Hydrogeologic Modeling Work Plan

Tronox LLC
Henderson, Nevada

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I hereby certify that I am responsible for the services described in this document and for the preparation of this document. The services described in this document have been provided in a manner consistent with the current standards of the profession and, to the best of my knowledge, comply with all applicable federal, state and local statutes, regulations and ordinances.

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TABLE OF CONTENTS

FIGURES

APPENDICES

1.0 INTRODUCTION

Northgate Environmental Management, Inc. (Northgate) has prepared this work plan on behalf of Tronox for the Tronox facility located in Henderson, Nevada (the Site; Figure 1). This document outlines the basis for the development of a three-dimensional, hydrogeological numerical model for the Site and surrounding areas (Figure 2) which will be referred to in this document as the "Tronox groundwater flow model" or "Tronox model". As presented in the *Capture Zone Evaluation Work Plan* (Northgate, 2010a), this model will be a key tool for completing the revised capture zone evaluation in accordance with United States Environmental Protection Agency (USEPA) guidance (USEPA, 2008).

1.1 Model Objectives and Uses

An overview of the planned capture zone evaluation, including use of the groundwater flow model, is included as Appendix A to this Work Plan. As indicated in Appendix A, specific model objectives include:

- Simulating groundwater flow patterns within the subsurface geologic units underlying the Site, including water sources and sinks, groundwater flow directions and horizontal and vertical gradients, and the impacts of remediation pumping, recharge, and barrier wall(s);
- Simulating particle flowpaths to delineate capture zones at the barrier wall/Interceptor Well Field (IWF), Athens Road Well Field (AWF), and Seep Well Field (SWF);
- Estimating perchlorate travel time and future "daylighting" of perchlorate from the Upper Muddy Creek Formation (UMCf) to the Quaternary alluvium (Qal); and
- Determining what, if any, well field modifications are needed to achieve target capture zones once they are established with the Nevada Division of Environmental Protection (NDEP).

In the longer term, the model can be used for ongoing optimization of capture and contaminant mass removal in well fields as conditions change over time. If necessary in the future, the Tronox model could be expanded to incorporate contaminant fate and transport for predicting cleanup times and other evaluations. Fate and transport modeling could include hexavalent chromium and other Site contaminants in addition to perchlorate.

1.2 Data Sources

Northgate plans to use existing Site data and the new data collected, as described in *Capture Zone Evaluation Work Plan* (Northgate, 2010a), to construct the Tronox model. Northgate will use new Site water level and flow data in conjunction with existing data to refine previous evaluations of groundwater flow directions and gradient magnitudes at the Site. In addition to Site-specific hydrogeologic data, Tronox will draw on data from the nearby BMI site, where significant data have recently been collected pertaining to vertical hydraulic connectivity, residence time, and flow velocity. Other information from nearby sites that may be useful in developing the Tronox site model will also be identified, reviewed, and used as appropriate in the early stages of the model development. Previous aquifer stress tests conducted by Tronox (e.g. Kerr-McGee, 1998; Kerr-McGee, 2001; ELM&A, 2000) and by others at neighboring sites will be used as sources for assigning initial hydraulic aquifer properties.

The McGinley and Associates (2007) numerical groundwater model constructed for the AWF, the DB Stephens & Associates, Inc. (DBS&A, 2006; DBS&A, 2008) numerical groundwater model constructed for the Basic Management, Inc. (BMI) common areas (which also includes the AWF area), and the recent groundwater capture zone model for the neighboring TIMET site (TIMET, 2009) will all be reviewed and used to the extent appropriate as a starting point for the new Tronox model.

2.0 SITE CONCEPTUAL MODEL

The Tronox model will be based on the *Conceptual Site Model, Kerr-McGee, Henderson, Nevada* (CSM; ENSR, 2005), as updated and refined based on newer data. The CSM is based on Site-specific data and an understanding of the regional hydrogeologic framework, and represents a scientifically-based understanding of how groundwater flows horizontally and vertically at the Site within the aquifer system, and groundwater sources and sinks in that system (Figure 3). The 2005 CSM, along with data collected from more recent investigations of the Site and nearby sites, form the foundation upon which the numerical model will be constructed. It is recognized that both the CSM and the Tronox model are evolving as more data become available. Observations made during numerical model calibration may indicate additional areas of the model or certain model input parameters that need to be re-evaluated, as well as concepts of groundwater flow that may need to be re-evaluated.

2.1 Key Model Input from Conceptual Site Model

Key aspects of the CSM that are important for the development of the groundwater flow model are discussed below. One of the first steps in developing the Tronox model will be to expand on and refine what is known about the hydrogeologic conditions/parameters and water sources/sinks. In particular, the water budget for the targeted model domain will be evaluated by quantitatively assessing the sources and sinks of groundwater discussed below to assure they balance. In addition, the current understanding of hydrogeologic conditions and parameters will be revisited and updated if warranted.

