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Toluene Remediation Using Low Vacuum Dual Phase Extraction

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Abstract

The site of a former chemical manufacturing plant is being remediated to risk-based standards for re-development. The site was constructed on uniform alluvial river sand fill dredged and placed over overbank silt or interbedded silt/sand deposits, which in turn overlie an alluvial sand aquifer. The overbank silts are suspected of being thin or absent in some locations as a result of site preparation activities during development. A perched groundwater table exists in the sand fill; the regional groundwater flow system located in the alluvial sand is influenced both diurnally by the adjacent river estuary and seasonally by the freshet. As a result of the daily and seasonal variation of potentiometric surface in the regional aquifer, vertical gradients between the perched aquifer and the regional aquifer vary. Natural vertical gradients are downwards, but reverse and become upwards as a result of dewatering during site remediation.

Raw products of the manufacturing plant included pure phase toluene and xylenes, and inorganic catalysts. Historic releases resulted in significant widespread BTX contamination of sand fill, overbank silts and the perched groundwater beneath the former plant. Characterization of the site resulted in quantity estimates of BTX in all forms up to 520,000 kg (18% benzene, 69% toluene, 13% xylenes). Risk-based criteria were agreed to with the provincial regulators that are intended to be protective of human health (vapour inhalation) and freshwater aquatic life.

In 1995, the former plant was demolished and, for the most part, building foundations removed. In 1999, the site Owners initiated a remediation plan for the site, with a five-year remediation objective. A conceptual remedial plan was developed, which comprised soil vapour extraction (SVE) in conjunction with dewatering.

Verification of the conceptual model consisted of the following activities: overbank silt deposit mapping using cone penetrometer testing (CPT); SVE pilot testing; collection of undisturbed (Shelby tube) samples of the overbank silt for triaxial testing to determine vertical permeability (leakage) of the aquitard; and, modelling. Data from the testing was used for modelling dewatering requirements/conditions (ModFlow) and SVE performance (AirFlow SVE).

Based on the results of the testing and modelling, the conceptual remedial design was refined so that remediation will occur in four blocks of approximately equal contaminant mass. The design for dewatering includes perimeter dewatering eductor wells, in conjunction with dual phase dewatering through the SVE wells using a drop tube. The design vapour flow rate ranges from 25 cfm to 35 cfm per well, and the total extraction rate is 2,000 cfm. Stainless steel well screens were indicated for use as eductor and SVE wells in areas of anticipated higher contamination due to the severe degradation of PVC well screens observed following the SVE pilot test. A performance-based specification was developed, and the successful remediation system contractor supplied all dewatering and vapour treatment equipment including a 2,000 cfm thermal/catalytic oxidizer. The original dual phase extraction design consisted of two 15 horsepower rotary lobe blowers with a maximum inlet vacuum of (70” H_2O). Water and vapour streams were separated and water was pumped to an onsite biox treatment plant. A separate eductor dewatering system accomplished with two 5 horsepower submersible pumps and extracted water discharged to the onsite biox plant. Full scale operation indicated the need to upgrade the blowers to two 40 hp horsepower blowers (140” H_20 vacuum), and reduce the scale of the eductor system, as slightly lower formation permeability than indicated in the SVE pilot test resulted in more dewatering occurring through the SVE wells than designed. To date, the system has removed over 170,000 kg BTX, and is in operation in the second block.

Introduction

Morrow Environmental Consultants Inc. (Morrow) was selected to implement a remediation plan at a former petrochemical processing plant located in southwestern British Columbia. Preliminary and detailed site investigations had previously been carried out by others, and an Approval in Principle (AIP) had been obtained from the provincial environmental regulators for the remediation plan. Several Areas of Environmental Significance (AES) had been identified at the site, with varying Contaminants of Concern (COC) identified and delineated within each AES. This paper is limited to the major COC within AES 1, the former main process area of the site.

This paper presents a case study of an on-going site remediation for volatile contaminants in soil and groundwater. The case is unusual in respect to the mass and volatility of the contaminants requiring remediation. In addition, an innovative approach to remediation was adopted by combining soil vapour extraction and groundwater depression using a low vacuum, dual-phase extraction well technique. The site is described and additional investigations required to evaluate design parameters for the remedial approach selected are discussed. The remedial system is presented in some detail. Finally, challenges encountered during site commissioning and maintenance, solutions to those difficulties, and remedial progress to date are described.

Site History and Contaminants of Concern

The site is located on an island within the estuary of a major river. Prior to construction of a flood-control dike the site flooded during unusually high spring tides. The site had a long history of farming, the most recent crop prior to industrial development being sugar beets.

The site was developed for industrial usage circa 1960. The organic silt loam topsoil was removed to improve settlement and foundation bearing conditions. Initial attempts to strip the site using scrapers and bulldozers failed due to soft soil conditions. Topsoil was subsequently stripped using a dragline. The site was then preloaded to reduce future settlement by hydraulically placing several meters of dredged sand fill over the central portion of the site. Following preloading, the site was graded to approximately 12 ft (3.5 m elevation), or 3 ft (1 m) above the estimated 200 year flood level).

A petrochemical plant was built at the site and commissioned in about 1963 (see Figure 1.) The major products produced by the plant over its 30-year history were benzoic acid and sodium benzoate, used as food preservatives. The major raw material used was toluene, which was brought to the site by tanker. The toluene was catalytically oxidised to phenol, and then subsequently converted to benzoic acid, which was shipped from the site by rail. A significant waste product from the process was benzene, which was recovered and used at the plant for its thermal value. Late in the operational life of the plant, toluic acid was produced by catalytically oxidising meta-xylene (m-xylene), but this production was minor in comparison to benzoic acid production.

