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Groundwater Assessment Report

**Tronox LLC
Henderson, Nevada**

February 14, 2011

Prepared For:

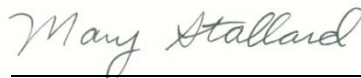
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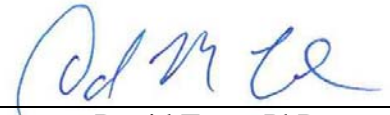
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ACRONYM LIST

Acronym	Meaning
AMPAC	American Pacific Corporation
AP&CC	American Potash and Chemical Company
BCL	basic comparison level
bgs	below ground surface
BHC	benzene hexachloride (also known as hexachlorocyclohexane)
BMI	Black Mountain Industrial
BRC	Basic Remediation Company
CLP	Contact Laboratory Program
COI	chemical of interest
CSM	conceptual site model
CWA	Clean Water Act
DCB	dichlorobenzene
DCE	dichloroethene
DQI	data quality indicator
DVSR	Data Validation Summary Report
ECA	Environmental Conditions Assessment
ft/ft	feet per foot
gpm	gallons per minute
HHRA	human health risk assessment
IX	ion exchange
KMCC	Kerr-McGee Chemical Corporation
LCS/LCSD	laboratory control sample/laboratory control sample duplicate
LDC	Laboratory Data Consultants
LOU	Letter of Understanding
MCL	maximum contaminant level
MDL	method detection limit
µg/L	micrograms per liter
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MGD	Megagallons per day
mph	miles per hour
MS/MSD	matrix spike/matrix spike duplicate
NPDES	National Pollutant Discharge Elimination System
NDEP	Nevada Division of Environmental Protection
OCP	organochlorine pesticide
OPP	organophosphate pesticide
ORP	oxidation-reduction potential
PARCC	precision, accuracy, representativeness, comparability, and completeness
POSSM	Pioneer/Olin Chlor-Alkali/Stauffer/Syngenta/Montrose
QA/QC	quality assurance/quality control



Acronym	Meaning
QAPP	Quality Assurance Project Plan
RAS	Remedial Alternative Study
RBGC	risk-based groundwater concentration
RCRA	Resource Conservation and Recovery Act
RIB	rapid infiltration basin
RPD	relative percent difference
RZ	remediation zone
SNWA	Southern Nevada Water Authority
SOP	standard operating procedure
SQL	sample-specific quantitation limit
SRC	site-related chemical
SVOC	semi-volatile organic compound
SWMU	solid waste management unit
TCE	Trichloroethene
TDS	total dissolved solids
TIMET	Titanium Metals Corporation
U.S. EPA	U.S. Environmental Protection Agency
VOC	volatile organic compound
WBZ	water-bearing zone
WECCO	Western Electrochemical Company



1 INTRODUCTION

On behalf of Tronox LLC (Tronox), Northgate Environmental Management, Inc. (Northgate) has prepared this report on the groundwater data collected as part of the Phase B investigation at the Tronox facility in Henderson, Nevada (the Site). This report:

1. Provides a summary of the Phase B data, as well as the earlier Phase A and Upgradient Investigations data, collected at the Site;
2. Identifies groundwater chemicals of interest (COIs) based on these data and related information;
3. Evaluates each COI in terms of source status, distribution in groundwater, and expected fate and transport; and
4. Recommends additional evaluations needed to improve the accuracy of the Site Conceptual Model.

Section 1 provides a brief background on the Site and the purpose and scope of the Phase B groundwater investigation. Section 2 summarizes the Phase B groundwater investigation work scope, as presented in the Phase B work plans (AECOM, 2008; ENSR; 2008a, 2008b, 2008c, 2008d) and modified during implementation. Section 3 summarizes the usability of groundwater data generated during Phase B. Section 4 presents a summary of the conceptual site model (CSM) for groundwater impact at the Site. Section 5 describes the COI screening process and lists and prioritizes the COIs identified through that process. Section 6 provides an evaluation and summary of the distribution of each COI. Section 7 summarizes the groundwater COI evaluation conclusions. References cited are presented as Section 8.

1.1 Site Description and History

The Site is located approximately 13 miles southeast of the city of Las Vegas and is surrounded by the unincorporated area of Clark County, Nevada, that comprises the City of Henderson. It covers approximately 450 acres, and lies in Sections 1, 12, and 13 of Township 22 S, Range 62 E (Figure 1). The Site is located within the Black Mountain Industrial (BMI¹) complex, which consists of several facilities owned and operated by chemical companies, one of which is Tronox.

¹ The acronym “BMI” has applied to several entities over the years: from 1941 until 1951 it referred to Basic Magnesium Incorporated; in 1951 a syndicate of tenants formed under the name of Basic Management, Inc. to provide utilities and other services at the complex, the group has also been known as Basic Metals, Inc., and at the present is called the Black Mountain Industrial complex.



1.1.1 Operational History

The BMI complex was first developed in 1942 by the U.S. Government as a magnesium plant for World War II operations. Later, a part of the BMI complex that would ultimately become the Tronox Site was leased by Western Electrochemical Company (WECCO). WECCO produced manganese dioxide, sodium chlorate, sodium perchlorate, and other perchlorates. WECCO also produced ammonium perchlorate (a powerful oxidizer) for the Navy during the early 1950s using a plant that was constructed on the Site by the Navy. WECCO merged with American Potash and Chemical Company (AP&CC) in 1956, and continued production of ammonium perchlorate for the Navy. In 1967, Kerr-McGee Chemical Corporation (KMCC) purchased AP&CC. KMCC began production of boron chemicals in the early 1970s (Kleinfelder, 1993). The production processes included elemental boron, boron trichloride (a colorless gas used as a reagent in organic synthesis), and boron tribromide (a colorless fuming liquid compound used in a variety of applications). The production of boron tribromide was discontinued in 1994, and the production of sodium chlorate and ammonium perchlorate were discontinued in 1997 and 1998, respectively. Perchlorate was reclaimed at the Site using existing equipment until early 2002. From the 1940's until the 1970's, the BMI facilities made extensive use of leach beds and unlined evaporation ponds to dispose of organic and inorganic industrial wastes.

Tronox's Henderson facility continues to produce electrolytic manganese dioxide, used in the manufacture of alkaline batteries; elemental boron, a component of automotive airbag igniters; and boron trichloride, used in the pharmaceutical and semiconductor industries and in the manufacture of high-strength boron fibers for products that include sporting equipment and aircraft parts. In 1994, NDEP issued a Letter of Understanding (LOU) to KMCC identifying 69 specific potential source areas or items of interest (NDEP, 1994). A detailed discussion of the specific areas or items of interest identified in the LOU, lists of the products made, years of production, and approximate waste volumes for WECCO, AP&CC, and Tronox, and actions taken for each LOU study item is presented in the CSM Report (ENSR, 2005).

1.1.2 Environmental Response Summary

During the 1970s, the U.S. Environmental Protection Agency (U.S. EPA), the State of Nevada, and Clark County investigated potential environmental impacts from the BMI companies' operations, including atmospheric emissions, groundwater and surface-water discharges, and soil impacts (ENSR, 2007b). In response to the 1972 Federal Water Pollution Control Act (CWA), between 1971 and 1976 KMCC modified its manufacturing processes and constructed lined surface impoundments to recycle and evaporate industrial wastewater. In 1976, the facility achieved zero-discharge status regarding industrial wastewater management, and in February 1977 Kerr-McGee obtained a National Pollutant Discharge Elimination (NPDES) permit under



the CWA authorizing up to 4 million gallons per day (MGD) discharge of non-contact cooling water to Las Vegas Wash. In 1980, the EPA requested specific information from the BMI companies regarding their manufacturing and waste management practices by issuing Section 308 letters.

A groundwater investigation was initiated by KMCC in July 1981 to comply with the federal Resource Conservation and Recovery Act (RCRA) standards for monitoring the existing onsite impoundments. In December 1983, the Nevada Division of Environmental Protection (NDEP) requested that KMCC investigate the extent of chromium impact in groundwater beneath the Site. Forty groundwater monitoring wells were installed, and in July 1985, Kerr-McGee submitted to NDEP a geohydrological investigation report delineating a chromium plume within the “near surface groundwater” (KMCC, 1985). A Consent Order between KMCC and NDEP was issued in September 1986 (NDEP, 1986) that stipulated the requirement for additional characterization and the implementation of corrective action to address chromium in groundwater. Remediation of hexavalent chromium in groundwater began in mid-1987, when four extraction wells (or “interceptor” wells) were installed downgradient of the Ammonium Perchlorate (AP) Plant. The interceptor well field extracted chromium contaminated water which was then pumped to a chromium treatment facility that would reduce the hexavalent chromium to trivalent chromium which would then be precipitated and removed. Treated water was subsequently reinjected at a series of recharge trenches downgradient of the interceptor well field.

In April 1991, KMCC was one of six past or present entities that conducted business within the BMI complex that entered into a Consent Agreement with the NDEP (NDEP, 1991) to conduct environmental studies to assess Site-specific environmental conditions at individual company sites, the BMI Common Areas, and any off-site waste management areas, which are the result of past and present industrial operations and waste disposal practices. In April 1993, and in compliance with a 1991 Consent Agreement with NDEP, KMCC submitted the Phase I Environmental Conditions Assessment (ECA) report to NDEP (Kleinfelder, 1993). The purpose of the report was to identify and document Site-specific environmental impacts resulting from past or present industrial activities. The Phase I ECA included a thorough assessment of the geologic and hydrologic setting, as well as historical manufacturing activities. The assessment identified 31 solid waste management units (SWMUs), 20 areas of known or suspected releases or spills, and 14 miscellaneous areas where Site activities may have impacted the environment. In 1994, NDEP issued a LOU to KMCC identifying 69 specific areas or items of interest and indicated the level of environmental investigation they wanted KMCC to conduct (NDEP, 1994). A detailed discussion of the specific LOU areas is presented in the CSM Report (ENSR, 2005). In 1996, KMCC and the other parties at the BMI complex entered into a Consent Agreement



with NDEP to perform a Phase II Environmental Conditions Investigation and to conduct Remedial Alternative Studies (RAS), Interim Measures, or Additional Work (NDEP, 1996). In 1996 and 1997, KMCC conducted additional data collection as part of a Phase II ECA that addressed 12 LOUs identified as needing additional characterization.

In late 1997 perchlorate contamination was discovered in Las Vegas Wash, and KMCC undertook a characterization study to determine both the subsurface pathway(s) and the perchlorate concentrations in shallow groundwater downgradient from the Site to the Las Vegas Wash (KMCC, 1997). A water collection system and temporary ion exchange (IX) treatment process for perchlorate removal was installed and began operation in November 1999. Tronox and NDEP entered into a consent agreement which defined initial remedial requirements (NDEP, 1999). The interceptor wells continued to capture onsite groundwater for removal of hexavalent chromium; however, instead of re-injecting the treated groundwater to the shallow aquifer downgradient of the extraction wells, it was impounded in an 11-acre lined pond (GW-11, constructed in late 1998) and held for additional treatment for perchlorate. Untreated Lake Mead water was reinjected into the groundwater system via the recharge trenches. An Administrative Order on Consent (AOC) in 2001 (NDEP, 2001) defined more permanent remedial requirements that included a low-permeability barrier wall with an upgradient collection (interceptor) well field, the construction of the Athens Road groundwater collection well field, the construction of the seep area collection well field, and the development of a treatment process that removes chromium and perchlorate from the collected water then discharges the water within the limits set forth in the existing National Pollutant Discharge Elimination System (NPDES) permit. The effectiveness of these remediation systems at removing contaminant mass, reducing groundwater concentrations, and reducing contaminant mass flux into Las Vegas Wash is presented in annual and semi-annual monitoring reports (e.g., Northgate, 2010a) and is summarized in Section 4.3 of this document.

A supplemental Phase II ECA was completed by KMCC between 1999 and 2001, the results of which were submitted to NDEP in April 2001 (ENSR, 2001). NDEP provided responses to KMCC's Supplemental Phase II ECA report in 2004, indicating that additional work would be required to investigate and characterize the Site. In 2005, a Conceptual Site Model (CSM) was prepared for the Site which integrated information gathered about environmental impact. In 2005, KMCC was renamed Tronox LLC. Since that time, Tronox has continued to undertake environmental investigations, including the Phase A and Phase B Source Area Investigations described in this report.



1.2 Physical Setting

Elevations across the Site range from 1,677 to 1,873 feet above mean sea level. The land surface across the Site slopes toward the north at a gradient of approximately 0.023 feet per foot (ft/ft). The developed portions of the Site have been modified by grading to accommodate building foundations, surface impoundments, and access roads. Offsite to the north, the topographic surface continues at the same gradient to approximately Sunset Road, at which point it flattens to a gradient of 0.011 ft/ft to the Las Vegas Wash (ENSR, 2005).

1.2.1 Climate

The climate of the Las Vegas Valley is arid, consisting of mild winters and dry hot summers. Average annual precipitation as measured in Las Vegas from 1971 to 2000 was 4.49 inches. Precipitation generally occurs during two periods, December through March and July through September. The winter storms generally produce low intensity rainfall over a large area. The summer storms generally produce high intensity rainfalls over a smaller area for a short duration. These violent summer thunderstorms account for most of the documented floods in the Las Vegas area. Winds frequently blow from the south- or northwest at a mean velocity around 9 miles per hour (mph); however, velocities in excess of 50 mph are not atypical when weather fronts move through the area. During these windy events, dust, sand, and soil at the ground surface becomes airborne and may travel several miles. Temperatures can rise to 120°F in the summer, and the average relative humidity is approximately 20%. The mean annual evaporation from lake and reservoir surfaces ranges from 60 to 82 inches per year (see references in Kleinfelder, 1993).

1.2.2 Regional Geology

The Site is located within the Las Vegas Valley, which occupies a topographic and structural basin trending northwest-southeast and extending approximately 55 miles from near Indian Springs on the north to Railroad Pass on the south. The valley is bounded by the Las Vegas Range, Sheep Range, and Desert Range to the north, by Frenchman and Sunrise Mountains to the east, by the McCullough Range and River Mountains to the south and southeast, and the Spring Mountains to the west. The mountain ranges bounding the east, north, and west sides of the valley consist primarily of Paleozoic and Mesozoic sedimentary rocks (limestones, sandstones, siltstones, and fanglomerates), whereas the mountains on the south and southeast consist primarily of Tertiary volcanic rocks (basalts, rhyolites, andesites, and related rocks) that overlie Precambrian metamorphic and granitic rocks (ENSR, 2007b).

In the Las Vegas Valley, eroded Tertiary and Quaternary sedimentary and volcanic rocks comprise the unconsolidated basin deposits, which can be up to 13,000 feet thick (ENSR,



2007b). The valley floor consists of fluvial, paludal (swamp), and playa deposits surrounded by more steeply sloping alluvial fan aprons derived from erosion of the surrounding mountains. Generally, the deposits grade finer with increasing distance from their source and with decreasing elevation. The structure within the Quaternary and Tertiary-aged basin fill is characterized by a series of generally north-south trending fault scarps.

1.2.3 Local Geology

The local geology and hydrology are defined by data collected from more than 1,100 borings and wells that have been installed in the area (Plates 1 and 2). Geologic cross-sections of the Site are included as Plates 3 through 5. The following descriptions are summarized from the CSM report (ENSR, 2005).

Alluvium. The Site is located on Quaternary alluvial (Qal) deposits that slope north toward Las Vegas Wash. The alluvium consists of a reddish-brown heterogeneous mixture of well-graded sand and gravel with lesser amounts of silt, clay, and caliche. Clasts within the alluvium are primarily composed of volcanic material. Boulders and cobbles are common. Due to the mode of deposition, no distinct beds or units are continuous over the area.

A major feature of the alluvial deposits is the stream-deposited sands and gravels that were laid down within paleochannels that were eroded into the surface of the Muddy Creek Formation during infrequent flood runoff periods. These deposits vary in thickness and are narrow and linear. These generally uniform sand and gravel deposits exhibit higher permeability than the adjacent, well-graded deposits. In general, these paleochannels trend northeastward.

The thickness of the alluvial deposits ranges from less than 1 feet to more than 50 feet beneath the Site. Soil types identified in onsite soil borings include poorly sorted gravel, silty gravel, poorly sorted sand, well sorted sand, and silty sand. The thickness of the alluvium, as well as the top of the underlying Muddy Creek Formation, was mapped to locate these paleochannels (Plates 3 and 4).

Muddy Creek Formation. The Pleistocene Muddy Creek Formation (UMCf) occurs in Las Vegas Valley as valley-fill deposits that are coarse-grained near mountain fronts and become progressively finer-grained toward the center of the valley. Where encountered beneath the Site, the Muddy Creek Formation is composed of at least two thicker units of fine-grained sediments of clay and silt (the first and second fine-grained facies, respectively) interbedded with at least two thinner units of coarse-grained sediments of sand, silt, and gravel (the first and second coarse-grained facies, respectively). Except for the southernmost 1,000 feet adjacent to Lake Mead Parkway, the first fine-grained facies (MCfg1) separates the first coarse-grained facies (MCcg1) from the overlying Quaternary alluvium at the Site. Within the southern 1,000 feet of



the Site, the Muddy Creek Formation's first fine-grained facies (MCfg1) pinches out along a roughly west-northwesterly trending line. South of this line, the coarse-grained facies (MCcg1) directly underlies the Quaternary alluvium.

The Muddy Creek Formation represents deposition in an alluvial apron environment from the Spring Mountains to the west grading into fluvial, paludal (swamp), playa, and lacustrine environments further out into the valley center. On the Site, the Muddy Creek does not crop out but instead subcrops beneath a veneer of Quaternary alluvium.

In onsite borings, the contact between the Quaternary alluvium and the Muddy Creek Formation (MCfg1) is typically marked by the appearance of a well-compacted, moderate brown silt-to-sandy silt or stiff clay-to-sandy clay, whereas near the Las Vegas Wash, the contact is marked by gray-green to yellow-green gypsiferous clays and silts.

1.2.4 Local Hydrogeology

Background information is described in detail in the CSM report (ENSR, 2005). Depth to groundwater ranges from about 27 to 80 feet below ground surface (bgs) and is generally deepest in the southernmost portion of the Site, becoming shallower as it approaches the Las Vegas Wash to the north. A potentiometric surface map depicting shallow groundwater flow during the 2009 timeframe is presented as Plate 6. The groundwater gradient averages 0.015 to 0.02 ft/ft south of the Athens Road well field, flattening to 0.007 to 0.010 ft/ft north of the well field (Northgate, 2010a). The groundwater flow direction at the Site is generally north to north-northwesterly, whereas north of the facility the direction changes slightly to the north-northeast. This generally uniform flow pattern may be modified locally by subsurface alluvial channels cut into the underlying UMCf, the onsite bentonite-slurry groundwater barrier wall, on- and offsite artificial groundwater highs or "mounds" created around the onsite recharge trenches and City of Henderson Water Reclamation Facility Rapid Infiltration Basins (RIBs), and by depressions created by the groundwater extraction wells at the three groundwater recovery well fields (Northgate, 2010a).

NDEP has defined three water-bearing zones (WBZs) that are of interest in the BMI complex: the Shallow Zone, which extends to approximately 90 feet bgs, is unconfined to partially confined, and is considered the "water table aquifer"; the Middle Zone, from approximately 90 to 300 feet bgs; and the Deep Zone, which is defined as the contiguous water-bearing zone that is generally encountered between 300 to 400 feet bgs (NDEP, 2009a). Environmental investigations at the Site have primarily focused on the Shallow Zone, although recent investigations (Northgate; 2009, 2010g) have included a number of Middle Zone wells to improve vertical delineation of hydrogeology and chemical constituent distribution.



At the Site, the Shallow Zone contains the saturated portions of the Qal and the uppermost portion of the UMCf to depths of approximately 90 feet bgs. Beneath the northern portion of the Site, the first groundwater encountered occurs within the Qal at depths of 30 feet bgs or more, and shallows northward, occurring near the ground surface at Las Vegas Wash. In the alluvial aquifer, groundwater flows towards the north-northeast with minor variations, generally mimicking the slope of the ground surface. The results of a 1998 pump test in the Athens Road area indicate a permeability of 50 gallons per day per square foot (gpd/ft²), a transmissivity of 1,300 gpd/ft, and a groundwater velocity of 220 feet per year for groundwater in the alluvial aquifer (KMCC, 1998). However, significantly higher groundwater velocities, ranging from approximately 600 to 2,500 feet per year, have been calculated based on alluvial well pumping and slug tests (KMCC, 1998), and a groundwater velocity of over 12,000 feet per year was reported based on a tracer test conducted in the alluvial channel between the Athens Road area and the Las Vegas Wash (Errol Montgomery and Associates, 2000).

Beneath the central portion of the Site, groundwater is first encountered within the Shallow Zone in the first fine-grained facies of the Muddy Creek Formation (MCfg1), and can be more than 50 feet bgs, as documented in historic water level measurements from well M-103. South of where MCfg1 pinches out, beneath the southern portion of the Site, the first groundwater encountered occurs within the first coarse-grained facies of the Muddy Creek Formation (MCcg1) and can be more than 70 feet bgs as documented in historical water level measurements from well M-103 and further confirmed from water level measurements from wells M-120 and M-121, which were installed as part of the upgradient investigation (ENSR, 2006b). The gradient of the potentiometric surface in both MCfg1 and MCcg1 (south of where MCfg1 pinches out) mimics the ground surface and the flow direction is to the north-northeast with minor variations. Both the horizontal and vertical hydraulic conductivities of the UMCf are one or more magnitudes of order less than those of the Qal (ENSR, 2005).

Middle Zone investigations at Tronox and surrounding sites indicate a vertically upward gradient between the Middle and Shallow Zones that generally increases with depth. Available data indicate that hexavalent chromium does not extend into the Middle Zone at concentrations above its NDEP risk-based groundwater concentration (RBGC) of 100 µg/L, and perchlorate attenuates markedly with increased depth to below its 18 µg/L RBGC at approximately 100-to-150 feet below ground surface within the Middle Zone (Northgate, 2009). In Section 6 of this report, the distribution of chemical constituents in the Middle Zone is discussed separately from the Shallow Zone.

