



Draft for Review
Area 1 Full Scale ISCR Work Plan
Former Plating Area
Eckles Road Site
Livonia, Michigan

RACER Trust

April 2016

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012607 | Report No 69

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1. Introduction

GHD Services Inc. (GHD), on behalf of Revitalizing Auto Communities Environmental Response Trust (RACER), has prepared this Area 1 Full-Scale ISCR Work Plan (Work Plan) for the RACER facility at 13000 Eckles Road Site in Livonia, Michigan (Site).

This Work Plan presents a scope of work for a full scale in-situ chemical reduction (ISCR) treatment program to chemically precipitate dissolved hexavalent chromium (chromium VI) and nickel in groundwater within the former plating area (identified as Area 1).

Figure 1 presents the Site Location. Figure 2 presents the Site plan.

1.1 Objective of the Full Scale ISCR Program

It is uncertain if continued long term operation of the existing groundwater treatment plant (GWTP) will achieve remedial objectives within projected RACER funding. It has been concluded based, in part, on pilot test results that a more aggressive remedial strategy with significantly lower long term O&M requirements offers a higher confidence level that remedial objectives will be met. In other words, converting future budgeted O&M funds into current capital expenditures is considered a more prudent remedial strategy.

Although there are no complete exposure pathways and an existing French drain, groundwater treatment plant (GWTP) and soil-bentonite barrier wall are controlling the migration of impacted groundwater, RACER would like to proactively reduce the on-site concentrations of chromium VI and nickel to eliminate the need for ongoing O&M of the GWTP. A series of pilot studies were conducted to: 1) evaluate the effectiveness of the reduction/precipitation of dissolved chromium VI and/or dissolved nickel which occurred through the use of individual or a combination of injected reagents and 2) evaluate and select the direct injection technique most effective at achieving an acceptable radius of influence that optimizes injection point spacing for full-scale remediation of the chromium VI and nickel impacted groundwater. To achieve this objective, in-situ chemical reduction (ISCR) injections were used to reduce chromium VI and/or nickel concentrations in the northern portion of Area 1. The results of the Expanded Pilot Study proved to be favorable and thus, full-scale implementation of the ISCR injection will be completed at the remaining areas of chromium VI and/or nickel-impacted groundwater within Area 1. The objective of full-scale implementation will be to inject the specified ISCR chemical solution at approximately 30 foot spacing throughout the on-site areas of chromium and nickel-impacted groundwater. The injections will be completed with a goal of generally reducing groundwater concentrations of nickel and chromium VI to near their respective drinking water criteria of 0.1 mg/L for each. It is not anticipated that a reduction to, or below, drinking water criteria will be achieved at each monitoring location or for all groundwater within Area 1. The need for any potential subsequent injections will be evaluated after a review of post-injection monitoring data. Following the proposed injections, up to two permeable reactive gates may be installed within the Area 1 barrier wall to passively treat any remaining impacted groundwater as it leaves Area 1. Installation of the reactive gates will allow termination/shutdown of the GWTP.

1.2 Report Organization

The remainder of this report is presented in the following sections:

- **Section 2 – Background Information** – provides details on the physical layout of the Site, historical site characterization reports, interim measures implemented at the Site and applicable cleanup criteria.
- **Section 3 – Groundwater Monitoring Plan Sampling** - provides details on the Area 1 Groundwater Monitoring Plan (GMP) sampling activities and results, including additional characterization activities. These details provide the means to define the areas to with impacted groundwater and facilitate proper remedial design.
- **Section 4 – Hydrogeologic Conceptual Site Model (CSM)** – utilizes the results of the RFI and ongoing groundwater sampling to update the CSM and includes geology, hydrogeology, hydrology, and groundwater use.
- **Section 5 - Field Pilot Study Results** - provides details on the laboratory treatability studies and subsequent field pilot studies conducted to evaluate treatment methods for remediation of Site impacts.
- **Section 6 – Full Scale ISCR Program Scope of Work** - provides details on the plan for ISCR injections to reduce chromium VI and nickel concentrations within Area 1.
- **Section 7 - Performance Monitoring Plan** - provides details on the monitoring and reporting activities that will be performed to evaluate and document the performance of the ISCR injections.
- **Section 8 - Schedule** - provides the general sequence of events that are anticipated for implementation of the Full Scale ISCR Program.
- **Section 9 - References** - provides a listing of reports used to facilitate development of this Work Plan.

2. Background Information

2.1 Historical Site Characterizations

The Site was historically used for the production of vehicle bumpers, leaf springs and strut assemblies, with Area 1 being used for chrome plating. Environmental decommissioning and demolition of the entire Site occurred during the 2000 to 2001 period. Resource Conservation and Recovery Act (RCRA) Corrective Action work was conducted by General Motors before its 2009 bankruptcy and subsequently by RACER pursuant to a 2011 agreement with the United States Environmental Protection Agency (U.S. EPA). A RCRA Facility Investigation (RFI) over several stages was conducted at the Site and included a risk assessment. The results are summarized in the RFI Report (CRA, March 2005) and Supplement to the RFI Report (CRA, April 2005). Following completion of the RFI, a Revised Corrective Measures Proposal (CRA, June 2005) was developed and submitted to the U.S. EPA. U.S. EPA issued a Final Decision and Response to Comments (U.S. EPA, March 2006) selecting final corrective measures for the Site, including continued operation of the groundwater extraction and treatment facility and barrier wall at Area 1.

During the RFI, nickel and chromium impacted groundwater was identified within Area 1. Chromium was not detected at concentrations above generic screening criteria at off-site locations during any RFI or CA750 sampling events. The chromium-impacted groundwater identified at Area 1 appears to be contained by the French drain collection system and Area 1 barrier wall. Nickel-impacted groundwater was identified in some off-site monitoring wells south of Area 1. As described below, the Area 1 barrier wall was completed around Area 1 to control the off-site migration of nickel impacted groundwater. Groundwater quality in Area 1 has been monitored through MW-OS-3D, MW-OS-4S, MW-OS-4D, MW-OS-5D, MW-OS-6D, MW-OS-7D, MW-OS-8D, MW-OS-9S, MW-OS-9D, MW-OS-10D, HA-MW-12, HA-15 and HA-16.

As proposed in the CA750 Report (Environ, October 28, 2004), groundwater samples were collected from off-site monitoring wells to monitor the concentrations of nickel and chromium in off-site groundwater. However, as described in a letter to U.S. EPA dated April 13, 2005, monitoring wells MW-OS-9S, MW-OS-9D, and MW-OS-10D were abandoned in February 2005 as requested by the owner of the property where these wells were located. In addition, due to a labor dispute at the facility across the street from Area 1, monitoring wells MW-OS-5D, MW-OS-6D, MW-OS-7D, and MW-OS-8D could not be accessed from May 2005 to January 2006. During this period, groundwater samples were collected from on-site monitoring wells to evaluate the effectiveness of the Area 1 barrier wall.

Analytical results from the on-site and off-site groundwater samples have been presented in Quarterly/Semi-Annual Progress Reports and are summarized in the Revised GMP. Nickel was detected in groundwater samples collected from off-site monitoring wells south of Area 1; however, the concentrations were lower than the site-specific, risk-based criteria for the non-potable groundwater exposures that were reasonably expected for this area (i.e., construction worker ingestion of and dermal contact with groundwater). As discussed in the RFI Report and the Supplement to the RFI Report, groundwater in this area is not being used as a drinking water supply and all properties in this area are serviced by a municipal water supply.

The Area 1 barrier wall appears to have intercepted the groundwater flow south of Area 1 and limited off-site migration of nickel-impacted groundwater. Chromium has not been detected in off-site groundwater samples at concentrations greater than generic screening criteria. There has been some variability in the concentrations of nickel in groundwater samples collected from immediately downgradient of Area 1 since the installation of the Area 1 barrier wall.

A Revised Groundwater Monitoring Plan (CRA, April 2008) defines ongoing monitoring requirements as part of the Operations, Maintenance, and Monitoring Plan (CRA, July 2007) at the Site. Results of the ongoing GMP sampling and additional characterization activities are discussed below in Section 3.

2.2 Historical Interim Measures

The southern portion of Area 1 contains the existing groundwater extraction and treatment system, which consists of a below grade perforated collection pipe (French drain) and aboveground treatment building. The French drain was installed in 1980/1981 and the alignment runs to the north of the Storm water Clarifier then doglegs to the south of the treatment building and continues for 400 feet parallel to Amrhein Road, ending approximately 80 feet from the eastern edge of Area 1. The collected groundwater was historically treated in the on-site wastewater treatment plants. The

collection/treatment system currently in operation collects groundwater impacted by historical chrome plating operations through the French drain. The current treatment system was constructed in 2000 prior to decommissioning and demolition of the on-site waste water treatment plant. The collected groundwater is treated by pH adjustment with sulfuric acid, followed by addition of sodium bisulfite, recycled solids, lime and polymer flocculent in subsequent tanks, the solids are settled in a clarifier, and the effluent passes through a sand filter prior to discharge. When the treatment system is operating, the water is treated continuously at an average rate of approximately 40 gallons per minute (gpm) and accumulated in a tank following clarification. The initially treated water is then polished through the sand filter in approximately 800-gallon batches and discharged to the DWSD sanitary sewer. Nickel and chromium are precipitated out as sludge and processed in a filter press. The non-hazardous filter cake is collected in a 20-cubic yard roll-off box and disposed of at a local landfill on an as necessary basis (approximately four times per year).

Early RFI data indicated that the French drain may not be fully effective in cutting off the migration of nickel at the eastern edge of the trench. Therefore, a groundwater cut-off barrier wall (soil-bentonite and jet grout) was installed around Area 1 in 2004 to provide complete physical containment. The groundwater treatment system is currently operated approximately 5 days per week to maintain an inward gradient across the Area 1 Barrier wall and to control the off-site migration of impacted groundwater.

2.3 Exposure Pathway/Clean-up Criteria Evaluation

Based on the data collected during historical site characterization activities, exposure pathways were reviewed to identify potentially applicable Part 201 Generic Cleanup Criteria under MDEQ RRD Operational Memorandum No. 1, updated 12/30/2013.

Potentially applicable criteria are based on complete pathways and recognized receptors and are dependent on the current and future land-use of the subject properties. The Eckles Road Site has a Declaration of Restrictive Covenant (DRC) recorded with the Wayne County Register of Deeds limiting it to non-residential land uses and prohibiting the use of groundwater. Therefore, non-residential criteria are applicable for this property and the drinking water pathway is not complete (i.e., criteria protective of the drinking water pathway do not apply). In portions of the property where impacts may migrate across the property boundary, off-Site receptors and pathways are still considered. However, groundwater is not used for drinking water at the properties located downgradient (south/southeast) of Area 1 and the City of Livonia enacted an ordinance in 2009 establishing a Prohibition on Use of Groundwater.

The volatilization to indoor air pathways is considered not applicable at this time and the DRC provides for soil vapor management should an owner want to build a structure in this area; further, metals are not likely to volatilize and therefore indoor air inhalation criteria have not been established for chromium VI or nickel.

The nearest surface water body is Newburgh Lake, located approximately 1/3 mile to the south of the Site. Based on analytical results, which have defined plume boundaries to just south of Area 1, no impacts to surface water bodies have been identified. Furthermore, based on the low levels of impact, the current corrective measures, and the alternative corrective measures being evaluated, it is unlikely that impacted groundwater will reach surface water at concentrations exceeding

groundwater surface water interface (GSI) criteria. Therefore, the GSI pathway is not currently complete and is not expected to become a complete pathway.

3. Groundwater Monitoring

Extensive groundwater quality investigations have been completed in Area 1 as part of the RFI sampling program. RFI groundwater sample results are provided in the RFI Report and Supplement to the RFI Report. Groundwater impacted by chromium and nickel has been delineated. Groundwater quality is currently monitored as described in the Revised Groundwater Monitoring Plan (CRA, April 2008).

3.1 Groundwater Monitoring Results

Annual groundwater monitoring activities were initiated in 2006 and were based on the results of the extensive groundwater monitoring that was conducted before and during the RFI, and the subsequent groundwater monitoring associated with the CA750 determination. These activities are also consistent with the DRC and City of Livonia Groundwater Use Prohibition which restrict groundwater use at the property as identified in the Corrective Measures Proposal (CMP) and Final Decision.

3.2 Area 1 Groundwater Sampling and Results

The Area 1 annual groundwater sampling was completed during September 2015 with additional pilot study sampling completed throughout 2015. Analytical results from 2015 and prior sampling indicates the following:

- Neither total chromium or chromium VI have been detected above generic criteria in off-site monitoring wells.
- Nickel has been detected at the property boundary and off-site monitoring wells at concentrations greater than Part 201 Drinking Water Criteria (DWC) and is delineated by off-site monitoring wells MW-OS-5D, MW-OS-6D, MW-OS-7D, and MW-OS-8D.
- Chromium VI and nickel have been delineated to the north, within the barrier wall, by monitoring wells MW-A1-4S/D, MW-38D-13 and MW-39D-13, MW-40D-13, and MW-A1-3S.

