AOC-65 *IN-SITU* CHEMICAL OXIDATION (ISCO) OPERATIONS AND MAINTENANCE MANUAL

Prepared For:

Camp Stanley Storage Activity

Boerne, Texas

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ACRONYMS AND ABBREVIATIONS

AOC	Area of Concern
CFR	Code of Federal Regulations
CSSA	Camp Stanley Storage Activity
DCE	dichloroethene
GAC	granular activated carbon
IRA	Interim Removal Action
ISCO	*in-situ* chemical oxidation
MCL	maximum contaminant level
MW	monitoring well
NELAP	National Environmental Laboratory Accreditation Program
O&M	operations and monitoring
ORP	oxidation-reduction potential
PCE	tetrachloroethene
PZ	piezometer
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
SDWA	Safe Drinking Water Act
SIW	steam injection well
SVE	soil vapor extraction
TAC	Texas Administrative Code
TCE	trichloroethene
TCEQ	Texas Commission on Environmental Quality
TSW	treatability study well
UIC	underground injection control
USEPA	United States Environmental Protection Agency
VEW	vapor extraction well
VOC	volatile organic compound
WB	Westbay® equipped monitoring well

CHAPTER 1
INTRODUCTION AND SUMMARY OF REMEDIAL DESIGNS

This Operations and Monitoring (O&M) Plan was created as a guide for operating the *in-situ* chemical oxidation (ISCO) injection system equipment and the associated monitoring efforts following ISCO applications at Camp Stanley Storage Activity (CSSA) in Boerne, Texas. ISCO infiltration galleries and ISCO injection wells were installed to remediate soil, fractured rock, and groundwater contamination underneath and around Building 90 and Area of Concern (AOC)-65.

The chemical oxidation process involves increasing the oxidation state of target compounds (i.e., chlorinated solvents) by introducing an oxidant into contaminated media. The targeted compounds are then transformed into by-products that are less harmful than the original compounds. Oxidation of the substance may occur by the addition of an oxygen atom, the removal of a hydrogen atom, and/or the removal of electrons without the removal of a proton from the target compound.

Several different oxidants may be considered for ISCO applications. Permanganate, Fenton's Reagent, ozone, and persulfate are a few of the more commonly applied oxidants used for environmental remediation applications. Each of these oxidants will oxidize contaminants differently based on the stoichiometry of the redox reaction between the oxidant and contaminant. The various oxidants differ in type of reaction, speed of reaction, and oxidant persistence, and specifics of the selected oxidants are discussed in Section 3.

Passive oxidant application is currently the preferred method to deliver oxidants and remediate chlorinated solvent contamination within suspected source area(s) at CSSA's AOC-65. The passive delivery of oxidants is achieved via the employment of oxidant-infused wax cylinders. The sustained-release oxidant cylinders consist of potassium permanganate ($KMnO_4$) and sodium persulfate ($Na_2S_2O_8$) crystals infused within a paraffin wax matrix, which are installed in wells around the site. Suppliers of chemical oxidants injected/applied, including oxidant infused cylinders, are presented in **Appendix A**.

Oxidant-infused wax cylinders allow for a long-term and sustained release of ISCO oxidant solution without changing groundwater gradients or flow directions. After the cylinder is installed within a well, the oxidant crystals within the cylinder will solubilize into the groundwater flowing through the well; as opposed to injecting large volumes of ISCO solution into the well, which may induce artificial groundwater mounding and create flow in directions contrary to natural gradients. The cylinder lifespan (months to more than a year) provides a long-term, on-demand oxidant source and therefore may treat contamination under the varying hydraulic conditions encountered throughout the deployment period.

Depending on the type of oxidant and application method, liquid oxidants may also be passively distributed within the treatment zone. Liquid oxidants can be passively applied if: 1) the selected oxidant is not subject to auto-decomposition (i.e. permanganate) and will only be consumed if it is in direct contact with a contaminant; and 2) the natural oxidant demand (NOD) is low and is applied such that it is released to the system/subsurface over a long period of time.

1.1 SITE HISTORY

In 2012, an interim removal action (IRA) was conducted to remove contaminated materials beneath the concrete-lined drainage swale on the west side of Building 90. Historic uses of tetrachloroethene (PCE) within Building 90 and subsequent releases into the ditch have resulted in long-term dissolved phase PCE and trichloroethene (TCE) contamination in local groundwater in the upper and lower members of the Glen Rose Formation. The 2012 IRA consisted of the excavation of a ~320-foot-long, 3.5-foot-wide, and between 12- and 15-foot-deep trench. The trench was subsequently converted into a series of infiltration galleries to facilitate the application of chemical oxidants for an ISCO treatability study. Prior to the 2012 IRA, a soil vapor extraction (SVE) system was operated at AOC-65; however, due to system inefficiencies, SVE activities were terminated, and system components (vapor extraction wells [VEWs]) were repurposed for ISCO monitoring. The SVE system was part of a vapor extraction pilot study in operation at AOC-65 since 2002.

Pilot and field-scale treatability studies were performed using sodium persulfate injected into infiltration galleries between 2012 and 2014. Results from the persulfate injections revealed a general reduction in PCE concentrations; however, increasing PCE concentration to the east suggested the injection volumes may have resulted in hydraulic transport of contaminated groundwater to the east (contrary to the natural groundwater gradient).

In August and November 2015, two additional injections were performed which focused on the area between Building 90 and the infiltration trench. Results from the permanganate injections revealed distribution of ISCO solution was more widespread than anticipated, given injection volumes were much smaller than persulfate applications. Variability in flow directions from ISCO injections, however, make it difficult to pinpoint application locations that provide the best distribution.

In December 2016, twelve oxidant-infused wax cylinders were installed within six wells at AOC-65. The cylinders consist of potassium permanganate and sodium persulfate crystals infused within a paraffin wax matrix in a ratio of 38:38:24. The cylinders provide a passive means for oxidant dispersal. As groundwater flows through the well around installed cylinders, the oxidant crystals infused within the wax dissolve, creating an oxidant-groundwater solution which is then transported away from the well along natural groundwater gradients into the subsurface.

