SULFATE APPLICATION REMEDIATION WORKPLAN

SELECTED CLEANUP ACTION ALTERNATIVE FOR ON-SITE GROUNDWATER RESTORATION

Kinder Morgan Liquids Terminals, LLC

Harbor Island Terminal

2720 13th Avenue Southwest

Seattle, Washington

Antea™ Group Project No. STKM-001-W
December 2011

Prepared for:
Kinder Morgan Liquids Terminals LLC
1100 Town & Country Road
Orange, CA 92868

Prepared by:
Antea™Group
4006 148th Avenue NE
Redmond, WA 98052
800 477 4711

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1.0 INTRODUCTION

Antea™Group (Antea Group) has prepared this Sulfate Application Remediation Workplan (Workplan) on behalf of Kinder Morgan Liquids Terminals LLC (KMLT) to for the installation of the selected cleanup action for on-site groundwater restoration at the Harbor Island Terminal in Seattle, Washington (Figure 1). The Workplan contains detailed information needed to design and install the components required to implement this remedial technology. This workplan serves as the Engineering Design Report and is prepared in accordance with the specifications in Section 173-340-410(4)(a) of the Washington Administrative Code (WAC). Construction plans and specifications will be prepared subsequent to review and approval of this workplan by the Washington Department of Ecology (Ecology).

1.1 Cleanup Action Plan

In November 1999, Ecology finalized a Cleanup Action Plan (CAP) for the Kinder Morgan Harbor Island Terminal, Seattle, Washington. The CAP was included in the Model Toxics Control Act (MTCA) Consent Decree 00-2-07760-2SEA , executed on April 4, 2000 between GATX Terminals Corporation (GATX) and the Washington Department of Ecology for the Kinder Morgan Liquids Terminals, LLC Harbor Island Terminal in Seattle, Washington (Site). Kinder Morgan Liquids Terminals LLC (KMLT) assumed the obligations of the Consent Decree with the purchase of GATX in 2001. .

The CAP included groundwater cleanup levels that were determined by Ecology to be surface water standards that are protective of aquatic organisms in Elliott Bay. These surface water standards are the adopted ambient water quality criteria (WAC 173-201A and Section 304 of the federal Clean Water Act). The category of ambient water quality standards selected as relevant and appropriate for the site are the chronic criteria for protection of aquatic organisms (WAC 173-201A-040). Surface water standards are not established for TPH; therefore, the groundwater cleanup levels for TPH-G, TPH-D, and TPH-O were selected as protective cleanup goals at this time and they are:

Product	No Sheen
Benzene	0.071 mg/L
Ethylbenzene	29.0 mg/L
Lead	0.0058 mg/L
Toluene	200.0 mg/L
TPH-G	1.0 mg/L
TPH-D	10 mg/L
TPH-O	10 mg/L

1.2 Selected Cleanup Action

A sulfate application pilot test was performed to evaluate bioremediation via sulfate-reducing bacteria at the site in July through October 2010. The test included the application of magnesium sulfate upgradient of two on-site monitoring wells (MW-7 and MW-19) which continue to exceed TPH-G cleanup criterion. Based on performance monitoring results of this pilot test, subsurface conditions appear favorable for sulfate application for groundwater remediation. Evaluation of sulfate and hydrocarbon constituent concentrations indicate that the existing naturally occurring biological population appear amenable to the introduction and utilization of sulfate reduction in remediating remaining hydrocarbons in groundwater. The pilot test was summarized in a report entitled *Sulfate Application Pilot Test Report,* dated January 2011 and prepared by Antea Group.

Subsequent to the pilot test, a Focused Feasibility Study (FFS, January 2011) was prepared to evaluate a focused series of remedial alternatives which may be applicable at the site for final on-site groundwater restoration. Of the remedial alternatives evaluated in this FFS, enhanced bioremediation using sulfate application appeared to be the best-available, most cost-effective remedial alternative. In a letter dated September 8, 2011, the Washington Department of Ecology (Ecology) approved the Pilot Test Report and the FFS, and approved sulfate application as the selected cleanup action for on-site groundwater restoration.

1.3 Operation and Maintenance of Cleanup Action

KMLT will own, operate, and maintain the cleanup action during and following the implementation of the remedial action.

2.0 ON-SITE GROUNDWATER CHARACTERIZATION

2.1 Summary of Geology and Hydrogeologic Conditions

Soils encountered during drilling consisted predominantly of dark grayish brown silty sand and sand to the total explored depth of 35 feet below grade. Soil composition is relatively uniform to the total depth explored and no significant interbeds have been observed. Grain size analyses performed on soil classifies the soil as poorly graded sand with silt and silty sand.

The shallow hydrology beneath the site consists of fresh water at depths of 3 to 10 feet below grade. Groundwater is reported to become brackish at 45 to 65 feet below grade (Weston, 1993). Groundwater gradient beneath the site trends predominantly to the south at a gradient of approximately 0.005 ft/ft, occasionally with a slight eastern or western component. Groundwater gradient and migration have remained relatively consistent throughout the years of observation. Groundwater elevation and contours from the May 2011 monitoring event is shown on Figure 2.

2.2 Separate Phase Hydrocarbons

Recent groundwater monitoring indicates that separate-phase hydrocarbons (SPH) have periodically been observed as sheens in 7 on-site monitoring wells (A-4, A-6, A-16, 12, MW-7, MW-9, and MW-21) and 2 off-site wells (MW-23 and MW-24). Measurable SPH has been observed in three wells (A-6, 12, and A-16) at thicknesses of up to 0.01 feet on a periodic basis.

