KLIEGMAN BROTHERS SITE
OPERABLE UNIT NO. 2
DESIGN ANALYSIS REPORT

Prepared for

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DIVISION OF ENVIRONMENTAL REMEDIATION
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1.0 INTRODUCTION

This report presents the design rationale, criteria, computations, and analysis for a remedial design at Operable Unit Number 2 (OU2) of the Kliegman Brothers Site (Site No. 2-41-031). This section presents the scope, site background, approach, and description of the remedial alternative selected for remediation of OU2 in accordance with the New York State Department of Environmental Conservation (NYSDEC) Record of Decision (ROD) for the site dated March, 2008.

1.1 Scope

The Kliegman Brothers site consists of Operable Unit Number 1 (OU1) and OU2. OU1 consists of soil contamination present on the Kliegman Brothers (Kliegman Bros.) property that is currently being remediated using a Soil Vapor Extraction (SVE) System initially constructed as an interim remedial measure (IRM) by URS in 2004 and expanded to a larger system by the NYSDEC in 2007. OU2 consists of groundwater contamination, consisting almost exclusively of tetrachloroethene (PCE), that was present on-site, and that has migrated from the site. The PCE concentrations from sampling events in 2002, 2003, 2005, 2009, 2010, 2011 and 2012 are shown on Figure 1-1. Remediation of PCE in offsite groundwater is the focus of this Design Analysis Report. This work is being performed for the NYSDEC under Work Assignment D007622-02 of the NYSDEC Standby Contract.

1.2 Site Background

The site is situated in a densely populated, urban, mixed-use residential/light-commercial setting. The Kliegman Bros. property is located at 76-01 77th Avenue in Queens County, New York. The on-site property is approximately 37,000 square feet (sf), of which 26,000 sf is occupied by a building.

Kliegman Brothers, Inc. formerly owned the on-site property. This property was used as a warehouse and distribution center for laundry and dry-cleaning supplies from the 1950s through the 1990s. Two 6,000-gallon above-ground storage tanks (ASTs) were used to store tetrachloroethene (PCE). The tanks have since been removed from the property. Although these tanks are the presumed source of contamination, it is unknown if, and when, product was released or, whether contamination was due to a single catastrophic release or a chronic leak problem. Kliegman Brothers ceased operation in 1999. The property was purchased by its current owners in 2000. Known contamination is unrelated to operations since 2000.

URS completed construction of an SVE system at the site as an IRM for OU1 in 2004. The system utilized three extraction wells (SVE-1, SVE-6S and SVE-6D). SVE-1 is a one-inch diameter well screened from 5 to 25 feet below ground surface (bgs). Wells SVE-6S and SVE-6D are two-inch diameter wells screened from 5 to 25 feet bgs (SVE-6S) and 30 to 65 feet bgs (SVE-6D). SVE-6S and SVE-6D are separate wells installed at the same location. Other wells (SVE-2 through SVE-5), originally installed by a previous site consultant in 2001 as SVE wells, were not used for the IRM. The three wells were connected through a subsurface trench to the SVE system consisting of a moisture separator, an extraction blower, and vapor phase carbon vessels. Operation of the system began on August 23, 2004. In 2007, URS designed a full scale SVE system that added six new SVE wells and a large vacuum blower and offgas treatment system. This system was installed in 2007 and has been operating continuously, along with the IRM system, since 2007.

URS conducted a residential air-sampling program as an additional part of the Remedial Investigation (RI) to determine if the PCE plume has resulted in soil vapor entering area residences. Results are presented in the 2006 URS report for NYSDEC entitled *Soil Vapor Intrusion Investigation Report*. Based on finding completed soil vapor intrusion pathways during the initial (February 2005) sampling program, the indoor air-sampling program was expanded as part of the IRM. The extent of the full program included indoor air and sub-slab sampling at 70 residences and Public School (P.S.) 119 based on their proximity to the site. Sampling followed the New York State Department of Health (NYSDOH) 2005 Draft Guidance for Evaluating Soil Vapor Intrusion in the State of New York. Based on the analytical data collected, NYSDEC in concurrence with NYSDOH, determined that 12 residences were eligible for installation of sub-slab depressurization systems. Of these 12 residences, 8 locations had the systems installed and the other 4 refused the installations.

1.3 ROD Approach

As discussed in the March 2008 ROD for OU2 remediation, the NYSDEC selected in situ chemical treatment within the concentrated plume area with continued vapor monitoring, and installation of residential vapor mitigation systems as required. PCE was proposed to be oxidized by sequential oxidation by two oxidants. First, Fenton's reagent would be injected in multiple rounds to provide the strongest oxidation power and to promote desorption of adsorbed PCE so that it could be oxidized. This would be followed by multiple rounds of permanganate injection. Post injection groundwater monitoring would evaluate the progress of remediation. Installation and operation of a groundwater extraction well to induce a hydraulic gradient to enhance the effectiveness of in situ chemical treatment was included; however, the feasibility of this option was to be examined during the remedial design.

Since the issuance of the ROD in March of 2008, the natural processes of diffusion and dispersion and the operation of the SVE system have reduced concentrations of PCE in groundwater at and downgradient of the site. Therefore, the approach presented in the ROD has been significantly modified as discussed in the remainder of Section 1 below.

1.4 Groundwater Contamination

URS investigated groundwater contamination through three rounds of well installation and sampling during the RI in 2002, 2003, and 2005. During each round of the investigation, wells were installed both at deeper depths and farther from the source area in an effort to define the horizontal and vertical extent of contamination. The results defined a rather large area impacted by PCE; every well installed contained PCE.

To support the design effort, additional groundwater sampling was performed in February/March 2009. Because the 2009 sampling results showed significant changes in PCE concentrations, a more extensive investigation was performed. Additional groundwater sampling locations were proposed. In order to gain vertical contaminant profiling information, the additional investigation initially used a Membrane Interface Probe (MIP). However, this effort encountered difficulties because of cobbles and other difficult boring conditions at several intervals which precluded the use of the MIP. Therefore, a revised approach using conventional drilling (hollow stem auger and mud rotary) and a hydropunch for depth-specific samples was performed during the period of October 2009 through February 2010. Subsequently, additional wells installed based on the hydropunch results, and several existing wells, were sampled in March 2010. Existing wells were sampled again in February 2011, February 2012 and June 2012. Analytical results are shown on Figure 1-1. Groundwater sampling results from all sampling events are compared on Table 1-1.

As shown on Table 1-1, the recent groundwater samples show that operation of the onsite SVE system has significantly reduced PCE concentrations throughout the area of investigation. Although PCE concentrations have been greatly reduced in most of the wells included on Table 1-1, there is one well (MW-14DR) where a significant concentration (greater than 1,000 ppb) of PCE was detected in the last sampling event in June 2012. MW-14DR is a replacement well for MW-14D that was destroyed in 2010.

1.5 Groundwater Remediation Area

The shallow groundwater zone (beginning at approximately 70 feet bgs) is the focus of remediation for this OU2 design. A perched groundwater zone that lies above a silty clay layer approximately 10 to 15 feet bgs is not addressed by the OU2 Design. The on-site perched groundwater is being remediated by the OU1 Remedy.

During the RI, and in a subsequent predesign investigation in 2010, portions of the plume were probed using a hydropunch to collect discrete depth-specific samples to gauge the thickness of the plume. At each of these locations, a well was installed below the water table (wells MW-10H, MW-12H, MW-13H, MW-14H, MW-27M, MW-29M, and MW-30M). The hydropunch sampling results for all but MW-14H are summarized in Table 1-2. MW-14H was investigated not with a hydropunch, but with a Membrane Interface Probe (MIP) attached to a direct-push rig. Due to problems advancing and withdrawing this tool, it was used only at this one location.

Discrete depth-specific samples taken from the hydropunch locations show that the plume remains near the top of the water table. Only at downgradient well location MW-30M) was the plume found to be present only below the top of the water table. Based on the review of the hydropunch data, the treatment zone is defined as the top 20 feet of the water table.

The latest sampling results confirm that the OU2 plume has attenuated as a result of the remediation activities at OU1. Therefore, the extensive injection scheme proposed in the ROD is not warranted - particularly in light of the difficulties associated with installing wells in a residential area with extensive underground utilities. A reduced scope of remediation will extend from just downgradient of MW-04D to just downgradient of MW-24D (the second most contaminated well in June 2012) as shown on Figure 1-2. The injection well locations have been selected based on the interpretation of the plume flow in a southerly direction from the former tank locations to the area near MW-14DR (the most contaminated well in June 2012). The proposed well locations are thus on the east side of 76th Street near 77th Avenue (starting near MW-04D which had a PCE concentration of 14,000 µg/L as recently as February 2012) and on the west side of 76th Street near MW-14DR and MW-24D.

1.6 Groundwater Extraction Well Evaluation

The ROD recommended Alternative 4 as the preferred remedy for the site which consisted of the installation of oxidant injection wells within the concentrated plume area. In order to create a larger hydraulic gradient and thus to increase the area reached by the injected oxidants to areas beyond the radius of influence of the injection wells, the ROD indicated that a groundwater extraction well and groundwater treatment facility be considered during the remedial design process.

The extraction well and treatment facility have been eliminated from the remedial design based on the following:

- Data collected since the ROD was published shows that the plume has attenuated in size;

- The extent of contamination requiring treatment is much smaller than originally delineated in the ROD;

- . Many of the residences in the area have been protected by subslab depressurization systems reducing concerns over potential migration of contamination under the residences and subsequent exposure by vapor intrusion.

1.7 Oxidant Recommendations

The remedy proposed in the ROD assumed that PCE was to be oxidized by sequential injection utilizing two oxidants. First, Fenton's reagent would be injected in multiple rounds. The Fenton's injection would provide the strongest oxidation power and promote desorption of adsorbed PCE so that it could be oxidized. This was recommended because the concentrations near the source area were at levels that indicated the presence of DNAPL. The stronger, but short-lived Fenton's treatment would be followed by multiple rounds of permanganate injection to provide longer-lived oxidation of the PCE, including PCE that was transferred from DNAPL to the dissolved phase by previous treatment with Fenton's.

Due to the significant reduction in PCE concentrations, including the current absence of concentrations that indicate the presence of DNAPL, the strong oxidation power of Fenton's reagent will not be necessary. A two phased approach is no longer required. Therefore, this Design calls only for permanganate injection.

2.0 IN SITU CHEMICAL OXIDATION (ISCO)

2.1 Description of Remediation

Based on the analysis and recommendations presented in Section 1, the Design will incorporate in situ oxidation within the 11,400 ft² remediation area identified on Figure 1-2. Due to the success of the SVE system and resulting reduced concentrations of PCE within the groundwater, only permanganate will be injected. Post injection groundwater monitoring will evaluate the progress of remediation.

2.2 Design Approach

Permanganate will be introduced during multiple injection events with performance monitoring conducted in between. The first injection event will provide implementation and treatment experience that can be used by the NYSDEC and the oversight engineer to direct the contractor to modify subsequent injection events, if appropriate.

2.3 Description of Oxidant

2.3.1 Chemistry

Permanganate is a common oxidant and has demonstrated significant effectiveness in oxidizing chlorinated solvents such as PCE. Permanganate is available either as potassium permanganate ($KMnO_4$) or sodium permanganate ($NaMnO_4$). $KMnO_4$ comes in a granular form that is mixed with water and has a relatively low solubility limit (i.e., 2% to 4% by weight), while $NaMnO_4$ comes as a liquid with a much higher solubility limit (approximately 40% by weight in solution). Permanganate destroys contaminants through an ionic reaction versus the hydroxyl radical production associated with Fenton's chemistry. No heat or gas is produced in the permanganate oxidation reaction, as shown in Equation 1, where MnO_4^- is the permanganate ion, H_2O is water, e^- is an electron, $MnO_{2(s)}$ is manganese dioxide solid, and OH^- is the hydroxyl ion.

$$MnO_4^- + 2H_2O + 3e^- \rightarrow MnO_{2(s)} + 4OH^- \qquad \text{Equation 1}$$

2.3.2 Oxidant Reactivity and Strength

Permanganate is more chemically stable and has a slower reaction rate (e.g., on the order of days or weeks) with PCE than other ISCO reagents (e.g., Fenton's). Therefore, permanganate has the potential to be effective for longer periods of time following injection and/or to move farther from the point of injection.

In terms of oxidative strength alone, permanganate is a weaker oxidant as compared to the hydroxyl radicals or persulfate, and is therefore less efficient in terms of volume of material delivered. Permanganate also reacts at a higher rate with other non-contaminant oxidizable materials. In terms of longevity, permanganate has the potential to be the most persistent oxidant within the subsurface and thus can travel with groundwater to reach areas not accessible via surface injection. The quantity of permanganate required for treatment depends primarily on the natural oxidant demand of the aquifer material. Natural oxidant demand (NOD) (e.g., oxidizable species present within the aquifer in addition to target contaminants) reacts with permanganate and consumes much of the oxidant. Target contaminants typically comprise a small to negligible quantity of the permanganate requirement.

2.3.3 Selection of Sodium Form of Permanganate

Sodium permanganate ($NaMnO_4$), available as a liquid, will be used rather than potassium permanganate ($KMnO_4$), available as a powder that requires dissolution onsite, because it generally reduces the complexities associated with storage, mixing and transportation of the material. In addition, $NaMnO_4$ is not subject to the Homeland Security regulations that apply to $KMnO_4$ further reducing the complexities associated with storage and transportation of the material.

A 5% by weight $NaMnO_4$ solution will be used for remediation at the Kliegman Brothers site. Injection of a 5% solution of $NaMnO_4$ reduces health and safety concerns associated with higher concentrations of $NaMnO_4$. Manufacturers specify that spills of $NaMnO_4$ must be reduced to 6% or less before they can be neutralized. In general, $NaMnO_4$ solutions of 6% by weight or less are very stable. Design calculations for $NaMnO_4$ injection are discussed below in Section 2.4.

2.4 Chemical Oxidant Dosage

The oxidant dosage estimated for applications of 5% by weight $NaMnO_4$ is based primarily on the NOD present in the soil – based on NOD data from samples collected in 2002, and estimates of target treatment volume. Oxidant dosage estimates for $NaMnO_4$ are described further in Appendix A.

Based upon 2002 soil samples collected for NOD analysis, variability in site lithology, and the inclusion of a safety factor, the NOD estimated for oxidant dosage is approximately one gram $KMnO_4$ per kilogram of soil, which is a relatively low NOD but within the expected range for lithology similar to this site. As presented in Appendix A, the quantity of $NaMnO_4$ required for direct oxidation of the estimated contaminant mass in groundwater is relatively small in comparison to the oxidant mass required for oxidation of the NOD. Less than 1% of the oxidant injected is needed to destroy the contaminants in groundwater. Additional detail concerning oxidant dosage for permanganate is provided in Appendix A.

As presented in Appendix A, approximately 21,000 gallons of 5% by weight $NaMnO_4$ solution will be required for the remediation area. Assuming the solution will be applied over two events, approximately 440 gallons of the 5% by weight solution will be injected into each of the 24 injection wells (twelve locations) for a total of 10,500 gallons during each of the injection events.

2.5 ISCO Infrastructure

The urban nature of the site puts constraints on the ISCO infrastructure. Ideally, injection wells would be installed in a triangular pattern. However, the active streets and the private residential properties (each of which is comprised of the house, driveway, and a small area behind each structure) will be avoided for well installation. Thus, injection wells are proposed to be located on a 30-foot spacing along the public sidewalks. The well spacing is based on lithology, vendor recommendations and previous experience with permanganate injections.

To determine whether it was physically possible to install wells on 30-foot spacing, URS performed a utility location survey through the subcontracted firm Radar Solutions. The utility location effort used Electromagnetic Induction (EMI), Ground-Penetrating Radar (GPR) and utility markouts to estimate the location of subsurface utilities along 76th St. The results of this survey are shown on Figure 2-1.

Based on the estimated locations of utilities, a conceptual arrangement of injection well locations is shown on Figure 2-2. This conceptual arrangement maintains the 30-foot (+/-) injection well spacing. The actual location of the injection wells will be finalized in the field; however, this exercise demonstrates that it is feasible to locate the planned injection wells within the remediation area.

In addition to underground constraints, there are also overhead constraints in the form of trees and power/communication lines. The Contractor will be required to work around and protect these features. This may require the use of short-mast drill rigs and power line protection cuffs and/or other similar measures.