Cylinders were originally installed at the base of the screened interval in each well to maximize contact with groundwater and provide a persistent source of oxidant; however, vertical profiling of VOCs and permanganate concentrations within two of the oxidant-infused cylinder-containing wells indicated untreated groundwater occurred above the installed cylinders. In effect, groundwater could flow through the upper portion of the well and bypass treatment. Cylinders were redistributed to cover the whole length of the well screens on November 14, 2017 (**Figure 2.1**), at which time an additional 1.35-inch diameter cylinder was installed in each of the six cylinder-installed wells (bringing the total to three cylinders per well).

The installed cylinders had reached or exceeded their anticipated life expectancy and required replacement by mid-2018. In October, all 18 cylinders (six wells with three cylinders each) were replaced. At that time, four more wells within AOC-65 were identified to receive cylinders, and an additional three cylinders were installed in each; bringing the total number of deployed cylinders to 30 within 10 wells. These 30 cylinders were replaced in March 2020 after detections of PCE were observed within cylinder-installed wells during quarterly performance monitoring.

Groundwater samples collected from within the middle infiltration cell (MIC) adjacent to Bldg. 90 as part of quarterly monitoring in 2018 showed an increase in VOC concentrations, and were paler in color than the typical dark purple seen in previous quarters. The color difference indicates the majority of the liquid oxidant applied in 2015 has been transported from the MIC into the surrounding subsurface and can no longer treat influent VOC-impacted groundwater. No samples were collected in the northern infiltration cell (NIC) as it has been dry since shortly after the 2015 oxidant application. Samples from the southern infiltration cell (SIC) indicate an appreciable amount of oxidant remains in place (dark color and low VOC concentrations). In January 2019, 500 gallons of 6.6% permanganate solution was injected into the NIC and MIC (250 gallons in each) to recharge the cells with oxidant. An additional 100 gallons was injected within ISCO injection wells (IIWs) that had been idle since the 2014 sodium persulfate injections. These wells are 125-foot-deep, open borehole wells, and are located west of Bldg. 90 near the western fence line. IIW-01 received 50 gallons and IIWs -02 and -04 each received 25 gallons of 6.6% permanganate solution.

The objective of oxidant applications is to destroy source contaminants located in the soils and bedrock beneath AOC-65 and ultimately reduce the migration of contaminants to groundwater. The objectives of continued monitoring activities are to gather additional data to allow an evaluation and optimization of the systems' performance. Analysis of monitoring results from on-going ISCO O&M activities at AOC-65 are examined in annual updates to the Annual AOC-65 ISCO Performance Report.

Although the ISCO injection system installed at AOC-65 is relatively simple, routine monitoring is required to determine efficacy and oxidant requirements for future applications. If significant problems are encountered with the operation of the system, the CSSA Environmental Office at (210) 295-7067 should be notified so repairs can be initiated and coordinated. Additional points of contact include Parsons Project Manager (Ms. Julie Burdey) at (512) 719-6000 and Parsons Onsite Manager (Ms. Samantha Elliott) at (210) 347-6012.

Site background and current conditions are discussed in Section 2 of this document. Descriptions of the ISCO injection system, including layout drawings and schematics, are provided in Sections 3. System O&M is discussed in Section 4, and reporting requirements are included in Section 5 of this plan. Manufacturer information for ISCO injection materials is included in **Appendix A**, and data collection sheets are included in **Appendix B**.

CHAPTER 2
SITE CONDITIONS

2.1 BACKGROUND

Chlorinated solvents containing PCE and TCE were used in Building 90 for more than 30 years. Their use at CSSA was eliminated in 1995 and replaced with a citrus-based cleaning solvent. No definitive conclusions were made as to the source of the contamination for AOC-65.

Source characterization of the Building 90 vicinity (main portion of AOC-65) included a 2001 soil gas survey which entailed collection and analyses of 319 soil gas samples. Results of the survey included detections of PCE, TCE, cis-1,2-dichloroethene (DCE) and trans-1,2-DCE in the area around Building 90. The detection of DCE indicates that natural degradation of PCE/TCE is occurring in the subsurface.

The Final Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) report for AOC-65 was completed in September 2002 (Parsons, 2002b). An IRA was also completed in 2002, and included the excavation of soils underlying the pavement and a drainage swale on the west side of the building. The drainage swale was lined with concrete to prevent rainwater run-off infiltration, and an SVE system was installed.

Pilot testing was initiated in 2002 at AOC-65 to evaluate the effectiveness of SVE for the removal of volatile organic compound (VOC) contamination from the vadose zone. SVE was demonstrated to be an effective method for source removal in surface formations at CSSA during an earlier pilot and treatability study at SWMU B-3. Two SVE systems were installed at AOC-65 in late 2007. These systems, known as the eastern and western AOC-65 SVE system(s), had the primary objectives of removing VOC contaminants from the soils, fractured limestone, and groundwater around AOC-65; and to decrease the migration of contaminants from the site. The western portion of the AOC-65 SVE system was expanded in 2007, and the eastern portion was expanded in 2011. The SVE pilot study was terminated in August 2012 due to reduced system efficiency. Additional details regarding the SVE treatability study at AOC-65 are described in the 2012 Update to AOC-65 Soil Vapor Extraction Operations and Maintenance Assessment Report (Parsons, 2012).

A second, more intrusive IRA was completed in 2012. This IRA included the excavation of a trench (~320 feet long, 3.5 feet wide, and between 12 and 15 feet deep) beneath the concrete-lined drainage swale west of Building 90 (installed following the 2002 IRA), and resulted in the removal of approximately 1,000 cubic yards of bedrock. The trench was subsequently converted to an infiltration gallery with discrete treatment zones to facilitate the application of chemical oxidants for the ISCO treatability study.

