drain from the facility, and minimize the amount of solution remaining in the tailings material when future lifts are placed. The cover designs that were evaluated included both a single-layer and two-layer system incorporating a capillary break.

INFILTRATION AND SEEPAGE MODELING

The DST facility was modeled at three points in time (after placement of the first lift, mid-operations, and fully stacked facility). In order to assess the quantity of infiltration that is expected under ambient conditions and above average precipitation conditions, as well as the performance of the cover system, the model simulated typical climate conditions, a worst case runoff conditions, and a multi-day storm (worst case infiltration conditions)

RESULTS AND DISCUSSION

The first model simulated the placement of the first lift of the DST in the facility. The drainage of the first lift of the tailings material was considered to be the most likely to influence the water content of the foundation soils, thus the highest potential to impact the regional groundwater system. Additionally, the first lift model precipitation events have the shortest flow path to the foundation layer.

The volumetric water content of the tailings decreases steadily after placement, as illustrated in Figure 2. Figure 2 presents the simulated change in water content at individual points along a vertical profile through the central portion of the first lift of the DST facility. The locations near the surface of the lift decrease most rapidly because water is being removed by both downward flux and evaporation. The deeper portions of the lift have a slower decline in water content because this area is not subject to evaporation and this area is receiving water from the upper portions of the lift. The one point starting with a lower water content of approximately 17% by volume is representative of the compacted tailings layer at the base of the facility. It should be noted that based on the results of the sensitivity analysis, regardless of the starting volumetric water content, over the one year period after placement of the first lift, the tailings drain to a water content that is just above the residual water content of the material.

The second scenario simulated the flux through the DST facility after five lifts of tailings have been placed (approximately the mid-point of the mine life). The volumetric water content of the mid-operations scenario model one year after placement is presented in Figure 3. The flux into the drainage network at the base of the facility decreases with time and as additional lifts are stacked on top, because the water content of the tailings in the lower layers of the dry stack is smaller than the water content in the newly placed tailings material. The water in the newly placed tailings material has fewer connected pathways to travel through to the lower layers because the underlying layers have a lower water content causing the pore spaces to be physically disconnected from each other. At the beginning of the placement of the fifth lift, the water begins to migrate downward. However, there is sufficient storage capacity within the underlying tailings material that the water “spreads out” through the facility ensuring low water contents throughout the entire facility.

The final DST facility modeling scenario was the completely constructed facility. When the last lift of the DST facility is placed, the water within the tailings moves downward through the facility as observed from the mid-operations model. As with the mid-operations model, because the lower lifts have partially drained, there is sufficient storage capacity within the tailings material to dissipate the water content throughout the facility, resulting in only small zones of slightly increased water content.