A well pair (shallow and deep) will be constructed at each location with screens at two different depth intervals. The two intervals reduce the likelihood of oxidant being injected into only higher permeability seams in the aquifer. Each well screen will be 10 feet in length. Data from the RI indicates that the water table fluctuates temporally between 65 and 68 feet bgs. On this basis, the shallow well screen will be installed from approximately 68 to 78 feet bgs, and the deep screen will be installed from 78 to 88 feet bgs.

The construction will require the use of sonic or rotary mud drilling techniques. Although these techniques are typically more expensive than hollow stem auger drilling, they are favored over hollow stem auger drilling for the following reasons:

- Public relations will be a significant challenge for this remedy. The injection wells will have to be installed at many locations within the right-of-way on residents' driveways, impacting their access. Sonic and rotary mud drilling allows for much faster installation of the wells and thus reduces the duration of residents' inconveniences during well installation.

- Although the stratigraphy in the area is primarily sand with some clay lenses, there are layers of cobbles that have posed difficulties with other drilling techniques. Previous investigations at this site have shown that direct push is not feasible because of cobbles, and hollow stem auger drilling had to resort to the use of drilling mud to advance the borings. The sonic and rotary mud techniques would not be subject to these cobble-induced drilling limitations.

- The ability of sonic and rotary mud drilling to pass through difficult layers more easily is an advantage. Because of the overhead constraints (trees and wires), a compact rig may be required. Smaller rigs are typically less powerful, and thus conventional drilling techniques would encounter even greater difficulties reaching the depths needed by this remedy.

The boreholes will not be logged continuously, but will be logged as they approach the water table during drilling in order to set the well screens at an appropriate depth and to identify localized geologic conditions. The delivery wells will be constructed of two-inch outer diameter (OD) Schedule 40 polyvinyl chloride (PVC) pipe with a threaded bottom cap, continuous wrap well screen (10-slot), and solid PVC riser to the ground surface. The annulus of each delivery well will be filled with appropriately sized sand mated to the slot size and the formation. The sand pack will extend from the bottom of the borehole to approximately two feet above the top of the screen. The flush mount surface completion for each delivery well will be constructed to tolerate moderate to heavy vehicle traffic. The wells will be fitted with locked well caps to deter tampering.

Sodium permanganate can be delivered to the site as a 40% by weight solution by the manufacturer, and can be mixed with water on site to reduce the concentration to 5% by weight. Alternatively, the 40% by weight solution can be mixed with water at an offsite location, and can be delivered to the site as a 5% by weight solution. Since little if any space is available on site for mixing operations, offsite mixing is preferred for remediation at this site. Offsite mixing will be addressed in the Contract Documents for remediation.

Because of the location of the injection wells along public sidewalks, no permanent above-grade components will be allowed. Injections will be made from a mobile delivery unit (e.g., tanker truck or a truck with reagent tanks). Materials used for above ground hoses used for transfer of oxidant, pumps used for transfer or injection, and storage containers will be compatible with sodium permanganate. The manufacturer's recommendations for decontamination and/or maintenance will be followed to prevent corrosion of hoses, pumps, and/or any equipment exposed to the sodium permanganate.

2.6 Injection Schedule

Two applications of $NaMnO_4$ solution injections are scheduled. Groundwater performance monitoring will be conducted between permanganate applications. Performance monitoring is discussed further in Section 2.7. Modifications to the injection program may be made following a review of the performance monitoring results.

Each $NaMnO_4$ application is anticipated to require approximately one to three work days depending on the number of wells that are injected simultaneously (see Appendix A). This does not include mobilization and demobilization. Site conditions and lithology may allow for increased or require decreased flow rates; the average anticipated flow rate (8 gallons per minute or approximately 50 minutes per well based on injection of 400 gallons in each well) is based upon consideration of site lithology, previous experience with permanganate applications, and vendor recommendations. A more detailed schedule for oxidant injection is presented in Section 4.0.

2.7 Performance Monitoring

Wells used for performance monitoring are shown on Figure 2-2. A total of 13 wells, including 10 existing wells, and 3 new well locations (MW-31D, MW-32D, MW-33D) to be installed during the remedial construction period, will be used for performance monitoring. Performance monitoring will include sampling and analysis for VOCs, alkalinity and dissolved metals (iron, manganese, chromium, arsenic, selenium and lead). Samples will be collected from the monitoring wells prior to initiation of injections and approximately eight weeks after each injection event. Each monitoring event is expected to be completed in 3 days. Performance monitoring will also include weekly measurement of field parameters (oxidation reduction potential, dissolved oxygen, specific conductivity, temperature and color). A more detailed schedule for monitoring is presented in Section 4.0.

2.8 Storage, Containment and Safety Measures

Permanganate solutions are hazardous substances and strong oxidizers. Sodium permanganate is a Class 2 oxidizer. For the purposes of this Design, it has been assumed that the $NaMnO_4$ will be delivered to the site as a 5% by weight solution after being mixed off site. The solution could be stored onsite (if the site is not being used or the space is available at the time of injections) or could be shipped in smaller (daily use) quantities for immediate use for injection. The latter method is preferred since onsite storage may not be possible or be very limited.

The New York State Fire Code and the NYSDEC bulk storage requirements (6NYCRR Parts 595-599) regulate the storage of oxidizers. Among other requirements included in the regulations, Chapter 40 of the Fire Code requires outdoor storage of Class 2 oxidizers to be stored a minimum of 35 feet from buildings, lot lines, streets, alleys, and means of egress.

Secondary containment is required by and must comply with the NYSDEC bulk storage regulations. Secondary containment is required for oxidant transfer, storage, and mixing operations. At connection points (e.g., hose and/or piping connections) secondary containment measures should be implemented whenever possible.

Any spilled material will be contained and reused, if possible. If reuse is not possible, permanganate solution will be neutralized using either a solution of dilute peroxide and acetic acid (e.g., vinegar) or dissolved sodium thiosulfate. Permanganate should be diluted and decomposed using sodium metabisulfite or sodium sulfite. Decontamination of equipment, storage, personal protection, and other related safety concerns should be in accordance with the Material Safety Data Sheets (MSDS) and vendor recommendations. Oxidant safety materials are presented in Appendix B.

2.9 Utilities

Since sodium permanganate will be shipped to the site in a 5% by weight solution, mixing will not be required, and utilities (electric and water) to accommodate mixing will not be required. Minimal power will be required for injection pumps that can be supplied by tapping into power lines in the remediation area or by running a portable generator. Water will need to be on hand to address spills, if they occur. Water could be obtained from hydrants or it could be trucked in.

2.10 Access Requirements

Work on private property will be avoided. Remediation activities will be confined to public sidewalks and rights-of-way. For instance, injection wells will be installed within the public rights-of-way along 76th Street. The construction contractor will be required to obtain a street-opening permit to install the injection wells in any off-site public areas. The areas impacted by well construction will be restored to city requirements at the completion of remediation.

3.0 PERMITS AND APPROVALS

Injection wells incidental to aquifer remediation and experimental technologies are distinguished from hazardous waste injection wells and are designated as Class V under the United States Environmental Protection Agency (USEPA) Underground Injection Control (UIC) Program. Class V wells covered by the Federal UIC Program are authorized by rule and do not require a separate UIC permit. However, URS will submit an Inventory of Injection Wells Form to the USEPA, as required by the USEPA UIC Program, to document well installation.

To install the wells in the public rights-of-way, New York City street opening permits will be required. Because parts of the road will be required to set up the drilling rigs, lane closure permits would be required. The Contractor will be required to submit a Traffic Control Plan that addresses lane closure and other traffic issues prior to commencing work. Operations will have to comply with New York City noise monitoring and mitigation requirements.

4.0 CONSTRUCTION SEQUENCING AND SCHEDULE

This section presents a preliminary schedule and description of construction sequencing. The remedial Contractor will determine the actual sequence and duration of work segments within the time frame specified in the Contract Documents. The major remediation work elements presented in the expected sequence of implementation are described below.

1. Mobilization of Equipment, Manpower, and Temporary Facilities: It is expected that any temporary facilities required will be located at the OU1 area.

2. Baseline Monitoring: A round of groundwater samples will be taken prior to treatment to update the baseline groundwater concentrations.

3. Injection and Monitoring Well Installation: Injection wells pairs will be installed at 12 locations and new monitoring wells will be installed at 3 locations.

4. Oxidant Injection: $NaMnO_4$ solution will be injected during two separate events at 12 locations. Groundwater will be monitored in between each injection to evaluate the effectiveness of oxidation and adjustments to the oxidant dose will be implemented as appropriate based on the monitoring results.

5. Demobilization: All temporary facilities will be removed from the site. Temporary utilities will be discontinued.

A preliminary general construction schedule is presented on Figure 4-1. The Contractor will be required to submit a work plan with a preliminary construction schedule to NYSDEC within 5 days after being notified that he is the apparent low bidder. The selected Contractor will submit a detailed construction schedule to NYSDEC and update the schedule in accordance with the Contract Documents after the construction contract has been awarded.

TABLES

TABLE 1-1

GROUNDWATER PCE RESULTS COMPARISON

Well ID[1]	2002-2005 Max Conc (ppb)	2009/2010 Max Conc (ppb)	2011 Conc (ppb)	Feb 2012 Conc (ppb)	June 2012 Conc (ppb)
	On-Site Samples				
MW-10D	55,000	170	51	44	Not Sampled
MW-10H	24,800	69	5	8.6	Not Sampled
MW-11D	5,900	67	Not Sampled	Not Sampled	Not Sampled
MW-02D	15,000	90	Not Sampled	Not Sampled	Not Sampled
	Immediately Downgradient				
MW-03D	43,000	580	200	48	54
MW-05D	31,000	360	44	7.3	4.1
MW-12H	51,200	17	9.8	21	Not Detected
MW-04D	75,000	700	8,200	14,000	460
	Downgradient				
MW-14D/14DR[2]	75,000	42,000	Not Sampled	Not Sampled	5,300
MW-14H	Not Sampled	12	54	Not Sampled	Not Sampled
MW-14L	Not Sampled	Not Sampled	Not Sampled	75	21
MW-14U	Not Sampled	Not Sampled	Not Sampled	83	22
MW-17D	8,400	490	Not Sampled	Not Sampled	Not Sampled
MW-24D	21,000	6,600	15,000	340	890
MW-24H	Not Sampled	1,400	2,500	86	160
	Farther Downgradient				
MW-23D	3,400	2,400	380	170	48
MW-19D	2,300	140	37	20	Not Sampled
MW-18D	5,700	140	Not Sampled	Not Sampled	Not Sampled
MW-07D	2,700	54	23	11	Not Sampled
MW-16D	350	30	Not Sampled	Not Sampled	Not Sampled

NOTES:

1. S – shallow; D – deep; H – hydropunch.

2. MW-14DR replaced MW-14D after MW-14D was destroyed in 2010.

TABLE 1-2

HYDROPUNCH DATA

LOCATION	DEPTH (FT. BGS)	PCE CONCENTRATION (µg/L)	YEAR
MW-10H	72	24,800	2003
	88	75	
	103	11	
	118	540	
	132	ND	
	148	16	
MW-12H	72	51,200	2003
	88	3,790	
	108	51	
	118	16	
MW-13H	72	809	2003
	88	ND	
	102	1	
MW-24H	72	14,000	2010
	82	480	
	92	20	
	102	7.1 J	
	112	4.7 J	
	122	ND	
MW-27M	72	29	2010
	82	6.4	
	92	62	
	102	1.2 J	
	112	ND	
	122	ND	
MW-28M	72	7.7	2010
	82	ND	
	92	ND	
	102	ND	
	112	ND	
	122	ND	
MW-29M	72	22	2010
	82	120	
	92	49	
	102	7.6	
	112	2.4 J	
	122	1.4 J	
MW-30M	72	ND	2010
	82	1,400	
	92	57	
	102	32	
	112	17	
	122	6.7	

TABLE 2-1
MONITORING WELL SCHEDULE

Well ID[1]	Installation Date	Depth (Ft.)	Description[1]	Proposed for Long Term Monitoring[2]
MW-01	2002	24	P	no
MW-01S	2002	20	P	no
MW-2D	2002	79.5	W	no
MW-3D	2002	76.5	W	yes
MW-4D	2002	75	W	yes
MW-5D	2002	75	W	yes
MW-6S	2002	14.25	P	no
MW-7D	2002	75	W	no
MW-8S	2002	16.5	P	no
MW-9S	2002	15	P	no
MW-10D	2003	72	W	no
MW-10H	2003	148	H	no
MW-11D	2003	75	W	no
MW-12H	2003	118	H	yes
MW-13H	2003	103	H	no
MW-14DR	2012	75	W	yes
MW-14H	2009	115	H	yes
MW-15D	2003	75	W	no
MW-16D	2003	70	W	no
MW-17D	2005	73	W	no
MW-18D	2005	74	W	no
MW-19D	2005	74	W	no
MW-20D	2005	75	W	no
MW-21D	2005	74	W	no
MW-22D	2005	74	W	no
MW-23D	2005	74	W	yes
MW-24D	2005	69	W	yes
MW-24H	2009	124	H	yes
MW-27M	2009	74	D	no
MW-28M	2009	74	D	no
MW-29M	2009	74	D	no
MW-30M	2009	96	D	yes

TABLE 2-1 Continued
MONITORING WELL SCHEDULE

Well ID[1]	Installation Date	Depth (Ft.)	Description[1]	Proposed for Long Term Monitoring[2]
MW-31D	New	75 (proposed)	D	yes
MW-32D	New	75 (proposed)	D	yes
MW-33D	New	75 (proposed)	D	yes

NOTES:

1. S – shallow; D – deep; H – hydropunch; R – re-drill, P – perched aquifer; W – water table aquifer.

2. The monitoring program will include analytical parameters as follows:
   VOCs
   alkalinity
   dissolved metals (i.e., iron, manganese, chromium, arsenic, selenium, and lead);
   and field parameters as follows:
   oxidation-reduction potential (ORP)
   dissolved oxygen (DO)
   temperature
   specific conductrivity
   color.