Pilot- and field-scale treatability studies were performed using sodium hydroxide-activated sodium persulfate applied to the trench infiltration gallery in 2012, 2013, and 2014. Approximately 10, 22, and 66 tons of activated persulfate were applied in those years, respectively. Results from the persulfate injections revealed a general reduction in PCE concentrations; however, increasing PCE concentration to the east suggested the injection volumes may have resulted in hydraulic transport of contaminated groundwater to the east.

In July 2015, three new infiltration galleries were installed adjacent to Building 90, and one additional infiltration gallery was installed inside a concrete vault located within the building. In August and November 2015, two permanganate injections were performed in the new infiltration galleries. Approximately 3,500 gallons and 7,000 gallons of sodium permanganate were applied in August and November, respectively. The transition from sodium persulfate to sodium permanganate was intended to reduce total volumes injected, thereby reducing artificial mounding and changes to the groundwater gradients and flow directions locally. Results from the permanganate revealed distribution of ISCO solution was more widespread than anticipated since injection volumes were much smaller than for persulfate applications. Variability in flow directions from ISCO injections, however, make it difficult to pinpoint application locations that provide the best distribution.

2.2 AOC-65 SITE DELINEATION

Based on the results of the site investigation and groundwater results from nearby discrete interval Westbay® (WB) wells and monitoring wells (TO 42 Well Installation Report, Volume 5-2.3, CSSA Environmental Encyclopedia), the area within AOC-65 containing VOCs that may be successfully treated by ISCO appears to extend immediately around Building 90 in the apparent down gradient direction to the west/southwest. VOC concentrations above the Safe Drinking Water Act (SDWA) Maximum Contaminant Levels (MCLs) for groundwater have been encountered at depths up to 300 feet below grade, and at significantly higher levels in monitoring wells screened near the surface (upper 50 feet). The total volume of the treatment area within AOC-65 is unknown. The location of the AOC-65 ISCO infiltration galleries and former solvent vat location are shown on **Figure 2.1**.

2.3 UNDERGROUND INJECTION CONTROL PERMITTING

The AOC-65 ISCO injection system operates under a Texas Commission on Environmental Quality (TCEQ) Underground Injection Control (UIC) Permit, Authorization Number 5X2600645.

Requirements associated with this UIC permit include:

- Construction of injection wells or galleries shall meet standards provided in 30 Texas Administrative Code (TAC) §331.132 and as-built construction diagrams or well logs shall be submitted to the UIC Permits Team, Radioactive Materials Division within 30 days of completion;
- Operational and status changes shall be reported to and approved by the UIC Permits Team;
- Closure (plugging) of injection wells shall comply with standards provided in 30 TAC §331.133. Closure reports, including injection well monitoring data (injection volumes, pressures, and results) and plugging reports, shall be submitted to the UIC Permits Team, Radioactive Materials Division within 60 days of conclusion of injection activities; and
- Status reports shall be submitted to the UIC Permits Section, Radioactive Materials Division, at mail code MC233 upon completion of the injection event and thereafter on an annual basis (based on June 22, 2016 Permit Revision). These shall consist of a report of the injection activities and the status of the activities over the past year.
- Following initial installation of oxidant-infused wax cylinders, groundwater

sampling was performed quarterly (see **Table 4.1** for list of sampling locations). Groundwater samples are also regularly collected from nearby monitoring wells, private water supply wells, and all zones of WB wells within ¼ mile of the injection point(s) of AOC-65. Additional analyses may include alkalinity, hydrogen sulfide, total dissolved solids, potassium, and total manganese, as well as the collection of field parameters, pH, temperature, dissolved oxygen, specific conductance, and oxidation-reduction potential.

Modification of the Class V UIC Permit was submitted to the TCEQ UIC Permits Team in October 2017. The requested modifications included the use of oxidant-infused cylinders as injectates and requested that all currently permitted injectates (sodium persulfate, sodium hydroxide, sodium permanganate, potassium permanganate) be allowed in all permitted wells at AOC-65 including: piezometers (PZs), treatability study wells (TSWs), vapor extraction wells (VEWs), steam injection well (SIW), ISCO injection wells (IIWs); and infiltration cells and infiltration trench. Approval of the requested modifications to the Class V Injection Well Authorization was granted by the TCEQ on November 13, 2017.