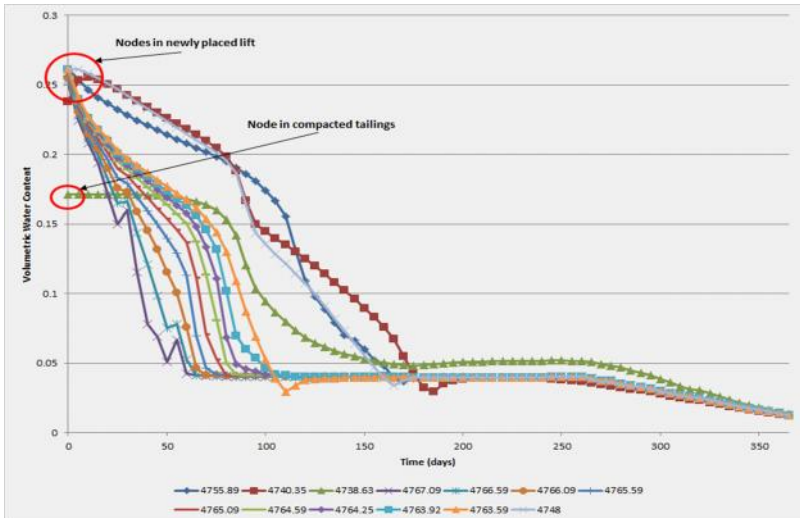

Figure 2 Volumetric Water Content with Depth – First Lift Model

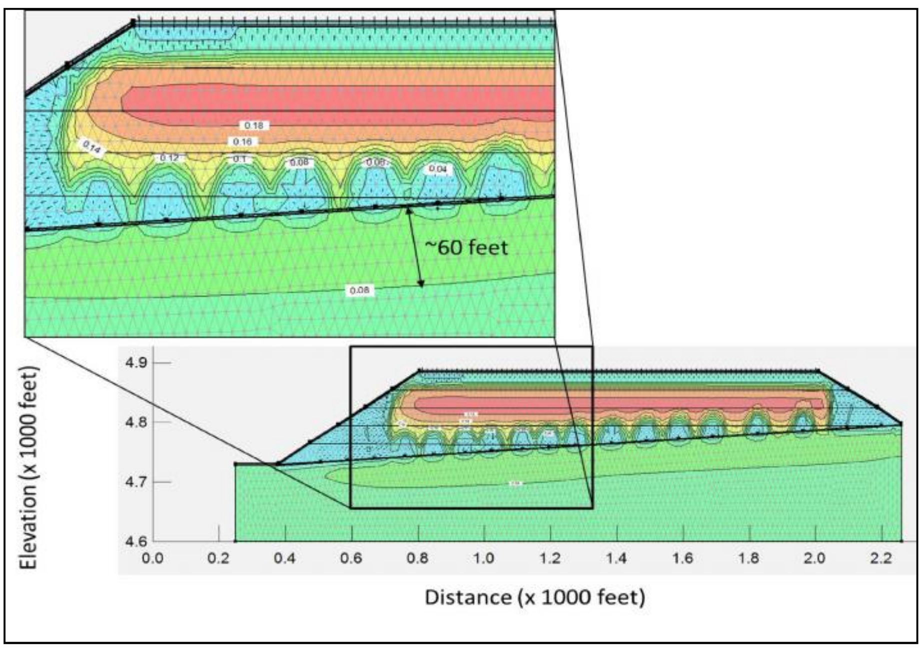

Figure 3 Volumetric Water Content DST Facility - Lift Five Model One Year After Tailings Placement

The net negative water balance of the site limits the amount of precipitation that infiltrates into the DST material. On average, only 29 days each year have measureable precipitation with approximately 18 cm (7 in) of snow. Based on the modeling, infiltration into the facility will be minimal under median and above average precipitation conditions. Figure 4 presents the daily flux of water into or out of the DST facility for the four climate scenarios modeled. The results suggest that only isolated storm events may result in infiltration into the upper surface of the tailings, and because of the high evaporation, this water is then later lost as it is drawn back out of the facility.

This behavior is typical of a store and release design, such as the evaluated cover systems. Annual evaporative water loss through the cover is calculated to be greater than annual precipitation for the Project. The placement of the cover improves the performance of the facility surface by reducing the flow of water, both into and out of the facility, by approximately 25%. These models only considered a one year period after placement of complete cover.