The Area 1 groundwater results from 2015 and recent prior years are summarized on Figure 3.

4. Hydrogeologic Conceptual Site Model

The hydrogeologic conceptual site model (CSM) was developed during the RFI to integrate information from historic and current investigations and identify potential exposure risks. This CSM summarizes the Site geology and hydrogeology.

4.1 Geology

Numerous soil borings and monitoring wells have been completed at the Site. A summary of historical soil borings and monitoring wells are presented in Revision 2 of the Current Condition

Report (CRA, June 2002) (CCR). Additional soil borings and monitoring wells were completed during the RFI and are presented in the RFI Report (CRA, March 2005) and Supplement to the RFI Report (CRA, April 2005). Geologic data from these soil borings and monitoring wells were used to determine the Site overburden geology and hydrogeology.

The subsurface geology in the vicinity of the Site consists of approximately 145 feet of overburden overlying the Antrim Shale bedrock. The Antrim Shale is comprised of hard, dark gray to black or brown, pyritiferous shale that contains abundant silt, making it a confining layer. The shale is generally too impermeable to be an aquifer and the abundance of pyrite restricts the water quality for use as a potable water supply. The shale is located at approximately 145 feet below ground surface (bgs).

The surficial glacial deposits in the area of the Site generally consist of a fine to coarse sand of approximately 22 feet to 28 feet in thickness underlain by a continuous clay layer. The sand unit is comprised of a surficial layer of fill sand that generally varies from 2 to 6 feet in thickness. Below the surficial fill material, the native sand unit is typically poorly graded and interbedded with lenses of coarse sand and gravel to a depth of 22 to 28 feet below ground surface (bgs). The clay layer underlying the glacial sand deposit is approximately 50 feet thick and is a laterally extensive unit that is present beneath the entire Site and throughout the area. The clay is underlain by interbedded gravel, boulders, sands, and clays to approximately 145 feet bgs, to the top of the shale bedrock.

4.2 Hydrogeology

Groundwater exists at the Site at a depth of approximately 5 to 12 feet bgs within the fine to coarse sand, which underlies the Site and generally appears to flow in a southeasterly direction. Groundwater within the Area 1 barrier wall generally appears to flow in a southerly direction towards the French Drain Collection System. Groundwater investigations indicate shallow groundwater at the Site has an approximate saturated thickness of 15 feet. Groundwater in the vicinity of the Site is not used as a drinking water supply.

Slug tests were performed in ten on-Site wells as part of the RFI. The calculated hydraulic conductivity for the surficial water bearing zone is 7.4×10^{-3} centimeters per second (cm/sec). Laboratory permeability tests performed on four soil samples as part of the RFI indicate that the vertical permeability of the continuous clay beneath the Site is 1.55×10^{-8} cm/sec. Based on information obtained from the RFI, the clay aquitard represents a barrier to vertical migration of groundwater.

4.3 Hydrology

No surface water bodies exist at the Site. The nearest surface water bodies are Newburgh Lake located approximately 1/3 mile south of the Site, and the Middle River Rouge located approximately 1/4 mile southwest of the Site.

4.4 Groundwater Use

The Detroit Water and Sewerage Department (DWSD) provides potable water supply for the Site and surrounding areas from the Springwells Plant located in Dearborn, Michigan. The water source for the Springwells Plant is the Detroit River. Groundwater at the Site is not used as a potable water

supply and groundwater use has been restricted at the Site. All properties located within approximately ¼ mile south and southeast of Area 1 (downgradient of Area 1) are serviced by a municipal water supply and there are no known current or historical uses of groundwater located south or southeast of Area 1. Current and historical uses of shallow groundwater in the residential area southeast of the Site were also evaluated as part of the RFI activities. All properties in the residential area southeast of the Site are serviced by a municipal water supply. The City of Livonia enacted a prohibition on the use of groundwater during 2009. Details of the ordinance are presented in the 2009 Annual Report (CRA, January 2010).

Based on documents reviewed, one water supply well historically existed on Site. The water supply well was installed in 1954 and was located approximately 135 feet east of Eckles Road on the west side of the Site. The well was used for the lawn sprinkler system at the Site. This well was 145 feet deep, which is well below the impacted surficial water bearing zone that extends to a maximum depth of 28 feet bgs. The screened interval is unknown but is expected to be below the clay layer that extends to approximately 80 feet bgs. No other information is available for this well however, no other water supply wells have been in use on Site since then.

5. Laboratory Treatability and Field Pilot Studies

A laboratory treatability study was previously performed to determine if a technology existed to reduce chromium and nickel concentrations in groundwater and eliminate or reduce the need for continued pump and treat operations. Following the completion of a successful laboratory treatability study, two iterations of field pilot studies were conducted to evaluate the selected technologies in the field.

5.1 Laboratory Treatability Study

During the laboratory treatability study, sodium dithionite was identified as the most cost effective reagent for the treatment of the dissolved chromium and nickel in the source area at the Site. A sodium dithionite concentration of 1.67 g/L was successfully used to reduce concentrations of dissolved chromium and nickel in Site groundwater by more than 90 percent within less than 72 hours after treatment with the reducing agent. In the presence of representative Site soil, a sodium dithionite concentration of 3.0 g/L was found to be a more effective concentration, achieving over 95 percent reduction in levels of dissolved chromium and nickel.

The chromium and nickel precipitated by treatment with sodium dithionite showed a high degree of stability under aerobic conditions and wide range of pH. Reversal of the precipitation occurred only under severe acidic conditions which are unlikely to occur at the Site due to the high buffering capacity of the Site soil.

Laboratory testing also evaluated the ability of sulfate reducing bacteria to treat chromium and nickel. Groundwater containing dissolved concentrations of chromium and nickel up to 36 mg/L and 2.85 mg/L, respectively was not toxic to sulfate reducing bacteria (SRB). Nutrients already present in the soil and water were adequate to sustain SRB activity. However, it was possible to enhance the growth and activities of the indigenous SRB population with the addition of a suitable carbon source such as molasses (0.4 g/L), or ethyl lactate (0.6 to 1.2 g/L).

Soil column tests performed to imitate actual conditions at the Site showed that the carbon source (0.4 g/L molasses) can be injected with the sodium dithionite to treat toxic concentrations of chromium and nickel using a combination of chemical and biological mechanisms. In this case, sodium dithionite is applied to reduce the toxicity of metals to levels amenable to bioremediation, while the carbon source is used to enhance biological treatment as polishing step. This treatment approach had the potential to achieve significant cost savings.

A field pilot study was recommended based on the results from the laboratory treatability study. Injections of sodium dithionite (5 percent) and an emulsified soy-lactate substrate (5 percent) were proposed in the field pilot study to determine dosage quantity and spacing required for effective Site remediation. Details of the treatability study are presented in the *Field Pilot Test and Full Scale Implementation Work Plan – Area 1 (Chrome Plating Area)* dated August 18, 2010.

5.2 Review of Selected Field Pilot Study Remedial Technologies

Reduction of Chromium and Nickel by Injection of a Reducing Agent

The oxidation states of chromium range from trivalent chromium (CrIII) to hexavalent chromium (CrVI), but only the CrIII and CrVI states are stable under most natural water conditions. CrVI is known to be toxic to humans, animals, and plants and is more mobile in the environment than CrIII. Conversely, CrIII is less toxic and readily precipitates as $\text{Cr}(\text{OH})_3$ under alkaline or even slightly acidic conditions. Therefore, reduction of CrVI to CrIII is a viable option for treatment of sites impacted with CrVI and can be accomplished by several methods.

In-situ geofixation of chromium is the process of introducing a suitable reducing chemical reagent into the subsurface to reduce CrVI to CrIII. The reduced chromium would be stable because it undergoes geochemical fixation onto the aquifer solids. Reagents such as calcium polysulfide, sodium dithionite, and sodium bisulfite can be used for the geofixation of chromium. The reduction of the chromium can be monitored by collection of groundwater samples. If the samples are yellow, CrVI is still present. If the yellow color disappears, chromium is being reduced. A blue or green color may be observed in the treated groundwater. Also, gray groundwater with a black precipitate is indicative of reducing conditions (sulfide formation) and suggests that chromium has been reduced.

The reaction of nickel with a reducing agent is different from the chromium reaction. In situ chemical reduction (ISCR) of nickel occurs when a sulfur containing reducing chemical reagent is injected into the subsurface. Nickel reacts with this reagent to form nickel sulfide. Nickel sulfide is insoluble and precipitates from groundwater. Nickel sulfide is stable because it undergoes geochemical fixation onto organic material in the soil matrix. As with chromium reduction, reagents such as calcium polysulfide, sodium dithionite, and sodium bisulfite can be used for the chemical precipitation of nickel.

Reduction of Chromium and Nickel by Enhanced Anaerobic Conditions

In this procedure, CrVI is chemically reduced by biological creation of reducing conditions. An organic substrate, typically a lactate, molasses or soy-lactate mixture is added and stimulates the growth of aerobic and anaerobic bacteria. These bacteria use up available electron acceptors such as oxygen, nitrate and sulfate which causes the oxidation-reduction potential (ORP) of the area to drop. Under these reducing conditions CrVI is chemically reduced to CrIII. CrIII readily precipitates

out of the groundwater under normal pH ranges. The organic substrates (lactate, molasses, or soy-lactate) are relatively low cost and are effective in creating reducing conditions.

The process for nickel precipitation is similar. Under anaerobic conditions sulfides are produced by sulfate reducing bacteria (SRB). Under reducing conditions these sulfides react with nickel to form nickel sulfide which precipitates from the groundwater as described above.

5.3 Field Pilot Study - 2010

A field pilot test was performed in order to determine the effectiveness of the technology selected in the laboratory treatability study. The objective of the field pilot test was to determine the effectiveness of ISCR for accelerated groundwater treatment to reduce groundwater concentrations within Area 1 at the Site. In November 2010 a field pilot test was performed by injecting 400 gallons of a solution containing 5 percent sodium dithionite, 5 percent emulsified soy-lactate, and 0.1 percent sodium bromide (as a tracer) into each of two injection wells located in Area 1 of the Site. An evaluation of this study was reported in a memorandum (CRA, August 2011). The results of this study suggested that sodium dithionite was effective in reducing groundwater concentrations of dissolved hexavalent chromium and nickel in the areas it contacted. The data suggested that the sodium dithionite was primarily consumed within a 10-foot radius of the injection well; therefore, decreases in dissolved hexavalent chromium and nickel concentrations were not observed outside this area. No effects of the emulsified vegetable oil (EVO) were observed during the 3-week monitoring period; however, SRB grow slowly, therefore, the effects of the EVO injection would not be expected after such a short time. Dispersion of the injected material was fast, dispersing up to 20 feet downgradient within the 3-week monitoring period.

Based on this study, it was recommended that for future injection events, the sodium dithionite injection concentration should be increased to 20 percent in order to deliver more reducing agent to the area. The combination of EVO with the injected chemicals led to foaming and difficulty during injections. If EVO were to be used, it would need to be applied during a separate injection event and may require multiple applications. Since a downgradient permeable reactive gate was planned, it was also recommended that the biological component of the treatment (EVO) be eliminated since polishing would occur at the permeable reactive gate. Additional detail is provided in the August 2011 memorandum.

5.4 Field Pilot Study - 2013

A second pilot study was performed in November 2013 to evaluate the use of direct push technology and the increased concentration and volume of sodium dithionite solution. Eight hundred gallons of a 20 percent sodium dithionite solution was injected on November 13, 2013, via direct push technology, in the vicinity of the previous pilot location (IW-A1-1) at the Site. Monitoring was performed prior to and after the injection. GHD's Innovative Technology Group (ITG) was requested to review the data from the second pilot study monitoring events, evaluate dissolved hexavalent chromium and nickel treatment, and suggest future treatment options.

Groundwater Monitoring

Baseline groundwater monitoring was performed on November 7, 2013, prior to the second pilot study injection. The first post-injection monitoring event took place 1 week after the injection on

November 20/21, 2013. The second post-injection monitoring event was performed 3 weeks after the injection on December 4, 2013, and the third post-injection monitoring event was performed 12 weeks after the injection on February 4, 2014. An additional post-injection monitoring event was performed 11 months after the injection on October 1, 2014.

Samples were collected from six monitoring wells in the injection area.

The injection was performed at injection well IW-A1-1. Observation well OW-24 is located approximately 5 feet upgradient of the injection well, and monitoring wells MW-A1-17, MW-A1-18, and MW-A1-19 are located 10 feet, 20 feet, and 30 feet downgradient, respectively. Side gradient wells MW-36D-13 and MW-37D-13 are located to the east of the downgradient wells. Well MW-36D-13 is offset from well MW-A1-17 by approximately 5 feet, and well MW-37D-13 is offset from well MW-A1-18 by approximately 10 feet. The wells are shown on Figure 4.