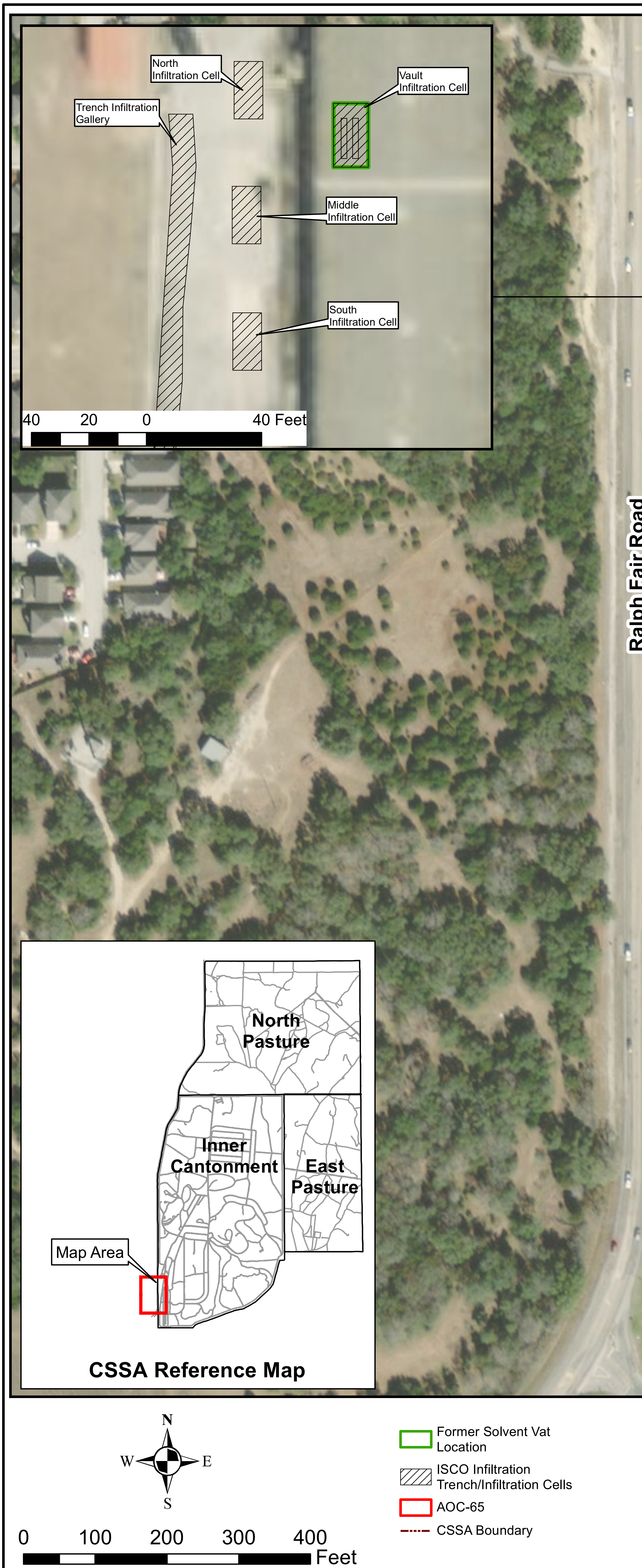

Figure 2.1

AOC-65
Site Map
Camp Stanley Storage Activity

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CHAPTER 3
SYSTEM DESCRIPTION

3.1 ISCO DISTRIBUTION SYSTEM

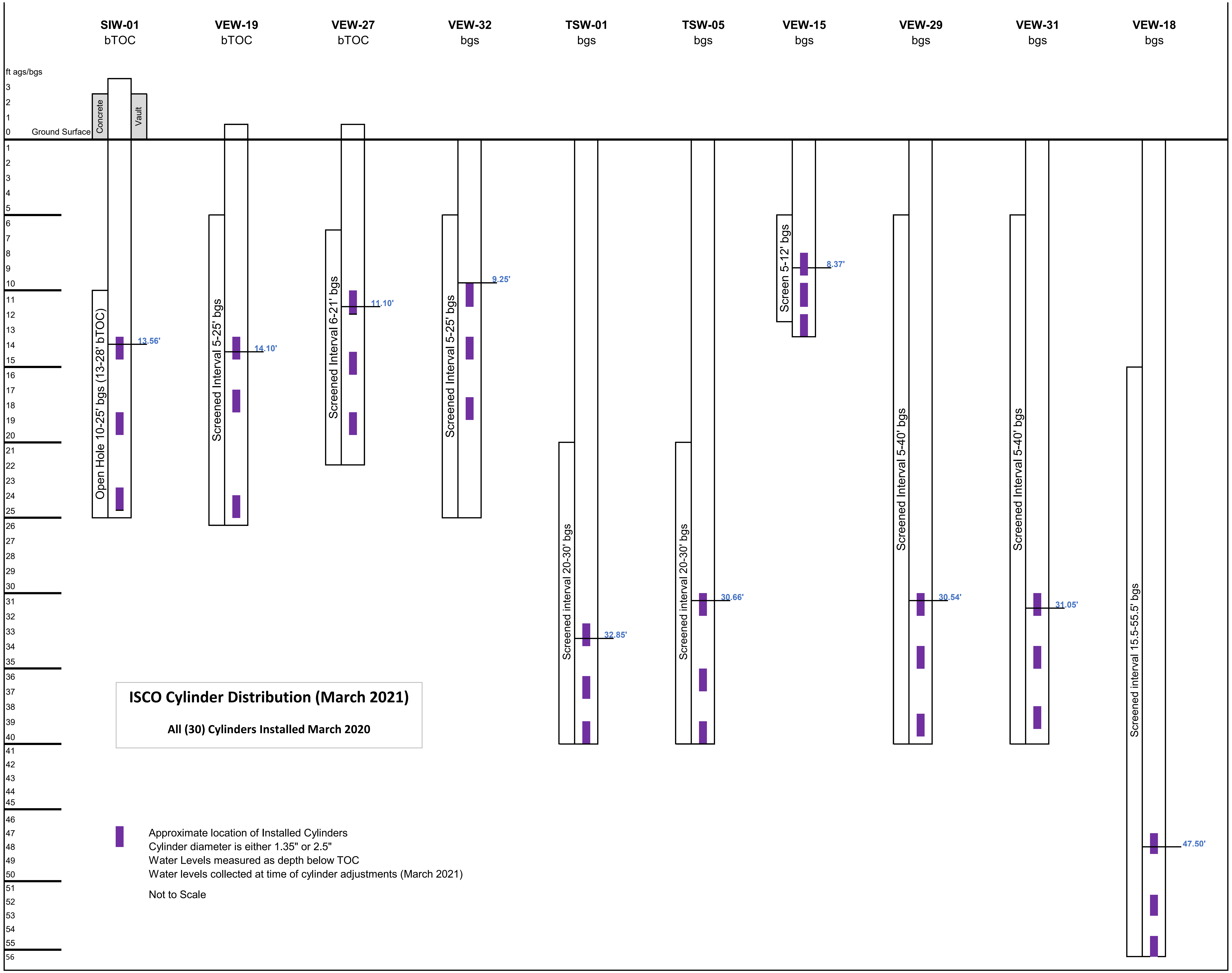
ISCO treatment at AOC-65 is currently achieved by suspending permanganate wax cylinders within ten monitoring wells known to have substantial VOC concentrations near Building 90 (TSWs -01 and -05, VEWs -15, -18, -19, -27, -29, -31, and -32, and SIW-01). Cylinder sizes are either 2.5 inches or 1.35 inches in diameter and are 18 inches in length and will easily fit in any 4-inch-diameter monitoring well. Typically, wells at AOC-65 are 4 inches in diameter, with SIW-01, VEWs -28A and -28B and the Westbay wells being the exceptions. Flexible polyethylene mesh sleeves are used to secure the cylinders so they can be lowered into place and removed during sampling. Knots tied in the mesh sleeves are used to separate cylinders to target specific intervals within well screens and maximize exposed surface area. Mesh sleeving may be cut to fit the total depth of each well so the sleeve can be secured at the top of the casing and maintain cylinder distribution throughout the screened interval. Where impractical by depth of well, the sleeves may be attached to a vinyl-coated, stainless steel cable with stainless steel thimbles and clamps, and cable ties and lowered into position. The sleeves are lowered so the top of the uppermost cylinder is aligned with the top of the well screen or at the groundwater interface, whichever is lower. The protective mesh sleeves, cable, fittings, and individual cylinders are inspected for damage and color loss and replaced as necessary during quarterly sampling events.

