Interim Groundwater Capture Evaluation and Vertical Delineation Report

Tronox LLC

Henderson, Nevada

March 23, 2010

Prepared For:

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and Vertical Delineation Report
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Responsible CEM for this project

I hereby certify that all laboratory analytical data was generated by a laboratory certified by the NDEP for each constituent and media presented herein.

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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EXECUTIVE SUMMARY

Tronox LLC (Tronox) operates three primary groundwater containment and extraction systems associated with its Henderson, Nevada Facility (the Site): the on-site Interceptor well field (IWF) and barrier wall, the Athens Road well field (AWF), and the Seep well field (SWF). The Nevada Division of Environmental Protection (NDEP) requires verification that the Tronox systems are effectively removing contaminants passing through the capture zones. The evaluation of groundwater capture found multiple lines of evidence to support the conclusion that the Interceptor extraction system is effective at hydraulic capture. Overall, the decrease in perchlorate loading in the Las Vegas Wash since 1999 is a strong line of evidence of the effectiveness of the combined systems over the last 10 years. In May 1999, the perchlorate loading in the Wash was 1,104 pounds/day vs. 55 pounds/day in July 2009, a 95 percent drop. However, additional data are needed to fully evaluate hydraulic capture at the extraction systems operating at the Site. To this end, a proposed scope of work and schedule for its completion are presented in the *Capture Zone Evaluation Work Plan*, to be dated March 25, 2010 (Northgate 2010).

At the IWF, capture zone analysis, flow budget, declining perchlorate concentrations downgradient from the barrier wall over time, and overlapping cones of depression are lines of evidence demonstrating effective capture. Perchlorate mass flux calculations based on May 2009 sampling data indicate a 99.6 percent capture of perchlorate mass in the Quarternary alluvium (Qal) and upper portion of the Upper Muddy Creek formation (UMCf) by the IWF. It is acknowledged that a small amount of perchlorate is present in groundwater flowing past the IWF on the west and east sides of the barrier wall, and that underflow beneath the barrier wall within the lower portion of the upper water-bearing zones (WBZ) and the middle WBZ occurs, but at a greatly reduced rate based on low hydraulic conductivities estimated in the 10^{-5} cm/s range. In addition, density-adjusted vertical hydraulic gradients measured at the Site are upward, suggesting that any contaminants present in the UMCf that pass beneath the barrier wall will eventually “daylight” into the alluvium and be captured downgradient at the AWF. Tronox is proposing additional pumping and evaluation in the IWF area to further increase the contaminant capture and confirm that the barrier wall is not leaking.

For the AWF, previously identified data gaps have been partially addressed. Installation of additional wells, repair of damaged and/or buried wells, and further data collection and evaluation are needed to fully address these data gaps. The primary lines of evidence supporting the effectiveness of capture at the AWF are the results of numerical modeling and the declining downgradient concentrations of perchlorate over time. A two-dimensionial numerical

MODFLOW model was constructed by McGinley and Associates (McGinley) to evaluate plume capture by the AWF (McGinley, 2007). According to a particle-tracking exercise and preliminary solute transport modeling performed by McGinley, the AWF demonstrated greater than 99 percent capture efficiency. However, McGinley also reported an inability to demonstrate capture using an analog capture analysis based on observed monitoring well water levels and concentration trends. Decreasing perchlorate concentrations have been consistently observed at monitoring wells downgradient of the AWF (PC-98R and MW-K5), but increasing concentrations have been observed over the past several quarters of routing monitoring in downgradient well MW-K4. Overlapping cones of depression are inferred from the cumulative drawdown results, but their interpretation is subject to uncertainty because of insufficient monitoring wells due to the loss of wells as a consequence of construction activities by the City of Henderson (COH). In addition, the calculated perchlorate mass flux moving toward the AWF is significantly less than the actual capture rate, suggesting that the available estimates of parameters needed to calculate the perchlorate mass flux are not well constrained. To address the identified AWF data gaps, Tronox proposes to increase the pumping rates of wells in the western and eastern subchannels, attempt to locate and uncover or replace monitoring wells buried by COH construction, and install new monitoring and/or recovery wells at locations chosen to reduce the uncertainty in the potentiometric contours and provide additional hydraulic containment.

Due to difficulties in obtaining permission from Basic Management, Inc. (BMI) to drill and install monitoring wells outside of an existing easement, field work at the Seep well field has not been completed, and the capture efficiency of the well field has not been calculated. A discussion of the Seep well field is therefore not included in this report.

In response to an NDEP request, Tronox completed eight nested wells in the middle water-bearing zone (WBZ) at four locations on the Tronox plant-site for the dual purpose of further delineating the vertical extent of contaminant plumes and evaluating vertical hydraulic gradients. Measured perchlorate concentrations appear to indicate that that the bottom of the perchlorate plume, as defined by the NDEP's interim action level of 18 micrograms per liter (µg/L), is located in the middle WBZ, near the approximate elevation screened by the vertical delineation wells at about 160 feet below the ground surface (bgs). Based on available data from these wells, the middle WBZ is not impacted by chromium. The calculated density-adjusted vertical hydraulic gradients from these wells all demonstrate upward gradients, with the strongest gradient measured between paired wells M-152 and M-156 north of the barrier wall and pond WC-1.

1.0 INTRODUCTION

This report presents the results of investigations to assess the effectiveness of the groundwater capture systems, the vertical extent of contaminant plumes, and vertical hydraulic gradients at the Tronox facility in Henderson, Nevada. In commenting on the Tronox *Semi-Annual Remedial Performance Report for Chromium and Perchlorate* dated February 28, 2007, NDEP (NDEP 2007a) requested that Tronox evaluate the effectiveness of its groundwater capture systems by considering at least three of six U.S. Environmental Protection Agency (USEPA) "lines of evidence" (USEPA 2002, 2005). In response to that request, a draft work plan was provided to NDEP on May 30, 2007 (ENSR 2007a). On June 26, 2007, NDEP provided comments on the *Draft Work Plan to Evaluate Effective Groundwater Capture at Tronox Extraction Systems* (NDEP 2007b). Additionally, McGinley also provided a report dated June 30, 2007, describing the results of capture analysis using both an analog approach and a numerical groundwater model constructed for the AWF. In their report, McGinley evaluated well field capture efficiency and provided recommendations to further evaluate the capture zone at Athens Road. Following discussions with NDEP, and in response to their June 2007 comments, and in consideration of the recommendations provided by McGinley (2007), a revised work plan (ENSR 2007c) was prepared and submitted on August 29, 2007. Subsequently, NDEP provided additional comments on October 3, 2007 (NDEP 2007c). On November 28, 2007, Tronox provided a letter responding to the additional NDEP comments (Tronox 2007). On December 11, 2007, NDEP approved the revised work plan with a few exceptions noted for the administrative record (NDEP 2007d). Field work consisting of borehole drilling, lithologic sample description, geotechnical sampling, well completion, well development, and well testing was completed by March 2008. On August 25, 2008, Tronox submitted the Groundwater Capture Evaluation as Appendix B of the *Annual Remedial Performance Report for Chromium and Perchlorate, July 2007-June 2008* (ENSR, 2008d). On October 6, 2008, NDEP provided comments on the Annual Remedial Performance Report and the Groundwater Capture Evaluation, requesting submission of a stand-alone Revised Groundwater Capture Evaluation Report (NDEP 2008b). Appendix A contains copies of the NDEP and Tronox correspondence.