The major contaminants of concern within the process area (AES 1) are toluene, benzene and, to a lesser extent, m-xylene. These contaminants entered the ground through routine minor spills and leaks, at least one recorded tank failure and failure of the original process sewer line under the site. Benzoic acid, phenols and metal catalysts also occur within the surficial soils in AES 1, but are outside the scope of this paper

Stratigraphy and Hydrogeology

Previous investigations had identified the site stratigraphy as consisting of approximately 10 ft to 12 ft (3 m to 3.5 m) of uniform medium sand fill overlying 3 ft (1 m) of overbank silt overlying an extensive deposit of uniform medium sand of deltaic origin (see cross sections, Figure 2.) The elevation of the upper surface of the silt was known to be variable, probably due to variation in stripping depths during site preparation. The silt deposit was known to be relatively continuous, but the possibility of gaps within it could not be discounted.

FIGURE 1 - SITE PLAN AND LAYOUT OF REMEDIAL BLOCKS

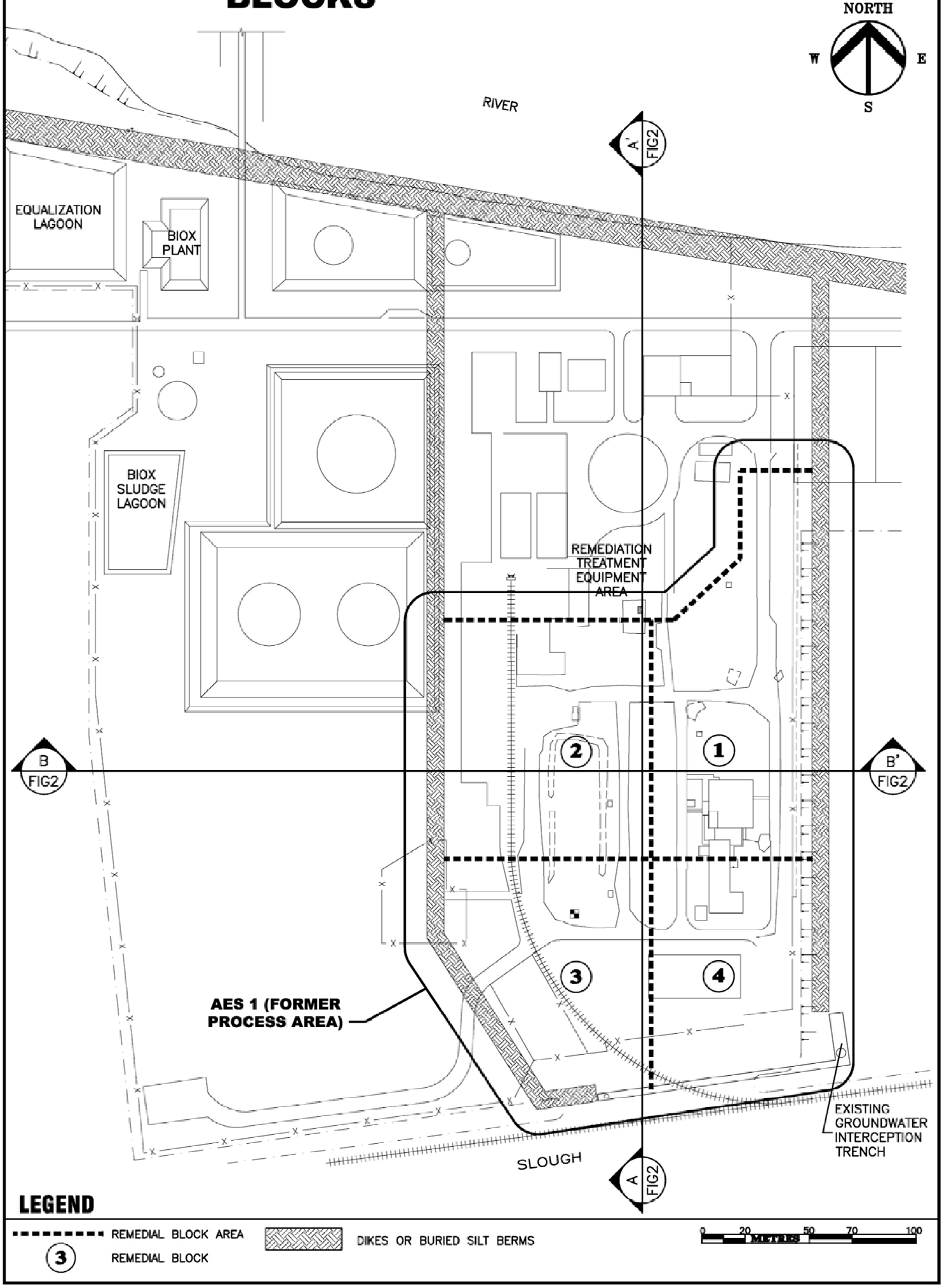
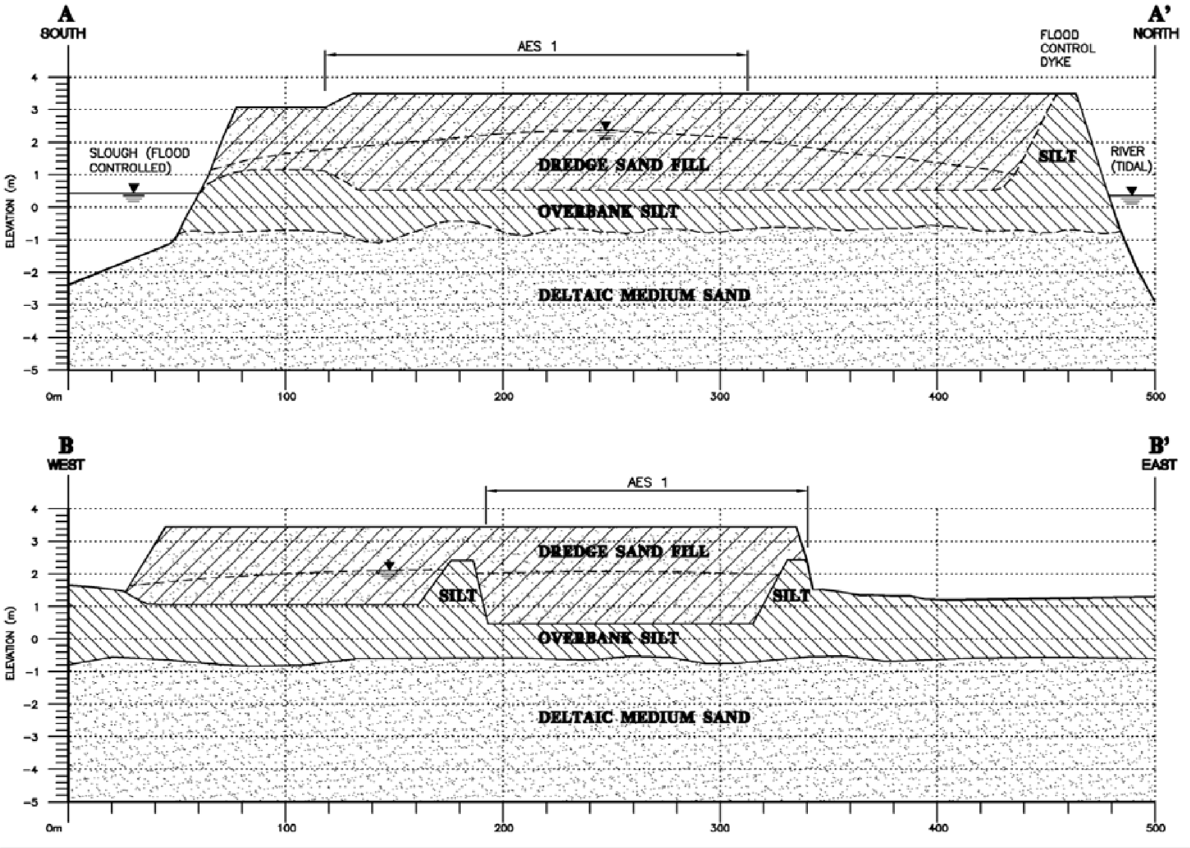