Assessment of Groundwater Monitoring Results

Chromium

Decreases in total chromium, dissolved chromium, and hexavalent chromium were observed at wells MW-A1-17, MW-A1-18, and MW-A1-19, which are located immediately downgradient of the injection well. At well MW-A1-17, the concentration of hexavalent chromium was reduced to less than 0.01 milligram per liter (mg/L), a greater than 99.9 percent removal, and the concentrations of total and dissolved chromium were reduced to less than 3 mg/L, a 99 percent removal. At this well, a reduction in chromium concentrations was observed at the 1-week post-injection monitoring event and was sustained throughout the 11-month monitoring period. At MW-A1-18, the reduction in chromium concentrations was not observed until the 3-week post-injection monitoring event and at MW-A1-19, the reduction was not observed until the 12-week post-injection monitoring event. These time lags represent the time required for the injected material to migrate downgradient and reach the wells that are further downgradient. At MW-A1-18, hexavalent chromium was reduced to non-detect levels, a greater than 99 percent removal, and concentrations of total and dissolved chromium were reduced to 5 mg/L, a 94 percent removal at the 3-week post-injection monitoring event and had rebounded slightly to 13 mg/L, a 84 percent removal by the 12-week post-injection monitoring event, but decreased again to 4 mg/L, a 95 percent removal over the 11-month monitoring period. At MW-A1-19, hexavalent chromium was reduced to 25 mg/L, a 81 percent removal, and total and dissolved chromium were reduced to 55-59 mg/L, a 60 percent removal after 3 months, but rebounded to 130 mg/L after 11 months. The greater chromium reductions observed at the closer wells indicated that due to consumption and dispersion, a weaker sodium dithionite solution reached the wells that were further downgradient and, therefore, chromium removal was less effective.

At the upgradient and side gradient wells, OW-24, MW-36D-13, and MW-37D-13, less chromium removal was observed. At well OW-24, the concentration of total and dissolved chromium increased after the injections but had returned to close to baseline levels by the 12-week post-treatment sampling event. Decreases in concentrations of hexavalent chromium were observed at this well, however, these concentrations fluctuated. Transient increases in total and dissolved chromium coupled with transient decreases in hexavalent chromium were also observed at wells MW-36D-13 and MW-37D-13. The increases in total, dissolved, and trivalent chromium observed immediately after the injections may be due to suspension of trivalent chromium in the water column due to

perturbation during the injection. The concentrations decreased with time, which supports this conclusion.

These data suggest that the sodium dithionite was effective for the precipitation of chromium and that the injected material moved downgradient with little lateral dispersion.

Nickel

Increases in nickel concentrations after the injections were observed in the closest downgradient wells MW-A1-17 and MW-A1-18. These concentrations did not drop until the 11-month post-injection monitoring event. An increase was also observed at well MW-A1-19. By the 11-month post-injection sampling event, the nickel concentration had increased to 160 mg/L at this location. Additional details on nickel concentrations are presented in the Area 1 Expanded Pilot Study Work Plan (CRA, February 2015).

For the upgradient and side gradient wells, no change in the concentrations of total and dissolved nickel were observed at well OW-24 during the monitoring period. Slight increases in nickel concentrations were observed in wells MW-36D-13 and MW-37D-13.

These data suggest that nickel was not treated effectively by the sodium dithionite injection. Nickel concentrations were generally an order of magnitude lower than chromium concentrations, and it is possible that more chromium treatment was observed due to the sodium dithionite being preferentially consumed by the higher chromium concentrations. Laboratory treatability study data also suggested that sodium dithionite was more effective for chromium precipitation than nickel precipitation.

Bromide, Sulfate and Sulfide

Bromide was injected during the injection event as a conservative tracer to track the flow of the injected material. Bromide was detected in downgradient wells, MW-A1-17, MW-A1-18, and MW-A1-19. For each of these wells, bromide was detected at the same monitoring event that showed a drop in chromium concentrations. These data indicated that when the injected material reached the well, the chromium concentration decreased. Bromide was detected at well MW-A1-17 at the 1-week post-treatment monitoring event, at well MW-A1-18 at the 3-week post-treatment monitoring event, and at MW-A1-19 at the 12-week post-treatment monitoring event. Bromide was not detected at either the upgradient or side gradient wells, which supported the conclusion drawn from the metals data that little of the injected material reached these wells.

Increases in sulfate and sulfide concentrations were observed in the downgradient wells. The increases in sulfate and sulfide in these wells coincided with the detection of bromide and with the reductions in chromium concentrations. Increases in sulfate and sulfide concentrations were not observed in the upgradient or side gradient wells.

Field Data

Field data including pH, oxidation-reduction potential (ORP), conductivity, and turbidity were monitored during the pilot study. A slight decrease in pH was observed in the downgradient wells. In well MW-A1-17, the pH dropped from 6.9 standard units (S.U.) prior to the injections to 6.1 S.U. at the 12-week post-treatment monitoring event. Decreases of smaller magnitudes were observed in

wells MW-A1-18 and MW-A1-19. Sodium dithionite can result in a decrease in pH and was present at the highest concentration at the closer downgradient wells, resulting in the observed decrease. The pH did not decrease to levels that would limit microbial activity. No significant change in pH was observed in the upgradient or side gradient wells.

Decreases in ORP to negative levels were observed in the closer downgradient monitoring wells MW-A1-17 and MW-A1-18. Sodium dithionite is a reducing agent and at high concentrations can result in significant decreases in ORP. These decreases showed that the sodium dithionite was concentrated enough to cause an ORP reduction when it reached wells MW-A1-17 and MW-A1-18. Decreases in ORP were not observed at MW-A1-19 or the upgradient or side gradient wells, indicating that sufficient sodium dithionite to cause this change did not reach these wells.

Slight increases in conductivity were observed at the wells closest to the injection wells showing the presence of the sodium dithionite salt. Turbidity results were consistent over the monitoring period with the exception of the two monitoring wells directly downgradient of the injection location; the turbidity slightly increased in MW-A1-17 at the 1-week post-treatment monitoring event and significantly increased in monitoring well MW-A1-18 at the 11-week post-monitoring event.

Observations

- The injected material moved downgradient with apparently little lateral dispersion.
- The dose of 800 gallons of 20 percent sodium dithionite solution was sufficient to achieve some treatment of chromium up to 30 feet downgradient.
- Injected material reached the 30-foot downgradient well within 12 weeks of the injection.
- A slight drop in pH was observed as a result of the sodium dithionite injection.
- Little nickel treatment was observed due in part to the kinetics of treatment of nickel, which was present at a much lower initial concentration than chromium, and, in part, because sodium dithionite is more a effective treatment for chromium than nickel.

Conclusions and Recommendations

The results of the field pilot study suggested that sodium dithionite was very effective in reducing groundwater concentrations of hexavalent chromium but less effective in reducing the concentration of dissolved nickel. Based on the pilot study results, a downgradient well spacing of 25 feet and a side gradient well spacing of 10 feet would be recommended. The dose of 800 gallons of 20 percent sodium dithionite was sufficient to achieve treatment at this spacing although if the well would accept a greater volume, more material could be injected.

Additional activities were recommended to verify that sufficient treatment of nickel is occurring. A further monitoring event for the 2013 pilot study conducted in October 2014 indicated that nickel concentrations had not decreased to pre-injection levels at the monitoring points downgradient of the injection point. Additional or alternative reagents are recommended for the treatment of nickel-impacted groundwater.

Treatability study testing performed for ex situ treatment of chromium in groundwater at this Site has shown that sodium sulfide is effective for the precipitation of nickel and chromium and that a combination of sodium dithionite and sodium sulfide can be effective for the irreversible precipitation

of both chromium and nickel. Therefore, it was recommended that the new study be performed to test sodium sulfide alone and a combination of sodium dithionite and sodium sulfide. The spacing of injection and monitoring wells should be similar to the second pilot study. Eight hundred gallons of a solution containing 20 percent sodium dithionite and 29 percent sodium sulfide would be injected into each injection wells where both reagents are to be used. Therefore, 1320 pounds of sodium dithionite and 2000 pounds of sodium sulfide would be required. Pretreatment and post-treatment monitoring should be performed. It was recommended that a new pilot study be performed in the north portion of Area 1 to test the individual and combined effectiveness of the sodium dithionate and sodium sulfide at reducing chromium VI and/or nickel concentrations in groundwater. Several direct injection techniques will also be evaluated with each of the chemical combinations in various locations of the expanded pilot study to evaluate the effective radius of influence of each.

5.5 Expanded ISCR Field Pilot Study

The Expanded ISCR Field Pilot Study took place in the northern portion of Area 1 from May to June 2015. Expanded Pilot Study activities were conducted in general accordance with a U.S. EPA-approved Area 1 Expanded Pilot Study Plan (CRA, February 2015). A description of the activities conducted, including field adjustments, and results of the Expanded Pilot Study are provided in a Draft Area 1 ISCR Pilot Study Summary Report (GHD, January 2016). A review of the recently received six month post-injection monitoring results is provided in Attachment A. Pilot Study injection and monitoring locations are provided on Figure 4. The pilot study area consisted of three sub-areas as follows. Sub-area A is the western side exhibiting elevated dissolved hexavalent chromium (CrVI) in groundwater. Sub-area B is the central portion exhibiting both nickel and chromium in groundwater, and Sub-area C had elevated nickel in groundwater. Twenty four additional monitoring wells (MW42D-15 through MW65D-15) were installed to supplement the existing monitoring well network and provide sampling locations to evaluate the effectiveness of the chemical injections and the radius of influence of the injection technologies. Groundwater samples were collected prior to injection, and 1 week, 3 weeks, 3 months, and 6 months following completion of injection for analysis of total and dissolved metals (chromium, iron, manganese, nickel, and sodium), chromium VI, bromide, sulfate, and sulfide. Field parameters were measured during sampling for pH, conductivity, temperature, turbidity, dissolved oxygen, and ORP. Real-time monitoring of the field parameters was conducted at eight locations using down-hole YSI EX01 Multiparameter Sondes that recorded real-time field data before, during and after the chemical injections.

Injections consisted of direct injection of 20 percent sodium dithionate solution, 29 percent sodium sulfide solution, or a combination of the two compounds at 83 injection locations across this area to assess the effectiveness of treatment. A bromide tracer was also added to the injection solution to monitor the spread of the solution subsurface over time. Two different injection methods were evaluated during this pilot study to determine whether one was more effective than the other.

During the expanded field pilot study, the two reagents for treatment in the Cr/Ni area were mixed into the same 800 gallons of water, yielding approximately 975 gallons of solution. The volume of reagent in the water led to some settling of undissolved reagent or precipitation of residual solids, possibly due to the usage of the treated Groundwater Treatment Plant effluent as a water source. To avoid this during the full scale ISCR program, a potable water supply should be used for mixing

the injection solution, or an evaluation of effluent quality will be completed to verify if the effluent is suitable for use and will only produce minimal solids/sludge during mixing of the injection solution.

In addition, 22 Electrical Conductivity (EC) borings were completed in the vicinity of various injection locations at varying directions (typically down-gradient and cross-gradient) around five sodium sulfide injection points to identify sodium as an indicator of the presence of sodium sulfide to determine the effectiveness of the injection systems.

The results of the expanded ISCR Field Pilot Study are summarized below.

The expanded ISCR Field Pilot Study results and conclusions are detailed in the Area 1 ISCR Pilot Study Summary Report.

Injection Summary

Sub-Area A

In the western half and southern portion of Sub-Area A, the injection interval was from approximately 15 to 25 feet bgs and targeted lower concentrations of Cr. At each of 12 direct push locations, 840 gallons of a 20 percent sodium dithionite solution were injected over the 10 foot injection interval. The solution consisted of 1,320 pounds of sodium dithionite and 800 gallons of water.

In the central portion, the targeted injection interval was from approximately 15 to 25 feet bgs for higher concentrations of Cr. At each of six direct push locations, 900 gallons of a 29 percent sodium sulfide solution were injected over the 10-foot injection interval. The solution consisted of 2,000 pounds of sodium sulfide and 800 gallons of water.

In the northeastern portion of Sub-Area A, the injection interval was from approximately 15 to 25 feet bgs and targeted higher concentrations of Cr. At each of five direct push locations, 975 gallons of a 20 percent sodium dithionite and 29 percent sodium sulfide solution were injected over the 10-foot injection interval. The solution consisted of 1,320 pounds of sodium dithionite and 2,000 pounds of sodium sulfide mixed into 800 gallons of water.

Sub-Area B

In the northwestern portion of Sub-Area B, the injection interval was from approximately 15 to 25 feet bgs and targeted dissolved Cr and Ni in groundwater. At each of seven direct push locations, 975 gallons of a 20 percent sodium dithionite and 29 percent sodium sulfide solution were injected over the 10-foot injection interval. The solution consisted of 1,320 pounds of sodium dithionite and 2,000 pounds of sodium sulfide mixed into 800 gallons of water.