FIGURES

MW-28M
3/2010, 9.8

MW-10H
4/30/2003, 24,800
2/2009, 14
3/2010, 69
2/16/2011, 5
2/08/2012, 8.6

MW-11D
4/30/2003, 3,500
12/16/2003, 5,900
6/14/2005, 920
2/2009, 67
3/2010, 24

MW-03D
10/17/2002, 25,000
4/30/2003, 22,000
12/2003, NS
6/16/2005, 43,000
2/2009, 490
3/2009, 580
3/2010, 290
2/16/2011, 200
2/08/12, 48
6/28/2012, 54

MW-02D
10/17/2002, 9,500
4/29/2003, 15,000
12/2003, NS
6/15/2005, 2,600
2/2009, 89
3/2010, 90

MW-10D
4/30/2003, 55,000
12/2003, NS
6/2005, NS
2/2009, 170
3/2009, 150
3/2010, 130
2/16/2011, 51
2/08/2012, 44

SVE-2
6/1/2001, 45,000

SVE-4
6/1/2001, 1,200

MW-16D
4/29/2003, 350
12/2003, NS
6/15/2005, 350
2/2009, 30

MW-15D
4/30/2003, 400
12/2003, NS
6/16/2005, 310
2/2009, 79

MW-13H
4/29/2003, 809

MW-05D
10/15/2002, 17,000
4/30/2003, 15,000
12/16/2003, 15,000
6/16/2005, 31,000
2/2009, 270
3/2009, 360
3/2010, 140
2/16/2011, 44
2/08/2012, 7.3
6/28/2012, 4.1

SVE-3
6/1/2001, 30,000

MW-07D
10/15/2002, 2,700
4/29/2003, 1,100
12/2003, NS
6/16/2005, 1,200
2/2009, 54
2/16/2011, 23
2/08/2012, 11

MW-12H
4/29/2003, 51,200
2/2009, 13
3/2009, 17
3/2010, 5
2/16/2011, 9.8
2/08/2012, 21
6/28/2012, ND

MW-04D
10/15/2002, 49,000
4/29/2003, 69,000
12/16/2003, 45,000
6/16/2005, 75,000
2/2009, 680
3/2009, 700
3/2010, 370
2/16/2011, 8,200
2/08/2012, 14,000
6/28/2012, 460

MW-27M
2/16/2011, 28
2/08/2012, 7

MW-21D
6/15/2005, 300

MW-14D
4/29/2003, 75,000
12/16/2003, 74,000
6/16/2005, 40,000
2/2009, 42,000
3/2010, NS

MW-29M
3/2010, 20

MW-14H
3/2010, 12
2/16/2011, 46
2/16/2011, 54

MW-14HL
2/08/12, 75
6/28/2012, 21

MW-14DR
6/28/2012, 5,300

MW-17D
6/15/2005, 8,400
2/2009, 490

MW-24H
3/2010, 1,400
2/16/2011, 2,500
2/08/2012, 86
6/28/2012, 160

MW-14HU
2/08/2012, 83
6/28/2012, 22

MW-24D
6/16/2005, 21,000
3/2009, 6,600
3/2010, 1,400
2/16/2011, 15,000
2/08/2012, 340
6/28/2012, 890

MW-22D
6/15/2005, 190

MW-18D
6/15/2005, 5,700
2/2009, 140

MW-23D
6/15/2005, 3,400
2/2009, 2,400
3/2010, 410
2/16/2011, 380
2/08/2012, 170
6/28/2012, 48

MW-20D
6/16/2005, 370

MW-19D
6/15/2005, 2,300
2/2009, 140
2/16/2011, 37
2/08/2012, 20

MW-30M
3/2010, 310
2/16/2011, 570
2/08/2012, 200
6/28/2012, 140

Legend

- ⯐ Sampling Location and Soil Vapor Extraction Well Location
- ⊕ Monitoring Well Location

Well Suffixes:
D - Screened at water table
H - Below water table (based on HP readings)
M - Screen at highest hydropunch reading

Location ID: **MW-14HL**
2/08/12, 75
6/28/2012, 21
Sample Date (Latest Sampling Round Shown in Red)
Tetrachloroethene (PCE) Concentration (µg/L)

NOTES:
NS - Not Sampled
ND - Not Detected

150 0 150 Feet

KLIEGMAN BROTHERS
GROUNDWATER SAMPLING RESULTS FOR PCE

URS

FIGURE 1-1

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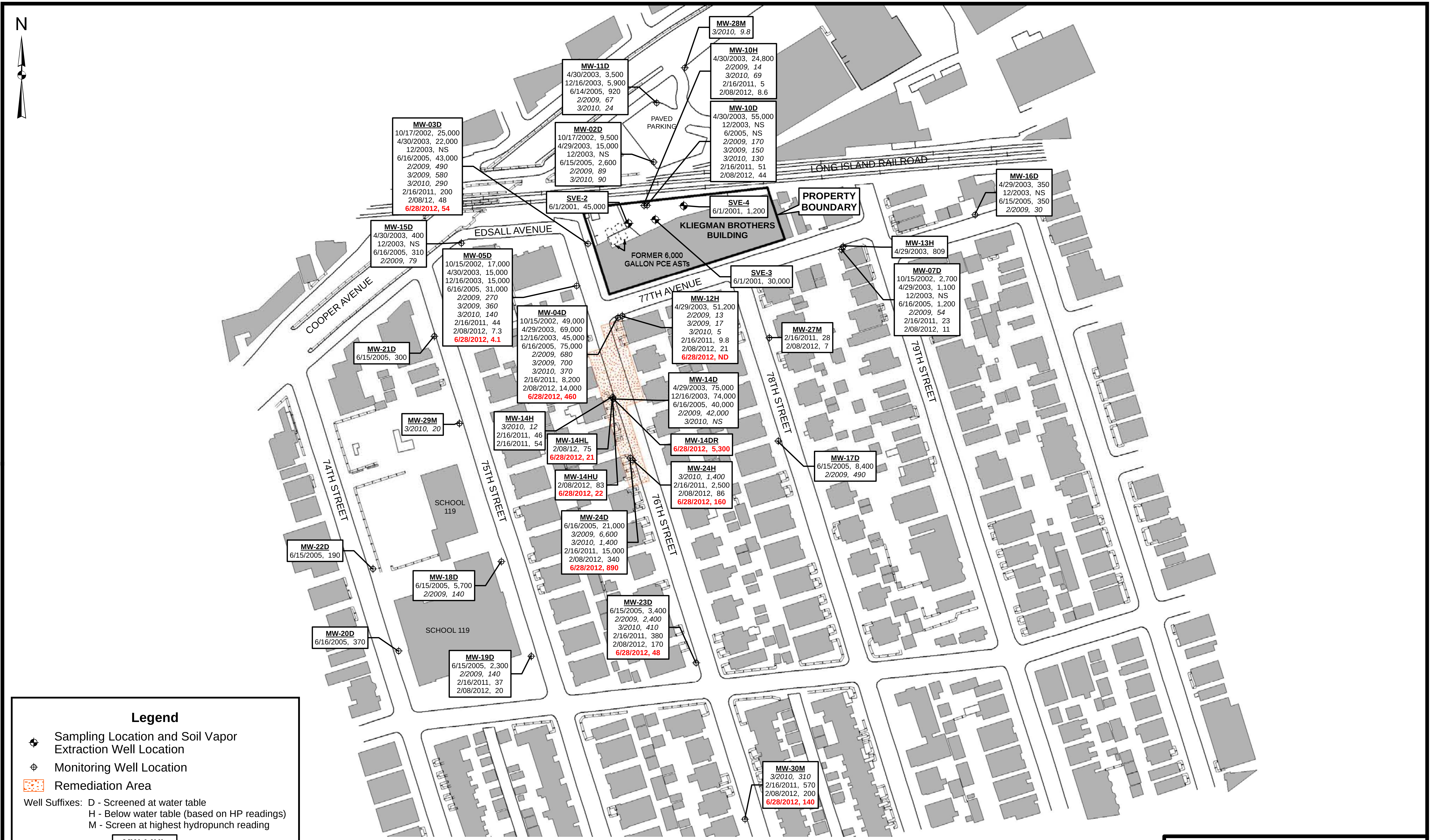

Legend

- ⊕ Sampling Location and Soil Vapor Extraction Well Location
- ⌖ Monitoring Well Location
- ▨ Remediation Area

Well Suffixes: D - Screened at water table
H - Below water table (based on HP readings)
M - Screen at highest hydropunch reading

MW-14HL
2/08/12, 75
6/28/2012, 21

Location ID

Sample Date (Latest Sampling Round Shown in Red)

Tetrachloroethene (PCE) Concentration (µg/L)

NOTES:
NS - Not Sampled
ND - Not Detected

150 0 150 Feet

KLIEGMAN BROTHERS
REMEDIATION AREA

URS

FIGURE 1-2

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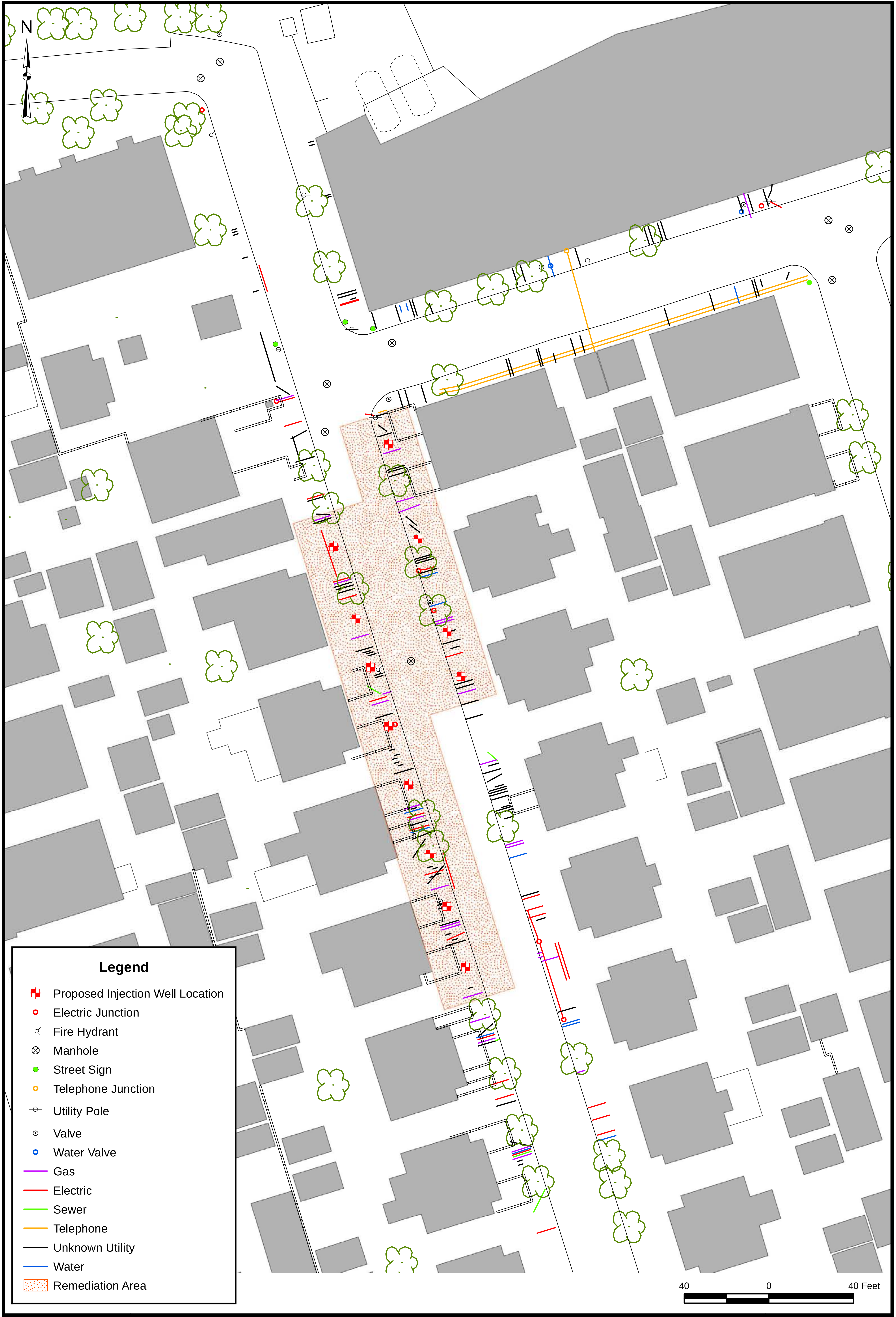

URS

KLIEGMAN BROTHERS
UTILITY LOCATIONS AND GPR SURVEY RESULTS

FIGURE 2-1

Legend

- ● Proposed Monitoring Well
- ✚ Proposed Injection Well Pair Location
- ⊕ Existing Monitoring Well
- ⊕ Performance Monitoring Well
- ▨ Remediation Area

KLIEGMAN BROTHERS
PROPOSED INJECTION AND PERFORMANCE
MONITORING WELL LOCATIONS

URS

FIGURE 2-2

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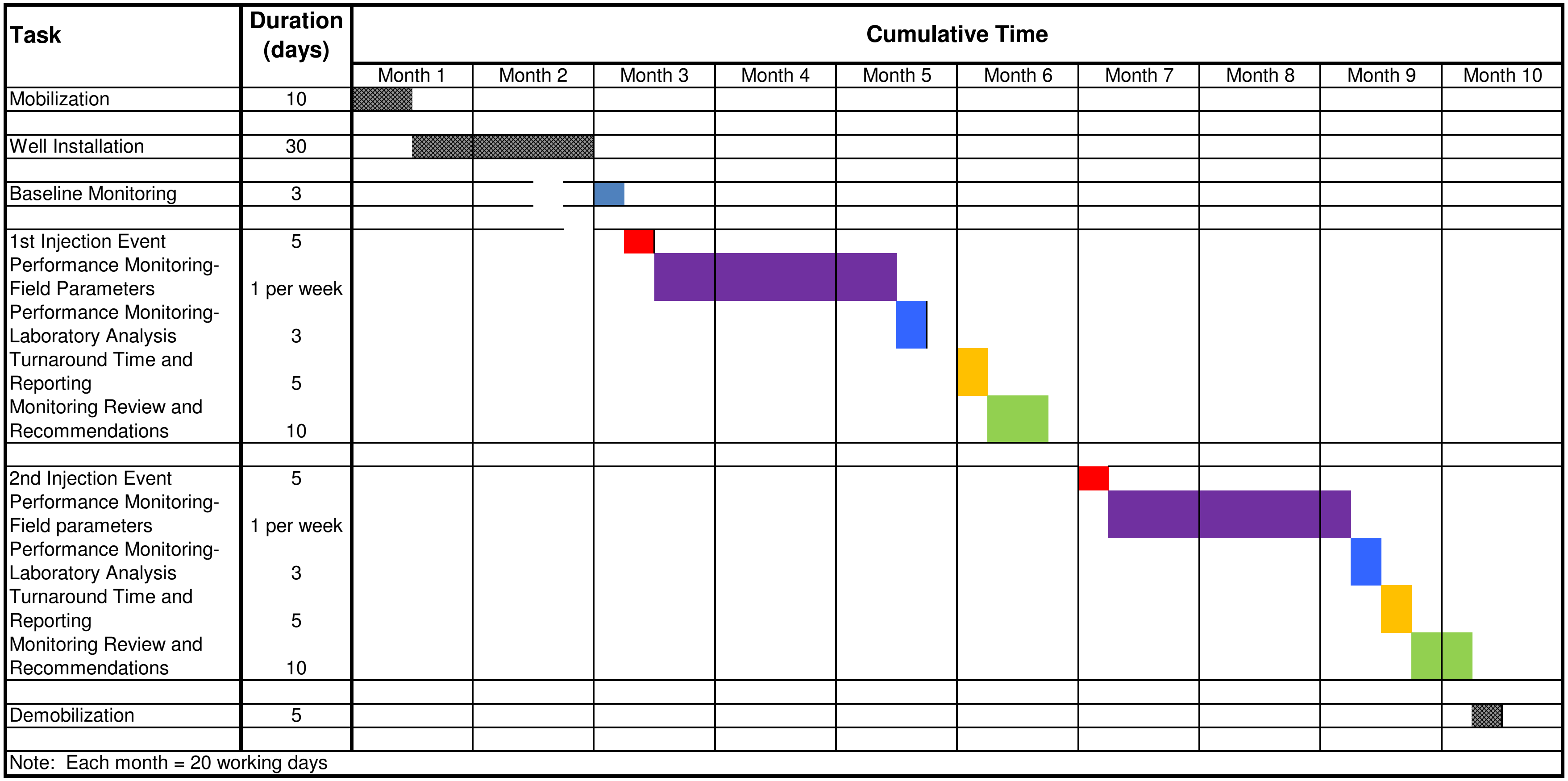
Figure 4-1
Preliminary Construction Schedule



Task	**Duration (days)**	**Cumulative Time**									
		Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10
Mobilization	10	▨									
Well Installation	30	▨	▨								
Baseline Monitoring	3			■							
1st Injection Event	5			■							
Performance Monitoring-Field Parameters	1 per week			■	■	■					
Performance Monitoring-Laboratory Analysis	3					■					
Turnaround Time and Reporting	5						■				
Monitoring Review and Recommendations	10						■				
2nd Injection Event	5							■			
Performance Monitoring-Field parameters	1 per week							■	■	■	
Performance Monitoring-Laboratory Analysis	3									■	
Turnaround Time and Reporting	5									■	
Monitoring Review and Recommendations	10									■	■
Demobilization	5										▨

Note: Each month = 20 working days

APPENDIX A

OXIDANT DOSAGE CALCULATIONS

JOB NO.: 11175788

MADE BY: C. Pawlewski DATE: November 1, 2012
CHECKED BY: D. McCall, Jon Sundquist DATE: November 2, 2012

PROJECT: **Kliegman Bros. Design**
SUBJECT: **Oxidant Demand Calculations**

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1. Background and Purpose

Operation at the Kliegman Brothers site led to a significant source of tetrachloroethene (PCE) contamination on site. This onsite source area has been largely cleaned up by SVE remediation of onsite soil that began in 2004. However, groundwater sampling has indicated that there is still some significant PCE contamination existing downgradient of the site. This calculation has been prepared to estimate the quantity of oxidant (sodium permanganate) necessary to effectively treat the remaining PCE contaminant mass present in an area just downgradient of the site source area.