FIGURE 2 - GEOLOGICAL X-SECTIONS



The water level within the river estuary adjacent to the site varies both with diurnal tides and with seasonal river stage. The river stage peaks in June, with tidal variations decreasing as the river stage increases. The water level within the slough to the south of site is maintained at a low level by a flap gate to the river. This gate allows drainage during low tide but prevents backflow during high tide.

The deltaic sand unit beneath the site forms a confined aquifer, with seepage northward to the river. Tidal variations within the aquifer decrease with increasing distance from the river, but persist to the southern boundary of the site. The dredge sand fill beneath the site forms a shallow, unconfined, non-tidal aquifer beneath the site with an estimated hydraulic conductivity of 2×10^{-4} m/s. Recharge to the shallow aquifer is from rainfall, which averages about 43 in (1.1 m) per year, with the maximum occurring in the winter and frequent rainfall through the spring and fall. A water table divide occurs beneath the northern portion of AES 1, with shallow groundwater seeping both northwards to the river and southwards to the slough. The location of the divide migrates northwards and southwards on a seasonal basis.

Remedial Objectives and Selection of Remedial Technologies

Following the tank failure, two product recovery sumps were installed and a groundwater interception trench was constructed along the southern site boundary to protect off-site infrastructure and the slough. After the site was decommissioned in approximately 1990, detailed site investigations delineated an estimated 100,000 yd^3 (80,000 m^3) of contaminated fill soil containing about 580 tons (520,000 kg) benzene, toluene and m-xylene (BTX) beneath AES 1. The BTX consisted on average of approximately 65% toluene, 20% benzene and 15% m-xylene. The contamination was found to be residual separate-phase BTX located within the sand fill, predominantly between 3 ft and 10 ft (1 m and 3 m) depth. Residual BTX extended into the underlying native silt at a few locations. Very limited mobile separate phase BTX (LNAPL) was identified during site monitoring, with a maximum apparent thickness of 3 in (70 mm) observed.

Risk-based remedial objectives were approved in the AIP. For AES 1, risk assessment indicated that there was no need for remediation of the native silt and sand soils, or of the deeper groundwater beneath the site. The objectives for BTX are listed in Table 1 below.

Table 1 Risk-based Remedial Objectives

Media	**Benzene**		**Toluene**		**m-Xylene**	
	Maximum Observed	Remedial Target	Maximum Observed	Remedial Target	Maximum Observed	Remedial Target
Soil:						
Shallow Sand Fill	7,650 mg/kg	30 mg/kg	17,600 mg/kg	100 mg/kg	6,830 mg/kg	100 mg/kg
Native Silt	not tested	-	not tested	-	not tested	-
Native Deltaic Sand	100 mg/kg	-	540 mg/kg	-	34 mg/kg	-
Groundwater:						
Shallow	120 mg/L	3 mg/L	630 mg/L	3 mg/L	7 mg/L	-
Deep	110 mg/L	-	400 mg/L	-	21 mg/L	-

A variety of remedial technologies were screened for potential application to AES 1. Technologies considered included excavation and ex situ treatment or disposal, groundwater depression/soil vapour extraction (SVE) and capping with long-term groundwater interception/treatment. Groundwater depression combined with SVE was selected as the preferred alternative due to its low risk of fugitive BTX vapour emissions, ability to meet remedial objectives in a timely manner and ability to utilise the existing water treatment plant capacity on site. A staged approach for AES 1 utilising nine remediation cells was proposed in the remedial plan.

