Workplan to Install a Perimeter Soil Vapor Extraction System

Southeast Site Perimeter at 100 East Patterson Street
Tecumseh, Michigan

November 2013

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Section 1
Introduction

This Workplan to Install a Perimeter Soil Vapor Extraction System – Southeast Site Perimeter at 100 East Patterson Street, Tecumseh, Michigan (Workplan) has been prepared by TRC Environmental Corporation (TRC) on behalf of Tecumseh Products Company (TPC). The United States Environmental Protection Agency (USEPA) facility identification number for the site is MID-005-049-440 and the Administrative Order on Consent (AOC) identification number is RCRA-05-2010-0012.

1.1 Purpose and Scope

TPC anticipates that soil and groundwater at the southern source area may be treated directly. However, in order to expeditiously address the potential vapor intrusion migration pathway, TPC proposes the installation of a perimeter soil vapor extraction (SVE) system downgradient of the southern source area. This perimeter SVE system will be designed to reduce or eliminate the potential for lateral migration of affected soil gas from the southern source area.

Section 2
Site Conditions

2.1 Site Description

The former TPC site is located at 100 East Patterson Street in Tecumseh, Michigan (Figure 1). The site is located in Lenawee County in southeast Michigan. The site is comprised of two parcels which occupy a total of approximately 50.5 acres. Parcel number 325-0250-00 is a 3.4-acre grass-covered area located outside of the southern site fence. Parcel number 325-0241-00 occupies 47.1 acres and is located along the northern portion of the site. This parcel includes an expanse of interconnected buildings/building additions that occupy approximately 750,000 square feet near the western perimeter of the site[1]. East of the main building, the site is occupied by the former parking area in the north and a grassy area in the south.

2.2 Site Topography

The site slopes at a grade of approximately 2-percent to the east. The surface elevation is approximately 803 feet above mean sea level (ft MSL) at southern source area, approximately 797 ft MSL near monitoring well MW-01s, and approximately 785 ft MSL at the southeast corner of the TPC property near monitoring well PRB-03s.

2.3 Geology

TRC evaluated the unconsolidated materials underlying the site through a review of logs from soil borings advanced at the site during field activities conducted by TRC from April 2009 through March 2013. Logs of soil borings and monitoring wells installed during the investigation activities were provided to USEPA in previous investigation reports.

Two geologic cross sections were developed from these boring logs to illustrate the shallow geology along the southeast perimeter of the former TPC site in the vicinity of the proposed SVE system location. Figure 2 shows the orientation of the cross-section transects, while Figures 3 and 4 provide the cross sections.

As shown on the cross sections, the site geology generally consists of a surficial silty/sandy clay interval ranging from 2 to 7 feet thick, underlain by unconsolidated fine to coarse sand and gravel. A deep clay layer is present beneath the sand and gravel layer. Soil boring data

[1] Plans for demolition of the majority of the building are underway. If the demolition is completed as proposed, only the northeast portion of the former TPC manufacturing building (P-Building and S-Building) will remain.

suggests that this second clay layer is continuous across the study area. The elevation of the top of the clay confining unit is approximately 750 ft MSL near the southeast perimeter of the site.

The unconsolidated fine to coarse sand and gravel is an unconfined aquifer beneath the site. Groundwater elevation data indicates that shallow groundwater typically ranges from 778 to 781 ft MSL (approximately 22 to 25 feet below ground surface [ft bgs]) at the southern source area; from 777.5 to 780.5 ft MSL (approximately 16.5 to 19.5 ft bgs) at monitoring well MW-01s; and from 777 to 779 ft MSL (approximately 6 to 8 ft bgs) at the southeast corner of the site near monitoring well PRB-03s. Groundwater flow in this area is to the east toward the River Raisin, the nearest body of water, which is located 1,500 to 2,500 feet east of the site.

The proposed perimeter SVE system will target the unsaturated permeable sand and gravel unit near the water table. The thickness of the unsaturated portion of this unit decreases from west to east, and in the area furthest east (near Maumee Street) the high water table intersects the overlying silty/sandy clay layer. Along the eastern interior perimeter of the site (south of monitoring well MW-01s) the thickness of the unsaturated sand and gravel unit varies temporally from approximately 12 to 15 feet (Figure 4). Along the southern perimeter of the site (between monitoring wells MW-01s and PRB-03s) the thickness of the unsaturated sand and gravel unit varies temporally from 12 to 15 feet in the west and from 0 to 1 foot in the east (Figure 3).

Section 3
System Design and Installation

3.1 Conceptual System Design

Investigation activities conducted at the former TPC site indicate that shallow groundwater and soil gas are affected by chlorinated volatile organic compounds (CVOCs) near the southeast perimeter of the property. Soil gas concentrations of trichloroethene (TCE) measured at soil gas sample point SG-01 typically exceed the Michigan Department of Environmental Quality (MDEQ) non-residential deep soil gas screening level (2,100 parts per billion by volume [ppbv]). A comparison of soil gas data and groundwater concentrations at other locations suggests that elevated soil gas concentrations at soil gas sample point SG-01 are due, at least in part to the lateral migration of affected soil gas from the source area located approximately 160 feet to the west. As described in Section 2, site geology near the southern source is favorable to lateral migration, e.g., a low permeability surficial silty/sandy clay which acts as a natural vapor barrier underlain by a high permeability sand and gravel unit having a significant unsaturated thickness.

The primary purpose of the proposed perimeter SVE system is to reduce or eliminate lateral migration and to expeditiously address the potential vapor intrusion migration pathway. However, this system was also designed to be expandable, i.e., the blower, carbon treatment system and associated components are sufficiently sized to manage flow from a possible future southern source SVE treatment system. Design details are described below. Engineering design drawings for the perimeter SVE system are provided in Appendix A.

3.2 Extraction Point Design and Installation Details

The design and layout of the extraction points was developed in large part using data from the SVE system that was installed beneath P-Building in 2012 (P-Building SVE System). Design details for the P-Building SVE System are provided in the February 2013 Full-Scale Vapor Extraction System Construction Documentation Report (TRC 2013a). Field data collected during the December 22, 2011 pilot study for active ventilation at PRB vents V-01 through V-03 were also used to help estimate the radius of influence, particularly in areas with a comparably thin permeable unsaturated zone.

Although soil type in the area of the proposed system is similar to that observed in the north, the following conditions influenced the perimeter system design:

- The proposed perimeter SVE system will be installed in an unpaved area;
- The unsaturated thickness of the sand and gravel unit, particularly in the east, is less than that observed under P-Building;

- The perimeter SVE system will not be installed in areas of affected soil; and
- The perimeter SVE system will not be used for soil treatment, but rather will be used to reduce or eliminate lateral migration of soil gas affected by on-site soil and groundwater contamination, and to increase air flow near the water table.

Based on the observed radius of influence at the P-Building SVE system and the December 22, 2011 pilot study for active ventilation at PRB vents, the minimum radius of influence is estimated to range between 35 and 45 feet at an applied vacuum of 5 inches of water, with the radius of influence increasing with the thickness of the unsaturated sand and gravel unit. The proposed perimeter SVE system includes ten extraction wells (SVE-S01 through SVE-S10) which will be installed on the former TPC site adjacent to the southeast site perimeter. The approximate locations of the proposed extraction wells are shown on Sheet 3 of 7 (Appendix A). The vapor extraction rate for each well and the subsequent radius of influence resulting from the applied vacuum will be evaluated during system start-up as described in Section 4.2; adjustment to the extraction point layout may be proposed if appropriate.

Extraction wells will be installed along the site perimeter as close to the adjacent perimeter fence as possible, given drilling equipment and work space requirements. Prior to extraction well installation, a ground survey will be conducted to determine the surface elevation at each of the proposed extraction well locations. The ground survey will be used to determine the target installation depth. The target depth will be approximately equal to the low water table elevation, except where the low water table is less than 12 ft bgs, in which case, the target depth will be a minimum of 12 ft bgs (top of screen at least 5 ft bgs) to minimize the potential for short-circuiting. Approximate low water table elevations are provided in Detail 1 on Sheet 7 of 7 (Appendix A)

Extraction wells will be constructed by drilling an 18-inch diameter hole to the target depth using 12.25-inch inside diameter hollow stem augers. The well will be constructed using a 7-foot long, 4-inch diameter, 30-slot (0.030-in) stainless steel well screen, installed to the target depth. The annular space surrounding the well screen will be backfilled with uniform washed pea gravel (Global No. 4. well gravel). Bentonite chips/granular bentonite (hydrated in place) will be placed above the pea gravel well screen to provide an effective surface seal and to minimize the potential for drawing air from the surface at each extraction well point. A non-shrinking concrete-bentonite grout will fill the remaining annular space to approximately 2.5 ft bgs.

The extraction well riser pipe will consist of 4-inch diameter schedule 40 PVC, and will extend from the top of the well screen to approximately 2-feet below the surface. A pipe tee (capped in the direction of the ground surface) will be installed at the top of the riser pipe, with the horizontal leg of the tee extending away from the site perimeter toward the adjacent header pipe. A minimum 8-inch diameter flush mount well cover will be installed to allow access to the vertical portion of the extraction well. Details of a typical extraction well are illustrated in Detail 1 on Sheet 7 of 7 (Appendix A).

3.3 Extraction Piping Design Details

From the soil vapor extraction well, 4-inch diameter Schedule 80 PVC pipe and fittings will be used to connect the extraction well to the header pipe. A horizontal section of the pipe, having a minimum length of 2.5 feet, will extend from the extraction well to a rectangular well vault. The portion of horizontal piping which extends through the well vault will be equipped with a lockable butterfly valve to control air flow from the well and three sample taps for the collection of vapor flow readings (one ½-inch diameter ball valve) and for differential vacuum pressure monitoring (one ball valve with a barbed sample port on either side of the butterfly valve). The rectangular well vault will be approximately 2 feet wide, 3 feet long and 2.5 feet deep. A horizontal section of the pipe having a minimum length of 2.5 feet will extend from the well vault to the header pipe. Details of a typical well vault and horizontal connection between the extraction well and the header pipe are illustrated in Detail 1 on Sheet 7 of 7 (Appendix A).

The layout of the header pipelines is illustrated on Sheets 4 and 5 of 7 in Appendix A. The horizontal connector pipe from each extraction well riser pipe will connect to one of two header pipes. The extraction wells along the eastern site perimeter (SVE-S01 through SVE-S03) will connect to an approximately 210-foot long 4-inch diameter Schedule 80 header pipeline (Header S1). The extraction wells along the easternmost portion of the southern site perimeter (SVE-S07 through SVE-S10) will connect to an approximately 290-foot long 4-inch diameter Schedule 80 header pipeline (Header S2). Near extraction well SVE-S06, the eastern 290-foot long portion of Header S2 will be connected to the western 270-foot long, 6-inch diameter portion of Header S2. The extraction wells along the westernmost portion of the southern site perimeter (SVE-S04 through SVE-S06) will connect to the approximately 270-foot long 6-inch diameter portion of Header S2.

All horizontal piping will be installed in trenches having a minimum depth of 2 feet. Pipe will be installed such that condensate, if any, will drain away from the SVE blower and back to the extraction wells (minimum slope of 0.1 feet per 100 feet). Pipes will be bedded in clean granular material, and the remainder of the trench will be backfilled with native material.

Adjacent to the location of the blower enclosure (near the location of monitoring well MW-01s), Schedule 80 pipe elbows will be used to turn each header pipe vertically upward. Each header pipeline will terminate approximately 3 feet above grade. The end of each header will be equipped with a male Cam Lock fitting to facilitate connection to the SVE blower enclosure via flexible hose.

3.4 SVE System Blower Enclosure Design and Details

The soil vapor extraction vacuum blower and appurtenances were selected to meet the following project objectives:

- To achieve the calculated minimum air flow as described in Appendix B; and
- To be sized and equipped such that the anticipated southern source area SVE system could use the same blower enclosure, specifically:
  - Three additional inlet lines are included in the design to allow for direct connection to additional header pipelines;
  - The blower will be selected to have the highest reasonable flow capacity for the anticipated system vacuum loss;
  - SVE enclosure plumbing will be sized to handle the anticipated maximum flow capacity with minimal vacuum loss; and
  - Other components (knock-out tank, air filter, and carbon treatment system) will be sized to manage the anticipated maximum flow capacity.

3.4.1 Target System Air Flow Calculations

Design calculations were performed to determine the minimum air flow required to control the potential volatilization to indoor air migration pathway for affected groundwater located beneath the adjacent non-residential property. These calculations are provided in Appendix B. The target perimeter SVE system air flow is greater than or equal to the calculated minimum air flow of 245 cubic feet per minute.

3.4.2 Development of System Curves

Design calculations were performed in order to develop system head loss curves for the proposed perimeter SVE system. Those system curves will be used to assist with blower selection, to design of the blower enclosure piping, and to design the carbon treatment system. The proposed SVE blower, treatment system and associated appurtenances will be designed such that they may be used for both the perimeter SVE system and the southern source area SVE system. Therefore system curves were developed for two different operating scenarios:

- Only the perimeter SVE system operational; and
- The perimeter SVE system and a hypothetical southern source area SVE system operating simultaneously such that perimeter SVE system operates near the minimum target flow rate, and the balance of system flow originates from the southern source area (combined SVE system).

The SVE system curve is a function of flow rate and vacuum loss. Total system losses under each scenario are the sum of 1) vacuum loss at the well(s), 2) vacuum loss in the piping, 3) vacuum loss through the blower enclosure, and 4) pressure drop across the carbon. Calculation sheets and system curves for each scenario are provided in Appendix C.

3.4.3 Blower Selection

A regenerative-type blower has been selected over a positive displacement (PD) blower as site conditions will support high flow rates at lower applied vacuum. Additionally, regenerative blowers generally afford lower operation and maintenance costs than PD style blowers, as PD blowers operate with tighter mechanical tolerances to achieve the higher operating pressure conditions that they offer.

Blower curves from various regenerative-type blowers will be plotted with the system curves to assist with blower selection and the final blower enclosure design details. Final blower selection will be made based on the following considerations:

- Flow rate at the anticipated operating point;
- Energy usage/operating cost;
- Operating noise levels;
- Shape of blower curve, e.g., a relatively steep blower curve indicating only small changes to extraction flow rates with modest differences in operating pressure;
- Maintenance requirements; and
- Capital cost to purchase and install the blower(s).

3.4.4 SVE System Blower Enclosure Design and Details

The SVE vacuum blower and appurtenances will be housed in a ventilated and insulated enclosure. The enclosure will be located on the former TPC property near monitoring well MW-01s, as shown on Sheet 3 of 7 (Appendix A). The two SVE header pipe lines (one from SVE-S01 through SVE-S03, and one for SVE-S04 through SVE-S10), as described above, will penetrate the ground adjacent to the blower enclosure. Flexible hose will connect to the header pipes to the intake manifold on the blower enclosure. The blower enclosure will be equipped with the following components:

- A five leg intake manifold constructed of Schedule 80 PVC (one leg for SVE-S01 through SVE-S03, one leg for SVE-S04 through SVE-S10, and three legs for system expansion). Each leg of the intake manifold will be equipped with a sample port, a flow control valve, a vacuum gage, and an air flow metering device with transmitter.

- An air-water separation tank, i.e., a water knock-out tank, to prevent fluids from entering the blower. The knock-out tank will be equipped with a vacuum gage, a relief valve, site tube to monitor the accumulation of fluids, a high level float switch to automatically shut-down the blower if water in the tank reaches that level, a high-high float back-up switch to provide a failsafe in the event that the high level switch fails, a manual bottom drain to remove fluids from the tank, and a manway for cleaning purposes.
- An inlet air filter to prevent particulates from entering the blower. A differential pressure switch/transmitter will automatically shut down the blower in the event that the filter excessively restricts air flow to the blower. The air filter unit will also be equipped with direct-read inlet and outlet vacuum gages to allow personnel to record and monitor the pressure drop across the filter during typical system inspections.
- A totalized air flow meter with transmitter between the knock out tank and the air filter.

As described above, the SVE system will be equipped with a regenerative-type blower(s) capable of operating at up to 120-inches of water (vacuum) with a target operating flow rate of at least 500 actual cubic feet per minute (acfm) at 60-inches of water (vacuum). The blower will be equipped with a variable speed drive unit that will allow manual motor speed adjustments to be made in order to optimize soil vapor extraction rate and energy demand. The blower exhaust manifold will be constructed of carbon steel pipe and equipped with the following components:

- Thermometer and thermostat (to shut the blower down on high temp condition caused by low air flow);
- Discharge silencer; and
- Exhaust stack vented 15 feet above ground surface.

Construction of the blower enclosure is expected to take 12 to 16 weeks (including the 12 weeks lead time required to obtain the selected blower).

Consumers Energy has been contracted to provide 200 amp, 240 volt, 3-phase electrical service. The power drop and meter will be located adjacent to Maumee Street near the southeast corner of the site. An electrician will be contracted to install an electrical conduit from the power drop to the SVE blower enclosure. This conduit may be placed in the same trench as the SVE extraction piping.

3.5 Carbon Treatment System Details

At present, the existing P-Building SVE extraction system operates under an MDEQ Permit to Install (PTI) air permit exemption. The limiting requirement for the PTI exemption is that the total controlled carcinogenic volatile organic carbon (VOC) emissions may not exceed 10 pounds per month.

To meet PTI exemption requirements, the combined carcinogenic emissions from the P-Building SVE system and the proposed perimeter SVE system cannot exceed 10 pounds per month. As documented in the Construction Documentation Report for the P-Building SVE system, carcinogenic emission from the P-Building system are maintained below one pound per month. Given observed concentrations in soil gas in the vicinity of the proposed perimeter SVE system, carbon treatment will likely be needed (at least initially) to ensure carcinogenic VOC emissions from the perimeter SVE system remain below 9 pounds per month.

The proposed carbon treatment system will be located adjacent to the blower enclosure. The carbon treatment system will be designed to ensure compliance with air permit exemption requirements while limiting increased SVE system backpressure that would reduce system flow. Additionally, the treatment system will be sized to be expandable, i.e., to manage flow from the anticipated southern source SVE treatment system. Details and components of the carbon treatment system are outlined below:

- Two steel vapor phase carbon vessels equipped with male cam lock inlet/outlet fittings, an outlet pressure gage, a ¼-inch outlet sample port equipped with a ball valve and barbed fitting, and a ¼-inch drain port equipped with a ball valve.
- Carbon vessels will be operated in series via interconnecting flexible hose equipped with cam lock fittings. Flexible hose will be connected to the exhaust stack via cam lock fittings. Air flow will be routed from the bottom port on the exhaust stack through the flexible hose to the inlet (bottom) of the lead carbon vessel. A screen at the bottom of each carbon vessel will help to distribute air flow and prevent preferential pathways. Air will flow up through the lead vessel, through the outlet port (top), through an additional length of flexible hose to the inlet (bottom) of the lag carbon vessel. Air will then flow up through the lag vessel, through the outlet and into a third length of flexible hose which is connected to the exhaust stack above the closed butterfly valve. Treated exhaust will then be discharged through the stack approximately 15 feet above ground surface.
- 4 x 10 reactivated vapor phase carbon will be used for carbon treatment.

3.6 Temporary Multi-Level Subsurface Vacuum Monitoring Point Details

Temporary subsurface vacuum monitoring points (TVP-S01 through TVP-S18) will be installed at 18 locations as shown on Sheet 3 of 7 (Appendix A). Radius of influence is expected to vary with the thickness of the unsaturated sand and gravel unit. Therefore vacuum monitoring point locations were selected to provide the required data for preparation of distance-drawdown plots for evaluating well efficiency and radius of vacuum influence for each well during the stepped-rate tests (see Section 4.2.1).

At each location, a single vacuum monitoring point or a nested pair of vacuum monitoring points will be installed, depending on the unsaturated thickness of the sand and gravel unit. At nested vacuum monitoring point locations, the deep point will be installed approximately 5 feet above the average water table and the shallow vacuum monitoring point will be installed below the top of the clay confining unit (with a minimum target depth of 5.5 feet below ground surface). A ground survey will be used to calculate the target installation depth for the deep monitoring point at each location using the target installation elevations provided in Detail 2 on Sheet 7 of 7 (Appendix A). If the unsaturated thickness is less than 9 feet, e.g., the target depths for the shallow and deep monitoring points are less than 3.5 feet apart (TVP-S11, TVP-S12, TVP-S13, TVP-S14, TVP-S15, TVP-S16, TVP-S17, and TVP-S18), only a single vacuum monitoring point will be installed. The single monitoring point will be installed below the surficial silty/sandy clay unit. Where the unsaturated thickness of the sand and gravel unit is sufficient, the multi-level vacuum monitoring point design is preferred because it allows for an assessment of flow patterns within the subsurface soils, specifically as it relates to thickness of the unsaturated granular soils.

Each nested pair will be constructed in a single borehole. The 2.5-inch borehole will be constructed to the target depth using Geoprobe® direct-push technology. Each vacuum monitoring point will be constructed with a 6-inch long stainless steel monitoring implant (Geoprobe® Vapor Implant AT8617S, or similar) and a length of ¼-inch outer diameter Teflon™ tubing. Multi-level vacuum monitoring points will be constructed as illustrated in Detail 2 on Sheet 7 of 7 (Appendix A), and single-level vacuum monitoring points will be constructed as illustrated in Detail 3 on Sheet 7 of 7 (Appendix A). Vacuum monitoring point construction details are described below:

- The deep monitoring point will be installed at the bottom of the borehole.
- The annular space surrounding the deep monitoring point screen will be backfilled with glass beads to approximately 6-inches above the top of the screen (filter pack).
- Granular bentonite chips will be placed above the filter pack in 6- to 8-inch lifts to approximately 6.0 ft bgs (6-inches below the bottom of the shallow monitoring point screen). Each lift will be hydrated in place prior to the addition of the next lift to help ensure an effective seal between the shallow and deep monitoring point.
- An approximately 6-inch thick glass bead filter pack (5.5 to 6.0 ft bgs) will be installed above the bentonite seal to ensure that the bentonite does not swell to plug the shallow monitoring point.

- The shallow monitoring point will be installed above the filter pack at approximately 5 to 5.5 ft bgs.
- The annular space surrounding the shallow monitoring point screen will be backfilled with glass beads to approximately 6 inches above the top of the screen (4.5 to 5 ft bgs).
- Granular bentonite will be placed above the filter pack in 6- to 8-inch lifts to approximately 1 ft bgs. Each lift will be hydrated in place prior to the addition of the next lift to help ensure an effective seal between the shallow and deep monitoring point.
- Tubing from each vacuum monitoring point will extend at least 12-inches above the top of the bentonite. Care will be taken to properly label each monitoring point so that the shallow and deep monitoring points are easy to distinguish.
- Each probe will be capped with a ball valve and equipped with a barbed hose fitting.
- Each vacuum monitoring point/nested pair will be finished with a flush-mount protective cover to protect it from inclement weather and on-site traffic.

During system start-up, a portable vacuum gauge will be connected to the probe, and the ball valve will be opened to measure vacuum propagation away from the extraction wells in order to assess zone of vacuum influence. Vacuum measurements will be taken at both shallow and deep probes to assess the distribution of subsurface flow vertically throughout the vadose zone soils.

Section 4
SVE System Optimization and Performance

As described in Section 1, the SVE system was designed to reduce or eliminate the potential for lateral migration of affected soil gas from the site. This section describes the maintenance, monitoring, and reporting activities associated with the perimeter SVE system operations at the former TPC facility in Tecumseh, Michigan. These described activities are based on proposed system operations. If operations are adjusted in the future, these activities, as described herein, may be modified as appropriate.

The following subsections describe the proposed SVE system optimization and performance evaluation. Specifically:

- Measurement, evaluation and calculations associated with flow and vacuum data.
- Qualitative and quantitative estimates of VOC emissions from the extraction system over time to ensure compliance with the MDEQ requirements associated with a PTI exemption and/or an air permit.
- Overall SVE system performance.

The proposed performance evaluation and optimization will include short-term stepped-rate tests for estimating individual extraction well capacities/system curves as well as a long-term performance monitoring to verify continued system performance. Testing and monitoring locations are displayed on Sheets 4 and 5 of 7 of the Soil Vapor Extraction System Design drawings contained in Appendix A.

4.1 Equipment Requirements

Equipment requirements for performance testing include:

- Vacuum Gauge(s) – Magnehelic® Differential Pressure Gages (or equivalent) with sensitivity to 0.01 inch of water
- Flow Measuring Device – Hot wire anemometer
- Portable Temperature Probe
- Draeger Pump and associated Draeger Tubes for field measurement of TCE concentrations (or equivalent)
- Thermometer

4.2 System Start-Up and Optimization

4.2.1 Stepped-Rate Test Evaluation – Individual Extraction Wells

The purpose of the step-rate test is to evaluate vapor recovery rates obtainable at various applied vacuum rates. Data collected will be used to determine well-specific radius of vacuum influences and to establish flow and pressure relationships at various operating conditions. Approximately four days will be dedicated to performing stepped-rate tests at the extraction points (SVE-S01 through SVE-S10).

Field Procedures and Data Collection

The following sequence describes the procedures and data collection requirements for performing a single stepped-rate test. Following the completion of this sequence, a different extraction well will be isolated and the sequence will be repeated.