The scope of work proposed for the on-site barrier wall, IWF and AWF was completed in 2008 as originally proposed (ENSR 2007c). Additional drilling of two soil borings and completion of one recovery well at the west end of the barrier wall was proposed in the 2008 *Annual Remedial Performance Report for Chromium and Perchlorate* (ENSR 2008d), and was completed in mid-2009. It is anticipated that the recovery well (I-AB) will begin extracting water by the second quarter of 2010. However, access agreement issues for the Seep well field still prevent the installation of the proposed groundwater monitoring wells in this area. Consequently, this revised report only evaluates the evidence that hydraulic capture is occurring at the on-site Interceptor and the Athens Road extraction systems, and offers recommendations to improve and strengthen each of the systems' effectiveness. An evaluation of the SWF will await completion of the proposed monitoring wells in that area. This report has been updated and revised based on second quarter sampling in May 2009 (with supplemental data from May and November 2008) and the additional drilling and well installation described above.

Additionally, a monitoring well completion program for eight middle WBZ wells, for the dual purpose of further delineating the vertical extent of contaminant plumes and vertical hydraulic gradients at the Site, was added to the scope of work in October 2008. These wells were completed in September and October 2009 and are discussed in this report.

Boring logs and well completion diagrams for the soil borings and monitoring wells completed in 2009 are presented in Appendix B. Well development records are presented in Appendix C. Boring and well location survey data is presented in Appendix D. Appendix F contains the Tronox response to NDEP's comments on the *Interim Groundwater Capture Zone Evaluation and Vertical Delineation Report* dated December 23, 2009.

1.1 Current Area Groundwater Plume Conditions

This discussion of current groundwater conditions is based on groundwater sampling data originally presented in the *Annual Remedial Performance Report for Chromium and Perchlorate* (Northgate 2009), covering the period between July 2008 and June 2009. Plates 2, 6, 7, and 8, and Table A-1 from that report are presented in Appendix E, and are referred to in the discussion below. The Plates illustrate the potentiometric surface and constituent loading in the shallow water-bearing zone at the Site. Table A-1 presents five quarters of analytical data (April 2008 to June 2009), including the water level and concentration data used to construct the plates.

Plate 2 (Appendix E), the *Potentiometric Surface Map: Shallow Water-Bearing Zone*, is based on groundwater elevation measurements taken in April-June 2009 by Tronox and AMPAC, and shows a generally north-northeast groundwater flow direction, with an average gradient of 0.02 feet per foot south of the AWF, flattening to approximately 0.007 feet per foot north of the well field approaching the Las Vegas Wash.

The extent of the chromium, perchlorate, and total dissolved solids (TDS) plumes at the Site interpreted from groundwater samples collected in May 2008 are shown on Plates 6, 7, and 8, respectively (Appendix E). There appears to be significant interaction between the perchlorate and chromium plumes originating from on-Site sources, and two TDS plumes originating from adjacent off-Site sources. Plate 8 shows that a plume of groundwater containing a very high level of TDS exists west of the Tronox facility. This plume of high TDS enters the Main Channel (a large alluvial channel that trends north-northeast towards the Las Vegas Wash) beneath the northwestern corner of the Tronox property. Likewise, east of the Tronox facility a high TDS area exists beneath the northern portion of the Timet property, with a maximum concentration of 13,000 mg/L reported in groundwater samples collected by Timet during the third quarter of 2009 (Broadbent, 2010). For the TDS plume originating on-Site, the highest TDS concentration (21,100 mg/L) was measured in extraction well I-T in the IWF. TDS concentrations above 10,000 mg/L are present upgradient of the barrier wall and trend about 1,800 feet south to an area around the Chemstar property. North of the barrier wall, TDS concentrations are in the 2,800 to 8,000 mg/L range due to the effective groundwater capture at the IWF and barrier wall and the recharge of low-TDS Lake Mead water.

Plates 6 and 7 show the configuration of the chromium and perchlorate plumes, respectively, from the site to the Las Vegas Wash. As mapped, both plumes occupy the inter-fluvial area east of the Main Channel from south of Warm Springs Road to Sunset Road where they begin to enter the channel. In the vicinity of the AWF, perchlorate and chromium monitoring data indicate that the plumes narrow and are tightly constrained. This is inferred to be due the morphology of underlying alluvial channels, and adjacent higher-density, high-TDS groundwater plumes in the channel prohibiting the chromium and perchlorate plumes from entering the Main Channel until the density difference dissipates downgradient.

1.2 Operational History

Tronox operates three primary groundwater containment and extraction systems associated with its Henderson Facility (Figure 1):

On-Site Barrier Wall and Interceptor Well Field: A bentonite-slurry wall was constructed as a physical barrier across the higher concentration portion of the perchlorate/chromium plume on the Tronox site. The barrier wall is 1,600 feet in length, about 60 feet in depth, and is combined with an upgradient series of 23 groundwater extraction wells that are situated due south of the barrier wall. The upgradient well field pumps about 70 gallons per minute (gpm) from the shallow WBZ, dewatering the Qal and the upper portion of the UMCf in the vicinity of the pumping wells. Most of the wells comprising the IWF are completed in both the Qal and unconfined portions of the upper fine-grained UMCf.

Athens Road Well Field: Located approximately 8,200 feet north (downgradient) of the barrier wall and IWF, the AWF includes a series of 14 groundwater extraction wells at seven paired well locations. The wells span roughly 1,200 feet of the alluvial paleochannel and pump from the shallow WBZ at a combined rate of about 250 gpm. The extraction wells are screened across the thickness of the saturated Qal.

Seep Area Collection System: Located near the Las Vegas Wash, approximately 4,500 feet north (downgradient) of the AWF, the system includes a surface capture pump for the intermittent surface stream (Seep) flow and 10 groundwater extraction wells in the SWF to capture subsurface flow. The extraction wells are completed in the Qal and pump from the shallow WBZ at a combined rate of about 560 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.

1.3 NDEP Guidance Concerning Evaluation of Groundwater Capture

NDEP (2007a) requires verification that the Tronox systems are effectively removing contaminants passing through the capture zones. The evaluation of the containment must consider three-dimensional capture including flow contributions from both the alluvium in the paleochannels and the upper portion of the UMCf (NDEP 2007a). NDEP has requested the demonstration and verification of mass and hydraulic capture at each remedial well field. Capture zone evaluations for the Tronox systems have followed USEPA guidance (USEPA 2002, USEPA 2005), which specifies that at least three of the six possible lines of evidence for capture are demonstrated.. The possible lines of evidence include the following:

1. Capture zone estimated through calculations of flow-budget or analytical modeling;
2. Demonstration of overlapping cones of depression via flow nets both in plan view and vertical cross-section;
3. Demonstration of inward flow from a compliance boundary using three-point gradient solutions at locations perpendicular to the boundary;
4. Concentration trends over time at sentinel wells located downgradient of the containment;
5. Particle tracking using a calibrated numerical model; and
6. Tracer testing.

USEPA has recently revised its capture zone guidance (USEPA 2008), and this newer guidance will be used for the ongoing capture evaluation.

2.0 EVALUATION OF GROUNDWATER CAPTURE

Section 2 discusses the on-Site IWF and the AWF groundwater capture systems, the results of recent capture related field work, and provides a performance evaluation based on recent data collected in May 2009. Data gaps in demonstrating effective capture are identified, and a scope of work to address those gaps is presented. Table 1 presents the well completion, geotechnical information, and 2008 and 2009 perchlorate and chromium concentrations for the recently installed wells. Table 2 presents the vertical gradient information for the recently installed wells.