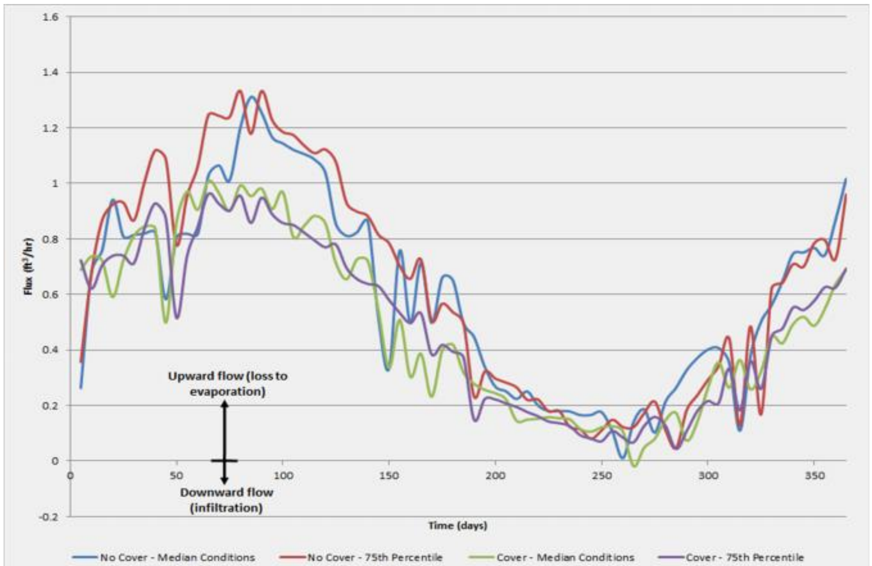

Figure 4 DST Water Flux at Tailings Surface – Completely Constructed Facility

FATE AND TRANSPORT MODELING

The flow modeling determined the quantity of water infiltrating into and seeping through the tailings in the DST facility, including the time of contact. To determine the quality of water that could potentially move downward from the base of the facility and seep into the foundation soil and possibly impact the underlying groundwater system, fate and transport modeling was completed.

Conceptual Fate and Transport Model

The fate and transport models were built from the same geometry and material properties as the infiltration and seepage models. As determined from the infiltration and seepage modeling, the general flow path through the DST is in the vertical direction. Therefore, the fate and transport modeling focused on the potential transport paths, both upward and downward within the DST.

Fate and transport modeling was completed in two separate steps. The first step involved particle tracking to determine the path of the water flow, including which materials the flow would come in contact with and the time required to reach the subsurface. The next step was a simple geochemical mixing model representing the water quality due to contact with the materials in the facility. The results of these two modeling steps were an estimation of where potential seepage would occur, including the water quality of the potential seepage. The following sections provide more detail of these two modeling steps.

Particle Tracking

Particle tracking modeling was performed using the program CTRAN/W (GEO-SLOPE, 2007b), another component of the GeoStudio software suite. The particle-tracking portion of the modeling estimated the flow paths of the water entering, traveling through, and exiting the DST facility. The particle tracking modeling also determined how long the water was in contact with each of the materials, and if seepage would be expected to travel into the foundation materials. The particle tracking model was run for a period of 10 years to allow sufficient time to determine water velocities, should it be determined that water is seeping into the foundation soil. This would allow for the calculation of travel times through the subsurface and the time required for water to reach the top of the regional groundwater system.

Geochemical Modeling

Geochemical modeling was conducted using the computer code PHREEQC (Parkhurst and Appelo, 1999), a reaction path chemical equilibrium model supplied by the U.S. Geological Survey (USGS). In addition to a computer code, geochemical modeling requires a database of thermodynamic and kinetic parameters associated with the chemical reactions. For this Project, the WATEQ4F database (Ball and Nordstrom, 1991) was chosen. However, this database did not include all of the metals of concern to the Project, so additional metals were added to the file. The information added was obtained from the PHREEQ database published with the computer code (Parkhurst and Appelo, 1999). The combination of the two databases provided the broad range of metals needed to predict water quality.

Model Construction

The particle tracking model used the same geometry and material properties as the infiltration and seepage model. The water content and flow conditions resulting from the flow modeling were also used as the starting conditions of the particle tracking models. The particles were placed near the top of the tailings surface, and throughout the facility. The model was run using a forward tracking solver, which calculates the path of the water flux within the facility and associated velocities.

The input solutions representing the leachable constituents in the geochemical modeling were based on the Meteoric Water Mobility Procedure data for three site specific tailings samples: Northwest Open Pit, Northwest Underground, and East/E2. All three samples are representative of tailings material to be placed within the DST facility. Solution concentration data from all three samples were mixed in equal proportions as the starting solution for fate and transport modeling. Each of the starting solutions was equilibrated with atmospheric concentrations of oxygen and carbon dioxide, which was also used to determine the relative pe (redox potential expressed as –log of electron activity). Starting solutions were also equilibrated with mineral phases commonly found within the DST to allow for precipitation or dissolution of minerals from solution.

Model Results

Based on the seepage and infiltration modeling, the water in the DST facility is expected to move downward through the tailings until drainage of the pore water is compete or the pore spaces become sufficiently disconnected to prevent further drainage. Therefore, fate and transport modeling was completed to determine if water draining to the compacted base of the facility would be captured by the drainage network, or if the water would seep through the compacted base, enter the foundation soils, and potentially be transported into the groundwater system.