1. With the blower off, collect vacuum pressure readings at each of the extraction wells and vacuum monitoring points to establish starting conditions.
2. Isolate flow to one extraction well by closing all wellhead butterfly valves except for the valve at the well to be tested.
3. With the butterfly valve on the extraction well to be tested completely open, turn on the blower, allow the system to equilibrate (10-15 minutes) and record the following:
   a. Time of each measurement collected.
   b. Vacuum pressure, temperature, and flow rate at the blower, and at the extraction well
   c. Vacuum pressure at adjacent monitoring locations, including closed extraction wells and vacuum monitoring points. If pressure influences are observed at adjacent locations, collect readings at additional locations moving radially away from the test well until no influence is observed.
4. Turn the blower off and allow the pressure at monitoring points to return to starting conditions.
5. Open one of the unused legs on the intake manifold to provide system dilution and decrease the vacuum/flow at the test extraction well. Turn the blower on, and adjust the valve such that the vacuum pressure at the

well is reduced by approximately 5 inches of water[2]. Allow the system to stabilize (approx. 10 to 15 minutes) and follow the data recording requirements outlined in Step 3.

6. Repeat Steps 4 and 5, opening the dilution valve further, and decreasing the vacuum applied by an additional 5 inches of water.[2]
7. Repeat Step 6, in a series of approximately equal decreases in the vacuum applied until the applied vacuum is zero.
8. Once the stepped-rate test is complete at a given well, turn off the blower and allow the system to return to staring conditions.
9. Repeat the stepped-rate test procedures at a new test extraction well beginning with Step 2 above.

Data Evaluation

Following the completion of the stepped-rate tests, data evaluation will include:

§ Preparation of system curves for each of the extraction wells. System curves will consist of plotting observed wellhead flow versus vacuum applied for each well tested.

§ Evaluation of the radius of influence (ROI) at each well.

§ Determination of whether extraction wells have the potential to be air flow limited within the range of vacuum pressure applied.

4.2.2 Stepped-Rate Test Evaluation – Entire System

Following the conclusion of individual stepped-rate tests, the SVE system will be configured to operate all 10 extraction wells. Valves at the SVE enclosure and at individual extraction wells will be used to balance flow between each extraction well. The system will be considered balanced if the flow at all extraction wells is within 20-percent of the average extraction flow rate. Once the system is balanced a stepped-rate test will be completed for the SVE system as a whole.

[2] If the observed vacuum at the test well during the Step 2 is less than 12 inches of water the reduction in vacuum pressure should be reduced so that the well can be tested under at least three different vacuum conditions. For example, if an initial vacuum of 10 inches of water is observed at the test well, the well should then be tested at an applied vacuum of approximately 6 inches of water and at an applied vacuum of approximately 2 inches of water.

Field Procedures and Data Collection

The following sequence describes the procedures and data collection requirements for performing a system-wide stepped-rate test.

1. Close all unused legs on the intake manifold value, i.e., no make-up air.
2. Balance the system as described above, turn on the blower, allow the system to equilibrate (10-15 minutes) and record the following:
   a. Time of each measurement collected.
   b. Vacuum pressure, temperature and flow rate at the blower, and at each extraction well.
   c. Vacuum pressure at vacuum monitoring locations.
3. Turn the blower off and allow the pressure at monitoring points to return to starting conditions.
4. Open one of the unused legs on the intake manifold to provide system dilution and decrease the total system flow by approximately 30-percent, and repeat Steps 2 and 3.
5. Repeat Step 4, opening the dilution valve further, and decreasing the total flow by an additional 30-percent.
6. Repeat Step 5, until the total flow is less than 140 CFM (i.e., two steps below the minimum target air flow).
7. Once the system-wide stepped-test is complete, establish long-term operating parameters by repeating Step 1 and Step 2.

Data Evaluation

Following the completion of the system-wide stepped-tests, data evaluation will include:

§ Preparation of system curves which will allow TRC to accurately predict system vacuum losses (at the well, in the extraction piping, in the blower enclosure, and in the carbon treatment system) under various flow conditions. These data may be used to ensure the system continues to operate as required and expected if/when system modifications are made (e.g., the installation of one or more additional exaction headers from the southern source area, variable frequency drive adjustments, etc.)

§ Evaluation/confirmation of the ROI for the entire system under various flow scenarios.

4.3 Long-Term SVE System Operation and Maintenance

4.3.1 Remote Operation and Maintenance

The SVE system will be equipped with remote sensing devises that transmit data (pressure, flow, and temperature) to the system's programmable logic controller (PLC) within the system control panel. The PLC records the data and triggers alarm conditions if data falls outside of the accepted "normal" limits of the system. Alarm conditions are displayed locally at the control panel. These data may also be viewed remotely, in real time, by way of the system telemetry. Additionally, system telemetry is used to automatically send collected data and any alarm conditions to designated project personnel via a cellular phone modem in the form of electronic mail. Data available remotely will include:

- Flow rate for each of the five intake manifold pipes as they enter the SVE blower enclosure;
- Total system flow rate (measured between the knock out tank and blower);
- Differential pressure across the air filter; and
- Blower exhaust temperature.

Flow, pressure, and temperature data will be recorded at 10-minute intervals, and will be automatically emailed to project personnel daily. These data will be compiled and reviewed regularly (typically at least monthly).

In addition to the ability to monitor routine system data remotely, the system will notify designated staff via email if deactivation of the blower occurs due to any of the following alarm conditions:

- Motor overload;
- High temperature at the exhaust stack;
- High or low vacuum;
- High or high-high water level reached in the knock out tank; or
- High differential pressure across the inlet air filter.

Following automatic notification of an alarm condition or identification of a significant anomaly in SVE system data by manual review, TRC will work to correct the problem as soon as possible either remotely or in person, as appropriate.

4.3.2 System Inspection – Blower, System Piping and Appurtenances

On-site system inspections will be conducted to verify, in the field, that the system is operating as expected. An operation and maintenance checklist will be completed by the field technician. System inspections will include the following:

- Flow and pressure readings at each extraction well;
- Differential pressure between the air filter inlet and outlet;
- Pressure and temperature at the blower (i.e., exhaust stack);
- Visual and auditory inspection of the blower and motor; and
- Visual inspection of accessible system piping, well vaults, and fittings.

Deficiencies identified during system inspections will be corrected as soon as possible, typically within 30 days of discovery. At a minimum, inspection of the blower, system piping and appurtenances will be completed on a quarterly basis for the first year of operation. The inspection frequency will be evaluated and adjusted, if appropriate, at that time.

4.3.3 Carbon Treatment System

Operation and maintenance of the carbon treatment system requires that the carbon in the carbon vessels be removed and replaced (i.e., carbon change out) once its absorptive capacity has been reached. As noted in Section 3.5, the carbon vessels are operated in series. Typically carbon change out will be arranged after breakthrough is observed on the lead vessel, but not on the lag vessel. As such, the lag vessel is used to maintain acceptable emissions throughout the carbon loading cycle, providing a margin of safety for the time lag between the observed breakthrough on the lead vessel and the carbon change out.

Field Measurement of TCE Concentrations

The carbon treatment system is designed to ensure that carcinogenic VOC emissions from the facility remain below 10 pounds per month, as required by MDEQ PTI exemption requirements. As documented in February 2013 P-Building Construction Documentation Report, TCE is expected to be the dominant carcinogenic COC to be removed with the carbon treatment system. A Draeger pump equipped with TCE-specific Draeger tubes (or equivalent) for field measurement of TCE will be used to monitor TCE concentrations through the treatment process as outlined below:

§ TCE concentrations will be measured at three locations: treatment system influent (sample port after the blower in the SVE blower enclosure), between the lead and lag vessels (lead vessel sample port), and system exhaust (lag vessel sample port).

- Prior to sample measurement, pump ambient air through the Draeger pump to flush the pump and purge residual contamination that may be residing in the pump prior to sample collection (approximately 5 pumps);
- Break the ends off the TCE Draeger tube;
- Connect a length of ¼-inch diameter flexible tubing to the influent end of the Draeger tube;
- Connect the other end of the tubing to the sample port;
- Open the sample port;
- Seat the effluent end of the Draeger tube in the Draeger pump;
- Use the Draeger pump to pull the sample through the Draeger tube (5 pumps or as called for in the Draeger tube instructions to achieve targeted concentration limits for the tube);
- Record the TCE concentration on TRC field forms.

Exhaust concentrations (assuming no significant modifications to the SVE system) are expected to decrease over time. Field measurement of TCE concentrations will be completed at a frequency appropriate to detect TCE breakthrough on the lead vessel prior to breakthrough on the lag vessel. Initially that frequency will be based on historical carbon usage rates for the P-Building SVE system. Specifically 1000 pounds of carbon should remove approximately 17 pounds of TCE. As data are collected from the perimeter SVE system, the carbon usage rate will be re-evaluated and adjusted as appropriate.

Sample Collection for Laboratory Analysis

In addition to field measurement of TCE concentrations, samples may be collected for laboratory analysis to confirm field measurements. Samples will be collected as described below:

- Grab sample(s) will be collected in a laboratory-supplied certified-clean 1-liter SUMMA® sample canister equipped with a barbed fitting. The canister will be evacuated to a nominal 26 to 30 inches of mercury and shipped to the field under Chain-of-Custody documentation.
- ¼ -inch diameter flexible tubing will be used to connect the sample canister to the sample port.
- The sample information, including canister number and initial canister vacuum will be recorded on TRC standard air sampling forms.

- The valve on the sample canister will then be opened to begin sample collection.
- Once the vacuum gage indicates that sample collection is complete, the valve on the sample canister will be closed. The final canister vacuum and ending sample collection time will be recorded.

Field procedures for sample documentation, handling, storage, shipment, preservation, and Chain-of-Custody will be conducted in accordance with the procedures outlined in the Quality Assurance Project Plan (QAPP) (RMT, 2010d). Samples will be analyzed by H&P Mobile Geochemistry using USEPA Method TO-15 or USEPA Method 8260B. Field personnel will document sample collection procedures on field data forms or in field notebooks.

Data Evaluation

Data evaluation during and following system sampling may include:

- Carbon usage will be based on TCE breakthrough as measured with TCE Draeger tubes. Specifically:
  - Prior to carbon change out –
    - If the TCE concentration between the lead and lag carbon vessel is greater than or equal to 50-percent of the concentration at the influent of the carbon treatment system, carbon change out will be arranged.
    - If the TCE concentration between the lead and lag carbon vessel is less than 50-percent of the concentration at the influent of the carbon treatment system, the next TCE field measurement will be scheduled.
  - At the time of carbon change out –
    - If the TCE concentration at the system exhaust is greater than or equal to 50-percent of the concentration at the influent of the carbon treatment system, carbon in both the lead and lag vessel will be replaced.
    - If the TCE concentration at the system exhaust is less than 50-percent of the concentration at the influent of the carbon treatment system, carbon in the lead vessel will be replaced and system piping will be adjusted so that the former lead vessel (new carbon) becomes the lag vessel and the former lag vessel (partially used carbon) becomes the lead vessel.

- § Exhaust samples may be collected from the SVE system to document compliance with PTI exemption requirements and/or verify Draeger Tube sample results.
- § As concentrations decrease, carbon treatment system influent samples may be used to determine whether continued operation of the carbon treatment system is required.

4.4 System Optimization and Performance Monitoring Schedule

4.4.1 System Start-up

- Stepped-rate tests at individual extraction wells will be conducted as soon as feasible following system installation.
- If stepped-rate tests at individual extraction wells indicate that the ROI is less than anticipated, and additional extraction wells are needed, system improvements will be made and stepped-rate tests will be conducted at any additional extraction wells.
- The stepped-rate test for the entire system will be conducted as soon as feasible following the completion of stepped-rate tests at individual extraction wells.
- As soon as the system-wide stepped-rate test is complete, long-term operating parameters will be established, and baseline conditions will be established by completing the following:
  - § An initial system inspection will be conducted as described in Section 4.3.2;
  - § Field measurement of TCE concentrations as described in Section 4.3.3; and
  - § Sample collection at the carbon treatment system influent as described in Section 4.3.3.

4.4.2 System Shake-Down Period

Routine system operation and maintenance will be conducted relatively frequently following system start-up to ensure the system continues to operate as anticipated and to more accurately predict when carbon change out will be needed. At a minimum operation and maintenance during the shake-down period will include:

- Inspection of the blower, piping and appurtenances as described in Section 4.3.2;
- Field measurement of TCE concentrations as described in Section 4.3.3; and
- Sample collection at the carbon treatment system influent as described in Section 4.3.3.

At a minimum, on-site operation and maintenance will be conducted on the following schedule after long-term operating parameters are established:

- 3 to 7 days
- Approximately 2 to 3 weeks
- Approximately 6 to 8 weeks
- Approximately 12 to 14 weeks

4.4.3 Long-term Operation and Maintenance

Following system start-up and shake-down, long-term operation and maintenance will be completed as described in Section 4.3. At a minimum, remote telemetry data will be compiled and reviewed monthly and on-site system inspections including field measurement of TCE will be conducted quarterly for the first year of operation. The inspection frequency will be evaluated and adjusted, if appropriate, after one year of operation.

4.5 Reporting

Reports/technical memoranda will be prepared as appropriate to document system installation and the results of operation and maintenance activities. At a minimum, the following reports will be prepared:

- A construction documentation report will be prepared following the completion of system installation, start-up and shake down period; and
- Annual performance monitoring reports or technical memoranda which summarize operation and maintenance activities for each year of operation.

Section 5
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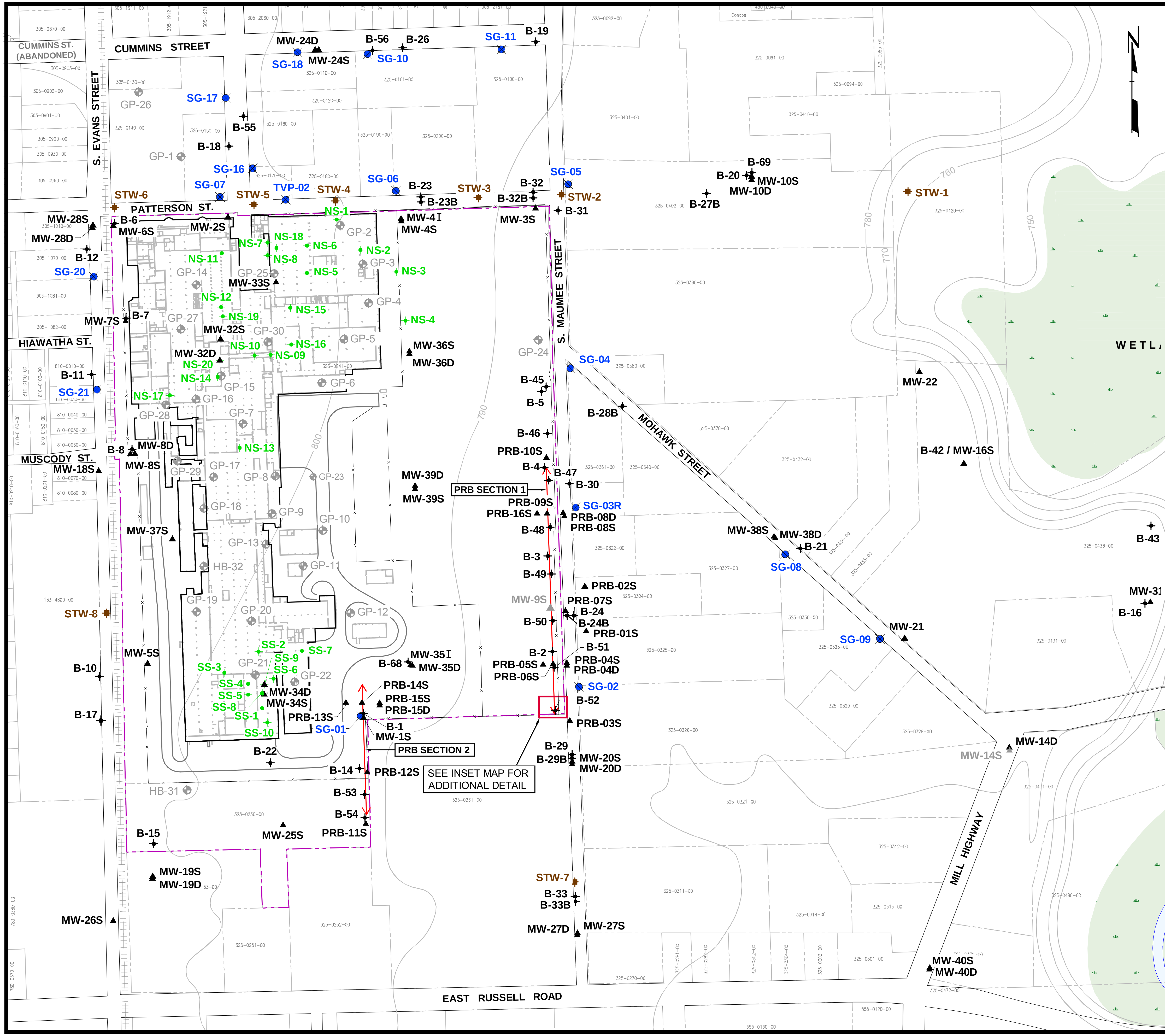
Figures

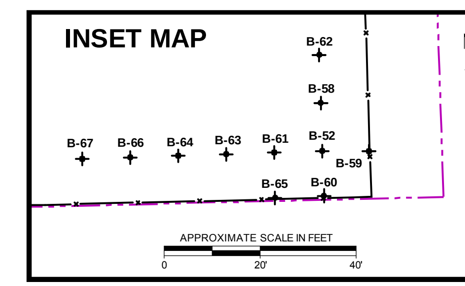


LEGEND

- FORMER TECUMSEH PRODUCTS SITE BOUNDARY
- PARCEL BOUNDARY
- RAILROAD TRACKS (APPROXIMATE LOCATION)
- 750 APPROXIMATE GROUND TOPOGRAPHY BASED OFF 7.5 MINUTE U.S.G.S. TOPOGRAPHIC QUADRANGLE MAP
- B-2 PERIMETER / OFF-SITE INVESTIGATION SOIL BORING LOCATION AND NUMBER
- MW-4S MONITORING WELL LOCATION AND NUMBER
- MW-9S DECOMMISSIONED MONITORING WELL LOCATION AND NUMBER
- SS-2 SOURCE AREA INVESTIGATION BORING LOCATION AND NUMBER
- SG-02 SOIL GAS SAMPLE LOCATION AND NUMBER
- SG-15 DECOMMISSIONED SOIL GAS SAMPLE LOCATION AND NUMBER
- STW-2 STORM WATER SEWER SAMPLE LOCATION AND NUMBER
- WL-01 APPROXIMATE SURFACE WATER SAMPLE LOCATION
- GP-2 ATC PHASE II ESA BORING LOCATION AND NUMBER
- FLOODPLAIN / WOODED WETLAND AREA
- PRB LOCATION
- FENCE LINE

NOTES

1. BASE MAP DEVELOPED FROM SITE PLAN PROVIDED BY THE CITY OF TECUMSEH, DRAWING NO. CITY.DWG, MARCH 2009.
2. GROUND TOPOGRAPHY BASED OFF 7.5 MINUTE U.S.G.S TOPOGRAPHIC QUADRANGLE MAP AND GROUND SURVEY DATA.



APPROXIMATE HORIZONTAL SCALE

0 300' 600'

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CHECKED BY: SEM		FILE NO. 207339.0000.01.01.dwg
APPROVED BY: GC	DATE PRINTED:	FIGURE 1
DATE: NOVEMBER 2013		

TRC
1540 Eisenhower Place
Ann Arbor, MI 48108
Phone: 734.971.7080
Fax: 734.971.9022

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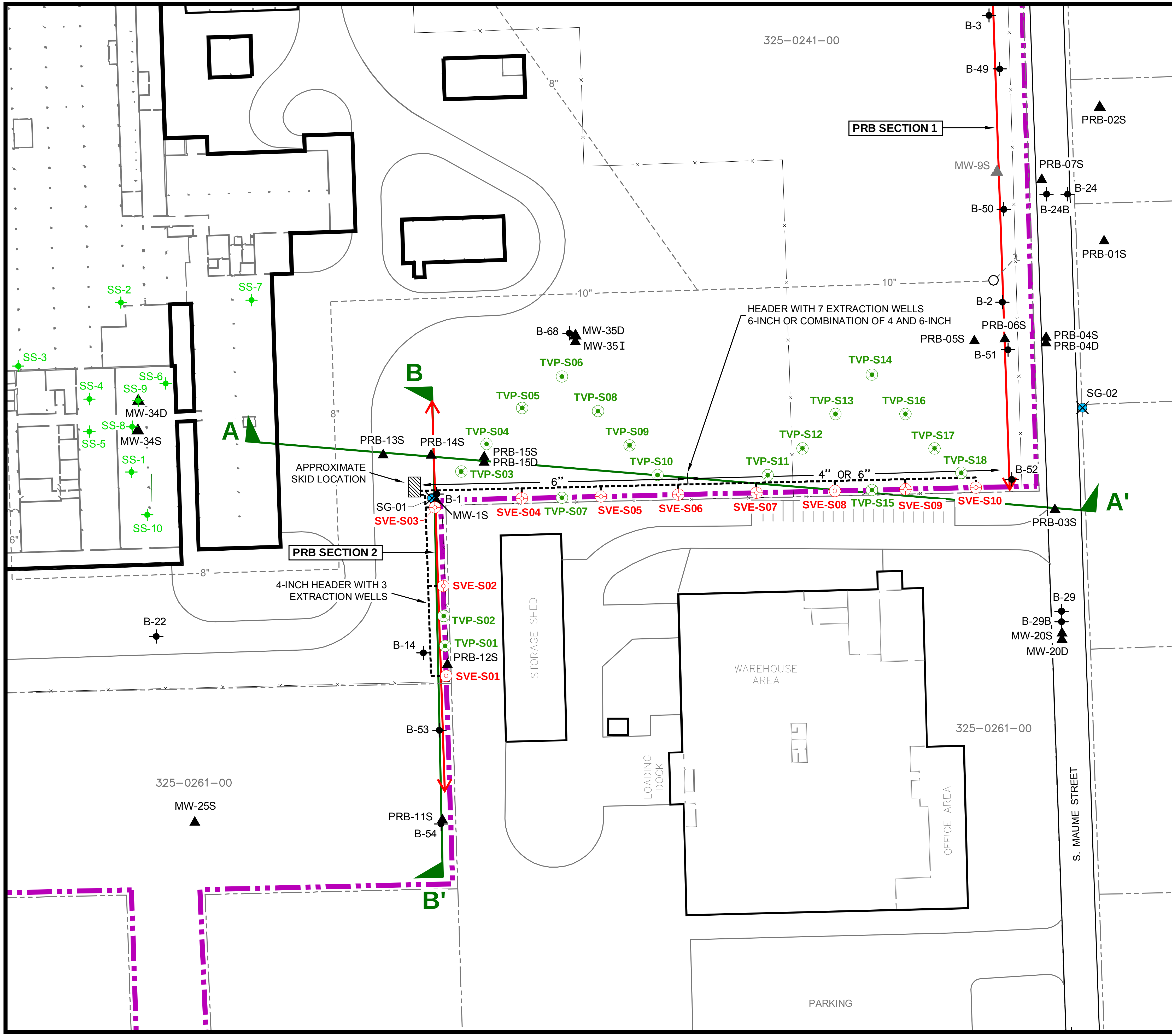

LEGEND

- FORMER TECUMSEH PRODUCTS SITE BOUNDARY
- PARCEL BOUNDARY
- B-54 — PERIMETER / OFF-SITE INVESTIGATION SOIL BORING LOCATION AND NUMBER
- MW-4S — MONITORING WELL LOCATION AND NUMBER
- MW-9S — DECOMMISSIONED MONITORING WELL LOCATION AND NUMBER
- SS-2 — SOURCE AREA INVESTIGATION BORING LOCATION AND NUMBER
- SG-02 — SOIL GAS SAMPLE LOCATION AND NUMBER
- 8" — PIPE DIAMETER AND APPROXIMATE LOCATION OF ON-SITE SANITARY SEWER
- PRB LOCATION
- FENCE LINE
- SVE-S16 — PROPOSED EXTRACTION WELL LOCATION
- TVP-S30 — PROPOSED VACUUM MONITORING POINT LOCATION
- CROSS-SECTION LOCATION

NOTES

1. BASE MAP DEVELOPED FROM SITE PLAN PROVIDED BY THE CITY OF TECUMSEH, DRAWING NO. CITY.DWG, MARCH 2009.
2. GROUND TOPOGRAPHY BASED OFF 7.5 MINUTE U.S.G.S TOPOGRAPHIC QUADRANGLE MAP AND GROUND SURVEY DATA.