2.1 On-Site Barrier Wall and Interceptor Well Field

The IWF and barrier wall are shown on Figure 2, along with the locations of the recently installed monitoring wells, recovery wells, and soil borings. Figure 3 is a conceptual hydrogeologic block model summarizing the hydrogeologic conditions around the well field as is interpreted to date. The diagram shows that the groundwater flows northward from the UMCf coarse- and fine-grained units beneath Lake Mead Parkway, entering into the Qal channels south of the well field. Flow is interrupted by the barrier wall and groundwater is extracted at a current rate of about 70 gpm by the well field. North of the barrier the recharge trenches infiltrate Lake Mead water back into the shallow WBZ. Nested wells, such as the M-74, M-132, and M-133 set shown here, exhibit upward density-adjusted vertical gradients.

2.1.1 Previously Identified Data Gaps and Discussion of Results

In order to strengthen the lines of evidence for capture, Tronox identified the following data gaps and proposed methods to address them in the *Revised Work Plan to Evaluate Effective Groundwater Capture at Tronox Extraction Systems, Tronox LLC, Henderson, Nevada* (ENSR, 2007c):

Data Gap # 1: Demonstrate the barrier wall is continuous and does not leak significantly along its length or have underflow from beneath.

Proposal: Pump wells M-70 through -72 on the downgradient side of the barrier wall and monitor the perchlorate concentrations over time. Concentrations of perchlorate are expected to decrease over time indicating that the barrier wall is functioning as designed. Tronox proposed to pump these three wells north of the barrier wall at a rate of about 1 gpm each, or as formation transmissivity permits. Capacity to handle the water in the Groundwater Treatment Plant (GWTP) will be made available by routing the discharge from selected wells connected to the west header, directly to the GW-11 pond.

Results: In anticipation of pumping these wells, M-70 through -72 were redeveloped in 2007. At that time they were found to be very poor producers, with M-71 yielding the most water at 0.75 gpm (see Table 2, Appendix B, ENSR, 2008d). Currently, no pumping has been performed at any of the wells. Tronox is working on securing a power source for the well pumps in wells M-70 through -72 (including solar panels) since pumping rates are expected to be low. It is anticipated that a power source can be secured and pumping can begin in the second quarter of 2010.

In the interim, water level fluctuations in monitoring wells north (downgradient) of the barrier wall provided an opportunity to assess the hydraulic connection between well pairs located across the barrier wall and evaluate possible leakage. The water level fluctuations in wells M-69 through -72 occurred as a result of variation in groundwater injection rates during refurbishment of the recharge trenches and subsequent maintenance work. Water elevation differences between well pairs located on opposite sides of the wall are shown on Figure 4, *Hydrograph Pairs across the Barrier Wall*. The hydrographs show the redevelopment of a groundwater mound on the north side of the barrier wall after recharge trench refurbishment (about February 2008), and its subsequent dissipation starting in July-August 2008 as recharge rates slowed due to issues related to the delay of installation of a water filtration system. With the trenches now performing near design levels (64.3 gpm as of November 2009), the mound is redeveloping and water levels in M-69 through -72 are once again increasing. The hydrographs (current to February 2010) show a relatively instantaneous rise of the water levels in the wells downgradient of the barrier wall (M-69 through -72) starting in July 2009. This is interpreted to be due solely to the increased quantity of water being recharged in the trenches. In contrast, the above-barrier wells (I-Y, M-55, M-56, and M-58) show only minor water elevation changes attributable to pumping rate changes in nearby recovery wells and general dewatering of the aquifer. Tronox has not observed any systematic correlation between water levels in the well pairs presented in Figure 4 that might indicate hydraulic communication or leakage through the wall.

Based on vertical perchlorate distribution and groundwater flow data, it is assumed that underflow beneath the barrier wall occurs. However, it is expected to be at a relatively low rate based on estimated hydraulic conductivities in the 10^{-5} cm/s range in the UMCf. In addition, as shown on Table 2, density-adjusted vertical hydraulic gradients measured at the Site, including on both ends of the barrier wall, are upward. This suggests that any contaminants present in the deeper UMCf that pass beneath the barrier wall will eventually “daylight” into the alluvium and be captured downgradient at the AWF.

Tronox believes that this data gap has been partially addressed by monitoring shallow groundwater elevation trends in well pairs located on opposite sides of the barrier wall. During the period (between March 2007 and February 2008) when the groundwater mound decreased and subsequently redeveloped following refurbishment of the infiltration trenches, the well pairs did not exhibit a significant hydraulic connection indicating that the barrier wall has negligible leakage. This data gap will be further addressed when water-level responses to proposed pumping in wells M-70 through -72 are evaluated, and with the results of additional investigation and modeling to confirm the integrity of the barrier wall and estimate conceptual trajectories and residence times for contaminants located in the UMCf.

Data Gap # 2: Demonstrate the upward gradient from the Muddy Creek to the alluvium.

Proposal: Install nested monitoring wells at the west and east ends of the barrier wall. Complete these wells in the alluvium and at different depths within the UMCf, and compare their respective static water levels to determine vertical groundwater gradient. The proposed nested wells will consist of two wells each completed in the UMCf at different depths adjacent to shallow wells that are used to evaluate horizontal flow around the west and east end of the barrier wall.

Results: Wells M-132 and -133 were completed in close proximity to M-74 on the east end of the barrier wall (see Figure 2). Table 2 provides the well completion data and shows that the May 2009 water elevation in the deepest well (M-132) is higher than the water elevation in adjacent shallower well M-133; thus indicating an upward density-adjusted vertical gradient. Further, the water level data for May 2009 show that the water elevation for well M-74, completed in the uppermost portion of the UMCf, is lower than both the water levels measured in wells M-132 and -133. This also indicates that there is an upward vertical gradient into the shallowest saturated portion of the UMCf. Likewise, on the western end of the barrier, wells M-134 through -136 were drilled and screened at different depths to a maximum of 90 feet (M-136). The May 2009 water elevations from these wells also show an upward, water density-adjusted, vertical gradient.

Core samples of the UMCf were taken from three borings on the east end of the barrier (M-129, -130, and -132) and one from the west end (M-136) and tested for physical property measurements which showed all samples to have vertical hydraulic conductivities in the 10^{-6} to 10^{-7} cm/s range (see Table 1).

This data gap has been addressed.

Data Gap # 3: Reconcile the flow budget around the west and east end of the barrier wall.

Proposal: To further evaluate the movement of groundwater around the west and east ends of the barrier wall, Tronox proposed to install at total of five monitor wells just past the ends of the barrier wall.

Results: As shown on Figure 2, between November 2007 and March 2008, wells M-129 and -130 were installed east of the barrier wall on TIMET property and wells M-131, -134, -135, and -136 were installed west of the barrier wall. Extraction well I-AA was also installed to enhance groundwater recovery on the west end of the barrier wall. Table 1 summarizes the well completion, water elevation, and 2009 perchlorate and chromium concentrations for each well. The cross-section of the IWF (Plate 1) shows that the M-130 boring encountered the previously inferred ridge of UMCf that separates I-K from CLD2-R. The water table in M-130 is located in the UMCf, and the overlying Qal above the ridge is dry. On the west, Plate 1 shows that I-AA and M-131 intersected a previously unknown alluvial channel to the west of an unsaturated Muddy Creek high. The thickness of saturated Qal in I-AA and M-131 is about 0.33 feet and 0.75 feet, respectively. After well I-AA was developed, short-term pumping showed that the well could only sustain a maximum pumping rate of approximately 1.3 gpm (see Table 2, Appendix B, ENSR, 2008d). In order to capture additional flow around the west end of the barrier wall from the UMCf, well I-AB was completed halfway between wells I-AA and I-B (see Figure 2 and Plate 1). Based on adjacent wells, well I-AB is expected to pump a maximum of 1 gpm. Extraction wells I-AA and I-AB will be hooked up to the IWF and begin pumping during the second quarter of 2010, and are expected to remove approximately 6.3 pounds per day of perchlorate, combined, as calculated using the estimated pumping rates given above and November 2009 perchlorate concentrations of 105 mg/L and 390 mg/L measured in I-AA and I-AB respectively. Capacity to handle the additional groundwater in the GWTP will be made available by routing the discharge from selected wells that are currently connected to the west header, directly to the GW-11 pond.