As described in the CSM (ENSR, 2005), groundwater flows predominantly horizontally from south to north in the shallow Qal and vertically upwards in the underlying tighter UMCf. Significant inflows to the groundwater system underlying the Site include artesian upflow from deeper units beneath the UMCf and from line recharge along the southern boundary of the Site. Relatively smaller input is derived from the precipitation recharge. Additionally there are likely inputs from anthropogenic sources such as leaking utility pipes. The major discharge is from the Qal unit to the Las Vegas Wash. Details of this conceptual system are described below.

2.1.1 Hydrogeology

Groundwater flow at the depths of interest occurs predominantly in the Qal. Horizontal groundwater flow in the Qal is generally towards the north, with local variability due to the orientation of stream channel deposits, pumping stresses and hydraulic structures. The hydraulic conductivity of the alluvium is variable, with conductivity greater within paleochannels than it is in inter-channel areas.

Both the horizontal and vertical hydraulic conductivities of the UMCf are substantially less than those of the Qal. Groundwater flow in the UMCf is dominated by vertically upward flow, with limited horizontal flow primarily in sporadically encountered thin sand or coarse-grained layers within the predominantly silty/clayey formation (DBS&A, 2008). A consistently upward vertical gradient has been reported between the UMCf and Qal at the Site based on well pairs or clusters where one well is screened in the Qal and one or more well is screened at various depths in the UMCf.

2.1.2 Water Budget

Recharge to the Qal occurs primarily from:

1. groundwater upflow from the underlying UMCf;
2. groundwater inflow from Qal upgradient;
3. infiltration from precipitation and stormwater runoff;
4. infiltration at several rapid infiltration basins (RIBs) and bird preserve ponds on and near the Site;
5. injection or infiltration of water at recharge trenches downgradient of the IWF;
6. seepage of water from Las Vegas Wash where the water level in the channel is higher than that in the adjacent alluvium (expected to be localized if present at all); and
7. leaks from utility piping.

Recharge to the UMCf that will be included in the model domain is primarily from the underlying UMCf and from UMCf upgradient of the domain.

Discharge from the Qal occurs primarily from:

1. seepage to the Las Vegas Wash where the water level in the alluvium is greater than that in the wash;
2. evapotranspiration from phreatophytes and possibly other plants where depths to water are within their rooting depth; and
3. groundwater extraction from the IWF, AWF, and SWF. Additional details on discharge from the remediation well fields are presented in Section 2.2 below.

2.1.3 Other CSM Considerations

The total dissolved solids (TDS) concentration in groundwater at and near the Site ranges from less than 1,000 milligrams per liter (mg/L) to over 20,000 mg/L. The significance of this is that the effects of higher density groundwater may need to be considered in the modeling. Therefore, Tronox will evaluate this issue during development of the groundwater flow model, and will provide documentation and rationale for simulating, or not simulating, such density-driven flow effects.

2.2 Description of Existing Groundwater Containment Systems

Tronox operates three primary groundwater containment and extraction systems associated with its Henderson Facility in accordance with the Consent Order for remediation of chromium-impacted groundwater at the Henderson facility, finalized September 9, 1986, and the Administrative Order on Consent (AOC) for remediation of perchlorate-impacted groundwater in the Henderson area, finalized October 8, 2001. The locations of groundwater containment and extraction systems are shown in Figure 1. In addition to chromium and perchlorate, the recent Phase B Investigation identified several other chemicals (i.e., metals, ammonia, cyanide, 4-chlorobenzenesulfonic acid, organochlorine pesticides, volatile and semi-volatile organic compounds) that impact groundwater quality at the Site. Northgate will consider these other chemicals as part of the assessment of groundwater capture and treatment. The three groundwater containment and extraction systems associated with the facility are described in the sections below.

2.2.1 On-Site Barrier Wall and Interceptor Well Field (IWF)

A bentonite-slurry wall was constructed as a physical barrier across the higher concentration portion of the perchlorate/chromium plume on the Tronox site in 2001 (Figure 1). The barrier wall is approximately 1,600 feet in length and 60 feet deep. The bottom of the barrier wall was constructed to tie into approximately 30 feet of UMCf. A series of 23 groundwater extraction wells were installed south (upgradient) of the barrier wall. In December 2009, this upgradient well field pumped about 73 gallons per minute (gpm), dewatering the Qal and the upper portion of the UMCf in the vicinity of the pumping wells. Most of the wells comprising the Interceptor Well Field are completed in both the Qal and unconfined portions of the upper fine-grained UMCf. North of the barrier wall, the groundwater is artificially recharged with clean (less than 5 parts per billion [ppb] perchlorate) from Lake Mead. This water is introduced into gravel-filled trenches to balance the groundwater removed from the Qal and UMCf by the IWF.

2.2.2 Athens Road Well Field (AWF)

Located approximately 8,200 feet north (downgradient) of the barrier wall, the AWF (Figure 1) includes a series of 14 groundwater extraction wells screened in the Qal at seven paired well locations. The pairs act as “buddy” wells with one pumping while the “buddy” well serves as a piezometer to monitor the impacts of pumping on the water levels adjacent to the well. The wells span roughly 1,200 feet of the Qal paleochannel. In December 2009, the AWF pumped at a combined rate of about 256 gpm.