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CHECKED BY: SEM	AS INDICATED	FILE NO. 207339.0000.01.02.dwg	
APPROVED BY: GC	DATE PRINTED:	FIGURE 2	
DATE: NOVEMBER 2013			

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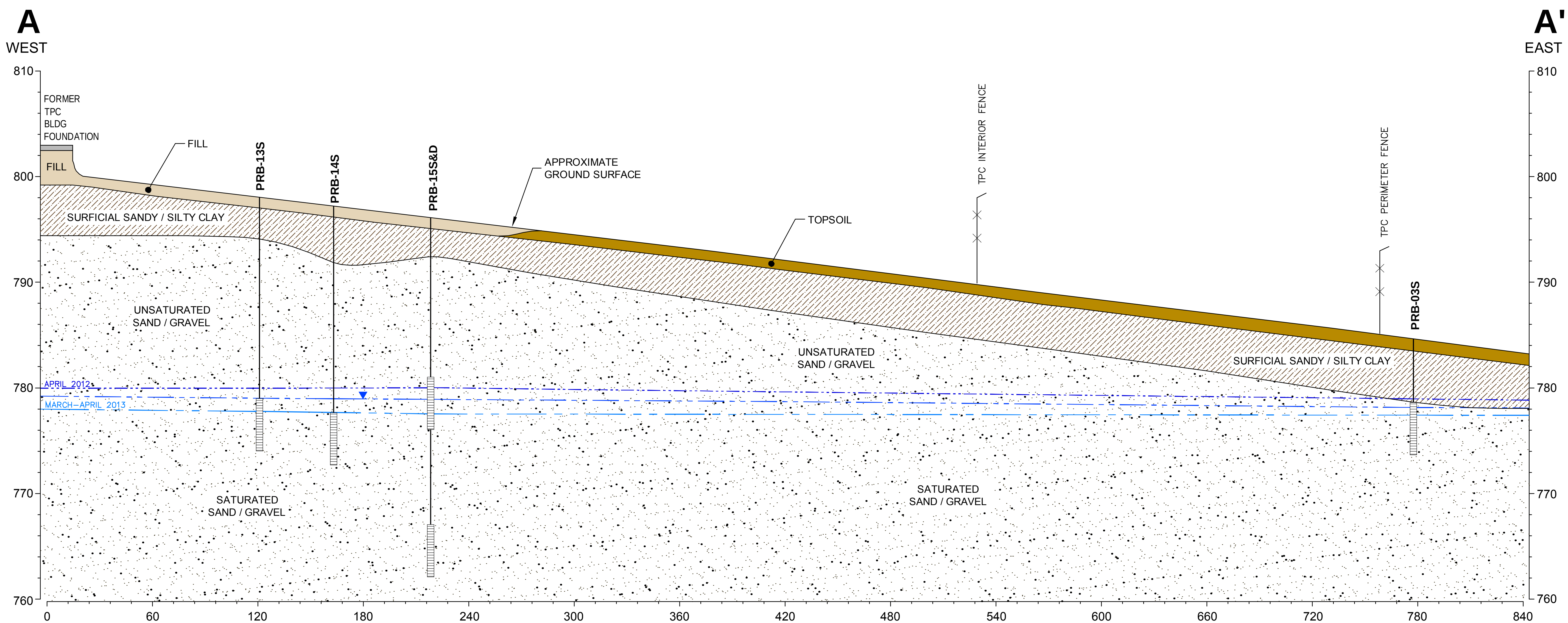
Fax: 734.971.9022



LEGEND

- WELL (MW OR PRB)
- WELL SCREEN
- WATER LEVEL - MAXIMUM
- WATER LEVEL - AVERAGE
- WATER LEVEL - MINIMUM

LITHOGRAPHY KEY

- TOPSOIL
- FILL
- SANDY / SILTY CLAY
- SAND / GRAVEL
- CONCRETE

VERTICAL SCALE IN FEET: 0, 10, 20

HORIZONTAL SCALE IN FEET: 0, 60, 120

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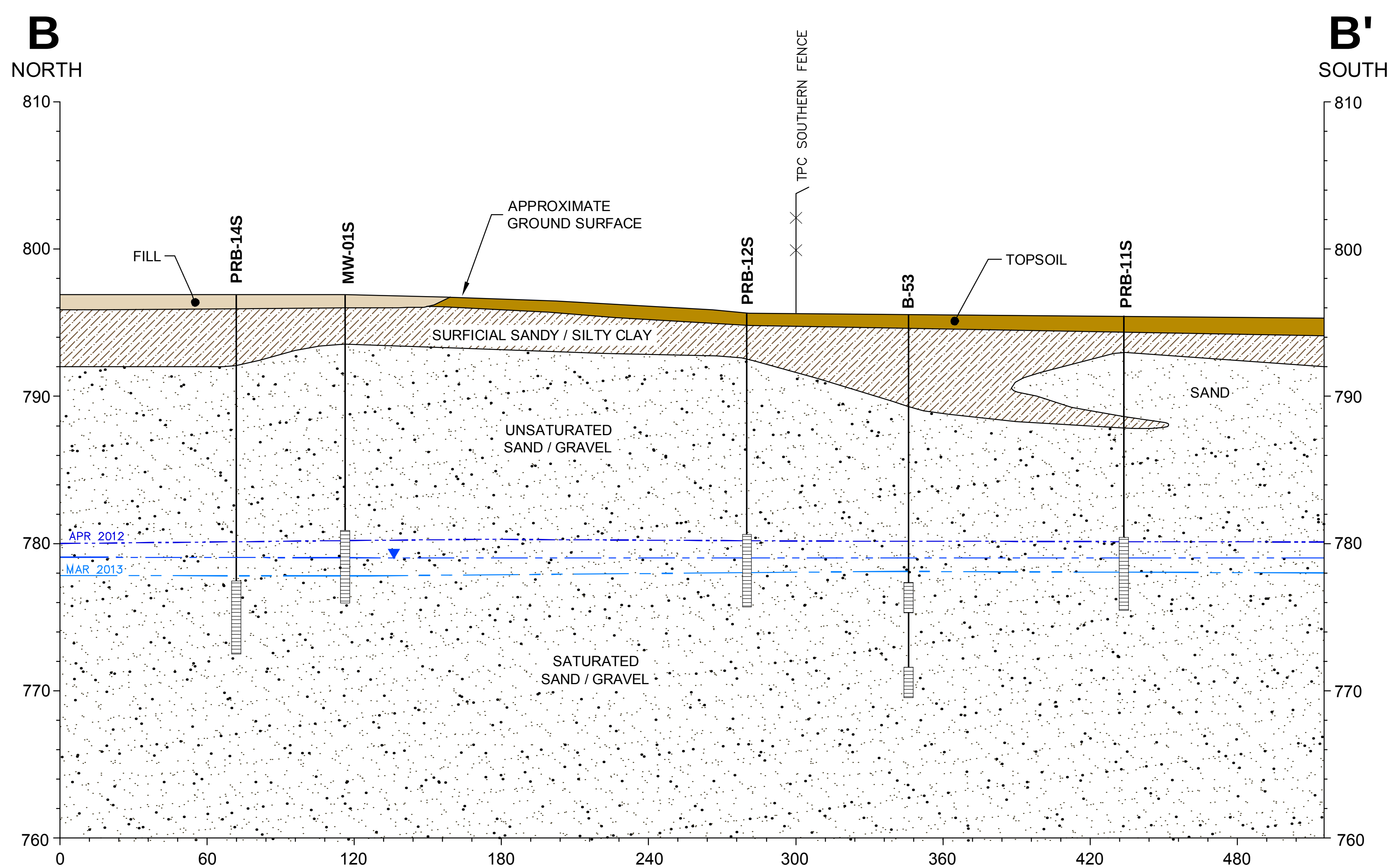

LEGEND

- WELL (MW OR PRB)
- WELL SCREEN
- WATER LEVEL - MAXIMUM
- WATER LEVEL - AVERAGE
- WATER LEVEL - MINIMUM

LITHOGRAPHY KEY

- TOPSOIL
- FILL
- SANDY / SILTY CLAY
- SAND / GRAVEL

VERTICAL SCALE IN FEET: 0, 10, 20

HORIZONTAL SCALE IN FEET: 0, 60, 120

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DATE: NOVEMBER 2013	DATE PRINTED:
	FIGURE 4

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Attached Images:
Layout: BB

Appendix A
Design Drawings

Tecumseh Products Company

Former Tecumseh Products Site

Tecumseh, Michigan

PERIMETER SOIL VAPOR EXTRACTION SYSTEM DESIGN

PREPARED FOR: Tecumseh Products Company
Ann Arbor, Michigan

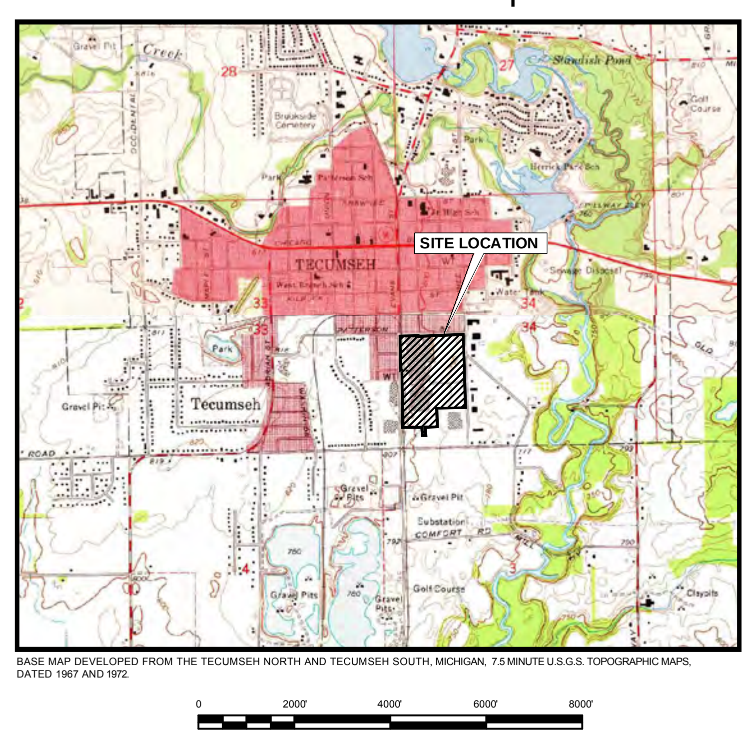
PREPARED BY: TRC Engineers Michigan, Inc.
Ann Arbor, Michigan

DATE: November 2013

Michigan

QUADRANGLE LOCATION

Site Location Map



BASE MAP DEVELOPED FROM THE TECUMSEH NORTH AND TECUMSEH SOUTH, MICHIGAN, 7.5 MINUTE U.S.G.S. TOPOGRAPHIC MAPS, DATED 1967 AND 1972.

Drawing Index

SHEET NUMBER	SHEET TITLE
1	**Title Sheet**
2	**Piping and Instrumentation Diagram Symbol Sheet**
3	**Site Plan**
4	**SVE System Layout (Southern Perimeter)**
5	**SVE System Layout (Northern Perimeter)**
6	**Piping and Instrumentation Diagram**
7	**Details**

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PIPING SYMBOLS (1)

- PIPING
- JACKETED PIPING
- HOT WATER HEAT TRACED AND INSULATED PIPING
- STEAM HEAT TRACED AND INSULATED PIPING
- ELECTRIC HEAT TRACED AND INSULATED PIPING
- INSULATED PIPING
- FLANGED OR UNION CONNECTION
- THREADED OR WELDED CONNECTION
- FLANGE OR UNION
- 1/2 OF FLANGED OR UNION CONNECTION
- PIPE ENDED IN BLIND FLANGE
- PIPE ENDED IN THREADED CAP OR PLUG
- PIPE ENDED IN WELDED CAP OR PLUG
- HOSEBIB
- CONCENTRIC REDUCER OR REDUCING BUSHING
- ECCENTRIC REDUCER OR REDUCING BUSHING WITH FLAT SIDE UP
- ECCENTRIC REDUCER OR REDUCING BUSHING WITH FLAT SIDE DOWN
- VENT
- VENT WITH SCREEN
- PIPE TRAP
- PIPE WITH SPRAY NOZZLES
- PIPE WITH DIFFUSERS
- DRAIN
- SPEC XXXXX / SPEC YYYYY — PIPING SPECIFICATION CHANGE
- A — PIPING CONTINUATION THIS DRAWING
- B SHEET 2 OF 2 — PIPING CONTINUATION ANOTHER DRAWING

VALVE SYMBOLS (2)

- GATE VALVE
- GLOBE VALVE
- ANGLE VALVE
- BALL VALVE
- BUTTERFLY VALVE
- PLUG VALVE
- DIAPHRAGM VALVE
- PINCH VALVE
- NEEDLE VALVE
- CHECK VALVE
- FLOAT OPERATED VALVE WITH FLOAT
- PRESSURE RELIEF VALVE
- VACUUM RELIEF VALVE
- PRESSURE REDUCING VALVE (SELF-CONTAINED)
- BACKPRESSURE VALVE (SELF-CONTAINED)
- 2-WAY SOLENOID VALVE
- 3-WAY SOLENOID VALVE
- QUICK-OPENING VALVE
- STOP CHECK VALVE
- HOSE BIBB
- BACK FLOW PREVENTER
- 3-WAY MANUAL VALVE

SPECIALTY SYMBOLS

- Y-TYPE STRAINER
- TEMPORARY STRAINER
- DIAPHRAGM SEAL
- FLEXIBLE CONNECTOR
- SILENCER
- BAG FILTER
- CARTRIDGE FILTER
- EDUCTOR
- STATIC MIXER
- STATIC MIXER WITH INTEGRAL INJECTION PORT
- PITLESS ADAPTER
- AIR OR GAS FILTER
- SPECTACLE BLIND
- BLIND FLANGE
- RING SPACER
- BLEED RING
- RESTRICTION ORIFICE
- WATER HAMMER ARRESTOR
- PULSATION DAMPENER
- RUPTURE DISC
- MIXING TEE WITH INJECTION QUILL
- QUICK-CONNECT HOSE CONNECTION
- HOSE BARB
- FLEXIBLE HOSE
- FLEXIBLE HOSE WITH QUICK-CONNECT FITTINGS
- FLEXIBLE HOSE WITH THREADED ENDS
- CLAMPED CONNECTION (PIPE-TO-HOSE)
- CLAMPED CONNECTION (HOSE-TO-HOSE)

EQUIPMENT SYMBOLS

- HORIZONTAL CENTRIFUGAL PUMP
- SUMP PUMP
- VERTICAL CENTRIFUGAL PUMP
- SUBMERGED VERTICAL TURBINE PUMP WITH INTEGRAL MOTOR
- CENTRIFUGAL FAN
- CENTRIFUGAL BLOWER
- ROTARY BLOWER OR COMPRESSOR
- ELECTRIC MOTOR
- POSITIVE DISPLACEMENT PROGRESSING CAVITY PUMP

INSTRUMENT LINE SYMBOLS (3)

- INSTRUMENT OR ELECTRIC MOTOR CONNECTION TO PROCESS
- ELECTRIC SIGNAL (ANALOG)
- ELECTRIC BINARY (ON-OFF) SIGNAL
- PNEUMATIC SIGNAL
- PNEUMATIC BINARY (ON-OFF) SIGNAL
- HYDRAULIC SIGNAL
- CAPILLARY TUBE
- ELECTROMAGNETIC OR SONIC SIGNAL (GUIDED)
- ELECTROMAGNETIC OR SONIC SIGNAL (NOT GUIDED)
- INTERNAL SYSTEM LINK (SOFTWARE OR DATA LINK)
- MECHANICAL LINK
- A — INSTRUMENT LINE CONTINUATION THIS DRAWING
- B SHEET 2 OF 2 — INSTRUMENT LINE CONTINUATION ANOTHER DRAWING
- BUBBLE (SINGLE) WITH LEADER
- BUBBLE (DOUBLE) WITH LEADER

TAGGING SYMBOLS

- L-200 — LINE TAG (DEFAULT STYLE)
- L-AAAAB CCC" — LINE TAG - STYLE A
- L-AAAB CC" — LINE TAG - STYLE B
- CC" — LINE TAG - STYLE C
- SL-AAAB CCC" — LINE TAG - STYLE D
- S-200 — SPECIALTY TAG
- V-200 — VALVE TAG

INSTRUMENT PRIMARY ELEMENT SYMBOLS

FLOW ELEMENTS

- FLOW METER
- TURBINE OR PROPELLER TYPE
- MAG — MAGNETIC TYPE
- POSITIVE DISPLACEMENT TYPE
- SONIC (IN-LINE) TYPE
- VORTEX TYPE
- TARGET TYPE (INSERTABLE PITOT TUBE OR HOT WIRE ANEMOMETER)
- ANNUBAR OR AVERAGING PITOT TUBE
- ROTAMETER
- FT — SONIC TYPE (OUTSIDE PIPE)
- FX
- FE
- ORIFICE FLANGE
- S — ELECTRIC SOLENOID VALVE ACTUATOR

TEMPERATURE ELEMENTS

- TW — THERMOWELL

GENERAL SYMBOLS

- AAA — TIE-IN NEW TO EXISTING
- LINE OF SLOPE

INSTRUMENT IDENTIFICATION CHART (3)

	FIRST LETTER		SUCCEEDING LETTERS		
	MEASURED OR INITIATING VARIABLE	MODIFIER TO FIRST LETTER	READOUT OR PASSIVE FUNCTION	OUTPUT FUNCTION	MODIFIER
A	ANALYSIS		ALARM		
B	BURNER, COMBUSTION				
C	USER'S CHOICE			CONTROL	
D	USER'S CHOICE	DIFFERENTIAL			
E	VOLTAGE		SENSOR (PRIMARY ELEMENT)		
F	FLOW RATE	RATIO (FRACTION)			
G	USER'S CHOICE		GLASS, VIEWING DEVICE		
H	HAND				HIGH, OPEN
I	CURRENT (ELECTRICAL)		INDICATE		
J	POWER	SCAN			
K	TIME, TIME SCHEDULE	TIME RATE OF CHANGE		CONTROL STATION	
L	LEVEL		LIGHT		LOW, CLOSED
M	USER'S CHOICE	MOMENTARY			MIDDLE, INTERMEDIATE
N	USER'S CHOICE				
O	USER'S CHOICE		ORIFICE, RESTRICTION		
P	PRESSURE, VACUUM		POINT (TEST) CONNECTION		
Q	QUANTITY	INTEGRATE, TOTALIZE			
R	RADIATION		RECORD		
S	SPEED, FREQUENCY	SAFETY		SWITCH	
T	TEMPERATURE			TRANSMITER OR TRANSDUCER	
U	MULTIVARIABLE		MULTIFUNCTION	MULTIFUNCTION	MULTIFUNCTION
V	VIBRATION, MECHANICAL ANALYSIS			VALVE, DAMPER, LOUVER	
W	WEIGHT, FORCE		WELL		
X	UNCLASSIFIED	X-AXIS	UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED
Y	EVENT, STATE OR PRESENCE	Y-AXIS		RELAY, COMPUTE, CONVERT	
Z	POSITION, DIMENSION	Z-AXIS		DRIVER, ACTUATOR, UNCLASSIFIED FINAL CONTROL ELEMENT	

INSTRUMENT AND FUNCTION SYMBOLS (3)

	LOCALLY MOUNTED	MOUNTED ON PRIMARY CONTROL PANEL (PCP)		MOUNTED ON AUXILIARY CONTROL PANEL (ACP)	
		NORMALLY ACCESSIBLE TO OPERATOR	NORMALLY INACCESSIBLE TO OPERATOR	NORMALLY ACCESSIBLE TO OPERATOR	NORMALLY INACCESSIBLE TO OPERATOR
DISCRETE INSTRUMENTS					
SHARED DISPLAY AND/OR SHARED CONTROL					
COMPUTER FUNCTION					
PROGRAMMABLE OR RELAY LOGIC CONTROL					

TANK SYMBOLS

- VERTICAL TANK CONE TOP-FLAT BOTTOM
- VERTICAL TANK DISHED TOP-DISHED BOTTOM
- VERTICAL TANK DISHED TOP-FLAT BOTTOM
- VERTICAL TANK DISHED TOP-SLOPED BOTTOM
- VERTICAL TANK FLAT TOP-CONE BOTTOM
- VERTICAL TANK FLAT TOP-DISHED BOTTOM
- VERTICAL TANK FLAT TOP-FLAT BOTTOM
- VERTICAL TANK FLAT TOP-SLOPED BOTTOM
- VERTICAL TANK OPEN TOP-CONE BOTTOM
- VERTICAL TANK OPEN TOP-DISHED BOTTOM
- VERTICAL TANK OPEN TOP-FLAT BOTTOM
- VERTICAL TANK OPEN TOP-SLOPED BOTTOM

MISCELLANEOUS INSTRUMENT SYMBOLS

DEFINITIONS OF ABBREVIATIONS

H-O-A	HAND-OFF-AUTOMATIC
ON-OFF	ON-OFF
O-A	OFF-AUTOMATIC

INSTRUMENT DESIGNATION

- AAA — INSTRUMENT IDENTIFICATION
- XXX — LOOP NUMBER (3 DIGITS)
- I — GENERAL INTERLOCK LOGIC

NOTES:

(1) INCLUDES PIPING, TUBING, AND DUCTING.

(2) VALVE SYMBOLS ARE FOR VALVES WITH MANUAL OPERATOR, EXCEPT WHERE A VALVE IS SHOWN WITH A HANDWHEEL EXTENTION OR WITH AN AUTOMATIC OPERATOR.

(3) ADAPTED FROM INSTRUMENT SOCIETY OF AMERICA STANDARD ISA-S5.1-1984 "INSTRUMENT SYMBOLS AND IDENTIFICATION".

NO.	BY	DATE	REVISION	APP'D
3				
2				
1				

PROJ: **PERIMETER VAPOR EXTRACTION SYSTEM DESIGN FORMER TECUMSEH PRODUCTS SITE TECUMSEH, MICHIGAN**

TITLE: **PIPING AND INSTRUMENTATION DIAGRAM SYMBOL SHEET**

DRAWN BY: DGS	SCALE: AS INDICATED	PROJ. NO.	207339.0000.01
CHECKED BY: SEM		FILE NO.	207339.0000.01.02.dwg
APPROVED BY: DM	DATE PRINTED:	SHEET 2 of 7	
DATE: NOVEMBER 2013			

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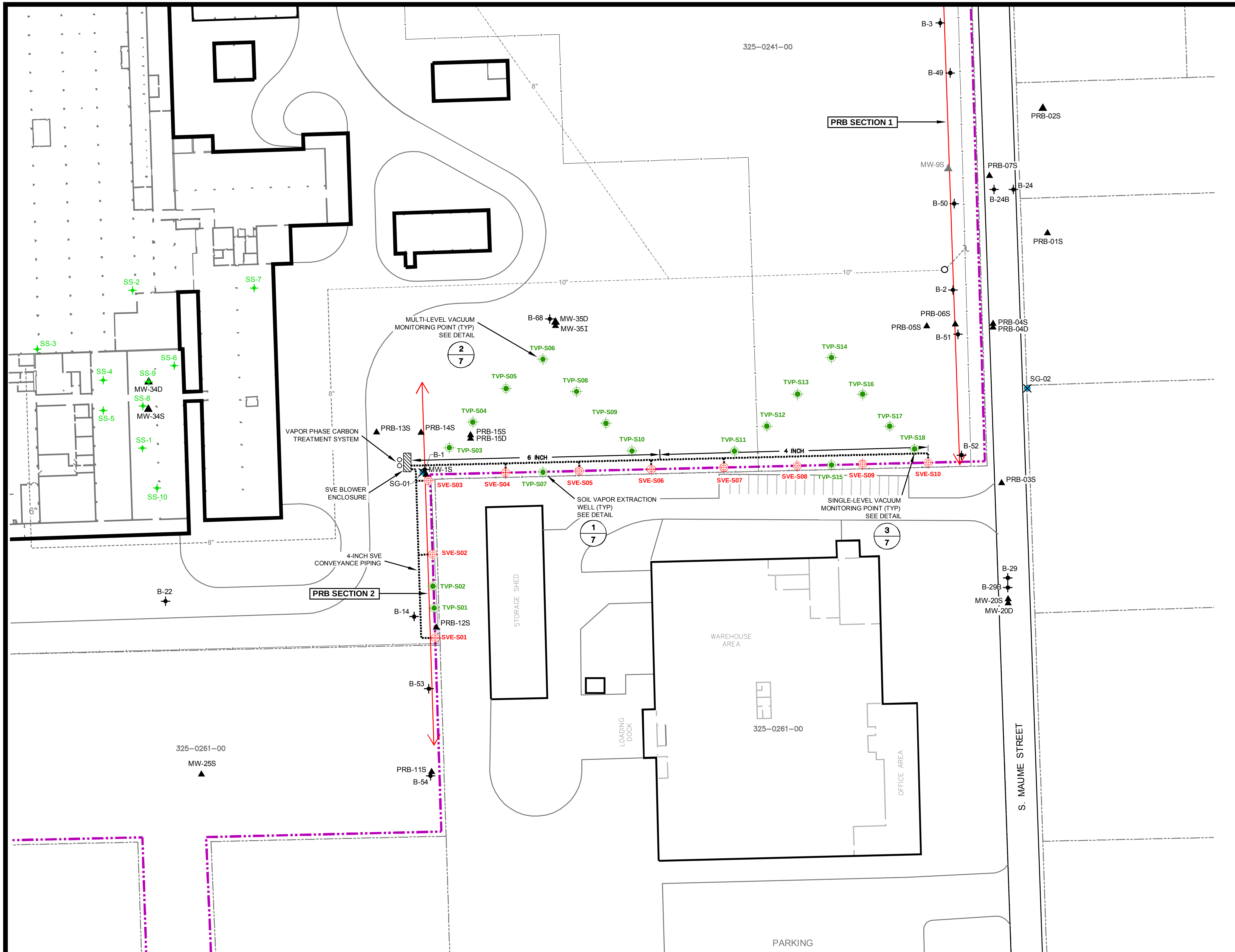