2.3 Dissolved Hydrocarbons

Groundwater samples have been analyzed for total petroleum hydrocarbons in the gasoline range (TPH-G) using Northwest Total Petroleum Hydrocarbons Method NWTPH-Gx; total petroleum hydrocarbons in the diesel (TPH-D) and oil range (TPH-O) using Northwest Total Petroleum Hydrocarbons Method NWTPH Dx; and benzene, toluene, ethylbenzene, and total xylenes (BTEX) using U.S. Environmental Protection Agency (USEPA) Method SW8260B.

Concentrations of TPH-D and TPH-O have been below the CAP-established cleanup criteria of 10 mg/l for each constituent in all monitoring wells for a minimum of 4 consecutive quarterly groundwater monitoring events. Concentrations of TPH-G exceed the CAP-established cleanup criterion of 1.0 mg/l on-site in the western portion of the B and D Yards (MW-7, MW-9, and MW-19), and in the northwestern corner of the A Yard (A-27). Concentrations of TPH-G exceed the cleanup criterion in off-site wells A-28R, MW-23, and MW-24. Concentrations of benzene are at or above the CAP-established cleanup criterion of 0.071 mg/l in on-site well MW-19 and off-site wells A-28R, MW-23, and MW-24.

Groundwater monitoring data from the May 2011 monitoring event is shown on Figure 3.

3.0 PROPOSED CLEANUP ACTION

3.1 Enhanced Bioremediation by Sulfate Application

The proposed cleanup action includes enhanced bioremediation by sulfate application. The process consists of the application of magnesium sulfate ($MgSO_4$) into hydrocarbon impacted groundwater and soil. Sulfate reduction is the predominant electron-accepting process for the degradation of hydrocarbons. Under appropriate conditions, addition of aqueous sulfate solution will accelerate degradation of residual hydrocarbons in groundwater by enhancing subsurface conditions to promote degradation by sulfate-reducing bacteria.

3.1.1 Summary of Sulfate Application Pilot Testing

A sulfate application pilot test was performed at the site in July through October 2010. The test included the installation of two sulfate application trenches upgradient of two monitoring wells (MW-7 and MW-19) which continue to exceed TPH-G cleanup criterion. One application of 350 gallons of 29% $MgSO_4$ solution was performed into each of the two trenches, and baseline and performance monitoring were performed for a period of 3 months following the application. Based on performance monitoring results of this pilot test, subsurface conditions appear favorable for sulfate application for groundwater remediation. Evaluation of sulfate and hydrocarbon constituent concentrations indicate that the existing naturally occurring biological population appear amenable to the introduction and utilization of sulfate reduction in remediating remaining hydrocarbons in groundwater. Results of the study are included in a report entitled *Sulfate Application Pilot Test Report,* dated January 2011 and prepared by Antea Group.

3.1.2 Estimated Area Affected by Sulfate Application

Based on most recent groundwater monitoring performed in September 2011, it is estimated that the required treatment zone is approximately 150 feet wide by 350 feet long, as delineated by the 1.0 mg/L isoconcentration contour shown on Figure 3. Due to the shallow occurrence of groundwater at the site, sulfate application proposed sulfate application program will be via infiltration trenches instead of injection wells. Based on type of soils encountered during drilling (sands and silty sands), on estimated hydraulic conductivity (3×10^{-3} cm/sec (8.5 ft/day) to 1×10^{-2} cm/sec (28 ft/day) and transmissivity (636 to 2,121 gallons/day/ft) reported in the 1994 Remedial Investigation Report[1], and an average historical observed groundwater gradient of 0.005 ft/ft, it is estimated that a 20-foot-long application trench can affect a minimum area of approximately 40 feet cross-gradient and 50 feet downgradient. Based on this estimate, it is anticipated that a network of 24 sulfate application trenches is needed to implement the selected remedial action. Final locations of application trenches will be determined based on field conditions and the presence of underground piping or structures. Most trench locations will be installed with the longest section perpendicular to groundwater flow. A conceptual layout is shown on Figure 4. A schematic of a typical sulfate application trench is shown on Figure 5.

3.1.3 Estimated Sulfate Dosage

Sulfate dosage is calculated based on plume area and thickness. Based on recent groundwater monitoring, it is estimated that the required treatment zone is approximately 150 wide by 350 feet long. Based on site geology and hydrogeology, a maximum plume thickness of 10 feet is estimated. Using the sulfate reducing bacterial reaction:

$$\text{Petroleum Hydrocarbon} + MgSO_4 + \text{Dissolved Iron} \rightarrow \text{Iron Sulfide} + H_20 + MgCO_3,$$

mass balance indicates that 4 pounds of sulfate is needed to remediate 1 pound of hydrocarbons. Additionally, to account for unquantified impacts associated with the soil smear zone and their ongoing contribution to the dissolved phase, a sulfate demand factor is applied. This factor is based on groundwater concentrations and response observed during previous sulfate application at the site (pilot test).

Table 1 summarizes the sulfate dosage requirement calculation for the proposed program. During pilot testing, sulfate in the 350 gallons of solution applied to the two areas was completely utilized after 30 and 60 days following the application. Therefore, a sulfate demand factor of 6 will be applied for the first application at the site. For the subsequent applications, a demand factor of 4 is estimated, however, will be determined in a similar manner based on evaluation of the results of the post application groundwater monitoring events.

3.2 Conceptual Sulfate Application Program

Based on the pilot study, the estimated area affected by sulfate application, and the estimated hydrocarbon mass, a conceptual sulfate application program was developed and includes the following:

A pre-mixed 29% magnesium sulfate solution (3 pounds of magnesium sulfate per gallon of water) is assumed in the application program.