As will be discussed in Section 2.1.2 below, the majority of groundwater flow in the area of the IWF, and thus the perchlorate and chromium mass flux, is within the saturated alluvium. As seen on the cross-section of the IWF (Plate 1), there is negligible alluvial groundwater flowing past the east side of the barrier wall and minimal alluvial groundwater (0.54 feet of average saturation) flowing around the west side. In order to evaluate the size of the newly discovered channel at M-131, two soil borings (M-157 and M-158) were recently drilled west of M-131 (see Table 1 for borehole data and chemical analyses). Cross-section A-A’ (Plate 1) shows that M-157 had a saturated thickness of only 0.3 feet in the alluvium. The new data were used to estimate the mass flux of perchlorate in groundwater flowing in the alluvium around the west end of the barrier wall, which is calculated to be about 1.1 pounds per day (see Table 4).

Data Gap # 4: Demonstrate that there are overlapping cones of depression for the Interceptor extraction wells.

Proposal: Conduct short-term shutdowns of up to four Interceptor wells with low pumping rates in areas lacking monitoring coverage within the well field in order to obtain water elevation data to aid in contouring cones of depression. Perform distance drawdown plots following procedures outlined in Driscoll (1986) to evaluate pumping well efficiency.

Results: Between June 2 and July 4, 2008, extraction wells I-B, -E, -F, -J, -K, -N, -R, -T, and -U were turned off for between 7 and 19 hours, and water levels were allowed to recover (see Attachment E, Appendix B, ENSR, 2008d). Distance drawdown tests were performed in wells I-K, -N, -R, and -T, wherein the wells were pumped at rates ranging from 0.4 to 4.2 gpm for a period between 150 and 200 minutes. The results from pumping well I-T provided adequate data in adjacent observation wells to assess the well efficiency, which was estimated to be about 20 percent (see NDEP correspondence dated October 6, 2008 in Appendix A). In the case of the other three wells, (I-K, -N, and -R), either drawdown could not be measured or there was only one well with measurable drawdown, which precluded evaluation of well efficiency following the methods described by Driscoll (1986). With regard to the influence measured during the short-term pumping, measurable drawdown was observed in observation wells located about 20 feet from the pumping well. Beyond this distance, measurable drawdown was not recorded in observation wells during the period of short-term pumping. The absence of drawdown beyond 20 to 25 feet is likely a function of the short-term nature of the testing, which may not have been long enough to adequately assess the influence of the pumping and the boundary effect that would be induced by the barrier wall. It would be anticipated that with a longer period of testing, the extent of the influence would have been greater than measured. However, the mounding effect caused by the barrier may have precluded collection of any usable drawdown data from these wells. Additional distance drawdown testing will not be performed due to the interfering influences of adjacent pumping wells, the boundary effects of the barrier wall, and the need to continue to extract a maximum amount of impacted groundwater.

In order to determine the extent of overlapping cones of depression and drawdown in the well field, a potentiometric surface map (Figure 5) was constructed. Inspection of this map in conjunction with the hydrogeologic cross-section (Plate 1) shows that the groundwater surface slopes eastward from M-57A toward I-X on the west and slopes westward from at least CLD2-R toward I-T on the east. Three-point problems were solved for the following well triplets using February 2009 data in the EPA On-line Hydraulic Gradient and Flow Direction calculator (accessed at www.epa.gov/athens/learn2model/part-two/onsite/gradient3ns.htm):[1]

Well Triplets Used for Gradient Calculation	x-coordinate	y-coordinate	GW Elev. (ft AMSL)	Hydraulic Gradient	Flow Direction
M-61	828671.937	26719953.97	1721.99	0.015	N6W
M-67	828508.518	26719829.72	1723.64		
M-68	828750.965	26719864.51	1723.49		
M-66	828183.642	26719787.47	1722.83	0.025	N15W
M-67	828508.518	26719829.72	1723.64		
I-W	828245.871	26719895.87	1720.59		
M-78	827777.453	26719838.17	1718.64	0.019	N15W
M-65	827899.716	26719746.36	1720.87		
M-56	827980.362	26719859.52	1719.22		
I-Y	827334.687	26719800.78	1721.44	0.016	N1W
M-14A	827045.361	26719382.67	1728.15		
M-25	827677.804	26719503.57	1726.32		

Note: AMSL – above mean sea level

Figure 6 of this report presents the flow direction vectors (calculated above) plotted on a map of the IWF. The calculated flow vectors indicate that the groundwater flow south of the IWF is towards the barrier wall and extraction wells, and is consistent with the overall gradient at the Site.

Tronox has proposed installing piezometers adjacent to several of the pumping wells in the IWF in order to provide the data necessary to adequately contour the potentiometric surface and further address this data gap (Northgate 2010).

2.1.2 Performance Evaluation

The current lines of evidence for effective groundwater capture at the IWF include calculated estimates of captured perchlorate mass, a groundwater flow budget, downgradient concentrations declining over time, and overlapping cones of depression. These lines of evidence are discussed further below.

[1] Tronox considered using the computer program Surfer™ to draw vectors for a groundwater direction analysis but rejected it because of the anticipated boundary condition problems due to the proximity of the barrier wall.

2.1.2.1 Capture Zone

The 1,600-foot long barrier wall was designed to provide a physical barrier to groundwater migration across most of the identified perchlorate plume. Based on May 2009 perchlorate concentrations, Table 4 shows that on the east end of the barrier wall and IWF all alluvial perchlorate except about 0.2 pounds/day (at 9.7 mg/L) in cell CLD2-R and all Muddy Creek formation perchlorate except about 0.4 pounds/day (at 25 mg/L) in cell M-130 is being recovered. On the west end of the barrier wall and IWF all alluvial perchlorate except about 1.1 pounds/day (at 114 mg/L) in cell M-131 and all perchlorate in the UMCf except about 0.8 pounds/day (at 250 mg/L) also in cell M-131 is being recovered. These estimates indicate that approximately 2.5 pounds/day perchlorate is getting past both ends of the barrier wall. It should be noted that these calculations do not include assumed underflow of perchlorate wthin the shallow and middle WBZs in the UMCf, which is discussed under Data Gap #1 in Section 2.1.1 above.

Using data and calculations presented in Table 4, a total of about 698 pounds/day of perchlorate is estimated to be flowing toward the well field and barrier wall. As shown on Table 4, this mass was calculated using estimated groundwater flow from different sources, as described in detail in Section 2.1.2.2 below, and estimates of average perchlorate concentrations for each groundwater source based on May 2009 monitoring data. Of the calculated 698 pounds/day, an estimated 2.5 pounds/day are bypassing the collection system. This equates to an estimated effective capture rate of 99.6 percent [(698 – 2.5)/698 = 0.996)]. For comparison, data presented in the *Annual Remedial Performance Report for Chromium and Perchlorate* (Northgate 2009) indicate that the IWF actually removed 849 pounds/day of perchlorate in May 2009, at an average pumping rate of about 69.3 gpm (pumping rate from June 2009 data).