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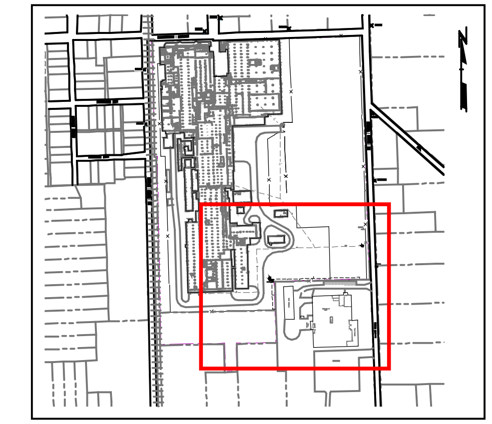

LEGEND

- FORMER TECUMSEH PRODUCTS SITE BOUNDARY
- PARCEL BOUNDARY
- B-54 — PERIMETER / OFF-SITE INVESTIGATION SOIL BORING LOCATION AND NUMBER
- MW-4S — MONITORING WELL LOCATION AND NUMBER
- MW-9S — DECOMMISSIONED MONITORING WELL LOCATION AND NUMBER
- SS-2 — SOURCE AREA INVESTIGATION BORING LOCATION AND NUMBER
- SG-02 — SOIL GAS SAMPLE LOCATION AND NUMBER
- 8" — PIPE DIAMETER AND APPROXIMATE LOCATION OF ON-SITE SANITARY SEWER
- PRB LOCATION
- FENCE LINE
- SVE-S04 — PROPOSED EXTRACTION WELL LOCATION
- TVP-S09 — PROPOSED VACUUM MONITORING POINT LOCATION
- SVE CONVEYANCE PIPING

NOTES

1. BASE MAP DEVELOPED FROM SITE PLAN PROVIDED BY THE CITY OF TECUMSEH, DRAWING NO. CITY.DWG, MARCH 2009.
2. DETAIL NUMBER IDENTIFICATION

3 — DETAIL NUMBER
7 — SHEET NUMBER CROSS REFERENCE

N

0 50 100 150 200
APPROXIMATE SCALE IN FEET

NO.	BY	DATE	REVISION	APP'D
3				
2				
1				

PROJ: **PERIMETER VAPOR EXTRACTION SYSTEM DESIGN**
FORMER TECUMSEH PRODUCTS SITE
TECUMSEH, MICHIGAN

TITLE: **SITE PLAN**

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DATE: NOVEMBER 2013		

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PLOT DATA
Drawing Name: J:_TRC\Tecumseh Products\Tecumseh MI\207339\0000\01_Design Set 2013 Nov\207339.0000.01.03.dwg
Operator Name: STEHLE, DIANAH
Drawing Plot Scale: 0.386863
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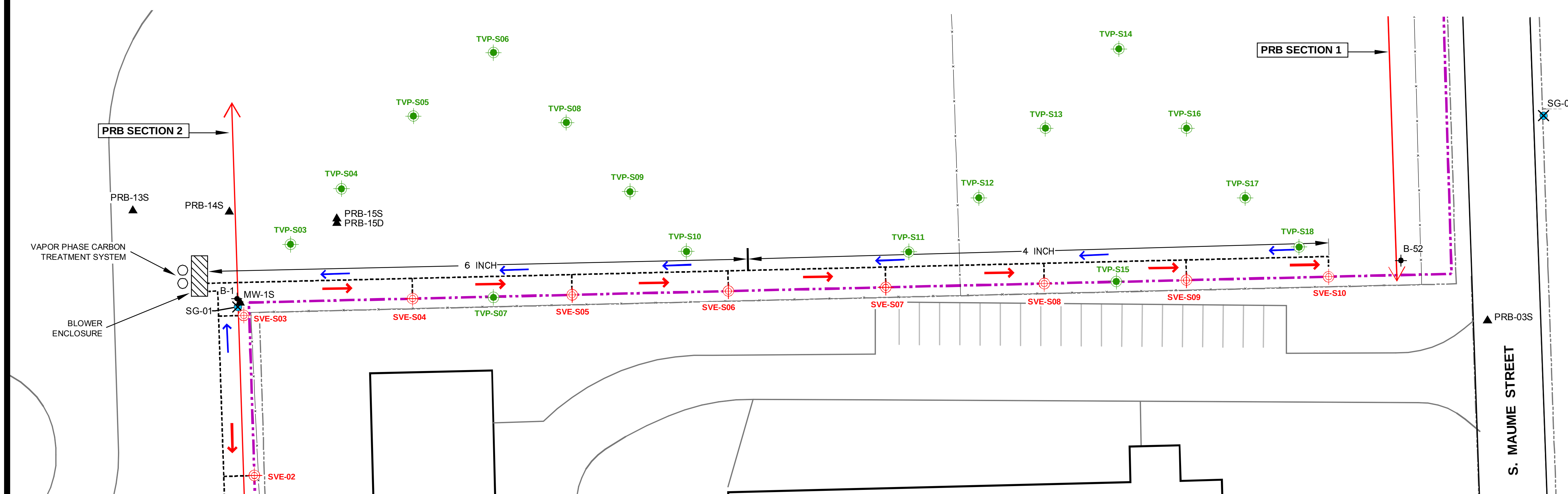
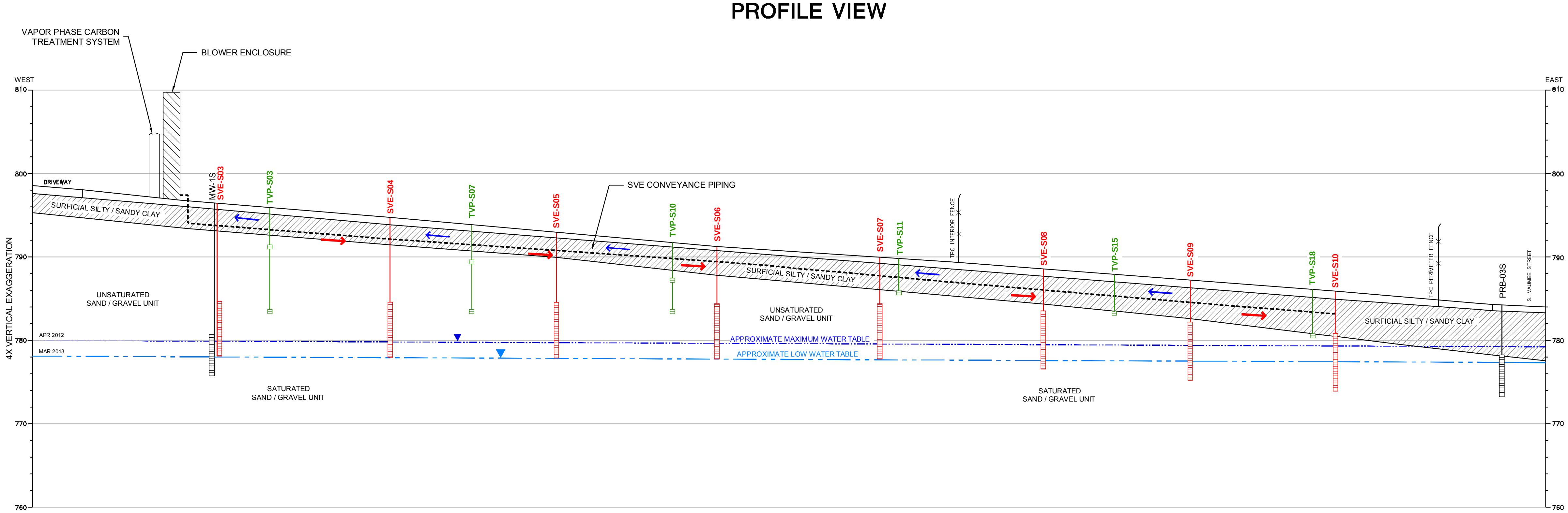
Plot Date: November 22, 2013
Plot Time: 12:03 PM
Attached Xrefs:
Attached Images:
Layout: SHT03 of 07 Site Plan

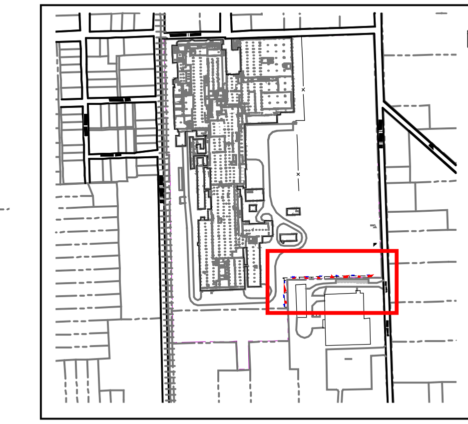
PLAN VIEW



PROFILE VIEW



MAP AREA



LEGEND

- FORMER TECUMSEH PRODUCTS SITE BOUNDARY
- PARCEL BOUNDARY
- B-54 PERIMETER / OFF-SITE INVESTIGATION SOIL BORING LOCATION AND NUMBER
- MW-4S MONITORING WELL LOCATION AND NUMBER
- SG-02 SOIL GAS SAMPLE LOCATION AND NUMBER
- PRB LOCATION
- FENCE LINE
- SVE-S04 PROPOSED EXTRACTION WELL LOCATION
- TVP-S09 PROPOSED VACUUM MONITORING POINT LOCATION
- SVE CONVEYANCE PIPING
- AIR FLOW DIRECTION
- PIPE SLOPE DIRECTION

NOTES

1. BASE MAP DEVELOPED FROM SITE PLAN PROVIDED BY THE CITY OF TECUMSEH, DRAWING NO. CITY.DWG, MARCH 2009.
2. PIPES SLOPED SO THERE IS CONTINUOUS SLOPE DIRECTION FROM HIGH POINT LOCATION (IN EACH RUN FROM EXTRACTION WELL TO MANIFOLD) BACK TOWARDS EXTRACTION WELL.
3. DETAIL NUMBER IDENTIFICATION

1 — DETAIL NUMBER
7 — SHEET NUMBER CROSS REFERENCE

0 30 60 90 120
APPROXIMATE SCALE IN FEET

NO.	BY	DATE	REVISION	APP'D
3				
2				
1				

PROJ: PERIMETER VAPOR EXTRACTION SYSTEM DESIGN
FORMER TECUMSEH PRODUCTS SITE
TECUMSEH, MICHIGAN

TITLE: SVE SYSTEM LAYOUT
(SOUTHERN PERIMETER)

DRAWN BY: DGS	SCALE:	PROJ. NO. 207339.0000.01	
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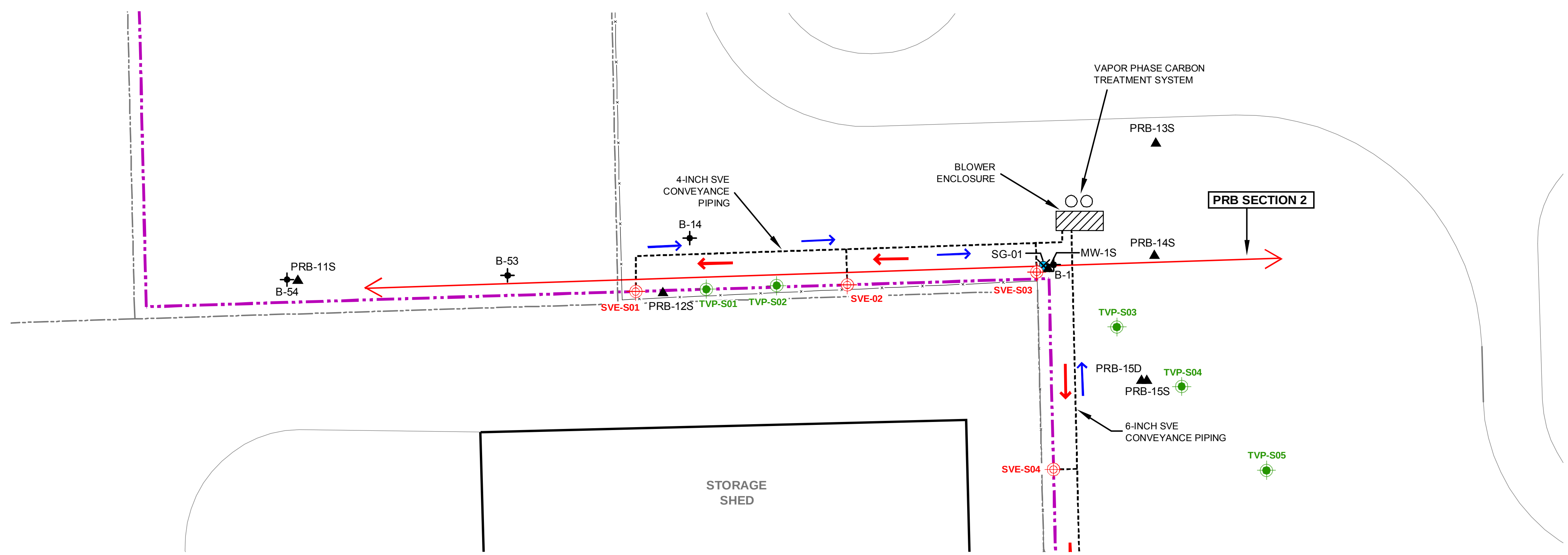
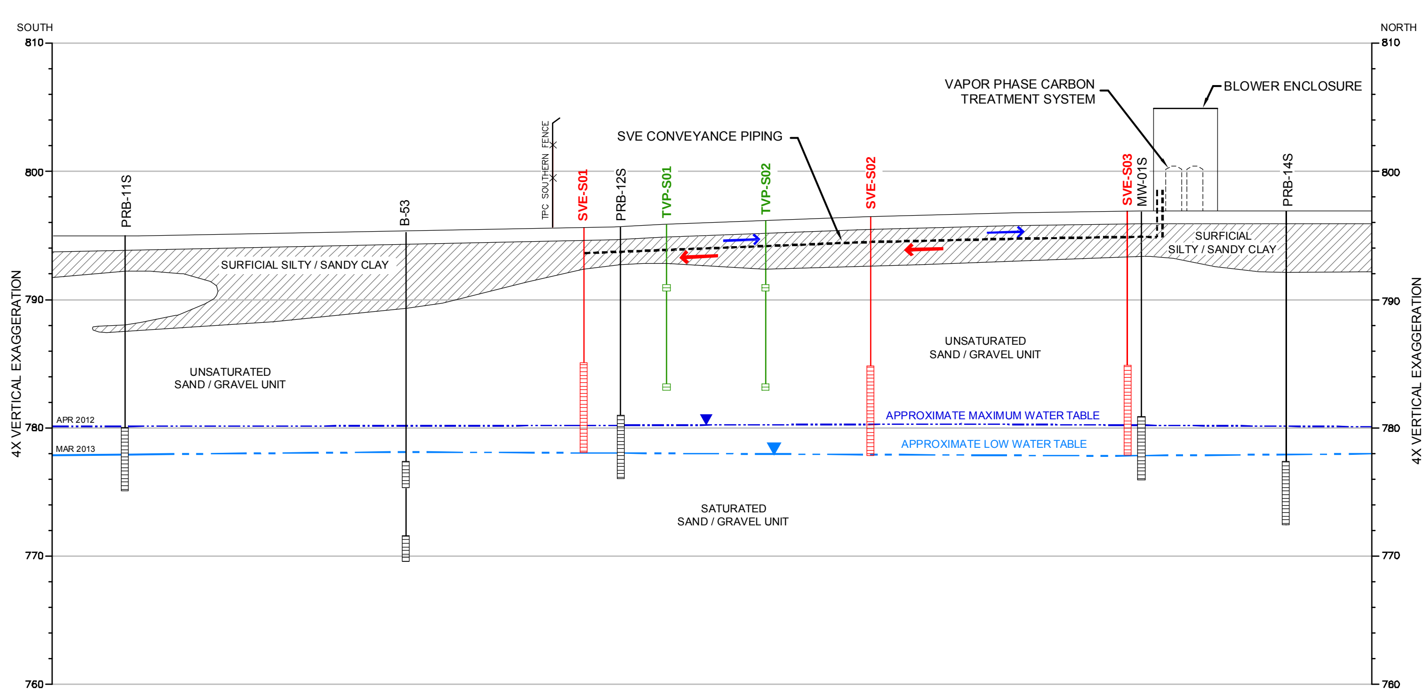
PLAN VIEW



PROFILE VIEW



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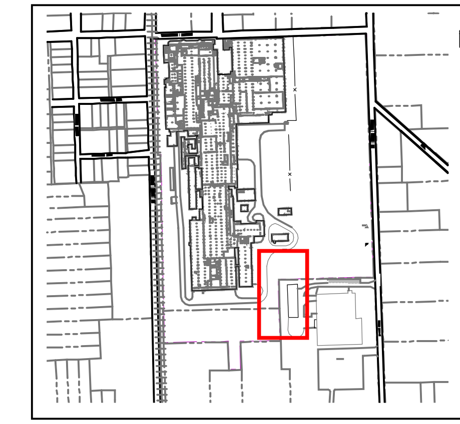

LEGEND

- FORMER TECUMSEH PRODUCTS SITE BOUNDARY
- PARCEL BOUNDARY
- B-54 PERIMETER / OFF-SITE INVESTIGATION SOIL BORING LOCATION AND NUMBER
- MW-4S MONITORING WELL LOCATION AND NUMBER
- SG-02 SOIL GAS SAMPLE LOCATION AND NUMBER
- PRB LOCATION
- FENCE LINE
- SVE-S04 PROPOSED EXTRACTION WELL LOCATION
- TVP-S09 PROPOSED VACUUM MONITORING POINT LOCATION
- SVE CONVEYANCE PIPING
- AIR FLOW DIRECTION
- PIPE SLOPE DIRECTION

NOTES

1. BASE MAP DEVELOPED FROM SITE PLAN PROVIDED BY THE CITY OF TECUMSEH, DRAWING NO. CITY.DWG, MARCH 2009.
2. PIPES SLOPED SO THERE IS CONTINUOUS SLOPE DIRECTION FROM HIGH POINT LOCATION (IN EACH RUN FROM EXTRACTION WELL TO MANIFOLD) BACK TOWARDS EXTRACTION WELL.
3. DETAIL NUMBER IDENTIFICATION

1 — DETAIL NUMBER
7 — SHEET NUMBER CROSS REFERENCE

0 30 60 90 120
APPROXIMATE SCALE IN FEET

NO.	BY	DATE	REVISION	APP'D
3				
2				
1				

PROJ: **PERIMETER VAPOR EXTRACTION SYSTEM DESIGN**
FORMER TECUMSEH PRODUCTS SITE
TECUMSEH, MICHIGAN

TITLE: **SVE SYSTEM LAYOUT**
(NORTHERN PERIMETER)

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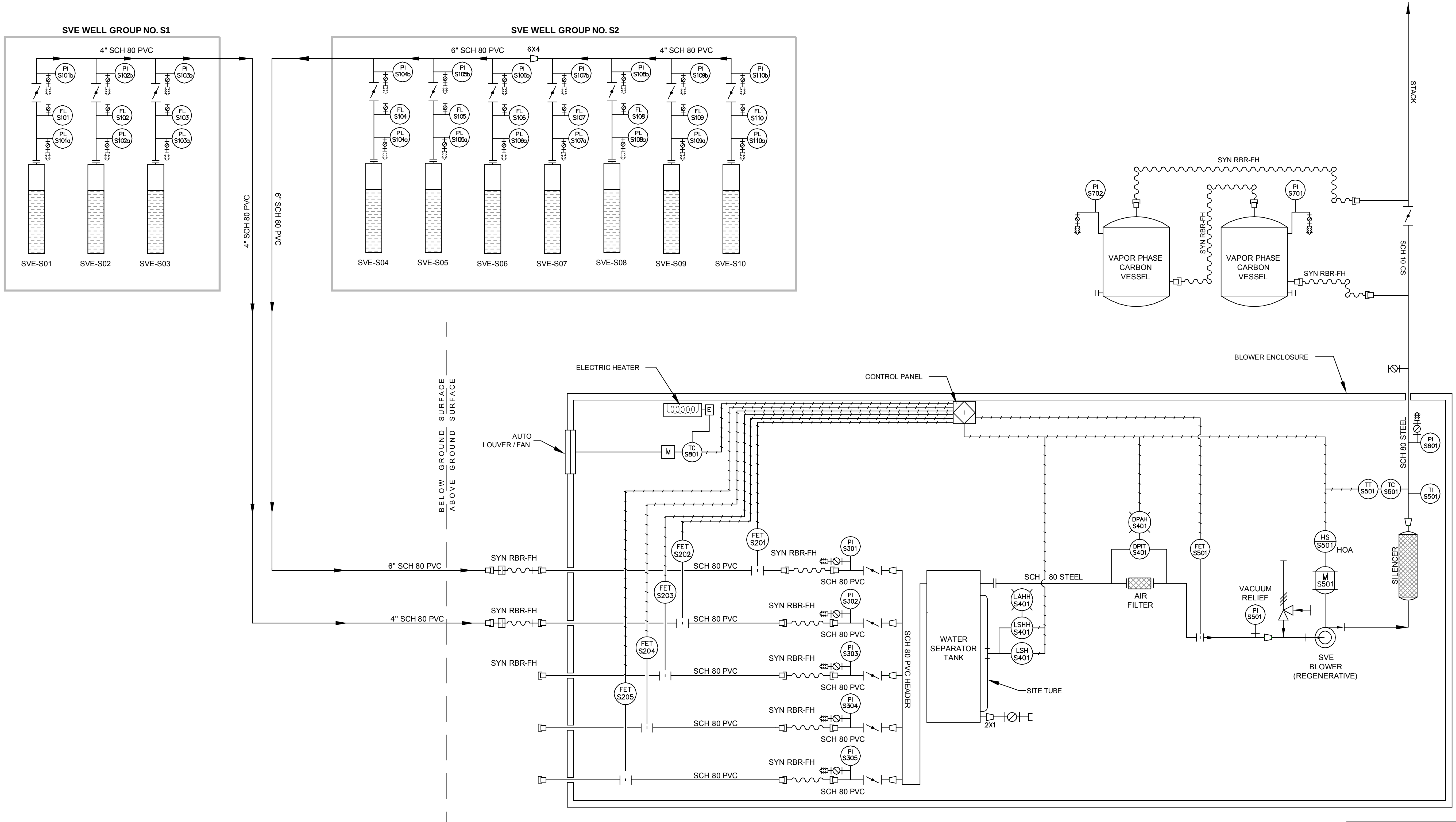

NOTES:

1. SIZE AND MATERIALS OF CONSTRUCTION TO BE DETERMINED AS PART OF THE FINAL DESIGN.

NO.	BY	DATE	REVISION	APP'D
3				
2				
1	DGS	TBD	AS-BUILT	DM

PROJ: **PERIMETER VAPOR EXTRACTION SYSTEM DESIGN**
FORMER TECUMSEH PRODUCTS SITE
TECUMSEH, MICHIGAN

TITLE: **PIPING AND INSTRUMENTATION DIAGRAM**

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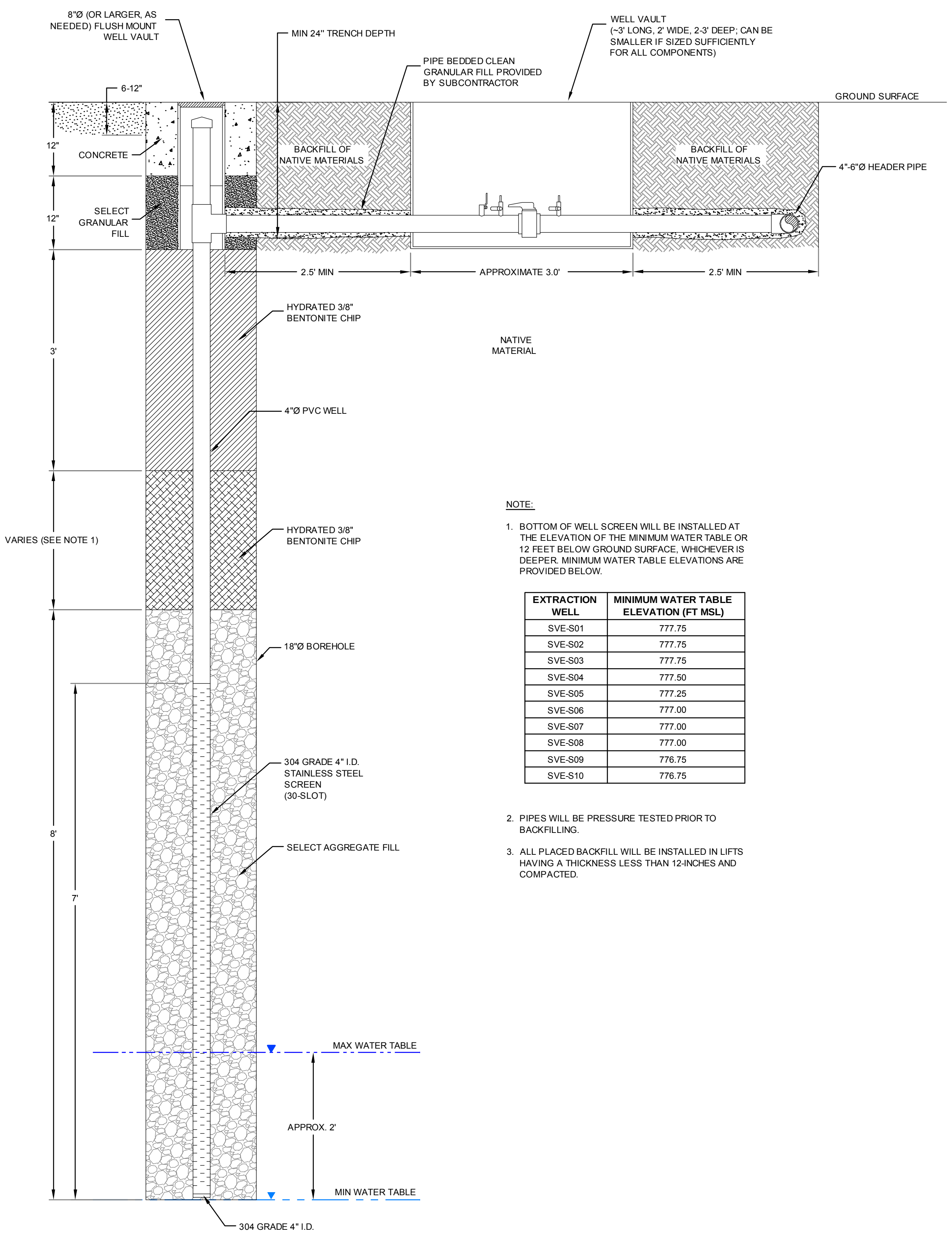


NOTE:

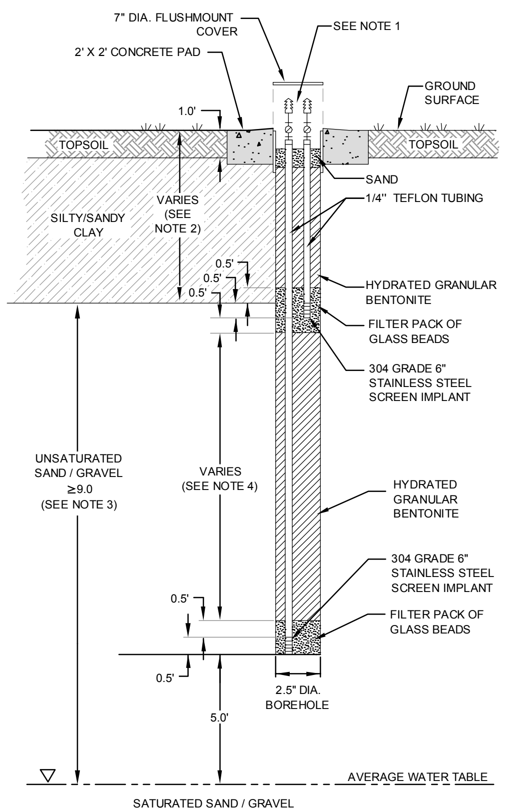
1. BOTTOM OF WELL SCREEN WILL BE INSTALLED AT THE ELEVATION OF THE MINIMUM WATER TABLE OR 12 FEET BELOW GROUND SURFACE, WHICHEVER IS DEEPER. MINIMUM WATER TABLE ELEVATIONS ARE PROVIDED BELOW.