2.2.3 Seep Area Collection System

Located near the Las Vegas Wash, approximately 4,500 feet north (downgradient) of the AWF (Figure 1), the Seep area system includes a surface capture pump for the intermittent surface stream (Seep) flow and 10 groundwater extraction wells in the Seep well field to capture subsurface flow. The surface stream has not flowed since April 2007.   The wells comprising the Seep Well Field (SWF) are completed in the Qal across the deepest portion of a buried paleochannel. In December 2009, the SWF pumped at a combined rate of about 580 gpm.

All groundwater from the hydraulic containment systems is routed for treatment to the Tronox facility and, following treatment, is discharged to the Las Vegas Wash under a National Pollution Discharge Elimination System (NPDES) permit.

3.0 ASTM STANDARD GUIDES

American Society for Testing and Materials (ASTM) has developed Standard Guides[1] for the modeling of groundwater flow and solute transport. The Standard Guides listed below will be considered and applied, as appropriate, in the development and application of the Tronox model.

- D-6170-97: Selecting a Ground-Water Modeling Code
- D-5609-94: Defining Boundary Conditions in Ground-Water Flow Modeling
- D-5610-94: Defining Initial Conditions in Ground-Water Flow Modeling
- D-5981-96: Calibrating a Ground-Water Flow Model Application
- D-5490-93: Comparing Ground-Water Flow Model Simulations to Site-Specific Conditions
- D-5611-94: Conducting a Sensitivity Analysis for a Ground-Water Flow Application
- D-5718-95: Documenting a Ground-Water Flow Model Application
- D-5880-95: Subsurface Flow and Transport Modeling

Site-specific data and conditions, computer code limitations, and other factors will dictate how and when the Standard Guides are followed. Tronox will use the ASTM Standard Guides as guidance documents, consistent with their intended use.

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[1] D-5447-93: Application of a Ground-Water Flow Model to a Site-Specific Problem, has been withdrawn by ASTM with no replacement

4.0 GROUNDWATER MODEL CODE SELECTION

As discussed in Section 2.1, it is known that plumes with TDS concentrations higher than 5,000 mg/L over wide areas, and higher than 20,000 mg/L in smaller areas, are present within the area to be modeled. The higher fluid densities associated with increased TDS concentrations can lead to spatial gradients in fluid density, potentially creating upward or downward buoyancy forces which under certain conditions can have a significant effect on the flow regime. The relative magnitude of these buoyancy forces with respect to the vertical hydraulic head gradients determines whether or not the flow regime around the high TDS plumes is governed primarily by buoyancy forces or by the vertical hydraulic head gradients (Bear, 1972; Holzbecher, 1998).

As part of the numerical model selection process, Tronox will analyze the flow regimes associated with the high TDS plumes to determine if it is necessary to use a numerical model capable of simulating variable-density groundwater flow. This analysis will include evaluations of the relative ratios of buoyancy forces to vertical head gradients and also the relative size of the high-TDS, high density plumes to the overall flow domain, in addition to a comparison of density corrected hydraulic heads and water levels. If the analysis shows that explicit accounting for the buoyancy forces is not required to adequately represent the flow regime, then MODFLOW-2000 (Harbaugh *et al.*, 2000) will be used as the numerical engine for the flow model.

MODFLOW solves the partial-differential equation describing transient ground water flow in a three-dimensional, heterogeneous, anisotropic medium, in which the axes of the hydraulic conductivity tensor are aligned with the model grid coordinate system. Additional assumptions include constant and uniform fluid (water) density, viscosity, and temperature. MODFLOW solves the flow equation using the finite-difference method in which the groundwater flow system is divided into a grid of cells. For each cell, there is a single point, called a node, at which the hydraulic head is evaluated. The finite-difference equation method used is documented in McDonald & Harbaugh (1992).

If the variable density flow evaluation shows that the flow regime associated with the high TDS plumes is strongly affected by buoyancy forces, then we will use SEAWAT Version 4 (Langevin *et al.*, 2008) instead of the standard MODFLOW-2000. The SEAWAT program has been developed by U.S. Geological Survey (USGS) and is a coupled version of MODFLOW-2000 and MT3DMS (Zheng *et al.*, 1999) designed to simulate three dimensional, variable-density, saturated groundwater flow. SEAWAT is part of the MODFLOW family of codes and has been designed to be compatible with the standard set of MODFLOW packages for specifying boundary conditions, sources, sinks, and heterogeneity throughout the model domain.

The commercially available software package, Groundwater Vistas Version 5, will be used as the pre- and post-processor for the model inputs and outputs. Groundwater Vistas includes an interface for defining input parameters and for running SEAWAT.

5.0 NUMERICAL FLOW MODEL DEVELOPMENT

This task involves accurately representing the elements of the CSM in terms of the numerical groundwater flow model. This includes selecting the model domain extent; creating the model grid and designating the active grid cells; assigning appropriate boundary conditions along the top, bottom, and lateral faces of the model domain; assigning aquifer hydraulic parameters (e.g. hydraulic conductivity, porosity, storage coefficients) to adequately represent the known distribution of lithologic units at the Site; and assign internal sinks and sources to account for infiltration, evapotranspiration, and pumping wells.