- Initial sulfate application of 525 gallons of magnesium sulfate solution per application trench.
- Second application of 350 gallons of magnesium sulfate solution, or as indicated based on performance monitoring, per application trench approximately 3 to 4 months after the initial application.
- Two additional applications of 350 gallons of magnesium sulfate solution, or as indicated based on performance monitoring, per application trench at 6 month intervals following the second application.

3.3 Estimated Time Frame to Complete Groundwater Restoration

During the progression of sulfate application program performance, it is anticipated that actual application dosages and frequency of application would be adjusted based on both performance results and on the distribution of residual sulfate through out the plume. Based on Antea Group's previous experience using sulfate application at over 200 sites, hydrocarbon concentrations may be expected to reduce to cleanup levels within a period of 2 to 3 years.

4.0 HEALTH AND SAFETY PLAN

A site specific health and safety plan (HASP) will be prepared for the cleanup actions by the contractor before the start of work at the site. The HASP will be prepared in accordance with the health and safety requirements of KMLT, Ecology (WAC 173-340-810), OSHA, and the Washington Industrial Safety and Health Act (WISHA) (WAC 296-24, 296-62, and 296-155). All workers involved in cleanup activities will be required to read and sign the HASP. A health and safety meeting will be conducted with the contractor, subcontractors, construction testing personnel, and applicable KMLT and Antea Group employees prior to commencement of cleanup activities at the site.

5.0 CONSTRUCTION TESTING AND QUALITY CONTROL

The contractor will perform construction quality control consistent with the requirements and provisions of the Final Construction Plans and Specifications, which will be submitted under separate cover. Construction quality control will include the necessary elements to ensure that contaminated materials are handled properly and that construction of the final cleanup action is performed properly. In accordance with WAC 173-340-400(7)(b), all aspects of construction will be performed under the supervision of a P.E. registered in the state of Washington or a qualified technician under the direct supervision of the engineer. The engineer and qualified technicians under his/her supervision are the quality assurance/quality control (QA/QC) managers.

A QA/QC plan will be provided in the Final Construction Plans and Specifications document and provided to the contractor. The QA/QC plan will provide the following information:

- Project organization
- Identification of QA/QC managers and responsibilities
- Description of construction testing
- Documentation.

6.0 SAFETY DESIGN

6.1 Handling of Excavated Soil

Soils generated during the installation of sulfate application trenches will be stockpiled for further characterization prior to disposal or re-use. Soils excavated during the installation of the trenches are expected to be clean backfill material because of the limited depth of excavation. However, excavated soils will be field-screened using a hand-held PID, and soils demonstrating elevated TVH concentrations will be stockpiled separately for further characterization.

Waste characterization will be performed as described in Section 7.1 to determine the appropriate disposal or its potential for re-use. Procedures to control spills will be incorporated into the construction bid documents and will include the use of a lined soil stockpile area for soils demonstrating elevated TVH concentrations with a lined and bermed decontamination area, and a minimal amount of liquids handling. Decontamination procedures will be described in the construction specification documents. In the event of any accidental discharge, the response and cleanup actions will be consistent with KMLT's emergency response plan. Because previous surface soil excavation performed in 2002 demonstrated that removal of lead and arsenic affected soils in the B Yard was completed, excavated soils are not expected to contain elevated concentrations of these metals. However, waste characterization, as described in Section 7.1, will include analyses for these constituents.

Erosion and sediment control measures will be implemented as necessary and may include:

- Plastic sheeting beneath and over soil stockpiles,
- Construction of temporary berms and water collection sumps as necessary to prevent runoff,
- Collection and storage of runoff and/or decontamination water,
- Dust control to prevent airborne soil movement during excavation and soil management, and
- Covers placed and secured on trucks if off-site transport of soil is required.

Due to the maximum anticipated depth of 2 feet for the installation of sulfate application trench components, it is not anticipated that groundwater will be encountered.

6.2 Handling of Magnesium Sulfate Solution

Pre-mixed 29 percent magnesium sulfate solution will be transported to the site by tanker truck. A temporary 6,500-gallon high-density polyethylene tank will placed on-site in the D Yard and will be used to temporarily store the solution during the application procedures. The tank will be equipped with a secondary containment berm.

6.3 Access Restriction

The site is an active operating facility and has restricted access (fences, signs, work permit requirements) as part of standard operations. These restrictions are in place 24 hour/day and 7 days/week. The Access and Operating Procedures for the KMLT site is contained in Exhibit C, of the Consent Decree.

7.0 MANAGEMENT OF RESIDUAL WASTES

7.1 Characterization and Disposal or Re-Use of Excavated Soil

Soils excavated during the installation of the sulfate application trenches are expected to be clean backfill material because of the limited depth of excavation. However, excavated soils will be field-screened using a hand-held PID, and soils demonstrating elevated TVH concentrations will be stockpiled separately for further characterization. The stockpile sampling frequency will be in accordance with the following Ecology guidance:

BULK CUBIC YARDS OF SOIL	MIN. NUMBER OF SAMPLES
0-100	3
101-500	5

It is anticipated that less than 100 cubic yards of soil will be generated during construction activities.

Soil samples will be analyzed for the following constituents:

- Benzene, Toluene, Ethylbenzene, and total Xylenes (BTEX) by EPA Method 8260;
- Total petroleum hydrocarbons as gasoline (TPH-G) by EPA Method NWTPH-Gx; and
- Total Petroleum Hydrocarbons as diesel (TPH-D) and Total Petroleum Hydrocarbons as oil (TPH-O) by EPA Method NWTPH-Dx with silica gel cleanup.
- Total lead and arsenic by USEPA Method 7000A.