EXTRACTION WELL	MINIMUM WATER TABLE ELEVATION (FT MSL)
SVE-S01	777.75
SVE-S02	777.75
SVE-S03	777.75
SVE-S04	777.50
SVE-S05	777.25
SVE-S06	777.00
SVE-S07	777.00
SVE-S08	777.00
SVE-S09	776.75
SVE-S10	776.75

2. PIPES WILL BE PRESSURE TESTED PRIOR TO BACKFILLING.
3. ALL PLACED BACKFILL WILL BE INSTALLED IN LIFTS HAVING A THICKNESS LESS THAN 12-INCHES AND COMPACTED.

1/3 **SOIL VAPOR EXTRACTION WELL (TYP)**

(NOT TO SCALE)



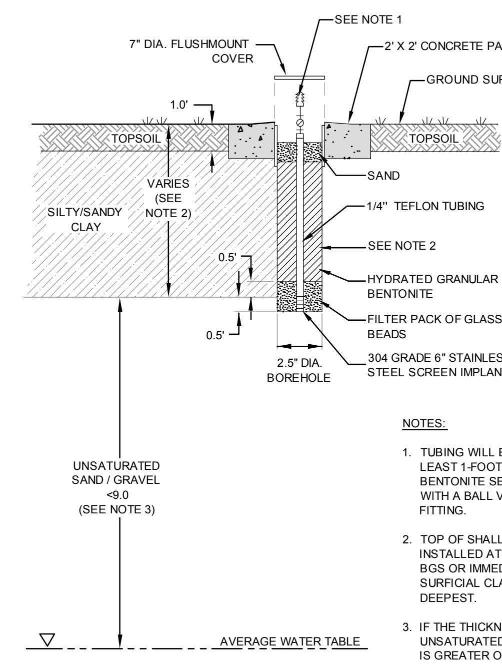
NOTES:

1. TUBING WILL BE CUT TO EXTEND AT LEAST 1-FOOT ABOVE THE BENTONITE SEAL AND EQUIPPED WITH A BALL VALVE AND BARBED FITTING.
2. TOP OF SHALLOW POINT WILL BE INSTALLED AT A DEPTH OF 5 FEET BGS OR IMMEDIATELY BELOW THE SURFICIAL CLAY, WHICHEVER IS DEEPEST.
3. IF THE THICKNESS OF THE UNSATURATED SAND / GRAVEL UNIT IS LESS THAN 9.0 FEET A SINGLE-LEVEL VACUUM MONITORING POINT WILL BE INSTALLED. (SEE DETAIL 3/3)
4. BOTTOM OF DEEP POINT WILL BE INSTALLED APPROXIMATELY 5-FEET ABOVE THE WATER TABLE.TARGET DEPTHS FOR DEEP VACUUM MONITORING POINTS, IF INSTALLED, ARE PROVIDED BELOW.

VACUUM MONITORING POINT	ELEVATION AT TARGET DEPTH (FT MSL)
TVP-S01	784.00
TVP-S02	784.00
TVP-S03	784.00
TVP-S04	784.00
TVP-S05	784.00
TVP-S06	783.75
TVP-S07	783.75
TVP-S08	783.75
TVP-S09	783.75
TVP-S10	783.75
TVP-S11	783.50
TVP-S12	783.50
TVP-S13	783.50
TVP-S14	783.50
TVP-S15	783.50
TVP-S16	783.25
TVP-S17	783.25
TVP-S18	783.25

2/3 **MULTI-LEVEL VACUUM MONITORING POINT (TYP)**

(NOT TO SCALE)



NOTES:

1. TUBING WILL BE CUT TO EXTEND AT LEAST 1-FOOT ABOVE THE BENTONITE SEAL AND EQUIPPED WITH A BALL VALVE AND BARBED FITTING.
2. TOP OF SHALLOW POINT WILL BE INSTALLED AT A DEPTH OF 5 FEET BGS OR IMMEDIATELY BELOW THE SURFICIAL CLAY, WHICHEVER IS DEEPEST.
3. IF THE THICKNESS OF THE UNSATURATED SAND / GRAVEL UNIT IS GREATER OR EQUAL TO 9.0 FEET THEN A MULTI-LEVEL VACUUM MONITORING POINT WILL BE INSTALLED (SEE DETAIL 2/3).

3/3 **SINGLE-LEVEL VACUUM MONITORING POINT (TYP)**

(NOT TO SCALE)

NOTES:

1. DETAIL NUMBER IDENTIFICATION

1 — DETAIL NUMBER
3 — SHEET NUMBER CROSS REFERENCE

NO.	BY	DATE	REVISION	APP'D
3				
2				
1				

PROJ: **PERIMETER VAPOR EXTRACTION SYSTEM DESIGN**
FORMER TECUMSEH PRODUCTS SITE
TECUMSEH, MICHIGAN

TITLE: **DETAILS**

DRAWN BY: WAB/DGS	SCALE: AS INDICATED	PROJ. NO. 207339.0000.01	
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APPROVED BY: DM	DATE PRINTED:	SHEET 7 OF 7	
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Appendix B
Air Flow Calculations

TRC Results you can rely on

Technical Memorandum

Date: September 30, 2013

To: Project File

From: Stacy Metz

cc: Dave McKenzie and Scot Pawlukiewicz

Project No.: 207339.0000, Phase 1

Subject: Perimeter Soil Vapor Extraction Design Calculations – Minimum Air Flow

Goal

Determine the minimum air flow from a perimeter soil vapor extraction (SVE) system required to control the potential volatilization to indoor air migration pathway at adjacent non-residential properties downgradient of the southern source area.

Parameters and Assumptions

- In this area, groundwater is primarily affected by 1,1,1-tricholorethane (TCA) and trichloroethene (TCE).
- Concentrations of TCA and TCE are similar.
- The toxicity of TCE is much greater than the toxicity of TCA. Therefore, mitigating the potential migration of TCE into indoor air will control SVE system design.
- Soil Properties (Default properties for sand in Johnson Ettinger Model Spreadsheet (Version 3.1, 02/2004)
  - Total porosity (n_T) = 0.375
  - Water filled porosity in vadose zone (n_w) = 0.053
  - Air filled porosity in vadose zone (n_a) = 0.322
  - Water filled porosity in capillary zone (θ_w) = 0.253
  - Air filled porosity in capillary zone (θ_a) = 0.122
  - Thickness of capillary zone (L_{cz}) = 17.05 cm

- Chemical Parameters of TCE (from USEPA VISL Calculator)
  - Henry's Law Constant at average groundwater temperature (H'): 0.187
  - Diffusivity in Air (D_a): 0.0687 cm^2/sec
  - Diffusivity in Water (D_w): 0.0000102 cm^2/sec
  - Target TCE concentration in soil gas: <12,000 ug/m^3 (MDEQ non-residential SGSL)
- Site Properties
  - Slab-on-Grade Construction
  - Depth below grade to water table (L_{WT}) = 280 cm
  - Depth below grade to bottom of floor (L_F) = 15 cm (default for slab-on-grade)
  - Average shallow groundwater concentration (C_{GW}) = 931 ug/L
  - Approximate off-site area (A) over which groundwater concentrations exceed 100 ug/L = 128,500 ft^2 (12,000 m^2)

Step 1: Calculate the Effective Diffusivity ($D_{eff\text{-}V}$)of TCE in the Vadose Zone[1].

$$D_{eff-V} = \frac{D_a \times {n_a}^{3.33}}{{n_T}^2} + \left(\frac{D_w}{H'} \times \frac{{n_w}^{3.33}}{{n_T}^2}\right)$$

$$D_{eff-V} = \frac{0.0687\ \frac{cm^2}{s} \times 0.322^{3.33}}{.375^2} + \left(\frac{0.0000102}{0.187} \times \frac{0.053^{3.33}}{0.375^2}\right) = 0.0112\ \frac{cm^2}{s}$$

Step 2: Calculate the Effective Diffusivity ($D_{eff\text{-}cz}$) of TCE in the Capillary Zone.

$$D_{eff-cz} = \frac{D_a \times {\theta_a}^{3.33}}{{n_T}^2} + \left(\frac{D_w}{H'} \times \frac{{\theta_w}^{3.33}}{{n_T}^2}\right)$$

$$D_{eff-cz} = \frac{0.0687\ \frac{cm^2}{s} \times 0.122^{3.33}}{.375^2} + \left(\frac{0.0000102}{0.187} \times \frac{0.253^{3.33}}{0.375^2}\right) = 0.000447\ \frac{cm^2}{s}$$

[1] Calculation taken from Johnson Ettinger Model Spreadsheet (Version 3.1, 02/2004).

Step 3: Calculate the Overall Total Effective Diffusivity ($D_{eff\text{-}T}$) of TCE.

$$D_{eff-T} = \frac{L_{WT} - L_F}{\left(\frac{L_{WT} - L_{cz} - L_F}{D_{eff-V}}\right) + \left(\frac{L_{cz}}{D_{eff-cz}}\right)}$$

$$D_{eff-T} = \frac{280cm - 15cm}{\left(\frac{280\ cm - 17.05\ cm - 15\ cm}{0.0112\ \frac{cm^2}{s}}\right) + \left(\frac{17.05\ cm}{0.000447\ \frac{cm^2}{s}}\right)} = 0.00440\ \frac{cm^2}{s}$$

Step 4: Calculate the Expected Near-Source Concentration in Soil Gas ($C_{SG\text{-}source}$).

$$C_{SG-source} = H' \times C_{GW}$$

$$C_{SG-source} = 0.187 \times 931\ \frac{\mu g}{L} \times \frac{1000\ L}{m^3} = 174{,}000\ \frac{\mu g}{m^3}$$

Step 5: Use Fick's Law to Calculate the Diffusive Flux (J) of TCE to the Building Slab via Soil Gas.

$$J = D_{eff-T} \times \frac{C_{SG-source}}{L_{GW} - L_F}$$

$$J = 0.00440\ \frac{cm^2}{s} \times \frac{174{,}000\ \frac{\mu g}{m^3}}{280\ cm - 15\ cm} \times \frac{1\ m}{100\ cm} = 0.0289\ \frac{\mu g}{m^2 \cdot s}$$

Step 6: Calculate the Mass Flux into Soil Gas at off-site property.

$$Mass\ Flux\ In = J \times A$$

$$Mass\ Flux\ In = 0.0289\ \frac{\mu g}{m^2 \cdot s} \times 12{,}000\ m^2 = 347 \frac{\mu g}{s}$$

Step 7: Calculate the Pore Volume (PV) of Soil Gas Beneath off-site property.

$$PV = A \times [(L_{WT} - L_F - L_{cz}) \times n_a + L_{cz} \times \theta_a]$$

$$PV = 12{,}000\ m^2 \times [(280\ cm - 15\ cm - 17.05\ cm) \times 0.322 + 17.05\ cm \times 0.122] \times \frac{1\ m}{100\ cm}$$

$$PV = 12{,}000\ m^2 \times [79.84\ cm + 2.08\ cm] \times \frac{1\ m}{100\ cm} = 9{,}830\ m^3$$

Step 8: Calculate the Minimum Air Flow ($Q_{air-min}$) beneath the off-site property to achieve the target soil gas concentration ($C_{SG-target}$).

The minimum air flow is calculated by creating a mass balance equation and assuming steady state conditions to achieve the target soil gas concentration.

$$Mass\ Flux\ In - Mass\ Flux\ Out = Accumulation$$

At steady state, accumulation = 0. Therefore

$$Mass\ Flux\ In = Mass\ Flux\ Out$$

$$Mass\ Flux\ In = Q_{air-min} \times C_{SG-target}$$

$$Q_{air-min} = \frac{Mass\ Flux\ In}{C_{SG-target}} = \frac{347\frac{\mu g}{s}}{12{,}000\ \frac{\text{ug}}{m^3}} = 0.0289\frac{m^3}{s} = 61.3\ \frac{ft^3}{min}$$

Step 9: Calculate the Target System Air Flow (Q_{target}).

The target air flow is calculated using the following assumptions:

- Up to 50-percent of the flow is a result of short-circuiting (factor of safety [FS]= 2); and
- The flow regime is symmetric such that approximately half of the flow (excluding short-circuiting) comes from beneath the off-site property and approximately half of the flow comes from on-site (former TPC property), e.g., target flow must be increased by a factor of 2.

$$Q_{target} = Q_{air-min} \times FS \times 2 = 245\ \frac{ft^3}{min}$$

References

VLOOKUP TABLES

SCS Soil Type	K_s (cm/h)	α_1 (1/cm)	N (unitless)	M (unitless)	n (cm^3/cm^3)	θ_r (cm^3/cm^3)	Mean Grain Diameter (cm)	Bulk Density (g/cm^3)	θ_w (cm^3/cm^3)	SCS Soil Name
	Soil Properties Lookup Table									
C	0.61	0.01496	1.253	0.2019	0.459	0.098	0.0092	1.43	0.215	Clay
CL	0.34	0.01581	1.416	0.2938	0.442	0.079	0.016	1.48	0.168	Clay Loam
L	0.50	0.01112	1.472	0.3207	0.399	0.061	0.020	1.59	0.148	Loam
LS	4.38	0.03475	1.746	0.4273	0.390	0.049	0.040	1.62	0.076	Loamy Sand
S	26.78	0.03524	3.177	0.6852	0.375	0.053	0.044	1.66	0.054	Sand
SC	0.47	0.03342	1.208	0.1722	0.385	0.117	0.025	1.63	0.197	Sandy Clay
SCL	0.55	0.02109	1.330	0.2481	0.384	0.063	0.029	1.63	0.146	Sandy Clay Loam
SI	1.82	0.00658	1.679	0.4044	0.489	0.050	0.0046	1.35	0.167	Silt
SIC	0.40	0.01622	1.321	0.2430	0.481	0.111	0.0039	1.38	0.216	Silty Clay
SICL	0.46	0.00839	1.521	0.3425	0.482	0.090	0.0056	1.37	0.198	Silty Clay Loam
SIL	0.76	0.00506	1.663	0.3987	0.439	0.065	0.011	1.49	0.180	Silt Loam
SL	1.60	0.02667	1.449	0.3099	0.387	0.039	0.030	1.62	0.103	Sandy Loam

Johnson Ettinger Model (Version 3.1, 02/2044) Soil Property Look-up Table

INTERMEDIATE CALCULATIONS SHEET

Source-building separation, L_T (cm)	Vadose zone soil air-filled porosity, θ_a^V (cm^3/cm^3)	Vadose zone effective total fluid saturation, S_{te} (cm^3/cm^3)	Vadose zone soil intrinsic permeability, k_i (cm^2)	Vadose zone soil relative air permeability, k_{rg} (cm^2)	Vadose zone soil effective vapor permeability, k_v (cm^2)	Thickness of capillary zone, L_{cz} (cm)	Total porosity in capillary zone, n_{cz} (cm^3/cm^3)	Air-filled porosity in capillary zone, $\theta_{a,cz}$ (cm^3/cm^3)	Water-filled porosity in capillary zone, $\theta_{w,cz}$ (cm^3/cm^3)	Floor-wall seam perimeter, X_{crack} (cm)
265	0.322	0.000	9.92E-08	1.000	9.92E-08	17.05	0.375	0.122	0.253	4,000

Johnson Ettinger Model (Version 3.1, 02/2044) Calculated Soil Properties based on Default Sand Soil Properties

2013 USEPA VISL Calculator - Chemical Properties p. 1 of 3

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
3			**Molecular Weight**		**Vapor Pressure**		**Pure Component Water Solubility**		**MCL**	**Henry's Law Constant @25°C**		**Henry's Law Constant @25°C[g]**	**Henry's Law Constant @ Tgw[g]**	**Henry's Law Constant Used in Calcs**	**Henry's Law Constant @ Tgw_GW[g]**
4			MW		VP		S		(ug/L)	Hc25		H'25	H'Tgw	HLC	H'Tgw_GW
5	**CAS**	**Alphabetized List of Compounds**	(g/mole)	source	(mm Hg)	source	(mg/L)	source		(atm-m^3/mol)	source	(unitless)	(unitless)	(unitless)	(unitless)
152	79-01-6	Trichloroethylene	131.39	a	6.90E+01	b	1.28E+03	a	5	9.85E-03	a	4.03E-01	1.87E-01	1.87E-01	4.03E-01

Temperature Set to 10 Degrees Celsius

NOTE: Values not currently included in the chemical parameter Regional screening table (see footnote a) were derived following the hierarchy outlined in the Regional Screening Tables User's Guide.
Available online at: http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/usersguide.htm

a Based on values reported in the U.S. EPA Regional Screening Tables. June 2013.
Available online at: www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm

b Experimental values. USEPA 2009. Estimation Programs Interface Suite™ for Microsoft® Windows, v 4.00. United States Environmental Protection Agency, Washington, DC, USA.
Available online at: http://www.epa.gov/opptintr/exposure/pubs/episuite.htm

c USEPA 1996. Soil Screening Guidance. Attachment C: Chemical Properties for SSL Development. EPA540/R-96/018. July, 1996.

d USEPA 2001. USEPA WATER9, Version 2.0. United States Environmental Protection Agency, Research Triangle Park, NC, USA.
Available online at: http://www.epa.gov/ttn/chief/software/water/index.html

e Syracuse Research Corporation (SRC). 2005. PHYSPROP Database. SRC. Syracuse, NY.
Available online at: http://www.syrres.com/what-we-do/databaseforms.aspx?id=386

f CRC Handbook of Chemistry and Physics, 76th Edition

g National Institute of Standards and Technology (NIST). Chemistry WebBook.
Available online at: http://webbook.nist.gov/chemistry/

h USEPA, 2001. FACT SHEET Correcting the Henry's Law Constant for Soil Temperature. Attachment.

j Weast, Robert C. CRC Handbook of Chemistry and Physics 1984-1985, 65th edition. Pages F-62 through F-64.

k McKay, D., et al. Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals. Second Edition.

kk Chemical-specific MSDS

m These properties are not used for any calculations in the spreadsheet, but are included to maintain consistency with other spreadsheet tools that do use these properties.

mm The Merck Index, 10th Edition

n United States National Library of Medicine. National Institutes of Health. TOXNET Toxicology Data Network.
Available online at: http://toxnet.nlm.nih.gov/

nn Weiss, G. Hazardous Chemicals Data Book, Second Edition, Noyes Data Corporation, 1986.

p DECHEMA Web Database, March 2003.

q No chemical property information available for this chemical, although toxicity data are available.

r California Environmental Protection Agency. Consumer Products Solvents Database. Entry for "Aromatic 150". 2004.
Available online at: http://www.arb.ca.gov/db/solvents/solvents.htm

s Calculated as average of m-xylene, o-xylene, and p-xylene isomers.

v Approximated using Tcrit = 1.5 x Tboil.

Note the "c" at the end of some sources indicates that the value presented in the table is converted from the value included in the reference source.