In the southwestern portion of Sub-Area B, the injection interval was from approximately 15 to 25 feet bgs to treat dissolved Cr and Ni in groundwater. At each of six direct push locations, 840 gallons of a 20 percent sodium dithionite solution was injected over the 10-foot injection interval. The solution consisted of 1,320 pounds of sodium dithionite and 800 gallons of water.

In the eastern portion of Sub-Area B, the targeted injection interval was from approximately 15 to 25 feet bgs to treat dissolved Cr and Ni in groundwater. At each of 13 direct push locations,

900 gallons of a 29 percent sodium sulfide solution were injected over the 10-foot injection interval. The solution consisted of 2,000 pounds of sodium sulfide and 800 gallons of water.

Sub-Area C

In the entire portion of Sub-Area C, the injection interval was from approximately 15 to 25 feet bgs to treat dissolved Ni in groundwater. At each of 34 direct push locations, 900 gallons of a 29 percent sodium sulfide solution were injected over the 10 foot injection interval. The solution consisted of 2,000 pounds of sodium sulfide and 800 gallons of water.

Two different injection methods were used in this area. Injections were completed at 20 locations on the western side with a Geoprobe® utilizing a 42-inch screen. On the eastern side, 14 locations were completed by Superior Drilling using the Badger system, a proprietary system which claims advanced injection technology using pore space dilation and downhole monitoring of pore-space pressures to maximize radius of influence, chemical distribution, and rates of injection.

Groundwater Monitoring

Groundwater monitoring was conducted to monitor the effectiveness of the ISCR Field Pilot Study and alternative injection technologies. Prior to initiating the injection activities, one round of baseline groundwater monitoring was completed to establish the initial constituent concentrations at 33 wells across the northern portion of Area 1. Following chemical injections, groundwater monitoring was conducted at these same locations at 1 week, 3 weeks, and 3 months post-injection.

Groundwater quality parameters collected during purging included pH, conductivity, temperature, turbidity, dissolved oxygen, and ORP. Samples were collected for laboratory analysis of total and dissolved metals (chromium, iron, manganese, nickel, and sodium), chromium VI, bromide, sulfate, and sulfide.

In addition to the field parameters monitored during the post-injection groundwater sampling events, 8 YSI EX01 Multiparameter Sondes were utilized within the monitoring wells that recorded real-time field data before, during and after the chemical injections. The Sondes were programmed to collect field data every 15 minutes for temperature, conductivity, specific conductivity, pH and ORP. The sondes were placed first into eight eastern monitoring wells (MW54D-15 through MW61D-15) from May 15, 2015 to June 16, 2015. Two sondes malfunctioned during this period. The remaining six sondes were placed into the western monitoring wells (MW42D-15, MW44D-15 through MW47D-15 and MW49D-15) from June 17, 2015 to July 6, 2015.

Results

A detailed summary of chromium and nickel concentration reductions within the monitoring network is provided in the attached *Review of In Situ Chemical Reduction Field Pilot Study Monitoring Data 13000 Eckles Road Site, Livonia, Michigan* memorandum, included as Appendix E of the Summary Report. The following section will provide a brief overview of results from the pilot study.

Injection Technique

Based on the EC data presented in Appendix D of the Summary Report, the SP 16 with the 42-inch long screen and the Badger System equally dispersed the chemical solutions into the formation. It

appears that neither technique was better at the horizontal or vertical dispersion. The EC boring logs show the sodium sulfide solution had an approximate 5-foot vertical dispersion range (approximately 19 to 24 feet bgs) and the horizontal range extended to approximately 10 feet (and occasionally 15 feet) beyond the injection point immediately after the injection activities (EC borings were completed 1-2 days following injections).

MW54D-15 thru MW57D-15 were installed in the center of the injection area completed by GHD and MW58D-15 thru MW61D-15 were installed in the center of the injection area completed by Superior to allow for evaluation of the different injection techniques in Sub-Area C. As shown on Figure 4, nickel concentrations in both well groupings were reduced following the injections.

Chemical Distribution

A radius of influence of 15 feet was achieved through both injection techniques as identified by groundwater sample results from monitoring wells as a result of additional dispersion and groundwater migration that occurred following the radius of influence evaluation utilizing the EC borings. . Reductions in chromium and nickel were observed in monitoring wells within close proximity of the injection locations. Additionally, EC borings completed near injection points confirmed increased EC readings were present within 15 feet of injection locations. Analytical results indicate injection material reached 25 feet downgradient during the 3-week post-injection sampling event. Reductions in metals concentrations were observed in some downgradient monitoring wells up to 60 feet away from the injection point by the 3-month post-injection sampling event.

Bromide was injected along with the reagent during the injection event as a conservative tracer to track the flow of the injected reagents. A high detection limit was encountered for bromide analysis due to the high concentrations of sulfate and sulfide in the groundwater samples. Therefore there were few detections of bromide and bromide was not a good indicator of reagent distribution.

Total and Dissolved Metals

The sodium sulfide and sodium dithionite/sodium sulfide mixtures were effective in reducing groundwater concentrations of dissolved chromium and dissolved nickel. It appears that the sodium sulfide solution alone was not effective at reducing elevated concentrations of dissolved chromium. There are no monitoring wells located in the immediate areas where the sodium dithionite only solution was injected to treat chromium-impacted groundwater as that was evaluated during previous pilot studies.

In general, dissolved chromium and nickel concentrations were reduced to below the 0.1-milligram per liter (mg/L) screening criteria in the middle of the treatment area while untreated areas remained at the periphery of the treatment area. Total metals results were generally higher than their associated dissolved metals concentrations indicating insoluble metals may not have precipitated out of or remained as suspended solids in the groundwater when samples were collected.

Results

As presented in the Summary, analytical results show a sodium dithionite/sodium sulfide mixture is effective in reducing groundwater concentrations with a mixture of dissolved chromium and dissolved nickel. Treatment of chromium and nickel-impacted groundwater was observed 15 feet

from injection points and up to 25 feet downgradient in the month after the injections and up to 67 feet from the injection points 3 months after the injections.

Based on the observed 15-foot radius of influence, a 30-foot side-gradient and downgradient spacing is recommended for injection points for the full-scale application. Treatment with 800 gallons of 29 percent sodium sulfide is recommended for the areas with nickel impacts and areas where chromium concentrations are less than approximately 1 mg/L. A mixture of 20 percent sodium dithionite and 29 percent sodium sulfide is recommended for the areas where both chromium and nickel concentrations are elevated.

Analytical results indicate a sodium sulfide solution was not effective in reducing groundwater with elevated chromium concentrations greater than approximately 1 mg/L. For areas with elevated chromium concentrations and no nickel impacts, a 20 percent sodium dithionite solution is recommended for full-scale application.

Thirteen injections points were completed by Superior utilizing the Badger injection system adjacent to an area where a traditional direct push injection technique utilizing a 42-inch long screen was utilized. Monitoring wells MW54-15 thru MW61-15 were used to compare injection techniques. Analytical results from each grouping of wells show both technologies were effective at significantly reducing the concentration of nickel in groundwater surrounding the injection points. The Badger injection system was able to inject the mixed solution at a greater rate than the traditional method, and Superior believed they would have had a greater radius of influence than what was identified in the field if they had more solution available to inject at each point. This anticipated result may also be applicable to the traditional injection method completed at the remainder of the injection points. Based on the results of the field evaluation of the injection techniques, the pilot study was inconclusive on determining the most effective injection technique. Further consideration of injection method cost, effectiveness, and time were recommended to be completed when developing the full-scale application work plan and bidding process.

Mixing of the sodium dithionite and sodium sulfide in batch volumes for one injection was a time-consuming portion of pilot study and consideration should be given to ensure it is not a limiting factor during full-scale implementation. Make-up water for the injections was sourced from the groundwater treatment plant treated effluent and the chemistry of the treated water is believed to have contributed to difficulties mixing the injection solution. Saturation of the combined solution may have also occurred.

A downgradient permeable reactive barrier (PRB) is being considered for this Area. A potential reactive matrix for the PRB is zero valent iron (ZVI). ZVI creates reducing conditions therefore treatment using the chemical reducing agents sodium sulfide and sodium dithionite would be compatible with this technology. If conditions in the groundwater reaching the PRB were already reducing, the life of the PRB would be extended since less of the ZVI would be oxidized. Residual sulfate from the injections is likely to be reduced to sulfide via abiotic and biological mechanisms in and around the ZVI PRB leading to a decrease in sulfate concentrations at the PRB. However it is expected that the amount of ZVI consumed by the sulfate will be minimal since biological sulfate reduction will be the primary mechanism. However, the sulfide would precipitate from the groundwater. Since sulfide particles are very small, it is not expected that the sulfide would clog the PRB. Residual sulfide from the injections would likely not reach a downgradient PRB due to its low

solubility in water. The primary risk that the sodium sulfide and sodium dithionite injections would pose to a ZVI PRB would be from the increased turbidity in the groundwater which could result in a lowering of the permeability of the PRB. For this reason it is recommended that the injections are not performed within 75 to 100 feet upgradient of the potential locations for PRBs. At a distance of 75 to 100 feet from the injection locations, the turbidity would have abated sufficiently that the permeability of the PRB would not be affected.

The full scale ISCR program should be implemented as described below.

6. Full Scale ISCR Program

The Full Scale ISCR Program will include the direct injection of sodium dithionite and/or sodium sulfide into as many as 147 injection locations, and the collection and analysis of groundwater samples in and downgradient of Area 1. The proposed injection locations are presented on Figure 5. The ISCR activities will be concentrated in three specific areas of Area 1 as follows: A) groundwater impacted with only chromium VI in the western portion of Area 1, B) groundwater impacted with both chromium VI and nickel in the central portion of Area 1, and C) groundwater impacted with only nickel in the eastern portion of Area 1. Additionally, supplemental injections will be conducted in the vicinity of monitoring wells MW-42D-15 through MW-45D-15 to target chromium VI as the previously conducted pilot study injections were ineffective.

The area treated during the 2015 Expanded Pilot Study across the northern portion of Area 1 is considered remediated, with the exception of the central portion of Sub-area A (in the vicinity of monitoring wells MW-42D-15 through MW-45D-15), where the treatment with sodium sulfide only did not achieve effective reduction of the dissolved chromium VI concentrations. Four additional injection points will be added in this area to inject sodium dithionite solution and provide additional treatment for chromium VI.

Approval for this full scale injection program will also be requested from the MDEQ to satisfy R 323.2210(u)(iii) of Part 22 – Groundwater Quality Rules.

6.1 Monitoring Well Installation

In addition to the existing monitoring network, 15 new monitoring wells will be installed in Area 1 to supplement the existing monitoring well network and provide sampling locations to evaluate the effectiveness of the chemical injections. Monitoring wells will be screened to sit on top of the clay layer, from approximately 15 to 25 feet bgs. The new monitoring wells will be developed prior to baseline sampling and prior to any injection events. The proposed monitoring network wells are shown on Figure 5.

6.2 ISCR Injections

A conceptual design of Full Scale ISCR treatment activities utilizing sodium dithionite and sodium sulfide was developed based on the previous treatability studies and field pilot studies, primarily the Expanded Field Pilot Study conducted in 2015. The design will include treating three areas previously identified as:

Sub-Area A chromium VI only (western portion of Area 1)

Sub-Area B elevated chromium VI (greater than 1 mg/L) and nickel, (central portion of Area 1), and

Sub-Area C chromium VI less than 1 mg/L and nickel and nickel only impacted areas (eastern portion of Area 1) as identified on Figure 5).

The volume of water and the quantities of chemicals included in the injected material may be adjusted based on field conditions, solubility of treatment chemicals, and the ability of the aquifer to accept the injected material.

The full scale ISCR injection will consist of one injection event. As both the direct push and Badger injection methods effectively injected the solutions, a particular method is not specified as part of this plan. It is anticipated that a base scope of work will be identified for bidding purposes and the injection method will be required to be identified by the bidder. The bidders will also be given the opportunity to propose alternate approaches or modifications to the base scope of work, and those alternates/modifications could include alternate injection procedures, methods, spacing, etc. that can be evaluated and considered to allow for an overall cost-effective implementation. A total of approximately 147 injection points are proposed for full scale ISCR injection, and an additional four to five injection points will be placed in the central western portion of sub-area A (from the Expanded Field Pilot Study) where the injection of sodium sulfide alone was not effective in reducing the higher concentrations of CrVI. Figure 5 shows the proposed injection locations.

