Appendix E

Groundwater Extraction and Treatment System Optimization Study: Analysis of Groundwater Extraction Rates and Capture at the Interceptor and Athens Road Well Fields

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APPENDIX E

Groundwater Extraction and Treatment System Optimization Study: Preliminary Analysis of Groundwater Capture and Extraction Rates at the Interceptor and Athens Road Well Fields

1. Introduction

The Nevada Environmental Response Trust (the Trust) operates a groundwater extraction and treatment system (GWETS) at the Site to remediate perchlorate and hexavalent chromium from shallow groundwater. The GWETS consists of three extraction well fields: (1) the onsite Interceptor Well Field (IWF) and barrier wall; (2) the Athens Road Well Field (AWF), which is situated approximately 8,200 feet north (downgradient) of the IWF; and (3) the Seep Well Field (SWF) situated approximately 4,500 feet north of the AWF near the Las Vegas Wash. The performance and monitoring of the GWETS are discussed in detail in remedial performance reports submitted to the Nevada Division of Environmental Protection (NDEP) on a semi-annual basis.

The purpose of this appendix is to evaluate groundwater capture at the IWF and the AWF based on current groundwater extraction rates and to propose alternative extraction rates for existing wells and target extraction rates for new wells. The operational changes recommended herein are designed to enhance capture, increase mass removal, and minimize impacts downgradient of the AWF. Further monitoring and analysis of capture and mass removal will be required to evaluate performance of the GWETS and to identify the optimal sustainable extraction rates for individual wells within each well field. Therefore, this study should be considered the first step of an iterative process to enhance performance of these two well fields.

To simplify the analysis, the IWF and the AWF were each analyzed independently (i.e., the effects of one well field on the other were not evaluated). Capture zone analysis of the SWF will be proposed for future studies.

2. Approach

The overall approach of this preliminary analysis is to compare the current estimated capture zones of the IWF and AWF to the extent of the perchlorate and chromium plumes, and then to make recommendations for turning on new wells or adjusting extraction rates at existing wells in order to address the potential gaps in capture and to improve mass removal.

2.1 Background

In December 2010, Northgate prepared a capture zone evaluation, "2010 CZE Report", to describe groundwater flow and perchlorate and chromium distributions and to evaluate the performance of the GWETS (Northgate, 2010a). The 2010 CZE Report was prepared on behalf of Tronox, the prior owner of the Site. NDEP has reviewed and provided comments on the 2010 CZE Report on April 5, 2011, some of which are being addressed by the Trust; however, this report has not yet been approved by NDEP. The 2010 CZE Report was a revised and expanded version of Northgate's Interim Capture Zone Evaluation and Vertical Delineation Report dated March 23, 2010, the "2010 Interim CZE Report" (Northgate, 2010b). As part of the development of the 2010 Interim CZE Report and the 2010 CZE Report, new groundwater wells were installed in order to address data gaps. A number of these new wells installed were designed as potential extraction wells that could be used to address gaps in groundwater capture. The construction details of the wells of the IWF and AWF, including the new potential extraction wells in these well fields, are included in Tables E-1A and E-1B, respectively.

The Trust took title to the Site and the GWETS in conjunction with the settlement of Tronox's bankruptcy proceeding on February 14, 2011. The Trust has been reporting on the performance of the GWETS since this time. In this current annual report (ENVIRON 2012), potential gaps in plume capture have been observed as evidenced by elevated concentrations (primarily of perchlorate, but also chromium) at the ends of the IWF and downgradient of the AWF (see Plates 6 and 7 of the annual reports). The gaps are generally consistent with capture gaps identified in the 2010 CZE Report, and therefore, some of the potential new extraction wells installed previously by Tronox could be utilized to enhance capture in these areas.

In conjunction with the 2010 CZE Report, a groundwater flow model was developed. Following a call between the Trust and NDEP on March 15, 2012, the groundwater flow model, supporting documentation, and responses to NDEP comments on the model were submitted to NDEP on April 25, 2012, and NDEP provided additional comments on the model on August 1, 2012. The Trust is currently addressing NDEP's most recent comments. Once the groundwater flow model is approved, further analysis of capture and optimization of the GWETS including recommendations on the recharge trenches and the associated "dead zone" between the barrier wall and the former recharge trenches will be performed.

2.2 Methodology

This section provides an overview of the methods used to perform this analysis. More detailed discussions of the methods and results are included in the specific sections cited below.