2. Design Criteria

Design criteria used for calculating the amount of oxidant (sodium permanganate) required for remediation are discussed below.

a. Area of Remediation

The treatment area includes an area along the east side of 76th Street which is approximately 30 feet wide and 140 feet long (4,200 square feet) and an area along the west side of76th Street which is approximately 30 feet wide and 240 feet long (7,200 square feet) as shown on the figure included as Attachment A. The total area is approximately 11,400 square feet.

b. Saturated Thickness

The treatment thickness across the remediation area is 20 feet beginning at the top of groundwater (i.e., approximately 70 to 90 feet below ground surface.

c. Soil Porosity

A porosity of 35% is used for the calculation based on the properties of silty sand (Attachment B).

d. Contaminant Groundwater Concentrations

The most contaminated wells in the remediation area include MW-04D, MW-14DR and MW-24D. Data from these wells is used to conservatively estimate the concentration of VOCs within the remediation area. Data for the last two sampling events at these locations is summarized below.

Well Location	**PCE Concentration (µg/L)**	
	February 2012	**June 2012**
MW-04D	14,000	460
MW-14DR	Not Sampled	5,300
MW-24D	340	890

The average of the PCE concentrations in these wells for the two events is 4,198 µg/L. A value of 4,200 µg/L (4.2 ppm) will be used for the calculation.

e. Permanganate Natural Oxidant Demand (PNOD)

The PNOD is a measure of the oxidant demand of the soil regardless of contamination, i.e., the oxidant demand occurring naturally. It is also referred to as permanganate soil oxidant demand or PSOD. Testing conducted in September 2002 (Attachment C) indicates that the NOD is very low, i.e. less than 1 gram $KMnO_4$ per kilogram soil ($gKMnO_4$/kg soil). A conservative value of 1 $gKMnO_4$/kg soil is used for this calculation.

f. Effective PNOD

Based on Carus Corporation's experience in the field, they have developed the concept of effective PNOD. They have determined that laboratory results for PNOD are not reflective of permanganate demand in the field, i.e., oxidant demand in the field is less than predicted by laboratory results. The discrepancy is due mainly to the following: 1.) laboratory results are based on well mixed soil that does not occur in the field when the oxidant is injected; and 2.) permanganate does not usually persist long enough in the field to oxidize all the PNOD present. The effective PNOD can vary;

however, based on Carus' experience the effective PNOD is typically 10% of the measured PNOD. A value of 10% is used in this calculation

g. Average Stoichiometric Demand

Different compounds require different amounts of permanganate for oxidation that is based on stoichiometry. The stoichiometric relationships for the chlorinated alkenes are presented in Principles and Practices of In Situ Oxidation Using Permanganate by Siegrist, et al. These stoichiometric relationships are included in Attachment D. For PCE, the stoichiometric demand is 0.96 lb MnO_4^-/lb contaminant.

h. Confidence Factor

The confidence factor is a safety factor applied to the estimate based on the availability of data for the site and the unknowns and variables associated with the remediation. The confidence factor generally ranges from 1 (very confident) to 5 (not confident because data is minimal or site geology is highly variable). For this site, there is some subsurface characterization data available for the target remediation area, and the geology is somewhat variable but reasonably well known. However, the remediation will occur in a residential area, so it will be desirable to minimize the number of injections to minimize disturbance in the residential neighborhood. Therefore, it seems prudent to use a conservative confidence factor to reduce the probability of needing more injections after the calculated quantity is injected. On this basis, a confidence factor of 4 was used for the calculation of total oxidant demand.

3. Oxidant Required for Remediation

The oxidant required for remediation was calculated using the Carus spreadsheet with the input parameters discussed in Section 2 above. These calculations are included Attachment E. Attachment E includes calculations for RemOx S (potassium permanganate) and RemOx L (sodium permanganate); however, only sodium permanganate will be used for remediation as discussed in Section 4 below.

The spreadsheet calculations are based on the following equation:

$T_R = [(C \times Q_w \times S) + (\text{Effective PNOD} \times Q_s)] \times C_F$

Where:

T_R = Total Oxidant Demand (lb)

C = Contaminant Concentration in Groundwater (mg/l) = 4.2mg/l

Q_w = Quantity of Water (l)
Q_w = remediation area x saturated thickness x porosity
$Q_w = 11{,}400\ \text{ft}^2 \times 20\ \text{ft} \times 0.35 \times 28.317\ \text{L/ft}^3$
$Q_w = 2{,}259{,}697\ \text{L}$

S = Average Stoichiometric Demand (lb/lb) = 0.96 lb/lb

Effective PNOD = Effective Permanganate Oxidation Demand (g/kg)
Effective PNOD = 1.0 g/kg x 10%
Effective PNOD = 0.1 g/kg

Q_s = Quantity of Soil (lb)

C_f = Confidence Factor = 4

For RemOx S (potassium permanganate),

$T_R = [(4.2\ \text{mg/l} \times 2{,}259{,}697\ \text{L} \times \text{lb}/454{,}000\text{mg} \times 0.96\text{lb/lb}) + (0.1\text{g/kg} \times (11{,}400\ \text{ft}^2 \times 20\ \text{ft} \times \text{CY}/27\ \text{ft}^3)\ \text{CY} \times 1350\text{kg/CY} \times \text{lb}/454\text{g})] \times 4$

$T_R = 10{,}124\ \text{lbs}$

For RemOx L (40% sodium permanganate solution), the oxidant demand is derived from the RemOx S demand as follows:

$T_{RemOx\ L}$ = T_R x (mol. wt. $NaMnO_4$/mol. wt. $KMnO_4$) / (0.4 lb $NaMnO_4$ per lb of solution)

$T_{RemOx\ L}$= (10,124 lb x (142g/mole/158g/mole))/ 0.4

$T_{RemOx\ L}$= (10,124 lb x 0.898)/0.4

$T_{RemOx\ L}$ = 22,728 lbs

4. Oxidant Type

Permanganate is available in two forms, namely, potassium and sodium permanganate. Sodium permanganate will be used for remediation at this site based on the following: 1.) The quantity of permanganate solution injected for each injection event would be reduced since potassium permanganate is generally injected at about 2% by weight solution and sodium permanganate is injected at about 5 to 10% by weight solution. This reduction in the volume injected reduces the complexities associated with mixing and transportation of permanganate and reduces the time required for the injection. This is a distinct advantage in the highly urban remediation area; and 2.) use of sodium permanganate eliminates concerns associated with Homeland Security requirements. In addition, injection of a 5% solution of sodium permanganate significantly reduces health and safety concerns associated with potential human or environmental exposure associated with higher concentrations of sodium permanganate. Carus specifies that spills of sodium permanganate must be diluted to 6% or below to safely neutralize the spill and thereby protect human health and the environment. In general, sodium permanganate solutions are very stable at concentrations of 6% or less and are much safer to work with.

5. Injection Volume

The 40% sodium permanganate solution will be diluted to a 5% solution before delivery to the site or before injection. Based on data from other sites, the density of the 5% solution is approximately 8.65 lb/gal. The volume of 5% solution to be injected is calculated as follows:

Volume 5% Solution = 22,728 lb 40% Solution x 0.4 lb $NaMnO_4$ /lb 40% Solution x 20 lb H_2O/lb $NaMnO_4$ x gal 5% Solution/8.65 lb 5% Solution

Volume 5% Solution = 21,020 gal

6. Oxidant Injection Volume Design

The oxidant will be injected in two equal-volume events, i.e. approximately 10,500 gallons will be injected during each event. Since there are 12 injection locations with two wells (shallow and deep) at each location, approximately 440 gallons of 5% sodium permanganate solution will be injected into each well during each event.

7. Injection Duration

Based on other sites with similar lithology, it is assumed that permanganate can be injected at an average rate of 8 gpm at each well although this rate is likely to vary depending on actual field conditions. On this basis, it will take about an hour to inject at each well. If the contractor were to inject one well at a time, it is reasonable to assume that 4 wells could be completed in one day-so the total injection time would be 6 work days. If the contractor used a manifold to inject three or more wells at one time, the injection could be completed in about two work days.

ATTACHMENT A

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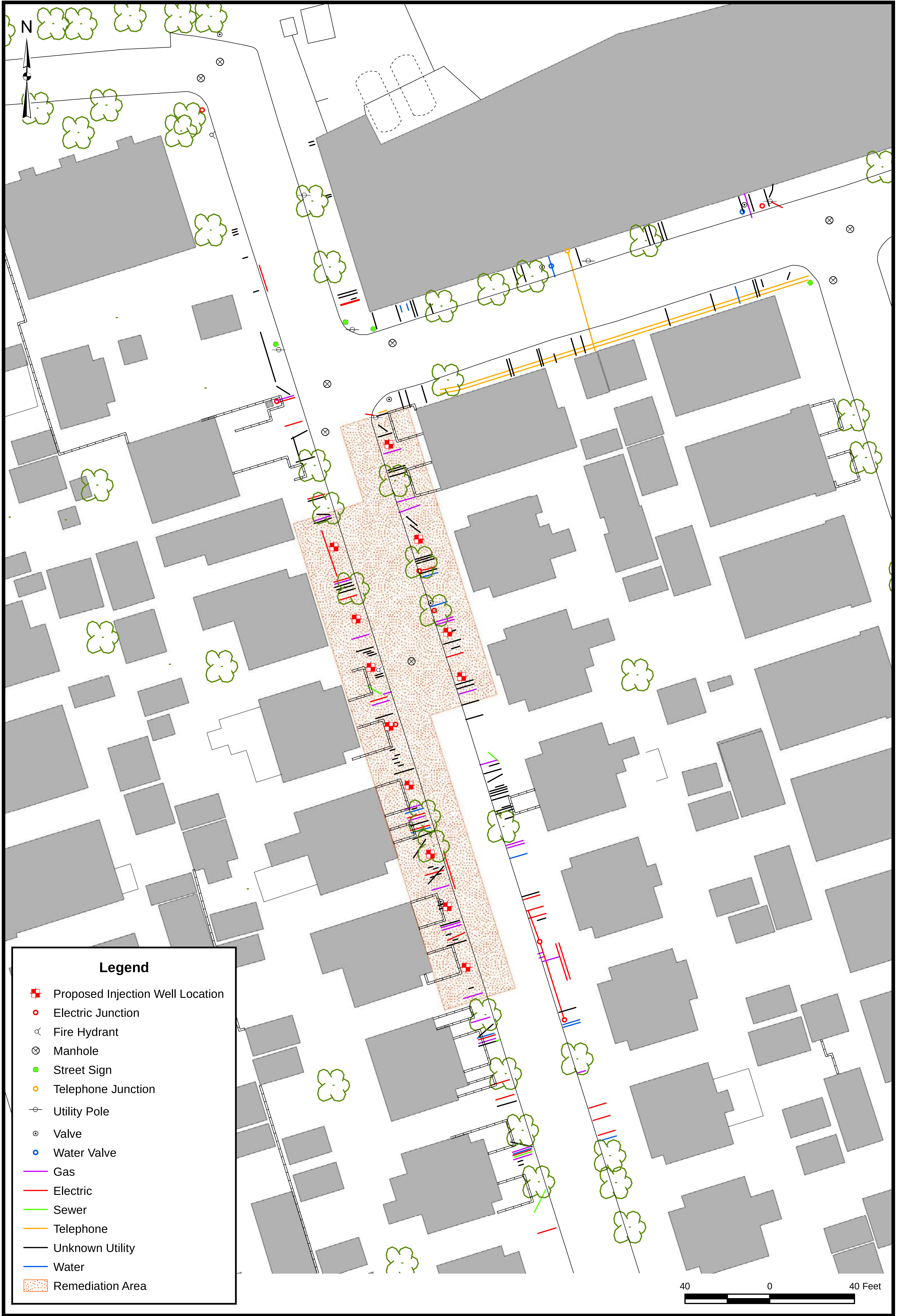


KLIEGMAN BROTHERS
UTILITY LOCATIONS AND GPR SURVEY RESULTS

FIGURE 2-1

ATTACHMENT B

Appendix B
Ref. 1

Soil Mechanics

T. William Lambe • Robert V. Whitman

Massachusetts Institute of Technology

1969

JOHN WILEY & SONS, New York • Chichester • Brisbane • Toronto • Singapore

SERIES IN SOIL ENGINEERING

Edited by

T. William Lambe
Robert V. Whitman
Professors of Civil Engineering
Massachusetts Institute of Technology

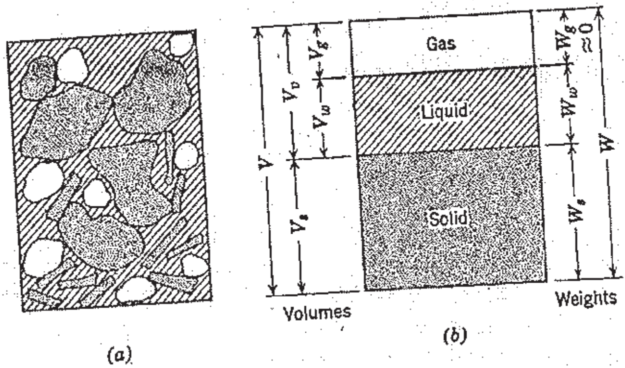
BOOKS IN SERIES:
Soil Testing for Engineers by T. William Lambe, 1951
Soil Mechanics by T. William Lambe and Robert V. Whitman 1968
Soil Dynamics by Robert V. Whitman (*in progress*)
Fundamentals of Soil Behavior by James K. Mitchell (*in progress*)

The aim of this series is to present the modern concepts of soil engineering, which is the science and technology of soils and their application to problems in civil engineering. The word "soil" is interpreted broadly to include all earth materials whose properties and behavior influence civil engineering construction.

Soil engineering is founded upon many basic disciplines: mechanics and dynamics; physical geology and engineering geology; clay mineralogy and colloidal chemistry; and mechanics of granular systems and fluid mechanics. Principles from these basis disciplines are backed by experimental evidence from laboratory and field investigations and from observations on actual structures. Judgment derived from experience and engineering economics are central to soil engineering.

The books in this series are intended primarily for use in university courses, at both the undergraduate and graduate levels. The editors also expect that all of the books will serve as valuable reference material for practicing engineers.

T. William Lambe and Robert V. Whitman



(a) (b)

Fig. 3.1 Relationships among soil phases. (a) Element of natural soil. (b) Element separated into phases.

Volume

Porosity:

$$n = \frac{V_v}{V} = \frac{e}{1+e}$$

Void ratio:

$$e = \frac{V_v}{V_s} = \frac{n}{1-n}$$

Degree of saturation:

$$S = \frac{V_w}{V_v}$$

$$n = \frac{e}{1+e}; \qquad e = \frac{n}{1-n}$$

Weight

Water content:

$$w = \frac{W_w}{W_s}$$

Specific Gravity

Mass:

$$G_m = \frac{\gamma_t}{\gamma_0}$$

Water:

$$G_w = \frac{\gamma_w}{\gamma_0}$$

Solids:

$$G = \frac{\gamma_s}{\gamma_0}$$

γ_0 = Unit weight of water at 4°C $\approx \gamma_w$

Note that $Gw = Se$

Unit Weight

Total:

$$\gamma_t = \frac{W}{V} = \frac{G + Se}{1+e}\gamma_w = \frac{1+w}{1+e}G\gamma_w$$

Solids:

$$\gamma_s = \frac{W_s}{V_s}$$

Water:

$$\gamma_w = \frac{W_w}{V_w}$$

Dry:

$$\gamma_d = \frac{W_s}{V} = \frac{G}{1+e}\gamma_w = \frac{G\gamma_w}{1 + wG/S} = \frac{\gamma_t}{1+w}$$

Submerged (buoyant):

$$\gamma_b = \gamma_t - \gamma_w = \frac{G - 1 - e(1-S)}{1+e}\gamma_w$$

Submerged (saturated soil):

$$\gamma_b = \gamma_t - \gamma_w = \frac{G-1}{1+e}\gamma_w$$

Specific gravity is the unit weight divided by the unit weight of water. Values of specific gravity of solids G for a selected group of minerals[3] are given in Table 3.1.

Table 3.1 Specific Gravities of Minerals

Quartz	2.65
K-Feldspars	2.54–2.57
Na–Ca-Feldspars	2.62–2.76
Calcite	2.72
Dolomite	2.85
Muscovite	2.7–3.1
Biotite	2.8–3.2
Chlorite	2.6–2.9
Pyrophyllite	2.84
Serpentine	2.2–2.7
Kaolinite	2.61[a] 2.64 ± 0.02
Halloysite (2 H_2O)	2.55
Illite	2.84[a] 2.60–2.86
Montmorillonite	2.74[a] 2.75–2.78
Attapulgite	2.30

[a] Calculated from crystal structure.