Surface water in the vicinity of the Site flows to the north toward Las Vegas Wash. Surface flow occurs as infrequent storm runoff in shallow washes. Drainage and diversion structures have been constructed around the perimeters of the BMI complex to channel surface water flow. Las



Vegas Wash is a tributary to Lake Mead and it is the only channel through which the valley's excess water flows to the lake. Lake Mead is a major reservoir on the Colorado River. There are no water supply wells reported within four miles of the Site that extract water from the Shallow, Middle, or Deep Zones (ENSR, 2005).

1.3 Overview of Phase B Groundwater Investigation

Previous Site investigations have included a Phase A investigation (ENSR; 2006a, 2007a, 2007b) and a Phase B investigation that further characterized conditions across the Site. The Site was subdivided into four areas for the Phase B investigation activities: Areas I, II, III, and IV. Separate investigation work plans were prepared for each area, which also addressed Site-wide groundwater conditions (AECOM, 2008; ENSR; 2008a, 2008b, 2008c, 2008d). A separate work plan was prepared for the Phase B soil gas investigation (ENSR, 2008e).

The Phase B work plans focused on collecting data from the potential source areas for Site-Related Chemicals (SRCs). Potential source areas were identified by NDEP in their 1994 LOU. LOU areas of investigation are outlined on Plate 2. The objective of data collection was to support potential source area and exposure pathway evaluations, soil remediation planning, and human health risk assessment. Groundwater samples were collected from Areas I, II, III, and IV, as well as Parcels A through E, I, and J, north of Area I. Phase B soil characterization and remediation activities are ongoing and are scheduled for completion in early 2011. Site-specific Human Health Risk Assessments (HHRAs) will be performed at the conclusion of soil remediation work. As presented in the approved HHRA Work Plan (Northgate, 2010b), potential exposure to residual chemicals in soil vapor and potential for leaching of chemicals to groundwater will be evaluated on a Site-wide basis. Following finalization of the Site-wide soil vapor report and leaching evaluation, which are currently under NDEP review, these pathways will be addressed in remediation zone- (RZ-) specific soil HHRA reports.

Section 2 of this report describes groundwater sampling activities that were performed in support of the Phase B Source Area Investigation, as well as variances from the work plans. The Phase B Groundwater Sampling and Analysis Plan is outlined in Table 1, and Tables 2 through 5 summarize the results of all groundwater samples collected. Appendix G provides chemical analytical results summaries for individual samples. Potential sources and COI concentrations and distributions in groundwater are discussed in Section 6. The potential for SRCs to leach to groundwater has been evaluated and presented in several technical memoranda to NDEP (most recently, Northgate, 2010c), and is therefore not discussed in detail in this document. However, general relationships between COIs in soil and groundwater are discussed in Section 6.



2 PHASE B FIELD ACTIVITIES

This section describes the field activities that were performed in support of the Phase B Source Area Investigation. The following subsections describe the methodologies used in the field and describe the variances from the NDEP-approved Phase B Work Plans (AECOM, 2008; ENSR; 2008a, 2008b, 2008c, 2008d).

Pre-field activities included underground utility clearance by a geophysical surveyor and notification of Underground Services Alert using the same procedures described in the *Phase A Source Area Investigation Work Plan* (ENSR, 2006c). Field procedures, data acquisition requirements and quality assurance/quality control (QA/QC) procedures were followed as per the Phase B Quality Assurance Project Plan (QAPP; AECOM-Northgate, 2009).

2.1 Groundwater Investigation

The Phase B groundwater investigation program involved the installation of 14 monitoring wells and the collection of 2,817 groundwater samples (total and dissolved) from new and existing wells in Areas I, II, III and IV, and wells north (downgradient), east and west of Area I (Plate 2). New groundwater monitoring wells were placed at the Site to further delineate SRCs detected in the groundwater grab samples collected during the Phase A Source Area Investigation (ENSR, 2007b). In addition, a replacement well was installed for well M-111, which was inadvertently damaged during Tronox decommissioning activities prior to the start of the Phase A field activities in 2006. The new well was designated M-111A and the original well (M-111) was abandoned in accordance with Nevada Administrative Code using the procedures described in standard operating procedure (SOP) *SOP 21–Monitoring Well Destruction*.

2.1.1 Monitoring Well Installation and Well Development

The groundwater monitoring wells were installed according to the procedures described in *SOP 2–Groundwater Monitoring Well Design and Installation*. Depending on the hydrostratigraphy encountered, the wells were screened within the saturated alluvial materials or the upper unconfined portion of the UMCf. Well screens completed in the alluvium extended a few feet into the UMCf. If groundwater was not encountered in the alluvium, the well was installed in the upper portion of the UMCf. Groundwater level measurements from adjacent wells were considered in selection of the screen interval. Boring logs and well completion diagrams for the wells installed for the Phase B investigation are included in Appendix A.

Each monitoring well was developed to remove sediments from the well and to improve the hydraulic communication between the well and the surrounding aquifer formation. Well development was performed according to the procedures described in *SOP 3–Groundwater*



Monitoring Well Development. To protect the well head, a steel protective casing was cemented in-place around the well. The well casing and steel protective casing extended at least one foot above the ground surface. A cement pad was placed on the ground surface around the steel protective casing. If the well was completed flush with the ground surface, a flush-mount well box with a traffic-rated steel lid was cemented around the well casing. Flush mounted well boxes were used in traffic areas.

2.1.2 Groundwater Sampling

Groundwater samples were collected using the procedures described in *SOP 5–Water Sampling and Field Measurements*. After water levels were measured, each well was purged using low flow micropurge methods. Once the parameters (e.g., pH, temperature, conductivity, dissolved oxygen, oxidation-reduction potential) had stabilized, water samples were collected. Groundwater parameter field measurements were recorded on a field data sheet for each well (Appendix B). Consistent with *SOP 5–Water Sampling and Field Measurements*, groundwater samples designated for metals and radionuclide analyses were filtered in the field if turbidity levels of 10 nephelometric turbidity units or lower were not achieved.

Purged (and well development) groundwater as well as equipment decontamination water was temporarily stored in DOT-approved 55-gallon drums with unique identification numbers. Following characterization, each drum of material was disposed of as appropriate per federal, state and local requirements.

2.1.3 Site Surveying

New monitoring wells were surveyed as described in *SOP 10–Surveying*. In general, locations were surveyed to an accuracy of 0.01-foot vertical and 0.1-foot horizontal relative to Nevada Coordinate System Datum (North American Vertical Datum 1983 and North American Datum 1983, Nevada East Plane) by a Nevada-licensed land surveyor.

2.1.4 Field Quality Assurance/Quality Control Program

Field QA/QC procedures described in the Phase B QAPP (AECOM-Northgate, 2009) were followed to ensure viability and integrity of sample analytical data. QA/QC samples were analyzed for the same suite of chemicals as the original samples and included the following:

- Two sets of field duplicates for every 10 samples, analyzed for the same chemical suite as the samples.
- Trip blanks for each sample shipment, with blanks consisting of laboratory reagent water shipped to and from the sample site, sealed in the same type of sample containers and



with the same preservative as the collected samples, and analyzed for the same chemical suite.

- At least one equipment decontamination blank for each day of sampling and each sampling team, with blank consisting of distilled water rinsed through clean sampling devices and analyzed for (on a daily basis) all SRC chemical categories, except organochlorine pesticides (OCPs) and dioxins/furans.
- Field blank samples consisting of the decontamination source water and analyzed for the full suite of Phase B analytes.

2.1.5 Variances from the Approved Work Plan

Groundwater samples were collected and analyzed in accordance with the *Revised Phase B Investigation Work Plan* (AECOM, 2008) and the *Revised Phase B Quality Assurance Project Plan* (AECOM-Northgate, 2009). Analysis as proposed in the *Revised Phase B Investigation Work Plan* was completed with the modifications listed below.

2.1.5.1 Area I Groundwater

- Groundwater from 12 monitoring locations—CLD2-R (destroyed), M-83 (well obstruction), M-86 (damaged), M-98 (dry), M-99 (dry), M-100 (dry), M-101 (dry), M-102 (dry), M-129 (poor producer), MC-32 (poor producer), MC-55 (dry), and MC-59 (dry)—was not collected as proposed.
- Groundwater from two monitoring locations (M-78B and MC-94B) was collected twice during both 2008 and 2009 for the analytical suite proposed in the Phase B Work Plan.
- Organophosphorous pesticides (OPP) and organic acids were not collected from monitoring location H-48 as proposed.
- Field duplicates of groundwater samples from seven monitoring locations—M-23, M-57A, M-65, M-67, M-123, M-126, and PC-40—were not collected, and unscheduled field duplicates were collected from locations M-14A, M-55D, and MC-66.
- Radiological parameters (radium 226/228, isotopic thorium, and isotopic uranium) were not collected for two groundwater monitoring locations (M-14AB and M-96B) as proposed.



2.1.5.2 Area II Groundwater

- Groundwater monitoring location M-38 was not sampled as proposed.
- A dissolved field duplicate was collected from monitoring location M-13AB.

2.1.5.3 Area III Groundwater

- Groundwater monitoring location CLU1 (abandoned) was not sampled as proposed.
- A dissolved field duplicate was collected from monitoring location M-11B.
- One additional field duplicate (M-147009B) was collected for the analytical suite proposed.

2.1.5.4 Area IV Groundwater

- Groundwater monitoring locations M-143 (dry) and M-93 (well obstruction) were not sampled as proposed.
- OPPs were not analyzed for groundwater monitoring location TR-6B as proposed.



3 DATA USABILITY ASSESSMENT

The primary objective of the data usability evaluation is to evaluate the acceptability of the Phase B data for use in decision making. All relevant Site characterization data were reviewed in accordance with the *Guidance for Data Usability in Risk Assessment* (Parts A and B; U.S. EPA, 1992a,b) and the *NDEP Supplemental Guidance for Assessing Data Usability for Environmental Investigations at the BMI Facility in Henderson, Nevada* (NDEP, 2008a). A QA/QC review was conducted on 100% of the analytical data, and findings are presented in the March 7, 2010, *Data Validation Summary Report, Phase B Investigation, Groundwater* (DVSR; Northgate, 2010d) to assess the validity (based on data validation) and usability (based on project objectives) of the Phase B groundwater data. NDEP approved the Phase B groundwater DVSR on April 14, 2010.

Based on the six U.S. EPA evaluation criteria by which data are judged for usability in risk assessment (U.S. EPA, 1992, a, b), the following summarizes Phase B data usability as described in detail in the DVSR:

1. Site data report content: The required information is available from documentation associated with the Site data and data collection efforts.
2. Documentation: The analytical data were reported in a format that provides adequate information for evaluation, including appropriate quality control measures and acceptance criteria.
3. Data sources: The Phase B data are adequate for use in combination with Phase A investigation results and more recent compliance monitoring results.
4. Analytical methods and detection limits: With the exception of ethylene dibromide, all samples had method detection limits below RBGCs (Tables 2 to 5). Therefore, the detection limits are considered adequate.
5. Data review: Laboratory data are of adequate quality. Less than 2% of analytical data were rejected. Although a small percentage of data exceeded certain laboratory limits, there does not appear to be a widespread effect on the quality of the analytical results. These data were appropriately flagged to indicate limitations on their use.
6. Data quality indicators (DQIs): No significant issues related to precision, accuracy, representativeness, or comparability were identified. Field completeness exceeded the 90% Work Plan goal and laboratory completeness exceeded the 95% goal.

A more thorough discussion of the data usability based on the approved DVSR is included as Appendix C. Based on the results of this data validation and evaluation, the data collected in Phase B are considered to be adequate for use in decision making.



4 CONCEPTUAL SITE MODEL

This section provides a general CSM based on the current understanding of potential contaminant sources, release mechanisms, contaminant distribution in soil and groundwater, effects of remediation, and potential migration pathways and receptors. More specific information on individual groundwater contaminants is presented in Section 6. General information regarding the Site description and history, physical setting and climate, regional and local geology, and local hydrogeology are presented in Section 1. A detailed discussion of the specific areas or items of interest identified in the LOUs, lists of the products made, years of production, and approximate waste volumes for WECCO, AP&CC, KMCC, and Tronox, and actions taken for each LOU study item are presented in the CSM Report (ENSR, 2005), a brief summary of which is included below.

4.1 Potential Contaminant Sources

Industrial activities have occurred on the BMI complex since 1942, which was originally sited and operated for the U.S. government as a wartime magnesium production plant (Kleinfelder, 1993). The BMI magnesium production facility consisted of the following major facilities:

- A brine purification facility that dissolved solar salt and removed calcium, potassium, strontium, sulfate, and bicarbonate impurities via a precipitation and filtering process;
- A chlor-alkali plant to produce sodium hydroxide and chlorine gas from the electrolysis of purified sodium chloride brine;
- A plant that created pellets of magnesium oxide and a carbon source;
- 10 Unit Buildings, each of which containing chlorinators that created molten magnesium chloride by reacting the magnesium oxide/carbon pellets with chlorine gas at high temperature and banks of electrolytic cells that produced magnesium metal by electrochemical reduction of the molten magnesium chloride;
- An extensive system of surface impoundments that were used to receive process effluent for evaporative disposal. This system originally included the Trade Effluent Ponds, and later included the Upper and Lower BMI Ponds, and the associated Alpha and Beta ditches used to transport effluent to the Ponds; and
- Associated support buildings for the storage and transport of raw materials and the purification and processing of magnesium metal into ingots.

During government operations, extensive volumes of liquid wastes containing dissolved and suspended solids were discharged to four unlined Trade Effluent Ponds. These liquids were generally composed of acid effluent and waste caustic liquor containing high levels of total



dissolved solids (TDS), dissolved metals, and to a lesser degree, chlorinated organics (see references in Kleinfelder, 1993). Waste water originating from site processes was also discharged to a storm sewer system that emptied into unlined drainage ditches (e.g., Alpha and Beta Ditches). The unlined drainage ditches routed waste water to a system of unlined ponds currently known as the Upper and Lower BMI ponds. Solid materials were placed in an open area south of the Trade Effluent Settling Ponds and north of the caustic settling ponds (see references in Kleinfelder, 1993). Although originally intended for evaporative disposal, these unlined surface impoundments allowed significant quantities of process effluent to infiltrate into the deep soil and percolated into the groundwater.

Following the end of magnesium production in 1944, the BMI complex was subdivided into three primary production areas. The facilities that were subsequently transferred to KMCC's control include: six process unit buildings (Units 1 through 6) and their attached chlorination buildings, rectifier buildings, motor generator buildings, and bridges; a flux plant; peat storage areas; an area with a salt storage building, pulverizer building, tunnel kiln building, rotary kiln building, pellet storage building, and magnesite silos; various other buildings and open storage areas; and an area occupied by two and one-fifth of the original four Trade Effluent Disposal Ponds (Kleinfelder, 1993).

Process activities at the Site since 1945 include the production of chlorate and perchlorate compounds, boron and boron-related compounds, and refined manganese oxide. From 1945 until the mid-1970s, process effluents from the chlorate, perchlorate, and boron-related production processes were sent to the unlined Upper and Lower BMI Ponds via the Beta Ditch (LOU 5) and manganese-related wastes were disposed in onsite leach beds (LOU 24). In the early 1970s, under the federal National Pollutant Discharge Elimination System (NPDES) program, the industries at the BMI Complex curtailed waste discharges to the Upper and Lower BMI Ponds. Following 1976, process effluents were sent to onsite lined surface impoundments to comply with zero-discharge standards. Several of these lined surface impoundments reported a number of known releases and liner failures and were eventually replaced with more effective double-lined systems.

Additional onsite sources include release of process chemicals from the basements of Units 4 and 5 (LOUs 43 and 61) and the Unit 6 basement (LOU 44). These basements served as sumps to collect process liquor, spillage, and wash water and leaked chemicals to groundwater as a result of cracks in the concrete basements. Remediation activities were undertaken in 1987 in the Unit 6 basement to remove the cracked concrete floor, followed by recontouring of the underlying soil and installation of a liner system (Kleinfelder, 1993). Additional sources for potential contamination of groundwater include documented process leaks and spills (Kleinfelder, 1993). These process effluents contained high levels of TDS, perchlorate, and to a lesser degree, hexavalent chromium.



No ongoing onsite releases of chemicals into the environment have been identified. Vadose zone soil remediation (excavation with offsite disposal) is currently underway, and will remove some of the chemicals remaining in soil that could present an ongoing threat to groundwater through leaching. Based on a Site-specific evaluation of potential leaching (Northgate, 2010c) chemicals that will remain in vadose zone soil after excavation at levels that could potentially present an ongoing threat to groundwater include perchlorate, arsenic, manganese, cobalt, magnesium, hexachlorobenzene, chloroform, alpha/beta/gamma-BHC, and dieldrin. As presented in Section 5, some of these have impacted groundwater above RBGCs; however, groundwater sampling data available for cobalt, hexachlorobenzene, beta- and gamma-BHC, and dieldrin indicate little or no impact to groundwater. An evaluation of potential for leaching of chemicals from soil to groundwater is ongoing, and will include an assessment of the potential groundwater impacts. In addition, water flushing and other potential in-situ methods to remove remaining vadose zone perchlorate and other leachable chemicals are being evaluated (Northgate, 2010e).

4.1.1 Neighboring Properties

The Pioneer/Olin Chlor-Alkali/Stauffer/Syngenta/Montrose (POSSM) property to the west of the Site occupies the location of the former BMI Complex chlor-alkali production facility. Post-1945 process activities on the POSSM property include operation of the chlor-alkali facility to produce chlorine gas, hydrochloric acid, and sodium hydroxide. In 1947, additional manufacturing facilities were constructed to produce pesticides and chlorinated organic compounds. Production of agricultural chemicals and organic compounds ceased in 1983, and production facilities were demolished and removed from the POSSM site in 1984. Operation of the chlor-alkali facility is ongoing. Since 1945, extensive volumes of process effluents and solid wastes were disposed in onsite unlined ponds and buried on the property. These wastes contained high levels of TDS, chlorinated organic compounds, and extensive amounts of phosphoric acid. Prior to 1976, certain process effluents were routed to the Upper and Lower BMI Ponds. These waste streams included large volumes of sulfuric and hydrochloric acid, as well as sulfonated metabolites of DDT (H+A, 2008a).

The TIMET property to the east of the Site includes four former BMI process units (Units 7 through 10) and refinery buildings. Activities conducted on what is now the TIMET site from 1951 until the present have included production of magnesium ingot, titanium tetrachloride, titanium sponge, and titanium ingot (TIMET, 2007). From 1951 until 1972, TIMET disposed of its caustic waste, leach liquor, and other process waste streams to the Upper BMI Ponds via the Beta Ditch. From 1972 until 1976, these waste streams were disposed in unlined surface impoundments on TIMET property. From 1976 to 1982, TIMET built 31 lined surface impoundments on top of the southwestern portion of the Upper Ponds where its process waste streams were discharged. Several of the lined ponds reported liner failures and were upgraded to double-lined systems. In 2005, a water conservation facility went online and discharge to the



ponds ceased. The TIMET process waste streams contained high levels of TDS and dissolved metal chlorides (LAW Engineering, 1993).

4.2 Overview of Impact to Groundwater

This section provides an overview of Site groundwater impacts, while Section 6 provides a detailed, chemical-by-chemical discussion of potential sources, distribution, and fate and transport mechanisms. Perchlorate is the chemical that has been identified as being of greatest environmental concern in Shallow Zone groundwater due to its relative toxicity, widespread distribution at elevated concentrations, persistence in the environment, and presence in the Lake Mead drinking water source. Perchlorate containment and removal has been the primary focus of groundwater remediation at the Site for the past 12 years. Hexavalent chromium has also received considerable focus due to its toxicity, fairly wide distribution, and elevated concentrations. The remedial performance monitoring described in annual reports (e.g., Northgate, 2010a) also include TDS, nitrate, and chlorate. As discussed in Section 6, the Phase A, Phase B, and other existing groundwater data show that Shallow Zone groundwater at the Site and vicinity has been impacted by a wide variety of chemicals. As presented in Sections 5 and 6, these chemicals include other metals, VOCs, and OCPs. The following general categories of potential sources and/or reactions resulting in groundwater impacts have been identified:

- Releases of chemicals from the onsite processes described in Section 4.1;
- Releases of chemicals from offsite processes at the POSSM property, west of the Site;
- Chemicals that were released from natural sources due to changes in geochemical conditions, resulting from processes at the POSSM property, west of the Site;
- Chemicals that formed in the environment (e.g. breakdown products) from other onsite or offsite process chemical releases; and
- Chemicals that are naturally occurring at levels (e.g. background levels) that exceed some relevant criteria.

Several attempts to define upgradient conditions for groundwater have been undertaken for the Tronox Site (ENSR,2006b), the TIMET Site (TIMET, 2009), the POSSM Site (H+A, 2008b) and the BRC Common Areas (BRC, 2010;DBS&A, 2010). The results of these investigations make it apparent that it is difficult to distinguish “background levels” for some chemicals (such as TDS and arsenic) due to regional groundwater quality impacts and the variability of groundwater chemical conditions in the shallow aquifer of the Las Vegas Valley area (Morgan and Dettinger, 1996; Bevans et al., 1998). In the study area, the groundwater chemistry of the “shallow aquifer(s)” is generally characterized as a sodium chloride-sulfate type and is classified as slightly to moderately saline. The shallow aquifer in the Las Vegas Valley is of low quality



(high TDS, nitrate, phosphorus, and arsenic), composed primarily of secondary recharge from landscape irrigation, septic tanks, and municipal wastewater disposal. Total dissolved solids in the shallow aquifer (generally 3,000 to 10,000 milligrams per liter [mg/L]) are concentrated via evaporation, transpiration, and dissolution of naturally occurring evaporite deposits in the vadose zone (Maxey and Jameson, 1948; Kaufmann, 1977; Plume, 1989; Morgan and Dettinger, 1996; Bevans et al., 1998). The definition of upgradient groundwater conditions is further complicated as Site “upgradient” wells are screened in the UMCf because the Qal is not saturated, and therefore may not be representative of Site Qal groundwater.