2.1.2.2 Flow Budget

The barrier wall installed in 2001 has dramatically improved groundwater capture. Current pumping rates of about 70 gpm are double those before the wall was installed. Water level data indicate the saturated alluvium portion of the shallow WBZ has been mined and is effectively dewatered behind the barrier wall. The barrier wall is keyed into approximately 30 feet of the fine-grained facies of the UMCf, and as noted above there is an upward vertical gradient in the vicinity of the wall. It would be anticipated that the upward flow of groundwater is enhanced by pumping upgradient of the barrier wall. Given this enhancement to upward flow, with the removal of the alluvial groundwater head, perchlorate mass present within the upper portion of the UMCf would be drawn upward in the vicinity of the IWF and barrier wall.

The known or inferred sources of water contributing to the saturated Qal portion of the shallow WBZ for ultimate capture by the IWF and barrier wall are:

- Upgradient (Offsite) Contribution of Groundwater to the Qal: Previous subsurface investigations in the southern (upgradient) portion of the facility indicate that the water table resides in either the coarse-grained facies of the UMCf (vicinity of Lake Mead Parkway) or the fine-grained facies of the UMCf (vicinity of the unit buildings). The Qal unconformably overlies both. Water occurring in the Qal in the upgradient area is due to residential overwatering and precipitation, and is subject to evapotranspiration. Any water that percolates through the vadose zone mixes with groundwater in the UMCf.
- UMCf "daylighting" groundwater into the Qal: Groundwater flow from the upgradient UMCf begins to "daylight" into the overlying Qal northeast of the unit buildings within one discrete alluvial channel cut into the UMCf. The average beginning point of this "daylighting" occurs approximately 1,200 feet south of the IWF. The width of this zone is defined as approximately the length of the barrier wall. Saturated alluvium thicknesses vary based on the topography of the UMC erosion surface.
- UMCf upwelling groundwater into the Qal: Since the vertical hydraulic gradient has been shown to be upward from the UMC into the alluvium the upward movement of groundwater continues to supplement the water already in the alluvium within this same area. This upwelling groundwater is in addition to the "daylighting" groundwater in the buried alluvial channel, as discussed above.
- Crossgradient flow of groundwater: The IWF and barrier wall is oriented east-west, approximately perpendicular to the overall northward groundwater flow. Potentiometric maps for the area upgradient of the IWF have consistently demonstrated a northward flow direction. Based on these maps, crossgradient flow in the shallow WBZ across the eastern and western boundaries of the target capture zone is not considered to be a significant source of groundwater captured by the IWF extraction system.
- Rainfall: Rainfall is not considered to be a significant source of recharge to the Qal at the site due to the minimal amount of annual precipitation (4 to 5 inches per year) combined with anticipated low rates of infiltration. Infiltration rates for undeveloped land in the vicinity of the Site are estimated at 2% (USGS 2007) or approximately 0.08 to 0.1 inches per year, although it is anticipated that Site-specific infiltration rates, which have not yet been established, could vary from this estimate.
- Onsite Water Line Leaks: The majority of the older water distribution lines at the facility carry untreated Lake Mead water. These lines were installed in the 1940s and have been the source of line failures and leaks many times in the past. Even though subsurface water delivery line leaks have occurred and are occurring onsite, the volume of water released to the subsurface cannot be quantified.

Since the installation of the barrier wall, the IWF at the barrier wall has recovered an average of 62 gpm (currently 70+ gpm). Based on this review of possible water sources for the saturated alluvium at the well field, the only significant source for the groundwater in the Qal is groundwater moving from the UMCf laterally into and upward into the alluvium, and sporadic water distribution line leaks. Whereas a volume calculation for groundwater moving from the UMCf can be determined, the actual total groundwater budget available for recovery at the IWF cannot be determined because of the non-quantifiable nature of water line leak contributions.

An estimate of the groundwater flow at the IWF and barrier wall was developed based on a solution of Darcy's Law assuming two main sources of groundwater potentially available for capture (ignoring the contribution of water line leaks):

- Groundwater in the Qal: As mentioned above, an area upgradient of the barrier wall contains variable thicknesses of saturated Qal. A flow budget was prepared using saturated alluvial thicknesses from the May 2009 data plotted on the hydrogeologic cross-section (Plate 1). The cross-sectional area used in the calculations is the plane of the barrier wall from M-131 on the west to CLD2-R on the east. From this estimate, a total of about 54.6 gpm is flowing toward the barrier wall in the Qal. Calculations and assumptions are shown on Table 4.
- Groundwater upwelling from the UMCf: As previously confirmed, groundwater in the UMCf has an upward vertical hydraulic gradient averaging about 0.07 and hydraulic conductivities on the order of 10^{-6} cm/s or about 0.06 gpd/feet^2. The southernmost upwelling occurs about 1,200 feet upgradient of the barrier wall and the width of the zone is the length of the barrier or about 1,600 feet. This is an area of about 1,920,000 square feet. Using Darcy's Law ($Q = KiA$) gives a result of 8,064 gpd or 5.6 gpm flowing upward into the alluvium from the UMCf upgradient of the barrier wall. Calculations and assumptions are shown on Table 4.

The total flow budget approaching the barrier wall from these two sources is about 60.6 gpm. An undeterminable amount (probably due to water line leaks) also contributes to the flow budget. It is not possible to calculate a more exact flow budget because of the unknown quantity of water released from line leaks.

As discussed above, in order to determine the perchlorate and chromium concentrations in the deeper parts of the UMCf, Tronox has installed eight deep Muddy Creek wells at four locations (two wells at each location) on the Tronox facility. These wells were completed in September/ October 2009 and will be discussed in Section 3.0, *Vertical Delineation of Contaminant Plumes and Hydraulic Gradient*.

2.1.2.3 *Downgradient Concentration Declines over Time*

Perchlorate itself is an effective tracer, since it migrates advectively and is not readily adsorbed to soils. The perchlorate in downgradient wells indicates reduction of a zone containing greater than 100 mg/L perchlorate downgradient of the recharge trenches, where stabilized lake water is added to offset extracted groundwater and maintain groundwater flow. As the recharge water flow is slightly less than the water volume being extracted upgradient of the barrier wall, the rapidly shrinking area containing greater than 100 mg/L perchlorate indicates perchlorate capture. Recently, because of trench clogging and diminished water infiltration, the reduction of the area of greater than 100 mg/L perchlorate has slowed. With the recent refurbishment of the infiltration trenches, this reduction is expected to accelerate. Figure 7 shows the perchlorate concentration decline over time in wells M-100 (1,000 feet north of the well line), M-23 (1,600 feet north of the well line), and M-96 (2,800 feet north of the well line). Well M-100, which contained 1,000 mg/L perchlorate in November 2001, contained 32.3mg/L in May 2009 and 5.4 mg/L in February 2010.

2.1.2.4 *Overlapping Cones of Depression*

Figure 5 and Plate 1 show that, based on May 2009 data, the groundwater surface slopes eastward from M-57A toward I-X on the west and slopes westward from at least CLD2-R toward I-T on the east. The areas between I-S and I-D, I-E and I-U, and I-J and I-K have groundwater elevations less than 1,720 feet above mean sea level (AMSL). Additional evaluation of cones of depression at the IWF will be performed after the installation of piezometers adjacent to IWF recovery wells as described in the *Capture Zone Evaluation Work Plan* (Northgate, 2010).