Soils demonstrating characteristics below TPH Hot-Spot criteria may be re-used on site in construction projects not related to this remedial installation project. Petroleum-affected soil exceeding TPH Hot Spot criteria will either be transported off-site for landfill disposal or transported to an off-site thermal desorption treatment facility. The selection of petroleum-contaminated soil disposition will be made during the construction bidding process. The selected facility will be determined by the nature of the waste, facility acceptance criteria, and treatment limitations of the soil. Facilities that will accept non-hazardous soil are TPS Technologies, Inc. in Tacoma, Washington, Rabanco Landfill in Roosevelt, Washington, Waste Management disposal facilities in Arlington, Oregon, or Columbia Ridge Landfill in Oregon.

The steps for sequencing of off-site disposal or treatment are described below:

- Verify approved waste profile by designated disposal or treatment facility. The selected facility will be determined by the nature of the waste (Washington State Dangerous Waste or Problem Waste) and acceptance criteria of the receiving facility.
- Load excavated contaminated soil into trucks.
- Cover contaminated soil.
- Transport soil directly to the facility or to a local landfill transfer station.
- Document the number of trucks, the approximate volume of soil transported from the site, and the weight of the material received at the landfill or treatment facility.

7.2 Management of Other Wastes

The following guidelines will be followed regarding wastes other than soil:

- All water generated during decontamination activities will be placed in 55-gallon drums or tanks,
- Drums or tanks will be labeled with the date filled, the location from which the contents were collected, and a description of the contents,
- Waste storage containers will be sealed and secured daily. An on-site staging area for the accumulation of drums and tanks will be established on site and containers will be stored in the designated temporary holding area until characterized for disposal,
- A record of all generated residuals as stored in drums and tanks will be maintained to expedite characterization and disposal upon completion of construction activities, and
- Disposable clothing and equipment will be placed in plastic bags and disposed of as solid waste.

8.0 PERFORMANCE MONITORING

8.1 Performance Monitoring

As indicated in the Focused Feasibility Study, 6 temporary groundwater monitoring wells are proposed to be installed concurrent with installation of sulfate application trenches to monitor sulfate concentrations, sulfate usage, and hydrocarbon concentrations. These temporary wells and existing wells MW-7 and MW-19 will be used to evaluate performance and modify application volumes and/or frequency as indicated. Additionally, Well 12 will be gauged for the purpose of monitoring for SPH or sheen only. Sheen has periodically been observed in this well. During the performance of the remedial action, performance monitoring will be conducted to confirm that the cleanup action is progressing to attain cleanup standards and treatment goals.

8.1.1 Proposed Performance Monitoring Program

Baseline and performance sampling of groundwater will be performed on the proposed performance monitoring wells. Groundwater samples will be collected prior to initiating sulfate application. The samples will be analyzed for total petroleum hydrocarbons in the gasoline range (TPH-G) using Northwest Total Petroleum Hydrocarbons Method NWTPH-Gx; total petroleum hydrocarbons in the diesel (TPH-D) and oil range (TPH-O) using Northwest Total Petroleum Hydrocarbons Method NWTPH Dx; and benzene, toluene, ethylbenzene, and total xylenes (BTEX) using U.S. Environmental Protection Agency (USEPA) Method SW8260B. Additionally, the samples will be analyzed for nitrate, sulfate, and sulfide by USEPA Method 300.0/SW9056-NO3-N and USEPA Method 300.0/SW9056-SO4, and USEPA Method 376.1, respectively. Dissolved oxygen, oxidation-reduction potential, total dissolved solids, and pH will be measured using a hand-held meter.

Following sulfate application, performance groundwater monitoring will be performed on a monthly basis.

9.0 SCHEDULE

The proposed remedial design and cleanup action schedule has been developed to meet the requirements of the Consent Decree.

TASK	SCHEDULE
Prepare Remedial Design	Within 60 days of receipt of Ecology's written approval of the Sulfate Application Remediation Workplan
Implement Remedial Design	Within 90 days after receipt of Ecology's written approval of the Sulfate Application Remediation Workplan
Prepare Construction Documentation Report	Within 60 days of completion of the construction of the remedial action components
Complete on-site groundwater restoration	Within 3 years after construction completion of the remedial action components

10.0 REMARKS

The recommendations contained in this report represent Antea USA, Inc.'s professional opinions based upon the currently available information and are arrived at in accordance with currently accepted professional standards. This report is based upon a specific scope of work requested by the client. The contract between Antea USA, Inc. and its client outlines the scope of work, and only those tasks specifically authorized by that contract or outlined in this report were performed. This report is intended only for the use of Antea USA, Inc.'s client and anyone else specifically identified in writing by Antea USA, Inc. as a user of this report. Antea USA, Inc. will not and cannot be liable for unauthorized reliance by any other third party. Other than as contained in this paragraph, Antea USA, Inc. makes no express or implied warranty as to the contents of this report.

Date: December 15, 2011

Dawna Leong, P.E.
Senior Engineer

Reviewed by:

Date: December 15, 2011

James Cuthberson
Consultant

Date: December 15, 2011

Ward Crell, L.G.
Senior Consultant

Tables

TABLE 1
SULFATE DOSAGE CALCULATION
Kinder Morgan Liquids Terminals, LLC
Harbor Island Terminal
2720 13th Avenue Southwest
Seattle, Washington