2013 USEPA VISL Calculator - Chemical Properties p. 2 of 3

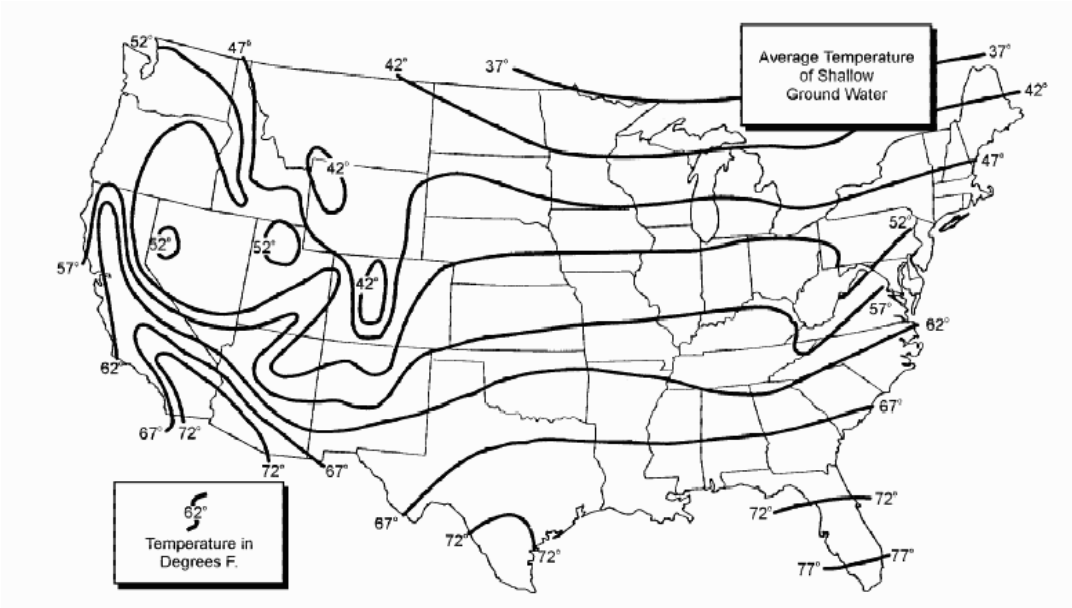
	A	B	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF
3			Henry's Law Constant Used in Calcs for GW-IA_calc	Vapor Pressure @ Tgw[g]	Diffusivity in air [m]		Diffusivity in water [m]		Normal Boiling Point		Critical Temperature		Enthalpy of vaporization at the normal boiling point		Organic Carbon Partition Coefficient [m]		Lower Explosive Limit		
4			HLC_GW	VPTgw	Da		Dw		Tboil		Tcrit		$DH_{v,b}$		Koc		LEL		
5	CAS	Alphabetized List of Compounds	(unitless)	(ug/m3)	(cm^2/s)	source	(cm^2/s)	source	(^oK)	source	(^oK)	source	(cal/mol)	source	(cm^3/g)	source	(% by vol)	source	
152	79-01-6	Trichloroethylene	4.03E-01	2.27E+08	6.87E-02	a	1.02E-05	a	3.60E+02	b	5.44E+02	h	7.51E+03	h	6.07E+01	a	8	N	

168		
169	NOTE:	Values not currently included in the chemical parameter Regional screening table (see footnote a) were derived following the hierarchy outlined in the Regional Scre
170		Available online at: http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/usersguide.htm
171		
172	a	Based on values reported in the U.S. EPA Regional Screening Tables. May 2013.
173		Available online at: www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm
174	b	Experimental values. USEPA 2009. Estimation Programs Interface Suite™ for Microsoft® Windows, v 4.00. United States Environmental Protection Agency, Washin
175		Available online at: http://www.epa.gov/opptintr/exposure/pubs/episuite.htm
176	c	USEPA 1996. Soil Screening Guidance. Attachment C: Chemical Properties for SSL Development. EPA540/R-96/018. July, 1996.
177	d	USEPA 2001. USEPA WATER9, Version 2.0. United States Environmental Protection Agency, Research Triangle Park, NC, USA.
178		Available online at: http://www.epa.gov/ttn/chief/software/water/index.html
179	e	Syracuse Research Corporation (SRC). 2005. PHYSPROP Database. SRC. Syracuse, NY.
180		Available online at: http://www.syrres.com/what-we-do/databaseforms.aspx?id=386
181	f	CRC Handbook of Chemistry and Physics, 76th Edition
182	g	National Institute of Standards and Technology (NIST). Chemistry WebBook.
183		Available online at: http://webbook.nist.gov/chemistry/
184	h	USEPA, 2001. FACT SHEET Correcting the Henry's Law Constant for Soil Temperature. Attachment.
185	j	Weast, Robert C. CRC Handbook of Chemistry and Physics 1984-1985, 65th edition. Pages F-62 through F-64.
186	k	McKay, D., et al. Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals. Second Edition.
187	kk	Chemical-specific MSDS
188	m	These properties are not used for any calculations in the spreadsheet, but are included to maintain consistency with other spreadsheet tools that do use these prope
189	mm	The Merck Index, 10th Edition
190	n	United States National Library of Medicine. National Institutes of Health. TOXNET Toxicology Data Network.
191		Available online at: http://toxnet.nlm.nih.gov/
192	nn	Weiss, G. Hazardous Chemicals Data Book, Second Edition, Noyes Data Corporation, 1986.
193	p	DECHEMA Web Database, March 2003.
194	q	No chemical property information available for this chemical, although toxicity data are available.
195	r	California Environmental Protection Agency. Consumer Products Solvents Database. Entry for "Aromatic 150". 2004.
196		Available online at: http://www.arb.ca.gov/db/solvents/solvents.htm
197	s	Calculated as average of m-xylene, o-xylene, and p-xylene isomers.
198	v	Approximated using Tcrit = 1.5 x Tboil.
199		Note the "c" at the end of some sources indicates that the value presented in the table is converted from the value included in the reference source.

2013 USEPA VISL Calculator - Chemical Properties p. 1 of 3

	A	B		AG
3				
4				
5	**CAS**	**Alphabetized List of Compounds**		**Alternative Chemical Name 1**
152	79-01-6	Trichloroethylene		
168				
169			NOTE:	:ning Tables User's Guide.
170				
171				
172			a	
173				
174			b	ıgton, DC, USA.
175				
176			c	
177			d	
178				
179			e	
180				
181			f	
182			g	
183				
184			h	
185			j	
186			k	
187			kk	
188			m	'ties
189			mm	
190			n	
191				
192			nn	
193			p	
194			q	
195			r	
196				
197			s	
198			v	
199				

http://www.epa.gov/athens/learn2model/part-two/onsite/ex/jne_henrys_map.html



WCMS
Last updated on Thursday, January 10, 2013

Target Soil Gas Concentration for TCE

INDOOR AIR, SOIL GAS, GROUNDWATER, AND SOIL SCREENING VALUES FOR THE VAPOR INTRUSION PATHWAY

NONRESIDENTIAL LAND USE

Hazardous Substance (a)	Chemical Abstract Service Number	INDOOR AIR		SOIL GAS				GROUNDWATER				SOIL	
		Vapor Intrusion Indoor Air Screening Levels (b)		Vapor Intrusion Shallow Soil Gas (sub-slab) Screening Levels (b) (Samples collected less than or equal to 1.5 meters bgs or building foundation)		Vapor Intrusion Deep Soil Gas Screening Levels (b)		Vapor Intrusion Groundwater Screening Levels (d,t)		Vapor Intrusion Shallow Groundwater Screening Levels (d,t)		Vapor Intrusion Soil Screening Levels (t)	
		$IA_{VI\text{-}nr}$		$SG_{VI\text{-}SS\text{-}nr}$		$SG_{VI\text{-}nr}$		$GW_{VI\text{-}nr}$		$GW_{VI\text{-}sump\text{-}nr}$		$S_{VI\text{-}nr}$	
		(ug/m^3)	(ppbv) (c)	(ug/m^3)	(ppbv) (c)	(ug/m^3)	(ppbv) (c)	(ug/L)		(ug/L)		(ug/kg)	
1,2,4,5-Tetrachlorobenzene	95943	4.40E+00	4.70E-01	5.80E+02	6.30E+01	5.80E+03	6.30E+02	2.00E+02		2.00E+00	t	1.39E+04	
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746016	3.10E-06	2.20E-07	4.10E-04	3.00E-05	4.10E-03	3.00E-04	2.90E-03		3.00E-05	d	7.30E+01	
1,1,1,2-Tetrachloroethane	630206	1.80E+01	2.60E+00	2.50E+03	3.40E+02	2.50E+04	3.40E+03	3.50E+02		1.00E+00	t	2.92E+02	
1,1,2,2-Tetrachloroethane	79345	2.40E+00	3.30E-01	3.10E+02	4.30E+01	3.10E+03	4.30E+02	3.00E+02		1.00E+00	t	2.30E+02	
Tetrachloroethylene	127184	1.80E+02	2.50E+01	2.30E+04	3.30E+03	2.30E+05	3.30E+04	4.60E+02		5.00E+00	d	1.03E+03	
Tetrahydrofuran	109999	7.90E+01	2.50E+01	1.10E+04	3.40E+03	1.10E+05	3.40E+04	5.20E+04		9.00E+01	t	1.14E+04	
Tetranitromethane	509148	9.10E-03	1.10E-03	1.20E+00	1.40E-01	1.20E+01	1.40E+00	1.00E+02	t	1.00E+02	t	5.00E+02	t
Toluene	108883	2.20E+04	5.50E+03	2.90E+06	7.40E+05	2.90E+07	7.40E+06	1.50E+05		1.00E+03	d	1.69E+05	
Tributylamine	102829	3.10E+01	3.80E+00	4.10E+03	5.10E+02	4.10E+04	5.10E+03	8.90E+03		8.90E+00		ID	
1,2,3-Trichlorobenzene	87616	1.20E+02	1.50E+01	1.60E+04	2.00E+03	1.60E+05	2.00E+04	4.40E+03		5.00E+00	t	7.58E+04	
1,2,4-Trichlorobenzene	120821	1.80E+01	2.20E+00	2.30E+03	3.00E+02	2.30E+04	3.00E+03	5.70E+02		7.00E+01	d	5.86E+03	
1,1,1-Trichloroethane	71556	2.60E+04	4.60E+03	3.50E+06	6.10E+05	3.50E+07	6.10E+06	7.10E+04		2.00E+02	d	6.66E+04	
1,1,2-Trichloroethane	79005	8.50E+00	1.50E+00	1.10E+03	2.00E+02	1.10E+04	2.00E+03	4.80E+02		5.00E+00	d	3.65E+02	
Trichloroethylene (e)	79016	8.80E+00	1.50E+00	1.20E+03	2.10E+02	1.20E+04	2.10E+03	4.10E+01		5.00E+00	d	5.00E+01	t
Trichlorofluoromethane	75694	2.50E+05	4.20E+04	3.30E+07	5.60E+06	3.30E+08	5.60E+07	1.20E+05		1.20E+02		1.18E+05	
1,1,2-Trichloro-1,2,2-trifluoroethane	76131	8.50E+04	1.10E+04	1.10E+07	1.40E+06	1.10E+08	1.40E+07	7.50E+03		7.50E+00		3.41E+04	
2,2,4-Trimethyl pentane	540841	1.50E+04	3.10E+03	2.00E+06	4.20E+05	2.00E+07	4.20E+06	2.30E+02		5.00E+01	t	4.30E+03	
1,2,3-Trimethylbenznene	526738	9.60E+02	1.90E+02	1.30E+05	2.50E+04	1.30E+06	2.50E+05	1.00E+04		1.00E+01		5.35E+04	
1,2,4-Trimethylbenzene	95636	9.60E+02	1.90E+02	1.30E+05	2.50E+04	1.30E+06	2.50E+05	7.30E+03		7.30E+00		3.69E+04	
1,3,5-Trimethylbenzene	108678	9.60E+02	1.90E+02	1.30E+05	2.50E+04	1.30E+06	2.50E+05	5.10E+03		5.10E+00		2.79E+04	
tris(2,3-Dibromopropyl)phosphate	126727	2.60E-01	8.60E-03	3.40E+01	1.10E+00	3.40E+02	1.10E+01	5.50E+02		1.00E+01	t	4.28E+04	
Vinyl acetate	108054	8.80E+02	2.40E+02	1.20E+05	3.20E+04	1.20E+06	3.20E+05	8.00E+04		1.00E+02	t	1.44E+04	
Vinyl chloride (f)	75014	3.10E+01	1.20E+01	4.10E+03	1.50E+03	4.10E+04	1.50E+04	5.20E+01		2.00E+00	d	4.00E+01	t
Xylenes	1330207	4.40E+02	9.60E+01	5.80E+04	1.30E+04	5.80E+05	1.30E+05	1.00E+04	d	1.00E+04	d	4.89E+03	

Footnotes:

a) Part 201 hazardous substances without inhalation toxicity values at this time are not included in this table.

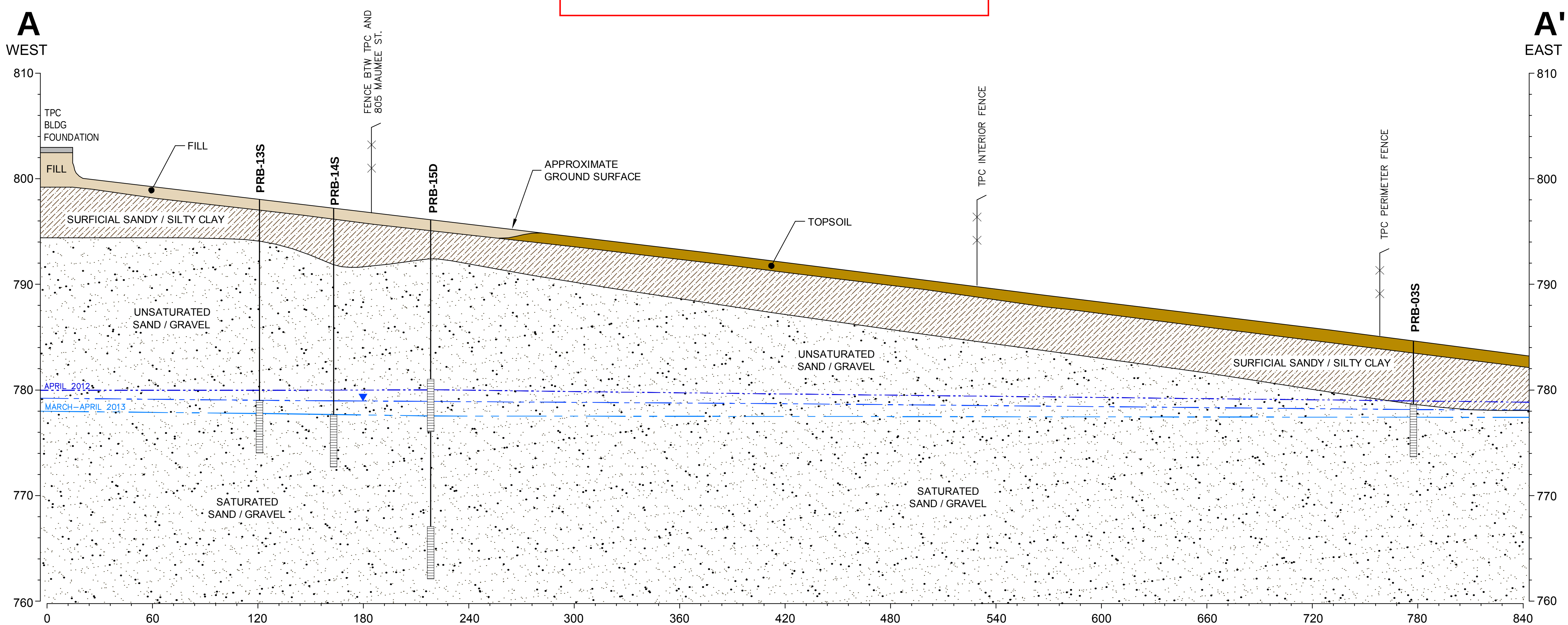
b) The IAVI and SGVI presented in this table are health-based values. The applicable IAVI and SGVI are based on the higher of the health-based value and the appropriate analytical reporting limit.

c) Conversion from ug/m^3 to parts per billion by volume (ppbv) uses this equation: ppbv = ([ug/m^3] x (283.15ºK)) / (12.187 x Molecular Weight(g/mol))

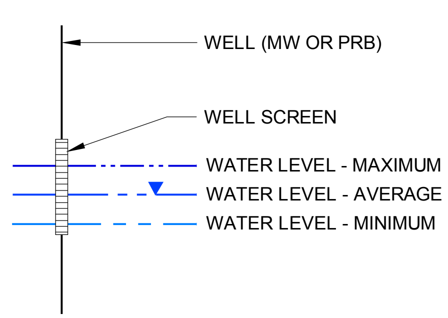
d) If the calculated criterion is below State of Michigan Safe Drinking Water Standard established pursuant to Section 5 of 1976 PA 399, MCL 325.1005, the criterion defaults to the Safe Drinking Water Standard.

Prepared by Remediation and Redevelopment Division
-Toxicology Unit 5/23/2013

Cross-Section along Southern Site Perimeter which illustrates surface elevation and water table elevation



LEGEND



LITHOGRAPHY KEY

- TOPSOIL
- FILL
- SANDY / SILTY CLAY
- SAND / GRAVEL
- CONCRETE

VERTICAL SCALE IN FEET: 0, 10, 20

HORIZONTAL SCALE IN FEET: 0, 60, 120

PROJECT: **FORMER TECUMSEH PRODUCTS SITE TECUMSEH, MICHIGAN**

SHEET TITLE: **CROSS-SECTION A-A'**

DRAWN BY: DGS	SCALE:	PROJ. NO.	203342.0001.03
CHECKED BY: SEM	AS INDICATED	FILE NO.	203342.0001.03.XSs.dwg
APPROVED BY: GC	DATE PRINTED:	**FIGURE 3**	
DATE: NOVEMBER 2013			

TRC
1540 Eisenhower Place
Ann Arbor, MI 48108
Phone: 734.971.7080
Fax: 734.971.9022

PLOT DATA
Drawing Name: J:_TRC\Tecumseh Products\Tecumseh MI\203342\0001\03_Workplan\203342.0001.03.XSs.dwg
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Dwg Size: 0.65 Mb
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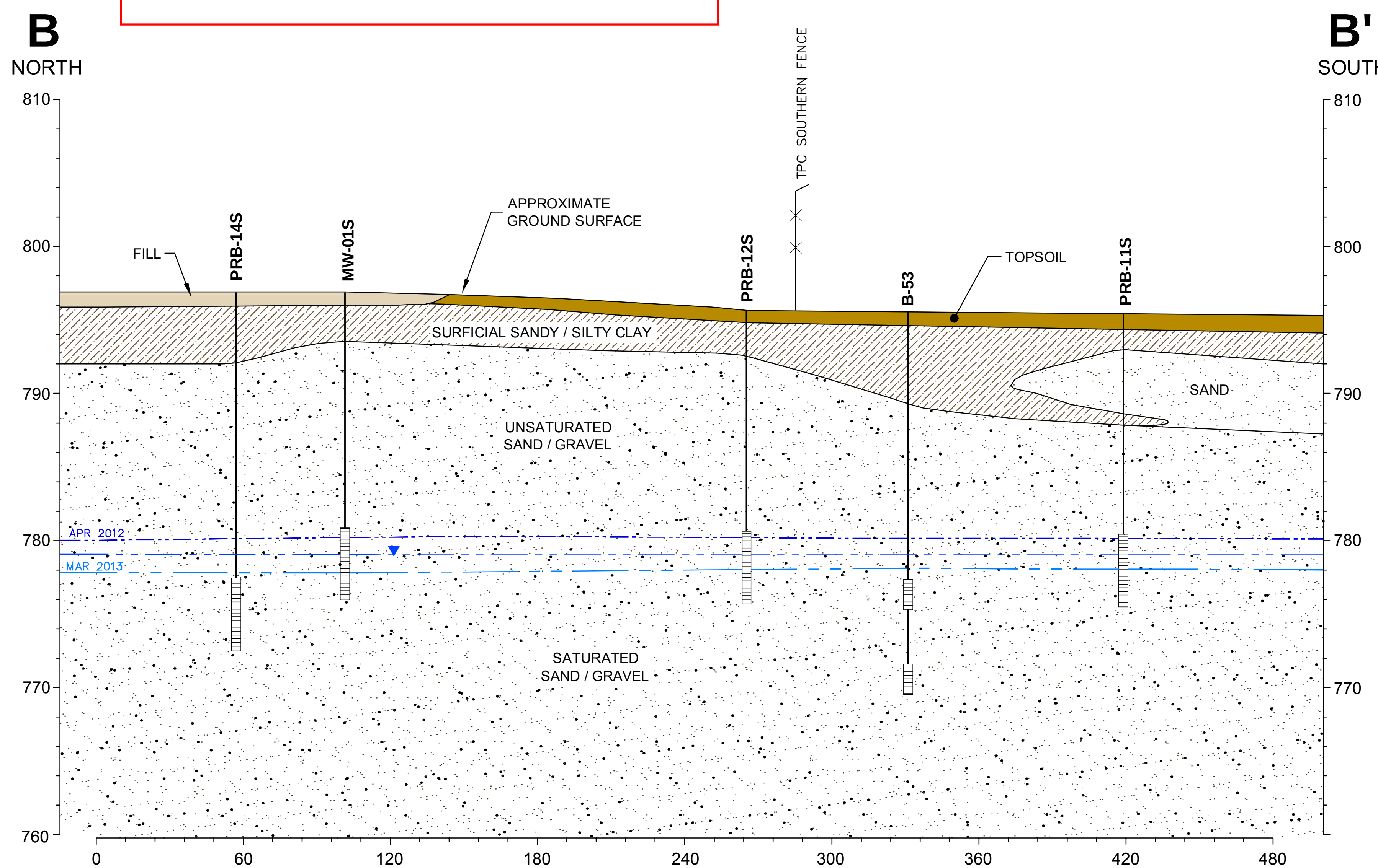
Plot Time: 11:58 AM
Attached Xrefs:
Attached Images:
Layout: AA

Cross-Section along Eastern Site Perimeter which illustrates surface elevation and water table elevation



LEGEND

- WELL (MW OR PRB)
- WELL SCREEN
- WATER LEVEL - MAXIMUM
- WATER LEVEL - AVERAGE
- WATER LEVEL - MINIMUM

LITHOGRAPHY KEY

- TOPSOIL
- FILL
- SANDY / SILTY CLAY
- SAND / GRAVEL

VERTICAL SCALE IN FEET: 0, 10, 20

HORIZONTAL SCALE IN FEET: 0, 60, 120

PROJECT: FORMER TECUMSEH PRODUCTS SITE TECUMSEH, MICHIGAN			
SHEET TITLE: CROSS-SECTION B-B'			
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CHECKED BY: SEM		FILE NO. 203342.0001.03.XSs.dwg	
APPROVED BY: GC	DATE PRINTED:	FIGURE 4	
DATE: NOVEMBER 2013			

TRC
1540 Eisenhower Place
Ann Arbor, MI 48108
Phone: 734.971.7080
Fax: 734.971.9022

PLOT DATA
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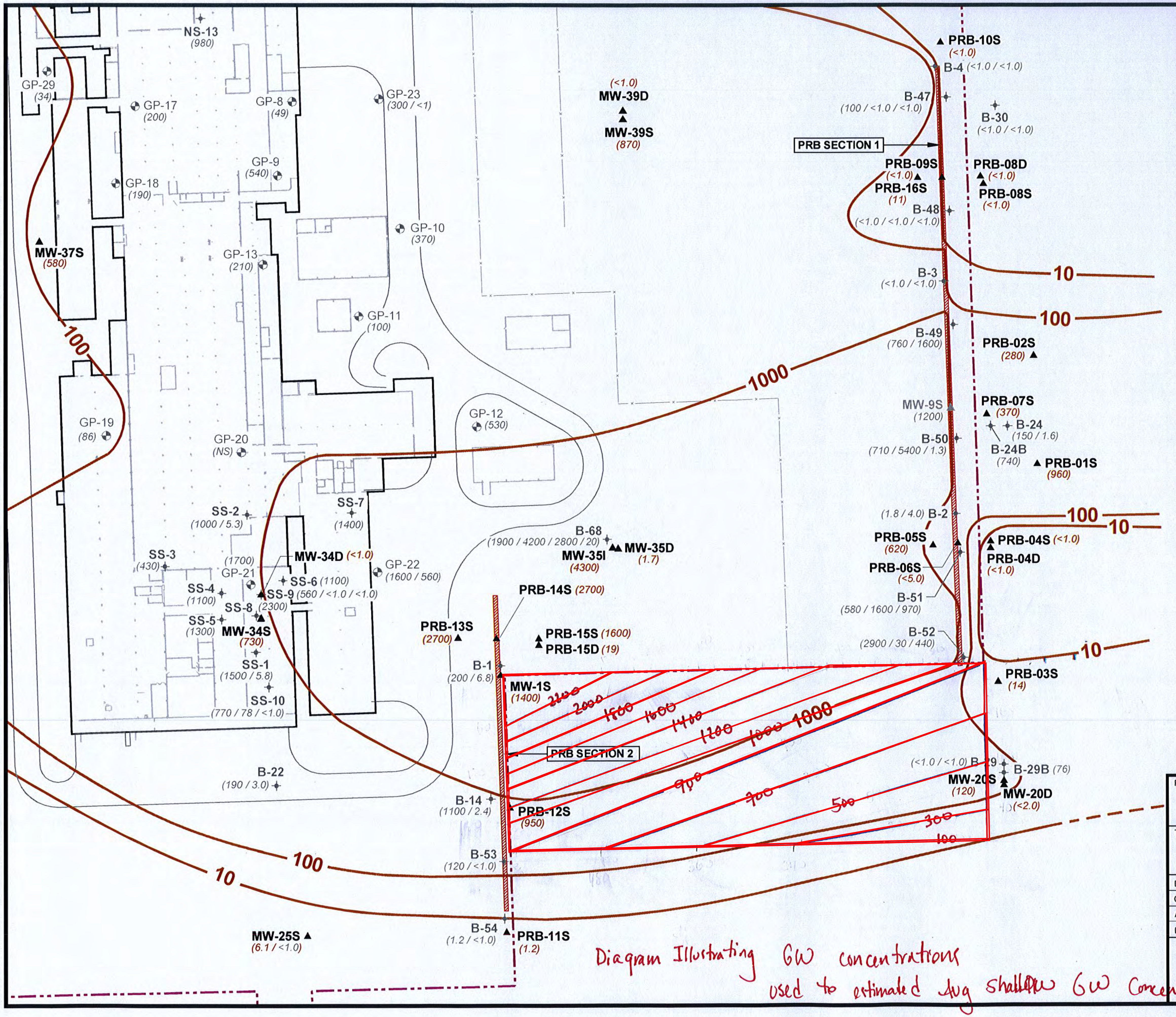
Operator Name: STEHLE, DIANAH
Drawing Plot Scale: 0.386863
Dwg Size: 0.65 Mb
Plot Date: November 20, 2013
Plot Time: 11:58 AM
Attached Xrefs:
Attached Images:
Layout: BB

Determination of Average Shallow Groundwater Concentration

Location (See Supporting Drawing Mark-Ups)	Concentration (ug/L)	Area (ft^2)	Percent of Area	Normalized Concentration (ug/L)
Corner near MW-01s	2200	4,115	3.2%	70.4
	2000	3,999	3.1%	62.2
	1800	5,173	4.0%	72.4
	1600	6,295	4.9%	78.4
	1400	8,716	6.8%	94.9
	1200	12,558	9.8%	117.2
1000 Contour	1000	10,456	8.1%	81.3
	900	13,730	10.7%	96.1
	700	27,512	21.4%	149.8
	500	19,656	15.3%	76.5
	300	12,165	9.5%	28.4
SE corner	100	4,166	3.2%	3.2
	Total	**128,541**	**100.0%**	**931**

Average Shallow GW Concentration



LEGEND

- FORMER TECUMSEH PRODUCTS SITE BOUNDARY
- PARCEL BOUNDARY
- B-2 — PERIMETER / OFF-SITE INVESTIGATION SOIL BORING LOCATION AND NUMBER (MARCH 2009-AUGUST 2012) (SEE NOTE 4)
- MW-4S — MONITORING WELL LOCATION AND NUMBER (SEE NOTE 5)
- MW-9S — DECOMMISSIONED MONITORING WELL LOCATION AND NUMBER (SEE NOTE 5)
- SS-2 — SOURCE AREA INVESTIGATION BORING LOCATION AND NUMBER (MARCH 2009-AUGUST 2012) (SEE NOTE 4)
- GP-24 — ATC GEOPROBE BORING LOCATION AND NUMBER (DECEMBER 2008-JANUARY 2009) (SEE NOTE 4)
- PRB LOCATION
- FENCE LINE
- 100 — APPROXIMATE TRICHLOROETHENE ISOCONCENTRATION LINE
- (13) — TRICHLOROETHENE CONCENTRATION IN ug/L (SEE NOTES 3 AND 4)
- (45 / 19) — TRICHLOROETHENE CONCENTRATION IN ug/L WHERE SAMPLES WERE COLLECTED AT MULTIPLE DEPTHS. CONCENTRATIONS ARE LISTED IN ORDER OF INCREASING DEPTH (SEE NOTES 3 AND 4)
- (NS) — NO SAMPLE COLLECTED FOR TRICHLOROETHENE ANALYSIS

NOTES

1. BASE MAP DEVELOPED FROM SITE PLAN PROVIDED BY THE CITY OF TECUMSEH, DRAWING NO. CITY.DWG, MARCH 2009.
2. GROUND TOPOGRAPHY BASED OFF 7.5 MINUTE U.S.G.S TOPOGRAPHIC QUADRANGLE MAP AND GROUND SURVEY DATA.
3. SEE TABLES IN APPENDIX D FOR FURTHER SAMPLE INFORMATION (SAMPLE COLLECTION DATE, SAMPLE DEPTH, ETC.).
4. SCREENED (GRAY) SAMPLE LOCATIONS WERE INSTALLED AND SAMPLED PRIOR TO MAY / JUNE 2013. TRICHLOROETHENE CONCENTRATION DATA FOR THESE LOCATIONS (ALSO SCREENED) WERE USED FOR UP GRADIENT PLUME DELINEATION.
5. CONCENTRATION DATA FROM THE MOST RECENT SAMPLE EVENT IS DISPLAYED.