5.1 Model Domain Extent

A preliminary estimation of the extent of the proposed model domain is shown in Figure 2. The active area of the model domain will be wedge-shaped, narrowing from south to north toward the Las Vegas Wash. From south to north, the proposed model domain will extend from south of Lake Mead Parkway to the Las Vegas Wash, approximately 20,000 feet (about 4 miles) in total length. Laterally (perpendicular to the regional groundwater flow direction), the model will extend east and west of the Tronox Site to include the existing groundwater capture systems at the BMI and POSSM properties to the west and the proposed groundwater barrier trench and capture wells at the TIMET site to the east. The large extent of the model domain is necessary to accurately reflect the hydraulic features which may impact the evaluation of groundwater capture zones and future plume evolution, and to avoid having the lateral boundaries of the active domain intersect active sources and sinks. As described in Section 5.2.1 below, this regional domain will be modeled using a relatively coarse grid size with the objective of describing the overall groundwater flow domain. Much smaller "sub-domains" in the vicinity of the Tronox well fields will be modeled at a greater level of detail for the purpose of capture zone evaluation.

Regional potentiometric maps for the shallow and the deeper water bearing zones will be developed based on data available from the Tronox Site, neighboring sites, and other publically available groundwater monitoring data from the USGS and Nevada Department of Water Resources. It should be noted that the potentiometric map shown in Figure 2 is only schematic. The exact lateral extent of the active model domain will be defined based on the streamline analysis derived from these potentiometric maps. Figure 2 depicts the maximum possible lateral extent expected for the model domain. The final lateral extent may be narrower based on the more detailed streamline analysis.

In the vertical direction, the model domain is expected to extend into the Middle Water Bearing Zone, as defined by NDEP (2009), within the UMCf and at least 200 feet bgs. The bottom depths will be determined in the early stages of model development based on evaluation of available perchlorate distribution and other data.

In general, the orientation of the model layers will follow the dip angle of alluvial fan sediments and the general Site topography. The model grid axes will be aligned as accurately as possible with the geologic structures of the valley to allow modeling of the hydraulic conductivity as diagonal tensors.

5.2 Domain Discretization

5.2.1 Horizontal Discretization

During the early phase of the model development, while establishing the appropriate large scale model boundary conditions and flow parameters, a uniform horizontal grid size will be used. The horizontal grid dimension should be sufficiently small to represent spatial heterogeneity in aquifer hydraulic properties at the smallest scale over which differences in parameters would affect hydraulic head distributions at the scale of observation, and also small enough to satisfy Peclet number criteria for typical transport modeling scenarios that may be run in the future. However, the grid size should not be so small that it makes simulation run-times prohibitively long. The smallest scale of heterogeneity that can likely be well characterized within the model domain would be some fraction of the width of buried alluvial paleo-channels incised into the UMCf. The initial grid size will be chosen with these types of considerations. The Site-wide model will be fully calibrated with all the information available. With the fully calibrated model at hand, Groundwater Vista's Telescoping Mesh Refinement (TMR) will be used to develop sub-models with finer discretization for focused areas of interest. The boundary conditions of the sub-models will be consistent with the Site-wide model. At this planning stage, it appears that Tronox will develop as many as three sub-models (one each for IWF, AWF, and SWF).

5.2.2 Vertical Discretization

One of the main goals of the flow model is to accurately model the potentiometric surface in the shallow Qal and near the Qal-UMCf contact. For this reason the model will have a finer vertical discretization in the Qal and along the Qal-UMCf contact. Initially we propose subdividing the Qal into three layers, with the combined thickness of these three layers ranging from 10 to 50 feet. The UMCf will initially be divided into two layers. The thicknesses of the model layers will generally increase with increasing depth. The layer thickness and layer depths will also be chosen in order to represent the screened intervals of pumping wells as best as possible. As with the horizontal discretization, consideration will also be given to fine choose vertical resolutions to satisfy Peclet number criteria for possible transport modeling in the future.

The elevations for the tops of grid cells in the upper layer of the model grid will be assigned based on the land surface elevations. As described in Section 5.1 above, the bottom of the model will be set in the UMCf at expected depths of at least 200 feet bgs, with a general trend representing a smoothed version of the general topographic variability and the general dip of the Qal-UMCf contact.

Lithologic data sets from across the Tronox Site and neighboring sites will be combined and used in constructing a map of the Qal-UMCf contact across the entire model domain.

5.2.3 Temporal Discretization

Initially, steady-state simulations will be performed for periods during which it has been established that hydrologic inputs and parameters can be considered constant. If it is determined that transient state simulations are needed, then the modeled transient state period will be divided into multiple stress periods within which the hydrologic inputs and parameters can be considered constant.