The expression $Gw = Se$ is useful to check computations of the various relationships.

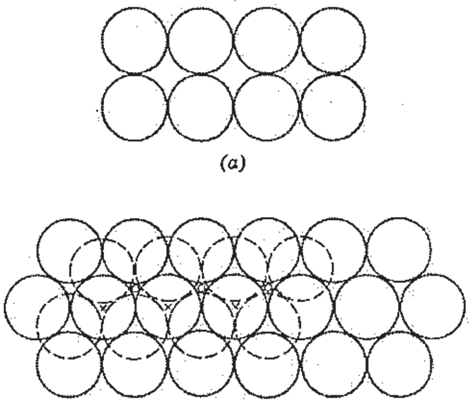
The student in soil mechanics must understand th meanings of the relationships in Fig. 3.1, convince him self once and for all that they are correct, and add the terms to his active vocabulary. These relationships a basic to most computations in soil mechanics and th are an essential part of soil mechanics.

Typical Values of Phase Relationships for Granular Soils

Figure 3.2 shows two of the many possible ways t a system of equal-sized spheres can be packed. The de packings represent the densest possible state for suc system. Looser systems than the simple cubic pack can be obtained by carefully constructing arches wi the packing, but the simple cubic packing is the loose the stable arrangements. The void ratio and porosit

---

[3] Chapter 4 discusses the common soil minerals.


(a)

(b)

Fig. 3.2 Arrangements of uniform spheres. (*a*) Plan and elevation view: simple cubic packing. (*b*) Plan view: dense packing. Solid circles, first layer; dashed circles, second layer; ∘, location of sphere centers in third layer: face-centered cubic array; ×, location of sphere centers in third layer: close-packed hexagonal array. (From Deresiewicz, 1958.)

these simple packings can be computed from the geometry of the packings, and the results are given in Table 3.2.

This table also gives densities for some typical granular soils in both the "dense" and "loose" states. A variety of tests have been proposed to measure the maximum and minimum void ratios (Kolbuszewski, 1948). The test to determine the maximum density usually involves some form of vibration. The test to determine minimum density usually involves pouring oven-dried soil into a container. Unfortunately, the details of these tests have not been entirely standardized, and values of the maximum density and minimum density for a given granular soil depend on the procedure used to determine them. By using special measures, one can obtain densities greater than the so-called maximum density. Densities considerably less than the so-called minimum density can be obtained, especially with very fine sands and silts, by slowly sedimenting the soil into water or by fluffing the soil with just a little moisture present.

Table 3.2 Maximum and Minimum Densities for Granular Soils

	Void Ratio		Porosity (%)		Dry Unit Weight (pcf)			
Description	e_{max}	e_{min}	n_{max}	n_{min}	$\gamma_{d\,min}$	$\gamma_{d\,max}$		γ_{avg}
Uniform spheres	0.92	0.35	47.6	26.0	—	—	n_{avg} 36.8	
Standard Ottawa sand	0.80	0.50	44	33	92	110	n_{avg} 38.5	101
Clean uniform sand	1.0	0.40	50	29	83	118	n_{avg} 39.5	100.5
Uniform inorganic silt	1.1	0.40	52	29	80	118	n_{avg} 40.5	99
Silty sand	0.90	0.30	47	23	87	127	n_{avg} 35	107
Fine to coarse sand	0.95	0.20	49	17	85	138	n_{avg} 33	111.5
Micaceous sand	1.2	0.40	55	29	76	120	n_{avg} 42	98
Silty sand and gravel	0.85	0.14	46	12	89	146	n_{avg} 29	117.5

B. K. Hough, *Basic Soils Engineering*. Copyright © 1957, The Ronald Press Company, New York.

The smaller the range of particle sizes present (i.e., the more nearly uniform the soil), the smaller the particles, and the more angular the particles, the smaller the minimum density (i.e., the greater the opportunity for building a loose arrangement of particles). The greater the range of particle sizes present, the greater the maximum density (i.e., the voids among the larger particles can be filled with smaller particles).

A useful way to characterize the density of a natural granular soil is with *relative density* D_r, defined as

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100\%$$

$$= \frac{\gamma_{d\,max}}{\gamma_d} \times \frac{\gamma_d - \gamma_{d\,min}}{\gamma_{d\,max} - \gamma_{d\,min}} \times 100\% \qquad (3.1)$$

where

e_{min} = void ratio of soil in densest condition
e_{max} = void ratio of soil in loosest condition
e = in-place void ratio
$\gamma_{d\,max}$ = dry unit weight of soil in densest condition
$\gamma_{d\,min}$ = dry unit weight of soil in loosest condition
γ_d = in-place dry unit weight

Table 3.3 characterizes the density of granular soils on the basis of relative density.

Table 3.3 Density Description

Relative Density (%)	Descriptive Term
0–15	Very loose
15–35	Loose
35–65	Medium
65–85	Dense
85–100	Very dense

Values of water content for natural granular soils vary from less than 0.1% for air-dry sands to more than 40% for saturated, loose sand.

Typical Values of Phase Relationships for Cohesive Soils

The range of values of phase relationships for cohesive soils is much larger than for granular soils. Saturated sodium montmorillonite at low confining pressure can exist at a void ratio of more than 25; saturated clays

ATTACHMENT C

Appendix B
Ref. 3

CARUS CHEMICAL COMPANY
Technology and Quality
Remediation Report

11 September 2002

Customer: URS
282 Delaware Avenue
Buffalo, NY 14202

Cc: B. Kelley
P. Vella
B. Veronda

Attention: Linda Warren

Keywords: $KMnO_4$
Soil

Chemist: Kelly Frasco
Tech # 9041

Subject: CAIROX® Potassium Permanganate Soil Oxidant Demand

Summary

The soil natural oxidant demand (NOD) for the low Cairox potassium permanganate ($KMnO_4$) dose averaged from 8 mg/kg at 1 hour to 41 mg/kg at 168 hours. The NOD for the high $KMnO_4$ dose ranged from 13 mg/kg at 1 hour to 78 mg/kg at 168 hours.

Background

A total of 4 soil samples were received from URS on August 28, 2002. The samples were sampled at the Queens, NY site and were identified as MW-2 (72-74), MW-3 (72-74), MW-4 (68-70), and MW-5 (68-70). The customer requested the natural oxidant demand be determined on each sample. The measurement of the natural oxidant demand is used to estimate the concentration of $KMnO_4$ that will be consumed by the natural reducing agents in the soil during a given time period.

Experimental

To determine the natural oxidant demand of the soil, the contaminants are removed prior to adding permanganate by drying the soil sample in an evaporation oven (103° C) for approximately 24 hours. A reaction vessel for each soil sample was then filled with 9 grams of soil and diluted to 90 mls with deionized water for both a low (295 mg/L) and high (2,675 mg/L) concentration of $KMnO_4$. At the start of each experimental run, 10 mls of concentrated oxidant solution was introduced into the reaction vessels. The reaction vessels were placed on a stir plate to achieve complete mixing. Reaction vessels were sampled for residual permanganate (MnO_4^-) at reaction times of 1, 3, 7, 24, 48 and 168 hours (1 week).

Results

The $KMnO_4$ demand is the amount of permanganate consumed in a given amount of time. The NOD results for the low and high oxidant doses can be seen in Tables 1 and 2, respectively.

$KMnO_4$ residual is plotted against time in Figures 1 and 2 for the low and high oxidant demands, respectively.

Table 1: Soil NOD for Low $KMnO_4$ Dose (295 mg/L)

Reaction Time (hours)	MW-1 (mg/kg)	MW-2 (mg/kg)	MW-3 (mg/kg)	MW-4 (mg/kg)
1	0	11	13	7
3	5	13	19	9
7	9	21	25	18
24	11	28	25	21
48	17	41	28	26
168	33	50	40	41

Figure 1: Soil NOD for Starting Dose of 295 mg/L $KMnO_4$

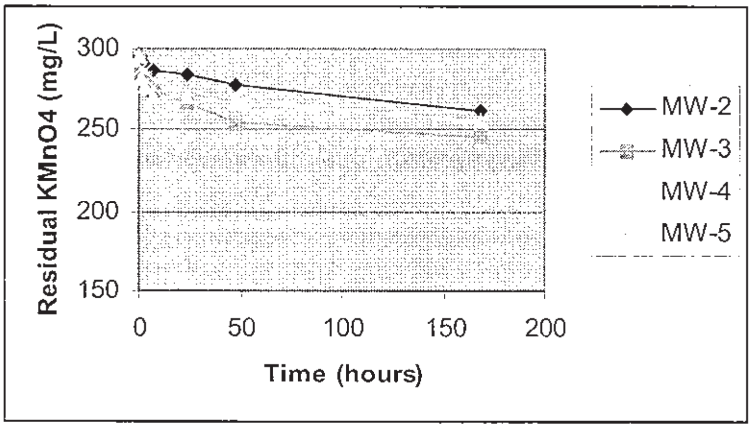
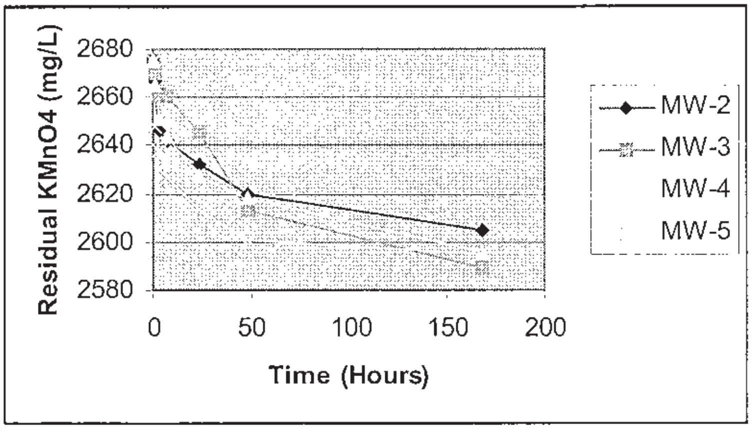


Table 2: Soil NOD for High $KMnO_4$ Dose (2,675 mg/L)

Reaction Time (hours)	MW-1 (mg/kg)	MW-2 (mg/kg)	MW-3 (mg/kg)	MW-4 (mg/kg)
1	8	5	10	27
3	29	14	24	37
7	33	15	31	49
24	43	30	48	62
48	55	62	57	74
168	70	86	79	80

Figure 2: Soil NOD for Starting Dose of 2,675 mg/L $KMnO_4$

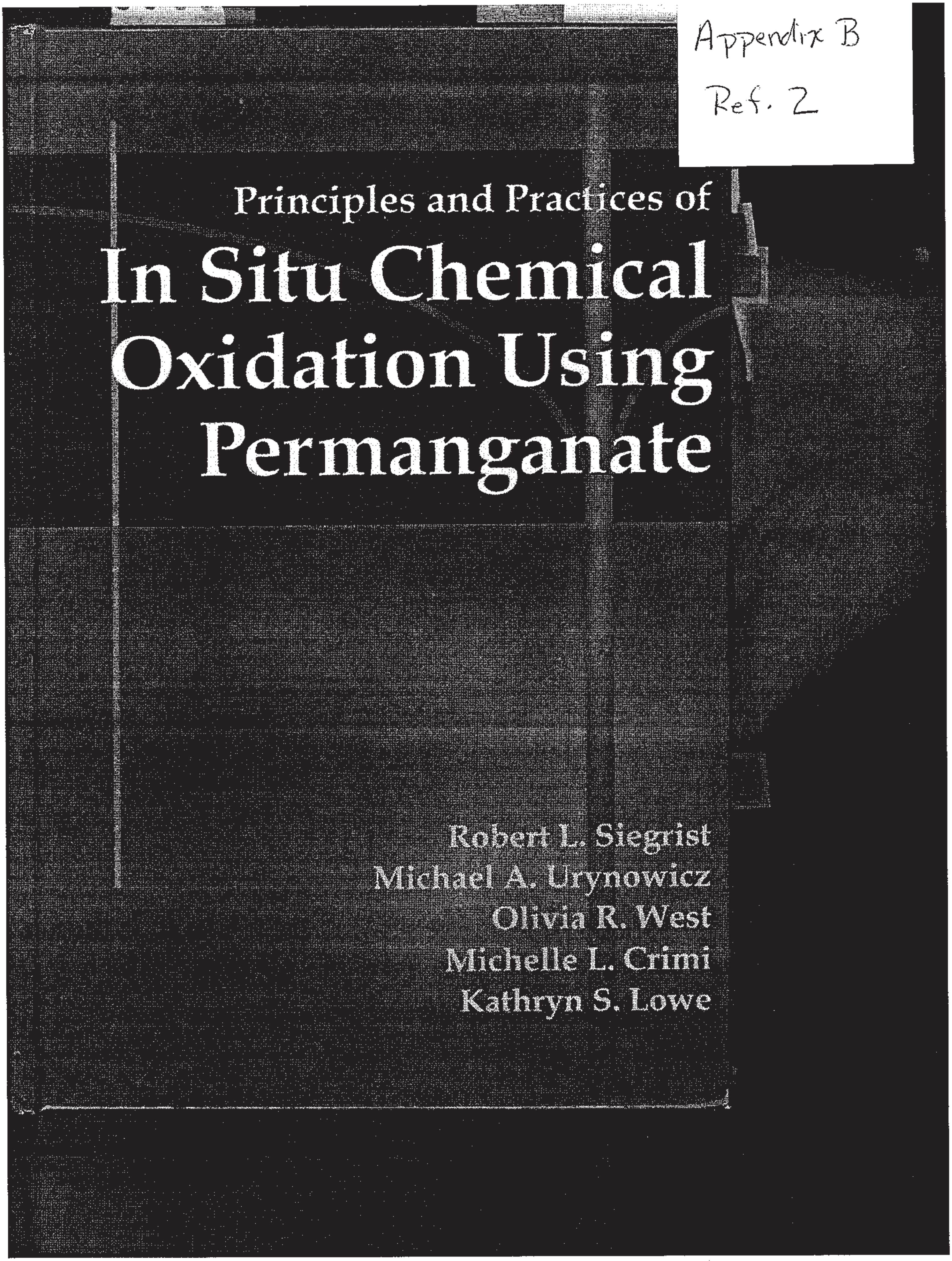


Conclusions

For this application the amount of $KMnO_4$ needed will be dependent on the reaction time allowed. During the 168 hours tested, there is a slight variation in the demands between all four soil samples at both oxidant doses. A slight variation in the NOD is to be expected within the site. These soil samples have a relatively low NOD. A low background oxidant demand is generally favorable for in-situ permanganate treatment.

ATTACHMENT D

Appendix B
Ref. 2



Principles and Practices of

In Situ Chemical Oxidation Using Permanganate

Robert L. Siegrist
Michael A. Urynowicz
Olivia R. West
Michelle L. Crimi
Kathryn S. Lowe

TABLE 2-1. **Properties and characteristics of potassium permanganate (CAIROX).**[1]

Property	Value and/or comments
Chemical formula	$KMnO_4$
Purity (% by weight)	Technical Grade = 98%, Free Flowing Grade = 97%, USP Grade = 99%
Molecular weight	158.03 g/mol
Form and features	Dark purple solid with metallic luster, sweetest astringent taste, odorless, granular crystalline, oxidizer
Specific gravity—solid	2.703 g/cm^3
Specific gravity—6% sol.	1.039 g/cm^3
Bulk density	90 to 100 lb/ft^3
Solubility in distilled water:	
0C	27.8 g/L
20C	65.0 g/L
40C	125.2 g/L
60C	230.0 g/L
Heat of solution	10.2 Kcal/mole
Packaging	25 kg pail, 50 kg drum, 150 kg drum, plus special packaging
Hazardous class (ID no.)	Oxidizer (UN1490)
Stability	Stable indefinitely if held in cool dry area in sealed containers
Incompatibilities	Avoid contact with acids, peroxides, and all combustible organics or readily oxidizable materials
Materials compatibility	In neutral or alkaline conditions $KMnO_4$ is not corrosive to iron, mild steel or stainless steel. However chloride corrosion may be accelerated. Plastics such as polypropylene, PVC, epoxy resins, Lucite, Viton A, and Hypalon are suitable but Teflon FEP and TFE, and Telzel ETFE are best. Natural rubbers and fibers are often incompatible

[1] Refer to Appendix A for additional manufacturer's information.

available. Sodium permanganate ($NaMnO_4$) is supplied by Carus as a concentrated liquid (min. 40 wt.% as $NaMnO_4$, Table 2-2). In this form, MnO_4^- ion is provided without the potassium (for sites where ^{40}K is a concern) and without dusting hazards associated with dry $KMnO_4$ solids.