PROJECT: FORMER TECUMSEH PRODUCTS SITE
TECUMSEH, MICHIGAN

TITLE: GROUNDWATER ISOCONCENTRATION MAP
TRICHLOROETHENE
MAY / JUNE 2013

DRAWN BY: DGS	SCALE:	PROJ. NO. 186299.0001.01	
CHECKED BY: SEM	AS INDICATED	FILE NO. 186299.0001.01.02.dwg	
APPROVED BY: GC	DATE PRINTED:	FIGURE 2	
DATE: SEPTEMBER 2013			

TRC
1540 Eisenhower Place
Ann Arbor, MI 48108
Phone: 734.971.7080
Fax: 734.971.9022

PLOT DATA
Drawing Name: J:_TRC\Tecumseh MI\186299\0001\01\2013 PRB ANNUAL RPT\186299.0001.01.02.dwg
Operator Name: STEHLE, DIANAH
Drawing Plot Scale: 0.386863
Dwg Size: 3.04 Mb
Plot Date: September 5, 2013
Plot Time: 12:30 PM
Attached Xrefs:
Attached Images:
Layout: FIG02 GW Iso TCE

Appendix C
System Curve Calculations

Technical Memorandum

Date: November 15, 2013

To: Project File

From: Stacy Metz

cc: Dave McKenzie and Scot Pawlukiewicz

Project No.: 207339.0000, Phase 1

Subject: Perimeter Soil Vapor Extraction Design Calculations – System Curve and Blower Selection

Summary and Goal

Develop system curves for the proposed perimeter soil vapor extraction (SVE) system, so that those system curves may be used to assist with blower selection and design of the blower enclosure and carbon treatment system. The proposed SVE blower, treatment system and associated appurtenances may be used for both the perimeter SVE system and the southern source area SVE system. Therefore system curves were developed for two different operating scenarios:

- Only the perimeter SVE system operational; and
- The perimeter SVE system and a hypothetical southern source area SVE system operating simultaneously such that perimeter SVE system operates near the minimum target flow rate, and the balance of system flow originates from the southern source area (combined SVE system).

The SVE system curve is a function flow rate and vacuum loss. Total system losses under each scenario are the sum of 1) vacuum loss at the well, 2) vacuum loss in the piping, 3) vacuum loss in the blower enclosure, and 4) pressure drop across the carbon. The perimeter SVE system curve is provided in Chart 1 and the system curve for the combined SVE system is provided in Chart 2.

System Design Parameters

- **Well design**
  - Each extraction well is teed approximately 2-feet below ground surface.
  - Extraction piping will extends horizontally from the extraction well to the nearest header pipe.

  - The horizontal connection between the well and the header is equipped with a butterfly valve to control and balance flow.
- The extraction well and piping **layout of the perimeter SVE system** is shown on the attached Figure and summarized below:
  - The perimeter SVE system has 2 header pipelines, Header S1 and Header S2.
  - The north-south pipeline, Header S1, has 3 extraction wells (SVE-S01 through SVE-S03)
  - The north-south pipeline will be composed of 4-inch diameter Schedule 80 PVC pipe.
  - The north-south pipeline will have a total length of 180 feet.
  - The east-west pipeline, Header S2, has 7 extraction wells (SVE-S04 through SVE-S10).
  - The east-west pipeline will be composed of a combination of 4-inch and 6-inch diameter Schedule 80 PVC pipe.
  - The four wells furthest east (SVE-S07 through SVE-S10) will feed into the 4-inch portion of Header S2, and extraction wells SVE-S04 through SVE-S06 will feed into the 6-inch portion of Header S2.
  - The east-west pipeline will have a total length of 560 feet, including 260 feet of 6-inch diameter pipe and 300 feet of 4-inch diameter pipe.
- The hypothetical extraction well and piping **layout of the southern source area SVE system** was developed for planning purposes. The draft layout which was developed based on passive soil gas survey results, is sketched on Figure 1.
  - The southern source SVE system will have a minimum of 2 header pipelines.
  - The southern source SVE system will have eleven extraction wells.
  - Extraction wells will be located, at most, 580 feet from the blower enclosure.
  - The worst-case source area pipeline will be composed of a combination of 4-inch and 6-inch diameter Schedule 80 PVC pipe.
  - The three furthest wells will feed into the 4-inch portion of worst-case header pipeline, and three additional extraction wells will feed into the 6-inch portion of the worst-case header pipeline.
  - The worst-case header pipeline will have a total length of 580 feet, including 260 feet of 4-inch diameter pipe and 320 feet of 6-inch diameter pipe.
- **System flow**
  - Flow within each of the perimeter SVE extraction wells will be approximately equivalent, e.g. balanced.

- Flow within each of the source area SVE extraction wells will be approximately equivalent, e.g. balanced.
- The calculated minimum target air flow for the perimeter SVE system is 245 cubic feet per minute (CFM).
- If both the perimeter and source area SVE systems are operated simultaneously, air flow from the source area will be maximized and air flow from the perimeter SVE system will be maintained near the calculated minimum target air flow. Actual air flow from the perimeter SVE system under this scenario is assumed to be 260 CFM, slightly greater than minimum target air flow (to allow for minor variations in flow).

Step 1 – Determine Loss at the Well

Assumptions and Design Parameters

- Wells will be constructed with the same materials as the wells in the northern SVE system.
- Soil parameters are similar between the northern SVE system and the perimeter/southern SVE system.
- Perimeter SVE Wells:
  - § Well will be screened near the water table from approximately 4.5 feet above the top of the high water table to the low water table for a total screen length of 7 feet.
  - § Unsaturated screened thickness is assumed to be 5 feet.
- Southern Source Area SVE Wells:
  - § Well will be screened near the water table from approximately 9.5 feet above the top of the high water table to the low water table for a total screen length of 12 feet.
  - § Unsaturated screened thickness is assumed to be 10 feet.
- Vacuum loss at the well is inversely proportional to screen length, e.g. with an unsaturated screened length of 5 feet compared to 10 feet in the north the vacuum loss will be two times higher.
- P-Building SVE system extraction wells have a 10-foot unsaturated screened interval.

Calculation

Vacuum and flow measurements are collected at each of the northern SVE system wells (SVE-01 through SVE-07) on a quarterly basis. As noted above, vacuum loss at the proposed wells to be installed in the perimeter and southern SVE systems are expected to be similar. Field data from the second quarter 2013 and the third quarter 2013 were used to plot observed vacuum loss at the well, $\Delta V_{10'well}$, as a function of flow at the well, Q_{well} (Chart 3). Microsoft Excel was used plot a best fit line and to determine the equation of that line:

$$\Delta V_{10'well} = 0.031 Q_{well} + 0.2944$$

Vacuum loss at the well is assumed to be inversely proportional to screen length. Therefore:

$$\Delta V_{\text{perimeter}-well} = \Delta V_{5'well} = 2\Delta V_{10'well} = 0.062 Q_{well} + 0.5888$$

$$\Delta V_{\text{source}-well} = \Delta V_{10'well} = 0.031 Q_{well} + 0.2944$$

Microsoft excel was used to calculate vacuum loss at the well at various different system flow rates, Q_{system}, at intervals of 150 CFM from 300 CFM to 1800 CFM for each of the operating scenarios.

For the perimeter system, which has 10 wells:

$$Q_{well} = \frac{Q_{system}}{10\ wells}$$

For the simultaneous operation of the perimeter and southern source systems:

$$Q_{system} = Q_{perimter} + Q_{source}$$

$$Q_{perimter} = 260\ CFM$$

Therefore,

$$Q_{well-perimeter} = \frac{Q_{perimeter}}{10\ wells} = 26\ CFM$$

And

$$Q_{source} = Q_{system} - Q_{perimter} = Q_{system} - 260\ CFM$$

And

$$Q_{well-source} = \frac{Q_{source}}{11\ wells} = \frac{(Q_{system} - 260\ CFM)}{11\ wells}$$

Vacuum loss was calculated for both the perimeter wells and the source area wells, as described above. The worst case (higher) vacuum loss was used to develop the system curve. Vacuum loss at the well is plotted as a function of flow on Chart 1 (perimeter) and Chart 2 (combined).

Step 2 – Determine Loss in System Piping

Assumptions and Design Parameters

- The perimeter SVE system will be constructed as shown on the proposed SVE system layout (See attached figure).
- For the perimeter SVE system, the worst case header pipe is Header S2 (east-west pipeline which includes 7 of the 10 proposed wells and extends in an approximately straight line from just west of monitoring well MW-01s to the east 560 feet [260 feet with a diameter of 6-inches and 300 feet with a diameter of 4-inches]).
- For the combined SVE system, the worst case header pipe depends on the total system flow. At low flow (e.g. where approximately 50-percent or more of the total flow is from the perimeter system) the worst case header pipe is Header S2 (as described above). At higher flows, a greater proportion of the total flow is directed through the hypothetical source area system and the worst-case header becomes the source area header which includes 6 of the 11 source area wells, and extends approximately 580 feet to the northwest [320 feet with a diameter of 6-inches and 260 feet with a diameter of 4-inches].
- The density (d) of air is assumed to be 1.21 kg/m^3.
- The viscosity (μ) of air is assumed to be 1.82 x 10^{-5} kg/(m*s)
- The specific roughness constant (e) for PVC is assumed to be 1.50 x 10^{-6} m.

Calculation

The total piping vacuum loss was calculated as the sum of vacuum loss from each segment of system piping, where each segment represents a different flow volume. Piping losses for each segment are calculated as a function of flow (Q_{pipe}), pipe diameter (D) and pipe length (L) (including equivalent lengths due to minor losses).

Equivalent Lengths for Sources of Minor Losses are Summarized Below:

Minor Loss Source	4-Inch Diameter Pipe	6-Inch Diameter Pipe
90 deg. Elbow	2.93	4.42
Tee (str. Thru)	1.96	2.95
Tee (Branched)	5.84	8.79
Gate Valve	0.78	1.18
Globe Valve	33.11	49.85
Butterfly Valve	4.38	6.60
Expansion	1.51	2.27
Contraction	0.78	1.18

Vacuum loss through the system piping was calculated as follows:

$$\Delta V_{piping} = \frac{f \times L \times v^2 \times d}{2D}$$

The air velocity, v, in the system piping is calculated as a function of flow (Q_{pipe}):

$$v = \frac{Q_{pipe}}{Internal\ Area} = \frac{Q_{pipe}}{\pi \times \left(D^2/_4 \right)}$$

The friction factor, f, is calculated empirically:

$$f = \frac{0.25}{log\left(\left[\frac{e/_D}{3.7} \right] + \left[\frac{5.74}{Re^{0.9}} \right] \right)^2}$$

Note the parameters e and D must be in the same units for this relationship to be valid.

The Reynolds Number (Re) is calculated as a function of pipe diameter (D), velocity (v), fluid density (d) and fluid viscosity (μ):

$$Re = \frac{D \times v \times d}{\mu}$$

Microsoft excel was used to calculate vacuum loss in the piping for both the perimeter wells and the source area wells, as described above. Vacuum loss at the well was calculated at various different system flow rates, Q_{system}, at intervals of 150 CFM from 300 CFM to 1800 CFM for each of the operating scenarios. For each operating scenario, the worst case (higher) vacuum loss was used to develop the system curve. Vacuum loss through the system piping is plotted as a function of total system flow on Charts 1 (perimeter) and 2 (combined).

Step 3 – Determine Loss in Blower Enclosure

Assumptions

Blower enclosure design (and vacuum losses) will be similar to the design for the P-Bulding SVE system blower enclosure. SVE system conveyance pipe headers may enter the blower enclosure at one of five inlet points. Flow through the blower enclosure is modeled to proceed as follows:

- SVE conveyance pipe (up to 5 total)
- 4- to 6-inch diameter (sized to match conveyance pipe) flexible hose (up to five total)

- Inlet Line (5 total)
  - 3-inch Schedule 80 PVC
  - 4-inch diameter flexible hose
  - 4-inch diameter Schedule 80 PVC
- 8-inch diameter Schedule 80 PVC Header
- 120 gallon air-water separator tank
- 6-inch diameter Schedule 80 Steel
- Air filter
- 8-inch diameter Schedule 80 PVC Header
- SVE Blower
- Silencer
- 4-inch diameter Schedule 80 Steel Pipe
- 6-inch diameter Schedule 80 Steel Stack
- 8-inch diameter flexible hose
- vapor phase carbon vessel;
- 8-inch diameter flexible hose
- vapor phase carbon vessel;
- 8-inch diameter flexible hose
- 6-inch diameter Schedule 80 Steel Stack

Note: These assumptions are based on the actual P-Building system design. The actual size and materials of construction may be modified to reduce losses through the blower enclosure. These calculations provide a "worst-case" baseline for vacuum loss through the blower enclosure.

Calculation

The total vacuum loss through the blower enclosure was calculated as the sum of vacuum loss from each component/segment of the blower enclosure piping. Losses for each component/segment are calculated as a function of flow through that portion of the system piping (Q_{pipe}), pipe diameter (D) and pipe length (L) (including equivalent lengths due to minor losses). Minor losses due to some components (e.g. air filters, camlock fittings and flexible hose) cannot be calculated based on text book correlations. Therefore piping lengths including equivalent lengths were calibrated against start-up data provided by Proact from the P-Building SVE blower enclosure. Following calibration of the equivalent lengths for the P-Building blower enclosure, vacuum loss through the proposed perimeter SVE system blower enclosure was calculated as described in Step 2 above.

The total vacuum loss through the blower enclosure was calculated at intervals of 150 CFM from 300 CFM to 1800 CFM. For each operating scenario, the highest flow (worst case) inlet line was used to develop the system curve. Vacuum loss through the blower enclosure is plotted as a function of total system flow on Chart 1 (perimeter) and Chart 2 (combined).

Step 4 – Determine Pressure Drop across Carbon

Assumptions

- Pressure drop across the carbon is a function of flow velocity and carbon bed height.
- The relationship between flow velocity and pressure drop per foot of carbon bed height was provided by Schrader Environmental.
- Physical parameters of the carbon are assumed to be:
  - § Carbon will be vapor phase granular activated carbon (GAC) size 4x10 US.
  - § Carbon is conservatively assumed to be densely packed.
  - § Carbon density is assumed to be 37 pounds per cubic foot (based on a typical mass of 2500 lbs in the 4 foot diameter, 5.3 foot tall vessels installed in the north).
  - § Total mass of carbon is assumed to be 7,500 lbs
- Two carbon vessels are assumed to have a capacity of 5000 lbs (5-foot diameter and 68-inch height).

Calculation

Schrader Environmental provided pressure drop (per foot of carbon bed height) data as a function of flow velocity (v) through the carbon. These data were plotted using Microsoft Excel and fitted with a second degree polynomial (Chart 4):

$$\Delta P\ (inches\ of\ H_2O) = (0.0004v^2 + 0.0161v + 6\text{x}10^{-6}) \times h$$

This equation described the pressure drop (ΔP) in inches of water is a function of flow velocity (v) in feet per minute across a carbon bed having a height (h) measured in feet.

Velocity through the carbon is calculated as a function of total flow (Q_{system}) and the cross-sectional area (A) of the carbon vessels:

$$v = \frac{Q_{system}}{A} = \frac{Q_{system}}{\pi \times \left(D^2/_4\right)}$$

Bed height is calculated as a function of the cross-sectional area of the vessels, the total mass of carbon (m) and the carbon density (d):

$$h = \frac{m}{d \times A} = \frac{m}{d \times \pi \times \left(D^2/_4\right)} = \frac{7500\ lbs}{37\frac{lbs}{ft^3} \times \pi \times \left([5\ ft]^2/_4\right)} = 10.2\ ft$$

Using the equation of the best fit line and the anticipated carbon bed height, the pressure drop across the carbon was calculated at various flow velocities. Pressure drop across the carbon treatment system was calculated at intervals of 150 CFM from 300 CFM to 1800 CFM for the total system flow. Vacuum loss through the carbon treatment system was plotted as a function of total system flow on Charts 1 (perimeter) and 2 (combined).

Step 5 – Develop Total System Curves for Each Operating Scenario

The total system curve for each operating parameter was determined by adding the vacuum loss or pressure drop across each component of the SVE system. These data were graphed in Microsoft Excel and fitted with a second degree polynomial:

For the perimeter only operating scenario:

$$\Delta V_{total} = 7x10^{-5}Q^2 + 0.0311Q$$

For the combined southern source and perimeter operating scenario:

$$\Delta V_{total} = 5x10^{-5}Q^2 + 0.0118Q$$

Where the total vacuum loss (ΔV_{total}) is measured in inches of water and total flow (Q) is measured in CFM. System curves are plotted on Charts 1 (perimeter) and 2 (combined).

Calculation Sheets

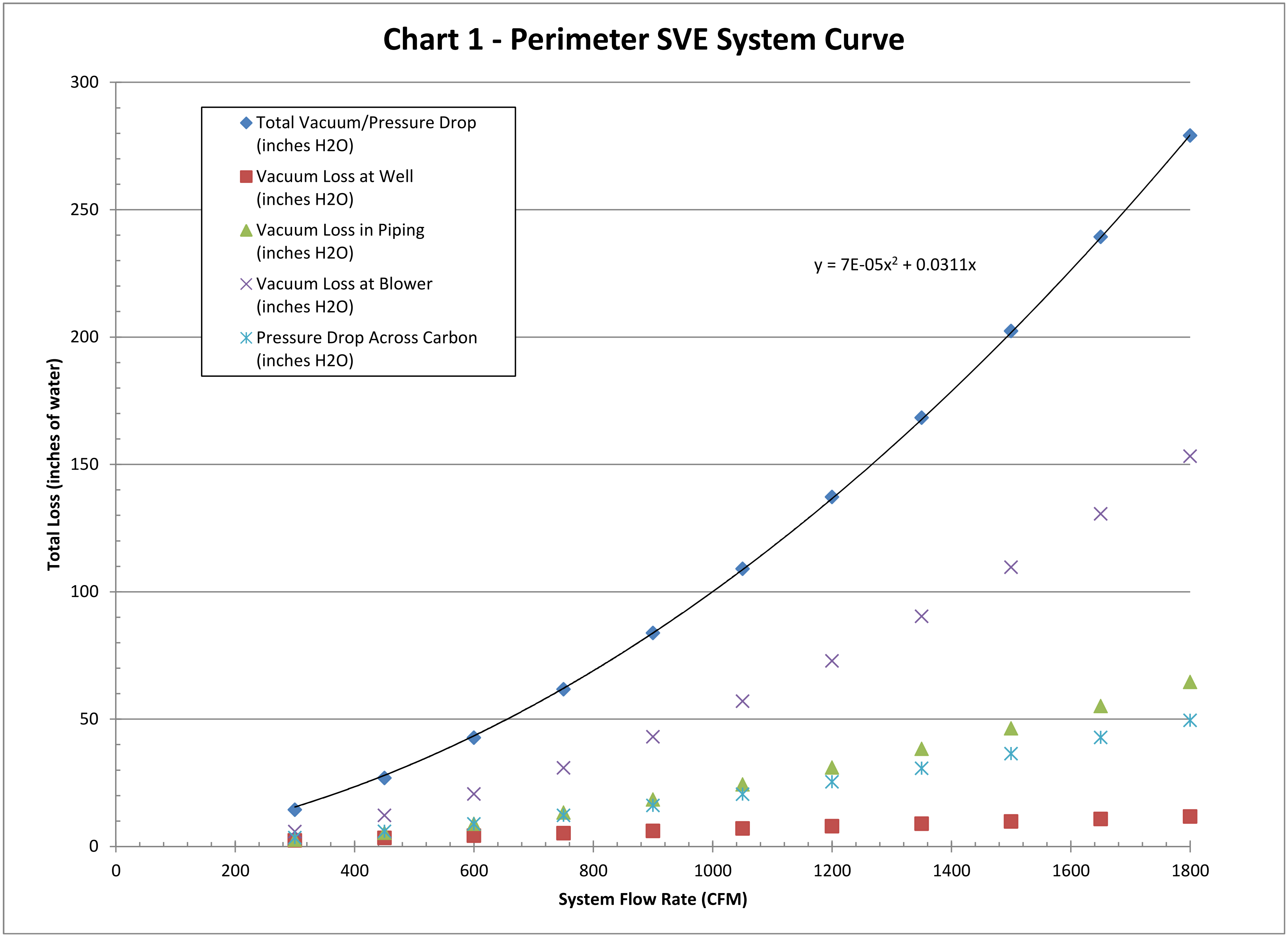


Chart 1 - Perimeter SVE System Curve
Total Vacuum/Pressure Drop (inches H2O)
Vacuum Loss at Well (inches H2O)
Vacuum Loss in Piping (inches H2O)
Vacuum Loss at Blower (inches H2O)
Pressure Drop Across Carbon (inches H2O)
y = 7E-05x² + 0.0311x
Total Loss (inches of water)
System Flow Rate (CFM)
0
50
100
150
200
250
300
0
200
400
600
800
1000
1200
1400
1600
1800