5.3 Aquifer Hydraulic Parameters

Initial estimates for the hydraulic properties assigned to the model will be based on: (1) field and laboratory measurements of hydraulic parameters for locations within the model, domain; (2) values of hydraulic parameters used in previous modeling efforts at the Tronox site and other neighboring sites; and (3) published ranges of parameter values for different geologic materials. Greatest weight will be placed on hydraulic parameters derived from aquifer tests (pump test, slug test, etc.), as the parameters obtained from aquifer tests are generally more representative of the average effective parameters at the model grid scale, than core scale measurements or values based on soil type.

The hydraulic parameters will be assigned to the model grid based on mapped hydro-lithologic zones, with different sets of parameters representing different features, such as paleo-channels. The initial set of parameter values applied to the model will be adjusted as part of the calibration process. References for all hydraulic properties used and refined during the calibration process during the model development will be documented.

5.4 Boundary Conditions

Accurate modeling of the hydraulic head distribution and flow paths depends on appropriate definitions of boundary conditions, sources and sinks. The boundary conditions and sources/sinks fundamentally provide the driving forces for flow within the model and control the mass flux of water entering and leaving the model domain. The boundary conditions listed below represent our initial approach (based on the CSM) at how to best represent them numerically in the flow model. It is expected that some modifications to the boundary conditions may be necessary as the model is developed.

5.4.1 *Top Boundary Conditions*

5.4.1.1 Recharge

The water table will be modeled as a flux boundary, based on the spatial distribution of recharge from precipitation, ponds, irrigation, and leaking utilities. Recharge will be modeled using the MODFLOW Recharge package (Harbaugh et al., 2000). Initial estimates of recharge rates will be taken from Basic Remediation Company's (BRC's) calibrated flow model for the BMI Lower and Upper Ponds Area (DBS&A, 2006; DBS&A 2008). It is likely that recharge rates will be assigned on a zonal basis based on differences in land use throughout the model domain (e.g., residential, industrial, and undeveloped, etc.). Initial estimates for these infiltration rates will be adjusted as a part of the model calibration process.

5.4.1.2 Evapotranspiration

Evapotranspiration (ET) will be simulated using the MODFLOW Evapotranspiration Package (Harbaugh et al., 2000). The ET package models ET with a maximum rate of ET0 at the land surface, decreasing linearly to zero at the extinction depth, below which it is assumed evapotranspiration does not occur. ET0 and extinction depth may vary spatially across the model domain depending on vegetation, soil type, and land use. Initial estimates of ET0 and the extinction depths will be based on a combination of published tables for evapotranspiration rates (e.g., Shevenell, 1996) and on values from the calibrated BMI Upper and Lower Pond Area model (DBS&A, 2008). Final values may be adjusted as part of the model calibration process.

5.4.2 *Bottom Boundary Condition*

The bottom boundary of the ground will represent the vertical inflow or outflow of water into or out of the deeper water bearing zone. A contour map showing variations in the vertical hydraulic gradient will be developed using hydraulic head data from monitoring wells screened in the upper and lower portions of the UMCf. These vertical gradient maps will be used as basis for calculating initial estimates of the vertical flux through the lower boundary of the model domain. The vertical gradient maps will also serve to identify if the vertical flux is spatially uniform, in which case the bottom boundary condition can be modeled with a single set of input parameters, or if there appear to be spatial variations in the upward flux (for example an upslope and downslope region of water flux). These initial values will serve as a starting point and it is expected that they be updated during the model calibration process. MODFLOW's general head boundary (GHB) package will be used to simulate the flux through the bottom boundary.

5.4.3 Lateral Boundary Conditions

5.4.3.1 Eastern and Western Edges

The eastern and western edges of active model domain will be chosen to coincide as closely as possible with observed streamlines. This will allow the lateral boundaries to be treated as no-flow boundaries.

5.4.3.2 Mountain-Front Recharge (Southern Edge)

Mountain front recharge to the basin sediments along the base of the McCullough Range, at the southern boundary of the model will be treated as a specified flux boundary condition. Initial estimates of this mountain front recharge flux will be based on estimates calculated using a water budget approach, as well as possibly empirical approaches based on precipitation in the McCullough Range (Wilson and Guan, 2004). MODFLOW's GHB package will be used to simulate the flux across the southern boundary.

5.4.3.3 Las Vegas Wash (Northern Edge)

The groundwater/surface water interaction along the Las Vegas Wash in the top layer of the model will be simulated using the MODFLOW River package consistent with the approach used in BRC's calibrated model for the BMI Lower and Upper Ponds Area (DBS&A, 2006; DBS&A 2008). The River package simulates groundwater flow to or from a stream based on the hydraulic head difference between the water level in the channel and the computed hydraulic heads in the model grid, multiplied by a streambed conductance term incorporating channel geometry, area, and hydraulic conductivity (Harbaugh *et al.*, 2000).

5.5 Internal Sources and Sinks

5.5.1 Groundwater Pumping

Pumping wells will be modeled using the MODFLOW Well Package (Harbaugh *et al.*, 2000) based on pumping records.

5.5.2 Groundwater Infiltration trenches

The groundwater infiltration trenches will be simulated using the MODFLOW Recharge package. Recharge rates will be based on the records recharge pump flow rates.