Site and neighboring site groundwater impacts from industrial activities on a chemical-by-chemical basis are discussed in Section 6. In general, chemical concentrations are highest at the Site or neighboring sites and decrease with distance downgradient towards the Las Vegas Wash. However, groundwater remediation at the Interceptor well field (which includes groundwater extraction and treatment, a bentonite slurry barrier wall, and clean water percolation trenches, as described in Section 4.3 below) has resulted in a relatively less-contaminated area immediately downgradient of the percolation trenches. Contaminant concentrations generally decrease with depth from the Shallow (< 90 feet below ground surface) to Middle (90 to 300 feet below ground surface) Water Bearing Zones (WBZ). However, there are notable exceptions that are discussed on a chemical by chemical basis in Section 6. Significant variability occurs in the overall distribution of the various chemicals impacting Site groundwater due to differences in source type, location, duration and strength, as well as chemical characteristics affecting fate and transport. This spatial variability is discussed on a chemical-by-chemical basis in Section 6.

4.3 Current Groundwater Remediation Program

Tronox operates two groundwater remediation systems at the Site: (1) a hexavalent chromium remediation system that treats water from the onsite Interceptor well field and from the offsite Athens Road well field lift station using ferrous sulfate to reduce hexavalent chromium to trivalent chromium, and (2) a perchlorate biological remediation system that treats extracted water from the onsite Interceptor well field, the offsite Athens Road well field, the offsite Seep well field, and the offsite Seep surface-flow capture sump (Plate 1) using perchlorate-reducing bacteria in a fluidized bed reactor. The Interceptor well field consists of a series of 23 groundwater extraction wells that are located immediately upgradient (south) of a low-permeability bentonite slurry barrier wall and pump a total of approximately 70 gallons per minute (gpm). Tronox is currently performing infrastructure upgrades necessary to connect seven additional extraction wells to the Interceptor well field recovery system (Northgate, 2010a). The Athens Road well field consists of a series of 14 groundwater extraction wells pumping a total of approximately 270 gpm, and the Seep well field consists of nine wells pumping a total of approximately 530 gpm (Northgate, 2010a).



In accordance with the Consent Order for remediation of chromium-impacted groundwater finalized on September 9, 1986, and the Administrative Orders on Consent for remediation of perchlorate-impacted groundwater in the Henderson area finalized on October 8, 2001, Tronox conducts an annual groundwater sampling event that is coordinated with several neighboring companies. Groundwater samples are collected and analyzed for perchlorate, TDS, chlorate, and nitrate. Groundwater sample and potentiometric data collected by neighboring companies are considered in the evaluation of Site conditions. Groundwater monitoring results and details regarding the remediation systems' operations are provided in annual remediation performance reports (e.g., Northgate, 2010a). In addition, Tronox performed a capture zone evaluation that incorporates the results of additional field investigations at the Site, and uses a three-dimensional hydrogeologic flow model to evaluate the percent mass capture of perchlorate and chromium at each of the interceptor well fields (Northgate, 2010m).

Chromium and perchlorate concentrations in monitoring wells immediately downgradient of the onsite groundwater barrier have declined significantly since the early 2000s (see Appendix D), reflecting groundwater capture and contaminant removal at the Interceptor well field and dilution by percolation of Lake Mead water in the recharge trenches. Concentrations of total chromium at the Seep well field continue to be below the laboratory method reporting limit. Perchlorate loading in the Las Vegas Wash has declined by nearly 94% over the last 10 years of groundwater capture system operation (Northgate, 2010a).

4.4 Potential Migration Pathways and Receptors

Potential contaminant migration pathways at or near the Site include air, soil, surface water, and groundwater. Contaminant transport can occur via the air pathway when contaminated surface soils and particulates are mobilized and carried by winds, or when contaminants volatilize from the soil, groundwater or surface water, releasing gases to the air. Near-surface contaminated soil may come into contact with human or ecological receptors through dermal adsorption or ingestion. Residual contaminants in the soil can be leached into groundwater via surface water infiltration or changes in groundwater elevation. In addition, contaminated soil can be eroded by surface water runoff and transported to potential downgradient receptors. This may occur via rainfall or other applied surface water sheet runoff, or via runoff in surface water control features such as the Beta Ditch. Soluble contaminants may be dissolved in surface water and transported in runoff and recharge, impacting the vadose zone and possibly the groundwater. Evaporation can also concentrate dissolved salts, as noted in Section 4.2. Where contaminated groundwater surfaces as a seep or discharges to drainages or lakes, surface water, such as the Las Vegas Wash or Lake Mead, may be impacted (ENSR, 2005).



Potential human receptors for contaminants include onsite workers, visitors, offsite workers, residents who live in communities downwind and downgradient of the site, and residents who receive drinking water from Lake Mead and the Colorado River. There are currently approximately 90 full-time workers employed at the Site. Immediate surrounding land use is predominantly industrial, although there are residential developments in all directions nearby the Site. Biological resources and ecological receptors are presented in the CSM Report (ENSR, 2005). Figure 2 presents a conceptual diagram of the groundwater impacts, pathways, and potential receptors.

As presented in the approved HHRA Work Plan (Northgate, 2010b), potential exposure to residual chemicals in soil vapor and potential for leaching of chemicals to groundwater will be evaluated on a Site-wide basis. Following completion of the Site-wide soil vapor report and leaching evaluation, these pathways will be addressed in each of the RZ-specific soil HHRA reports. No groundwater risk assessment is currently planned; however, NDEP has established RBGCs for comparison with groundwater concentrations, as discussed in Section 3. These RBGCs are based on the use of the water for residential drinking water supply. The Site groundwater is not a current drinking water source, nor is it likely to be in the future due to its naturally poor quality (see Section 4.2 above). However, shallow Site groundwater migrates and discharges into the Las Vegas Wash which and then flows into Lake Mead, which is a drinking water source.



5 SELECTING CHEMICALS OF INTEREST

The Phase B groundwater data were reviewed to determine a list of chemicals that may be of interest in evaluating potential risks to human health and the environment and/or for understanding groundwater conditions. These are not necessarily chemicals that present a threat or require action; rather they are chemicals of interest (COIs) for understanding the Site groundwater conditions. This section describes the COI screening process and results.

5.1 COI Screening Criteria

The following criteria were used to retain a chemical as a COI for this assessment:

- Detections in more than 15% of the Phase B groundwater samples and exceedances of the RBGC in more than 10% of the samples;
- Concentrations in soil gas above Site-specific screening levels (Northgate, 2010f; *Tronox/NDEP meeting minutes for February 23, 2010*);
- Records of onsite use;
- Detections in offsite groundwater at high concentrations;
- Significant contributors to TDS or other water quality issues; and/or
- Daughter products and chemicals associated with other COIs.

5.2 COI Screening Results

Based on the above criteria, the chemicals noted below were retained as COIs (Table 6). These chemicals are discussed in greater detail in Section 6.

5.2.1 Inorganics

Ammonia - Ammonia was detected above the practical quantitation limit in 67.6% of Shallow Zone groundwater samples and 28.4% of the detected samples exceeded the RBGC of 730 µg/L (the BCL is calculated from the inhalation reference dose for noncarcinogenic effects based on residential water exposure assumptions (NDEP, 2008b)).

Arsenic - Total (unfiltered) arsenic was detected in 97.3% of Shallow Zone groundwater samples and 100% of Middle Zone samples at concentrations above the RBGC. Dissolved (filtered) arsenic was detected in 90.9% of Shallow Zone groundwater samples at concentrations above the RBGC. The arsenic RBGC of 10 µg/L is based on the U.S. EPA Primary MCL.



Boron - Total (unfiltered) boron was detected in 99% of Shallow Zone groundwater samples and 21.6% of the detected samples exceeded the RBGC. The boron RBGC of 7,300 µg/L is the BCL calculated from the inhalation reference dose for noncarcinogenic effects based on residential water exposure assumptions (NDEP, 2008b).

Chlorate - Chlorate appears to be associated with the perchlorate plume and has therefore been retained as a COI. It was also used at the Site and is a significant contributor to TDS.

Chloride - Chloride was detected in all groundwater samples and was above the RBGC in 91.2% of the Shallow Zone groundwater samples and 12.5% of the Middle Zone samples. The chloride RBGC of 250 mg/L is based on the U.S. EPA Secondary MCL.

Chromium (total) and Hexavalent Chromium - Total (unfiltered) chromium was detected in 89.2% of Shallow Zone groundwater samples and 54.9% of the detected samples exceeded the RBGC. Dissolved chromium was detected in 81% of Shallow Zone groundwater samples and 47.6% of the detected samples exceeded the RBGC. Hexavalent chromium was detected in 69.3% of Shallow Zone groundwater samples and 52.5% of the detected samples exceeded the RBGC. Hexavalent chromium was also detected in 62.5% of Middle Zone groundwater samples, and 12.5% of the detected samples exceeded the RBGC. The total and hexavalent chromium RBGC of 100 µg/L is based on the U.S. EPA Primary MCL.

Magnesium - Total (unfiltered) magnesium was detected in every groundwater sample and 51% of the Shallow Zone groundwater samples had concentrations above the RBGC. Dissolved magnesium was also detected in every Shallow Zone groundwater sample and 23.8% of the samples exceeded the RBGC. The magnesium RBGC of 207,000 µg/L is the BCL calculated for noncarcinogenic effects based on residential water exposure assumptions (NDEP, 2008b).

Manganese - Total (unfiltered) manganese was detected in 85.3% of Shallow Zone groundwater samples and 19.6% of the detected samples exceeded the RBGC. Dissolved manganese was detected in 85.7% of Shallow Zone groundwater samples and 19% of the detected samples exceeded the RBGC. The manganese RBGC of 511 µg/L is the BCL calculated from the inhalation reference dose for noncarcinogenic effects based on residential water exposure assumptions (NDEP, 2008b).

Nitrate - Nitrate was detected in 91.2% of Shallow Zone groundwater samples and 42.2% of the detected samples exceeded the RBGC. The nitrate RBGC of 10 mg/L is based on the U.S. EPA Primary MCL.

Perchlorate - Perchlorate was detected in 88.3% of Shallow Zone groundwater samples at concentrations above the RBGC. Perchlorate was also detected in 62.5% of Middle Zone



groundwater samples and 50% of the detected samples exceeded the RBGC. The perchlorate RBGC of 18 µg/L is the provisional action level established by NDEP calculated from the ingestion reference dose for noncarcinogenic effects based on residential water exposure assumptions (NDEP, 2008b).

Phosphorus – Phosphorus was detected in 33.3% of Shallow Zone groundwater samples and 12.7% of the detected samples exceeded the RBGC. The phosphorus (phosphoric acid) RBGC of 73 µg/L is the BCL calculated from the inhalation reference dose for noncarcinogenic effects based on residential water exposure assumptions (NDEP, 2008b).

Strontium - Strontium was used at the Site in the production of sodium chlorate in Units 4 and 5 and discharged to many of the process ponds (Kleinfelder, 1993). Strontium was detected in 100% of the groundwater sample collected during the Phase B investigation and 5.9% exceeded the RBGC. The strontium RBGC of 21,900 µg/L is the BCL calculated for rachitic effects based on residential water exposure assumptions (NDEP, 2008b).

Sulfate - Sulfate was detected in every groundwater sample collected during the Phase B Investigation. Sulfate was detected above the RBGC in 99% of the Shallow Zone groundwater samples and 75% of the Middle Zone samples. The sulfate RBGC of 250 mg/L is based on the U.S. EPA Secondary MCL.

Total Dissolved Solids - TDS was detected in every groundwater sample at concentrations above the RBGC. The TDS RBGC of 500 mg/L is based on the U.S. EPA Secondary MCL.

Uranium - Total (unfiltered) uranium was detected in 98% of Shallow Zone groundwater samples and 60.8% of the detected samples exceeded the RBGC. Dissolved (filtered) uranium was detected in 90.5% of Shallow Zone groundwater samples and 33.3% of the detected samples exceeded the RBGC. Uranium was also detected in every Middle Zone groundwater sample and 12.5% of the detected samples exceeded the RBGC. The uranium RBGC of 30 µg/L is based on the U.S. EPA Primary MCL.

Bicarbonate - Bicarbonate was used at the Site and is a significant contributor to TDS.

Calcium - Calcium was used at the Site and is a significant contributor to TDS.

Potassium - Potassium was used at the Site and is a significant contributor to TDS.

Sodium - Sodium was used at the Site and is a significant contributor to TDS.



5.2.2 Organics

Alpha-BHC - Alpha-BHC was detected in 29.4% of Shallow Zone groundwater samples, all of which exceeded the RBGC. The alpha-BHC RBGC of 0.0107 µg/L is the BCL calculated for carcinogenic effects based on residential water exposure assumptions (NDEP, 2008b).

Benzene - Benzene was detected in 15.7% of Shallow Zone groundwater samples and 10.8% of the detected samples exceeded the RBGC. The benzene RBGC of 5 µg/L is based on the U.S. EPA Primary MCL. Benzene was also detected upgradient and offsite at high concentrations.

Chlorobenzene - Chlorobenzene was detected in 23.5% of Shallow Zone groundwater samples and 11.8% of the detected samples exceeded the RBGC. The chlorobenzene RBGC of 100 µg/L is based on the U.S. EPA Primary MCL. Chlorobenzene was also detected upgradient and offsite at high concentrations.

1,2-Dichlorobenzene (1,2-DCB) - 1,2-DCB was detected in 36.3% of Shallow Zone groundwater samples and 2% of the detected samples exceeded the RBGC. The 1,2-DCB RBGC of 600 µg/L is based on the U.S. EPA Primary MCL. 1,2-DCB appears to be associated with the upgradient, offsite benzene plume and was detected offsite at high concentrations.

1,4-Dichlorobenzene (1,4-DCB) - 1,4-DCB was detected in 15.7% of Shallow Zone groundwater samples and 4.9% of the detected samples exceeded the RBGC. The 1,4-DCB RBGC of 75 µg/L is based on the U.S. EPA Primary MCL. 1,4-DCB appears to be associated with the upgradient, offsite benzene plume and was detected offsite at high concentrations.

Carbon Tetrachloride - Carbon tetrachloride was detected in 48% of the Shallow Zone groundwater samples and 3.9% of the detected samples exceeded the RBGC. The carbon tetrachloride RBGC of 5 µg/L is based on the U.S. EPA Primary MCL. Carbon tetrachloride was also detected in upgradient and offsite groundwater at high concentrations.

Chloroform - Chloroform was detected in 96.1% of Shallow Zone groundwater samples and 91.2% of the detected samples exceeded the RBGC. Chloroform was detected in 62.5% of Middle Zone groundwater samples and 50% of those samples exceeded the RBGC. Chloroform was detected in soil gas at several locations at the Site at concentrations above the Site-specific soil gas screening level. Chloroform was also detected in upgradient and offsite groundwater at high concentrations. The chloroform RBGC of 1.62 µg/L is the BCL calculated for carcinogenic effects based on residential water exposure assumptions (NDEP, 2008b).



Trichloroethene (TCE) - TCE was detected in 53.9% of Shallow Zone groundwater samples and 13.7% of the detected samples exceeded the RBGC. The TCE RBGC of 5 µg/L is based on the U.S. EPA Primary MCL. TCE was also detected in soil gas at several locations at the Site.

1,1-Dichloroethene (1,1-DCE) – 1,1-DCE was detected in 24.5% of the Shallow Zone groundwater samples and 2% of the detected samples exceeded the RBGC. The 1,1-DCE RBGC of 7 µg/L is based on the U.S. EPA Primary MCL. 1,1-DCE, a daughter product of 1,1,1-TCA and potential daughter product of TCE, may be associated with the TCE plume.

1,1-Dichloroethane (1,1-DCA) - 1,1-DCA was detected in 28.4% of the Shallow Zone groundwater samples and 5.9% of the detected samples exceeded the RBGC. The 1,1-DCA RBGC of 11.8 µg/L is the BCL calculated for carcinogenic effects based on residential water exposure assumptions (NDEP, 2008b). 1,1-DCA is a daughter product of 1,1,1-TCA, of which there is documented former use at the Site, and may be associated with the TCE plume.



6 COI EVALUATION

A list of COIs and screening criteria is presented in Table 6. Summary tables of analytical results for Phase B groundwater samples are provided in Tables 2 through 5. Plate 1 shows the locations of the groundwater wells sampled for the Phase B investigation. Each COI is further evaluated in the following subsections. The inorganic COIs are presented first, followed by organic COIs. Perchlorate has been identified as the driver COI in groundwater at the Site. However, since it is the contaminant associated with remediation, associated annual remediation performance reports (e.g., Northgate, 2010a), and a recent capture zone evaluation report, (Northgate, 2010g), this report does not include an extensive evaluation.

Isoconcentration maps prepared for this report are based primarily on the Phase B groundwater data, but also include compliance monitoring data to supplement Phase B data where needed. Although not used in the isoconcentration maps, data from the previous Phase A and Upgradient investigations were also reviewed for general consistency with the more recent Phase B and compliance data. Summaries of these data sets, as reported in *Phase A Source Area Investigation Results* (ENSR, 2007b) and *Upgradient Investigation Results* (ENSR, 2007c), are provided in Appendix E. To provide a regional perspective on COI distribution, the isoconcentration maps incorporate groundwater monitoring data from American Pacific Corporation (AMPAC), the POSSM companies, Southern Nevada Water Authority (SNWA), and Titanium Metals Corporation (TIMET), obtained from the NDEP BMI Complex, BMI Common Areas, and Vicinity Database. The COI evaluations presented in the following subsections focus on the Phase B groundwater data, but also discuss the regional distribution.

The maps were generated using Shallow Zone groundwater data collected during the 2008-2009 time period. Data collected specifically for the Phase B investigation were preferred, and if multiple parties sampled a well during that time, the Tronox data was used for contouring. If a primary and duplicate sample were collected on the same day, the higher of the two sample results were used in contouring. Non-detect data were included in the modeled dataset, using the SQL as the detection limit and including J-flagged data below the SQL and above the method detection limit (MDL). The dissolved (filtered) inorganic fraction was used if available, the total (unfiltered) metals analytic result if not.

Outliers and anomalous data were screened by using professional judgment by evaluating the data for each COI in time-series concentration plots, histograms, box/whisker plots, and spatial distributions. Non-detect results that were greater than one-half the mean of the detected values for each COI were considered elevated and omitted from the map data set. Retained data were contoured using SURFER[®] using a kriging algorithm applied to log-transformed data using a COI-specific variogram model. Contour intervals for each COI were set at the chemical-specific RBGC and increase by orders of magnitude (with a few exceptions where other intervals were



more appropriate for visualization). These isoconcentration maps are intended to provide a general depiction of areas with higher and lower concentrations of a given chemical, and may not accurately represent actual groundwater concentrations at all locations. The presence of paleochannels, thickness of saturated Qal, and other hydrogeologic factors may have significant influences on the chemical distribution in the Shallow Zone, but these factors were not considered in contouring. Due to uncertainties and differences in hydrogeologic interpretation by various parties, this approach was followed in an attempt to provide unbiased plume depictions.

Copies of the laboratory reports for the Phase B investigation analyses were provided in the groundwater DVSR (Northgate, 2010d).

6.1 Inorganic Chemicals of Interest

6.1.1 Ammonia

Ammonia was detected above the laboratory SQL in 69 of 102 groundwater samples collected in the Shallow Zone (detection frequency of 67.6%), with 29 of those samples exceeding the RBGC of 730 micrograms per liter ($\mu\text{g/L}$) (Table 2). The highest reported value in the Shallow Zone was 301,000 $\mu\text{g/L}$ at monitoring well IAR. Ammonia was detected in four of eight groundwater samples collected in the Middle Zone (detection frequency of 50%), with none of the detected values exceeding the RBGC (Table 3). The highest reported value in the Middle Zone was 178 $\mu\text{g/L}$ at monitoring well M121.

Spatial analysis of ammonia concentrations measured in samples collected from the Shallow Zone indicates that a single plume with concentrations exceeding 100,000 $\mu\text{g/L}$ occurs under the western area of the AP Plant and appears to be contained by the groundwater barrier wall to the north (Plate 7). Analysis of ammonia concentrations from samples collected from the Middle Zone indicate no significant contamination on the Site, although elevated levels of ammonia occur downgradient from the northwest of the Site to the Las Vegas Wash with a maximum concentration of 13,800 $\mu\text{g/L}$ at monitoring well MCF-05. Analysis of concentration data from the Deep Zone indicates elevated levels of ammonia extending from northwest of the Site to the Las Vegas Wash with a maximum concentration of 25,900 $\mu\text{g/L}$ at monitoring Well MCF 21-A.

Ammonia in Site groundwater is likely a result of the self-dissociation of ammonium ions from historical ammonium perchlorate contamination. Potential onsite source areas include Ponds AP-1, AP-2, and AP-3 (LOUs 16 and 17). A leak from Pond AP-2 was reported in 1979 and the liner was replaced prior to 1980. By late 1983, frequent patching was required to mitigate leaks until the liners were replaced with double liner systems. Other potential sources include the area affected by the July 1990 fire (LOU 55), where water used to fight an ammonium perchlorate



fire may have infiltrated into the groundwater, AP Plant Cooling Tower overflows in the AP Plant area, New D-1 Building wash down (LOU 57), and from reported leaks from AP Plant transfer lines to the Sodium Chlorate Process (LOU 58). Phase B soil investigation revealed ammonia concentrations exceeding 100 milligrams per kilogram (mg/kg) at soil depths of 30 feet in the western area of the AP Plant (Northgate, 2010h-k; *Tronox/NDEP meeting minutes for February 5 and February 12, 2010*). These levels of ammonia are indicative of past releases of ammonium perchlorate that infiltrated the soil and reached the groundwater. Although ammonia may have been created from the volatilization of urea used in the sodium chlorate process, this is not likely to be a major source of ammonia contamination.