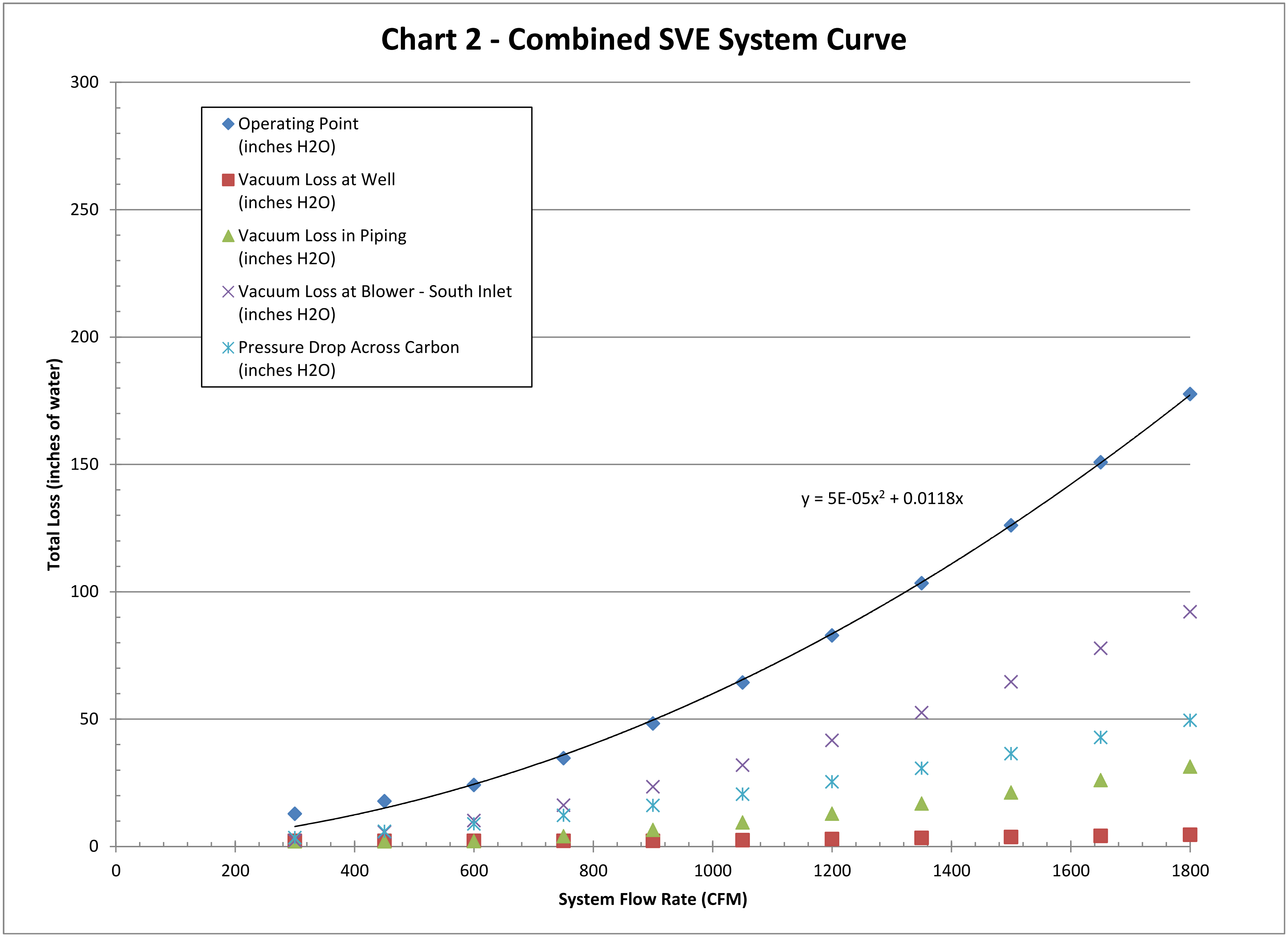
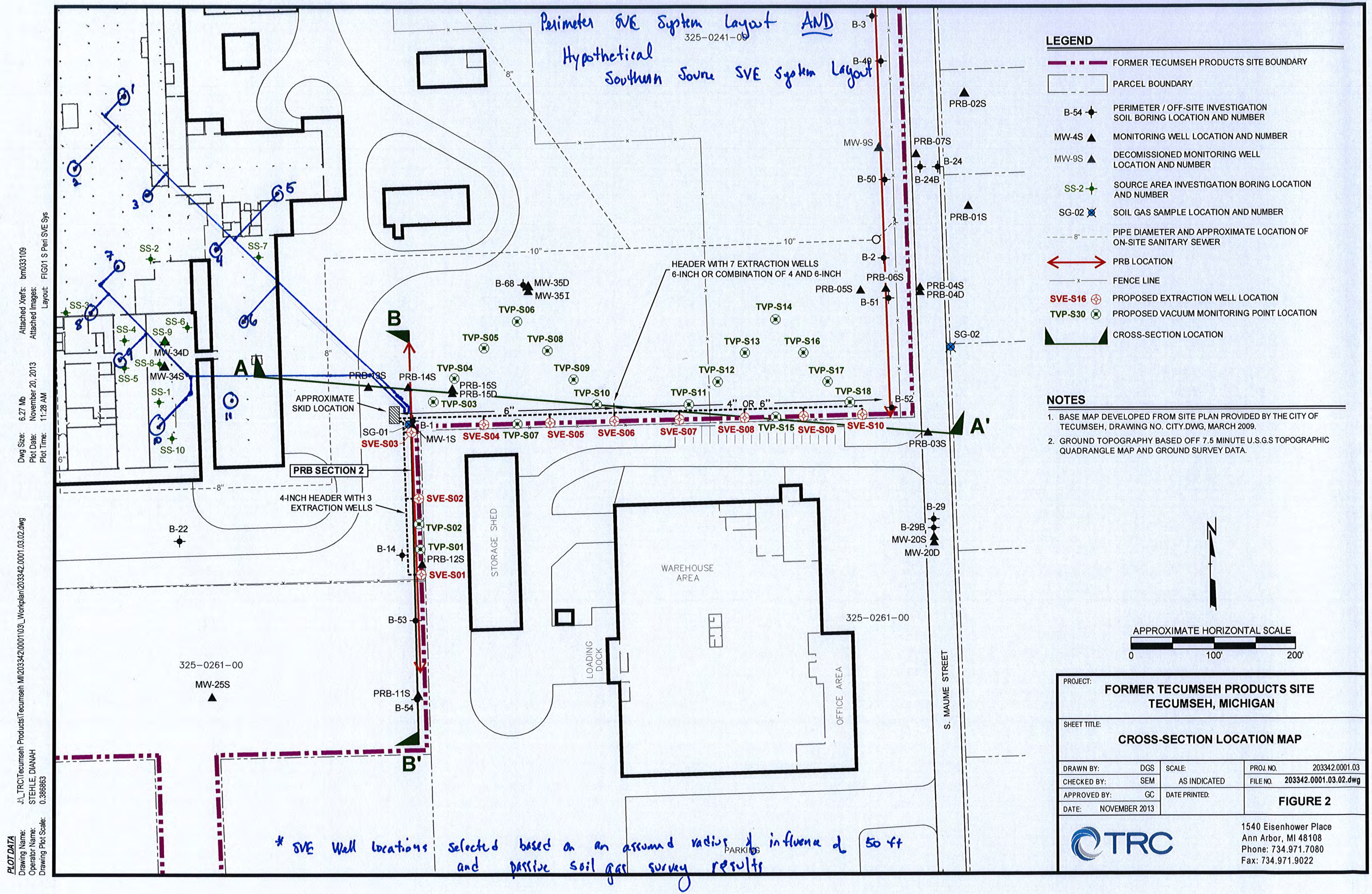


Chart 2 - Combined SVE System Curve
Operating Point (inches H2O)
Vacuum Loss at Well (inches H2O)
Vacuum Loss in Piping (inches H2O)
Vacuum Loss at Blower - South Inlet (inches H2O)
Pressure Drop Across Carbon (inches H2O)
y = 5E-05x² + 0.0118x
Total Loss (inches of water)
300
250
200
150
100
50
0
200
400
600
800
1000
1200
1400
1600
1800
System Flow Rate (CFM)



Perimeter SVE System Layout AND
Hypothetical Southern Source SVE System Layout
LEGEND
FORMER TECUMSEH PRODUCTS SITE BOUNDARY
PARCEL BOUNDARY
B-54 PERIMETER / OFF-SITE INVESTIGATION SOIL BORING LOCATION AND NUMBER
MW-4S MONITORING WELL LOCATION AND NUMBER
MW-9S DECOMISSIONED MONITORING WELL LOCATION AND NUMBER
SS-2 SOURCE AREA INVESTIGATION BORING LOCATION AND NUMBER
SG-02 SOIL GAS SAMPLE LOCATION AND NUMBER
8" PIPE DIAMETER AND APPROXIMATE LOCATION OF ON-SITE SANITARY SEWER
PRB LOCATION
FENCE LINE
SVE-S16 PROPOSED EXTRACTION WELL LOCATION
TVP-S30 PROPOSED VACUUM MONITORING POINT LOCATION
CROSS-SECTION LOCATION
NOTES
1. BASE MAP DEVELOPED FROM SITE PLAN PROVIDED BY THE CITY OF TECUMSEH, DRAWING NO. CITY.DWG, MARCH 2009.
2. GROUND TOPOGRAPHY BASED OFF 7.5 MINUTE U.S.G.S TOPOGRAPHIC QUADRANGLE MAP AND GROUND SURVEY DATA.
HEADER WITH 7 EXTRACTION WELLS 6-INCH OR COMBINATION OF 4 AND 6-INCH
APPROXIMATE SKID LOCATION
PRB SECTION 2
4-INCH HEADER WITH 3 EXTRACTION WELLS
STORAGE SHED
WAREHOUSE AREA
LOADING DOCK
OFFICE AREA
S. MAUME STREET
PARKING
325–0241–00
325–0261–00
APPROXIMATE HORIZONTAL SCALE
0 100' 200'
PROJECT: FORMER TECUMSEH PRODUCTS SITE TECUMSEH, MICHIGAN
SHEET TITLE: CROSS-SECTION LOCATION MAP
DRAWN BY: DGS
CHECKED BY: SEM
APPROVED BY: GC
DATE: NOVEMBER 2013
SCALE: AS INDICATED
DATE PRINTED:
PROJ. NO. 203342.0001.03
FILE NO. 203342.0001.03.02.dwg
FIGURE 2
TRC
1540 Eisenhower Place
Ann Arbor, MI 48108
Phone: 734.971.7080
Fax: 734.971.9022
* SVE Well locations selected based on an assumed radius of influence of 50 ft and passive soil gas survey results
PLOT DATA
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Layout: FIG01 S Peri SVE Sys

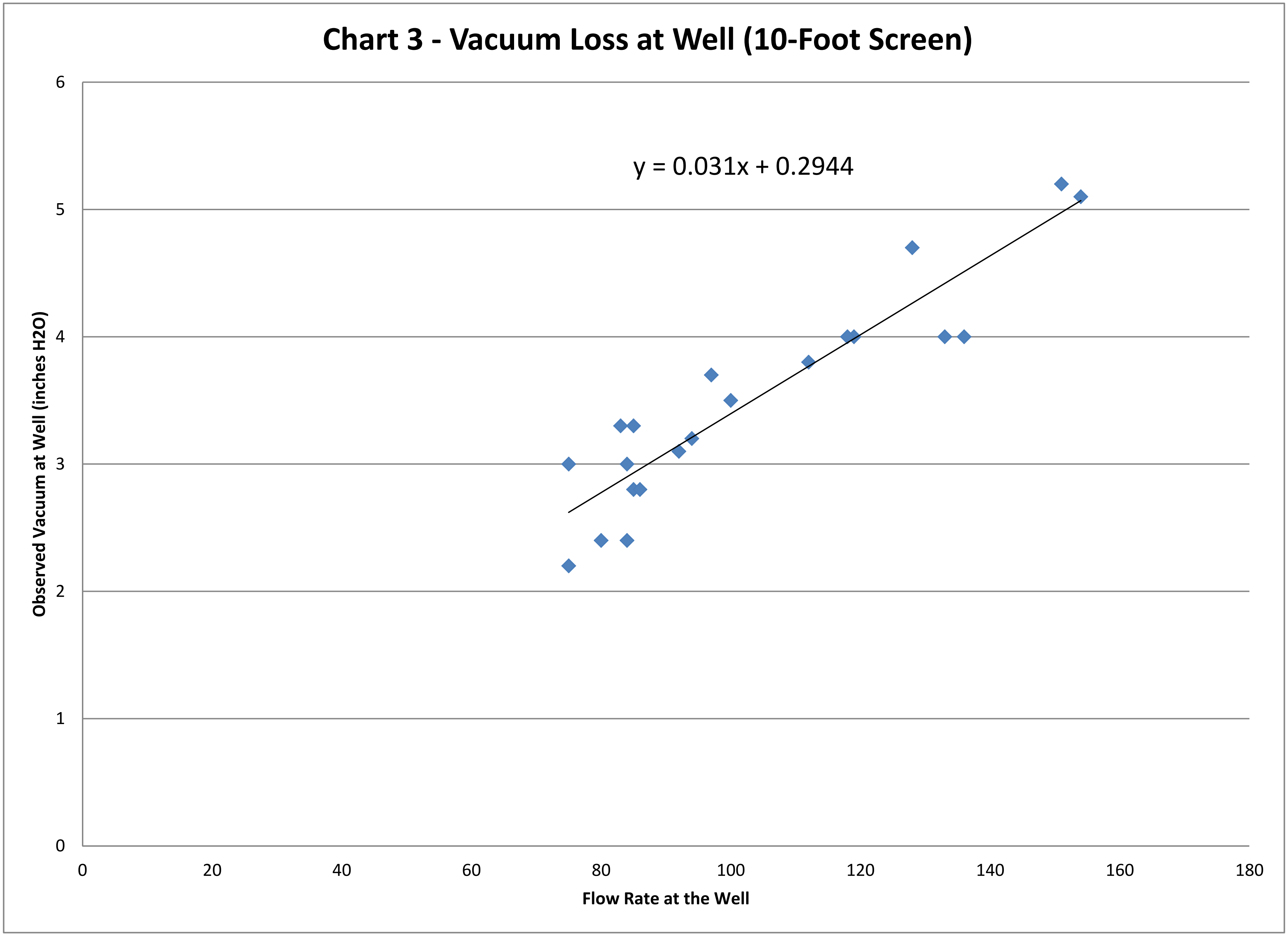
Chart 3 - Vacuum Loss at Well (10-Foot Screen)
y = 0.031x + 0.2944
Observed Vacuum at Well (inches H2O)
Flow Rate at the Well
0
1
2
3
4
5
6
0
20
40
60
80
100
120
140
160
180

Piping Loss - Perimeter SVE System

User Defined Parameters

Total Number of Wells	10

Layout of Worst Case Header Pipe

Segment	A	B	C	D	E	F	G	H	I	J
Length	100	80	80	80	75	75	70	0	0	0
Nominal Pipe Diameter	5.761	5.761	5.761	3.826	3.826	3.826	3.826	3.826	3.826	3.826
Number of segments served	7	6	5	4	3	2	1	1	1	1
Quantities										
90 deg. Elbow	*4*	*0*	*0*	*0*	*0*	*0*	*1*	0	0	0
Tee (str. Thru)	*1*	*1*	*1*	*1*	*1*	*1*	*0*	0	0	0
Tee (Branched)	*0*	*0*	*0*	*0*	*0*	*0*	*1*	0	0	0
Gate Valve	*0*	*0*	*0*	*0*	*0*	*0*	*0*	0	0	0
Globe Valve	*0*	*0*	*0*	*0*	*0*	*0*	*0*	0	0	0
Butterfly Valve	*0*	*0*	*0*	*0*	*0*	*0*	*1*	0	0	0
Expansion	*0*	*0*	*0*	*0*	*0*	*0*	*0*	0	0	0
Contraction	*0*	*0*	*0*	*0*	*0*	*0*	*0*	0	0	0

References

Nominal Pipe Diameters	
2-inch pipe	1.939
3-inch pipe	2.900
4-inch pipe	3.826
6-inch pipe	5.761

Piping Loss - Southern Source (Hypothetical)

User Defined Parameters

Total Number of Wells	21	
Perimeter Wells	10	
Southern SVE Wells	11	
Minimum Flow - Perimeter SVE	260	CFM

Layout of Worst Case Header Pipe

Segment	A	B	C	D	E	F	G	H	I	J
Length	60	90	110	30	60	230	0	0	0	0
Nominal Pipe Diameter	3.826	3.826	3.826	5.761	5.761	5.761	3.826	3.826	3.826	3.826
Number of Wells Served	1	2	3	4	5	6	1	1	1	1
Quantities										
90 deg. Elbow	*1*	*0*	*0*	*0*	*0*	*4*	*0*	0	0	0
Tee (str. Thru)	*0*	*1*	*1*	*1*	*1*	*1*	*0*	0	0	0
Tee (Branched)	*1*	*0*	*0*	*0*	*0*	*0*	*0*	0	0	0
Gate Valve	*0*	*0*	*0*	*0*	*0*	*0*	*0*	0	0	0
Globe Valve	*0*	*0*	*0*	*0*	*0*	*0*	*0*	0	0	0
Butterfly Valve	*1*	*0*	*0*	*0*	*0*	*0*	*0*	0	0	0
Expansion	*0*	*0*	*0*	*0*	*0*	*0*	*0*	0	0	0
Contraction	*0*	*0*	*0*	*0*	*0*	*0*	*0*	0	0	0

References

Nominal Pipe Diameters	
2-inch pipe	1.939
3-inch pipe	2.900
4-inch pipe	3.826
6-inch pipe	5.761

Loss through Blower Enclosure - Perimeter SVE System

User Defined Parameters

Max Number of Wells/Inlet Line	7
Number of Wells/Inlet 2	3
Number of Wells/Inlet 3	0
Total number of wells	10

Piping Loss Estimate - Based on Northern SVE System Design, Values Calibrated against Proact Skid Test Data

Segment	Inlet 1a	Inlet 1b	Inlet 1c	Header a	Header b	Header c	Air Filter	Blower In 1	Blower In 2	Blower
Length	20	8	4	4	4	4	4	15	2	0
Nominal Pipe Diameter	3.826	2.900	3.826	7.625	7.625	7.625	5.761	7.625	3.826	3.826
Number of wells served	7	7	7	7	10	10	10	10	10	10
Quantities										
90 deg. Elbow	*0*	*0*	*1*	*0*	*0*	*1*	*1*	4	1	*1*
Tee (str. Thru)	*0*	*1*	*1*	*1*	*1*	*1*	*3*	1	0	*0*
Tee (Branched)	*0*	*0*	*1*	*0*	*0*	*0*	*3*	0	0	*0*
Gate Valve	*0*	*0*	*0*	*0*	*0*	*0*	*0*	0	0	*0*
Globe Valve	*0*	*0*	*0*	*0*	*0*	*0*	*0*	0	0	*0*
Butterfly Valve	*0*	*0*	*1*	*0*	*0*	*0*	*0*	0	0	*0*
Expansion	*0*	*1*	*1*	*0*	*0*	*0*	*1*	0	0	*0*
Contraction	*1*	*0*	*0*	*0*	*0*	*1*	*0*	1	0	*0*

References

Nominal Pipe Diameters	
2-inch pipe	1.939
3-inch pipe	2.900
4-inch pipe	3.826
6-inch pipe	5.761
8-inch pipe	7.625

Loss through Blower Enclosure - Southern Source (Hypothetical)

User Defined Parameters

Max Number of Wells/Inlet Line	6
Number of Wells/Inlet 2	5
Total Perimeter Wells	10
Max Perimeter Wells/Inlet 3	7
Min Perimeter Wells/Inlet 4	3
Total number of southern wells	11

Additional Flow from Perimeter System

Inlet 3 = 182

Inlet 3 = 78

Piping Loss Estimate - Based on Northern SVE System Design, Values Calibrated against Proact Skid Test Data

Segment	Inlet 1a	Inlet 1b	Inlet 1c	Header a	Header b	Header c	Header d	Air Filter	Blower In 1	Blower
Length	20	8	4	4	4	4	4	15	15	2
Nominal Pipe Diameter	3.826	3.826	3.826	7.625	7.625	7.625	7.625	5.761	7.625	3.826
Number of South wells served	6	6	6	6	11	11	11	11	11	11
Quantities										
90 deg. Elbow	*0*	*0*	*1*	*0*	*0*	*0*	*1*	*1*	4	2
Tee (str. Thru)	*0*	*1*	*1*	*1*	*1*	*1*	*1*	*3*	1	0
Tee (Branched)	*0*	*0*	*1*	*0*	*0*	*0*	*0*	*3*	0	0
Gate Valve	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	0	0
Globe Valve	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	0	0
Butterfly Valve	*0*	*0*	*1*	*0*	*0*	*0*	*0*	*0*	0	0
Expansion	*0*	*1*	*1*	*0*	*0*	*0*	*0*	*1*	0	0
Contraction	*1*	*0*	*0*	*0*	*0*	*0*	*1*	*0*	1	0

References

Nominal Pipe Diameters	
2-inch pipe	1.939
3-inch pipe	2.900
4-inch pipe	3.826
6-inch pipe	5.761
8-inch pipe	7.625

Pressure Drop across Carbon Treatment System - Both Scenarios

Physical Parameters and User Input Values

Carbon Vessels Features		
Diameter	5	ft
Height	5.6667	ft
Area	20	ft^2
Volume	111	ft^3
Number of Vessels	2	
Physical Parameters of Carbon		
Mass of Carbon	7500	lbs
Density of Carbon	37	lbs /ft^3
Volume of Carbon	201	ft^3
Height of Carbon	10.2	ft

Relationship between Pressure Drop and Flow Rate

Flow Velocity (ft/min)	Pressure Drop (inches H2O/ft carbon)
15	0.35
30	0.8
45	1.5
60	2.55
75	3.5
89	4.7
104	6.2
119	7.9

* Data taken from chart provided by Schrader for Densely Packed Vapor Phase GAC (4x10 US)

Calculated Pressure Drop

Flow Rate (CFM)	**Flow Velocity (ft/min)**	**Pressure Drop (in H2O)/ft carbon**	**Total Pressure Drop (inches H2O)**
300	15	0.34	3.5
450	23	0.58	5.9
600	31	0.87	8.9
750	38	1.20	12.3
900	46	1.58	16.2
1050	53	2.00	20.5
1200	61	2.48	25.4
1350	69	3.00	30.7
1500	76	3.56	36.5
1650	84	4.18	42.8
1800	92	4.84	49.5

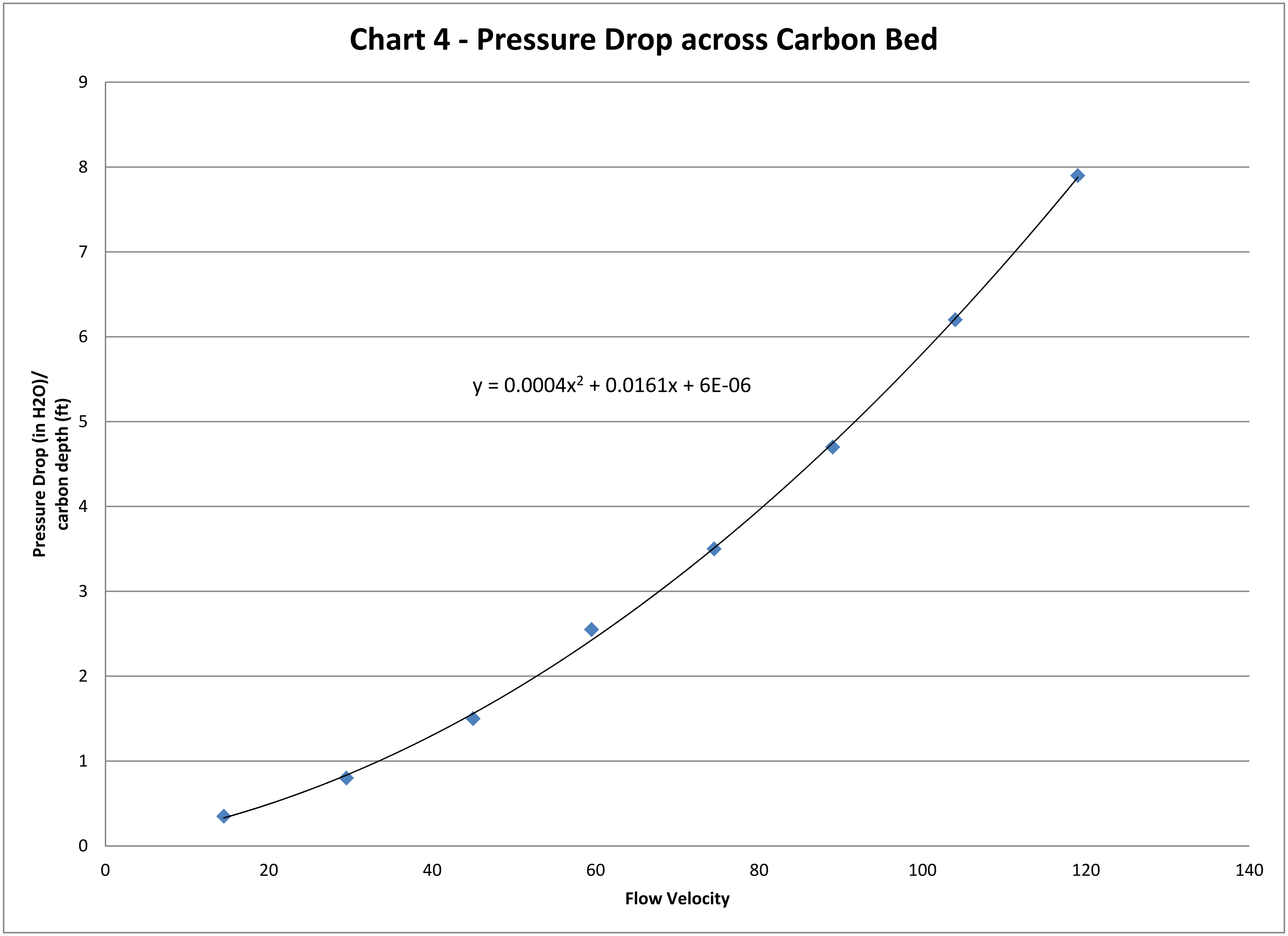

Chart 4 - Pressure Drop across Carbon Bed
y = 0.0004x² + 0.0161x + 6E-06
Pressure Drop (in H2O)/ carbon depth (ft)
Flow Velocity
0
1
2
3
4
5
6
7
8
9
0
20
40
60
80
100
120
140