5.6 Initial Conditions

Initially a steady state model will be developed for the objectives stated in Section 1.1. Subsequently, a transient model can be developed from the steady state model if this is necessary to meet project objectives.

5.7 Model Calibration

The purpose of the calibration process is to ensure that all hydrologic input parameters are made to best describe the target (observed) hydraulic heads and/or fluxes in the model domain within an acceptable degree of accuracy.

5.7.1 Steady-State Calibration

The model will be calibrated to steady-state conditions. A timeline of known changes in hydraulic conditions across the site will be developed and used as a basis for identifying periods where the flow field is thought to have been at approximately steady. Furthermore, hydrographs and other hydraulic records (such as pumping rates, rainfall, etc.) will be analyzed to confirm these periods of approximate steady-state conditions.

5.7.2 Transient-Calibration

Tronox will evaluate the availability of existing pump test data for tests conducted in the model domain for possible use in transient model calibration. This includes evaluation of aquifer stress tests conducted by Tronox (e.g., Kerr-McGee, 1998; ELM&A, 2000), and tests conducted at neighboring sites.

5.8 Sensitivity Analysis

After model calibration, a series of sensitivity analyses will be conducted to identify which model input parameters (including aquifer hydraulic properties, boundary conditions, etc.) have the greatest effect on the predicted hydraulic heads and on any of the conclusions derived from the model. The sensitivity analysis will be conducted in accordance with ASTM Standard Guide D-5611.

6.0 PREDICTIVE SIMULATIONS

6.1 Capture Zone Evaluation with Current Conditions

After the model has been calibrated and parameter sensitivity assessed, the model will be used to delineate capture zones for the IWF, AWF, and SWF under the latest operational conditions. This will be accomplished through particle tracking analysis using PMPATH and following USEPA guidance (USEPA, 2008). Particle tracking analysis will also be used to evaluate the pathway and timing for perchlorate migration from various locations and depths in the UMCf upward into the Qal.

6.2 Optimization of Groundwater Systems to Achieve Target Capture or Improve Efficiency

The results of the simulation described in Section 6.1 above will be presented to NDEP, and target capture zones for the Site well fields will be established. If the model simulations indicate that the agreed-upon target zones are not being met under current conditions, physical modifications will be simulated in the Tronox model to improve the efficiency with which the target capture is achieved.

7.0 DOCUMENTATION

All the modeling tasks presented above will be documented in a completion report. The report and electronic model input and output files will be provided to NDEP in draft form for review and comment prior to completion of the final report. The modeling documentation and report will be prepared in accordance with the ASTM Standard Guide D-5718. This modeling report will be an appendix to the capture zone evaluation report as described in *Capture Zone Evaluation Work Plan* (Northgate, 2010a).

8.0 SCHEDULE

Compilation of data and information to be used in the flow model is already underway, including development of a quantitative water budget for the Site. Detailed design and construction of the model will begin upon NDEP approval of this work plan. As it becomes available, information on the model input and output results (including calibration runs and particle tracking simulations) will be included in the capture zone evaluation status memoranda to be submitted to NDEP monthly. As presented in *Capture Zone Evaluation Work Plan* (Northgate, 2010a), the draft capture zone evaluation report is currently scheduled for submittal to NDEP in early December 2010, and the modeling report will be included as an appendix to that submittal.

9.0 REFERENCES

Bear, J., 1972, Dynamics of Fluids in Porous Media: New York, Dover Publications, Inc., 764 p. 1972.

Daniel B. Stephens & Associates, Inc. (DBS&A). 2006. Groundwater Modeling Work Plan for BMI Upper and Lower Ponds Area. Prepared for Basic Remediation Company, Henderson, Nevada. November, 2006.

DBS&A 2008. Groundwater Flow Model Calibration: BMI Upper and Lower Ponds Area. Prepared for Basic Remediation Company, Henderson, Nevada. November 2008.

Devitt, D.A., L.K. Fenstermaker, M. Young, B. Conrad and B. Bird, 2009. Evapotranspiration of Mixed Shrub Communities in Phreatophytic Zones of the Great Basin. American Geophysical Union, Fall Meeting 2009, abstract #H43D-105. December 2009.

ENSR International, 2005, Conceptual Site Model Kerr-McGee Facility, Henderson, Nevada. Prepared for Kerr-McGee Chemical LLC, Henderson, Nevada. August 2005.

Errol L. Montgomery & Associates (ELM&A), 2000. Analysis of Rate of Groundwater Movement Based on Results of Tracer and Hydraulic Tests Conducted Between Pittman Lateral and the Seep Area, Henderson, Nevada: prepared December 19, 2000.

Harbaugh, A.W., 1992, A Generalized Finite-Difference Formulation for the U.S. Geological Survey Modular Three Dimensional Finite-Difference Ground-Water Flow Model: U.S. Geological Survey Open-File Report 91-494, 60 p. 1992.

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000, MODFLOW-2000, the U.S. Geological Survey Modular Ground-Water Model—User Guide to Modularization Concepts and the Ground-Water Flow Process: U.S. Geological Survey Open-File Report 00-92, 121 p. 2000.