No potential offsite sources were identified that would have led to ammonia contamination of groundwater within the Site boundaries. Historical releases of liquid ammonium perchlorate process wastes to the Upper and Lower BMI Ponds via the Beta Ditch (LOU 5) is a potential source for ammonia contamination of the BMI site and the Las Vegas Wash (Kleinfelder, 1993).

Ammonia levels in Site groundwater will likely decrease with time due to ongoing groundwater extraction as well as several degradation pathways, including the volatilization of ammonia from groundwater into soil, the nitrification of ammonia into dissolved nitrate, and the adsorption of ammonium ions onto mineral surfaces.

6.1.2 Arsenic

Total (unfiltered) arsenic was detected above the laboratory SQL in 99 of 102 groundwater samples collected in the Shallow Zone (detection frequency of 97.3%), with all of the detected values exceeding the RBGC of 10 µg/L (Table 2). Dissolved (filtered) arsenic was detected in 20 of 22 samples (detection frequency of 90.9%), with all of the detected values exceeding the RBGC (Appendix G). The highest reported value in the Shallow Zone was 750 µg/L at monitoring well M12A². Arsenic was detected above the RBGC in all eight groundwater samples collected in the Middle Zone (Table 3). The highest reported value in the Middle Zone was 200 µg/L at monitoring well M120.

Spatial analysis of arsenic concentrations in the Shallow Zone indicates there are four areas with elevated arsenic levels in the Shallow Zone (Plate 8):

- The first area is located on the southern portion of the Site, where the highest level of arsenic detected was 750 µg/L at well M12A² located north of Unit 4 (LOU 43). Arsenic was detected at 340 µg/L at well M138, which is located approximately 1,200 feet south

² This value represents the dissolved fraction of arsenic in well M12A. Total (unfiltered) arsenic was detected at 760 µg/L.



of the Unit Buildings 2 and 3. This monitoring well is located on the former site of State Industries, Inc. (LOU 62).

- The second area is located along the western boundary of the Site, where arsenic was detected at 309 µg/L at well M127. Plate 8 shows that this is most likely an offsite source centered on the location of the CAMU slit-trench area to the west of the Site.
- The third area is located along the eastern boundary of the Site, where arsenic was detected at 380 µg/L at well CLD4R.
- The fourth area is located along the northern boundary of the Site, where arsenic was detected at 260 µg/L at well H-56A.

A potential onsite source is the former Hardesty Chemical Site (LOU 4). Hardesty leased property in the vicinity of Unit 2 and produced several chemicals, including sodium arsenite solution (ENSR, 2005). No other potential onsite or offsite sources of arsenic were identified.

Arsenic is a naturally occurring element in rocks, soils, and the waters in contact with them. High concentrations of arsenic in the western U.S. are generally associated with basin-fill deposits of alluvial/lacustrine origin, volcanic deposits, areas of geothermal activity and uranium and gold-mining areas (Welch et al., 1988). Within alluvial basins, arsenic concentrations exceeding 10 µg/L in groundwater are most likely due to the dissolution of volcanically-derived sediments and the subsequent concentration of dissolved arsenic onto the ferric oxyhydroxides that commonly coat the surfaces of most sediments (Welch et al., 1988).

Anthropogenic arsenic contamination of groundwater may result from a variety of sources, including oxidation of mining waste, the discharge of industrial waste, and the application of arsenic-based herbicides and pesticides. Arsenic exhibits a complex geochemical behavior. Arsenic in groundwater typically occurs as As(III) (arsenite) or As(V) (arsenate) under reducing and oxidizing conditions, respectively. As(III) is a neutral species and tends to be mobile in groundwater while As(V) is an anion and tends to adsorb and become concentrated onto the ferric oxyhydroxides that commonly coat the surface of most sediments (U.S. EPA, 2004b).

Several geochemical reactions can drive the mobilization of arsenic in groundwater. If conditions in the subsurface become reducing due to biological or chemical activity, the ferric oxyhydroxide surfaces that bind arsenic can be reduced to ferrous iron and dissolve. This dissolution will lead to releases of arsenic, which will likely be in the As(III) neutral state and highly mobile. Other potential mechanisms include the presence of anionic species that compete for available sorption sites on the ferric oxyhydroxides surface. Phosphate competes for adsorption sites, and groundwater with high phosphate concentrations can lead to the desorption of arsenic (Welch et al., 2000; U.S. EPA, 2004b). Reaction of synthetic organic compounds with ferric oxyhydroxides is another mechanism for the release of bound arsenic into groundwater



(Bauer and Blodau, 2006; Welch et al., 2000). Significant sources of dissolved organic carbon exist on- and offsite, which can lead to dissimilatory iron reduction and the subsequent release of arsenic from ferric oxyhydroxide (Bauer and Blodau, 2006; Lovley, 1991).

The origin of the arsenic plumes on the Site is complex, but it is likely that the arsenic is primarily natural in origin and has been mobilized due to anthropogenic modification of the geochemistry of the Site groundwater. While above-background arsenic levels have been detected in Site soil in some areas (Northgate, 2010h-k; *Tronox/NDEP meeting minutes for February 5 and February 12, 2010*) and have been identified as a potential concern for future leaching to groundwater (Northgate, 2010c), these occurrences are limited and cannot explain the widespread distribution of elevated arsenic in groundwater.

Significant amounts of phosphate have been introduced into the groundwater from onsite and offsite sources. Onsite sources include a sodium hexametaphosphate-based manganese dioxide cathode wash solution was discharged to Pond C-1 (LOU 20) and Pond MN-1 (LOU 21). State Industries (LOU 62) used phosphate chemicals in the production of hot water heaters. From 1970 until 1972, State Industries used the acid drain system (LOU 60) to dispose of phosphate-laden process waste to the acid drain system. State Industries also operated two surface impoundments to hold process wastes. These wastes were pumped to the impoundments at the rate of 35,000 gallons/month and included spent sulfuric acid, borax, anhydrous sodium carbonate, and phosphates. Records indicate that both impoundments were in operation from approximately 1972 until 1988 and were known to have leaked on several occasions (Kleinfelder, 1993). Significant offsite sources of phosphate exist on the former Stauffer and Montrose facilities. Between 1960 and 1970, a portion of the phosphoric acid waste stream (20,000 tons) generated by as part of the thiophenol/parachlorothiophenol waste stream was discharged to the Former Leach Field and Phosphoric Acid Pond/Trenches (H+A, 2008a). Additional offsite sources for phosphorus include contamination resulting from the use of nitrogen-phosphate lawn fertilizers.

While there appears to be no direct correlation between dissolved phosphorous and arsenic concentrations, it is likely that the long term release of phosphates has led to a significant reduction in the arsenic sorption capacity of ferric oxyhydroxide-coated aquifer material. No apparent correlation was found between arsenic concentrations and the measured oxidation-reduction potential (ORP; Plate 9) or between arsenic and dissolved oxygen (Plate 10). There also does not appear to be any significant portions of the Site where reducing conditions are causing the mobilization of arsenic through the reduction and dissolution of ferric hydroxides.

Due to the reduced sorption capacity of aquifer material from historic phosphorus release, and potential phosphorus contamination of the Shallow Zone from fertilizer use and lawn



maintenance, arsenic levels in Site groundwater may remain elevated in spite of the ongoing groundwater extraction and Lake Mead water injection.

6.1.3 Boron

Total (unfiltered) boron was detected above the laboratory SQL in 101 of 102 groundwater samples collected in the Shallow Zone (detection frequency of 97.3%), with 22 of those samples exceeding the RBGC of 7,300 µg/L (Table 2). Dissolved (filtered) boron was detected in 20 of 21 groundwater samples (detection frequency of 95.2%) in the Shallow Zone, with only two of those samples exceeding the RBGC (Appendix G). The highest reported value in the Shallow Zone was 18,200 µg/L at monitoring well M141. Boron was detected in eight of eight groundwater samples in the Middle Zone (detection frequency of 100%), with none of the detected values exceeding the RBGC (Table 3). The highest reported value in the Middle Zone was 2,100 µg/L at monitoring well M121.

Analysis of boron data from the Shallow Zone indicates several areas with concentrations exceeding 10,000 µg/L north of Unit 5 (LOU 61) that appear to be contained by the groundwater barrier wall to the north (Plate 11). The highest concentration between the barrier wall and the Las Vegas Wash is 11,500 µg/L (M94) and the concentration at the Wash is 2,760 µg/L (PC-94), which is below the RBGC of 7,300 µg/L. Analysis of boron concentration data from the Middle Zone suggests no significant boron contamination at these depths on the Site, although elevated levels of boron exist downgradient of the Site with a maximum concentration of 11,800 µg/L at monitoring well COH-2. Analysis of boron concentration data in the Deep Zone indicates elevated levels towards the Las Vegas Wash, with a maximum concentration of 18,400 µg/L at monitoring Well MCF-08A.

Boron is a naturally occurring element in groundwater, and is commonly found as a result of leaching of evaporite deposits (Hem, 1985), which may be present in the vicinity of the Site. Concentrations of boron in groundwater throughout the world vary widely, ranging from 300 to 100,000 µg/L (ECETOC, 1997).

Elemental boron, boron tribromide, and boron trichloride have been produced at the Site since 1972. Potential onsite source areas for boron contamination include the production area in Unit 5 (LOU 61) and the newer boron trichloride production facilities north of Unit 4. Between 1972 and January 1976, liquid process wastes were discharged to the BMI Ponds via the Beta Ditch (LOU 5). From October 1975 until 1983, liquid wastes were discharged to Ponds S-1 (LOU 13) and P-1 (LOU 14), both of which had known releases due to liner failures. Discharge of liquid process wastes following 1983 was sent to Pond C-1 (LOU 20). Phase B soil investigation revealed boron concentrations exceeding 50 mg/kg at soil depths of 34 feet in the area of Unit 5 and 65 mg/kg at a depth of 24 feet in the area of Pond C-1 (Northgate, 2010h-k). These high



levels of boron are indicative of past releases of boron-containing process liquids that infiltrated into the deep soil and potentially percolated into the groundwater.

State Industries Inc. (LOU 62) leased portions of the Site approximately 1,200 feet south of Units 2 and 3 from 1969 until 1988, and discharged approximately 4,000 pounds of sodium borate annually in its process waste stream. Prior to 1974, State Industries used the Acid Drain System (LOU 60) to convey process wastes to the Beta Ditch. After 1974, State Industries operated two surface impoundments for the solar evaporation of process wastes. These surface impoundments were known to have leaked on three separate occasions (Kleinfelder, 1993). The Phase B soil investigation revealed concentrations of boron exceeding 65 mg/kg at depths of 55 feet in the eastern area of the former State Industries facility (Northgate, 2010h-k). These high levels of boron are indicative of past releases of boron-containing process waste that infiltrated into the deep soil and potentially percolated into the groundwater.

Dissolved boron typically exists in groundwater as a combination of neutral boric acid (H_3BO_3) and the monoborate anion ($H_2BO_4^-$), although at high concentrations it can polymerize into larger polyborate anions (Baes and Mesmer, 1976). Boron tends to be mobile in groundwater, but may be adsorbed by soils and sediments at pH 7.5-9.0 through adsorption of the negatively charged borate anion onto positively charged mineral surfaces (Waggott, 1969; Keren and Mezuman, 1981; Keren et al., 1981). Boron adsorption can vary from being fully reversible to irreversible, depending on the type of soil, pH, salinity, organic matter content, iron and aluminum oxide content, iron- and aluminum-hydroxyl content, and clay content. Borate ions present in aqueous solution are essentially in their fully oxidized state. No aerobic processes are likely to affect their speciation, and no biotransformation processes are reported.

No significant ongoing vadose zone sources of boron to groundwater have been identified (Northgate, 2010c). Levels of dissolved boron in the Shallow Zone should decrease over time through a combination of groundwater extraction, clean water injection, other dilution processes and adsorption onto mineral surfaces.

6.1.4 Chlorate

Chlorate was detected above the laboratory SQL in 91 of 103 groundwater samples collected in the Shallow Zone (detection frequency of 88.3%) (Table 2). The highest reported concentration in the Shallow Zone was 8,740 mg/L at monitoring well M50. Chlorate was detected in five of eight groundwater samples collected in the Middle Zone (detection frequency of 62.5 percent; Table 3). The highest reported value in the Middle Zone was 20.2 mg/L at monitoring well TR-10.

Analysis of chlorate concentration data from the Shallow Zone indicates a large plume north of Units 4 and 5 (LOUs 43 and 61) that appears to be contained by the groundwater barrier wall to



the north (Plate 12). The highest concentration was 8,740 mg/L at well M50 upgradient of the barrier wall. Between the barrier wall and the Las Vegas Wash, the maximum concentration was 750 mg/L (PC-130) along Sunset Road. Chlorate concentrations continue to decrease northward towards the Wash with a maximum concentration of 63.4 mg/L at well COH-2A.

Extensive volumes of chlorates were produced at the Site from 1945 until approximately 1993. Potential source areas for chlorate include the basements of Unit 4 and 5, which served as sumps to collect chlorate and perchlorate-laden process liquor, spillage, and wastewater. Deterioration and cracking of these concrete foundations led to the release of chlorate-containing solutions to underlying soils and groundwater (Kleinfelder, 1993). Although operation of the electrolytic cells in Units 4 and 5 has been discontinued, the buildings and structures remain for future use (ENSR, 2005). The Phase B soil investigation revealed chlorate concentrations exceeding 7,200 mg/kg at depths of 37 feet in the western area of Unit 4 (Northgate, 2010h-k).

From 1945 until 1975, chlorate production process waste effluents were sluiced to the Upper and Lower BMI Ponds via the Beta Ditch (LOU 5). From 1975 until 1990, liquid process effluents were discharged to the Old P-2 Pond (LOU 7), the Old P-3 Pond (LOU 8), and the New P-2 Pond (LOU 9). Both the Old P-2 and P-3 Ponds reportedly leaked unknown quantities of process solutions on more than one occasion, as well as suffered multiple liner failures (Kleinfelder, 1993). The Phase B soil investigation revealed chlorate concentrations exceeding 8,600 mg/kg at a depth of 30 feet below Old P-2 Pond, 3,870 mg/kg at a depth of 27 feet below AP-3 Pond (LOUs 16 and 17), and 2770 mg/kg at a depth of 23 feet below AP-4 Pond (LOU 18). These elevated chlorate levels are indicative of a release of chlorate-containing solutions that infiltrated into the deep soil and percolated into the groundwater.

No potential offsite sources were identified that would lead to chlorate contamination of the groundwater below the Site or on the greater BMI property.

Because chlorate is a relatively large anion with a low diffuse charge, it is non-complexing, forms no insoluble minerals, and sorbs poorly to most solids. Sodium chlorate is extremely soluble with solubilities of approximately 1,010 g/L at 20°C. Because chlorate sorbs poorly to most geologic materials, in the absence of biodegradation, chlorate plumes should move at roughly the same velocity as the groundwater. The biological treatment plant for perchlorate remediation also destroys the chlorate in water during perchlorate removal.

No significant ongoing vadose zone sources of chlorate to groundwater have been identified (Northgate, 2010c). Concentrations of chlorate in the Shallow Zone should decrease over time due to ongoing groundwater extraction.



6.1.5 Chloride

Chloride was detected above the laboratory SQL in all 102 groundwater samples collected in the Shallow Zone (detection frequency of 100%), with 93 of the samples exceeding the RBGC of 250 mg/L (Table 2). The highest reported value in the Shallow Zone was 12,800 mg/L at monitoring well MC3. Chloride was detected in all eight groundwater samples collected in the Middle Zone (detection frequency of 100%), with one sample exceeding the RBGC (Table 3). The highest reported value in the Middle Zone was 306 mg/L at monitoring well TR-4.

Spatial analysis of chloride data from the Shallow Zone indicates a chloride-containing plume originating on the POSSM site (Plate 13). The plume results in elevated levels along the western boundary of the Site where chloride concentrations exceed 5,000 mg/L. Elevated levels of chloride also exist to the east of the Site with concentrations exceeding 2,500 mg/L on the TIMET site. Analysis of groundwater data from the Middle Zone indicate elevated concentrations of chloride downgradient of the Site, with concentrations exceeding 20,000 mg/L towards the Las Vegas Wash. Analysis of chloride levels in the Deep Zone indicates brine-like concentrations near Las Vegas Wash, with a maximum concentration of 114,000 mg/L at monitoring well MCF-18A.

Chloride occurs naturally in groundwater as a result of leaching from rocks, soils, and the dissolution of evaporites. Chlorides, primarily in the forms of sodium chloride and hydrochloric acid (HCl), were also used extensively in many processes at the Site from 1945 until the present day. From 1942 until 1944, magnesium was produced at the Site through the electrolytic reduction of magnesium chloride. Extensive amounts of dissolved chlorides were sent to the Former Trade Effluent Ponds (LOU 1), as well as to the Upper and Lower BMI Ponds via the Beta Ditch (LOU 5).

Potential offsite sources that could lead to chloride contamination of groundwater on the Site include the brine sludge waste stream from the chlor-alkali production facility on the adjacent, upgradient POSSM site. Prior to 1976, this waste stream was discharged to the Upper and Lower BMI Ponds via the Beta Ditch, and to the unlined Former Wastewater Ponds 1 and 2 (POSSM LOU 6) and Chlor-Alkali Ponds (H+A, 2008a). Other potential offsite sources that could lead to chloride contamination of the greater BMI site include the historical TIMET other process waste, leach liquor and caustic waste streams. From 1951 until 1977, TIMET disposed of over 5.6 million tons of liquid process effluent with typical chloride concentrations exceeding 100,000 mg/L into unlined ponds (LAW Engineering, 1993).

Chloride ions do not significantly enter into oxidation or reduction reactions, form no important solute complexes with other ions unless the chloride concentrations are extremely high, do not form salts of low solubility, and are not significantly adsorbed to mineral surfaces (Hem, 1985).



Although chloride concentrations in the Shallow Zone are expected to decrease over time due to dilution, it is likely that levels will continue to exceed the RBGC of 250 mg/L due to high background levels of chloride in the Shallow Zone (Bevans et al., 1998).

6.1.6 Hexavalent Chromium

Hexavalent chromium was detected above the laboratory SQL in 70 of 101 groundwater samples collected in the Shallow Zone (detection frequency of 69.3%), with 53 of the samples exceeding the RBGC of 100 µg/L (Table 2). The highest reported value in the Shallow Zone was 33,600 µg/L at monitoring well M50. Hexavalent chromium was detected in five of eight groundwater samples collected in the Middle Zone (detection frequency of 62.5%), with one sample exceeding the RBGC (Table 3). The highest reported value in the Middle Zone was 104 µg/L at monitoring well TR-10.

Spatial analysis of hexavalent chromium data from the Shallow Zone indicates a large plume north of Units 4 and 5 (LOUs 43 and 61) that appears to be largely contained by the groundwater barrier wall to the north (Plate 14). The highest concentration upgradient of the barrier wall was 33,600 µg/L at well M50. Between the barrier wall and the Las Vegas Wash, the maximum hexavalent chromium concentration was 5,100 µg/L (PC-64). Concentrations continue to decrease northward towards the Wash with a maximum concentration of 24 µg/L at well PC-94. Analysis of hexavalent chromium data shows no significant contamination of the Middle or Deep Zone.

Hexavalent chromium in the form of sodium dichromate ($\text{Na}_2\text{Cr}_2\text{O}_7$) was used extensively at the Site from 1945 until approximately 1993 (Kleinfelder, 1993). Sodium dichromate was added to sodium chlorate and sodium perchlorate production solutions to reduce cathode corrosion, increase current efficiencies, and prevent anodic oxygen generation. Potential source areas for hexavalent chromium include the basements of Units 4 and 5. The Phase B soil investigation revealed hexavalent chromium concentrations of 15 mg/kg at depths of 37 feet in the northern area of Unit 5 (Northgate, 2010h-k).

Additional potential source areas include areas where chromium-laden filter cake waste was stored or disposed, including the On-Site Hazardous Waste Landfill (LOU 10), Sodium Chlorate Filter Cake Drying Pad (LOU 11), and the BMI Landfill. The Phase B soil investigation revealed hexavalent chromium concentrations of 28.2 mg/kg at depths of 39 feet in the area of the Filter Cake Drying Pad (Northgate, 2010h-k). Prior to 1976, chromium-laden process solutions and filter cake waste were sluiced to the Upper and Lower BMI Ponds via the Beta Ditch (LOU 5). Following 1976, chromium-laden sodium chlorate waste streams were sent to Old P-2 Pond (LOU 7), P-3 Pond (LOU 8), and the new P-2 Pond (LOU 9). The Old P-2 Pond and P-3 Pond reported numerous leaks and liner failures before being closed and replaced with



the P-3 Pond (Kleinfelder, 1993). The Phase B soil investigation revealed hexavalent chromium concentrations of 8.13 mg/kg at depths of 27 feet in the area of Old P-2 Pond (Northgate, 2010h-k). Potential source areas also include Ponds AP-1, AP-2, and AP-3 (LOUs 16 and 17), and Pond AP-4 (LOU 18). These Ponds and their associated transfer lines received chromium-laden process liquor. The Phase B soil investigation revealed hexavalent chromium concentrations of 8.13 mg/kg at a depth of 27 feet in the area of AP-3 Pond and 28.2 mg/kg at a depth of 39 feet in the area of AP-4 Pond (Northgate, 2010h-k).

Chromium in the environment exists predominately in two oxidation states: Cr(VI) and Cr(III). Cr(VI) is mobile in groundwater, acutely toxic, and carcinogenic, while Cr(III) is relatively immobile under most groundwater conditions and exhibits low toxicity (Richard and Bourg, 1991). At concentrations present at the Site, Cr(VI) will primarily exist as monomeric chromate (HCrO_4^- , CrO_4^{2-}) anions. However, at higher concentrations, such as those in the sodium chlorate process liquor, Cr(VI) exists as dimeric dichromate ($\text{Cr}_2\text{O}_7^{2-}$) anions. At the slightly alkaline pH conditions encountered at the Site, Cr(III) will readily precipitate to an insoluble chromium hydroxide ($\text{Cr}(\text{OH})_3$).