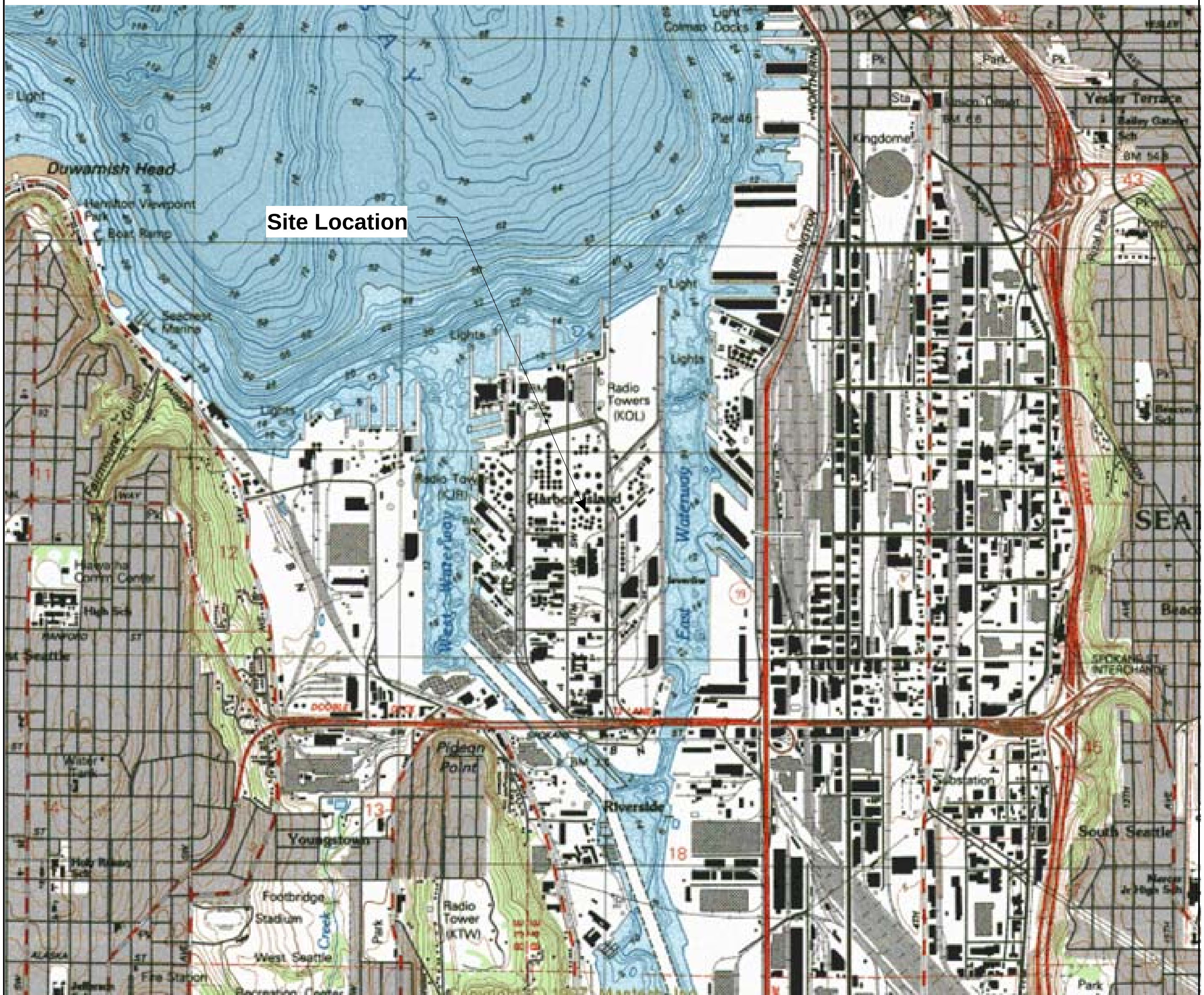
	Initial Application	Subsequent Applications
Demand Factor[1]	**6**	**4**
Length of treatment zone - feet:	**350**	**350**
Width of treatment zone - feet:	**150**	**150**
Thickness of treatment zone - feet:	**10**	**10**
Porosity of treatment zone:	**0.3**	**0.3**
Pounds of magnesium sulfate per gallon[2]:	**2.99**	**2.99**
Pounds of magnesium sulfate needed[3]:	**37,800**	**25,200**
Total gallons of solution needed:	**12,634**	**8,428**
Gallons of solution needed per trench	**525**	**350**

Notes:
[1] In general, demand factors can be applied as follows:
Low = 1 = <1,000 ppb BTEX; Medium = 2 = 1,000 to 5,000 ppb BTEX; High = 3 = > 5,000 ppb BTEX. However, demand factors can also be modified based on site specific information including pilot testing results, previous site applications and background sulfate concentrations

[2] Assume saturated 29% magnesium sulfate solution

[3] Pounds of magnesium sulfate needed is calculated using the mass balance that 4 pounds of sulfate is needed to remediate 1 pound of hydrocarbons

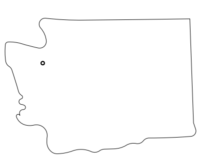
Figures



North

GENERAL NOTES:

BASE MAP USGS 7.5-MINUTE TOPOGRAPHIC MAP
SEATTLE SOUTH, WASHINGTON
1983



QUADRANGLE LOCATION

0 2000 FT

APPROX. SCALE

FIGURE 1

SITE LOCATION MAP

KINDER MORGAN LIQUID TERMINALS, LLC
HARBOR ISLAND TERMINAL
2720 13TH AVENUE SOUTHWEST
SEATTLE, WASHINGTON

PROJECT NO.	DRAWN BY
STKM-001-W.0001	RG
FILE NO.	PREPARED BY
STKM001W.0001	MM
REVISION NO.	REVIEWED BY
	DL

anteagroup

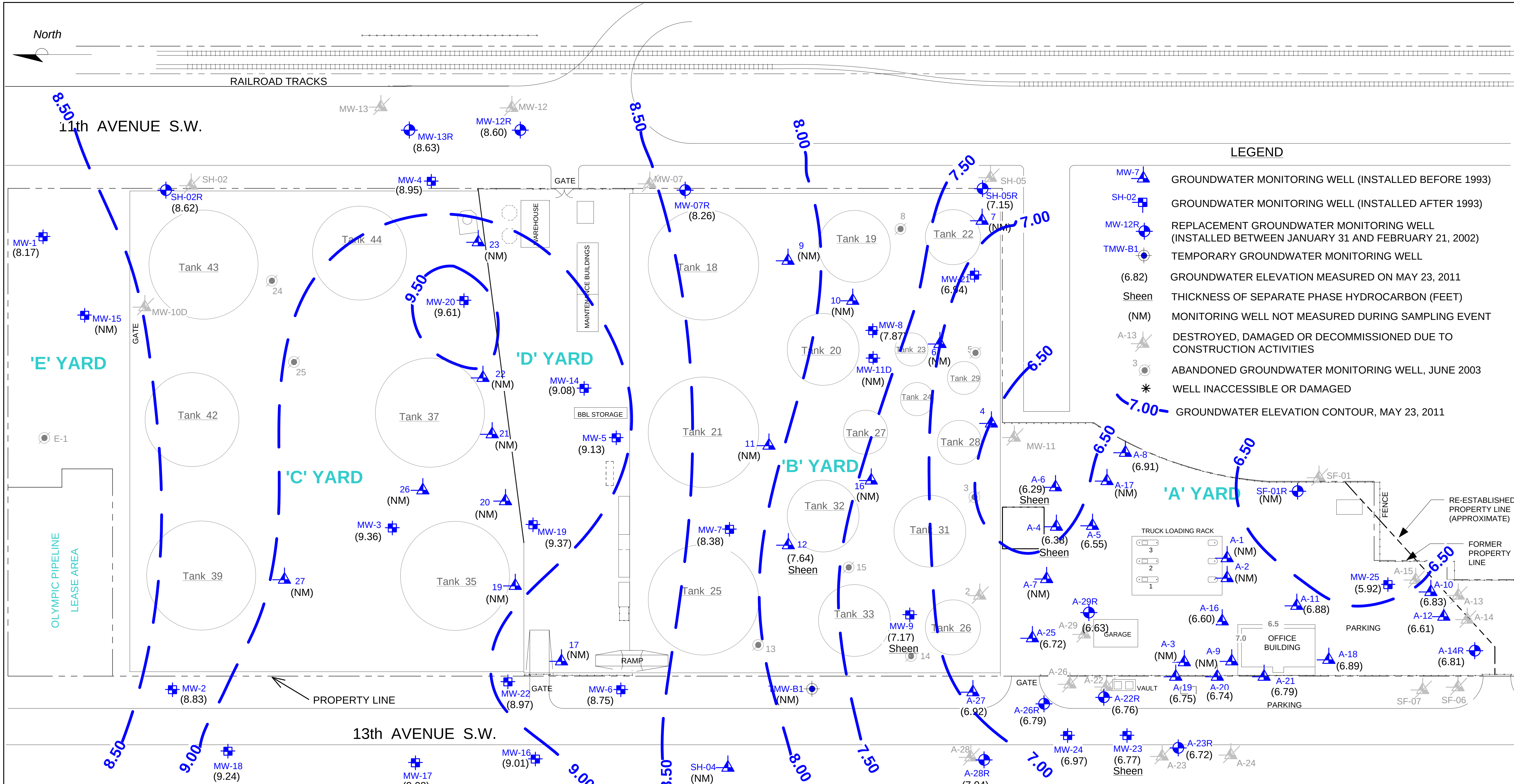


FIGURE 2

GROUNDWATER ELEVATION CONTOUR MAP
KINDER MORGAN LIQUIDS TERMINALS, LLC
HARBOR ISLAND TERMINAL
2720 13TH AVENUE SOUTHWEST
SEATTLE, WASHINGTON

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REVISION NO. 0	REVIEWED BY DL