Kerr-McGee Chemical LLC, 1998. Preliminary Report on a Hydrologic Investigation of Channel-Fill Alluvium at the Pittman Lateral, Henderson Nevada, prepared by Steven R. Lower, Hydrology Services Gourp. October 19, 1998.

Kerr-McGee Chemical LLC, 2001. Seep Area Groundwater Characterization Report, Henderson Nevada Facility. Prepared January 18, 2001.

Langevin, C.D., Thorne, D.T., Jr., Dausman, A.M., Sukop, M.C., and Guo, Weixing, 2008, SEAWAT Version 4: A Computer Program for Simulation of Multi-Species Solute and Heat Transport: U.S. Geological Survey Techniques and Methods Book 6, Chapter A22, 39 p. 2008.

McGinley 2007, Athens Road Well Field Modeling Report – Near BMI Industrial Complex, Henderson, Nevada: McGinley and Associates, Reno, Nevada. June 30, 2007.

Northgate 2010a, Capture Zone Evaluation Work Plan, Tronox LLC, Henderson, Nevada. Prepared by Northgate Environmental Management, Inc., Oakland, California. March 25, 2010.

Northgate 2010b, Interim Groundwater Capture Evaluation and Vertical Delineation Report, Tronox LLC, Henderson, Nevada. Prepared by Northgate Environmental Management, Inc. March 23, 2010.

Shevenell, L. 1996. Statewide Potential Evapotranspiration Maps for Nevada. Report 48, Nevada Bureau of Mines and Geology.1996.

Timet, 2009, Revised Remedial Design for the First Water Bearing Zone, Titanium Metals Corporation Facility, Henderson, Nevada. October 14, 2009.

USEPA 2008, A Systematic Approach for Evaluation of Capture Zones at Pump and Treat Systems: U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/003. 2008.

Wilson, J.L., Guan, H., 2004. Mountain-block hydrology and mountain-front recharge. In: Hogan, J.F., Phillips, F.M., Scanlon, B.R. (Eds.), Groundwater Recharge in a Desert Environment: The Southwestern United States, Water Science and Application 9. American Geophysical Union, Washington DC, pp. 113-137. 2004.

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

APPENDIX A
OVERVIEW OF CAPTURE ZONE EVALUATION

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This addendum provides an overview of the planned groundwater capture zone re-evaluation and briefly describes how the proposed new groundwater flow model will be used in this evaluation. The groundwater capture evaluation will build on the previous evaluation presented in the revised *Interim Groundwater Capture Evaluation and Vertical Delineation Report* (Northgate, 2010b). It will provide a systematic evaluation of capture following the process described in the USEPA's 2008 guidance (USEPA, 2008) and will incorporate new data collected as described in *Capture Zone Evaluation Work Plan* (Northgate, 2010a). The following subsections briefly describe the planned work associated with each of the six steps for capture zone evaluation that are recommended in the 2008 USEPA guidance. As described below, the use of the new groundwater flow model is a key element of Steps 4 and 6 of the evaluation.

Step 1: Review Site Data, Site Conceptual Model and Remedy Objectives

Step 1 of the USEPA capture zone evaluation process includes three parts:

1 evaluating the available plume definition and hydrogeologic data to determine if they are adequate for capture evaluation;

2 confirming that there is an adequate Conceptual Site Model (CSM); and

3 assessing whether the remedy objective is clear.

The first part of Step 1 (assessing data adequacy) has been under evaluation since at least mid-2007, with a number of identified data gaps already filled, as described in the revised *Interim Groundwater Capture Evaluation and Vertical Delineation Report* (Northgate, 2010b). Additional data collection activities that will enhance the capture zone evaluation were described in *Capture Zone Evaluation Work Plan* (Northgate, 2010a), and these data will be collected over the next several months. With completion of these planned activities, adequate data should be available to conduct a thorough and complete capture zone evaluation for the Tronox Site.

As discussed in Section 2 of this Work Plan, an adequate CSM has been developed for the Site (ENSR International, 2005) and this CSM will be used and refined in the capture zone evaluation to address the second part of Step 1. Regarding the third part of Step 1, target capture zone(s) have not been established for the Tronox site, so the remedy objectives are not clearly stated at this time (see Step 2 below). Current assumptions about the groundwater extraction system remedy objectives are that: 1) the primary objective is hydraulic capture, with a secondary objective of cleanup (mass removal); and 2) capture at both the IWF and AWF should be as close to 100% of perchlorate mass as is practical. Remedy objectives will be refined in concurrence with NDEP as the capture zone evaluation progresses.

Step 2: Define Site-Specific Target Capture Zone(s)

Although target capture zones have been discussed amongst representatives of Tronox and NDEP, none have been firmly established. Based on discussions between Tronox and NDEP at an April 16, 2010, project meeting, the current plan is to conduct the capture zone evaluation and determine actual capture first, then define (with NDEP approval) appropriate and reasonable target capture zones. Assumptions related to these target capture zones include:

- Target capture will be defined for both the IWF and the AWF.
- Target capture will likely be defined based on a percentage of perchlorate mass flux, a perchlorate concentration contour, property boundaries, or a combination of these; and
- Target capture will be designed with the goals of capturing as much mass as practical at the IWF and eliminating the Seep Well Field (SWF) in the near future.