Thirty oxidant-infused wax cylinders are installed within ten wells at AOC-65. The cylinders consist of potassium permanganate, sodium persulfate, and paraffin wax in a ratio of 38:38:24. The cylinders are 18 inches long and either 2.5 or 1.35 inches in diameter. The 2.5-inch cylinders each weigh 5.75 pounds, and the 1.35-inch cylinders weigh 2.875 pounds. The cylinders are distributed vertically to cover the screened interval more evenly in each of the ten wells. Two 2.5-inch cylinders and one 1.35-inch cylinder are installed in each well with the exception of SIW-01, which can only accommodate 1.35-inch cylinders and therefore contains three of the smaller diameter cylinders. Cylinder distribution within each well is depicted in **Figure 3.1**.

Permanganate has a moderate oxidation potential (1.7V) and permanganate solution is denser than water, which allows for more effective vertical dispersal within fractures or porous media. Permanganate does not auto-decompose; therefore, oxidant degradation occurs only due to the reaction with contaminants (VOCs) or other encountered natural oxidant demands, including naturally-occurring organic carbon. Very low concentrations of permanganate are effective for the transformation of PCE to benign compounds. The persistence of permanganate also allows for greater dispersal from the application site, and therefore may affect a greater volume of contaminated media than faster-reacting or less persistent oxidants.

Persulfate has a slightly higher direct oxidation potential (2.1V) than permanganate. In addition to direct oxidation, persulfate may be induced to form sulfate radicals, which are one of the strongest aqueous oxidizing species with an oxidizing potential of 2.6V. While persulfate will auto-decompose, generally within a few weeks, persulfate oxidation is kinetically fast, and the sulfate radical is relatively stable, allowing for greater transport within the subsurface than other radical species.

Figure 3.1
Cylinder Distribution within AOC-65 Injection Wells



3.2 MONITORING SYSTEM

The monitoring system for the ISCO injection system includes the network of wells within and surrounding AOC-65 including VEWs, monitoring wells (MWs), WBs, treatability study wells (TSWs), ISCO injection wells (IIWs), and piezometers (PZs) (**Figure 3.2**). Additional monitoring may be performed within the north, middle, and south ISCO injection cells (NIC, MIC, and SIC).

3.2.1 Field Parameter Collection

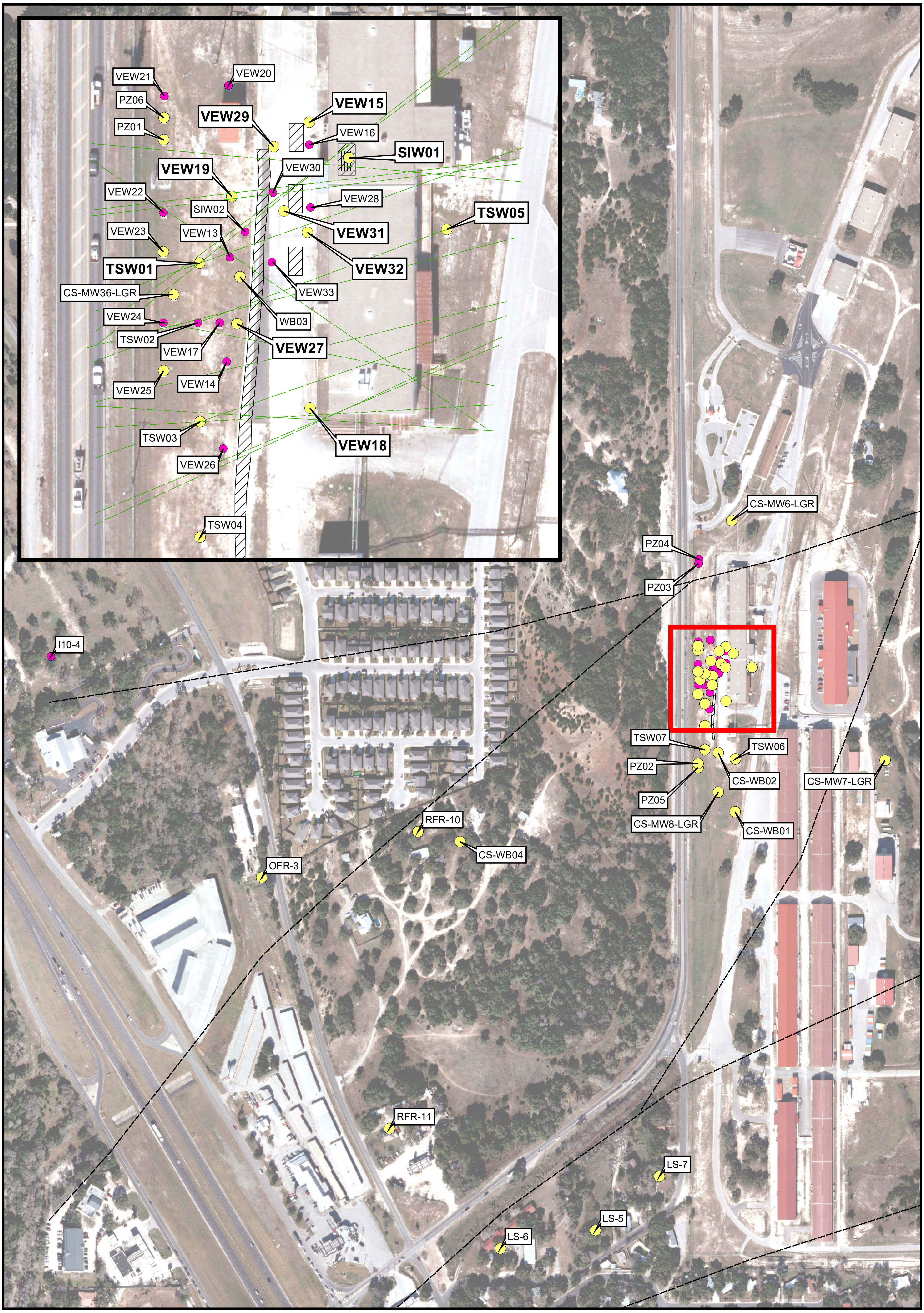
Field parameters will be collected using a hand-held water quality multi-parameter meter. A YSI-556 (or similar) will be used to collect temperature, pH, conductivity, dissolved oxygen, and oxidation-reduction potential. Field parameters will be collected at shallow monitoring locations provided there is greater than 0.5 feet of saturated thickness within the well. If insufficient saturated thickness is present, no field parameters will be collected. For deep wells, a bailer will be used to collect a sample for field parameter analysis if no pump is installed; however, if sample collection with a bailer is deemed impracticable due to well design or configuration, no field parameters will be collected. Field parameters will not be collected at WB wells unless this data is deemed necessary for treatability study effectiveness.