The model showed that there is minimal downward movement of water within the DST after the initial drainage of the interstitial water, as would be expected because the system is not saturated. Modeling that focused on the first lift of the DST facility showed that the particles primarily moved laterally towards the drains. None of the particles were shown to travel from the facility into the underlying foundation soils. This suggests that the slightly increased water content in the foundation soils observed in the seepage modeling is an equilibration condition instead of actual water movement. The results of the particle tracking of the full facility also show minimal movement of the particles. The greatest movement is only in the zone of highest water content, which does drain downward. Once those zones draindown, the remaining particles moved very little. The particles placed near the outer surface of the facility show the strong influence evaporation has on this facility. The particles in this area are moving upward toward the surface of the facility. The lower water contents and drying in the outer areas of the facility supports this movement.

Even though the flow and the particle tracking models suggests that no water will be transported to the regional groundwater system, the quality of the seepage from the facility was estimated using a geochemical mixing model to demonstrate it would meet regulatory standards. The results of the mixing model suggest that any potential seepage from the DST facility would still be of generally good quality and below NDEP Profile 1 Reference Values.

CONCLUSION

Based on the results of the infiltration and seepage modeling, the DST facility is not expected to impact the regional groundwater system. Under median and above average climate conditions, the water balance of the facility is negative, where draindown of entrained water into the network of drains and subsequent ponds and evaporation are the largest components of the system. Under these conditions potential seepage is limited to the entrained solution in the tailings material, and not precipitation. The flow of entrained solution into the foundation soils and increase in water content of the foundation soils is anticipated to be minimal throughout operations and into closure. The stacking plan includes periods of draining prior to the placement of subsequent tailings lifts, which maximizes the amount of solution that is allowed to drain into the drainage networks.

The compacted tailings layer placed under the main tailings mass is sufficiently impermeable to limit the seepage of water into the foundation soils, and to help move the drained solution to the drainage network. Regardless of the permeability of the compacted tailings layer, even with minor seepage into the foundation soils, there would only be a two percent increase in the volumetric water content. The depth of influence based on the modeling is less than 24 m (80 ft) below the base of the facility, indicating no anticipated impact to regional groundwater system, approximately 90 m (300 ft) below the facility. Based on particle tracking, there is no movement of water from the DST to the zone of influence suggesting equilibration of the system rather than transport.

NDEP reviewed the modeling and through discussions with the mining company, approved the facility's Water Pollution Control Permit in August 2013 including the DST facility. A field test cell was agreed upon to demonstrate over a minimum of a one-year period that the DST concept and the alternate lining approach would be fully protective of the environment, particularly the underlying groundwater system. Initial tailings deposition cells will be constructed with an HDPE liner while the test cell is constructed and data analyzed. Additional project work is currently underway to develop, design, construct, instrument, and develop success criteria for the test cell to demonstrate its protectiveness of the environment.

REFERENCES

Ball, J.W. and Nordstrom, D.K., (1991). WATEQ4F – User's Manual with Revised Thermodynamic Database and Test Cases for Calculating Speciation of Major, Trace, and Redox Elements in Natural Water. USGS Open-File Report 90-129, 185 p.

GEO-SLOPE International, Ltd. (GEO-SLOPE), (2007a). Vadose Zone Modeling with VADOSE/W 2007: An Engineering Methodology. GEO-SLOPE International Ltd.: Calgary, Alberta, Canada.

GEO-SLOPE, (2007b). Contaminant Modeling with CTRAN/W 2007: An Engineering Methodology. GEO-SLOPE International Ltd.: Calgary, Alberta, Canada.

Parkhurst, David L. and Appelo, C.A.J., (1999) User's Guide to PHREEQC (Version 2) – A Computer Program for Speciation, Batch-Reaction, One-Dimensional Transport, and Inverse Geochemical Calculations. USGS WRIR 99-4259.

Tetra Tech, 2010a. NI 43-101 Preliminary Economic Assessment Update. Pumpkin Hollow Copper Project. Prepared for Nevada Copper Corporation. January 13, 2010.

Western Regional Climate Center (2011). Yerington, Nevada (269229) Period of Record Daily Precipitation. http://www.wrcc.dri.edu. Accessed May 1, 2011.