As presented in Section 3 of this appendix, the current capture zones for the IWF and AWF were estimated based on contour maps of Shallow Zone water elevations collected in May-June

2012 by the Trust and adjacent property owners, including American Pacific Corporation (AMPAC), Olin/Stauffer/Syngenta/Montrose (OSSM), Southern Nevada Water Authority (SNWA), and Titanium Metals Corporation (TIMET). The water elevation contours were generated with KT3D_H2O v3.0 (Karanovic, 2009), a program for kriging water level data that incorporates extraction well pumping rates. Since KT3D_H2O is limited in its ability to account for low or no flow conditions, the water level contours generated by KT3D_H2O near the barrier wall were corrected manually. A similar approach was used to interpret water level data in the 2010 CZE Report. Potential gaps in capture were identified by overlaying the current isoconcentration contours for perchlorate and chromium on the groundwater contours and estimated capture zones.

As presented in Section 4, current and historical perchlorate and chromium mass removal estimates for each well were calculated using available pumping rate data and perchlorate and chromium concentration data for the time period July 1, 2002 to June 30, 2012. Based on the well extraction histories and professional judgment, a maximum sustainable flow rate of each well was estimated. The mass removal for each well was calculated using available extraction rates and chemical concentration measurements. If the measured concentrations were not available, the concentrations were interpolated from the isoconcentration maps available for Second Quarter 2012.

The estimates of mass removal for individual wells were used to recommend adjusted extraction rates for existing wells in order to increase mass removal while accommodating the initial extraction rates of new wells identified to address gaps in capture. The recommended adjusted extraction rates are discussed in Section 5.

The extraction rates at the IWF and AWF were adjusted such that the proposed cumulative extraction rates from each of the well fields do not exceed certain limits due to the following operational and design constraints of the GWETS:

- The GWETS is operating near its design average annual hydraulic loading of 950 gallons per minute (gpm) at the Fluidized Bed Reactors (FBRs) (the design 30-day average maximum flow is 1,000 gpm);
- The on-site chromium treatment plant, referred to as the “GWTP”, is operating near its current operational maximum hydraulic loading of 85 gpm (including the 8-10 gpm of recycle);
- Lift Station 3, which conveys extracted water from the AWF to Lift Station 2, is pumping at close to its maximum sustainable flow of 290 gpm; and
- The pumping at Lift Station 2, which conveys water from the SWF and the AWF to the onsite treatment plant is limited—it has a maximum sustainable flow of 900 gpm—but since Lift Station 2 is downstream of Lift Station 3, it is not directly limiting the flow from the AWF.

Based on these constraints, particularly the limitations of the GWTP and Lift Station 3, which are the most constraining, maximum cumulative extraction rates were set for the IWF and the AWF at 75 and 290 gpm, respectively. Recommendations on upgrades to these components are not

part of the scope of this analysis, but may be part of future studies to enhance the performance of the GWETS.

3. Estimated Capture Zones and Potential Gaps in Capture

Figures E-1 and E-2 show the detailed potentiometric map at the IWF along with the estimated capture zone and perchlorate and chromium isoconcentration contours, respectively. As shown on Figure E-1, the IWF is capturing high concentrations of the perchlorate plume (generally greater than 1,000 mg/L) at the barrier wall. However, on both ends of the barrier wall, lower concentrations of perchlorate appear to be outside of the inferred capture zone of the IWF. The potential capture gap is wider on the western side of the barrier wall where groundwater with perchlorate concentrations higher than 250 mg/L exists outside the capture zone. As seen on Figure E-2 the potential capture gap is visible on the western side of the barrier wall where groundwater with a total chromium concentration of about 0.1 mg/L exists outside of the capture zone. To address this gap, ENVIRON proposes to begin pumping the several new wells, which is described in more detail in the following sections.

Figure E-3 and Figure E-4 show the detailed potentiometric map at the AWF along with the estimated capture zone and perchlorate and chromium isoconcentration contours, respectively. Pumping at the AWF is already partially dewatering the alluvium as indicated by a localized area of unsaturated alluvium in the middle of the AWF, where the contact between alluvium and the Upper Muddy Creek Formation (UMCf) is relatively shallow, creating a subsurface geologic feature known as the UMCf ridge. The paleochannels on either side of the UMCf ridge are preferential pathways for groundwater flow. As can be seen on Figures E-3 and E-4, there is a potential gap in the capture zone identified at the center of the AWF centered at PC-149 and extending to the east and west past wells PC-148 and PC-150, respectively. To address this gap, ENVIRON proposes to begin pumping some of the new wells, which is described in more detail in the following sections.