The composition of potassium permanganate has two facets that are relevant to water quality effects but that are unrelated to in situ o

TABLE 2-2. **Properties and characteristics of sodium permanganate (LIQUOX).**[1]

Property	Value and/or comments
Chemical formula	$NaMnO_4$
Purity	40.0 % by weight minimum as $NaMnO_4$
Molecular weight	141.93 g/mol
Form and features	Dark purple liquid with metallic luster, sweetest astringent taste, odorless, granular crystalline, oxidizer
Specific gravity	1.36 to 1.39 g/cm^3 for a 40% solution
Solubility in water	Miscible with water in all proportions
Insolubles	100 to 1900 ppm
Potassium	1000 to 2200 ppm
pH	6.0 to 7.0
Packaging	18.9L Jerrican, 18.9L steel drum, 208L steel drum
Hazard class (ID no.)	Oxidizer (UN3214)
Stability	Stable for >18 mon
Incompatibilities	Avoid contact with acids, peroxides, and all combustible organics or readily oxidizable materials
Materials compatibility	In neutral or alkaline conditions $NaMnO_4$ is not corrosive to carbon and 316 stainless steel. However chloride corrosion may be accelerated. Plastics such as Teflon, polypropylene, HDPE, and EDPM are compatible, but Teflon FEP and TFE, and Telzel ETFE are best

[1] Refer to Appendix A for additional manufacturer's information.

The stoichiometric reactions for the complete destruction of several common chlorinated organic solvents in an aqueous system are given in eqn. 2.11.

Tetrachloroethene (PCE)

$$4KMnO_4 + 3C_2Cl_4 + 4H_2O \rightarrow 6CO_2 + 4MnO_2 + 4K^+ + 8H^+ + 12Cl^- \quad (2.8)$$

Trichloroethene (TCE)

$$2KMnO_4 + C_2HCl_3 \rightarrow 2CO_2 + 2MnO_2 + 2K^+ + H^+ + 3Cl^- \quad (2.9)$$

Dichloroethene (DCE)

$$8KMnO_4 + 3C_2H_2Cl_2 \rightarrow 6CO_2 + 8MnO_2 + 8K^+ + 6Cl^- + 2OH^- + 2H_2O \quad 2.10)$$

Vinyl chloride (VC)

$$10KMnO_4 + 3C_2H_3Cl \rightarrow 6CO_2 + 10MnO_2 + 10K^+ + 3Cl^- + 7OH^- + H_2O \quad (2.11)$$

Based on the above stoichiometry, the oxidant demand and product formation for chemical oxidation of the four chlorinated ethenes are given in Table 2-4. Note that the reactions are comparable in permanganate demand whether it is supplied in the potassium form or sodium form. As shown in Table 2-4, on a unit mass basis, halocarbons with higher chlorine substitution (e.g., PCE vs. DCE) consume less oxidant (per the stoichiometric requirement) and produce less MnO_2 solids.

Reaction Pathways

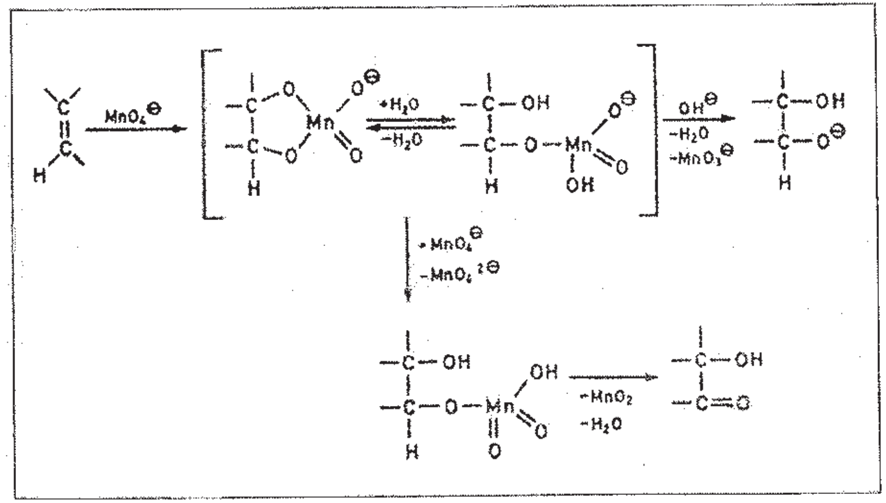
The hydroxylation of olefins by MnO_4^- has been known for many years (Wagner 1895). It is generally accepted that under neutral to acidic pHs, MnO_4^- initially reacts with the carbon-carbon double bond to form a five-member cyclic hypomanganate ester (Figure 2-1). That reaction consumes 1 mole of permanganate for each mole of olefin, and that cycloaddition has been reported to be the rate-determining step in degradation (Wiberg and Saegebarth 1957, Stewart 1965, Freeman 1976). Yan and Schwartz (1998, 1999) recently proposed a similar reaction scheme for the chemical oxidation of TCE in which the cyclic ester can then undergo decomposition to carbon dioxide along several oxidative or hydrolysis pathways depending on pH. Several carboxylic acid intermediates including formic, oxalic, glyoxylic and glycolic acids were also identified. In highly alkaline solutions, hydroxyl radicals, which can contribute to oxidative destruction, also may be formed. The degradation

TABLE 2-4. Stoichiometric requirements for mineralization of organic compounds by permanganate.[1]

Target compound	Compound molecular weight (g/mol)	Oxidant demand (g MnO_4^- / g of target)	MnO_2 produced (g MnO_2 / g target oxidized)
Tetrachloroethene	165.6	0.96	0.70
Trichloroethene	131.2	1.81	1.32
Dichloroethene	96.8	3.28	2.39
Vinyl chloride	62.4	6.35	4.64
Phenol	94.1	11.8	8.62
Naphthalene	128.2	14.8	10.8
Phenanthrene	178.2	14.7	10.7
Pyrene	202.3	14.5	10.6

[1] Molecular weight of MnO_4^- = 118.9 g, MnO_2 = 86.9 g, $KMnO_4$ = 158 g, and $NaMnO_4$ = 141.9 g.

FIGURE 2-1. Pathway for oxidation of olefins such as TCE.



ATTACHMENT E

CARUS®

CARUS REMEDIATION TECHNOLOGIES

In Situ Chemical Oxidation (ISCO) *In Situ* Bioremediation (BIO) *In Situ* Biogeochemical Stabilization (ISBS)

RemOx® S and L ISCO Reagents Estimation Spreadsheet

Input data into boxes with blue font.

	Estimates	Units
Treatment Area Volume		
Length	**400**	ft
Width	**70**	ft
Area	28000	sq ft
Thickness	**20**	ft
Total Volume	20741	cu yd
Soil Characteristics/Analysis		
Porosity	**35**	%
Total Plume Pore Volume	1466182	gal
Avg Contaminant Conc	**22**	ppm
Mass of Contaminant	269.19	lb
PNOD	**1**	g/kg
Effective PNOD	**10**	%
Effective PNOD Calculated	0.1	
PNOD Oxidant Demand	6160	lb
Avg Stoichiometric Demand	**0.96**	lb/lb
Contaminant Oxidant Demand	258.42	lb
Theoretical Oxidant Demand	6418.42	lb
Confidence Factor	**4**	
Calculated Oxidant Demand	25673.684	
Injection Volumes for RemOx S		
RemOx S Injection Concentration	**2.0%**	%
Total Volume of Injection Fluid	153,827	gal
Pore Volume Replaced	0.10	%
Amount of RemOx S ISCO Reagent Estimated	**25,674 pounds**	
Injection Volumes for RemOx L		
RemOx L Injection Concentration	**5.0%**	%
Calculated Specific Gravity	1.03717	g/ml
Total Volume of Injection Fluid	53,274	gal
Pore Volume Replaced	0.04	%
Amount of RemOx L ISCO Reagent Estimated	**57,637 pounds** **5,043 gallons**	

APPENDIX B

OXIDANT SAFETY INFORMATION

TASK HAZARD ANALYSIS

HAZARD IDENTIFICATION	
Task	Hazards
Chemical Mixing, Handling and Storage	Chemical exposure and/or release; lifting; heavy equipment; sharp objects; pinch points; fire hydrant considerations; and/or weather complications

Chemical Hazards and Controls	
Potential Hazards	Controls
Potassium Permanganate ($KMnO_4$)	***Engineering and Administrative:*** • Educate site personnel on site hazard communication procedures. • Potassium permanganate ($KMnO_4$) is a strong oxidizer. • Contact of wet or dry concentrated material with skin my cause burns. • Contact of wet or dry concentrated material with combustibles may result in fire. • Exposure to $KMnO_4$ slurry (e.g., wet oxidant solids), powder, or solution: • Exposure to eyes: Flush with water from eye wash station or hose for at least 15 minutes, holding lids open. Do not neutralize chemically. Seek medical attention immediately. • Exposure to skin: Wash with water or neutralize chemically. Remove contaminated clothing. Seek medical attention if irritation is persistent or severe. • Inhalation: Remove worker from contaminated area. Resuscitate and seek medical attention if necessary. • Ingestion: If conscious, give large quantities of water and seek medical attention. Do not induce vomiting. Never give anything orally to an unconscious person. • Store material in sealed containers under weatherproof protection away from combustible materials. • Mixing equipment must be assembled within secondary containment for the management of unexpected spills and /or releases. • Inspect equipment and hose connections prior to use. • Stay clear of pumps and mixing equipment. • Use enclosed handling and mixing systems. • Clearly label all containers and maintain handling instructions on site. • Refer to MSDS for additional information. • Perform activities upwind when dry chemicals are being handled. • A wind indicator shall be placed at the site to be used during material transfer activities (e.g., $KMnO_4$). Workers will locate themselves to be positioned up- or crosswind of material transfer activities (e.g., during material transfer of $KMnO_4$ to the mixing rig). • Secondary containment is required for the mixing rig. The secondary containment measures are recommended to separate equipment such that oxidant materials can be recovered for reuse or neutralization without contamination from other compounds (e.g., petroleum

Chemical Hazards and Controls	
Potential Hazards	Controls
	compounds used in energy supply equipment). Permanganate should not be expected to treat non-target compounds (e.g., gasoline, hydraulic oil) used in equipment operations. • Applicable provisions of the subcontractors' health and safety plan will be incorporated into the HASP as determined necessary by the project manager and field task leader. • Refer to SMS 2 Hazard Communication. ***Personal Protective Equipment:*** • Provide an ANSI approved eye-wash and plenty of wash water in the work area. • Wear safety glasses with side shields and gloves when around the fracturing rig. • The fracturing rig operator must utilize appropriate PPE to prevent and minimize eye and skin contact, and inhalation; this includes face shield, tyvek or similar apron with long sleeves, and long chemical gloves. • The subcontractor must visually screen all subcontractor employees on a routine basis for the proper use and maintenance of PPE to prevent chemical exposure (e.g., prolonged skin exposure causing chemical burns). ***Monitoring:*** • Visually monitor for dust when dry chemical is being handled. • Visually monitor wind indicator during dry material transfer or handling activities. • Visual and/or pressure monitoring for surfacing slurry and/or concentrated solution.
Spill Response for $KMnO_4$	• When slurry or concentrated solution is observed to be surfacing from a monitoring well, abandoned soil boring, or other conduit, collect as much of the material into an appropriate container (e.g., poly or metal bucket) for temporary storage and later reuse or neutralization. Collected material may be filtered to remove debris for later use. • Material spilled within the secondary containment around mixing and/or injection equipment will be collected and temporarily stored until reuse. General housekeeping of the secondary containment must be conducted to prevent slips, trips, falls, and/or spread of oxidant material outside the secondary containment. • If neutralization is required, experienced personnel should be present for the neutralization of significant volumes of slurry. • Neutralization of concentrated material must not be performed in a small or enclosed container; a large container made of suitable material (e.g., poly or metal bucket) should be used if neutralization is required. • Neutralization of materials should be performed with an aqueous sodium thiosulfate solution; due to the exothermic (i.e., generating heat) nature of the reaction between $KMnO_4$ and sodium thiosulfate,

Chemical Hazards and Controls	
Potential Hazards	Controls
	and the low solubility of both $KMnO_4$ and sodium thiosulfate, the addition of powdered or granular sodium thiosulfate to slurry material (e.g., liquid mixture containing $KMnO_4$ **solids**) should not be performed. • Other organic materials, such as mulch or garden soil can be mixed with slurry materials for neutralization at the ground surface (e.g., to facilitate visual appearance or general site housekeeping requirements). Note that some garden supply materials may be coated with preservatives or may individually react with the $KMnO_4$ in a vigorous manner. Prior to using any organic materials for neutralization, test a small volume of oxidant solution in a heat resistance open container (e.g., 5-gallon poly or metal bucket) to evaluate the reaction potential of neutralization.
Sodium Thiosulfate	• Minimize inhalation; remove to fresh air; seek medical attention for difficulty breathing. • Ingestion – induce vomiting immediately as directed by medical personnel. Never give anything by mouth to an unconscious person. Get medical attention. • Minimize skin contact by using appropriate PPE; wash exposed area with soap and water. Get medical advice if irritation develops. • Avoid eye contact; wash thoroughly with running water. Get medical advice if irritation develops. • For neutralization of $KMnO_4$ material see above section Spill Response for $KMnO_4$.
Hydrogen Peroxide (30%)	• Minimize inhalation; Remove from exposure to fresh air immediately; seek medical attention for difficulty breathing. If not breathing, give artificial respiration; do not give mouth-to-mouth respiration. • Ingestion – do not induce vomiting. If victim is conscious and alert, give 2 to 4 cupfuls of milk or water. Never give anything by mouth to an unconscious person. Get medical attention immediately. Call poison control center. • Minimize skin contact by using appropriate PPE; flush exposed area with soap and water for at least 15 minutes. Remove contaminated clothing. Get medical advice if irritation develops or persists. Wash clothes before reuse • Avoid eye contact; immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower lids. Get medical aid immediately. Do not allow victim to rub of keep eyes closed. Extensive irrigation is required. • For use in neutralizing permanganate solution (e.g., dissolved in water or groundwater) or small amounts of $KMnO_4$ solids, 3% to 12% hydrogen peroxide is recommended. Hydrogen peroxide in 3% to 5% concentrations is typically available at grocery stores. Mix 3% to 5% hydrogen peroxide with equal parts store bought vinegar (i.e., dilute acetic acid) to use as neutralizer.

Chemical Hazards and Controls	
Potential Hazards	**Controls**
Acetic Acid (e.g., Vinegar)	• Minimize inhalation; remove to fresh air; seek medical attention for difficulty breathing. If not breathing, give artificial respiration. • Ingestion – do not induce vomiting. Give large quantities or water of milk, if available. Never give anything by mouth to an unconscious person. Get medical attention. • Minimize skin contact by using appropriate PPE; wash exposed area with water for at least 15 minutes. Remove contaminated clothing. Get medical advice if irritation develops or persists. Wash clothing before reuse. • Avoid eye contact; immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower lids. Get medical aid immediately. Do wash thoroughly with running water. Get medical advice if irritation develops or persists. • For use in neutralizing permanganate solution (e.g., dissolved in water or groundwater) or small amounts of $KMnO_4$ solids, dilute concentrations of acetic acid (i.e., vinegar), typically available at grocery stores, is recommended. Mix vinegar (i.e., dilute acetic acid) with equal parts store bought hydrogen peroxide (i.e., 3% to 5% concentration) to use as neutralizer.

MATERIAL SAFETY DATA SHEETS

RemOx™ S
ISCO Reagent

CAS Registry No. 7722-64-7
EINECS No. 231-760-3

Fact Sheet

RemOx™ S ISCO Reagent has been specifically manufactured for environmental applications such as remediation of soils and associated groundwater. This product can be used to degrade a variety of contaminants including chlorinated solvents, polyaromatic hydrocarbons, phenolics, organo-pesticides and substituted aromatics. RemOx™ S ISCO Reagent is shipped with a Certificate of Analysis (COA) to document assay, insolubles, and weight loss as well as a manufacturing Certificate of Conformance (COC) for trace metals.