2.1.3 Evaluation of Groundwater Velocity Downgradient of the Barrier

As suggested by NDEP (2007b), Tronox has completed a qualitative evaluation to determine the times at which perchlorate and chromium plumes might reach the AWF. The evaluation was done through an analysis of “break over”, wherein the effect of the recharged Lake Mead water was used to approximate the groundwater velocity north of the barrier. The resulting groundwater velocity was used to approximate the travel time to the AWF for both the perchlorate and chromium plumes. The calculations indicate that the mitigating effects of the onsite barrier wall will reach the AWF between the years 2010 and 2015, depending on velocity. This discussion is contained in the *Revised Work Plan to Evaluate Effective Groundwater Capture at Tronox Extraction Systems* (ENSR, 2007c).

2.1.4 Data Gaps and Proposed Additional Evaluation

In addition to the previously identified data gaps discussed above, Tronox has identified the following data gap and corresponding proposal to strengthen the lines of evidence for capture at the IWF:

Data Gap #1: More impacted groundwater should be recovered from the IWF.

Proposal: Tronox will connect wells I-AA, -AB, -X, -W, and -Y to the recovery system to improve containment. A schedule for this work is included in the *Capture Zone Evaluation Work Plan* (Northgate, 2010). Capacity to handle the additional groundwater in the GWTP will be made available by routing the discharge from selected wells (containing low chromium concentrations) now connected to the west header, directly to the GW-11 pond.

2.2 Athens Road Well Field

The locations of the recently installed monitoring and recovery wells and soil borings in the vicinity of the AWF are shown on Figure 8. Figure 9 is a conceptual hydrogeologic block model summarizing the hydrogeologic conditions around the well field as is interpreted to date. Groundwater flows northward in the alluvium beneath Sunset Road toward the well field. The ART-series wells extract the impacted water at a current rate of about 257 gpm and pump it back to the fluidized bed reactors (FBRs) on the Tronox plant site. The well field is dewatering the alluvium, and deeper water from the UMCf is flowing upward based on vertical gradient calculation from deep well pairs such as PC-136 and -137 (see Table 2).

In their assessment of the AWF, McGinley (2007) used both numerical groundwater modeling and analog methods to evaluate capture effectiveness and mass recovery efficiency.

The numerical model consisted of a two-dimensional MODFLOW model of the AWF area. Results of the numerical groundwater model showed:

- In a particle-tracking study where a total of 260 particles released at the southern boundary of the model, all of the particles were captured by the AWF; and
- A mass flux evaluation indicated the well field was over 99 percent efficient in mass recovery. However, a solute transport model did indicate that low concentrations of perchlorate escaped capture due to contaminant dispersion.

Results of the analog assessment showed:

- Flow vectors using triangulated extraction wells (ART) and downgradient monitor wells (ARP) did not show inward flow, suggesting capture might not be achieved using the ARP wells as the compliance boundary; and
- Perchlorate concentrations in downgradient wells did not indicate that complete capture was achieved.

McGinley (2007) concluded that the numerical groundwater model provided some use in showing the well field had a high degree of efficiency, but that installed well pairs did not exist that could validate model predictions. They recommended that:

- Analog capture analysis be considered using a standard procedure;
- Five monitoring wells be completed to evaluate inward flow and to provide vertical definition across the extraction well field; and
- Data gathered from pump tests conducted on the proposed new wells be used in expanding the site conceptual model and for possible updating of the numerical groundwater model.

The McGinley groundwater modeling results agree with those of a model previously constructed by Tronox that was used in designing the AWF. In both cases, calibrated numerical models, constructed independently, demonstrated complete particle capture, one of the USEPA criteria required to demonstrate capture. McGinley's 99+ percent mass recovery is also a significant result that would support the demonstration of effective well field capture.

2.2.1 Previously Identified Data Gaps and Discussion of Results

To further evaluate the capture zone at Athens Road and strengthen the lines of evidence for capture, Tronox identified the following data gaps and proposed methods to address them:

Data Gap #1: In contrast to numerical modeling results, McGinley (2007) was not able to demonstrate inward flow using water level data from the second half of 2006 due to the absence of sufficient monitor wells. Also, there are insufficient data to demonstrate influence from pumping of the AWF on water within the underlying UMCf.

Proposal: In order to demonstrate upward vertical head and inward flow, two additional nested well pairs will be completed within 100 feet downgradient of recovery wells ART-3 and -9 in the western and eastern sub-channels, respectively. The new wells will allow calculation of flow vectors and vertical head to confirm capture.

Results: Nested wells PC-134 and -135 were constructed 41 and 38 feet north, respectively, of ART-3; whereas nested wells PC-136 and -137 were constructed 47 and 54 feet north, respectively, of ART-9 (see Figure 8). The cross-section of the AWF (Plate 2) shows the new wells projected into the plane of the section. The most recent (August 2008) water data from the PC-134/135 pair (Table 2) show that the water elevation is highest in the deepest well (PC-134), confirming upward vertical gradient. Unfortunately, due to an oversight by the field sampling crew, no groundwater temperature measurements have been made in PC-135, so the density-adjusted gradient cannot be calculated. Likewise, in the PC-136/137 pair, the deepest well (PC-137) has the highest water elevation (based on the most recent May 2008 data), but because no temperature data exist the density-adjusted gradient cannot be calculated. Due to ongoing City of Henderson construction activities at the well field, all four wells are now buried under parking lots.

One core sample from each of the two well pairs was collected from the UMCf and tested for various physical properties including hydraulic conductivity. Table 1 shows the tests performed and that the hydraulic conductivities of both samples are in the 10^{-6} cm/s range.

In order to determine the extent of the cones of depression and drawdown in the well field, a potentiometric surface map (Figure 10) was constructed. Inspection of this map in conjunction with the hydrogeologic cross-section (Plate 2) shows that the groundwater surface slopes eastward from L637 toward ART-4 and -4A in the western subchannel. In the eastern subchannel, the groundwater surface slopes westward from at least PC-122 and eastward from ART-6 toward ART-7 and -7A. To calculate horizontal flow directions in the vicinity of the Athens Road recovery wells, three-point problems were solved for the following well triplets using May/June 2008 and November 2008 data in the EPA On-line Hydraulic Gradient and Flow Direction calculator (accessed at www.epa.gov/athens/learn2model/part-two/onsite/gradient3ns.htm).

Wells Used for Gradient Calculation	x-coordinate	y-coordinate	GW Elev. (ft AMSL)	Related Athens Road Recovery Well	Hydraulic Gradient	Flow Direction
ART-4	828850.71	26728085.28	1588.22	ART-3	0.0075	S19E
PC-17	828732.629	26728089.23	1588.54			
PC-135	828765.25	26728123.177	1588.70			
ART-6	829472.92	26728140.63	1584.99	ART-9	0.012	N29E
ART-7A	829576.521	26728145.71	1584.35			
PC-136	829517.888	26728191.374	1584.22			

Note: Groundwater elevation data are from June 2008 for the ART-3 and ART-9 areas, with the exception that the May 2008 groundwater elevation was used for well PC-136, as reported in Appendix A of the Tronox *Annual Remedial Performance Report for Chromium and Perchlorate, Tronox LLC, Henderson, Nevada*, July 2008 – June 2009, dated August 21, 2009.

Calculations of flow vectors using the USEPA online tool and May/June 2008 water elevations (see table above) indicate inward flow is being achieved at ART-3, but cannot confirm that inward flow is being achieved at ART-9. Concerning the ART-3 well triangle, the differences in groundwater elevation among the wells was very slight, indicating that additional pumping may be necessary to increase the inward flow under this configuration of wells.

Another solution of the ART-3 three-point problem for November 2008 indicated that inward flow could not be confirmed (see table below). As in June 2008, the hydraulic gradient was a very flat 0.007; however, the flow vector in November was calculated to be N42E. As discussed above, no additional flow vectors can be calculated for either the ART-3 or ART-9 three-point problems until wells PC-134 through -137 are unburied or redrilled.