Step 3: Interpret Water Levels

Water levels measured in existing and new Tronox wells will be used for this part of the evaluation. The new wells proposed in *Capture Zone Evaluation Work Plan* (Northgate, 2010a) that will enhance the water level measuring point network include:

- ***IWF:***
    1. piezometers adjacent to selected recovery wells will provide accurate measure of drawdown in these areas;
    2. seven new wells screened at varying depth in UMCf will provide additional information on vertical gradient; and
    3. restoration/replacement of up to six missing/damaged monitoring wells will restore these additional water level measuring points.

- ***AWF:***
    1. three new monitoring wells near recovery wells, four new wells near edges of recovery well field, and two new monitoring wells in UMCf high will provide water level data to better define flow and capture; and
    2. restoration/replacement of up to eight missing/damaged monitoring wells will restore these additional water level measuring points.

Groundwater elevation measurements at the IWF and AWF will be used to evaluate flow directions based both on water level maps and on gradient control pairs. Water level maps will be prepared using measurements for wells screened across the Qal, excluding extraction wells. Water levels from extraction wells will not be used, except potentially in rare cases where data are sparse and well losses have been evaluated and water levels have been adjusted accordingly. The water levels will be hand-contoured taking into account what is known about the subsurface hydrogeology and previous interpretations. Vertical gradients will be calculated for well clusters screened in the Qal and at various depths in the UMCf. As described in Section 5 of this Work Plan, the Site and surrounding area water level measurements will be used in setting up and calibrating the flow model. Where potentially useful for establishing gradient near capture zone boundaries, water levels in well pairs identified as "gradient control points" may also be evaluated as another line of evidence for capture.

Step 4: Perform Calculations

The work planned for this step in the capture zone evaluation includes: 1) revisiting and updating the previous flow rate and mass flux calculations for the IWF and AWF areas (Northgate, 2010b); and 2) using the calibrated groundwater flow model and particle tracking to delineate capture zones. The groundwater flow model will play a prominent role in this part of the capture zone evaluation. As described in Section 5 of the work plan, it will be calibrated using the measured Site and surrounding area water levels. Particle tracking will be used in the flow model to define capture zones at the IWF, AWF, and SWF. In addition, particle tracking will be used to predict where and when UMCf contaminants originating at various locations and depths will enter the Qal. The purpose of this exercise is to confirm that contaminants in the UMCf will eventually be captured by the Qal recovery well fields and to evaluate if the timeframe of that future capture is acceptable.

Step 5: Evaluate Concentration Trends

This step will involve expanding and updating the evaluation of perchlorate concentration trends down gradient of the IWF and AWF that was presented in *Interim Groundwater Capture Evaluation and Vertical Delineation Report* (Northgate, 2010b). This evaluation will be based on monitoring data collected through May 2010 for remedial performance reports. In addition, an evaluation of shorter-term perchlorate concentration trends focused specifically on the integrity of the barrier wall will be performed. This evaluation will involve tracking perchlorate concentrations (and water levels) in wells between the barrier wall and recharge trenches in response to pumping and subsequent recovery in selected wells in this area. Additional details on this evaluation were presented in *Capture Zone Evaluation Work Plan* (Northgate, 2010a) and will be further described in a final response to comments on this document to be submitted to NDEP.

Step 6: Interpret Capture and Identify Next Steps

The last step described in the USEPA guidance (USEPA, 2008) involves assessing the interpreted capture zones based on Steps 1 through 5 to identify uncertainties in interpretation and data gaps and to determine whether target capture zones are being achieved, and if not what modifications could be made so that targets are met. Uncertainties will be evaluated by comparing the results of different lines of evidence for capture and through sensitivity analysis for the flow model. Because capture zone data gaps have been assessed over the past few years, and remaining identified gaps are currently being filled, significant additional data gaps are not expected to be identified. Any that are identified will be filled to the extent practical.

Because target capture zones have not yet been established, the initial evaluation under this part of Step 6 will be to determine what capture is being achieved under current conditions and to assess what effect the new barrier wall and extraction system at the neighboring TIMET site will have on Tronox site flow and capture. These evaluations will be used as the basis for discussions with NDEP to establish appropriate target capture zones for the IWF and AWF. As mentioned above, target capture zones may be defined based on a percentage of perchlorate mass flux, a perchlorate concentration contour, property boundaries, or a combination of these. If mass flux is to be considered, the groundwater flow model will be used to determine groundwater flux and perchlorate concentrations will be assigned based on recent monitoring data. Once target capture zones are agreed upon, the groundwater flow model will be used to evaluate what, if any, changes should be made to the IWF and/or AWF to most efficiently achieve these targets. As described in the guidance (USEPA, 2008), the steps and tools described above will continue to be used in the future for periodic re-evaluations and optimization of the groundwater capture system as Site conditions change.