Product Specifications

Assay, %	≥ 98.8 as $KMnO_4$
Insolubles, %	≤ 0.2
Weight Loss (18 hrs. over silica gel), %	≤ 0.5
Trace Metals	See Table 1

Chemical/Physical Data

Formula	$KMnO_4$
Formula Weight	158.0 g/mol
Form	Granular Crystalline
Specific Gravity	
Solid	2.703 g/cm^3
3% Solution	1.020 g/mL by weight, 20°C / 4°F
Bulk Density	Approximately 100 lb/ft^3

Decomposition may start at 150°C.

Applications

RemOx^{TM-} S ISCO Reagent is used for soil and groundwater remediation by in-situ or ex-situ chemical oxidation and as active agent in subsurface reactive barriers for treatment of:

- Chlorinated Ethenes-PCE, TCE, Vinyl Chloride, etc.
- Phenolics-PCP, Phenol, Cresol, etc
- Polyaromatic Hydrocarbons-Naphthalene, Phenanthrene, Benzo(a) Pyrene, etc.
- TNT, RDX, HMX, etc.
- Various pesticides

Solubility in Distilled Water

Temperature		**Solubility**	
°C	°F	g/L	oz/gal
0	32	27.8	3.7
20	68	65.0	8.6
40	104	125.2	16.7
60	140	230.0	30.7
70	158	286.4	38.3
75	167	323.5	43.2

Shipping Containers

25 kg pail (55.125 lb) net, with handle, made of HDPE, weighs 3.1 lbs. It is tapered to allow nested storage of empty drums, stands approximately 15½ inches high and has a maximum diameter of 12 inches.

150 kg drum (330.750 lb) net, made of 22-gauge steel, weighs 22.4 lbs. It stands approximately 29½ inches high and is approximately 19¾ inches in diameter.

Special Packages will be considered on request.

Packaging meets UN performance oriented packaging requirements.

Description

Crystals or granules are dark purple with a metallic sheen, sometimes with a dark bronze-like appearance. RemOx™ S ISCO Reagent has a sweetish, astringent taste and is odorless.

Handling and Storage

Protect containers against physical damage. When handling RemOx™ S ISCO Reagent, respirators should be worn to avoid irritation of or damage to mucous membranes. Eye protection should also be worn when handling RemOx™ S ISCO Reagent as a solid or in solution.

RemOx™ S ISCO Reagent is stable and will keep indefinitely if stored in a cool, dry area in closed containers. Concrete floors are preferred to wooden decks. To clean up spills and leaks follow the steps recommended in our MSDS. Be sure to use goggles, rubber gloves, and respirator when cleaning up a spill or leak.

Avoid contact with acids, peroxides, and all combustible organic or readily oxidizable materials including inorganic oxidizable materials and metal powders. With hydrochloric acid, chlorine gas is liberated. RemOx™ S ISCO Reagent is not combustible, but will support combustion. It may decompose if exposed to intense heat. Fires may be controlled and extinguished by using large quantities of water. Refer to the *MSDS* for more information.

Shipping

RemOx™ S ISCO Reagent is classified by the Hazardous Materials Transportation Board (HMTB) as an oxidizer. It is shipped under Interstate Commerce Commission's (ICC) Tariff 19.

Harmonized Code for Export: 2841.61.0000
Proper Shipping Name: Potassium Permanganate
Hazard Class: Oxidizer
Identification Number: UN 1490
Packaging Requirements: 49 CFR Parts 100 to 199
Sections: 173.152, 173.153, 173.194
Label Requirements: Oxidizer, 5.1
Shipping Limitations:

Minimum quantities

Rail car: See Tariff for destination
Truck: No minimum

Postal regulations

Information applicable to packaging of oxidizers for shipment by the U.S. Postal service to domestic and foreign destinations is readily available from the local postmaster.

United Parcel Service accepts 25 pounds as largest unit quantity properly packaged; consult United Parcel Service.

Regulations concerning shipping and packing should be consulted regularly due to frequent changes.

Corrosive Properties

RemOx™ S ISCO Reagent is compatible with many metals and synthetic materials. Natural rubbers and fibers are of incompatible. Solution pH and temperature are also import factors. The material must be compatible with either the acid or alkali also being used

In neutral and alkaline solutions, RemOx™ S ISCO Reagent is not corrosive to iron, mild steel, or stainless steel. However, chloride corrosion of metals may be accelerated when an oxidant such as RemOx™ S ISCO Reagent is present in solution. Plastics such as polypropylene, polyvinyl chloride Type I (PVC I), epoxy resins, fiberglass reinforced plastic (FRP) and TFE, and Tefzel ETFE are best. *Refer to Material Compatibility Chart.*

Aluminum, zinc, copper, lead, and alloys containing these metals maybe be slightly affected by RemOx™ S ISCO Reagent solutions. Actual studies should be made under the conditions in which RemOx™ ISCO Reagent will be used.

Table 1: Typical Trace Metal Content and Specifications

Element	Typical Analysis	Specification	DL* mg/kg	Element	Typical Analysis	Specification	DL* mg/kg
Ag	ND	0.25	0.048	Hg	ND	0.050	0.004
Al	12.7	80.0	0.28	Na	49.48	100	NA
As	0.77	4.0	0.006	Ni	ND	0.25	0.048
Ba	2.89	15.00	0.016	Pb	ND	1.0	0.20
Be	ND	0.5	0.10	Sb	ND	1.0	0.20
Cd	ND	0.1	0.02	Se	ND	1.000	0.0002
Cr	1.41	7.5	0.028	Sr	0.088	0.30	0.018
Cu	0.07	2.000	0.034	Tl	ND	5.0	1.00
Fe	9.05	15.000	0.066	Zn	1.12	3.0	0.016

*DL = Detection Limit

Carus Chemical Company

During its 90-year history Carus' ongoing emphasis on research and development, technical support, and customer service has enabled the company to become the world leader in permanganate, manganese, oxidation, and base-metal catalyst technologies.

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Web: www.caruschem.com
E-Mail: remediation@caruschem.com

MATERIAL SAFETY DATA SHEET

CAIROX® Potassium Permanganate

Section 1 Chemical Product and Company Identification

PRODUCT NAME: CAIROX® potassium permanganate, $KMnO_4$

SYNONYMS:
Permanganic acid potassium salt
Chameleon mineral
Condy's crystals
Permanganate of potash

MANUFACTURER'S NAME: CARUS CHEMICAL COMPANY

MANUFACTURER'S ADDRESS:
Carus Chemical Company
1500 Eighth Street
P. O. Box 1500
LaSalle, IL 61301

TRADE NAME: CAIROX® potassium permanganate

TELEPHONE NUMBER FOR INFORMATION: 815/223-1500

EMERGENCY TELEPHONE NO: 800/435-6856

AFTER HOURS NO. 815/223-1565
5:00 PM-8:00 AM Central Standard Time
Monday-Friday, Weekends and Holidays

CHEMTREC TELEPHONE NO.: 800/424-9300

Section 2 Composition/Information on Ingredients

Material or component	CAS No.	%	Hazard Data	
Potassium permanganate	7722-64-7	97% min $KMnO_4$	PEL-C	5 mg Mn per cubic meter of air
			TLV-TWA	0.2 mg Mn per cubic meter of air

Section 3 Hazards Identification

1. Eye Contact
   Potassium permanganate is damaging to eye tissue on contact. It may cause severe burns that result in damage to the eye.

2. Skin Contact
   Contact of solutions at room temperature may be irritating to the skin, leaving brown stains. Concentrated solutions at elevated temperature and crystals are damaging to the skin.

3. Inhalation
   Acute inhalation toxicity data are not available. However, airborne concentrations of potassium permanganate in the form of dust or mist may cause damage to the respiratory tract.

4. Ingestion
   Potassium permanganate, if swallowed, may cause severe burns to mucous membranes of the mouth, throat, esophagus, and stomach.

Section 4 First Aid Measures

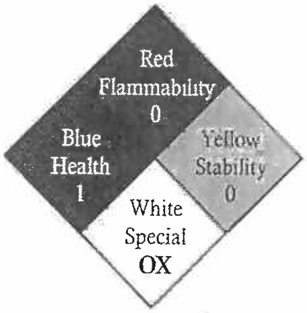
1. Eyes
   Immediately flush eyes with large amounts of water for at least 15 minutes holding lids apart to ensure flushing of the entire surface. Do not attempt to neutralize chemically. Seek medical attention immediately. Note to physician: Soluble decomposition products are alkaline. Insoluble decomposition product is brown manganese dioxide.
2. Skin
   Immediately wash contaminated areas with large amounts of water. Remove contaminated clothing and footwear. Wash clothing and decontaminate footwear before reuse. Seek medical attention immediately if irritation is severe or persistent.
3. Inhalation
   Remove person from contaminated area to fresh air. If breathing has stopped, resuscitate and administer oxygen if readily available. Seek medical attention immediately.
4. Ingestion
   Never give anything by mouth to an unconscious or convulsing person. If person is conscious, give large quantities of water. Seek medical attention immediately.

Section 5 Fire Fighting Measures

NFPA* HAZARD SIGNAL

Health Hazard 1 = Materials which under fire conditions would give off irritating combustion products.
(less than 1 hour exposure) Materials which on the skin could cause irritation.
Flammability Hazard 0 = Materials that will not burn.
Reactivity Hazard 0 = Materials which in themselves are normally stable, even under fire exposure conditions, and which are not reactive with water.
Special Hazard OX = Oxidizer

*National Fire Protection Association 704



FIRST RESPONDERS:

Wear protective gloves, boots, goggles, and respirator. In case of fire, wear positive pressure breathing apparatus. Approach site of incident with caution. Use Emergency Response Guide NAERG 96 (RSPA P5800.7). Guide No. 140.

FLASHPOINT	None	
FLAMMABLE OR EXPLOSIVE LIMITS	Lower: Nonflammable	Upper: Nonflammable
EXTINGUISHING MEDIA	Use large quantities of water. Water will turn pink to purple if in contact with potassium permanganate. Dike to contain. Do not use dry chemicals, CO_2, Halon® or foams.	
SPECIAL FIREFIGHTING PROCEDURES	If material is involved in fire, flood with water. Cool all affected containers with large quantities of water. Apply water from as far a distance as possible. Wear self-contained breathing apparatus and full protective clothing.	

Section 6 Accidental Release Measures

STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED

Clean up spills immediately by sweeping or shoveling up the material. Do not return spilled material to the original container. Transfer to a clean metal drum. EPA banned the land disposal of D001 ignitable waste oxidizers. These wastes must be deactivated by reduction. To clean floors, flush with abundant quantities of water into sewer, if permitted by Federal, State, and Local regulations. If not permitted, collect water and treat chemically (Section 13).

PERSONAL PRECAUTIONS

Personnel should wear protective clothing suitable for the task. Remove all ignition sources and incompatible materials before attempting clean-up.

Section 7 Handling and Storage

WORK/HYGENIC PRACTICES

Wash hands thoroughly with soap and water after handling potassium permanganate, and before eating or smoking. Wear proper protective equipment. Remove contaminated clothing.

VENTILATION REQUIREMENTS

Provide sufficient area or local exhaust to maintain exposure below the TLV-TWA.

CONDITIONS FOR SAFE STORAGE

Store in accordance with NFPA 430 requirements for Class II oxidizers. Protect containers from physical damage. Store in a cool, dry area in closed containers. Segregate from acids, peroxides, formaldehyde, and all combustible, organic or easily oxidizable materials including anti-freeze and hydraulic fluid.

Section 8 Exposure Controls/Personal Protection

RESPIRATORY PROTECTION

In the case where overexposure may exist, the use of an approved NIOSH-MSHA dust respirator or an air supplied respirator is advised. Engineering or administrative controls should be implemented to control dust.

EYE

Faceshield, goggles, or safety glasses with side shields should be worn. Provide eye wash in working area.

GLOVES

Rubber or plastic gloves should be worn.

OTHER PROTECTIVE EQUIPMENT

Normal work clothing covering arms and legs, and rubber or plastic apron should be worn.

Section 9 Physical and Chemical Properties

APPEARANCE AND ODOR	Dark purple solid with a metallic luster, odorless
BOILING POINT, 760 mm Hg	Not applicable
VAPOR PRESSURE (mm Hg)	Not applicable
SOLUBILITY IN WATER % BY SOLUTION	6% at 20°C (68°F), and 20% at 65°C (149°F)
PERCENT VOLATILE BY VOLUME	Not volatile
EVAPORATION RATE (BUTYL ACETATE=1)	Not applicable
MELTING POINT	Starts to decompose with evolution of oxygen (O_2) at temperatures above 150°C (302°F). Once initiated, the decomposition is exothermic and self-sustaining.
OXIDIZING PROPERTIES	Strong oxidizer
SPECIFIC GRAVITY	2.7 @ 20°C (68°F)
VAPOR DENSITY (AIR=1)	Not applicable

Section 10 Stability and Reactivity

STABILITY Under normal conditions, the material is stable.

CONDITIONS TO AVOID Contact with incompatible materials or heat (>150°C/302°F).

INCOMPATIBLE MATERIALS Acids, peroxides, formaldehyde, anti-freeze, hydraulic fluids, and all combustible organic or readily oxidizable inorganic materials including metal powders. With hydrochloric acid, toxic chlorine gas is liberated.

HAZARDOUS DECOMPOSITION PRODUCTS When involved in a fire, potassium permanganate may liberate corrosive fumes.

CONDITIONS CONTRIBUTING TO HAZARDOUS POLYMERIZATION Material is not known to polymerize.

Section 11 Toxicological Information

Potassium permanganate: Acute oral LD_{50}(rat) = 780 mg/kg Male (14 days); 525 mg/kg Female (14 days)
The fatal adult human dose by ingestion is estimated to be 10 grams. (Ref. Handbook of Poisoning: Prevention, Diagnosis & Treatment, Twelfth Edition)

EFFECTS OF OVEREXPOSURE

1. Acute Overexposure
   Irritating to body tissue with which it comes into contact.

2. Chronic Overexposure
   No known cases of chronic poisoning due to potassium permanganate have been reported. Prolonged exposure, usually over many years, to heavy concentrations of manganese oxides in the form of dust and fumes, may lead to chronic manganese poisoning, chiefly involving the central nervous system.

3. Carcinogenicity
   Potassium permanganate has not been classified as a carcinogen by OSHA, NTP, IARC.

4. Medical Conditions Generally Aggravated by Exposure
   Potassium permanganate will cause further irritation of tissue, open wounds, burns or mucous membranes.

   Registry of Toxic Effects of Chemical Substances
   RTECS #SD6476000

Section 12 Ecological Information

Entry to the Environment

Potassium Permanganate has a low estimated lifetime in the environment, being readily converted by oxidizable materials to insoluble manganese dioxide (MnO_2).

Bioconcentration Potential

In non-reducing and non-acidic environments manganese dioxide (MnO_2) is insoluble and has a very low bioaccumulative potential.

Aquatic Toxicity

Rainbow trout, 96 hour LC_{50}: 1.8 mg/L
Bluegill sunfish, 96 hour LC_{50}: 2.3 mg/L

Section 13 Disposal Consideration

DEACTIVATION OF D001 IGNITABLE WASTE OXIDIZERS BY CHEMICAL REDUCTION

Reduce potassium permanganate in aqueous solutions with sodium thiosulfate (Hypo), or sodium bisulfite or ferrous salt solution. The thiosulfite or ferrous salt may require some dilute sulfuric acid to promote rapid reduction. If acid was used, neutralize with sodium bicarbonate to neutral pH. Decant or filter, and mix the sludge with sodium carbonate and deposit in an approved landfill. Where permitted, the sludge can be drained into sewer with large quantities of water Use caution when reacting chemicals. Contact Carus Chemical Company for additional recommendations.

Section 14 Transport Information

U. S. DEPARTMENT OF TRANSPORTATION INFORMATION:

Proper Shipping Name:	49 CFR 172.101	.... Potassium Permanganate
ID Number:	49 CFR 172.101	.... UN 1490
Hazard Class:	49 CFR 172.101	.... Oxidizer
Division:	49 CFR 172.101	.... 5.1
Packing Group:	49 CFR 172.101	 II

Section 15 Regulatory Information

TSCA Listed in the TSCA Chemical Substance Inventory

CERCLA Hazardous Substance

Reportable Quantity: RQ - 100 lb 40 CFR 116.4; 40 CFR 302.4

RCRA Oxidizers such as potassium permanganate meet the criteria of ignitable waste. 40 CFR 261.21

SARA TITLE III Information

Section 302	Extremely hazardous substance: Not listed
Section 311/312	Hazard categories Fire, acute and chronic toxicity
Section 313	GAIROX® potassium permanganate contains 97% Manganese Compound as part of the chemical structure (manganese compounds CAS Reg No. N/A) and is subject to the reporting requirements of Section 313 of Title III, Superfund Amendments and Reauthorization Act of 1986 and 40 CFR 372.