Cr(VI) anions are mobile in groundwater, but have been demonstrated to sorb to surface sites on iron oxyhydroxides (Leckie et al., 1984). The strength of adsorption of Cr(VI) anions is intermediate between those of strongly binding anions, such as phosphate and arsenate, and weakly binding anions like sulfate (Davis et al., 2000). It has been demonstrated that high concentrations of sulfate will reduce chromate adsorption, but this typically occurs under acidic conditions that are not typically observed at the Site (Leckie et al., 1984). Other naturally occurring anions such as bicarbonate and dissolved silica can also compete for adsorption sites (van Geen et al., 1994; Zachara et al., 1987). The high sulfate and bicarbonate concentrations on the Site should reduce the natural sorption of Cr(VI) onto mineral surfaces.

Cr(VI) remaining in vadose zone soil is not expected to significantly impact groundwater (Northgate, 2010c). Concentrations of Cr(VI) at the Site are expected to decrease over time due to the ongoing groundwater extraction, and by natural attenuation via sorption onto mineral surfaces and via reduction into insoluble Cr(III) hydroxides from reactions with organic carbon.

6.1.7 Magnesium

Total (unfiltered) magnesium was detected above the laboratory SQL in all 110 groundwater samples collected in the Shallow Zone (detection frequency of 100%), with 52 of the samples exceeding the RBGC of 207 mg/L (Table 2). Dissolved (filtered) magnesium was detected in all 21 groundwater samples collected in the Shallow Zone (detection frequency of 100%), with five samples exceeding the RBGC (Appendix G). The highest reported value in the shallow Zone was 895 mg/L at monitoring well M5A. Magnesium was detected in all eight groundwater samples collected in the Middle Zone (detection frequency of 100%) with none of the detected



values exceeding the RBGC (Table 3). The highest reported value in the Middle Zone was 111 mg/L at monitoring well M120.

Analysis of magnesium data from the Shallow Zone indicates elevated levels of magnesium along the western boundary of the Site with concentrations exceeding 500 mg/L (Plate 15). A potential source for this plume is magnesium-containing brine wastes that were discharged into unlined Former Wastewater Ponds 1 and 2 on the POSSM site (H+A, 2008a). A second plume with magnesium concentrations above 200 mg/L appears to originate north of Unit 6 (LOU 44) and be constrained by the barrier wall to the north. This magnesium plume is comingled with a sulfate plume, indicating that manganese production operations in Unit 6 may be a current and ongoing source of magnesium contamination. A third plume with concentrations exceeding 300 mg/L exists to the northwest of the Site and continues toward the Las Vegas Wash. A potential source for this plume is the historical magnesium-laden TIMET leach liquor waste stream that was discharged into unlined ponds (LAW Engineering, 1993).

Analysis of magnesium data from the Middle Zone indicates high levels to the northwest of the Site with a maximum concentration of 8,190 mg/L at well COH-1. Analysis of concentration data in the Deep Zone indicates brine-like levels of magnesium to the northwest of the Site, with a maximum concentration of 15,800 mg/L at well MCF-06A-R.

Magnesium is commonly found in groundwater as a result of leaching from rocks and soils. Magnesium was produced on the BMI site from 1942 to 1944 and magnesium-containing compounds have been used in Site production processes since 1945. Large quantities of magnesium-containing liquid wastes were discharged to the unlined Former Trade Effluent Ponds (LOU 1) and to the Upper and Lower BMI Ponds via the Beta Ditch (LOU 5). In addition to the liquid wastes, over 14,000 tons of magnesium-containing solid process waste (cell mud) was disposed in the BMI Landfill.

Potential onsite source areas for magnesium include the boron production area in Unit 5 (LOU 61). Magnesium sulfate has been generated as a byproduct of the elemental boron production process at the Site since 1972. Between 1972 and January 1976, magnesium-containing liquid process wastes were discharged to the BMI Ponds via the Beta Ditch. From October 1975 until 1983, magnesium-containing liquid wastes were discharged to Ponds S-1 (LOU 13) and P-1 (LOU 14), both of which had known releases due to liner failures. Another potential source of magnesium is the magnesium-containing cathode wash solution from the manganese production in Unit 6. The Unit 6 basement served as a sump to collect process liquor, spillage, and wash water, and leaked chemicals to groundwater as a result of cracks in the concrete floor. Remediation activities were undertaken in 1987 in the Unit 6 basement to remove the cracked concrete floor, followed by recontouring of the underlying soil and installation of a liner system (Kleinfelder, 1993).



Potential offsite sources that could lead to magnesium contamination of groundwater on the Site include the brine sludge waste stream from the chlor-alkali production facility on the POSSM site. This waste stream contained significant amounts of magnesium hydroxide, which was precipitated out of the brine prior to the chlor-alkali process. Prior to 1976, this waste stream was discharged to the Upper and Lower BMI Ponds via the Beta Ditch, and to the unlined Former Wastewater Ponds 1 and 2 (POSSM LOU 6) and Chlor-Alkali Ponds (H+A, 2008a). Additional sources that could lead to magnesium contamination of the overall BMI site include the historical TIMET leach liquor waste stream. Between 1951 until 1977, TIMET disposed of over 1.2 million tons of liquid process effluent with typical magnesium concentrations of 37,000 mg/L into unlined surface impoundments (LAW Engineering, 1993).

Magnesium in the environment exists in the Mg(II) oxidation state and is mobile in groundwater. Magnesium levels in groundwater are primarily controlled by carbonate reactions. Magnesium in shallow (surface to two feet below surface) vadose zone soil in two areas of the Site has been identified as a potential concern for ongoing leaching to groundwater (Northgate, 2010c). Provided this potential concern is adequately addressed, magnesium levels in the Shallow Zone should decrease over time through ongoing groundwater extraction.

6.1.8 Manganese

Total (unfiltered) manganese was detected above the laboratory SQL in 87 of 102 groundwater samples collected in the Shallow Zone (detection frequency of 85.3%), with 20 of those samples exceeding the RBGC of 511 µg/L (Table 2). The highest value in the Shallow Zone was 200,000 µg/L at monitoring well M29³. Total manganese was detected in seven of eight groundwater samples collected in the Middle Zone (detection frequency of 87.5%) with none of the detected values exceeding the RBGC (Table 3). The highest reported value in the Middle Zone was 11.9 µg/L at monitoring well TR2.

Dissolved (filtered) manganese was detected above the laboratory SQL in 18 of 21 groundwater samples collected in the Shallow Zone (detection frequency of 85.7%), with four of those samples exceeding the RBGC (Appendix G). The highest reported value of dissolved manganese in the Shallow Zone was 1,960 µg/L at monitoring well H11. Dissolved manganese was not analyzed in Middle Zone samples.

Analysis of total manganese in the Shallow Zone (Plate 16) shows what appears to be a plume with concentration levels exceeding 200,000 µg/L to the north of Unit 6 (LOU 44) and exceeding 49,000 µg/L in the area of the Former Eastern Leach Beds (LOU 34E). However, dissolved manganese (i.e., filtered samples) data shows a maximum concentration of only 987

³ The highest reported value was in well H-48 (at 399,000 µg/L), but data for this well are considered suspect due to unrepresentative geochemical conditions, possibly resulting from effects of the well's construction.



µg/L in the area of the Former Eastern Leach Beds (LOU 34E). This indicates that the total manganese results likely reflect chemical analysis of suspended manganese-containing precipitates and not dissolved manganese in solution. Graphs showing the relationship of dissolved versus total manganese in groundwater (as well as other metals) are provided in Appendix G.

Manganese is a naturally occurring metallic element commonly present in groundwater due to the weathering and leaching of manganese-bearing minerals and rocks into aquifers. Manganese dioxide has been produced at the Site since 1951, primarily for the manufacture of dry cell batteries (Kleinfelder, 1993). Manganese ore is roasted to increase the solubility of the manganese and then leached with sulfuric acid to produce a concentrated manganese sulfate solution at the manganese dioxide leach plant. The solution was then fed to the electrolytic cells in Unit 6 (LOU 44). Prior to 1986, chemicals in Unit 6 were known to have leaked into the groundwater through cracks in the concrete basement (Kleinfelder, 1993). The Phase B soil investigation revealed elevated manganese concentrations of 2,520 mg/kg at depths of 34 feet in the southern area of the Unit 6 (Northgate, 2010h-k).

Leachate from the manganese tailings pile and wastewater from the dewatering of manganese tailings were released onto onsite Leach Beds (LOU 24) where the manganese-containing leachate infiltrated into the soil and likely percolated into the groundwater. The Phase B soil investigation revealed manganese concentrations of 160,000 mg/kg at depths of 10 feet and at 2,000 mg/kg at depths of 51 feet in the area of the Leach Beds (Northgate, 2010h-k). Manganese tailings were disposed in the Historic Manganese Tailings Area (LOUs 34E, 34W). The Phase B soil investigation revealed manganese concentrations of 21,600 mg/kg at depths of 34 feet in the area of the Former Eastern Leach Beds (LOU 24) (Northgate, 2010h-k). Liquid wastes from the manganese process have historically been released to the S-1 Pond (LOU 13), P-1 Pond (LOU 14), and Mn-1 Pond (LOU 21). The Phase B soil investigation revealed no significant manganese contamination around any of the surface impoundments (Northgate, 2010h-k).

Manganese in soils and groundwater typically exists in the Mn(II) and Mn(IV) oxidation states. Mn(IV) is the predominate state in aerobic environments and tends to exist as insoluble oxyhydroxides (Scott et al., 2002). In neutral to slightly acidic groundwater with low oxygen levels, Mn(IV) can be reduced to Mn(II) via oxidation-reduction (redox) reactions that may be abiotic or microbially mediated. Reduction of Mn(IV) to Mn(II) in neutral to slightly alkaline groundwater can lead to the formation of insoluble manganese carbonates.

Manganese remaining in vadose zone soil has been identified as a potential concern for ongoing leaching to groundwater (Northgate, 2010c). Provided this potential concern is adequately addressed, dissolved manganese levels in Site groundwater are likely to remain at relatively low levels unless redox and pH conditions are perturbed from their current state. If reductive in-situ



bioremediation of perchlorate in the vadose zone is performed in areas with manganese-contaminated soil, as is currently being considered (Northgate, 2010), the local ORP and pH will be lowered, leading to reduction of insoluble Mn(IV) to soluble Mn(II). It is likely that Mn(II) released into groundwater will reoxidize to insoluble Mn(IV) as it leaves the reaction zone and mixes with groundwater under oxidizing conditions, based upon the apparent rapid attenuation of dissolved manganese at the Site.

6.1.9 Nitrate

Nitrate was detected above the laboratory SQL in 93 of 102 groundwater samples collected in the Shallow Zone (detection frequency of 91.2%), with 43 of those samples exceeding the RBGC of 10 mg/L (Table 2). The highest reported value in the Shallow Zone was 111 mg/L at monitoring well M110. Nitrate was detected in all eight groundwater samples collected in the Middle Zone (detection frequency of 100%), with none of the detected values exceeding the RBGC (Table 3). The highest reported value in the Middle Zone was 2.82 mg/L at monitoring well TR-8.

Analysis of nitrate concentration data from the Shallow Zone indicates a plume with concentration levels exceeding 100 mg/L in the vicinity of the AP Plant (Plate 17). This nitrate plume is co-located with the ammonia plume (Plate 7) and appears to be contained by the groundwater barrier wall to the north. A second plume with nitrate concentrations exceeding 200 mg/L exists to the northwest of the Site and continues to the Las Vegas Wash, where concentrations still exceed the RBGC of 10 mg/L. It is unclear whether this contamination is a historical nitrate plume from the Site that has been cut off by the barrier wall, is nitrate fertilizer contamination from the overlying community, or results from historical releases of nitrate-laden TIMET process effluent into unlined ponds (LAW Engineering, 1993). Analysis of nitrate concentration data from the Middle Zone shows no significant contamination on the Site.

Nitrate is normally present in groundwater as result of agriculture sources such as inorganic fertilizer and animal manure. Nitrates do not appear to have been produced at the Site or used as raw materials in any of the reported production processes. The presence of nitrate at the Site is likely due to the nitrification of ammonia and ammonium ions that have been released into the groundwater from ammonium perchlorate contamination.

No potential offsite sources of nitrate that could lead to contamination of groundwater on the Site were identified. Additional sources that could lead to nitrate contamination of the greater BMI site include the historical TIMET leach liquor waste stream. From 1951 until 1977, TIMET disposed of over 1.2 million tons of liquid process effluent into unlined ponds with typical nitrate concentrations of 20,000 mg/L (LAW Engineering, 1993).



Nitrates are highly soluble and mobile in groundwater as they do not tend to bind to mineral surfaces (Yates and Healy, 1975). The groundwater extraction systems will continue to remove nitrate mass from Shallow Zone groundwater, which will then be destroyed in the biological treatment plant. The transport and fate of nitrate in the Site groundwater will most likely be dominated by denitrification under reducing conditions (Puckett and Hughes, 2005).

6.1.10 Perchlorate

Perchlorate was detected above the laboratory SQL in 91 of 103 groundwater samples collected in the Shallow Zone (detection frequency of 88.3%), with 91 of the samples exceeding the RBGC (NDEP provisional limit) of 18 µg/L (Table 2). The highest reported value in the Shallow Zone was 2,870,000 µg/L at monitoring well IAR. Perchlorate was detected in five of eight groundwater samples collected in the Middle Zone (detection frequency of 62.5%), with four of those samples exceeding the RBGC (Table 3). The highest reported value in the Middle Zone was 1,910 µg/L at monitoring well M121.

Spatial analysis of perchlorate concentration data from the Shallow Zone indicates a large plume north of Units 4 and 5 (LOUs 43 and 61) that appears to be contained by the groundwater barrier wall to the north (Plate 18). The highest concentration upgradient to the barrier wall was 2,870,000 µg/L at well IAR. Between the barrier wall and the Las Vegas Wash, the maximum perchlorate concentration is 892,000 µg/L (M94) along the northern Site boundary. Concentrations continue to decrease northward towards the Wash with a maximum concentration of 18.4 µg/L at well MW-K6.

Perchlorate was manufactured at the Site from 1945 until approximately 1998 and recovery operations continued for several additional years. Sodium perchlorate was produced in Units 4 and 5 and was used primarily as feedstock for the production of ammonium perchlorate. Potential onsite sources of perchlorate include the Units 4 and 5 basements. These basements served as sumps to collect sodium chlorate and sodium perchlorate-laden process liquor, spillage, and wastewater. Deterioration and cracking of the concrete foundation led to the release of process liquor to underlying soils and groundwater (Kleinfelder, 1993). Operation of the electrolytic cells in Units 4 and 5 was discontinued in the late 1990s (ENSR, 2005).

From 1945 until 1976, process waste streams from the sodium perchlorate and ammonium perchlorate process were discharged to the BMI Ponds via the Beta Ditch (LOU 5). From 1976 until 1983, sodium perchlorate process liquids were sent to Ponds S-1 (LOU 13) and P-1 (LOU 14). Both of these ponds reported leaks. Potential source areas for ammonium perchlorate contamination include Ponds AP-1, AP-2, and AP-3 (LOUs 16 and 17). A leak from Pond AP-2 was reported in 1979 and the liner was replaced prior to 1980. By late 1983, frequent patching was required to mitigate leaks until the liners were replaced with double-liner systems. Other



potential sources include the area affected by the July 1990 fire (LOU 55), where water used to fight an ammonium perchlorate fire could have infiltrated into the groundwater. Additional potential onsite source areas include the AP Plant Area New D-1 Building Wash-Down (LOU 57), AP Plant Cooling Tower overflows, and reported leaks from AP Plant Transfer Lines to the Sodium Chlorate Process (LOU 58). The Phase B soil investigation revealed concentrations of perchlorate exceeding 1,200 mg/kg in soil at depths of 10 feet in the eastern area of the former Unit 4, 1,200 mg/kg at depths of 29 feet in the vicinity of the AP Tank Farm (LOU 53), 1,800 mg/kg at depths of 30 feet near Pond AP-1, and over 8,000 mg/kg at a depth of 30 feet adjacent to the AP Plant Area Old Building D-1 Wash down (LOU 56) (Northgate, 2010h-k). No potential offsite sources that could lead to perchlorate contamination of groundwater on the Site were identified. Perchlorate contamination from the former AMPAC site is a potential offsite source for the greater BMI site.

Perchlorate is a large anion with a relatively low diffuse charge. It is non-complexing, forms no insoluble minerals, and sorbs poorly to most solids. Sodium and ammonium perchlorate are highly soluble with solubilities of approximately 200 g/L at 20°C. Partition coefficients describing perchlorate sorption to geologic media are essentially zero. Because perchlorate sorbs so poorly to most geologic materials, in the absence of biodegradation, perchlorate plumes should move at roughly the same velocity as groundwater.

Significant perchlorate remains in Site vadose zone soil, and has been identified as presenting a potential ongoing source to groundwater through leaching (Northgate, 2010c; *Tronox/NDEP meeting minutes for February 5 and February 12, 2010*). Soil flushing and other remedial options are currently being considered as source control measures for this constituent (Northgate, 2010e). Provided the potential leaching concern is adequately addressed, perchlorate concentrations should continue to decline in Shallow Zone groundwater due to ongoing groundwater extraction.

6.1.11 Total Phosphorus

Total phosphorus was detected above the laboratory SQL in 34 of 102 groundwater samples collected in the Shallow Zone (detection frequency of 33.3%), with 13 of those samples exceeding the RBGC of 73 µg/L (Table 2). The highest reported value in the Shallow Zone was 9,320 µg/L at monitoring well MC3. Total phosphorus was detected in one sample in the Middle Zone, 51.6 µg/L at monitoring well TR-2, which did not exceed the RBGC (Table 3).

Spatial analysis of phosphorus in Shallow Zone groundwater indicates that there are elevated levels of phosphorus to the north of Unit 6 and a large phosphorus plume that originates on the POSSM site and continues most of the way to the Las Vegas Wash (Plate 19).



Significant amounts of phosphate have been introduced into the groundwater from onsite and offsite sources. Onsite sources include sodium hexametaphosphate-based manganese dioxide cathode wash solutions discharged to Pond C-1 (LOU 20) and Pond Mn-1 (LOU 21). State Industries (LOU 62) used phosphate chemicals in the production of hot water heaters. From 1970 until 1972, State Industries used the acid drain system (LOU 60) to dispose of phosphate-laden process waste. State Industries also operated two surface impoundments to hold process wastes. Wastes were pumped to these impoundments at the rate of 35,000 gallons/month and included spent sulfuric acid, borax, anhydrous sodium carbonate, and phosphates. Records indicate that both impoundments were in operation from approximately 1972 until 1988 and were known to have leaked on several occasions (Kleinfelder, 1993). Significant offsite sources of phosphate exist on the former Stauffer and Montrose facilities. Between 1960 and 1970, a portion of the phosphoric acid waste stream (20,000 tons) generated by as part of the thiophenol/parachlorothiophenol waste stream was discharged to the Former Leach Field and Phosphoric Acid Pond/Trenches (H+A, 2008a).

Phosphate generally attenuates in groundwater via adsorption on iron oxyhydroxides and by reacting with dissolved calcium to precipitate apatite (Geelhoed et al., 1997). Phosphate concentrations in Site groundwater are expected to decline over time as a result of these processes and ongoing groundwater extraction.

6.1.12 Strontium

Strontium was detected above the laboratory SQL in all 102 groundwater samples collected in the Shallow Zone (detection frequency of 100%), with six of the samples exceeding the RBGC of 21.9 mg/L (Table 2). The highest reported value in the Shallow Zone was 34.8 mg/L at monitoring well M126. Strontium was detected in eight groundwater samples in the Middle Zone (detection frequency of 100%), with none of the samples exceeding the RBGC (Table 3). The highest reported value in the Middle Zone was 3.7 mg/L at monitoring well M120.

Analysis of strontium data from the Shallow Zone (Plate 20) shows a plume with concentration levels exceeding 30 mg/L to the north of Units 4 and 5 (LOUs 43 and 61). The plume appears to be contained by the groundwater barrier wall to the north. A second plume of strontium exists on the western boundary of the Site and appears to be originating from the old BMI Landfill. A third plume with concentrations generally below the RBGC exists downgradient of the Site and appears to be a historical plume that was cut off by the construction of the groundwater barrier wall and treatment system. Analysis of strontium concentration data from the Middle Zone shows no significant strontium contamination on the Site, although elevated levels of strontium exist downgradient towards the Las Vegas Wash, with a maximum concentration of 15.1 mg/L at monitoring well COH-2. Analysis of strontium concentration data from the Deep Zone shows significant contamination with a maximum concentration of 61.7 mg/L at monitoring well MCF-18A.



Strontium is a naturally occurring element in rocks, soils, and the waters in contact with them, and is commonly found in groundwater as a result of leaching from evaporite deposits. Strontium carbonate was used at the Site as a raw material in the production of sodium chlorate (Kleinfelder, 1993). Potential source areas for strontium include the basements of Units 4 and 5, which served as sumps to collect strontium-containing sodium chlorate and sodium perchlorate-laden process liquor, spillage, and wastewater. Deterioration and cracking of the concrete foundation led to the release of process liquor to underlying soils and groundwater (Kleinfelder, 1993). Operation of the electrolytic cells in Units 4 and 5 was discontinued in the late 1990s, but the buildings and structures remain for future use (ENSR, 2005). The Phase B soil investigation revealed strontium concentrations of 2,280 mg/kg at depths of 34 feet in the northern area of Unit 5 (Northgate, 2010h-k).