In the CrVI area (Sub-Area A), 22 injection points are proposed, plus the additional 5 injection points in the previously treated pilot study area. In the combined elevated Cr/Ni area (Sub-Area B) there are 62 injection points proposed, and there are 63 locations proposed in the low Cr/Ni and Ni only area (Sub-Area C). Location and spacing of the injection points may vary depending on field conditions. Injection points are not currently planned in an approximate 100-foot buffer zone upgradient of the existing French drain collection system as part of the full-scale ISCR activities; however, supplemental injection points may be warranted following cessation of GWTP operations. Additionally, injection points are not currently planned as part of the full-scale ISCR activities within approximately 75 feet of the southern slurry wall alignment to avoid potentially impacting future PRB locations. Supplemental injection points may be warranted following evaluation of performance monitoring results or selection of final PRB gate locations. The proposed design for the full scale injection point locations is based on the field pilot studies and represents a radius of influence of 15 feet in the lateral direction (east-west) and 30-foot spacing downgradient (south) as shown on Figure 5. A summary of the proposed ISCR program for Sub-Areas A, B, and C is described below:

Sub-Area A

- To treat the elevated CrVI in the groundwater of this area, approximately 840 gallons of a 20 percent sodium dithionite solution consisting of 1320 pounds of sodium dithionite dissolved in 800 gallons of water will be injected into a 10-foot thick interval from approximately 15 to 25 feet bgs at a total of 22 locations. The portion of Sub-Area A treated during the pilot study with sodium sulfide alone will be re-treated as described above with sodium dithionite solution at an additional four to five locations.

Sub-Area B

- To treat the elevated Cr and Ni in the groundwater in Area B, approximately 975 gallons of a 20 percent sodium dithionite/ 29 percent sodium sulfide solution consisting of 1320 pounds of sodium dithionite and 2000 pounds of sodium sulfide dissolved into 800 gallons of water will be injected into a 10-foot thick interval from approximately 15 to 25 feet bgs at a total of 62 locations.

Sub-Area C

- To treat the low Cr/Ni and Ni only area (Sub-Area C), approximately 900 gallons of a 29 percent sodium sulfide solution consisting of 2000 pounds of sodium sulfide dissolved into 800 gallons of water will be injected into a 10-foot thick interval from approximately 15 to 25 feet bgs at a total of 63 locations.

If multiple injection points are completed simultaneously, it is recommended they not be performed in adjacent locations to avoid increased potential for daylighting or increased injection time. All injection points shall be appropriately abandoned by grouting via tremie method to prevent preferential pathways for future daylighting of injected material or for any surficial spills or infiltration into the saturated zone.

6.3 Chemical Storage and Handling

Both reagents are strong reducing agents which have a number of incompatibilities, including contact with moisture. Sodium Dithionite is also on the Chemical Facility Anti-Terrorism Standards Appendix A list which may require notification of the Transportation Security Administration for purchase, receipt, and storage of certain threshold quantities of material. For sodium dithionite, any commercial grade applies, and if the quantity requires placarding for transportation, the chemical must be reported to The US Department of Homeland Security. In the case of Sodium Dithionite, placarding is required for any amount over 1,000 lbs.

Provisions will be made for storage of the large amounts of reagent in a secure, well ventilated, dry, indoor facility having adequate spill protection and fire protection equipment and procedures in place. In total, it is anticipated that approximately 117,480 pounds of sodium dithionite and 250,000 pounds of sodium sulfide are required for the ISCR injection program.

The contractor selected for the ISCR injection should demonstrate prior experience with storage, handling and application of these chemicals, and should provide, as part of their response to the RFP, their procedures and their plan for implementing a program of this size, including chemical storage, chemical handling, emergency plans for spill control and fire, PPE, mixing procedure, and injection procedure.

7. Performance Monitoring Plan

7.1 ISCR Groundwater Monitoring

In order to monitor the effectiveness of the ISCR Program, groundwater performance monitoring will consist of collection of groundwater samples from 18 existing monitoring wells and the 15 new monitoring wells located within the areas of injection as shown on Figure 5.

Based on the ISCR injection objective, the groundwater monitoring program will provide data to evaluate the injection effectiveness. Results of the Baseline and Post-Injection Monitoring will be used to assess the effective reduction in Cr and Ni levels resulting from the ISCR injections for the remaining areas of Area 1 to determine whether additional ISCR injections may be required and where. The planned monitoring network for the ISCR injections is presented on Figure 5.

Baseline Monitoring

One round of baseline monitoring will be completed to establish the constituent concentrations prior to implementing the ISCR activities. The baseline monitoring will consist of groundwater sample collection from 18 existing and 15 proposed monitoring wells within the injection area. Groundwater samples will be analyzed for total and dissolved metals (chromium, iron, manganese, nickel, and sodium), chromium VI, sulfate, and sulfide. Low-Flow sampling techniques will be used to collect the groundwater samples. Each monitoring well will be purged at approximately 100-200 milliliters/minute in accordance with low-flow protocols. Field analyses of the purge water will consist of pH, conductivity, temperature, turbidity, dissolved oxygen, and ORP (groundwater quality parameters). These field parameters will be monitored during purging to ensure stabilization of the groundwater within each monitoring well prior to sampling. The analytical results will be used to establish a baseline for metals, general chemistry, and groundwater quality parameters.

Post-Injection Monitoring

The same monitoring well network will be sampled 3 months following completion of the injection program. The monitoring wells will be sampled as described above for the parameters listed above. Any future monitoring will be proposed after evaluation of the 3 month post-injection sampling results.

Sample collection or monitoring of groundwater quality parameters during injection activities may occur at select interior wells as a check on effectiveness while the program is ongoing. The need for these samples will be determined in the field.

7.2 Reporting

A full scale ISCR summary report will be prepared following the injection event to document the activities completed and any recommendations at that point. A 3 month post-injection groundwater technical memorandum will be prepared to document the data obtained, the findings, and any recommendations at that point.

Following completion and evaluation of the 3-month post-injection groundwater monitoring, the Site groundwater flow and contaminant transport model will be updated with the most current

groundwater data to assist in finalizing the size, location, and ZVI content of proposed PRBs, which will allow for treatment of any residual groundwater impacts and eliminate the requirement to operate the GWTP.

8. Schedule

The following general sequence of events and target dates are anticipated for implementation of the proposed full scale ISCR activities:

<i>Task:</i>	<i>Target Date:</i>
Meet with U.S. EPA to review this Work Plan	April 2016
Order ISCR Supplies and begin Subcontractor procurement (Initiated upon preliminary U.S. EPA approval April, 2016)	April/May 2016
Install New Monitoring Wells and Implement Baseline Monitoring (Dependent upon receipt of U.S. EPA approval)	July/August 2016
ISCR Injections (Dependent upon receipt of U.S. EPA and MDEQ approvals, and receipt of chemicals)	September/October 2016
Post-ISCR Injection Sampling	December 2016/January 2017
ISCR Implementation Summary Report	March 2017
3 Month Post-Injection Monitoring Technical Memo	March/April 2017

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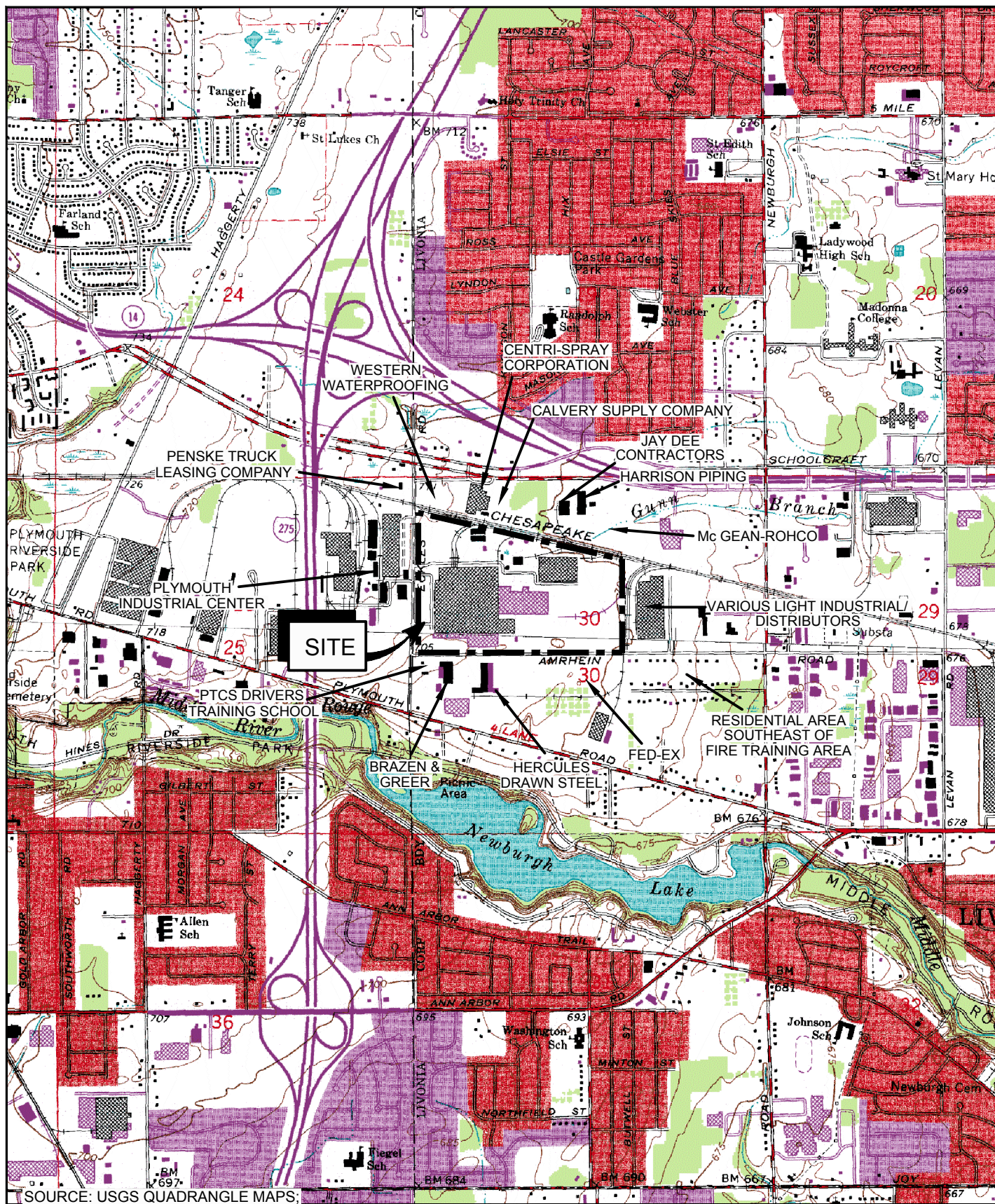
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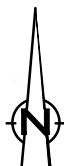
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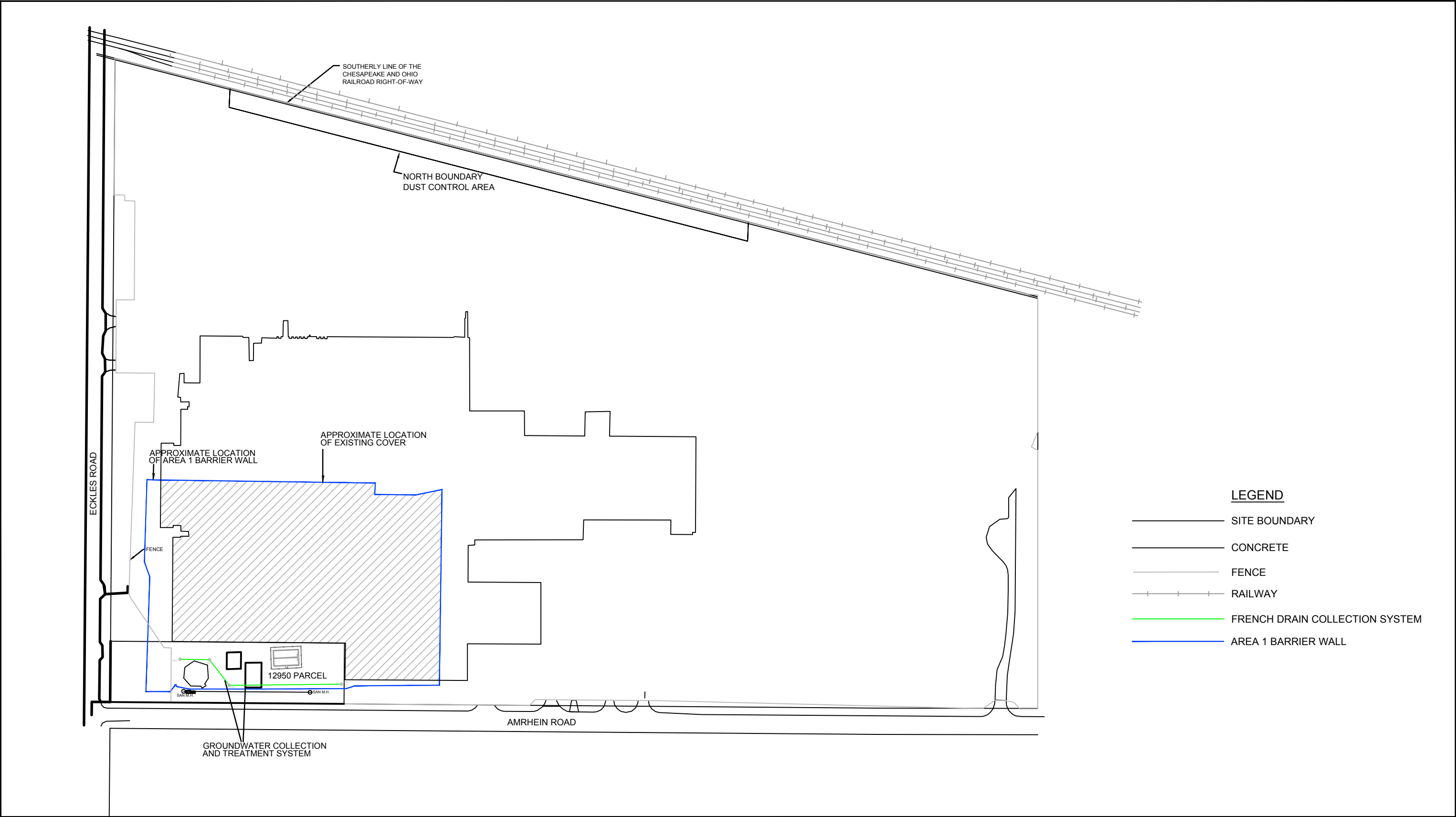