3.2.2 Water Level Collection

Water levels are collected using a standard water level indicator at monitoring wells. Depth to water will be measured from the top of casing, and then used to calculate water table elevations. Pressures will be recorded in WB wells for water level calculation during scheduled sampling events.

3.2.3 Analytical Sample Collection

Samples are collected via disposable polyethylene bailers, WB MOSDAX sampling equipment, peristaltic pumps or well-installed pumps (QED or electric submersible) within supply or monitoring wells.



Fracture Trends Identified in IRA
USGS Mapped Faults
ISCO Infiltration Gallery/Cells
Primary Monitoring Locations
Secondary Monitoring Locations
Bold label = ISCO Cylinder Installation Well

Figure 3.2

AOC-65 ISCO Monitoring Locations Camp Stanley Storage Activity

PARSONS

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CHAPTER 4
SYSTEMS OPERATION AND MONITORING

O&M activities to be performed on the CSSA ISCO injection system include oxidant installation and regulatory monitoring. These activities are discussed in the following subsections.

4.1 OXIDANT INSTALLATION

ISCO application at AOC-65 is completed by suspending permanganate wax cylinders within ten monitoring wells known to have VOC concentrations near Building 90 (TSWs -01 and -05, VEWs -15, -18, -19, -27, -29, -31, -32, and SIW-01). Cylinder sizes are 2.5 or 1.35 inches in diameter and 18 inches in length. Flexible polyethylene mesh sleeves are used to secure the cylinders and act as a holder so they can be lowered into place and removed during sampling. The cylinders are separated via knots tied in the mesh sleeve at intervals to distribute cylinders along the screened interval and maximize exposed surface area. The mesh is then lowered so the top of the uppermost cylinder is at or near the top of the static water level or top of the well screen (whichever is lower). The mesh sleeve is secured to the top of the well casing or protective well cover to ensure that the cylinders remain in place. The mesh and cylinders will be lowered to the top of the encountered groundwater to provide adequate cylinder distribution over the screened interval and ensure cylinders remain submerged for as long as possible. The protective netting will be inspected for damage and replaced as necessary during quarterly sampling events. Cylinder longevity is affected by the rate of natural oxidant demand and site groundwater seepage velocity. Due to a relatively low natural oxidant demand at AOC-65, cylinders are expected to continuously release oxidant for a year or more. In order to maintain a consistent source of oxidant at the site, cylinders will be visually inspected during each quarterly sampling event and replaced when the permanganate-crystal color is noticeably faded (**Appendix C**), or if significant increases in VOC concentrations are observed in groundwater samples collected from cylinder-installed wells.

Although the cylinders are the preferred method for application of oxidants, liquid permanganate injections may also be performed on an as-needed basis at any of the infiltration cells, infiltration gallery, ISCO injection wells (IIWs), VEWs, SIWs, or TSWs. RemOx-L (sodium permanganate ISCO reagent) may be diluted with raw (unchlorinated) water from well CS-10 and gravity fed into any of the listed injection points. Concentration ranges for injected permanganate solutions range from 3 to 10%. As an example; 50 gallons (1 drum) of 40% permanganate solution may be diluted with 200 gallons of raw water to yield 250 gallons of 8% solution. The raw CS-10 water may be transported to AOC-65 in a 250-gallon poly tank, where the contents of a 50-gallon drum of 40% RemOx-L may be added and mixed. A hose attached to the poly tank is then installed within the well or infiltration cell for easy ISCO solution application.

4.2 MONITORING

Monitoring the progress of the ISCO applications includes baseline and post-installation sampling. Sampling is conducted at on- and off-post wells (MWs and VEWs) on a semi-annual basis. In addition to groundwater sampling, field analysis of permanganate, total chlorinated solvents using field test kits, and collection of field parameters, including pH, oxidation-reduction potential (ORP), and specific conductance may be completed at on-post wells and VEWs.