As expected, the current estimated capture zones at IWF and AWF are very similar to those presented in the 2010 CZE Report, due to the fact that average pumping rates have remained relatively constant for the last five years.

As described in the remainder of this appendix, ENVIRON is proposing to adjust the pumping rates at both well fields including the commencement of pumping at several wells that were installed by Tronox in June 2010, but have not yet been used for extraction.

4. Analysis of Mass Removal

4.1 Historical Extraction Rates and Mass Removals

To evaluate alternatives for effective operation and to enhance the performance of the GWETS, historical perchlorate and chromium mass removal estimates were calculated for each well using available extraction rates and perchlorate and chromium concentration data for the time period July 1, 2002 to June 30, 2012.

The mass removal estimates were calculated using daily extraction rates and available (generally monthly) analytical results for perchlorate and chromium. Linear interpolation was used to estimate daily concentrations allowing calculation of daily mass removals. Daily chromium and perchlorate mass removal results were then summed for each fiscal year from 2002/2003 to 2011/2012 and plots were generated with the software package MATLAB 7.8.0.

For calculation of the mass estimates, non-detect values were substituted with half the reporting limit. For the two pairs of wells that share a pump (ART-6/ART-9 and PC-99R2/99R3), the concentration data for the two wells were averaged for each day, if available. Otherwise, the concentration from the well having data for that day was used. Likewise for all other wells, any duplicate data reported on the same day, such as from field duplicate samples, were averaged.

Historical extraction rates and mass removal plots for perchlorate and chromium for each well in the IWF and AWF are provided in Attachments E-1 and E-2, respectively. Historical extraction rates and mass removal plots for perchlorate only for each well in the SWF are provided in Attachment E-3. The SWF mass removal plots are provided only for comparison as the analysis described herein is focused on the IWF and AWF only.

4.2 Mass Removal at IWF

Table E-1A contains well construction details for the IWF wells. Figure E-5 presents the current (Second Quarterly 2012) extraction rates, perchlorate concentrations, and mass removals for the IWF wells. An equivalent figure showing chromium concentrations and mass removals in individual IWF wells is included as Figure E-6. Attachment E1 presents the historical extraction rates and mass removal plots for perchlorate and chromium for each well in the IWF.

The annual average perchlorate mass removal at the IWF has declined to 601 pounds/day in 2011-12 from 1,043 pounds/day in 2002-03. Overall, mass removed at the IWF is approximately 50% of the total mass removed by the three well fields. The historical concentration plots for each IWF well in Attachment E-1 further show that the perchlorate concentration is declining over time. There is a significant decline at well I-AR where the concentration declined from 12,000 mg/L to 2,200 mg/L in the last nine years of operation. The total mass removal at the IWF has been stable since approximately 2007.

As shown on Figure E-5, well I-Z is the highest capacity well at the IWF which is currently extracting at a rate of 6.7 gpm. The corresponding perchlorate concentration at this well is 310 mg/L. In contrast, wells such as I-A-R extract at a much lower rate (1.0 gpm), but achieve relatively high mass removal due to high perchlorate concentrations (2,200 mg/L). There are other wells (I-Y, I-W and I-X) which are not operating, but located in an area of relatively high

perchlorate concentration. In addition, there are non-operating wells located outside of the current capture zone that could be activated to extend the capture zone laterally. Comparing Figures E-5 and E-6 demonstrates only one significant difference between the lateral distribution of perchlorate and chromium at the IWF: the high concentrations of perchlorate on the west side of the IWF (centered around well I-A-R) are not associated with elevated concentrations of chromium as is the case further east within the IWF where high concentrations of both perchlorate and chromium are centered around well I-U.

4.3 Mass Removal at AWF

Table E-1B contains well construction details for the AWF wells. Figure E-7 presents the current (Second Quarter 2012) extraction rates, perchlorate concentrations, and mass removals for the AWF wells. An equivalent figure showing chromium concentrations and mass removals in individual AWF wells is included as Figure E-8. Attachment E-2 presents the historical extraction rates and mass removal plots for perchlorate and chromium for each well in the AWF.