RACER TRUST
13000 ECKLES ROAD SITE
LIVONIA, MICHIGAN

SITE LOCATION

012607-T02
Mar 18, 2016

FIGURE 1

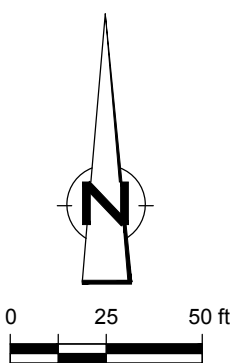


- LEGEND**
- SITE BOUNDARY
 - CONCRETE
 - FENCE
 - RAILWAY
 - FRENCH DRAIN COLLECTION SYSTEM
 - AREA 1 BARRIER WALL



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Client
RACER TRUST

Project
**13000 ECKLES ROAD SITE
LIVONIA, MICHIGAN**

No.	Issue	Drawn	Approved	Date
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Drawn	DRAWN	Designer	DESIGNED	
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Drafting Check	DRAFT_CHECK	Design Check	DESIGN_CHECK	
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Project Manager	PM	Date	Mar 18, 2016	
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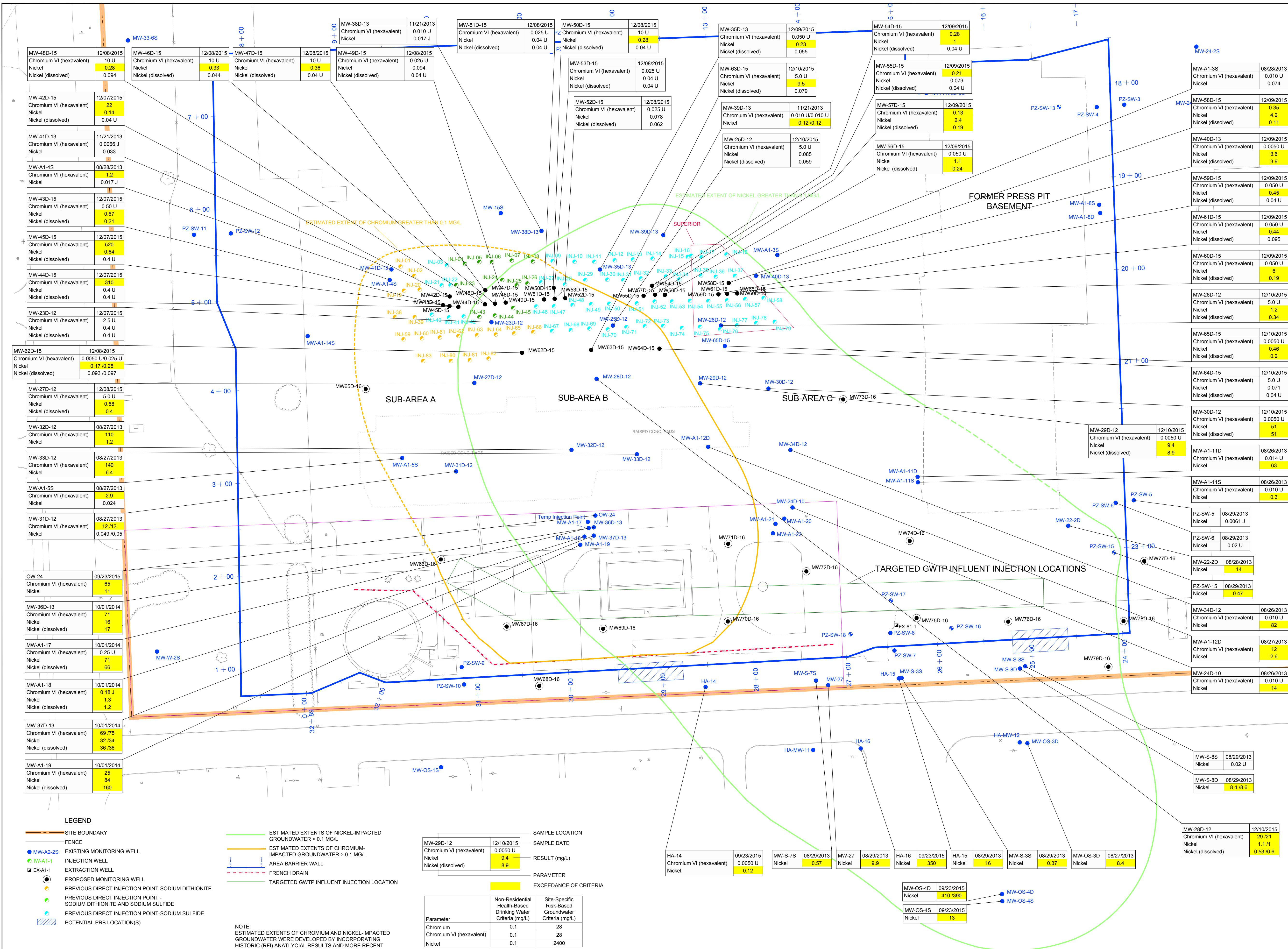
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Project No. **012607-T02**

Title
**AREA 1
GROUNDWATER RESULTS**

Sheet No.

FIGURE 3

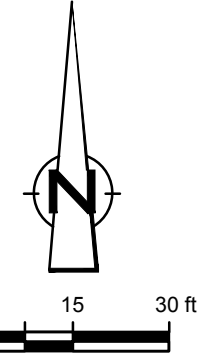




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Project 13000 ECKLES ROAD SITE

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Drafting	DRAFT_CHECK	Design	DESIGN_CHECK	
Project Manager	PM	Date	Mar 18, 2016	
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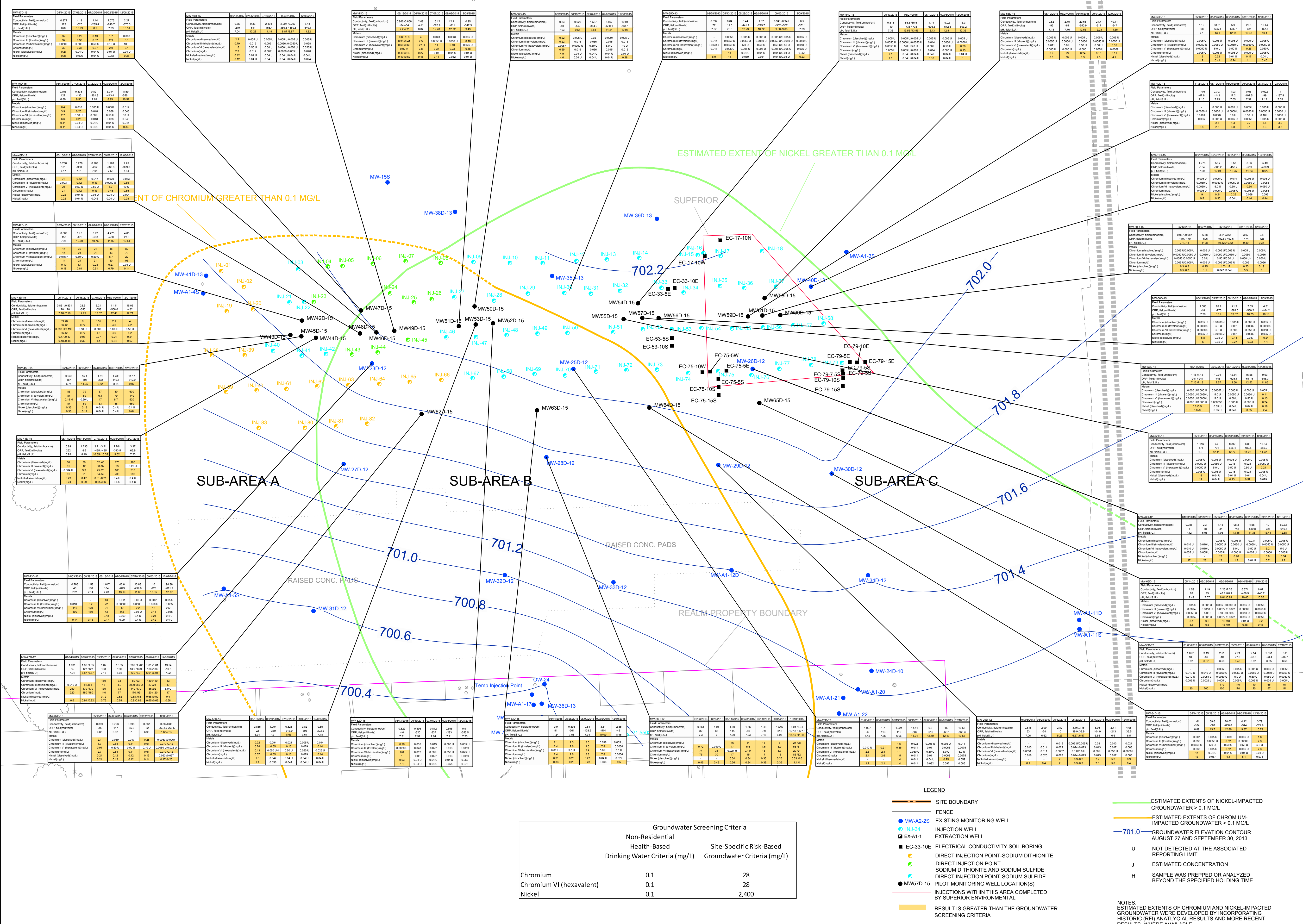
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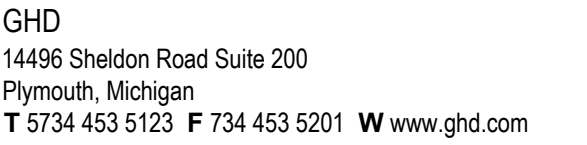
AREA 1 2015 PILOT STUDY GROUNDWATER MONITORING RESULTS

Sheet No.

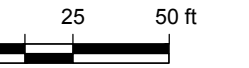
FIGURE 4

Sheet 1 of 1





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**13000 ECKLES ROAD SITE
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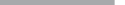
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Title

PROPOSED AREA 1 FULL SCALE ISCR INJECTION AND MONITORING WELL LOCATIONS

FIGURE 5

Sheet 1 of 1



STATUS

Appendix A

Memorandum Review of In Situ Chemical Reduction Field Pilot Study Monitoring Data



Memorandum

To: Chris Meincke

Ref. No.: 012607

From: Alan Weston/Sophia Dore/eew/9

Date: March 9, 2016

cc: Tom Kinney

**Re: Review of In Situ Chemical Reduction Field Pilot Study Monitoring Data
13000 Eckles Road Site
Livonia, Michigan**

1. Introduction

Groundwater in Area 1 at the 13000 Eckles Road Site (Site) in Livonia, Michigan contains chromium and nickel. Following the completion of a successful laboratory treatability study in 2003, treatment of the metals with in situ chemical reduction (ISCR) followed by biological polishing was recommended. Field pilot tests were performed in order to test the effectiveness of this technology in situ.

The objective of the field pilot tests were to determine the effectiveness of this alternative for accelerated groundwater treatment to reduce groundwater dissolved concentrations of chromium and nickel within Area 1 of the Site. Groundwater from this area is currently being extracted and treated at a groundwater treatment plant (GWTP); however, the installation of a downgradient permeable reactive barrier (PRB) is being considered in order to eliminate or reduce GWTP operation. In situ treatment of the high dissolved metals concentrations in Area 1 would enhance the effectiveness and extend the life of the PRB and could eliminate the need for the GWTP.