4.2.1 Monitoring Locations

Monitoring locations are presented on **Figure 3.2**. Following ISCO cylinder installation, samples were collected quarterly for VOCs, total dissolved solids, chloride, and metals analyses at six off-post wells and a selection of on-post wells (**Table 4.1**). Field parameters are collected from TSWs and at additional on-post monitoring locations including VEWs, WBs (various zones), PZs, and MWs. Samples may be collected from additional wells (TSWs, PZs, VEWs, MWs) or WB well zones for field and/or laboratory analyses from among those wells not sampled on a regular quarterly basis to determine the region of influence.

4.2.2 Sample Collection

Several sampling methods are required to obtain samples from the various types of wells included in the ISCO monitoring network. The monitoring network includes monitoring wells with or without QED pumps installed, WB multi-port monitoring wells, VEWs, PZs, and water supply wells with submersible electric pumps and granular activated carbon (GAC) filters. Samples are collected with dedicated or disposable polyethylene bailers, WB equipment or installed pumps. Pre- and post-GAC samples will be collected at GAC-equipped supply wells.

4.2.3 Sample Analyses

Samples will be analyzed by a National Environmental Laboratory Accreditation Program (NELAP)-certified laboratory for VOCs by United States Environmental Protection Agency (USEPA) Method 8260B and priority pollutant metals (antimony, arsenic, beryllium, cadmium, chromium, copper, lead, magnesium, manganese, mercury, nickel, selenium, silver, sodium, thallium, and zinc) by USEPA Method 6010B/7470A. Additional samples may be collected for total manganese by USEPA Method M4500, and sulfate and chloride by USEPA Method 300.0. A review of the list of analytes was performed during the 2020 LTMO update, and while VOCs and metals analysis are deemed necessary to adequately monitor plume and corrective measure status, anions (chloride and sulfate) are not, and therefore, are collected on an as-needed basis. ISCO monitoring will be performed semi-annually or on an as-needed basis. The most recent sampling data collected prior to cylinder installation (September 2016) serves as the baseline data for comparison. Specific analytes for the various analytical methods are given in **Table 4.2**.

4.2.4 Additional Field Parameter Collection (Performance Monitoring)

Field parameters will be collected using a hand-held water quality multi-parameter meter. A YSI-556 (or similar) will be used to collect temperature, pH, conductivity, dissolved oxygen, and oxidation-reduction potential. Field parameters will be collected at shallow monitoring locations, provided there is more than 0.5 feet of saturated thickness within the well. If insufficient saturated thickness is present, no field parameters (other than water level) will be collected. For deep wells, a bailer will be used to collect a sample if no pump is installed; however, if sample collection with a bailer is deemed impracticable due to well design or configuration, no field parameters will be collected. Field parameters will not be collected at WB wells unless sample results indicate a need for this data.

Water levels will be collected using a standard water level indicator at monitoring wells. Depth to water will be measured from the top of casing, and then used to calculate water table elevations. Pressures will be recorded in WB wells for water level calculation during scheduled sampling events. Performance monitoring will be conducted in accordance with the long-term monitoring optimization plan. Forms for recording field data are provided in **Appendix B**.

4.3 MONITORING SCHEDULE

Following initial application of the ISCO materials, groundwater sampling was performed quarterly at a selection of monitoring wells located within AOC-65. Groundwater samples are collected from nearby monitoring wells, private water supply wells, and a selection of WB well zones (UGR-01, LGR-01, and LGR-09 or LGR-11) within ¼ mile of AOC-65. The monitoring schedule may be adjusted to include sampling associated with additional cylinder applications, or on an as-needed basis based on changes in field conditions or monitoring results. Analysis of sampling frequencies was performed as part of the 2020 Long-Term Monitoring Optimization (LTMO) update. Results from those analyses indicate that semi-annual sampling is adequate to monitor remedial progress and the status of installed cylinders, therefore, following the September 2020 sampling event, ISCO sampling is performed semi-annually, with samples collected in the spring and fall. Field parameter collection, including water level gauging, and cylinder adjustments are performed more frequently to ensure cylinders are positioned for maximal effect within wells.

Table 4.1
ISCO Corrective Measure Monitoring Locations

Off-Post Wells	On-Post Wells	Additional On-Post Monitoring Locations
LS-5	CS-MW6	VEWs (13, **15**, 16, **18**, **19**, 20, 21, 23, 25, **27**, 28A, 28B, **29**, **31**, and **32**)
LS-6	CS-MW7	CS-WB-01 (UGR-01, LGR-01)
LS-7	CS-MW8	CS-WB-02 (UGR-01, LGR-01)
RFR-10	CS-MW36	CS-WB-03 (UGR-01, LGR-01)
RFR-11	CS-WB01-LGR09	TSWs (**01**, 02, 03, 04, **05**, 06, and 07)
OFR-3	CS-WB02-LGR09	PZs (01, 02, 05, and 06)
CS-WB04 (UGR-01, LGR-01, LGR-11)	CS-WB03-LGR09	**SIW-01**
		IIWs (01, 02, 03, 04)
		Infiltration Cells (MIC and SIC)

***BOLD** denotes permanganate cylinder installation locations.

Table 4.2
ISCO Corrective Measure Analyte List

Analysis	Volatile Organic Compounds	Priority Pollutant Metals	
Method	SW8260B	SW6010B/7470A	
Analytes	1,1-dichloroethene *Cis*-1,2-dichloroethene Tetrachloroethene Trichloroethene *Trans*-1,2-dichloroethene Vinyl chloride	Antimony Arsenic Beryllium Cadmium Chromium Copper Lead Manganese	Magnesium Mercury Nickel Selenium Silver Sodium Thallium Zinc
Analysis	Anions	Total Metals	
Method	300.0	M4500	
Analytes	Chloride Sulfate	Total Manganese	

CHAPTER 5
REPORTING REQUIREMENTS

5.1 DOCUMENTATION

An ISCO Phase V Assessment Report will be prepared throughout the operational period. This report will include documentation of any new monitoring/injection well installations and infiltration gallery maintenance, analytical data from sampling events, performance monitoring data, and a summary of O&M activities carried out during the operational period.