From 1945 until 1975, strontium-containing sodium chlorate production process effluent was sluiced to the Upper and Lower BMI Ponds via the Beta Ditch (LOU 5). From 1975 until 1990, liquid process effluent was sent to the Old P-2 Pond (LOU 7), Old P-3 Pond (LOU 8), and New P-2 Pond (LOU 9). Both the P-2 and P-3 Ponds reported leaks including an unknown quantity of process solution on more than one occasion, as well as multiple liner failures (Kleinfelder, 1993). The Phase B soil investigation revealed strontium concentrations of 5,670 mg/kg at depths of 36 feet in the western area of P-3 Pond (Northgate, 2010h-k). Between 1975 and 1980, solid strontium-containing filter cake wastes were disposed in the unlined BMI Landfill. From 1980 until 1983, solid filter cake waste was disposed in the On-Site Hazardous Waste Landfill (LOU 10). Following 1982, solid filter cake waste was disposed offsite at the U.S. Ecology facility in Beatty, Nevada.

No potential offsite sources were identified that would lead to strontium contamination of the groundwater at the Site or on the greater BMI site. No ongoing source of strontium to Site groundwater has been identified (Northgate, 2010c). Strontium in solution is expected to be predominantly present as the uncomplexed Sr^{2+} ion. Strontium exists in nature only in the +2 oxidation state and has a similar ionic radius to that of calcium. As such, it behaves very similar to calcium in solution and substitutes for calcium in a variety of minerals. In environments with a pH greater than 9 and dominated by carbonates, coprecipitation with CaCO_3 and/or precipitation as SrCO_3 may become an increasingly important mechanism controlling strontium removal from solution (Lefevre et al., 1993). Strontium in Site groundwater is expected to decrease over time in response to the ongoing groundwater extraction.

6.1.13 Sulfate

Sulfate was detected above the laboratory SQL in all 102 groundwater samples collected in the Shallow Zone (detection frequency of 100%), with 101 of the samples exceeding the RBGC of 250 mg/L (Table 2). The highest reported value in the Shallow Zone was 21,300 mg/L at



monitoring well PC-37. Sulfate was detected in all eight groundwater samples collected in the Middle Zone (detection frequency of 100%), with six of the samples exceeding the RBGC (Table 3). The highest reported value in the Middle Zone was 1,420 mg/L at monitoring well M121.

Analysis of sulfate concentration data from the Shallow Zone shows several areas at the Site with levels exceeding 2,000 mg/L (Plate 21). The first area with elevated concentrations is downgradient of the former State Industries (LOU 62) production facility. The second is to the north of Unit 6 (LOU 44) and appears to extend to the Current and Historical Leach Plant Area Manganese Ore Piles (LOU 47). A sulfate plume with levels exceeding 2,000 mg/L exists on the western boundary of the Site and originates from a source on the POSSM site. A third plume with sulfate levels exceeding 2,500 mg/L exists to the northwest of the Site and extends towards the Las Vegas Wash. The origin of this plume is unclear, but it could be a historical plume of pre-1976 releases of sulfate-laden process waste on the POSSM, Tronox, and TIMET sites. Analysis of Phase B sulfate concentration data from the Middle Zone shows only one elevated concentration of 3,400 mg/L along the western boundary of the Site, but there is significant contamination northwest of the Site that extends all the way to the Las Vegas Wash, with sulfate concentrations in excess of 50,000 mg/L. Analysis of sulfate concentration levels in the Deep Zone shows extensive contamination from the northwest of the Site with concentrations exceeding 80,000 mg/L.

Sulfate is a naturally occurring element in rocks, soils, and the waters in contact with them, and is commonly found in groundwater as a result of the dissolution of gypsum deposits and oxidation of pyrites. Sulfates have been extensively used on the Site in the production of chlorates, manganese, and boron products (Kleinfelder, 1993). Significant sources also include the Leach Beds and Manganese Tailings Area (LOU 24) and Current and Historical Leach Plant Area Manganese Ore Piles (LOU 47), where leachate from manganese purification percolated into unlined leach beds, as well as tank releases from the Leach Plant Anolyte Tanks (LOU 48) and the Current and Historical Leach Plant Area Leach Tanks (LOU 49). The Phase B soil investigation revealed concentrations of sulfate exceeding 20,000 mg/kg at depths of 35 feet in the vicinity of the Current and Historical Leach Plant Area Manganese Ore Piles (Northgate, 2010h-k). Source areas for sulfate also include Unit 6 (LOU 44), where manganese is produced from electrolytic reduction of manganese sulfate solutions and magnesium sulfate is generated as a by-product of the elemental boron production process.

Prior to 1986, sulfate-containing process solutions were known to have been released into the soil and groundwater through cracks in the concrete basement of Unit 6. Prior to 1976, sulfate-containing wastes were sluiced to the Upper and Lower BMI ponds through the Beta Ditch (LOU 5). After 1976, sulfate-containing wastes were sent to the following Ponds: S-1 (LOU 13),



P-1 (LOU 14), AP-1 through AP-4 (LOUs 16, 17, 18), and Mn-1 (LOU 21). Ponds S-1 and P-1 are known to have multiple releases from liner failures (Kleinfelder, 1993).

State Industries Inc. (LOU 62) leased portions of the Site approximately 1,200 feet south of Units 2 and 3 from 1969 until 1988 for the manufacture of hot water heaters. State Industries used sulfate (sulfuric acid) in its production process and discharged approximately 34,000 gallons annually in its process waste stream. Prior to 1974, State Industries used the Acid Drain System (LOU 60) to convey process wastes to the Beta Ditch. After 1974, State Industries operated two surface impoundments for evaporation of process wastes. These surface impoundments are known to have leaked on three separate occasions (Kleinfelder, 1993). The Phase B soil investigation revealed sulfate levels exceeding 20,000 mg/kg at depths of 55 feet in the eastern area of the former State Industries facility (Northgate, 2010h-k). These high concentrations are indicative of past releases of sulfate-containing process waste that infiltrated into the deep soil and potentially percolated into the groundwater.

Potential offsite sources that could lead to sulfate contamination of groundwater on the Site include the sulfate slurry waste stream from the chlor-alkali production facility on the POSSM site. Prior to 1976, this waste stream was discharged to the Upper and Lower BMI Ponds via the Beta Ditch and to the unlined Former Wastewater Ponds 1 and 2 (H+A, 2008a). Additional sources that could lead to sulfate contamination of the greater BMI site include the historical TIMET leach liquor and caustic waste streams. From 1951 until 1977, TIMET disposed of over 5.6 million tons of liquid process effluent with typical sulfate concentrations exceeding 100,000 mg/L into unlined ponds (LAW Engineering, 1993).

Sulfates are typically highly soluble and mobile in groundwater. Sulfates form surface complexes on iron oxyhydroxides, which can lead to some natural attenuation of sulfate in the absence of competing ions such as phosphate or arsenate (Geelhoed et al., 1997). Sulfate concentrations in Shallow Zone groundwater are expected to decline in response to ongoing groundwater extraction; however, concentrations will likely remain above the RBGC due to natural sources (USGS, 1998).

6.1.14 Total Dissolved Solids

TDS was measured above the laboratory SQL in all 102 groundwater samples collected in the Shallow Zone, and all samples exceeded the RBGC of 500 mg/L (Table 2). The highest reported value in the Shallow Zone was 25,900 mg/L at monitoring well MC3. TDS exceeded the RBGC in all eight groundwater samples collected in the Middle Zone (Table 3). The highest reported value in the Middle Zone was 2,320 mg/L at monitoring well M121.



Spatial analysis of TDS concentration data from the Shallow Zone indicates a plume with TDS concentrations exceeding 15,000 mg/L originating from sources around Units 4 and 5 (LOUs 43 and 61) and appears to be constrained by the groundwater barrier wall to the north (Plate 22). The chemical composition of this TDS plume is dominated by perchlorate and chlorate. A second TDS plume with concentrations in exceeding 20,000 mg/L exists along the western boundary of the Tronox Site, originating from sources on the POSSM site. A third TDS plume with concentrations exceeding 15,000 mg/L exists east of the Site and appears to be from historical discharges on the TIMET site. The maximum TDS concentration between the barrier wall and the Las Vegas Wash is 13,600 mg/L (PC40). The TDS concentrations decrease northwards and are 3,500 mg/L (PC-96) at the Las Vegas Wash.

Analysis of TDS concentration data from the Middle Zone indicate high TDS levels of 180,000 mg/L (MCF-05) to the northwest of the Site and 89,900 mg/L (COH-2) at the Las Vegas Wash. TDS data from wells in the Deep Zone also indicate high TDS concentrations northwest of the Site with a maximum concentration of 178,000 mg/L (MCF-06A-R). It is not clear whether these very elevated TDS levels are a result of historical contamination or due to dissolution of natural evaporite deposits.

TDS is a measure of the combined inorganic and organic solids contained in a liquid in molecular, ionized, or suspended colloidal form. The most common chemical constituents in groundwater are calcium, sodium, potassium, magnesium, chloride, sulfate, carbonate, bicarbonate, and nitrate, which are a significant contributor to measured TDS. Groundwater at the Site is naturally elevated in TDS. Groundwater in the shallow aquifer of the Las Vegas Valley contains high levels of dissolved solids (generally 3,000 to 10,000 mg/L). These high levels of dissolved solids result from enrichment through evaporation, transpiration, as well as dissolution of naturally occurring evaporite deposits in the vadose zone (Maxey and Jameson, 1948; Kaufmann, 1977; Plume, 1989; Morgan and Dettinger, 1996; USGS, 1998). Extensive TDS contamination of groundwater at the Site has occurred since 1945. Magnesium metal was produced on the BMI site from 1942 to 1944. Waste streams with high levels of TDS were disposed in the Former Trade Effluent Ponds (LOU 1), to the Upper and Lower BMI Ponds through the Beta Ditch (LOU 5), and to the Caustic Evaporations Ponds.

Prior to 1976, combined effluents of the chlorate, perchlorate, and boron waste streams were discharged to the Upper and Lower BMI Ponds via the Beta Ditch, containing high levels of TDS. Following 1976, process effluent with high TDS was sent to the Old P-2 Pond (LOU 7), the Old P-3 Pond (LOU 8), the New P-2 Pond (LOU 9), the S-1 Pond (LOU 13), the P-1 Pond (LOU 14), Ponds AP-1, AP-2 and AP-3 (LOUs 16 and 17), Pond AP-4 (LOU 18), the AP-5 Pond (LOU 19), the C-1 Pond (LOU 20), and the Mn-1 Pond (LOU 21). Several of these ponds have reported leaks of unknown quantities of chemicals as well as numerous liner failures



(Kleinfelder, 1993). Significant amounts of manganese tailings and residual leach liquor were also disposed in onsite Leach Beds (LOU 24).

Other potential onsite sources of TDS include the Units 4 and 5 basements (LOUs 43 and 61), as well as the Unit 6 basement (LOU 44). The basements of these process buildings served as sumps to collect process liquor, spillage, and wash water and leaked chemicals to groundwater as a result of cracks in the concrete floors. Remediation activities were undertaken in 1983 and 1984 to seal and repair the Units 4 and 5 basement floors. Operation of the sodium chlorate and sodium perchlorate electrolytic cells has since been discontinued. Remediation activities were undertaken in 1987 in the Unit 6 basement to remove the cracked concrete floor, followed by recontouring of the underlying soil and installation of a liner system (Kleinfelder, 1993).

Potential offsite sources of elevated TDS in groundwater at the Site and the greater BMI site include historical discharges of sodium hypochlorite solution, phosphoric acid, thiophenol aqueous waste, imidan-trithion aqueous waste, and brine sludge to unlined ponds on the POSSM site and to the Upper and Lower BMI Ponds via the Beta Ditch. Potential offsite sources for TDS contamination of the greater BMI site include historical process waste streams discharged by TIMET into onsite unlined ponds, as well as to the Upper and Lower BMI Ponds via the Beta Ditch (LAW Engineering, 1993).

TDS levels in the Shallow Zone may decrease locally over time in response to ongoing groundwater extraction of water with elevated TDS. TDS will likely remain above the RBGC due to naturally occurring high levels of TDS in the Shallow Zone (Maxey and Jameson, 1948; Kaufmann, 1977; Plume, 1989; Morgan and Dettinger, 1996; USGS, 1998).

6.1.15 Uranium

Total (unfiltered) uranium was detected above the laboratory SQL in 100 of 102 groundwater samples collected in the Shallow Zone (detection frequency of 98%), with 62 of those samples exceeding the RBGC of 30 µg/L (Table 2). Dissolved (filtered) uranium was detected above the laboratory SQL in 19 of 21 groundwater samples collected in the Shallow Zone (detection frequency of 90.5%), with seven of those samples exceeding the RBGC (Appendix G). The highest reported value in the Shallow Zone was 145 µg/L at monitoring well M96. Uranium was detected in all eight groundwater samples collected in the Middle Zone, with one value exceeding the RBGC (Table 3). The highest reported value in the Middle Zone was 47.4 µg/L at monitoring well M120.

Low concentrations of uranium are common in groundwater as a result of leaching from rocks and soils. Higher levels of uranium can exist in groundwater from leaching of naturally-occurring ore deposits or uranium mill tailings. No potential onsite or offsite anthropogenic



sources were identified that could lead to uranium contamination of groundwater at the Site (Plate 23).

The fate and transport of uranium is somewhat complex (U.S. EPA, 1999). In essentially all geologic environments, U(IV) and U(VI) are the most important oxidation states of uranium. U(VI) species predominate in oxidizing environments and readily hydrolyze to form uranyl (UO_2^{2+}) ions. In groundwater with low TDS, dissolved uranyl concentrations will likely be controlled by cation exchange and adsorption processes. The uranyl ion and its complexes adsorb onto clays (Chisholm-Brause et al., 1994), and oxides (Hsi and Langmuir, 1985; Waite et al., 1994). Uranium sorption to iron oxide minerals and smectite clay has been shown to be extensive in the absence of dissolved carbonate (Ames et al., 1982).

As the TDS of the groundwater increases, other ions, notably Ca^{2+} , Mg^{2+} , and K^+ , will compete for surface exchange sites and displace the uranyl ion from mineral surfaces, thereby forcing it into solution. Not only will other cations dominate over the uranyl ion in competition for exchange sites, but the presence of anions, such as carbonate, further lowers the sorption of the uranyl ion while increasing the total amount of uranium in solution (Yeh and Tripathi, 1991). This is because uranyl ions form negatively-charged uranyl carbonate ($\text{UO}_2(\text{CO}_3)^{2-}$, for instance) complexes in the presence of carbonate at pH values greater than 5. These large anionic complexes are mobile in groundwater because most rocks and soils have a negative surface charge. The uranyl ion can also form complexes with phosphate (Sandino and Bruno, 1992) when phosphate levels exceed those of carbonate. The uranyl ion can also form complexes with sulfate and chloride, but their stability is considerably less than those of the carbonate and phosphate complexes (Langmuir, 1978; Wanner and Forest, 1992). For all of these reasons, the uranyl ion is particularly mobile in groundwater with high TDS. Recent work has shown that Ca-UO₂-CO₃ ternary complexes predominate in water with high concentrations of calcium and bicarbonate, similar to those observed at the Site. These ternary complexes are resistant to bacterial reduction (Brooks et al., 2003; Neiss et al., 2007) and show reduced sorption to natural sediments (Stewart et al., 2010).

U(IV) species dominate in reducing environments and tend to hydrolyze and form strong hydrolytic complexes that form sparingly soluble precipitates that commonly control U(IV) concentrations in groundwater. Near a uranium source, or in reduced environments, these processes tend to become increasingly important and several (co)precipitates may form depending on the environmental conditions (Falck, 1991; Frondel, 1958). Reducing conditions may exist in deep aquifers, marsh areas, or engineered barriers that may cause U(IV) to precipitate.



Uranium levels in the Shallow Zone are likely to decrease as the bicarbonate and calcium concentrations decrease over time.

6.1.16 Other Inorganic Constituents

The distribution and potential sources of bicarbonate, calcium, potassium, and sodium in shallow groundwater are discussed in the following subsections. Although there are no chemical-specific RBGCs for these constituents, they are significant components of TDS in Site groundwater.

6.1.16.1 Bicarbonate

Bicarbonate was detected above the laboratory SQL in all of the groundwater samples collected in the Shallow Zone, with a maximum value of 839 mg/L at monitoring well MC3⁴ (Table 2, Plate 24). Bicarbonate was detected in all of the groundwater samples collected in the Middle Zone, at a maximum value of 888 mg/L detected at monitoring well TR2 (Table 3).

Bicarbonate is a naturally occurring complex of carbon in the environment and is common in rocks, soils, and the waters in contact with them. Bicarbonates and carbonates have been used as raw materials on the Site, and from 1945 until 1976 were extensively released into process waste streams that were disposed in the Former Trade Effluent Ponds (LOU 2), the Lower and Upper BMI Ponds via the Beta Ditch, and unlined ponds on the POSSM and TIMET sites (H+A, 2008a; LAW Engineering, 1993).

6.1.16.2 Calcium

Calcium was detected above the laboratory SQL in all of the groundwater samples collected in the Shallow Zone, with a maximum value of 1,260 mg/L at monitoring well M126 (Table 2, Plate 25). Calcium was detected in all of the groundwater samples collected in the Middle Zone, with a maximum value of 1,200 mg/L detected at monitoring well M121 (Table 3).

Calcium is a naturally occurring element in the environment and is common in rocks, soils, and the waters in contact with them. Calcium-containing compounds have been used as raw materials on the Site, and from 1945 until 1976 were extensively released into process waste streams that were disposed of the Former Trade Effluent Ponds (LOU 1), the Lower and Upper BMI Ponds via the Beta Ditch, and unlined ponds on the POSSM and TIMET sites (H+A, 2008a; LAW Engineering, 1993).

⁴ The highest reported value is 1,530 mg/L at well I-B. This is likely a laboratory error because the bicarbonate concentration, which should be the same as alkalinity, is 10 times the alkalinity value of 153 mg/L.



6.1.16.3 Potassium

Potassium was detected above the laboratory SQL in all of the groundwater samples collected in the Shallow Zone, with a maximum value of 71.4 mg/L at monitoring well MC3 (Table 2).

Potassium was detected in all of the groundwater samples collected in the Middle Zone with a maximum value of 14.7 mg/L at monitoring well M121 (Table 3).

Analysis of potassium concentrations in the Shallow Zone indicates a plume with levels of exceeding 50 mg/L that appears to originate from Unit 4 (LOU 43) where potassium chlorate solutions have been released into groundwater via cracks in the concrete basement floor (Plate 26). Elevated levels of potassium (43.7 mg/L at well M29) exist to the north of Unit 6 (LOU 44), indicating the possibility of ongoing release of potassium-containing process solutions. Elevated potassium levels are also detected along the western boundary of the Site from a potassium plume with concentrations exceeding 50 mg/L originating on the POSSM site. A third plume with concentrations exceeding 30 mg/L originates on the TIMET site and continues to the Las Vegas Wash, where potassium exceeds 100 mg/L (MW-13).

Analysis of concentrations in the Middle Zone indicates extensive contamination to the northeast of the Site, with a maximum potassium concentration of 16,300 mg/L at well MCF-16B.

Analysis of concentrations in the Deep Zone indicates extensive contamination to the northeast of the Site, with a maximum potassium concentration of 16,500 mg/L at well MCF-16A. It is unclear as to whether these very high potassium levels are a result of historical contamination or due to dissolution of evaporite deposits.

Potassium is a naturally occurring element in the environment and is common in rocks, soils, and the waters in contact with them. Potassium-containing compounds have been used as raw materials at the Site, and from 1945 until 1976 were extensively released into process waste streams that were disposed in the Former Trade Effluent Ponds (LOU 1), the Lower and Upper BMI Ponds via the Beta Ditch, and unlined ponds on the POSSM and TIMET sites (H+A, 2008a; LAW Engineering, 1993). Additional potential onsite sources of potassium include the Unit 4 basement (LOU 43) and Unit 6 basement (LOU 44). Unit 4 was used for the production of potassium chlorate and Unit 6 generated potassium phosphate cathode wash solutions. The basements of these process buildings served as sumps to collect process liquor, spillage, and wash water, and leaked chemicals to groundwater as a result of cracks in the concrete floors. Remediation activities were undertaken in 1983 and 1984 to seal and repair the Unit 4 basement. Operation of the potassium chlorate electrolytic cells in Unit 4 has since been discontinued. Remediation activities were undertaken in 1987 in the Unit 6 basement to remove the cracked concrete floor, followed by recontouring of the underlying soil and installation of a liner system (Kleinfelder, 1993).



Potassium levels in the Shallow Zone should decrease over time in response to ongoing groundwater extraction and diluting processes.

6.1.16.4 Sodium

Sodium was detected above the laboratory SQL in all of the groundwater samples collected in the Shallow Zone, with a maximum value of 8,480 mg/L at monitoring well MC3 (Table 2). Sodium was detected in all of the groundwater samples collected in the Middle Zone, with a maximum value of 387 mg/L detected at monitoring well M121 (Table 3).

Analysis of concentrations in the Shallow Zone shows a plume with levels of sodium exceeding 2,000 mg/L that appears to originate from Units 4 and 5 (LOUs 43 and 61), where sodium chlorate and sodium perchlorate solutions have been released into groundwater via cracks in the concrete basement floors (Plate 27). Elevated levels of sodium along the western boundary of the Site originate from a plume with sodium concentrations exceeding 2,000 mg/L on the POSSM site. A third plume with concentrations exceeding 2,000 mg/L originates on the TIMET site and continues to the Las Vegas Wash where sodium levels exceed 700 mg/L (PC94).

Analysis of concentrations in the Middle Zone indicates extensive contamination to the northeast of the Site, with a maximum sodium concentration of 19,500 mg/L at well MCF-05. Analysis of concentrations in the Deep Zone indicates extensive contamination to the northeast of the Site, with a maximum sodium concentration of 58,900 mg/L at well MCF-18A. It is unclear as to whether these very high sodium levels are a result of historical contamination or due to dissolution of evaporite deposits.