Additional Investigations and Pilot Testing

Prior to implementing remediation, Morrow undertook selected additional investigations to provide remedial design parameters and address data gaps. Design parameters required were radius of influence of SVE wells, SVE well flow rates, vapour concentrations with time, dewatering requirements, seasonal flow rates and dewatering system radius of influence. The major data gap identified was the continuity and vertical permeability of the overbank silt unit, and its resultant impact on groundwater flow under both natural and dewatered conditions.

Drilling and Shelby Tube Sampling

Limited auger drilling was carried out to investigate the nature of the silt unit underlying the fill sand beneath AES 1. Samples of the fill sand and silt were collected for grain-size analysis and analytical testing. Sub samples were collected for analytical testing immediately upon opening the split spoon sampler by coring with a syringe sampler and placing the cores directly in methanol for extraction and analysis.

Shelby tube samples were collected to obtain undisturbed silt samples. Shelby tubes were capped using plastic plugs with o-ring seals, then opened in the laboratory under fume hood conditions. Once opened, the samples were visually logged, and intervals selected for grain size testing, Atterberg limits testing and triaxial permeameter testing.

The fill was confirmed to consist of uniform and medium sand, with a D_{10} grain size of approximately 0.004 in to 0.008 in (0.1 mm to 0.2 mm) and a coefficient of uniformity (D_{60}/D_{10}) of approximately 1.5 to 2. In general, BTX soil concentrations in the sand fill were somewhat lower than expected based on previous investigations. Residual BTX was identified within the native silt at one location tested.

The native silt was found to be layered and more variable in both thickness and grain size than had been previously characterised. Layers within the silt varied from silty fine sand to high-plasticity organic clayey silt. Laboratory triaxial permeability test estimates of cohesive layers selected for testing from within the silt unit were in the range of $8x10^{-9}$ m/s to $1.5x10^{-8}$ m/s, confirming that the clayey silt layers within the unit form an effective aquitard.

Cone Penetrometer Testing

Cone penetrometer testing was carried out to locate the upper and lower surfaces of the silt unit, as well as to characterise the local nature of the layered unit. Testing was carried out on a uniform 66 ft by 66 ft (20 m by 20 m) grid, locally refined to 33 ft by 33 ft (10 m by 10 m) where the unit was found to be thinner or coarser grained. Cone penetrometer results were corrected for confining stress, and then interpreted for stratigraphy over 4 in (0.1 m) intervals. The interpreted stratigraphic results were correlated with the results of previous auger drilling and Shelby tube sampling at selected locations.

The silt unit was found to vary in thickness from about 1 ft (0.3 m) to in excess of 6 ft (2 m.) The unit was not absent at any test location, however a minimum thickness of 1 ft (0.3 m) of silty fine sand was identified at two locations. These locations corresponded to deeper areas of the upper silt surface, suggesting deeper excavation during site preparation. Contouring of the upper silt surface elevation indicated the presence of several linear troughs, again suggesting over-excavation during dragline stripping.

Computer Modelling of Groundwater Flow and Dewatering

A three-dimensional groundwater flow model was constructed of the entire site using Visual MODFLOW (Waterloo Hydrogeologic Inc., 1999.) The model incorporated precipitation recharge and river stage variations on a seasonal basis, although tidal fluctuations were averaged. The silt unit was incorporated using averaged thickness and vertical hydraulic conductivity values, with the effects of thin zones or gaps investigated using sensitivity analyses.

The model could not be initially calibrated to measured water level data using the initial conceptual hydrogeological model of the site. Measured water levels could only be matched if north-south oriented flow barriers were incorporated beneath the middle and east sides of the site (either side of the central process area, AES 1.) Drilling subsequently confirmed the presence of silt berms within the sand fill (see Figure 1 and Section B, Figure 2.) It is speculated that these silt berms were constructed for the hydraulic placement of dredge sand fill on the site, although the available records do not identify them. There is no berm between the south end of the site and the slough, allowing free drainage of shallow groundwater to the slough.

The revised computer model, which incorporates the berms, was able to successfully simulate shallow groundwater contours on a seasonal basis. The calibrated model was then used to simulate dewatering of treatment blocks. Issues investigated were: quantity of groundwater discharge required on a seasonal basis; sources of the groundwater requiring discharge; need for a perimeter interception or low-flow barrier around treatment blocks, and; effect of thin zones or gaps in the native silt unit on dewatering. It was found that, using the existing Biox plant treatment capacity of 55 USgpm (300 m^3/day), treatment blocks on the order of 350 ft (110 m) square could be dewatered, even under unusually wet conditions (one standard deviation above mean precipitation.) Major inflows occurred from both the block perimeter and upwards from the underlying silt unit. Perimeter inflows could be handled either by closely spaced perimeter well points or by flow barriers such as sheet piles. Sufficient water treatment capacity was available to make perimeter well points the cost effective alternative.

Soil Vapour Extraction Pilot Testing

An SVE pilot test was performed to determine the air permeability characteristics of the soil for purposes of full-scale design. The test data was also used for calibration of the airflow model, Airflow SVE (Guiguer, Franz and Zaidel, 1995.) The test was set up using six multi-level monitoring wells: two sets of multi-level monitoring wells aligned at 90 degrees to the test well and spaced at 3 ft, 9 ft, and 20 ft (1 m, 3 m and 6 m).

The multi-level wells were completed at three discrete depths: 2 ft, 5 ft and 7 ft (0.6 m, 1.2 m and 2 m) below grade surface. The water table was measured at about 6 ft (1.8 m) below grade surface at the time of the test. The test was carried out only on the upper two meters of the fill, as a dewatered SVE pilot test would have required the installation of sheet piling around the test cell. Two tests were performed: one with a 30 ft by 30 ft (9 m by 9 m) ground cover tarp centred over the test well and one without a tarp.