Additionally, an Annual UIC Status Report that provides a summary of ISCO activities conducted at AOC-65 during the prior year will be prepared and submitted to TCEQ as specified by the UIC permit (Authorization No. 5X2600645).

APPENDIX A
RECOMMENDED MATERIALS

Recommended Materials	Supplier	Contact
Sustained-Release Oxidant Cylinders – RemOx SR+	Carus Corporation	(815) 223-1500 email: salesmkt@caruscoporation.com
Liquid Oxidant – RemOx L	Carus Corporation	(815) 223-1500 email: salesmkt@caruscoporation.com
Polyethylene Mesh Sleeves	McMaster-Carr Catalog #: 5969K47	(404) 346-7000 email: atl.sales@mcmaster.com

APPENDIX B
DATA COLLECTION SHEETS

ISCO Sampling AOC-65

Personnel: ______________________ **Bold = Performance Monitoring Samples**

candles installed

Well ID	TD / pump depth	Water Level ('BTOC)	Sample Date	Sample Time	Temp. (°C)	Cond. (ms/cm^2)	DO	pH	ORP
AOC65-VEW13-LGR	41								
AOC65-VEW14-LGR	61								
AOC65-VEW15-UGR	13								
AOC65-VEW16-LGR	41								
AOC65-VEW17-LGR	52.5								
AOC65-VEW18-LGR	56								
AOC65-VEW19-UGR	26								
AOC65-VEW20	25.7								
AOC65-VEW21	27								
AOC65-VEW22	50.5								
AOC65-VEW23	21								
AOC65-VEW24	50								
AOC65-VEW25	21.5								
AOC65-VEW26	50								
AOC65-VEW27	21								
AOC65-VEW28A	120								
AOC65-VEW28B	179								
AOC65-VEW29	40								
AOC65-VEW30	24.5								
AOC65-VEW31	40								
AOC65-VEW32	24								
AOC65-VEW33	24.5								
AOC65-PZ01-LGR	132.35								
AOC65-PZ02-LGR	50.26								
AOC65-PZ03-LGR	134.2								
AOC65-PZ04-LGR	43.1								
AOC65-PZ05-LGR	126.87								
AOC65-PZ06-LGR	43.64								
AOC65-TSW-01	40								
AOC65-TSW-02	40								
AOC65-TSW-03	40								
AOC65-TSW-04	40								
AOC65-TSW-05	40								
AOC65-TSW-06	51								
AOC65-TSW-07	40								
AOC65-SIW-01	25								
AOC65-SIW-02	25.4								
AOC65-North-IC	4.2								
AOC65-Middle-IC	9.65								
AOC65-South-IC	11.77								
IIW-01	116								
IIW-02	125								
IIW-03	125								
IIW-04	125								

Personnel: ______________________________ Permit required samples shaded gray.

Bold = Performance Monitoring Samples

Westbay Zone	Depth	Sample Date	Sample Time	ATM pressure	Outside Pressure	Inside Pressure
WB01-UGR-01	48					
WB01-LGR-01	86					
WB01-LGR-02	113					
WB01-LGR-03	133					
WB01-LGR-04	168					
WB01-LGR-05	196					
WB01-LGR-06	220					
WB01-LGR-07	244					
WB01-LGR-08	280					
WB01-LGR09	300					
WB02-UGR-01	41					
WB02-LGR-01	71					
WB02-LGR-02	100					
WB02-LGR-03	135					
WB02-LGR-04	158					
WB02-LGR-05	187					
WB02-LGR-06	213					
WB02-LGR-07	248					
WB02-LGR-08	287					
WB02-LGR-09	297					
WB03-UGR-01	32					
WB03-LGR-01	63					
WB03-LGR-02	95					
WB03-LGR-03	122					
WB03-LGR-04	139					
WB03-LGR-05	180					
WB03-LGR-06	211					
WB03-LGR-07	240					
WB03-LGR-08	287					
WB03-LGR-09	297					
WB04-UGR-01	47					
WB04-LGR-01	79					
WB04-LGR-02	100					
WB04-LGR-03	130					
WB04-LGR-04	180					
WB04-LGR-06	226					
WB04-LGR-07	256					
WB04-LGR-08	292					
WB04-LGR-09	315					
WB04-LGR-10	335					
WB04-LGR-11	367					

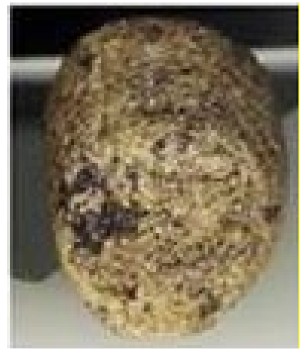
ISCO Permanganate Candle Placement
AOC-65

Personnel: ______________________________

Well ID	TD / pump depth	Water Level ('BTOC)	Date	Time	Top of Candle 1 (ft. BTOC)	Top of Candle 2 (ft. BTOC)	Top of Candle 3 (ft. BTOC)
AOC65-VEW15-UGR	13						
AOC65-VEW18-LGR	56						
AOC65-VEW19-UGR	26						
AOC65-VEW27	21						
AOC65-VEW29	40						
AOC65-VEW31	40						
AOC65-VEW32	24						
AOC65-TSW-01	40						
AOC65-TSW-05	40						
AOC65-SIW-01	25						

APPENDIX C
OXIDANT CONSUMPTION RATE EXAMPLES

New permanganate wax cylinder



Consumed permanganate wax cylinder