The AWF annual average perchlorate mass removal has declined to 553 pounds/day in from July 2011-June 2012 from approximately 800 pounds/day in 2004-05. Historical concentration plots in Attachment E-2 show that the decline in perchlorate mass removal at the AWF is due primarily to perchlorate concentrations decreasing at AWF wells over time. There is a significant decline at well ART-2 where the concentration declined from approximately 400 mg/L to 50 mg/L in the last nine years of operation. Total perchlorate mass removal at the AWF has been stable since about 2009. The perchlorate mass removed by the AWF is approximately 46% of the total mass removed by the GWETS.

As shown on Figure E-7, the wells ART-1 and ART-2 have relatively low mass removal rates, but high pumping rates as compared to other wells in the AWF. In contrast, well ART-4 has a relatively low mass removal rate even though it is in an area of high perchlorate concentration due to the low extraction rate exhibited in this well. There are other wells (ART-7B and PC-150), which are not operating but are located in an area of relatively high perchlorate concentration. Moreover, PC-150 is located outside of the current capture zone and could be activated to enhance mass capture and address the capture gap discussed previously. There are not significant differences in the perchlorate and chromium distributions based on Figures E-7 and E-8.

5. Recommendations

The objective of this preliminary analysis is to maximize efficiency of the IWF and AWF by identifying alternative extraction rates for existing wells and target extraction rates for new wells that in combination are expected to enhance mass capture. ENVIRON believes that the operational adjustments recommended below will serve as a first step in increasing the capture efficiency of these two well fields.

5.1 Proposed Changes to IWF Extraction Rates

The proposed extraction rates for each well in the IWF and expected mass removal rates are shown in Table E-2. Since the new extraction wells are not routinely sampled, the perchlorate and chromium concentrations at these wells are interpolated from the isoconcentration maps from second quarter 2012 (Plates 6 and 7 of the annual report). The extraction rates are proposed to be adjusted on the basis of mass removal while also considering the maximum sustainable flow rates for each extraction well that have been established based on historical operations of the wells, results of the IWF rehabilitation project undertaken by Tronox in 2007-2008, and professional judgment. The combined extraction rate for the IWF is proposed to increase, but as discussed in Section 2.2, is limited to 75 gpm due to the hydraulic limitations of the GWTP. Furthermore, until testing can be performed it is unclear whether this proposed combined extraction rate is sustainable given current hydrogeologic conditions.

Extraction rates in wells I-G, I-Q and I-U (currently at 0.1 gpm, 0.3 gpm and 0.7 gpm, respectively) are proposed to be increased to 0.5 gpm, 2.5 gpm and 0.8 gpm, respectively. The pumping in wells I-K, I-S and I-J is proposed to decrease to 2.0 gpm, 5.0 gpm and 2.5 gpm respectively. The pumping in well I-Z is proposed to decrease from 6.7 gpm to 5.5 gpm.

It is recommended that extraction from seven new wells in the IWF be initiated. Wells I-W, I-X, and I-Y are targeted to pump at 2.5, 2.5, and 4.1 gpm, respectively, with wells located at the edges of the IWF (I-AA, I-AB, I-AC and I-AD) assigned a target pumping rate of 1.0 gpm. The actual sustainable extraction rates of the new wells would be determined following shakedown and pump testing. Effects on capture would be evaluated using the groundwater flow model. With the proposed pumping rates, ENVIRON estimates that perchlorate mass removal at the IWF would increase from approximately 695 pounds/day to 851 pounds/day (Figure E-9). The chromium mass removal is estimated to increase from 6.64 pounds/day to 8.54 pounds/day (Figure E-10).

5.2 Proposed Changes to AWF Extraction Rates

Proposed extraction rates for each well in the AWF and expected mass removal rates are shown in Table E-3. The perchlorate concentration at new extraction wells is inferred as discussed in Section 4.2. The extraction rates are proposed to be adjusted on the basis of mass removal while also considering the maximum sustainable flow rates for each extraction well, which have been established based on historical operations of the wells. The combined extraction rate for the AWF is proposed to increase, but as discussed in Section 2.2, is limited to 290 gpm due to the hydraulic limitations of Lift Station 3. Furthermore, until testing can be performed it is unclear whether this increased combined extraction rate is sustainable given current hydrogeologic conditions.

Extraction rates in wells ART-3 and ART-8 (currently at 46.1 gpm and 62.7 gpm) are proposed to increase to 52.5 gpm, and 85.0 gpm, respectively. To minimize the dewatering of the Shallow Zone and to accommodate increased pumping, it is further proposed to decrease pumping in well ART-1 from 14.1 gpm to 1.0 gpm. The pumping rate for wells ART-2 and ART-9 are not proposed to change significantly.