Section 15 Regulatory Information (cont.)

STATE LISTS	Michigan Critical Materials Register:	Not listed
	California Proposition 65:	Not listed
	Massachusetts Substance List:	5 F8
	Pennsylvania Hazard Substance List:	E
FOREIGN LISTS	Canadian Domestic Substances List (DSL)	Listed
	Canadian Ingredient Disclosure List	Listed
	European Inventory of Existing Chemical Substances (EINECS)	2317603

Section 16 Other Information

NIOSH	National Institute for Occupational Safety and Health
MSHA	Mine Safety and Health Administration
OSHA	Occupational Safety and Health Administration
NTP	National Toxicology Program
IARC	International Agency for Research on Cancer
TSCA	Toxic Substances Control Act
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act of 1980
RCRA	Resource Conservation and Recovery Act
SARA	Superfund Amendments and Reauthorization Act of 1986
PEL-C	OSHA Permissible Exposure Limit-OSHA Ceiling Exposure Limit
TLV-TWA	Threshold Limit Value - Time Weighted Average (American Conference of Governmental Industrial Hygienists)

Kenneth Krogulski

Kenneth Krogulski
May 2000

CARUS

Responsible Care®
A Public Commitment

THE SAFE USE AND HANDLING OF PERMANGANATE PRODUCTS

The Safe Use and Handling of Permanganate Products

Responsible Care

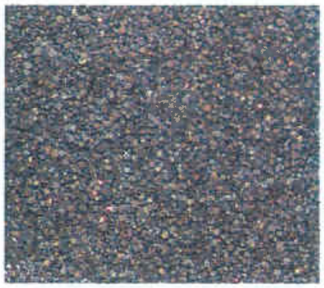
Responsible Care® Good Chemistry at Work no accidents ▪ no injuries ▪ no harm to the environment

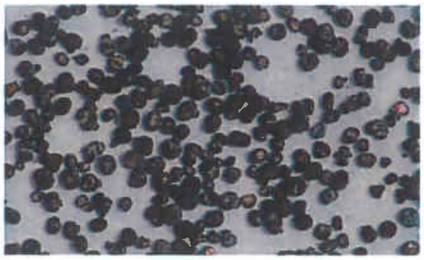
Responsible Care® Performance Excellence

- Facility Security
- Reducing Emissions
- Energy Efficiency
- Employee, Transportation, and Process Safety
- Product Safety and Communication
- Accountability

•Product Overview

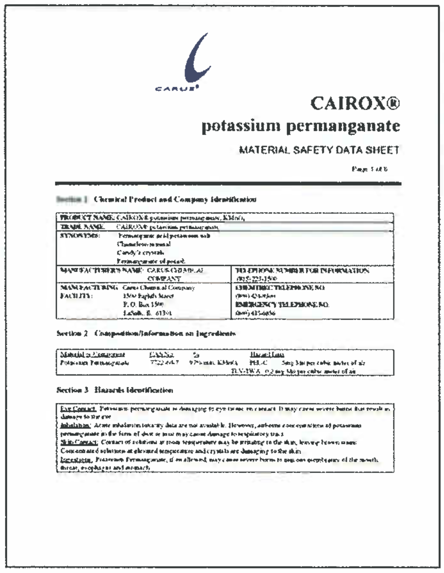
- Permanganate products are available as:
  - Crystalline Solids
  - Concentrated Liquids





•Crystalline Permanganate Safety and Handling

- Crystalline permanganate is a hazardous chemical
  - Strong oxidant
  - It can react violently with oxidizable materials
- Permanganate presents no health hazard during ordinary handling and storage.
- Solid Form (>97% active):
  - Stable under normal conditions.
  - Incompatible with acids, peroxides, combustible organics, metal powders, oil and grease.
- Dilute Solution (1-6%):
  - Very stable



CAIROX®
potassium permanganate
MATERIAL SAFETY DATA SHEET

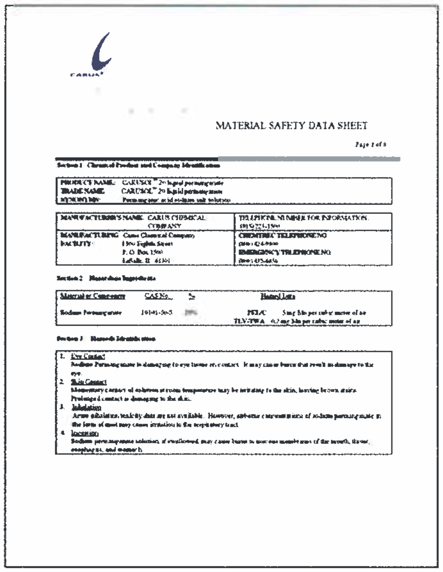
Section 1 Chemical Product and Company Identification

Section 2 Composition/Information on Ingredients

Section 3 Hazards Identification

•Liquid Permanganate Safety and Handling

- Liquid permanganate is a hazardous chemical
  - Strong oxidant
  - It can react violently with oxidizable materials.
- Concentrated Form 17%-40%):
  - Stable under normal conditions.
  - Incompatible with acids, peroxides, combustible organics, metal powders, oil and grease.
  - Can cause a fire if left on rags or paper towels and thrown in the garbage. Dilute to less than 6% with water and neutralize.
- Dilute Solution (1-6%):
  - Very stable



MATERIAL SAFETY DATA SHEET

•Handling Permanganate Safely

- Eye protection must be worn.
  - Safety glasses with side shields as well as goggles or a face shield.
- Provide adequate ventilation.
  - Dust or mist may irritate the respiratory tract.
- Avoid skin contact with permanganate.
  - In addition to normal work clothing covering arms and legs, wear plastic gloves and apron.
- Do not eat or drink permanganate.
  - If permanganate is swallowed, it may cause severe burns of the mouth, throat, esophagus, and stomach.

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Flexible Intermediate Bulk Container (FIBC)

- FIBC is enclosed in a plastic corrugated box with a bottom tray and top sheet.
- It is stretch-wrapped to prevent rips, tears or leaking material.
- Bag fabric
  - Coated circular woven polypropylene
  - 0.006 LDPE liner glued in the bag

CARUS®

Handling Permanganate Safely in Flexible Intermediate Bulk Container (FIBC)

- Store FIBCs of potassium permanganate protected from rain and prolonged sunlight.
- Use lifting gear of sufficient capacity to take the suspended load.
  - Do not tilt the mast of the fork lift forward.
  - Ensure that fork lift tines are level.
  - Ensure that the edges of the fork lift tines are smooth or protected.
- Do not stop or start suddenly during transport.
- Do not exceed Safe Working Load under any circumstances.
- ***Do not allow personnel under a suspended FIBC.***

CARUS®

Handling Permanganate Safely in Flexible Intermediate Bulk Container (FIBC)

- **The receiving vessel must be large enough to accept the entire contents of the FIBC. Once the material starts to flow it is not possible to stop the flow.**
- **Plastic liner can get pulled away from bag during discharge. Take caution if utilizing automated feed equipment.**
- **Take appropriate measures in regard to dust control.**
- **Make sure all material is discharged from FIBC by shaking the sack.**
- **There will be dust on the bag and liner. Use proper PPE (personal protective equipment) whenever handling the used bags.**

CARUS®

FIBC Disposal
Special Considerations

- Make sure all product is discharged during unloading process. It is easy for permanganate to become trapped in the FIBC.

- FIBCs must be cleaned prior to disposal.

- The FIBC should be immersed in a tank of water containing bisulfite or mild cleaning solution until there is no pink residue remaining.

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•Inhalation

- Provide adequate ventilation.
  - Airborne concentrations of permanganate in the form of dust or must may be irritating to the respiratory tract.
  - NIOSH-MSHS approved dust or mist respirators are recommended.

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•Eye Glasses

- Eye protection must be worn
  - Decomposition products are alkaline and may cause burns that result in damage to the eye.
  - Safety glasses with side shields and goggles or a face shield are recommended.

•Skin Contact

- Avoid contact with permanganate.
  - Momentary contact may be irritating to the skin and leave brown stains.
  - Contact with concentrated solutions or crystals will damage the skin.
  - In addition to normal work clothing covering arms and legs, wear plastic gloves and an apron.

•Ingestion

- DO NOT Eat or Drink Permanganate or any other Chemical.
- If permanganate is swallowed, it may cause severe burns to the mouth, throat, esophagus, and stomach.
- Always wash hands before eating, drinking, or smoking.

•Thermal Stability of Permanganates

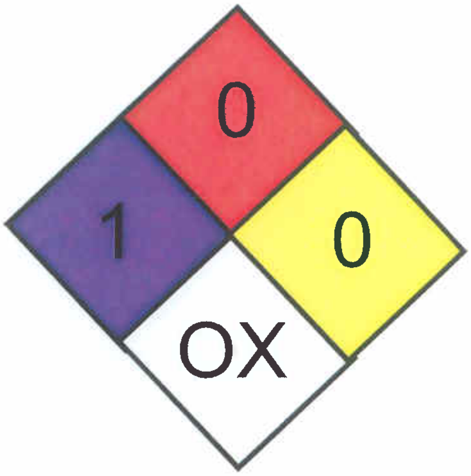
$5\ MnO_4^- \Rightarrow MnO_4^{3-} + MnO_4^{2-} + 3\ MnO_2 + 3\ O_2$

Crystalline Permanganate
Decomposition may start at 302° F (150° C)

Liquid Permanganate
Decomposition may start at 275° F (135° C)

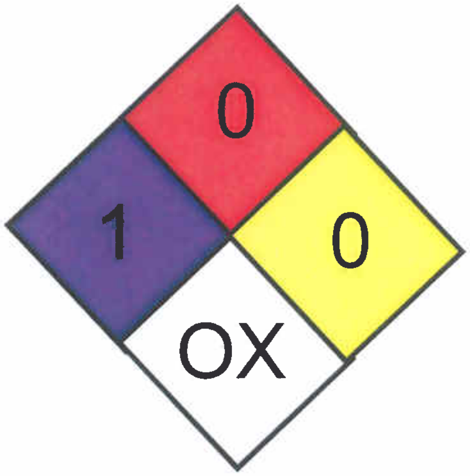
•NFPA Hazard Code

- Under Fire conditions will give off irritating combustion products
- Flammability Hazard – 0
    - Nonflammable: will not burn, but will support combustion.
- Reactivity Hazard – 0
    - Normally stable, not reactive with water.
- Special Hazard – OX
    - .Oxidizer



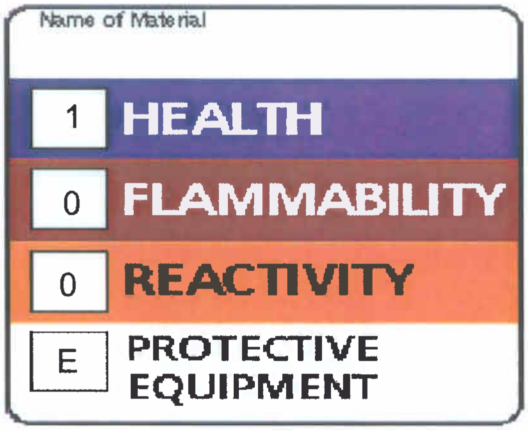
•Fire Extinguishing

- Use large quantities of water.
- Berm to contain the water.
- DO NOT use dry chemical extinguishers such as CO2, Halon®, or foams.



•HMIS Hazard Code

- [illegible]
  - Under Fire conditions will give off irritating combustion products
- Flammability Hazard – 0
  - Nonflammable: will not burn, but will support combustion.
- Reactivity Hazard – 0
  - Normally stable, not reactive with water.
- Protective Equipment - E
  - Safety glasses, gloves, dust respirator



•Permanganate Storage Requirements

- Stable under normal conditions.
- Keep dry and away from heat.
- Do not store next to acids, peroxides, combustible organics, such as brake fluid or antifreeze, metal powders, or other materials identified in the MSDS.
- Take care to protect the containers from physical damage.
- Permanganate can react with Hydrochloric Acid, resulting in chlorine gas as a byproduct. Do not breath chlorine gas.

•Dry Permanganate Spill Clean-up

- Crystalline permanganate
  - Clean up immediately by sweeping or shoveling.
  - Do not return to the original drum. Transfer to clean clean metal drum and dispose of according to approved local regulations.

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•Liquid Permanganate Spill Clean-up

- Contain and isolate the liquid, collecting in a pit or holding area**.
- Dilute the solution with water until the permanganate concentration is less than 6% (MnO_4^-)
- Neutralize the permanganate using a solution of sodium thiosulfate, bisulfite, or ferrous salt.

**The following materials have been tested and found to be compatible with 40% sodium permanganate:

  - PIG® Haz Mat Adsorbent Sock
  - Spill-tek Adsorbent Pad
  - United Sorbents Polypropylene Adsorbent Pad

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•Additional Safety Considerations for Liquid Permanganates

- WATER…………WATER
- NEVER neutralize a concentrated solution.
  - Always dilute the permanganate to less than 6% before attempting any type of chemical neutralization.
- May ignite wood, cloth, or paper.
  - If clothing becomes contaminated wash with water immediately.
  - Spontaneous ignition may occur with wood or paper.
  - Store on a concrete floor.

•Permanganate Neutralization

Sodium thiosulfate

$8\ MnO_4^- + 3\ Na_2S_2O_3 + H_2O \Rightarrow$
$3\ SO_4^= + 3\ Na_2SO_4 + 8\ MnO_2 + 2\ OH^-$

Weight ratio: 0.375 parts $Na_2S_2O_3$ to 1 part MnO_4^-

Sodium bisulfite (meta)
$2\ MnO_4^- + 3\ NaHSO_3 + H_2O \Rightarrow$
$3\ NaHSO_4 + 2\ MnO_2 + 2\ OH^-$

Weight ratio: 1 part $NaHSO_3$ to 1 part MnO_4^-

Permanganate Neutralization Reactions

•MnO_2 Stain Removal

- Cleaning Solution
  - 30 parts water
  - 40 parts white household vinegar
  - 30 parts 3% hydrogen peroxide

- Never use on sensitive tissue
  - Eyes, mucous membranes, open wounds, burns, etc.
- DO NOT add directly to concentrate permanganate solutions.
- Dilute the permanganate solution to less than 6% with water before using this stain removal solution.

•Hazardous Materials Transportation Act

- In the Unites States, domestic shipments of hazardous commodities over the highway is governed by Title 49, Code of Federal Regulations (CFR).

  - Identifies and Classifies Hazardous Materials.
  - Establishes quantity limitations.
  - Specifies the proper packaging.
  - Describes how to mark and label the package.
  - Defines shipping certificates.
  - Details how to placard the vehicle transporting the shipment.

•Department of Transportation

Proper Shipping Name - Crystalline
Potassium permanganate

ID Number	Reportable Quantity
UN 1490	100 lb.

Proper Shipping Name – Liquid
Permanganates, inorganic, aqueous solutions

ID Number	Reportable Quantity
UN 3214	none established

Hazard Class	Division	Packing Group
Oxidizer	5.1	II

•Release of Permanganate to the Environment

- Resource Conservation and Recovery Act (RCRA) 1976
  - Establishes 4 characteristics of hazardous waste:
    - Ignitability
    - Corrosivity
    - Reactivity
    - EP Toxicity

It identifies oxidizers as hazardous under the ignitable waste characteristic and lists potassium permanganate by name.

- Comprehensive Environmental Response Compensation, and Liability Act (CERCLA) 1980 “Superfund”
  - A crystalline or liquid permanganate release to the environment must be reported if it exceeds the “reportable quantity.”

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Reportable Quantities

- Dry crystalline permanganate has an RQ of 100 lbs.
- To report a release to the environment contact the National Response Center (NRC) at 1-800-424-8802.

CARUS®

Questions

Carus Chemical Company
Switchboard: 815-223-1500

Carus Representative	shelley.corban@caruschem.com	(815) 224-6533
Carus Representative	john.boll@caruschem.com	(815) 224-6508
Carus Representative	tim.colgan@caruschem.com	(815) 224-6526

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Good Chemistry at Work