The results of the laboratory treatability study identified that treating the source of groundwater contamination by ISCR using sodium dithionite as a reducing agent resulted in significant reductions in the dissolved metal concentrations.

In November 2010, a field pilot test was performed. Four hundred gallons of a solution containing 5 percent sodium dithionite, 5 percent emulsified soy-lactate, and 0.1 percent sodium bromide (as a tracer) were injected into each of the two injection wells located in Area 1 of the Site. The results of this study showed that sodium dithionite was an effective treatment for reducing groundwater concentrations of hexavalent (dissolved) chromium and dissolved nickel in the areas it contacted. The data suggested that the sodium dithionite was primarily consumed within 10 feet of the injection well, and decreases in metals concentrations were not observed outside this area. No effects of the emulsified soybean oil were observed during the three-week monitoring period; however, sulfur reducing bacteria (SRB) grow slowly so the effects of sulfur reduction would not be expected to be observed in such a short time. Migration of the injected material was fast, up to 20 feet downgradient within the 3-week monitoring period.

Based on this study, it was recommended (Review of ISCR Field Pilot Study Monitoring Data, August 29, 2011) that for future injection events, the sodium dithionite concentration in the injection be increased to 20 percent in order to deliver more reducing agent to the area. Since a downgradient PRB was being considered, it was also recommended that the biological component of the treatment (soy-lactate) be eliminated since polishing would occur in the PRB.

A second pilot study was performed in November 2013. Eight hundred gallons of a 20 percent sodium dithionite solution were injected into 1 well (IW-A1-1) at the Site. Monitoring was performed prior to and after the pilot study injection. The results of the second pilot study showed that sodium dithionite was a very effective treatment for reducing groundwater concentrations of hexavalent chromium but less effective for reducing the concentration of dissolved nickel. Sodium sulfide was shown to be an effective treatment for the nickel in the treatability study; therefore, it was recommended that sodium sulfide treatment be included in future treatment events. Based on the pilot study results, a downgradient well spacing of 25 feet and a side-gradient well spacing of 10 feet was recommended (Review of Field Pilot Study Monitoring Data, memo from Alan Weston and Sophia Dore to Chris Meincke, March 21, 2014). The dose of 800 gallons of 20 percent sodium dithionite was sufficient to achieve treatment at this spacing, although if the well would accept a greater volume, a larger dose could be injected.

A third, larger scale pilot study was performed in May and June 2015. Eight hundred gallons of a 29 percent sodium sulfide solution were injected at 54 locations where dissolved nickel was the primary compound of concern; 800 gallons of a 20 percent sodium dithionite solution were injected at 18 locations where dissolved chromium was the primary compound of concern, and both sodium sulfide and sodium dithionite were injected at 12 locations where both dissolved nickel and dissolved chromium were present. The sodium sulfide injections were performed in May and included six locations where chromium was the primary compound of concern to evaluate the possibility of using only sodium sulfide for treatment. The injections including sodium dithionite were performed in June.

GHD was requested to review the data from the monitoring events, evaluate the treatment to date, and recommend future actions. This memo contains the evaluation.

2. Reduction of Metals by Injection of a Reducing Agent

The oxidation states of chromium (Cr) range from CrII^- to CrVI^+ , but only the CrIII^+ and CrVI^+ states are stable under most natural water conditions. Hexavalent Chromium (CrVI^+) is known to be toxic to humans, animals, and plants, and is more mobile in the environment than CrIII^+ . Conversely, CrIII^+ is less toxic and readily precipitates as Cr(OH)_3 under alkaline or even slightly acidic conditions. Therefore, reduction of CrVI^+ to CrIII^+ is a viable option for treatment of sites contaminated with CrVI^+ and can be accomplished by several methods.

In situ geofixation of chromium is the process of introducing a suitable reducing chemical reagent into the subsurface to reduce CrVI^+ to CrIII^+ . The reduced chromium would be stable because it undergoes geochemical fixation onto the aquifer solids. Reagents such as calcium polysulfide, sodium dithionite, and sodium bisulfite can be used for the geofixation of chromium. The reduction of the chromium can be monitored by collection of groundwater samples. When the groundwater samples turn gray in color with a distinct, black precipitate, chromium is being reduced. If the samples are yellow, CrVI^+ is still present. It has

also been observed that the amount of other dissolved metals such as iron may increase but their levels are well below their toxicity limit.

Reduction of chromium can also be accomplished by the injection of ferrous iron (Fe^{2+}). CrVI^{+} reduction by Fe^{2+} is of interest because it is found in various soil types and is a primary electron donor in subsurface environments. Fe^{2+} can be released from primary silicates and oxides and secondary layer silicates such as vermiculite and chlorite. Adsorption onto solid surfaces, or redox reactions with other oxidants in the solids are two potential reactions that could affect chromium removal by Fe^{2+} . Slightly more than stoichiometric amounts of Fe^{2+} and CrVI^{+} are necessary to achieve near complete removal.

ISCR of metals is the process of introducing a suitable chemical reducing agent into the subsurface to precipitate metals as insoluble metal sulfides, thereby preventing the continued migration of the impacted groundwater. The metal sulfides are stable because they are insoluble and undergo geochemical fixation onto the aquifer soil matrix. Reagents such as sodium sulfide and sodium dithionite can be used for the chemical reduction of metals. For nickel, ISCR is based on the injection of a reducing agent into the aquifer in order to promote the precipitation of soluble nickel and converting it into a stable compound, such as nickel sulfide.

3. Groundwater Monitoring

Groundwater monitoring was performed at the Site on May 12-14 prior to the sodium sulfide injections, on May 27-29 and June 9-11 after the sodium sulfide injections, and on July 6-7, July 20; September 1-10, 2015; and December 7-10, 2015 after all injections were complete. All monitoring wells were not sampled at all sampling events.

The locations of the monitoring wells and injection points are shown on Figure 4 of the Area 1 Full Scale ISCR Work Plan.

4. Assessment of Groundwater Monitoring Results

4.1 Chromium and Nickel

In general, dissolved chromium and nickel concentrations were reduced to below the 0.1 milligram per liter (mg/L) screening criteria in the middle of the treatment area while untreated areas remained at the periphery of the treatment area.

Wells MW46D-15 to MW49D-15 all contained significant concentrations of dissolved chromium prior to the pilot study injections. Dissolved nickel concentrations were lower but still above the 0.1 mg/L screening criterion. After the pilot study injections, the concentrations of dissolved chromium and nickel at these wells had been reduced to below 0.1 mg/L by the July 20 monitoring event. This represented reductions in dissolved chromium concentrations of up to 99.9 percent and reductions in nickel concentrations of up to 92 percent. At the September monitoring event, some rebound in metals concentrations was observed. At wells MW47D-15, and MW48D-15, the concentration of dissolved chromium had increased significantly; however, the concentrations of hexavalent chromium remained low or non-detect. The concentrations of dissolved chromium still remained at least an order of magnitude below their pretreatment concentrations. At the December monitoring event, the concentrations of dissolved chromium at these wells had decreased

again. At well MW47D-15, the concentration of total nickel increased in September although the concentration of dissolved nickel remained low. In December a further increase in total nickel to above 0.1 mg/L was observed at this well and similar increases were observed at wells MW-46D and MW-48D. The dissolved nickel concentrations remained low at these wells. No rebound in metals concentrations was observed at well MW49D-15. Each well in this cluster of monitoring wells is approximately 15 feet from the nearest well. The wells in this area were combined sodium dithionite/sodium sulfide injection wells, and these data indicate that this combination of sodium dithionite and sodium sulfide was effective for the precipitation of both chromium and nickel.

Moving from west to east, the next cluster of monitoring wells consists of wells MW50D-15 to MW53D-15. Prior to the pilot study injections, these wells generally contained dissolved nickel at concentrations greater than 1 mg/L and dissolved chromium at lower concentrations that still exceeded 0.1 mg/L. After the pilot study injections, nickel and chromium concentrations at these wells were all reduced to below 0.1 mg/L by the July 20 monitoring event. At the September monitoring event, further reductions in chromium concentrations were observed at wells MW51D-15, MW52D-15, and MW53D-15 and dissolved and hexavalent chromium concentrations at all the wells in this cluster remained low at the December monitoring event although slight increases in total and trivalent chromium were observed at wells MW51D-15 and MW53D-15. Further reductions in nickel concentrations were also observed at wells MW51D-15 and MW53D-15 at the September monitoring event and nickel concentrations also remained low at the December monitoring event except for an increase in total nickel observed at well MW-50D-15. No rebound in dissolved metals concentrations was observed at this well cluster. Each well in this cluster of monitoring wells is approximately 15 feet from the nearest sodium sulfide injection well. Reductions in concentrations of nickel and chromium were observed at this well cluster before the sodium dithionite injections were performed; therefore, the reductions appear to be largely due to the sodium sulfide.

The next cluster of monitoring wells consists of wells MW54D-15 to MW57D-15. High dissolved nickel concentrations were present in these wells prior to treatment; however, dissolved chromium was not present in these wells. After the injections at the June 10 monitoring event, concentrations of dissolved nickel were reduced to below 0.1 mg/L in all the wells except well MW56D-15 where the dissolved nickel concentration after treatment was 0.14 mg/L. This represented reductions in nickel concentration of up to 99.9 percent. At the September monitoring event, total nickel had decreased at well MW54D-15, but some rebound in the concentrations of total and dissolved nickel was observed at well MW55D-15. At wells MW56D-15 and MW57D-15, concentrations remained unchanged from the June monitoring event except that the total nickel increased at well MW57D-12. At the December monitoring event an increase in the chromium concentrations to above baseline levels was observed at wells MW54D-15, MW55D-15, and MW-57D-15. An increase in total nickel was also observed at well MW54D-15, and increases in total and dissolved nickel were also observed at wells MW-56D-15 and MW57D-15. The total nickel concentration at well MW55D-15 decreased. Impacted groundwater that was not treated as part of the pilot study was present north of this area, and the increases observed may have been due to the migration of this untreated groundwater into the area of this well cluster. Each well in this cluster of monitoring wells is approximately 15 feet from the nearest sodium sulfide injection well.

The eastern well cluster in the treatment area consists of wells MW58D-15 to MW61D-15. As with the previous cluster, high concentrations of dissolved nickel were present at these wells prior to treatment, but dissolved chromium was not detected. By the June monitoring event, concentrations of nickel were reduced to less than 0.1 mg/L in all wells except for well MW58D-15, where dissolved nickel was reduced to

0.24 mg/L. This represented reductions in nickel concentration of up to 99.8 percent. At the September and December monitoring events, dissolved nickel was further reduced to 0.15 mg/L and 0.11 mg/L at well MW58D-15. However, in September an increase in total nickel was observed at wells MW59D-15, MW60D-15, and MW61D-15 with an increase in dissolved nickel observed at well MW59D-15. The total nickel concentrations remained at these increased concentrations in December, however, the dissolved nickel concentration at well MW59D-15 returned to non-detect levels. Slight increases in hexavalent chromium were observed at the September monitoring event at wells MW59D-15 and MW61D-15; however, these levels had returned to non-detect by the December monitoring event. A slight increase in hexavalent chromium was observed at this monitoring event at well MW58D-15. The increases in total nickel may be related to perturbations during sampling. The fluctuations in hexavalent chromium do not appear to show a trend; therefore it does not appear that significant metals rebound is occurring at this well cluster. Each well in this cluster of monitoring wells is approximately 15 feet from the nearest sodium sulfide injection well.

Wells not located in clusters include the monitoring wells located south of the treatment area, which are wells MW27D-12 to MW30D-12 and MW62D-15 to MW65D-15. Wells MW62D-15 and MW27D-12 are located to the south of the sodium dithionite injection wells. At MW62D-15, which is located approximately 25 feet from the closest sodium dithionite injection well, a 50 percent reduction in dissolved nickel and a 97 percent reduction in dissolved chromium were observed after the injections. At the September monitoring event, the concentration of dissolved chromium had rebounded slightly; however, the dissolved nickel concentration had not and at the December monitoring event both chromium and nickel levels had decreased further such that both were below 0.1 mg/L. The greater removal of chromium versus nickel is expected when sodium dithionite is used.

At the December monitoring event, at well MW27D-12, which is located approximately 30 feet from the closest sodium dithionite injection well, no change in metals concentrations was observed until the December monitoring event when an 88 percent reduction in the concentration of dissolved chromium was observed. A slight reduction in the concentration of dissolved nickel was also observed.

The remaining wells are located south of the sodium sulfide injection areas. At MW64D-15, the concentration of dissolved nickel was reduced from 14 mg/L prior to the injections to non-detect (less than 0.04 mg/L) after the injections. An increase in chromium concentrations was observed at well MW64D-15 in December; however, nickel concentrations did not increase. The nearest sodium sulfide injection well is located approximately 25 feet from this monitoring well.