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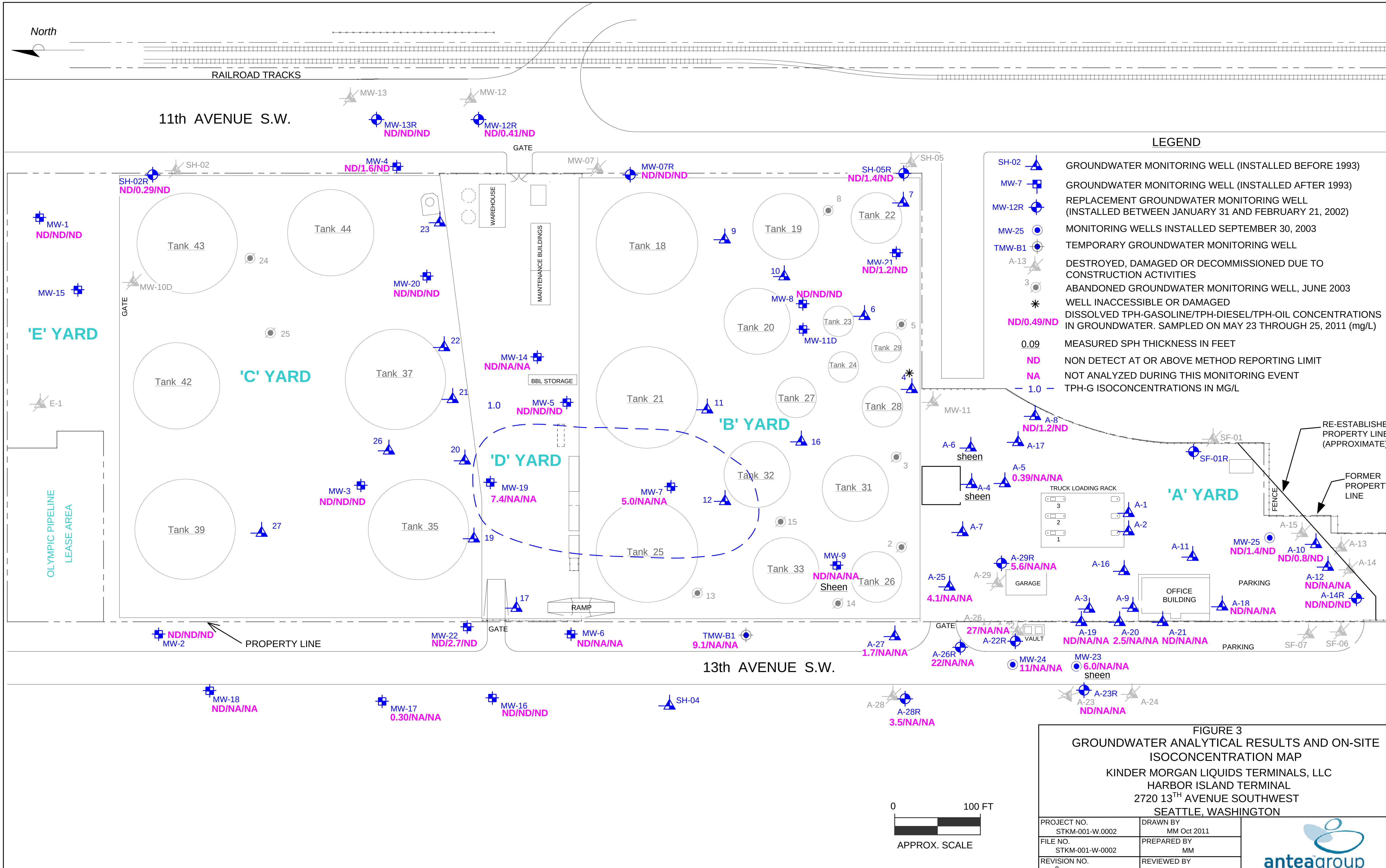

FIGURE 3
GROUNDWATER ANALYTICAL RESULTS AND ON-SITE ISOCONCENTRATION MAP
KINDER MORGAN LIQUIDS TERMINALS, LLC
HARBOR ISLAND TERMINAL
2720 13TH AVENUE SOUTHWEST
SEATTLE, WASHINGTON