Sodium occurs naturally in the environment and is common in rocks, soils, and the waters in contact with them. Sodium-containing compounds have been used as raw materials on the Site, and from 1945 until 1976 were extensively released into process waste streams that were disposed in the Former Trade Effluent Ponds (LOU 1), the Lower and Upper BMI Ponds via the Beta Ditch, and unlined ponds on the POSSM and TIMET sites (H+A, 2008a; LAW Engineering, 1993). Additional potential onsite sources of sodium include the Units 4 and 5 basements (LOUs 43 and 61). Units 4 and 5 were used for the production of sodium chlorate and sodium perchlorate. The basements of these process buildings served as sumps to collect process liquor, spillage, and wash water, and leaked chemicals to groundwater as a result of cracks in the concrete floors. Remediation activities were undertaken in 1983 and 1984 to seal and repair the basement floors. Operation of the sodium chlorate and sodium perchlorate electrolytic cells in Units 4 and 5 has since been discontinued.

Sodium levels in the Shallow Zone should decrease over time in response to ongoing groundwater extraction and diluting processes.



6.2 Organic Compounds

6.2.1 Alpha-BHC

Alpha-BHC was detected above the laboratory SQL in 30 of the 102 Shallow Zone samples collected during Phase B activities (Table 4). Alpha-BHC was not detected in any Middle Zone samples (Table 5). Alpha-BHC was detected above the RBGC of 0.0107 $\mu\text{g/L}$ in wells AABW02, CLD1R, H28A, H38, H49A, MC3, MC45, MC53, MC62, MC65, MC66, MC94, MC97, M5A, M19, M22A, M23, M48, M57A, M61, M65, M68, M88, M96, M125, M127, M130, PC40, and TR-6 (Plate 28). The highest concentration sample was collected at well M127 (41 $\mu\text{g/L}$). Although they were not retained as COIs due to the low number of detected samples exceeding the RBGC, beta-BHC was also detected above the RBGC of 0.0374 $\mu\text{g/L}$ in wells H38, MC3MC45, MC53, MC62, MC94, MC97, and M130, and gamma-BHC was detected above the RBGC of 0.2 $\mu\text{g/L}$ in wells H38, MC62, and PC40. Delta-BHC, which does not have an action level, was also detected in several wells where alpha-BHC was detected: wells AABW02, H28A, H49A, MC45, MC53, MC62, MC65, MC94, MC97, M5A, M19, M22A, M96, M127, and M130 PC40. Except for well M130, which is located on the eastern Site boundary adjacent to the TIMET facility, all of these wells are near the western edge of the Site, downgradient of the POSSM property.

Based on the concentrations and distribution of alpha-, beta-, and gamma-BHC in groundwater, it appears these chemicals occur at the Site via groundwater migrating from the west. Comparing the lateral and vertical distribution of OCPs detected in soil, including soil concentrations that exceed leaching-based Site-specific levels (LSSLs; Northgate, 2010c; *Tronox/NDEP meeting minutes for February 5 and February 12, 2010*), minimal, yet potential, onsite sources for alpha-BHC include the former Beta Ditch (LOU 5), Trade Effluent Settling Ponds (LOU 1), and Hardesty Chemical Company (LOU 4). However, the distribution of beta-BHC in shallow soil is indicative of Site-wide dispersion, perhaps due to wind-blown material containing OCPs produced by the various BMI complex companies operating west of the Tronox Site (discussed further below). There does not appear to be a strong spatial correlation between OCPs in Site soil and the same compounds in groundwater.

No onsite sources of alpha-BHC have been identified except the potential sources noted above. Potential offsite sources for alpha-BHC include the POSSM properties. Stauffer produced agricultural chemical products from 1946 through 1984, including lindane (gamma-BHC) from 1946 through 1958. Historic correspondence notes the burial of 200,000 cubic yards of alpha- and beta-BHC on the Stauffer or BMI property between 1946 and 1958 (Stauffer, 1987). This was most likely waste from the production of gamma-BHC, and the same material Stauffer referred to as “BHC cake”. BHC cake was also stockpiled in three areas of the former Stauffer facility. These stockpiles were eventually consolidated into “BHC Cake Pile 3” and capped



under 1-foot of clay in 1980. From 1945 through 1975, waste effluent from the Stauffer operations and the Montrose facilities, as well as storm water runoff from the two properties, was discharged to the sewer system (H+A, 2008a). Stauffer constructed an asphalt cap over the sites of the former lindane plant and BHC Cake Piles 1 and 2 in 2003-2004. Alpha-, beta-, delta- and gamma-BHC are detected in the vadose zone and in the Shallow and Middle Zones beneath the POSSM properties (H+A, 2008a; H+A, 2010).

There are eight isomers of the synthetic chemical benzene hexachloride (BHC), also called hexachlorocyclohexane. Only the alpha, beta, delta, and gamma isomers have commercial significance. Technical-grade BHC, a mixture of several isomers, was historically used as an insecticide in the U.S. Gamma-BHC is commonly distilled from technical-grade BHC into a 99% pure form (Anderson et al., 2007). Gamma-BHC, often referred to as lindane, continues to be used as an insecticide on fruit, vegetables, and forest crops, and is also available as a lotion, cream, or shampoo to treat lice and scabies. It is a white solid that may evaporate into the air or become attached to small particles of soil and dust. Lindane has not been produced in the U.S. since 1976, but continues to be imported for regulated use (ATSDR, 2005a).

BHC isomers have relatively low solubilities in water and are denser than water. Accordingly, they are considered DNAPLs, and when released into groundwater, migrate downward, leaving residual DNAPL in soil pore spaces (Anderson et al., 2007). Estimated retardation factors for alpha-BHC range from 3.5 to 22.5, with a similar range reported for beta- and gamma-BHC (Anderson et al., 2007). BHC isomers persist in soils in a wide variety of climates (Singh et al., 2000). Based on laboratory soil column leaching studies that used soils of both high and low organic carbon content, alpha- and gamma-BHC have low mobility in soils and adsorption to soil particulates is generally a more important partitioning process than leaching to groundwater, but not to the extent that leaching to groundwater is not possible (see references in ATSDR, 2005a). The presence of BHC in soil may inhibit both oxidation and reduction reactions and inhibitory or toxic to certain populations of bacteria. However, there appear to be a number of microorganisms that are capable of biodegrading BHC isomers via dehalogenation, dehydrohalogenation, isomerization, and oxidation (see references in ATSDR, 2005a and Singh et al., 2000). The U.S. EPA has classified alpha-BHC as a probable human carcinogen, beta-BHC as a possible human carcinogen, and gamma-BHC as having suggestive evidence of carcinogenicity, but not sufficient evidence to assess human carcinogenic potential (ATSDR, 2005a).

6.2.2 Benzene

Benzene was detected above the laboratory SQL in 16 of the 102 samples collected from the Shallow Zone during Phase B activities (Table 4). Benzene was not detected in any Middle



Zone samples (Table 5). Benzene was detected above the RBGC of 5 µg/L in several wells near the western edge of the Site, downgradient of the POSSM property: AABW02, H38, MC3, MC62, M5A, M123, M125, M126, M127, MW16, and TR-6 (Plate 29). The highest concentrations were detected at wells M123 (24,000 µg/L) and H38 (48,000 µg/L), which is a POSSM well located west of the Site boundary.

Based on the concentrations and distribution of benzene in groundwater, it appears that benzene is migrating beneath the Site via groundwater migration from the west. Concentrations of benzene in soil above the BCL were also detected along the western Site boundary, at depths between 30 and 40 feet bgs (Northgate, 2010h-k; *Tronox/NDEP meeting minutes for February 5 and February 12, 2010*). There does not appear to be a correlation between benzene in groundwater and the location of the former Hardesty Chemical site. Benzene levels detected in Site soil are not indicative of a potential ongoing concern for leaching to groundwater (Northgate, 2010c; *Tronox/NDEP meeting minutes for February 5 and February 12, 2010*).

The only identified potential onsite source for benzene is the former Hardesty Chemical site (LOU 4). Hardesty Chemical Company operated a chemical plant within electrolysis Building 2 and the adjacent chlorination building and operated from 1945 through 1949 (BRC, 2007). The company produced chlorobenzene, 1,2-dichlorobenzene, and 1,4-dichlorobenzene, all of which are manufactured through the chlorination of benzene (Kleinfelder, 1993).

Offsite sources of benzene include the POSSM properties. The former Montrose facility produced chlorobenzene and polychlorinated benzenes from 1947 through 1983 (H+A, 2008a). Benzene was used as a raw material for the manufacturing process. A 540,000-gallon above-ground storage tank for benzene occupied the facility near the former plant site. A 1966 release from a railcar loading operation was documented for the benzene tank, but no spill volumes are available. Waste streams from the Montrose site included impurities of benzene, as well as chlorobenzene, carbon tetrachloride, chloroform, and several other contaminants (see references in H+A, 2008a). There were two 40,000-gallon underground storage tanks for benzene at the former Stauffer facility. A 30,000-gallon leak was documented for one of the tanks in 1976. Both tanks were later closed by filling with inert materials (see references in H+A, 2008a).

Benzene is detected in the vadose zone (in soil and soil gas), the alluvial aquifer (Shallow Zone), and the Middle Zone beneath the POSSM properties (H+A; 2008a, 2010). Increases in benzene concentrations were observed in Middle Zone groundwater samples in the vicinity of well MC-MW-18 in 2009 compared to previous sampling events. In 2009, benzene was detected at a dissolved concentration of 43,000 µg/L in well MC-MW-18. Benzene was also detected in mixed DNAPL collected from the well at a concentration of 16,000,000 µg/kg, or 1.6% (H+A, 2010).



Benzene concentrations in groundwater downgradient of the POSSM source areas are being reduced by the Montrose extraction well field and air stripping system in Parcel E., and elevated concentrations in groundwater are not detected beyond the downgradient Site boundary. Benzene biodegradation is expected to occur fairly readily under most aerobic conditions (Aronson et al., 1999), and can be successfully oxidized to carbon dioxide in the presence of certain inorganic ions (Lovley et al., 1996). Benzene is typically considered recalcitrant under anaerobic groundwater conditions. It is ubiquitous in the atmosphere, originating from tailpipe emissions, tobacco smoke, and volatilization from subsurface releases of industrial discharges, landfill leachate, and gasoline UST leaks, as well as natural sources such as oil seeps and forest fires. Benzene rapidly volatilizes from groundwater or soil into air, where it has a short half-life of a few hours to a few days. Benzene is a human carcinogen (ATSDR, 2007).

6.2.3 Chlorobenzene

Chlorobenzene was detected above the laboratory SQL in 24 of the 102 samples collected from the Shallow Zone during Phase B activities (Table 4). Chlorobenzene was not detected in any Middle Zone samples (Table 5). Chlorobenzene was detected above the RBGC of 100 µg/L in nearly the same group of wells where benzene was detected near the western edge of the Site, downgradient of the POSSM property: AABW02, H28A, H38, MC3, MC62, M5A, M123, M125, M126, M127, MW16, and TR-6 (Plate 30). The highest concentrations were detected at wells M123 (46,000 µg/L), M125 (10,000 µg/L), and H38 (43,000 µg/L), which is a POSSM well located west of the Site boundary.

Based on the concentrations and distribution of chlorobenzene in groundwater, it appears the chemical is migrating beneath the Site via groundwater migration from the west. Offsite sources of chlorobenzene include the POSSM properties. The former Montrose facility produced chlorobenzene and polychlorinated benzenes from 1947 through 1983 (H+A, 2008a). Waste streams from the Montrose site included impurities of chlorobenzene, as well as carbon tetrachloride, chloroform, benzene, and several other contaminants (see references in H+A, 2008a). Chlorobenzene is detected in the vadose zone (in soil and soil gas), the alluvial aquifer (Shallow Zone), and the Middle Zone beneath the POSSM properties (H+A; 2008a, 2010). In 2009, chlorobenzene was detected at a dissolved concentration of 430,000 µg/L in well MC-MW-18. Chlorobenzene was also detected in mixed DNAPL collected from the well at a concentration of 620,000,000 µg/kg, or 62% (H+A, 2010).

The only identified potential onsite source for chlorobenzene is the former Hardesty Chemical Site (LOU 4). Hardesty Chemical Company operated a chemical plant within electrolysis Building 2 and the adjacent chlorination building and operated from 1945 through 1949 (BRC, 2007). The company produced synthetic detergents, muriatic acid, chlorobenzene



(monochlorobenzene, benzene chloride), 1,2-dichlorobenzene (orthodichlorobenzene), 1,4-dichlorobenzene (paradichlorobenzene), DDT, and sodium arsenite solution (ENSR, 2005). There is no apparent correlation between chlorobenzene in groundwater and the location of the former Hardesty Chemical site.

Historically, chlorobenzene was used as an intermediate in phenol and DDT production, although use as a solvent for some pesticide formulations continues today. Chlorobenzene is volatile and is only moderately soluble in groundwater, and readily biodegrades in soil and in aerobic aquifers (see references in ATSDR, 1990a).

6.2.4 1,2-Dichlorobenzene

Thirty-seven of the 102 Shallow Zone samples collected during Phase B activities contained 1,2-dichlorobenzene above the laboratory SQL (Table 4). The compound was not detected in any Middle Zone samples (Table 5). The 1,2-dichlorobenzene RBGC of 600 µg/L was exceeded in two wells, M123 (620 µg/L) and M127 (740 µg/L), both of which are on the western portion of the Site adjacent to the POSSM property (Plate 31).

Based on the concentrations and distribution of 1,2-chlorobenzene in groundwater, it appears the chemical is migrating beneath the Site via groundwater migration from the west. As described above, Hardesty Chemical Company operated a chemical plant within electrolysis Building 2 and the adjacent chlorination building (BRC, 2007). The company and its successor, AMECCO Chemicals, produced chlorobenzene, 1,2-dichlorobenzene, and 1,4-dichlorobenzene. The former Hardesty Chemical Company is not currently active and the above-ground underground storage tanks (ASTs and USTs) associated with fuel oil and chemical storage have been removed from the site. There is no apparent correlation between 1,2-dichlorobenzene in groundwater and the location of the former Hardesty Chemical site.

Offsite sources of 1,2-dichlorobenzene include the POSSM properties. The former Montrose facility produced chlorobenzene, 1,2-dichlorobenzene, 1,4-dichlorobenzene, and trichlorobenzene from 1947 through 1983 (H+A, 2008a). A 540,000-gallon above-ground storage tank for dichlorobenzene was located at the facility from at least 1964 to 1976, and was removed in approximately 1978-1979 (H+A, 2008a). Vadose zone soil and groundwater in the Shallow and Middle Zones beneath the POSSM properties are impacted with 1,2-dichlorobenzene (H+A, 2008a). An increase in 1,2-dichlorobenzene was observed in Middle Zone groundwater in the vicinity of well MC-MW-18 in 2009 compared to previous sampling events. In 2009, 1,2-dichlorobenzene was detected at a dissolved concentration of 680,000 µg/L in well MC-MW-18. It was also detected in mixed DNAPL collected from the well at a concentration of 49,000,000 µg/kg, or 4.9% (H+A, 2010).



Dichlorobenzene isomers are chlorinated aromatic compounds used primarily as precursors for herbicides and insecticides, typically produced from liquid benzene and gaseous chlorine in the presence of a catalyst. Dichlorobenzenes readily volatilize to the atmosphere from soil and water, but adsorption to soil particulates may inhibit volatilization. Biodegradation is an important mechanism for dichlorobenzenes in aerobic aquifers (see references in ATSDR, 2006).

6.2.5 1,4-Dichlorobenzene

Sixteen of the 102 Shallow Zone samples collected during Phase B activities contained 1,4-dichlorobenzene above the laboratory SQL (Table 4). The compound was not detected in any Middle Zone samples (Table 5). The 1,4-dichlorobenzene RBGC of 75 µg/L was exceeded in several wells on the western portion of the Site adjacent to the POSSM property: MC3, M123, M126, M127, and TR-6 (Plate 32). The highest concentration of 1,4-dichlorobenzene was detected in well M123 (1,200 µg/L).

Based on the concentrations and distribution of 1,4-dichlorobenzene in groundwater, it appears the chemical is migrating beneath the Site via groundwater migration from the west. The only identified potential onsite source for 1,4-dichlorobenzene is the former Hardesty Chemical Site (LOU 4), as previously described in Sections 6.2.3 and 6.2.4. There is no apparent correlation between 1,4-dichlorobenzene in groundwater and the location of the former Hardesty Chemical site.

As described above, the former Montrose facility produced chlorobenzene, 1,2-dichlorobenzene, 1,4-dichlorobenzene, and trichlorobenzene from 1947 through 1983 (H+A, 2008a). Vadose zone soil and groundwater in the Shallow and Middle Zones beneath the POSSM properties are impacted with 1,4-dichlorobenzene (H+A, 2008a). An increase in 1,4-dichlorobenzene was observed in Middle Zone groundwater in the vicinity of well MC-MW-18 in 2009 compared to previous sampling events. In 2009, 1,4-dichlorobenzene was detected at a dissolved concentration of 270,000 µg/L in well MC-MW-18. It was also detected in mixed DNAPL collected from the well at a concentration of 130,000,000 µg/kg, or 13% (H+A, 2010).

Dichlorobenzene isomers are chlorinated aromatic compounds used primarily as precursors for herbicides and insecticides, typically produced from liquid benzene and gaseous chlorine in the presence of a catalyst. The current principle uses of 1,4-dichlorobenzene is as deodorant for toilets and refuse containers, and as a fumigant for control of moths, mold, and mildew. Dichlorobenzenes readily volatilize to the atmosphere from soil and water, and 1,4-dichlorobenzene readily sublimates from its solid form at room temperature. Biodegradation is an important mechanism for 1,4-dichlorobenzene in aerobic aquifers (see references in ATSDR, 2006).



6.2.6 Carbon Tetrachloride

Nearly half of the Shallow Zone groundwater samples collected during Phase B activities contained carbon tetrachloride above the laboratory SQL (Table 4). The compound was detected in one Middle Zone well (TR-8), at 0.37 µg/L (Table 5). The RBGC of 5 µg/L was exceeded in samples from four wells: CLD3R and CLD4R (which are on the TIMET property, east of the Site), and TR-6 and M123, which are on the western portion of the Site adjacent to the POSSM property. The highest concentration detected was 840 µg/L in well M123.

Based on the concentrations and distribution of carbon tetrachloride in groundwater, it appears the chemical is migrating beneath the Site via groundwater migration from the west (Plate 33). Carbon tetrachloride was also detected in soil above the BCL along the western Site boundary, at depths between 30 and 33 feet bgs, although concentrations were not indicative of a potential ongoing concern for leaching to groundwater (Northgate, 2010c; *Tronox/NDEP meeting minutes for February 5 and February 12, 2010*).

There are no documented onsite sources of carbon tetrachloride. Offsite sources of carbon tetrachloride include the POSSM properties. The former Montrose and Stauffer facilities are located where the chlorine and caustic soda plant was constructed for the original BMI industrial complex (H+A, 2008a). Waste streams from the Montrose site included impurities of carbon tetrachloride, as well as chloroform, benzene, chlorobenzene, and several other contaminants (see references in H+A, 2008a). Historic correspondence notes the disposal of 10 tons of liquid carbon tetrachloride waste at the BMI dump between 1977 and 1980 (Stauffer, 1987). Carbon tetrachloride is detected in the vadose zone (in soil and soil gas), the alluvial aquifer (Shallow Zone), and the Middle Zone beneath the POSSM properties (H+A; 2008a, 2010). In 2009, carbon tetrachloride was detected in mixed DNAPL collected from well MC-MW-18 at a concentration of 3,500,000 µg/kg, or 0.35% (H+A, 2010).

Carbon tetrachloride has historically been widely used as an industrial solvent, degreaser, and grain fumigant. Because it is often used to rinse out the cylinders in which chlorine gas is supplied, it is also one of the most common contaminants present in the chlorine gas (Ivahnenco and Barbash, 2004). Carbon tetrachloride has a low affinity for soil and is resistant to natural attenuation, although it is capable of biodegradation (specifically, reductive dechlorination) under strongly reducing conditions (Biteman et al., 2007). Chloroform is one of several dechlorination daughter products. Carbon tetrachloride readily volatilizes from soil and groundwater, however, it is a stable compound that degrades quite slowly. Retardation factors for carbon tetrachloride range from approximately 1.1 to 1.7 (see references in ATSDR, 2005b).



6.2.7 Chloroform

Chloroform was detected above the laboratory SQL in over 96% of the samples collected from the Shallow Zone during Phase B activities (Table 4). Chloroform exceeded the RBGC of 1.62 µg/L in 93 of the 98 shallow zone samples in which it was detected. It was also detected in five of the eight Middle Zone wells that were sampled, at concentrations up to 10 µg/L, exceeding the RBGC in four samples (Table 5). Chloroform was detected above the RBGC in two general areas: near the western Site margin and near/downgradient the Unit 3 and 4 buildings and LOUs 43, 34, 5, 13, 14, 16, and 18 extending towards and beyond the groundwater barrier wall (Plate 34). The highest concentrations were detected at wells H38 (100,000 µg/L), M123 (28,000 µg/L), M125 (18,000 µg/L), M127 (9,100 µg/L), and M126 (6,100 µg/L) along the western Site margin, and wells M50 (3,100 µg/L), M17A (2,200 µg/L), M22A (2,200 µg/L), M65 (1,500 µg/L), M89 (1,400 µg/L), M2A (1,200 µg/L), and M12A (1,200 µg/L) downgradient of the Unit 3 and 4 buildings. Chloroform is also detected in the vadose zone (in soil and soil gas), the Shallow Zone, and the Middle Zone beneath the POSSM properties (H+A; 2008a, 2010).

Based on the concentrations and distribution of chloroform in groundwater, it appears that there may be a onsite source in the vicinity of Units 4 and 5, and/or downgradient of this area near LOU 34. Chloroform is also migrating beneath the Site via groundwater migration from the west, in both the Shallow and Middle Zones. Chloroform was also detected in soil at concentrations above the BCL along the western Site boundary, in several locations along the Beta Ditch, and in roughly a half-dozen samples collected in Area II (generally coinciding with the location of the onsite groundwater plume), at depths between 20 and 47 feet bgs. Chloroform concentrations in soil indicate that there may be a potential ongoing concern for leaching to groundwater (Northgate, 2010c; *Tronox/NDEP meeting minutes for February 5 and February 12, 2010*). Elevated levels of chloroform were measured in soil gas in the western portion of the Site and below the Unit 4 building (AECOM, 2009), generally coinciding with the higher concentration areas of the groundwater plumes. There is also commingling of the chloroform plumes at the Site and the neighboring TIMET property to the east.