Plotting the measured vacuum readings as a percentage of applied vacuums vs. log distance from the test well (Beljin, et al., 1996) indicated that 1% of the applied vacuum was achieved at 13 ft (4 m) from the test well. The addition of the ground cover tarp did not change the test results significantly. The wellhead conditions during the test were 35 scfm at 30" H_2O (1 m^3/min at 750 mm H_20.)

Soil Vapour Extraction Modelling and Vapour Treatment Equipment Sizing

The computer model Airflow/SVE was calibrated to the results of the SVE pilot test then used to simulate contaminant removal for the fully dewatered case. Areas of the site were classified as having low, moderate or high degrees of contamination, and typical BTX mixtures and concentrations versus depth were generated statistically from the available soil analytical data. Simulations of contaminant removal versus time were run for low, moderate and highly contaminated wells at a variety of well spacing.

Mass removal rates and cleanup times were found to vary with well spacing, extraction rates, and depth and concentration of contaminants. BTX concentration immediately above the capillary fringe, estimated to be about 2 in (5 cm) thick, was the limiting factor. Vapour concentrations versus time showed the expected exponential decline, with very high initial concentrations followed by a long asymptotic tail. At a vapour flow rate of 35 scfm (1 m^3/min) per well, low concentration wells were simulated to clean up to targets within 30 days, with high concentration wells requiring 180 days or more.

The results of the mass removal versus time simulations were used to evaluate varying remediation block sizes, total vapour flow rates and thermal versus catalytic oxidizers. A conceptual remediation approach was developed where high concentration wells were phased in, limited by the influent vapour concentration of the treatment system. Once all high concentration wells were running, the medium and low concentration wells would be started and cycled through until clean-up was achieved. Thermal oxidation allows higher influent vapour concentrations, which was expected to allow much more rapid phase-in of high concentration wells in each remedial block. Catalytic oxidation was much more cost-effective for the long, asymptotic portion of the vapour concentration curve.

Remedial System Design Approach

Based on the results of the additional investigations, it was determined that dewatering/SVE was a feasible and cost-effective approach to site remediation. Major components of the remedial system would be perimeter dewatering wells, internal dewatering wells within each block, SVE wells, vapour treatment and groundwater treatment.

As both dewatering wells and SVE wells would be required on grids within each block, an innovative solution was proposed. SVE wells were designed as low-vacuum dual phase extraction wells. Slurp tubes would be inserted within each well to the base of the well screen. Wellhead vacuum and discharge pipe sizing would be increased to accommodate water and vapour flow. In this way, the required number of wells and piping networks would be significantly decreased, and upwelling at the SVE wells would be prevented. Two rows of eductor wells were selected for block perimeter groundwater interception. Eductor wells were selected in order to reduce vapour treatment requirements relative to perimeter multiphase wells. Perimeter well spacing was selected to be 6 m along rows and 4 m between rows, with well locations offset between the rows.

A variety of treatment block sizes, equipment sizes, vapour flow rates and SVE well spacing were evaluated. One of the client's objectives was to complete remediation in a relatively short time frame. It was found that dividing AES 1 into four remediation blocks best utilised the capacity of the existing water treatment system at the site. Within each block, SVE wells would be spaced on a uniform 33 ft by 33 ft (10 m by 10 m) grid. Wells in medium to high contaminant concentration areas would have a design extraction rate of 35 scfm (1 m^3/min), with low concentration wells having a design rate of 20 scfm (0.6 m^3/min). Options were presented to the client for 1,000 scfm or 2,000 scfm (28 m^3/min or 57 m^3/min) vapour treatment using either catalytic oxidation or convertible thermal/catalytic oxidation. Capital costs, operating costs and anticipated remediation time frames were estimated for each option. A contingency was also included for the addition of an oil/water separator, should monitoring indicate that significant quantities of separate-phase BTX were being recovered in the water discharge.

The client selected the higher capital cost, lower time frame option of a 2,000 scfm (57 m^3/min) vapour recovery/treatment system utilising a convertible thermal/catalytic oxidizer.

Design/Procurement

Following the client's approval of the design approach a short list of equipment suppliers were developed through a pre-qualification process. A performance specification was prepared that specified performance parameters forthe eductor and SVE systems, and vapour treatment. The equipment supplier was selected based on their proposal quality, lump sum cost, and perceived ability to meet performance specification.

Well Installation

Design extraction and eductor well locations were laid out in the field by professional survey. The tender for the drilling contractor tender included specifications of well screens of nominal 1 m (3.3 ft) length, minimum open area (1.3 in^2/ft [30 cm^2/m] for the 2 inch [50 mm] wells and 2.3 in^2/ft [48 cm^2/m] for the 3 inch [75 mm] wells) and slot size to effectively filter the sand fill material based on its grain size characteristics. Two well material types were utilized to address material compatibility concerns in toluene: stainless steel "V" wire wrapped screens in medium to high soil concentration areas and PVC at other locations. Slot size for the PVC and stainless steel wells was 0.010 in (0.25 mm).

Initially the contractor proposed well installation using a direct push method with no bentonite seal. The direct push technique proved to be not possible, and wells were subsequently placed directly in solid stem auger holes and bentonite chips placed over the upper 1.5 m (5 ft) of well.

Eductor System

The eductor system for Block 1 had 94 dewatering wells each with a design extraction flowrate of approximately 0.24 gpm (0.9 L/min) from an average depth of 5 m below grade. The total eductor groundwater design recovery rate was estimated at 22 USgpm (80 L/min). The eductor system was split into two parallel eductor strings each with a separate supply pump that could operate independently if the other required maintenance, thus always providing some level of dewatering. Selection and sizing of the eductor wellheads and eductor pumps was left as a performance design issue to the remediation contractors.