Wells Used for Gradient Calculation	x-coordinate	y-coordinate	GW Elev. (ft AMSL)	Related Athens Road Recovery Well	Hydraulic Gradient	Flow Direction
ART-4	828850.71	26728085.28	1588.54	ART-3	0.00744	N42E
PC-17	828732.629	26728089.23	1589.11			
PC-135	828765.25	26728123.177	1588.76			

Note: Groundwater elevation data are from November 2008 for the ART-3 area, as reported in Appendix A of the Tronox *Annual Remedial Performance Report for Chromium and Perchlorate, Tronox LLC, Henderson, Nevada*, July 2008 – June 2009, dated August 21, 2009.

Figure 10 shows the contoured potentiometric surface in the well field area. The 1,585-foot contour in the eastern subchannel and the 1,590-foot contour in the western subchannel are interpreted and drawn as closed contours based on the distribution of groundwater elevation measurements within the contour line (Figure 10), the significant local drawdown of up to 13.2 feet centered on the pumping wells (see Figure 11 and Table 5), and past experience at the Site. However, currently available and accessible monitoring wells are insufficient to confirm the precise location of these contours.

This data gap was partly filled with the demonstration of upward vertical gradients in nested well pairs PC-134/135 and PC-136/137, and will be further addressed by increasing the pumping rates to improve inward flow in the areas of ART-3 and -9 as will be described in Section 2.2.3.

Temperature data will be collected from nested well pairs during future monitoring events, after COH allows the wells to be located and unburied or replaced. A scope of work to address this data gap, including refurbishment and/or replacement of buried or damage monitoring wells as well as installation of additional monitoring and recovery wells, is presented in the *Capture Zone Evaluation Work Plan* (Northgate 2010).

Data Gap # 2: Since the abandonment of downgradient monitor wells ARP-4, -5 and -6A in March 2007, there is inadequate monitoring capability north of the well field.

Proposal: The three recently abandoned ARP-series piezometers, ARP-4, -5, and -6A downgradient of the well field will be re-established near their former locations.

Results: Three new wells ARP-4A, -5A, and -6B were installed near the abandoned wells. Table 1 shows a summary of the well completion, groundwater elevation and chemical data.

This data gap has been filled.

2.2.2 Performance Evaluation

Capture Zone: The AWF was designed to provide a hydraulic barrier spanning the approximate 1,160-foot width of the identified perchlorate plume in this area (i.e., greater than 5 mg/L perchlorate). The well field is stopping the downgradient flow of perchlorate above about 1 mg/L perchlorate on the west end and about 5 mg/L on the east end. This means that the capture zone is defined as extending 1,160 feet from about 50 feet west of ART-2 to about 50 feet east of PC-122. As shown on the west-east cross-section (Plate 2), a zone of unsaturated alluvium about 480 feet wide separates the western sub-channel from the eastern sub-channel so the alluvial portion of the capture zone is only a total of 880 feet wide.

Flow Budget: Table 6 shows the calculated groundwater underflow and perchlorate mass flux condition at the well field in May 2009. The table shows that about 131 gpm, containing about 234 pounds per day perchlorate, were calculated to be flowing toward the well field in the Qal whereas the UMCf calculation yields only 0.027 pounds per day flowing through the entire width of the capture zone to a depth of approximately 70 feet bgs. The table also shows the estimated perchlorate loading on either side of the 5 mg/L capture zone, which indicates that 0.05 pounds per day (PC-55 cell) and 0.3 pounds per day (PC-122 EAST cell) are flowing around the west and east ends, respectively. This calculated water flow and mass flux is significantly lower than the documented May 2009 well field recovery of 257 gpm containing

655 pounds per day perchlorate (Northgate 2009), suggesting that the available estimates of parameters used to calculate the perchlorate mass flux are not well constrained.

Tronox has considered performing new pump tests in the recovery wells but has rejected the idea because of the interference that would be expected from the adjacent pumping wells and the importance of keeping all of the wells on-line. In the meantime Tronox has increased the pumping rate in the west subchannel in order to further increase recovery.

Overlapping Cones of Depression: As shown on Figure 10, the potentiometric surface is mapped to include closed contours around the wells in both the western and eastern sub-channels. Though these contours cannot be conclusively drawn because of the limited data between the well field and the ARP wells to the north, it is thought that such a representation is warranted because of the significant drawdown, 12.7 feet in monitor well ART-3, 13.2 feet in monitor well ART-7A and the large zone of greater than 8 feet drawdown that extends at least 350 feet north to the ARP wells, as demonstrated with the drawdown presented in Table 5. Tronox appreciates that drawdown does not indicate capture. Currently, there is insufficient data to demonstrate overlapping cones of depression or to fully evaluate capture at the AWF.

Numerical Modeling: A numerical evaluation by an NDEP contractor (McGinley, 2007) using MODFLOW showed that particles released in the model were completely captured by the AWF, and that mass flux within the model showed greater than 99 percent capture efficiency. However, a solute transport study also performed by McGinley indicated that low concentrations of perchlorate were not captured. Additionally, the McGinley report stated that it was not possible to demonstrate capture at the AWF using analog methods such as flow paths, demonstration of inward flow, and downgradient concentration trends.

Downgradient Concentration Declines over Time: Figure 12 shows that downgradient wells PC-98R and MW-K5 have exhibited consistent decreasing trends of perchlorate concentrations over time with minor reversals. These wells are located about 2,000 feet downgradient of the AWF. The figure shows that the rate of decline has decreased since early 2004. Currently the wells are experiencing a slight increase in concentration, probably in response to a temporary decrease in pumping rate in the west subchannel wells due to well pump issues. In addition, an increasing concentration trend is observed in downgradient well MW-K4. The historic decrease in perchlorate shown on the figure does not appear asymptotic at this time.

2.2.3 Data Gaps and Proposed Additional Evaluation

To further evaluate the capture zone at Athens Road, Tronox has identified four additional data gaps and has developed proposals to address them; these are in addition to the previously identified uncompleted data gaps discussed above:

Data Gap #1: Tronox was not able to demonstrate consistent inward flow in the western and eastern subchannels using water level data from May 2008.

Data Gap #2: Wells ARP-2 and -3 were buried during COH construction activities. There are currently no monitoring data points between ARP-1 and MW-K4.

Data Gap #3: Wells PC-134, -135, -136, and -137, used to prove inward flow, were buried during COH construction activities.

Data Gap #4: Additional monitoring wells may be needed to map closed potentiometric surface contours around the eastern and western parts of the well field.

Proposal: Tronox has proposed to attempt to locate and uncover or replace monitoring wells buried by COH construction, install new monitoring and/or recovery wells at locations chosen to reduce the uncertainty in the potentiometric contours and provide additional hydraulic containment, and increase pumping in existing recovery wells to improve hydraulic containment. A scope of work and schedule for the completion of this work is presented in the *Capture Zone Evaluation Work Plan* (Northgate 2010).

3.0 VERTICAL DELINEATION OF CONTAMINANT PLUMES AND HYDRAULIC GRADIENT

In response to an NDEP request in May 2008 (NDEP 2008), Tronox added a task to the capture evaluation work plan to complete up to eight nested wells in the middle WBZ at four locations on the Tronox plant site. These wells, sited adjacent to existing monitor wells completed in the shallow WBZ, were completed in September-October 2009. Well development records appear in Appendix B and borehole lithology logs and well completion diagrams appear in Appendix C. A summary of the well completion and chemical data is shown in Table 1, and the evaluation of vertical hydraulic gradients at the Site is shown in Table 2.