There are no known releases or production of chloroform at the Site. Small amounts of chloroform were used in the analytical lab near Unit 3 and chloroform may have been formed in the chlorate and perchlorate production process. However, chlorine and magnesite were the two primary raw materials used to produce magnesium during the original industrial activities at the Site. Production of liquid chlorine and sodium hydroxide (NaOH, also known as caustic or lye) from sodium chloride (NaCl) has occurred at or adjacent to the Site from the 1940s to the present day. Chlorine is moderately soluble in water, and when treated with a hydroxide, such as NaOH or Ca(OH)₂, a solution containing the hypochlorite ion results (OCl⁻). Sodium hypochlorite is the active ingredient of chlorine laundry bleach, and calcium hypochlorite is used as a disinfectant in



swimming pools. Gaseous chlorine reacts with hydrocarbons to form chlorinated hydrocarbons. Chlorine will replace the hydrogen atoms in methane (CH₄), sequentially producing chloromethane (CH₃Cl), methylene chloride (CH₂Cl₂), chloroform (CHCl₃), and carbon tetrachloride (CCl₄) (Shakhashiri, 2006). Several studies have demonstrated that chloroform may be produced from the transformation of carbon tetrachloride by microorganisms under iron- or sulfate-reducing conditions (see references in Ivahnenko and Barbash, 2004).

Tronox and its predecessors have operated several types of electrolytic cells on the Site since the 1940s, which historically used large quantities of chlorine. These include:

- Sodium chlorate cells converting NaCl to NaClO₃;
- Sodium perchlorate cells converting NaClO₃ to NaClO₄; and
- Manganese cells plating MnO₂ from manganese sulfate solutions.

Currently, the manganese dioxide cells in Units 5 and 6 (LOUs 61 and 44) are the only electrolytic cells in operation at the Site (AECOM, 2008). They operate using a sulfate-based anolyte and thus do not use chlorine. Both the historic sodium chlorate and sodium perchlorate cells generated free chlorine (a degradation product of sodium hypochlorite, an intermediate compound in the electrolytic operation). Chlorine and sodium hydroxide are produced simultaneously through the electrolysis of brine after it has been purified (BRC, 2007).

Aqueous process waste streams that may have contained chlorine were discharged to various surface impoundments on the Site. The former Trade Effluent Settling Ponds (LOU 1) received aqueous process waste streams from the acid neutralization plant, as well as solid waste. Waste streams discharged to the former Trade Effluent Settling Ponds may have potentially affected the area beneath or around Ponds WC-West and WC-East, which were constructed in 1988 and remain in operation at the Site. Concentrated brine and hypochlorite were discharged at Ponds WC-West (LOU 22) and WC-East (LOU 23). Historically, both ponds received composite liquid waste streams from Units 3, 5, and 6. These ponds are lined and bermed (ENSR, 2008a). Pond C-1 (LOU 20) received non-hazardous aqueous waste from Units 4 and 5 and the steam plant. Chlorine and hydrochloric acid for absorber towers and waste streams from the chlorination process in the Unit buildings were discharged to LOU 2, the open area located south of the former Trade Effluent Settling Ponds and north of the Beta Ditch. The Beta Ditch (LOU 5) conveyed process waste streams from the southern portion of the Site and from the POSSM properties to the west. The Acid Drain System (LOU 60) conveyed effluent to the former Trade Effluent Settling Ponds via an above-ground flume from the effluent neutralization plant along the northern boundary of LOU 2. It's possible that any of these impoundments or areas received chloroform-containing wastes.



Offsite sources of chloroform include the POSSM properties. In 2009, chloroform was detected in mixed DNAPL collected from well MC-MW-18 at a concentration of 2,900,000 µg/kg (H+A, 2010). The former Montrose and Stauffer facilities are located where the chlorine and caustic soda plant was constructed for the original industrial complex (H+A, 2008a). Although the components of the chlor-alkali manufacturing facilities have changed over time, the production of liquid chlorine and sodium hydroxide from sodium chloride has continued under the operation of Pioneer from 1988 to the present day. Additionally, the Montrose site's CSM indicates that soil and groundwater beneath and around the company's closed pond areas are significantly impacted with chloroform, chlorobenzene, 1,2-dichlorobenzene, 1,4-dichlorobenzene and benzene (Geosyntec, 2008). The POSSM waste streams historically included:

- Brine sludge, disposed via a sewer system to Wastewater Ponds 1 and 2 and Chlor Alkali Ponds and offsite regulated facility;
- Electrolytic chlorine cell materials, disposed in the BMI Landfill;
- Chlorine liquefaction sludge (carbon-based impurities combined with chlorine to form chloroform, carbon tetrachloride, and hexachloroethane), disposed in the Leach Beds and BMI Landfill;
- Spent carbon tetrachloride, disposed in the BMI Landfill and offsite regulated facility;
- Sodium hypochlorite waste, disposed via a sewer system to the Wastewater Ponds 1 and 2 and Chlor Alkali Ponds; and
- Fume scrubber wastes containing a variety of organics and heavy metals, disposed via the Beta Ditch to the BMI ponds (H+A, 2008a).

Chloroform is a trihalomethane and a common byproduct of water chlorination. Potential sources of trihalomethanes in groundwater include the discharge of chlorinated drinking water and wastewater, either intentional (e.g., irrigation, septic systems, or regulated discharges to surface water or through groundwater recharge systems) or inadvertent (Ivahnenko and Zogorski, 2006). It is also possible for trihalomethanes (such as chloroform) to form from the reaction of sodium hypochlorite with soil (Jackman and Hughes, 2010). Chloroform can be produced from acetone and bleaching powder by addition of sulfuric acid (Merck Index, 10th Edition). It is used as a solvent for fats, oils, rubber, alkaloids, waxes, and resins; in the rubber industry; and to lower the freezing temperature of carbon tetrachloride in fire extinguishers. Chloroform is an extremely common VOC in samples from public and domestic water supply wells (and it was the most frequently detected VOC in nation-wide samples collected as part of the USGS's National Water Quality Assessment Program), although concentrations above the U.S. EPA's MCL are rare. A five-year USGS study did not detect any trihalomethanes above the federal MCL of 80 µg/L for total trihalomethanes (Ivahnenko and Zogorski, 2006).



Chloroform has a high vapor pressure, indicating that it will volatilize out of groundwater into the soil matrix and the atmosphere. It is denser than water, accumulating as a DNAPL at concentrations exceeding its solubility limit (8,000 mg/L). Chloroform's high solubility limit, combined with a relatively high Henry's Law Constant and vapor pressure, means that chloroform in soil should rapidly volatilize to the atmosphere or leach into the subsurface. The relatively low organic carbon-water partition coefficient (K_{oc}) values for chloroform suggest relatively low affinities for soil. Therefore, if an onsite source existed (e.g., product in the vadose zone), it would be likely to have migrated quickly through soil to the dissolved or vapor phase.

Concentrations of chloroform dissolved in groundwater are elevated at the Site and likely to persist for several decades or more. Assuming a retardation factor in the range of 2.5 to 3.8 (Ivahnenko and Barbash, 2004), a dissolved chloroform plume would migrate at roughly a third of the speed of groundwater through aquifers low in organic carbon. Although chloroform can naturally degrade in groundwater under favorable conditions, it does not do so readily. In addition, chloroform is persistent under oxic conditions. Therefore, chloroform dissolved in groundwater would be expected to create relatively long and long-lived plumes, particularly in low organic carbon aquifers (Ivahnenko and Barbash, 2004).

The presence of chloroform in groundwater is a potential human health concern for ingestion and vapor intrusion. There is also some evidence that chloroform can be absorbed through dermal contact (Ivahnenko and Barbash, 2004). Chloroform is classified as a probable human carcinogen (ATSDR, 1997a).

6.2.8 Trichloroethene

TCE was detected above the laboratory SQL in over half of the 102 samples collected from the Shallow Zone during Phase B activities (Table 4). It was detected in one Middle Zone well (TR-8), at 0.5 $\mu\text{g/L}$ (Table 5). TCE was detected above the RBGC of 5 $\mu\text{g/L}$ in two general areas: near the western Site margin and near/downgradient of LOU 4 and the Unit 2 and 3 buildings in a narrow plume extending to the groundwater barrier wall (Plate 35). Along the western Site margin, TCE was detected above the RBGC in wells H28A, MC3, and M137. Near and downgradient of LOU 4 and the Unit 2 and 3 buildings, TCE was detected above the RBGC in wells M2A, M13, M21, M25, M55, M65, M78, and M89. The highest concentrations were detected at wells M13 (25 $\mu\text{g/L}$) and M137 (18 $\mu\text{g/L}$).

Based on the concentrations and distribution of TCE in groundwater, it appears that there may be relatively minor onsite sources in the vicinity of LOU 13, LOU 4 and the Unit 2 and 3 buildings, or upgradient of this area near LOU 62. TCE was detected at relatively elevated levels in soil



gas near the former State Industries catch basin (LOU 62) and in the vicinity of Pond S-1 (LOU 13) and the Steam Plant (AECOM, 2009). TCE was not detected in soil at concentrations above the BCL or at levels indicative of a concern for leaching to groundwater (Northgate, 2010c; *Tronox/NDEP meeting minutes for February 5 and February 12, 2010*). TCE may also be migrating beneath the Site via groundwater migration from the west, although elevated detection limits for TCE samples on the POSSM properties create uncertainty in the correlation. There does not appear to be a correlation between TCE at the Site and TCE detected at the TIMET property.

TCE is an anthropogenic chemical that does not occur naturally in the environment. ATSDR reports that TCE is the most frequently reported organic contaminant in groundwater (ATSDR, 1997b). It is commonly released from industrial discharges of waste water streams or assumed to enter the subsurface as landfill leachate. There are no known releases or uses documented for TCE at the Site. However, there are elevated concentrations of PCE in groundwater to the west of the Site. PCE is a common industrial, dry cleaning, and textile solvent and the parent compound for TCE generated through a reductive dechlorination pathway. PCE was likely present in solvents used in the paint shop at the neighboring TIMET site to the east, where relatively low concentrations of PCE and TCE have been detected in shallow groundwater (TIMET, 2007).

TCE has a high vapor pressure and is moderately soluble in water and soil. It is denser than water, accumulating as a DNAPL at concentrations exceeding its solubility limit (1,000 mg/L). TCE's low solubility in water, combined with a relatively high Henry's Law Constant and high vapor pressure, means that TCE in soil should rapidly volatilize or leach into the subsurface. Therefore, if an onsite source exists, it is likely to migrate quickly through soil and sediment to the dissolved or vapor phase. Assuming a retardation factor of approximately 2 (Russell et al., 1992), a dissolved TCE plume would migrate at half the speed of groundwater through aquifers low in organic carbon (and theoretically slower with increasing organic carbon content). Concentrations of TCE dissolved in groundwater are relatively low at the Site. TCE can naturally degrade in groundwater under favorable conditions, typically anaerobically transforming into a series of less-chlorinated daughter products including cis-1,2-DCE, 1,1-DCE, vinyl chloride, ethane, and ethene. The U.S. EPA considers TCE a possible to probable human carcinogen (ATSDR, 1997b).

6.2.9 1,1-Dichloroethene

Approximately 25% of the 102 samples collected from the Shallow Zone during Phase B activities contained 1,1-DCE above the laboratory SQL (Table 4). It was detected in one Middle Zone well (TR-8), at 0.61 µg/L (Table 5). The 1,1-DCE RBGC of 7 µg/L was exceeded in two



wells, M92 (18 µg/L) and M97 (30 µg/L), both of which are located in the vicinity of LOUs 4 and 63 (Plate 36).

Based on the concentrations and distribution of 1,1-DCE in groundwater, it appears that there may be a relatively minor onsite source in the vicinity of LOU 4 and the Unit 2 and 3 buildings, or that 1,1-DCE is a daughter product of TCE or 1,1,1-TCA degradation in that area. The distribution may also be due to 1,1-DCE migrating beneath the Site from the POSSM properties to the west, although elevated detection limits create uncertainty in that correlation.

In general, the primary sources of 1,1-DCE in the environment are related to the synthesis, fabrication, and transport of 1,1-DCE and its use in the fabrication of polymers (ATSDR, 1994). There are no known releases or uses documented for 1,1-DCE at the Site. However, 1,1-DCE may be formed as a byproduct of the hydrolysis of 1,1,1-TCA. There were several potential onsite sources for 1,1,1-TCA at the Site, comprising the Former Satellite Accumulation Point facilities: the Unit 3 Maintenance Shop, Unit 6 Maintenance Shop, AP Laboratory, and AP Maintenance Shop (LOUs 36-39, respectively). In addition, there are elevated concentrations of PCE in groundwater to the west of the Site, and although it's a less common pathway than the degradation of 1,1,1-TCA, 1,1-DCE can be generated as a daughter product of PCE and TCE through anaerobic or cometabolic degradation (Zhang et al., 2006).

No ongoing vadose zone source of 1,1-DCE to groundwater has been identified at the Site (AECOM, 2009; Northgate, 2010c; Northgate, 2010h-k; *Tronox/NDEP meeting minutes for February 5 and February 12, 2010*). The calculated partition coefficient for 1,1-DCE indicates that if an onsite source exists, it is likely to migrate quickly through soil and sediment, and a relatively high Henry's constant value indicates that it will continue to volatilize out of water. Concentrations of 1,1-DCE are relatively low at the Site and it can naturally degrade in groundwater under favorable conditions. In groundwater, 1,1-DCE can biodegrade under both aerobic and anaerobic conditions (ATSDR, 1994).

6.2.10 1,1-Dichloroethane

Approximately 28% of the 102 samples collected from the Shallow Zone during Phase B activities contained 1,1-DCA above the laboratory SQL (Table 4). It was not detected in any of the Middle Zone wells (Table 5). The 1,1-DCA RBGC of 11.8 µg/L was exceeded in six wells: AA-BW-02, H-28A, M-127, M-5A, MC-3, and PC-40 (Plate 37). The highest concentrations were detected at wells M-5A (48 µg/L) and M-127 (45 µg/L). Except for well PC-40, all of these wells are near the western boundary of the Site, downgradient of the POSSM property.

Based on the concentrations and distribution of 1,1-DCA in groundwater, it appears the chemical is migrating beneath the Site via groundwater migration from the west, or that 1,1-DCA is a



daughter product of 1,1,1-TCA degradation in that area, which is only detected at trace concentrations in Site groundwater.

Typical uses for 1,1-DCA include as an intermediate in the manufacture of other products such as vinyl chloride and 1,1,1-TCA. It also has limited use as a solvent and a degreaser. Historical use as an anesthetic has been discontinued (ATSDR, 1990b). There are no known releases or uses documented for 1,1-DCA at the Site, however, it is a degradation product of 1,1,1-TCA. The Former Satellite Accumulation Point facilities (the Unit 3 Maintenance Shop, Unit 6 Maintenance Shop, AP Laboratory, and AP Maintenance Shop) are potential sources for 1,1,1-TCA at the Site.

No ongoing vadose zone source of 1,1-DCA to groundwater has been identified at the Site (AECOM, 2009; Northgate, 2010c; Northgate, 2010h-k; *Tronox/NDEP meeting minutes for February 5 and February 12, 2010*). Concentrations of 1,1-DCA are relatively low at the Site and it can naturally degrade in groundwater under favorable conditions. In groundwater, 1,1-DCA can biodegrade under both aerobic and anaerobic conditions (ATSDR, 1990b).



7 CONCLUSIONS

Site groundwater has been impacted by historical chemical manufacturing activities at the BMI complex and ongoing activities including applied water such as irrigation and wastewater disposal, disposal of industrial waste, and the release of chemicals from leaks in process ponds, conveyances, and storage tanks. Long-term irrigation of agricultural crops and landscaping in the Las Vegas Valley Area has led to elevated levels of dissolved solids and nutrients in the Shallow Zone, rendering it unfit as a drinking water source (e.g., USGS, 1998; Maxey and Jameson, 1948; Kaufmann, 1977; Plume, 1989; Morgan and Dettinger, 1996; Bevans et al., 1998). Locally, large volumes of process effluent containing inorganic and organic wastes were disposed in unlined surface impoundments and leach beds from 1942 until 1976, further degrading Site groundwater. Since surface disposal of process effluent ceased in 1976, TDS levels in Site groundwater have decreased through a combination of Site remedial efforts and natural attenuating processes. Site groundwater impacts are primarily the result of historical waste disposal practices, leaks of chemicals from process ponds, conveyances, and tanks and migration of chemicals from offsite sources within the BMI complex.

Perchlorate remains the primary contaminant of concern in Site groundwater, and has migrated offsite to the Las Vegas Wash, which flows into Lake Mead and then to the Colorado River. Lake Mead and the Colorado River are drinking water sources for a large population, and Site groundwater remediation activities have been focused and successful at significantly reducing the perchlorate loading to Las Vegas Wash via groundwater plume containment and treatment. Perchlorate in vadose zone soil has been identified as a concern for potential ongoing leaching to groundwater (Northgate, 2010c) and may also need to be remediated.

Although hexavalent chromium has impacted Site groundwater, a combination of remediation activities begun in 1987 and natural attenuation have successfully prevented contamination of the Las Vegas Wash and Lake Mead. Hexavalent chromium remaining in vadose zone soil is not expected to cause additional significant groundwater impact (Northgate, 2010c).

Elevated levels of manganese exist in localized areas downgradient of Unit 6 and underneath the manganese tailings piles. It is not clear if this is dissolved (mobile) manganese ions or the result of suspended colloidal manganese. However, manganese levels downgradient are very low, indicating that if manganese was dissolved, it rapidly attenuates.

Elevated levels of ammonia and nitrate result from the hydrolysis of dissolved ammonium perchlorate and the subsequent nitrification of ammonium ions to nitrate. The GWETS successfully removes and treat nitrate from groundwater.



Elevated levels of boron exist upgradient of the interceptor well field as well as downgradient of the Site. Boron appears to rapidly attenuate downgradient of the Site.

Elevated levels of TDS exist upgradient throughout the Site and are result of high background levels in the shallow aquifer of the Las Vegas Valley as well as the result of extensive contamination of Site and off-Site groundwater with TDS-laden process effluent. The GWETS will transform the perchlorate and chlorate components to chloride, but will cannot remove TDS. The dissolved sodium, magnesium, potassium, carbonate, sulfate, and chloride components will remain untreated and are discharged to the wash in the treated effluent. Reduced levels of TDS downgradient of the interceptor well field and groundwater barrier wall exist due to the historical reinjection of Lake Mead water, which has a TDS content lower than the Site groundwater.

Elevated levels of arsenic and uranium in groundwater appear to be primarily the result of anthropogenic modification of Site groundwater geochemistry from the significant amounts of off-Site applied wastewater that mobilized these naturally occurring metals.

Of the organic constituents, chloroform is a contaminant of concern because it occurs in Site groundwater at concentrations significantly above RBGCs, it has been detected in soil above LSSLs, it has been detected in soil gas above Site-specific screening levels, and it has been detected in indoor air samples. Given chloroform's low affinity for soil and that the majority of elevated detections in soil samples were from depths near the water table (e.g., below 30 feet bgs), it is likely that chloroform remaining in the vadose zone resides in soil pore water within the capillary zone, and chloroform measured in soil gas and in indoor air samples from volatilization from the pore water and shallow groundwater. Dissolved chloroform in the Shallow Zone and chloroform as DNAPL in the Middle Zone remain ongoing sources. The current groundwater extraction and treatment systems are capturing and groundwater impacted with chloroform and the existing perchlorate treatment process reduces chloroform levels in the treated water, but meaningful reductions of the Site and offsite chloroform plumes are not anticipated given the spatial extent, likely longevity, and limitations of the treatment technology. Groundwater redox conditions, which appear to be weakly reducing to weakly oxidizing in the areas impacted by chloroform (Plates 35 and 36), are not favorable for significant natural biodegradation of the chloroform within a reasonable timeframe (several decades or more). A low-concentration TCE plume (<50µg/L) at the Site appears to be related to (and is generally co-located with) detections of 1,1-DCE and 1,1-DCA. TCE concentrations are above RBGCs in limited areas at the Site, primarily in the vicinity of LOU 13, LOU 4 and the Unit 2 and 3 buildings, or upgradient of this area near LOU 62. Because the detection limits for POSSM groundwater samples were elevated for these constituents during Phase B, evaluation of the relationship between onsite and offsite concentrations of these chlorinated solvents is not possible at this time.



Significant offsite sources of OCPs, benzene, chlorobenzene, dichlorobenzenes, and carbon tetrachloride exist on the POSSM properties. These constituents are present in Shallow Zone samples from a large number of wells at concentrations up to 5-orders of magnitude above the RBGCs, and present as separate-phase DNAPL in Middle Zone samples in several wells. Residual DNAPL acts as a long-term source for dissolved groundwater concentrations that may remain relatively stable until the source is depleted. Alpha-BHC may also be a concern due to the ongoing potential for leaching from soil to groundwater.

Retardation factors, the ratio of the groundwater velocity to the rate that organic chemicals migrate in the groundwater, represent the reduction in the rate at which dissolved contaminants move through an aquifer due to interactions of contaminants with the aquifer matrix. Where retardation factors are available for the organic COIs listed above, they suggest significant retardation relative to groundwater flow. This retardation both slows migration and decreases downgradient COI concentrations.

With completion of the Phase B groundwater investigations, sufficient data are available for understanding the nature and extent of anthropogenic chemicals in the Site Shallow Zone groundwater. Other than perchlorate and hexavalent chromium, no groundwater chemicals at the Site have been identified as requiring cleanup, and no specific remedial action objectives (RAOs) have been established even for perchlorate and hexavalent chromium. Therefore, an important next step is to identify appropriate and achievable RAOs for Site groundwater. Based on the agreed-upon RAOs, additional groundwater data may need to be collected in order to determine an appropriate means of achieving the objectives.



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