The equipment supplier selected a suitable eductor to provide the required groundwater extraction. The total motive flow is approximately 60 USgpm (225 L/min) at 50 psi (345 kPa) for each eductor string supplied by two submersible pumps. The design incorporates an eductor recirculation tank with storage capacity for recovered groundwater. Level controls in the recirculation tank operate a transfer pump that discharges recovered groundwater directly to the site Biox plant. All eductor piping is above ground PVC with no frost protection. Weather forecasts are monitored during the winter months and the eductor system is drained in the event temperatures are predicted to decrease below approximately 25° F (-3° C.) The constant recirculation of water prevents the pipes from freezing while operating below 0° C. The eductor recirculation tank is sealed, with a vacuum from the SVE system applied to prevent ambient discharge of untreated vapours.

Low Vacuum Dual Phase Extraction System

The low vacuum DPE system for Block 1 had 88 extraction wells. Based on the pilot testing results, the vapour extraction/vapour treatment system performance specification was: 43” H_2O (110 cm H_2O) of vacuum at the knock out tank; a vapour flow rate of 2000 scfm (57 m^3/min); two vacuum blowers in parallel capable of operating independently; inlet filtration, and; a water discharge capacity from the knockout tank of up to 37 USgpm (135 L/min). Design vapour flow rates were 35 scfm (1 m^3/min) from the 2” SVE wells and 20 scfm (0.6 m^3/min) from the 3” wells. The design groundwater extraction flow rate through the SVE system was 10 USgpm (39 L/min) or approximately 30% of the maximum design groundwater recovery – 70% of the groundwater recovery was to be recovered through the perimeter dewatering system.

The equipment supplier selected two 15 hp, 1,000 scfm rotary lobe blowers to provide the system vacuum. A knockout tank to remove liquids from the SVE effluent stream comprised of a custom built steel vessel 4 ft (1.2 m) diameter and 5 ft (1.5 m) in depth with tangential entry and vertical exit through the top cover plate via a 10 in (0.25 m) diameter opening. The exit had a 10 in shroud that extended 14 in (0.35 m) into the tank. The discharge pump from the knockout tank was a submersible pump located inside the tank.

Oxidizer

The oxidizer was specified as a convertible thermal/catalytic oxidizer. The oxidizer specification required 99.9% destruction in both thermal and catalytic modes with a capacity up to 2,000 scfm and a heat exchanger. The selected oxidizer had a capacity of up to 3000 scfm (85 m^3/min) and contained 5 ft^3 (0.14 m^3) of catalyst media. A process flow diagram of the process is illustrated in Figure 3.