Reductions in the concentrations of dissolved chromium and nickel were not observed at the other wells in this group until the September monitoring event, which indicated that the injected sodium sulfide took approximately 4 months to migrate to these wells. The reductions observed were at well MW28D-15, where a 50 percent reduction in dissolved and hexavalent chromium was observed at the September monitoring event; well MW30D-15, where a reduction in nickel concentration of approximately 50 percent was observed; and MW63D, where a 97 percent reduction in dissolved chromium was observed and dissolved nickel was reduced to non-detect levels. Further reductions in levels were observed at well MW63D at the December monitoring event. Wells MW28D-15 and MW30D-15 are located 53 and 67 feet away, respectively, from the nearest sodium sulfide injection well.

Well MW25D-12 and MW35D-12 are single monitoring wells located close to sodium sulfide injection wells, and concentrations of dissolved chromium and nickel were reduced to below criteria in these wells. By the September monitoring event, the dissolved nickel concentration had rebounded slightly at well MW25D-12,

although the dissolved chromium concentration remained low. At the December monitoring event the dissolved nickel concentration had been reduced again and the concentration of dissolved chromium remained low. No rebound was observed at well MW35D-12 in September. However, in December a slight increase in the concentration of total nickel was observed although the concentration of dissolved nickel remained low. Well MW26D-12 is also a single monitoring well located close to the sodium sulfide injection wells. Nickel concentrations were reduced at this well, rebounded at the September monitoring event and then decreased again at the December monitoring event.

Well MW23D-12 is a single monitoring well located close to the combined sodium sulfide/sodium dithionite injection area. Dissolved chromium and nickel concentrations were reduced to non-detect levels at this well after the injections. A rebound in both dissolved chromium and nickel concentrations was observed at the September monitoring event. Dissolved nickel had returned to pretreatment levels, but dissolved chromium remained four orders of magnitude below pretreatment concentrations. By the December monitoring event, the concentration of dissolved chromium and nickel had returned to non-detect levels.

The well cluster at the western end of the treatment area consists of wells MW42D-15 to MW45D-15. Prior to treatment, these wells contained high concentrations of dissolved chromium (greater than 10 mg/L) with lower concentration of dissolved nickel that were generally less than 1 mg/L but greater than 0.1 mg/L. Probe refusals and difficulties with injections in this area suggest that some underground structure may be present which limited injections and may have limited dispersion. After the injections, no significant reduction in the concentrations of chromium and nickel were observed at wells MW42D-15 or MW44D-15 until the September monitoring event, when the nickel concentrations were reduced to non-detect levels at well MW44D-15 and the December monitoring event when the dissolved nickel concentration was reduced to non-detect levels at well MW42D-15. At well MW43D-15, the concentration of dissolved chromium was reduced from 69 mg/L to 0.55 mg/L after the injections, a 99.2 percent removal; however, it had rebounded slightly by the September monitoring event and remained similar at the December monitoring event. No reduction in the nickel concentration was observed at this well. At well MW45D-12, the concentration of dissolved nickel was reduced from 0.36 mg/L to less than 0.04 mg/L, an 88.9 percent reduction. No reduction in the concentration of chromium was observed. By the December monitoring event, the concentration of chromium had increased to above pre-treatment levels. No rebound in the concentration of dissolved nickel was observed, however. Each well in this cluster of monitoring wells is approximately 15 feet from the nearest sodium sulfide injection well. No sodium dithionite was injected into the area around these wells. These data suggest that sodium dithionite is required for optimum treatment of high concentrations of chromium.

4.2 Bromide, Sulfate, Sulfide and Sodium

Bromide was injected during the injection event as a conservative tracer to track the flow of the injected reagents. A high detection limit was used for bromide due to the high concentrations of sulfate and sulfide in the samples; therefore, there were few detections of bromide. Bromide was detected at wells MW23D-12 on July 6, September 3 and December 7; well MW26D-12 on December 10, well MW43D-12 on June 18, July 7 and December 7; wells MW44D-15, MW45D-15 and MW46D-15 on December 7; well MW50D -15 on June 19 and December 8; wells MW54D-15 and MW55D-15 on December 9; well MW56D -15 on June 10; and wells MW58D-15 and MW59D-15 on December 9. These monitoring wells are all located in the treatment area and would be in the area contacted by the injected reagents.

Increases in sulfate, sulfide, and sodium concentrations were observed at the wells where reductions in the concentrations of chromium and nickel were observed. For the wells located south of the treatment area (wells MW27D-12 to MW30D-12 and MW62D-15 to MW65D-15) at the June and July monitoring events, an increase in the concentration of sulfate, sulfide, and sodium was observed only at well MW64D-15, which is the only well where treatment of dissolved metals was observed at these sampling events. These data suggest that the injected material made early contact with this well. Increases in sodium and sulfate concentrations were observed at MW27D-12 at the September monitoring event, and increases in sodium concentrations were observed in wells MW63D-15 and MW65D-15 at the September monitoring event, which correspond to the decreases in chromium and nickel observed at these wells. These data suggest that the injected material took until September to reach these wells and was still creating reducing conditions. Reductions in sulfide and sodium concentrations were observed at the December monitoring event indicating that the sulfide is precipitating and the sodium is dispersing from the treatment area.

Increases in concentrations of sulfate, sulfide, and sodium were also observed in the MW42D-15 to MW45D-15 well cluster; however, larger increases were observed at wells MW43D-15 and MW45D-15, where reductions in concentrations of dissolved metals were also observed. These data suggest that the injected material did make contact with the wells in this area, which supports the observation that sodium sulfide alone is not the optimum treatment for high levels of chromium. Reductions in sulfide and sodium concentrations were again observed at the December monitoring event indicating that the sulfide is precipitating and the sodium is dispersing from the treatment area.

Sodium and sulfate are soluble; therefore their concentrations in the treatment area will decrease over time as they disperse out of the treatment area. Heavy metal sulfides are typically insoluble. The sulfide from sodium sulfide is expected to react with the heavy metals present in the treatment area such as iron and precipitate them as their metal sulfides. Therefore, sulfide is not expected to be detected in groundwater over the long term. The decreasing heavy metals concentrations, which have reached non-detect levels in many wells confirm that this is occurring.

Increases in dissolved iron were observed in many of the wells as a result of the injection. These increases were expected since iron is more soluble under reducing conditions. The solubilized iron will either react with residual sulfide in the groundwater and precipitate as iron sulfide or, as conditions return to pre-treatment conditions at the Site, the iron will be converted to ferric iron and precipitate. The increases in dissolved iron have already decreased at most of the wells and are not expected to persist over the long term. Similar increases in dissolved manganese concentrations were not observed after the pilot study injections.

4.3 Field Data

Field data for pH, oxidation-reduction potential (ORP), dissolved oxygen (DO), and turbidity were monitored during the pilot study. Sodium sulfide has a high pH, and increases in pH were observed at most wells that were contacted by the sodium sulfide solution. Sodium sulfide and sodium dithionite are reducing agents and created reducing conditions at the Site. By the September 2015 monitoring event, the pH was beginning to decrease in most areas but remained well above baseline levels. Increases in pH were not observed at wells MW27D-12 to MW30D-12 except at well MW28D-12 at the December monitoring event however, a decrease in ORP was observed at wells MW27D-12, MW28D-12 and MW30D-12 after the injections. By September, the ORP had rebounded slightly at wells MW27D-12 and MW28D-12 but remained low at well MW30D-12. A decrease in ORP at well MW29D-12 was observed in September, indicating that the reducing conditions created by the injections took longer to reach this well. An increase in pH and ORP was not observed at well

MW62D-15; however, increases in pH and decreases in ORP were observed at wells MW63D-14 and MW65D-15 at the September and December monitoring events, and an increase in pH and decrease in ORP were observed at well MW64D-15 at the May and June monitoring events, which were sustained through the December event. Increases in pH were observed at wells MW42D-15, MW43D-15, MW44D-15, and MW45D-15, which support the conclusion drawn above that the injected material reached these wells but that sodium sulfide alone was not able to treat the high concentrations of chromium. A decrease in ORP was observed at most of the wells after the injections. Reductions in ORP were observed at some of the wells, where the precipitation of metals, increases in sulfate, sulfide, and sodium, and an increase in pH were not observed including well MW63D-14. These data showed that the chemical injections were creating reducing conditions in areas beyond their radius of influence. Due to dilution of the reagents, direct precipitation of chromium and nickel did not occur in these areas, however these conditions may result in some secondary precipitation of chromium and nickel.

5. Observations

- Dissolved chromium and nickel concentrations in the treatment area were generally reduced to below the 0.1 -mg/L screening criteria.
- Reductions in chromium and nickel concentrations of up to 99.9 percent were observed.
- A radius of influence of at least 15 feet was observed for the injections.
- The injected material travelled up to 25 feet downgradient by the July monitoring event and up to 63 feet downgradient by the September monitoring event.
- Satisfactory reductions in dissolved metals concentrations were not observed at the MW42D-15 to MW45D-15 well cluster, and the monitoring data suggested that the injected material reached these wells; however, sodium sulfide only was injected into the wells in this area. The data suggest that the addition of sodium dithionite is required to treat high concentrations of dissolved chromium.
- Wells where dissolved chromium and nickel concentrations were reduced also showed increases in sulfate, sulfide, and sodium concentrations, and an increase in pH, which indicated that the injected sodium sulfide material reached the area.
- Samples collected on July 20 and in September showed slightly lower pH levels indicating that the high pH conditions caused by the sodium sulfide were abating.
- Some rebound in dissolved chromium and nickel concentrations was observed at the September and December monitoring events, which is expected since this was a pilot test and all areas of the Site were not treated; therefore, untreated groundwater containing higher dissolved chromium and nickel concentrations would be migrating back into the treatment area.
- Additional decreases in dissolved chromium and nickel concentrations were also observed at the September and December monitoring events indicating that the injected materials are continuing to disperse and have not been completely consumed.
- The high pH levels observed in the wells where reductions in chromium and nickel were observed suggested that sodium sulfide reached. No monitoring wells were located in the immediate areas of the sodium dithionite injections because the effects of sodium dithionite injections were examined in the previous pilot studies performed at this Site.

6. Conclusions and Recommendations

The results of the pilot study show that sodium sulfide and sodium dithionite/sodium sulfide mixtures were effective in reducing groundwater concentrations of dissolved chromium and dissolved nickel. No monitoring wells were located in the immediate areas of the sodium dithionite injections. Previous pilot studies performed at the Site have shown that it is an effective treatment for high concentrations of chromium but is less effective for nickel treatment. Treatment of chromium and nickel was observed 15 feet from injection wells and up to 25 feet downgradient in the month after the injections and up to 67 feet from the injection wells 4 months after the injections. Based on the observed 15 foot radius of influence, a 30 foot spacing is recommended for injection wells for the full-scale application. The dose of 800 gallons of 29 percent sodium sulfide was sufficient to achieve treatment in the high nickel areas, and a mixture of 20 percent sodium dithionite and 29 percent sodium sulfide was sufficient to achieve treatment in the areas with elevated concentrations of both chromium and nickel. The data also showed that sodium sulfide alone was not a completely effective treatment for high concentrations of chromium; therefore, sodium dithionite should be added to the solution in areas where chromium concentrations are high. Therefore, for the full-scale application, treatment with 800 gallons of 29 percent sodium sulfide is recommended for the high nickel plume, and a mixture of 20 percent sodium dithionite and 29 percent sodium sulfide is recommended for the area where both chromium and nickel concentrations are elevated. For areas with high chromium but no nickel, a 20 percent sodium dithionite solution is recommended. The results of the pilot study suggest that a single injection event would be sufficient to treat the groundwater, although it is possible that some additional targeted injections would be required in areas where the first injection did not make good contact with the groundwater.

A downgradient PRB is being considered for this Area. A potential reactive matrix for the PRB would be zero valent iron (ZVI). ZVI creates reducing conditions therefore treatment using the chemical reducing agents sodium sulfide and sodium dithionite would be compatible with this technology. If conditions in the groundwater reaching the PRB were already reducing, the life of the PRB would be extended since less of the ZVI would be oxidized. Residual sulfate from the injections is likely to be reduced to sulfide via abiotic and biological mechanisms in and around the ZVI barrier leading to a decrease in sulfate concentrations at the barrier. However, it is expected that the amount of ZVI consumed by the sulfate will be minimal since biological sulfate reduction will be the primary mechanism. However, the sulfide would precipitate from the groundwater. Since sulfide particles are very small, it is not expected that the sulfide would clog the barrier. Residual sulfide from the injections would likely not reach a downgradient barrier due to its low solubility in water.

The only risk that the sodium sulfide and sodium dithionite injections would pose to a ZVI barrier would be from the increased turbidity in the groundwater which would result in a lowering of the permeability of the barrier. For this reason it is recommended that the injections are not performed within 20 feet immediately upgradient of the barrier. At a distance of 20 feet from the injection locations, the turbidity would have abated sufficiently that the permeability of the barrier would not be affected.