Plate 3, the *South-North Hydrogeologic Cross-Section C-C'*, shows the location of these eight new middle WBZ wells (M-149 through M-156) and the hydrogeologic and stratigraphic subsurface relationships along the line of cross-section. The cross-section shows that all of the wells except M-154 and M-155 were screened in the first fine-grained facies of the UMCf (UMCf-fg1), whereas the two exceptions were screened in the second coarse-grained facies of the UMCf (UMCf-cg2). Well M-156, on the north end of the section, was screened in an interfluve unit between two channel deposits. As shown on Table 2, all of the calculated density-adjusted vertical hydraulic gradients are upward, with M-155 exhibiting an artesian condition.

Table 1 contains chemical data for perchlorate and total chromium from September, October, and November 2009. November 2009 chemical test results are also presented on Plate 3. Well samples from September and October were collected as grab samples using clean disposable bailers. For the November 2009 sampling, well was purged of water using a Grundfos submersible pump or a combination of the pump and a bailer. Samples were collected from each well using a clean disposable bailer after the well had been allowed to recover at least 80% of its original capacity. The November sample results show a significant decreases in perchlorate concentrations in all wells compared to the earlier grab samples. Conversely, total chromium concentrations, though still low, were measured in six wells that had non-detectable concentrations of total chromium in previous sampling events. These data appear to indicate that the chemical test results of the grab samples collected during the September and October sampling events may not be respresentative of aquifer conditions in the middle WBZ. The November 2009 sampling data are further discussed below.

Perchlorate was detected in seven of the eight wells at concentrations ranging from 0.004 to 413 mg/L. The highest perchlorate concentration was measured in M-149 (413 mg/L), the shallowest delineation well located closest to the on-Site contaminant source. The next highest perchlorate concentration was measured in well M-150 (15 mg/L). Perchlorate concentrations measured in the deeper of the paired wells were all less than 1 mg/L. Perchlorate concentrations measured in well pair M-151 and M-155 were both below the NDEP interim action level for perchlorate of 18 mg/L. It should be noted that the largest vertical hydraulic gradient measured in the vertical delineation wells was between M-151 and M-155. Based on the November 2009 test results, it appears that the base of the perchlorate plume, as defined by the interim action level, is located near or above the deeper of the paired wells in the middle WBZ, screened at depths of approximately 150 to 200 feet bgs.

Chromium was detected in each of the seven wells sampled at concentrations ranging from 0.01 to 0.029 mg/L, all of which are below the USEPA Maximum Contaminant Level (MCL) of 0.100 mg/L for hexavalent chromium. Based on these test results, the chromium plume does not appear to have impacted the middle WBZ at the locations sampled. Due to a sampler error, a sample for total chromium analysis was not collected at the first well sampled, M-149. Total chromium test results for well M-149 from September and October 2009 were 0.014 and 2.9 mg/L, respectively. These results are not consistent with each other, and as noted above it is not clear that they are representative of concentrations in the aquifer formation being monitored. Well M-149 will be resampled during the second quarter of 2010 and the results will presented in the 2010 annual report.

4.0 CONCLUSIONS

Tronox has performed this evaluation to verify the effectiveness of the groundwater extraction systems at the Site. Overall, the decrease in perchlorate loading in the Las Vegas Wash since 1999 is a strong line of evidence of the effectiveness of the combined systems over the last 10 years. In May 1999, the perchlorate loading in the Wash was 1,104 pounds per day vs. 55 pounds per day in July 2009, a 95.0 percent drop. The evaluation of groundwater capture found multiple lines of evidence to support the conclusion that the Interceptor extraction system is effective at hydraulic capture. However, capture at this system is not 100 percent and additional data and evaluation are proposed (Northgate 2010) to establish the appropriate target capture zone and evaluate its attainment. There are not yet sufficient data to demonstrate hydraulic capture at the Athens Road and Seep extraction systems. Tronox has made every effort to fill data gaps in the Athens Road and Seep areas, but has not yet been able to collect the additional data necessary to support a complete capture evaluation. This interim report is being submitted at the request of NDEP, and a revised and updated final report will be submitted after implementation of the *Capture Zone Evaluation Work Plan* (Northgate 2010).

At the IWF, capture zone analysis, flow budget, and declining perchlorate concentrations downgradient from the barrier wall over time are lines of evidence indicating effective capture. Perchlorate mass flux estimates based on May 2009 sampling data suggest a 99.6 percent capture of perchlorate mass in the Qal and upper portion of the UMCf by the IWF. It is acknowledged that a small amount of perchlorate is present in groundwater flowing past the IWF on the west and east sides of the barrier wall, and that underflow in the shallow and middle WBZs beneath the barrier wall within the UMCf occurs, but at a greatly reduced rate based on low hydraulic conductivities estimated in the 10^{-5} cm/s range. In addition, density-adjusted vertical hydraulic gradients measured at the Site are upward, suggesting that any contaminants present in the UMCf that pass beneath the barrier wall will eventually daylight into the alluvium and be captured downgradient at the AWF. Tronox is proposing additional pumping and evaluation in the IWF to further increase the contaminant capture and confirm that the barrier wall is not leaking. These planned activities and additional evaluations are described further in *Capture Zone Evaluation Work Plan* (Northgate 2010).

For the AWF, previously identified data gaps have been partially addressed. However, installation of additional wells, repair of damaged and/or buried wells, and additional data collection are needed to fully address these data gaps. The primary lines of evidence supporting the effectiveness of capture at the AWF are the results of numerical modeling and declining downgradient concentrations of perchlorate over time. According to the McGinley 2007

MODFLOW study, the AWF has greater than 99 percent capture efficiency; however, this study has limitations that must be addressed to better document actual capture. Decreasing perchlorate concentrations have been consistently observed at monitoring wells downgradient of the AWF (PC-98R and MW-K5), although a recent slight increase in concentrations, inferred to be the result of a temporary decrease in the pumping rate in the western subchannel wells, will need to be evaluated further. Based on available calculated hydraulic conductivities, the estimated perchlorate mass flux moving toward the AWF is significantly less than the actual capture rate, suggesting that the available estimates of parameters needed to calculate the perchlorate mass flux are not well constrained. Tronox is proposing additional work to address the remaining data gaps. Several wells buried or destroyed by COH construction activities will be uncovered and/or replaced, including ARP-2, ARP-3,
PC-134, PC-135, PC-136 and PC-137. Recovery well ART-7 will be deepened to allow increased pumping from the eastern subchannel. Pumping will also be increased in the western subchannel to improve inward flow in this area. Tronox will also install additional monitoring wells between the AWF and the ARP well line to provide additional data to reduce the uncertainty in the potentiometric contours in the area. These planned activities and additional evaluations are described further in *Capture Zone Evaluation Work Plan* (Northgate 2010).

In response to an NDEP request, Tronox completed eight nested wells in the middle WBZ at four locations on the Tronox plant-site for the dual purpose of further delineating the vertical extent of contaminant plumes and evaluating vertical hydraulic gradients. Measured perchlorate concentrations indicate that the bottom of the perchlorate plume, based on the interim action level of 18 µg/L, is located in the middle WBZ at or near the deeper delineation wells at about 150 to 200 ft bgs. Based on available data, the chromium plume does not appear to impact the middle WBZ. However, well M-149 needs to be resampled to confirm chromium concentrations. The calculated density-adjusted vertical hydraulic gradients from well triplets using these eight wells all demonstrate upward gradients.

5.0 REFERENCES

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