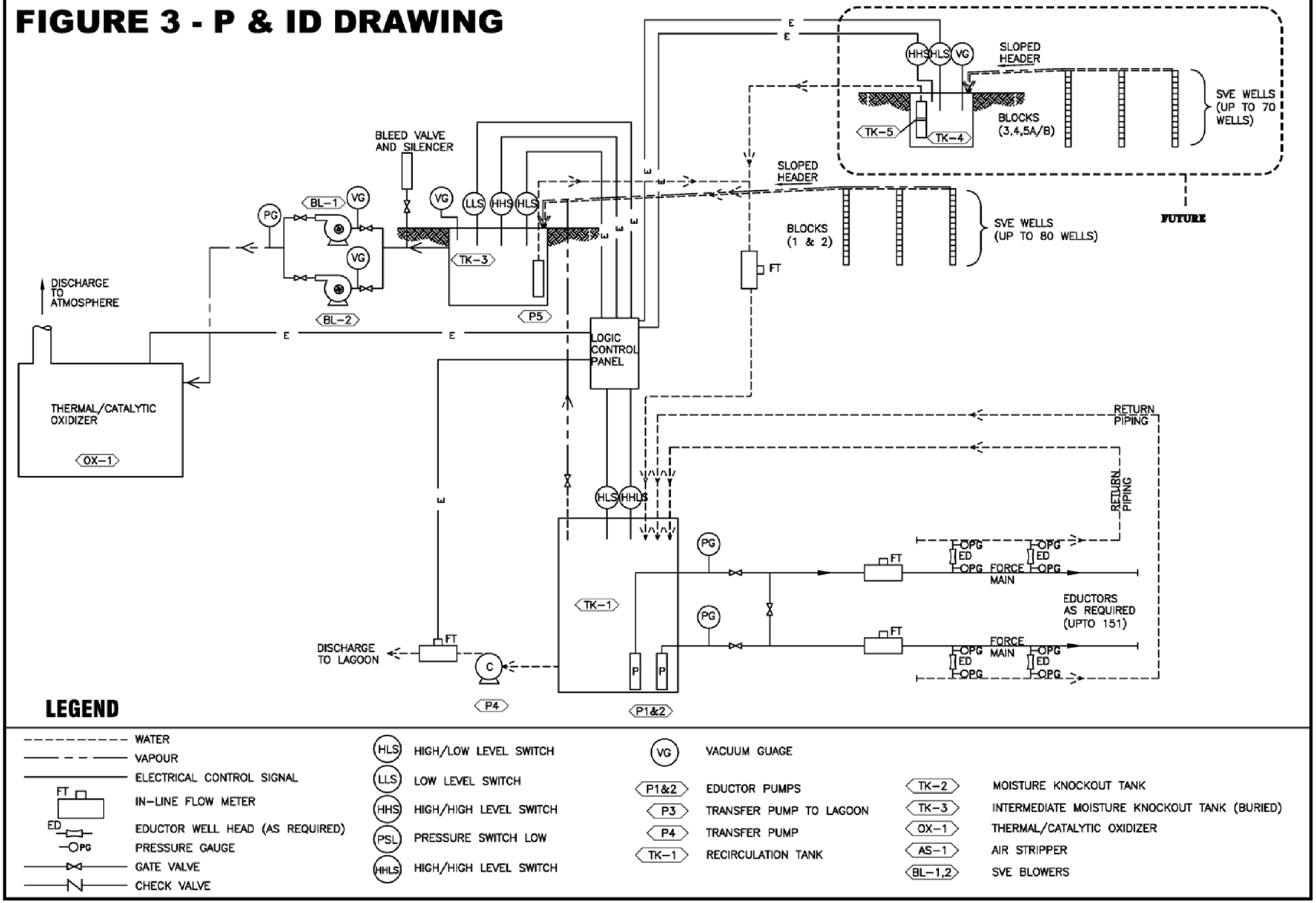
Piping Design

The dual phase recovery piping system is designed to have pressure losses no greater than approximately 1 in (25 mm) H_2O per 100 ft (30 m) of pipe. The piping slopes at 0.5 % slope toward the lowest point at the knockout tank. The furthest point away from the equipment area will be approximately 1000 ft (300 m) during the remediation of Block 4. An intermediate knockout tank and transfer pump will be necessary for the remediation of Blocks 3 and 4, as the supported piping height already exceeds 7 ft (2 m) at the furthest areas of Block 2. The intermediate knock out tank will create a new drainage point for the recovery piping in Blocks 3 and 4.

Supply and return eductor piping was sized based on the motive flow requirements and the expectation that air from the eductor wells would be entrained with the return piping. The dual phase return flow introduced the design consideration for additional pressure losses that resulted in 2 in diameter supply piping and 3 in diameter return piping. The eductor branch is a 1 in diameter flexible hose with a _ in (19 mm) eductor suction pipe.

Since the full system design approach is sequential from one Block to the next, the design incorporates the concept of reusing the dual phase and eductor piping from Blocks 1 and 2 for the remediation of Blocks 3 and 4.

FIGURE 3 - P & ID DRAWING



Remediation System Operational Issues

The first year of operation was plagued with equipment issues and system uptime was less than 50% with the majority of the uptime at less than full capacity (i.e. only one blower operating.) The first major issue dealt with was pipe vibration caused by the positive displacement rotary lobe blowers. The constant pulsing of the reciprocating blowers caused an irritating sound at greater than 100 dBA and, more importantly, caused weld failure of the oxidizer inlet plenum. The issue was resolved by the equipment supplier through the installation of vibration dampeners at the blower discharge.

When the system operation was switched to catalytic mode for the first time it was noticed that the oxidizer inlet pressure gradually increased over several days. Upon inspection of the oxidizer a film of fibreglass insulation was noticed on the catalyst surface. Apparently, the refractory fibreglass insulation was being carried with the airflow through the oxidizer to the catalyst surface. The fibreglass lining became problematic when physical entry was necessary to remove and install the catalyst. The oxidizer manufacturer corrected the problem using hardened fibreglass covered with stainless steel sheeting.

The most persistent maintenance issue was water carry over through the knock out tank to the rotary lobe blowers. The water carry-over resulted in the rebuilding of the blowers three times – one blower twice and the other once. The root cause of the water carry-over problem was the inefficiency of the knock out tank. Attempts to solve the water carry over problem included: modification to the knockout tank internal discharge shroud and demister; replacement of the paper particulate filter cartridges with non-paper filters, and; replacement of the internal submersible pump with an externally-mounted centrifugal pump. Finally, a secondary knockout tank was installed which solved the water carry-over problem.

Despite the performance limitations of the dual-phase system during the first year of operation, it was recognised that available wellhead vacuum was limiting the effectiveness of dewatering. The design groundwater flow rate from the dual phase system was 10 USgpm (39 L/min) or 30% of the total recovered volume; however, the actual flow rate was considerably higher at 21 USgpm (80 L/min), or 70% of the total recovered volume. The vacuum generated at the wellheads was being utilized more for water recovery than for vapour recovery as intended. It is believed that discontinuities in the underlying silt aquitard are greater than those modelled and cause increased groundwater upwelling from the confined lower sand unit. Moreover, the eductor system did not recover as much groundwater as predicted with the design modelling, as the vacuum-enhanced SVE wells are inherently more efficient for water entry than the gravitational gradient controlling water entry into the eductor wells. In any case, the empirical data suggested that more dewatering was occurring through the dual phase system than originally anticipated. As such, more energy was required to dewater the sand unit than was available using the existing equipment. The blower motors were upgraded from 15 hp to 40 hp each to allow the blowers to operate at up to (120 in or 3 m H_2O) vacuum. Contingency horsepower was added to allow for the future possibility of increasing vapour flow rate to 3000 scfm (85 m^3/min.) The power upgrades were initiated at the back end of Block 1 remediation in the summer of 2002.

The recovery of groundwater and vapours was also hampered in several areas of the site due to fouling in the recovery wells and suction piping. Sludge build-up also occurs in the eductor recirculation and knockout tanks. The fouling is primarily attributed to the presence of ferrous iron in the groundwater, and thought to be aggravated by the intermittent operation of the system during the first year. Process water sampling indicates up to 44 ppm total iron and 2 ppm benzoic acid. It appears that benzoic acid may be contributing to the fouling issue based on visual observation of precipitated benzoic acid crystals on the slurp tubes and in soil samples. Sample results indicate the sludge from the knock out tank contains up to 200 mg/kg benzoic acid and 50% iron.