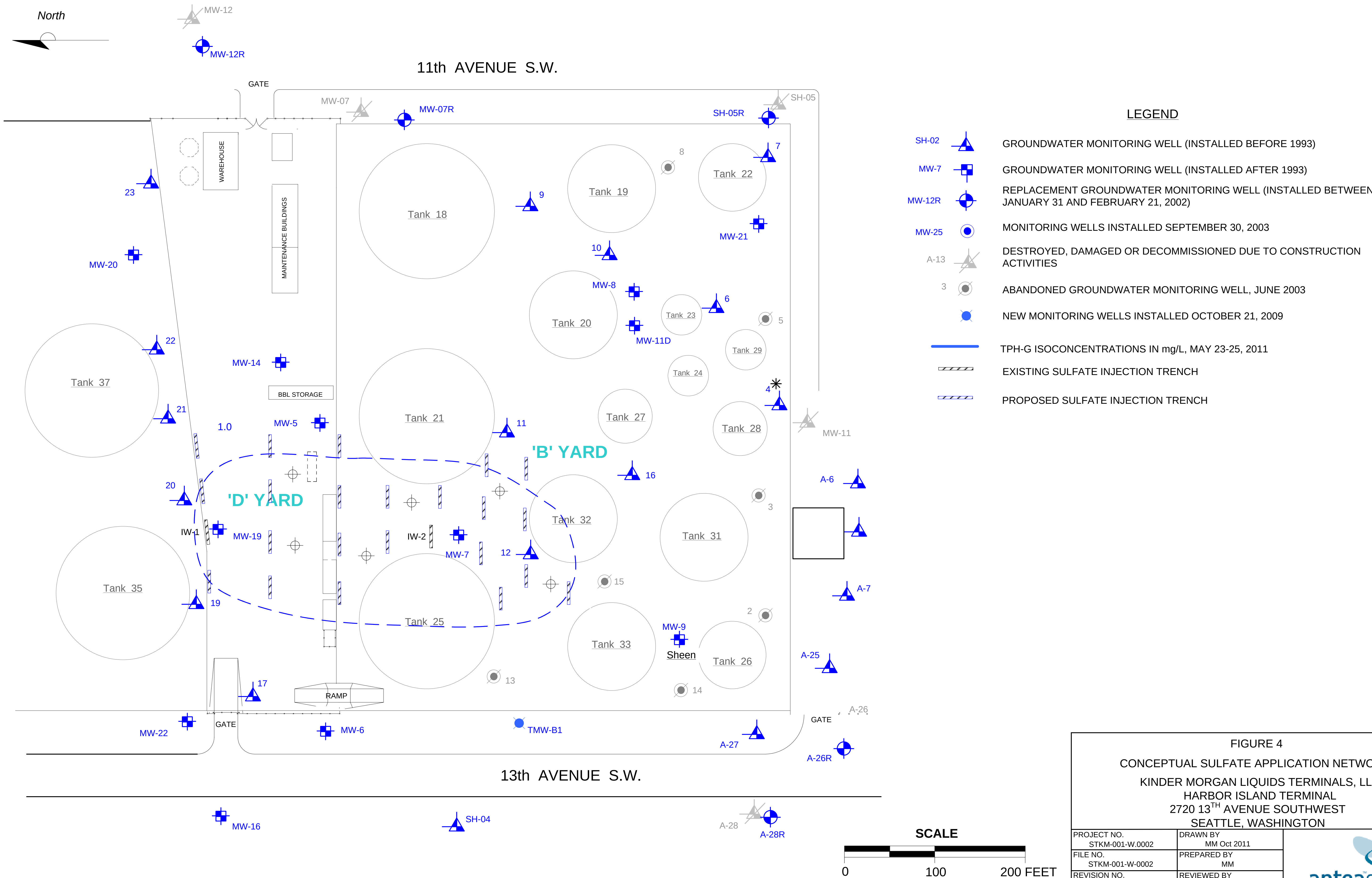

FIGURE 4

CONCEPTUAL SULFATE APPLICATION NETWORK

KINDER MORGAN LIQUIDS TERMINALS, LLC
HARBOR ISLAND TERMINAL
2720 13TH AVENUE SOUTHWEST
SEATTLE, WASHINGTON

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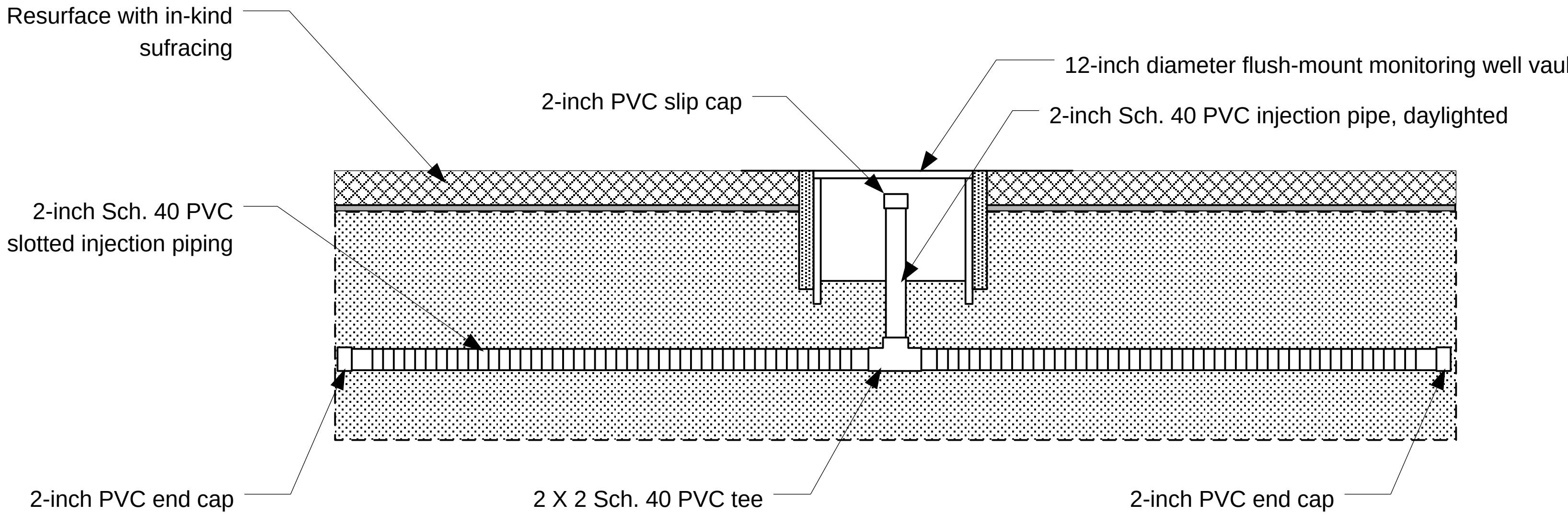
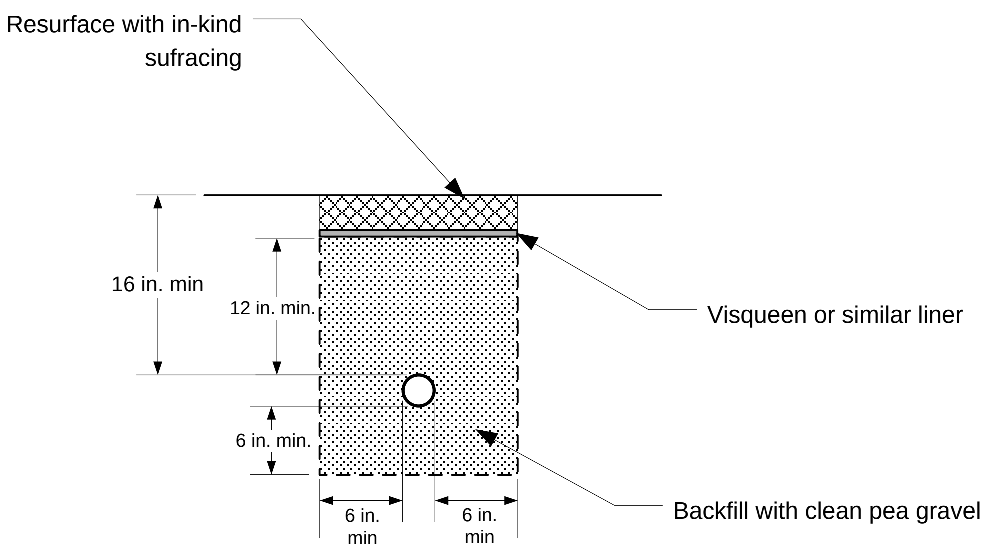


Typical Sulfate Application Trench Elevation

Not to Scale



Typical Sulfate Application Trench Cross Section

Not to Scale

FIGURE 5

SCHEMATIC – TYPICAL SULFATE APPLICATION TRENCH

KINDER MORGAN LIQUIDS TERMINALS, LLC
HARBOR ISLAND TERMINAL
2720 13TH AVENUE SOUTHWEST
SEATTLE, WASHINGTON

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