New extraction wells ART-7B and PC-150 are proposed to be placed into active operation and pumped at their maximum capacities. For the purpose of estimating mass removal, extraction rates of 31.0 gpm and 5.0 gpm have been selected as reasonably achievable extraction rates for ART-7B and PC-150, respectively, based on professional judgment. The actual sustainable extraction rates of the new wells would be determined following shakedown and pump testing. It is expected that the proposed extraction from ART-7B would replace ART-7, since the wells are collocated; therefore, for this analysis it is assumed that the extraction rate for ART-7 would be zero under the proposed scenario. Effects on capture using the proposed rates would be evaluated in a future study using the groundwater flow model. The wells located within the area of unsaturated alluvium, PC-148 and PC-149, are not proposed for pumping at this time due to concerns that they will not yield significant water; however, if future capture zone analyses suggest additional pumping is necessary at this location, pumping could be attempted. ENVIRON estimates that perchlorate mass removal at the AWF would increase from approximately 667 pounds/day to 801 pounds/day (Figure E-9) upon implementation of the operational changes proposed above. The chromium mass removal rate is expected to increase from 1.38 pounds/day to 1.64 pounds/day at the AWF with the proposed extraction rates (Figure E-10).

5.3 Startup and Testing of New Wells

The adjusted extraction rates presented in Tables E-2 and E-3 will require the startup of nine new extraction wells: I-AA, I-AB, I-AC, I-AD, I-X, I-Y, and I-Z at the IWF and ART-7B and PC-150 at the AWF. The seven new IWF wells have already been connected to the GWETS; however, shakedown testing of these wells would be necessary to confirm they are in proper working order. The two new wells at the AWF would need to be plumbed and wired before startup and testing could commence. However, since PC-150 is located within the secured area of Lift Station 3, it is expected that the initial pumping and testing of this well could be performed with temporary lines to evaluate its performance prior to trenching and installation of permanent lines.

As additional wells are brought online, it would be necessary to perform testing of each of the new wells to evaluate its performance and effect on nearby wells. The well testing, the specifics of which would be described in a subsequent work plan, would be used to evaluate the extraction rates proposed herein and to determine the spatial effects of pumping on the aquifer and effects on the capture zone. This testing would be coordinated with the analyses performed using the groundwater flow model to provide multiple lines of evidence of capture.

Furthermore, as this work would require NDEP approval and coordination among numerous entities, including the operators and maintenance providers for the GWETS and the City of Henderson (owners of the property on which the AWF is situated), a work plan would be

prepared describing the steps for construction, startup, and testing of the new extraction wells. The work plan would also describe risk management measures, methods of managing soil and groundwater generated during construction, and procedures to minimize disturbance to active groundwater remediation in accordance with the Site Management Plan developed for the Site (ENVIRON 2012).

5.4 Capture Zone Analysis Using the Groundwater Model

A more detailed evaluation of the effect of the operational changes proposed in this appendix on the capture zones of the IWF and AWF systems would be conducted using the groundwater flow model once the model has been approved by NDEP.

6. References

ENVIRON International Corporation. 2012. Annual Remedial Performance Report for Chromium and Perchlorate, Nevada Environmental Response Trust Site, Henderson, Nevada July 2011 – June 2012. August 31.

ENVIRON International Corporation. 2011a. Annual Remedial Performance Report for Chromium and Perchlorate, Nevada Environmental Response Trust Site, Henderson, Nevada July 2010 – June 2011. August 26.

ENVIRON International Corporation. 2012. Site Management Plan (SMP) Nevada Environmental Response Trust Site, Clark County, Nevada. April.

Karanovic, M., Tonkin, M., and Wilson, D. 2009. *KT3D_H2O:* A Program for Kriging Water Level Data Using Hydrologic Drift Terms. Ground Water, Vol. 47, N0. 4:580-586.

Northgate Environmental Management, Inc., 2010a. Capture Zone Evaluation Report, Tronox LLC. Henderson, Nevada. December 10.

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

Attachment E-1

Historical Extraction Rates and Mass Removal Plots for all Wells in the Interceptor Well Field

Attachment E-2

Historical Extraction Rates and Mass Removal Plots for all Wells in the Athens Road Well Field

Attachment E-3

Historical Extraction Rates and Mass Removal Plots for all Wells in the Seep Well Field