Remediation Success

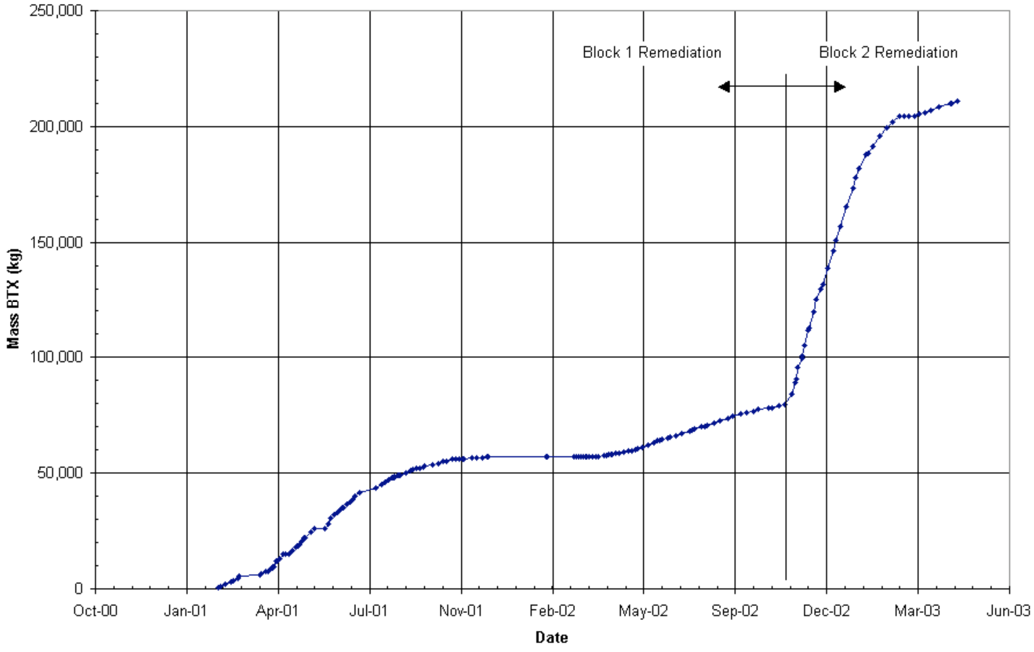
The remediation activities to date (mid-May, 2003) have removed an estimated 470,000 lbs (213,000 kg) of BTX from the subsurface within the SVE vapour phase. The vapour phase is calculated using a portable FID calibrated prior to each use with toluene calibration gas and correlated with periodic carbon tube samples for comparison. Vapours recovered to date have consisted of approximately 85% toluene, 6% benzene and 9% m-xylene. The total volume of water discharge to the Biox plant is approximately 11.9 million gallons (45,000 m^3). An additional 30,000 lb (14,000 kg) of BTX is estimated to have been recovered within the water phase.

Remediation of Block 1 is largely complete, although some local areas of soil and groundwater contamination require further treatment. Dewatering of the shallow aquifer has resulted in the mobilisation and migration of separate-phase BTX to the SVE wells. This has resulted in the migration of BTX across the boundaries separating Block 1 from Blocks 2 and 4. The BTX migration has delayed the remediation of soil along these block boundaries. The separate-phase BTX volatilises within the SVE piping and enters the oxidizer for treatment; it has not been necessary to install an oil-water separator within the treatment system. It also appears that a former product recovery sump in Block 1 has resulted in local high concentrations of soil contamination within the capillary fringe immediately above the silt horizon. Additional SVE wells have to be installed around the former sump. Should this not be sufficient, it may be necessary to undertake excavation in this localised area to meet remediation targets.

Overall, the mass of contaminants within Block 1 has been significantly less than prior estimates indicated. Approximately 180,000 lb (80,000 kg) of BTX have been removed from Block 1 to date; the prior estimate of mass within Block 1 was approximately 290,000 lb (130,000 kg.)

Block 2 operation commenced in October 2002. Block 2 remediation was begun from a largely dewatered state due to prior remediation of Block 1. The oxidizer was operated in thermal mode for 3 months, with the number of wells operating being restricted to limit mass loading during most of this time, and continues in catalytic mode since the change over in December 2002. Oxidizer operation in thermal mode proved to be highly effective during the initial 3 months of Block 2 remediation. The mass of BTX removed from Block 2 to date (290,000 lb or 130,000 kg) already exceeds the prior estimate of BTX mass within the block (approximately 240,000 lb or 110,000 kg.) Block 3 remediation is scheduled to commence in the fall of 2003.

Figure 4: Cumulative Vapour Phase BTX Extracted



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Biographical Sketches

R. Donald (Don) Burnett, M.Sc., P.Eng.

Mr. Burnett is a Senior Hydrogeologist with 17 years experience in the environmental industry in Canada. He obtained his M.Sc. from University of Waterloo in 1986. He is recognized as a technical expert in the evaluation and modelling (both 2-D and 3-D models) for groundwater flow and contaminant transport. His extensive knowledge of hydrogeological and hydrochemical behaviour of contaminants allows him to design field programs aimed at investigation, quantification, and remediation of contamination associated with subsurface soils and groundwater. He has specific experience in the design and execution of field investigation programs aimed at delineation and quantification of contamination associated with hydrocarbons, wood preservative chemicals, chlorinated solvents, metals and landfills.

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Christopher (Chris) P. Lach, P.Eng., MBA

Mr. Lach has 12 years experience in the environmental industry. Mr. Lach's area of specialty focuses on remediation system design with specialization in pilot scale testing, assessment of remediation options for groundwater and soil contamination, system design, specification, installation, and commissioning of full scale remediation systems. Mr. Lach's remediation system project management focuses on assessing and optimizing performance of operating systems, reducing costs and time for remediation. He has been involved in over 60 in situ remediation system designs located at petro-chemical bulk plants, service stations, refineries, railyards, airports, and wood processing plants.

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Alan D. Walker, P.Eng.

Mr. Walker is a Senior Project Manager with 15 years experience in site assessment and remediation of soil and groundwater at sites in British Columbia, Alberta, Ontario, Yukon Territory and the USA. He has been involved in sites which include rail yards, chemical manufacturing plants, refineries, bulk plants, mines, landfills, low level radioactive waste storage facilities, and sites whose historical industrial land use included incinerators, dip tanks, asphalt batch plants, galvanizing facilities, and paint and pesticide storage.

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