Client Testimonials

“We completed an in-situ pilot-scale application of the Ivey-sol surfactant technology at an industrial site with VC, DCE and TCE chlorinated contamination. We commenced site remediation with MPE with very good results, but eventually the rate of vapor, dissolved, and DNAPL phase mass recovery reduced over time. The introduction of Ivey-sol significantly increased mass recovery of all phases, leading to our decision to go to full scale, pairing the MPE and Ivey-sol technologies as an effective remediation strategy for the site”

Dennis Tu, Executive Director Remediation

AECOM

“We increased the TPH Mass Recovery Rate by 10x, removed TPH-d from vadose zone and lowered groundwater concentrations. Regulatory Agency agrees to a risk based closure in contamination levels continue to decrease”

Galen Kenoyer, Senior Hydrogeologist
Chris D’Sa, Senior Project Manager

TRC
Results you can rely on

We have been operating a dual-phase vacuum extraction (DPVE) system at an active grain elevator for approximately 9 years to address a groundwater source area consisting of carbon tetrachloride, carbon disulfide, and chloroform. In 2015, Burns & McDonnell conducted a pilot-scale application of Ivey-sol surfactant in an effort to enhance DPVE efficiency and recover the remaining source area contamination at the site. The pilot study indicated significant increases in contaminant mass removal. As a result, Burns & McDonnell conducted a full-scale surfactant application, consisting of up to 275 gallons of surfactant mixed to approximately 1 to 2-percent by volume, to the source area in late 2016. The introduction of the Ivey-sol surfactant significantly increased dissolved-phase mass removal and the effects of this increase on DPVE efficiency were observed up to 6 months after the application. During both the pilot and full-scale phases, existing DPVE infrastructure was utilized to complete the surfactant delivery and recovery, thus significantly reducing the cost of remediation. Burns & McDonnell was very pleased in the performance of the Ivey-sol surfactant and continued support by Ivey-sol staff.

Eric Dulle, PE, Project Manager

BURNS & McDONNELL

At an EU military site the UTCHEM model was able to simulate the Pilot SEAR and that injected fluids were contained within the pilot application area. Further, the simulations estimated an approximate 1000 % increase in jet-fuel oil mass recovery with the application of the Ivey-sol® surfactant technology, compared to a water injections without Ivey-sol®. The model also showed that the main process for mass removal during SEAR was production of a micro-emulsion.

Soren Rygaard Lenschow, Project Manager

NIRAS

“The in-situ application of the Ivey-sol surfactant technology significantly increased the DNAPL and BTEX mass recovery from the impacted soil and groundwater on-site. We were very pleased by these results leading to our recommending a full scale site application as a rapid and cost effective method to achieve site clean-up”

Martin Beaudoin, Project Engineer
Sanexen Environmental Services Inc.

“Ivey-sol has been proven highly effective at remediating both oil-based contamination and chlorinated solvents in a variety of different soil types, ranging from sands to clays. Given the current need for innovative and cost-effective cleanup technologies, usage of Ivey-sol will significantly increase in the upcoming years.”

Bruce Tunnicliffe, President

“We accomplished more with $50,000 of Ivey-sol than we did with the first $500,000 we spent on the site over the previous 4 years. Ivey-sol Increased our rate of contaminant recovery by >400%”

Daniel Smith, Hydrogeologist - HANDEX of Connecticut

“Using low concentrations of Ivey-sol solution, free product was successfully removed from shale. Soil shale washing with Ivey-sol is a cost-effective technology for on-site treatment of impacted soils. Based on the parameters above, projected treatment price for a small scale project (< 2,000 tones) would be $35 per ton, which is currently less expensive than disposing of the impacted material at a landfill and replacement with clean fill. Obviously, with larger projects, the economies of scale will drive the price down even lower”

Kyle Dacey, Manager of Technical Services - Terratechnik Environmental Ltd.

“The project we are now working on is in tight clay soil, 6 meters deep, 35 meters by 20 meters in area. The projected clean-up will be 9 to 12 months. This is very fast compared to any other in-situ process that we are aware of. The only thing faster is digging up the site and hauling away the soil.” “This process is very cost effective and will save between $40,000 to $60,000 compared to the closest available technology that we are aware of.

Terry Timothy, Manager of Environmental Services - Key Safety Services Inc.

“I credit this technology with saving my company tens of thousands of dollars after using it to treat a fuel-oil spill. Drinking water was contaminated and I looked at a number of technologies. They wanted to put recovery towers in and stripper systems costing more than $100,000, and I was told remediation would take five to seven years. But Ivey-sol did it in less than 18 months saving some $60,000, while meeting stringent environmental standards.”

Peter Clark, President

“After excavation and bio-piling of the soil, the surfactant enhanced bioremediation (SEB) treatment was applied and the bio-pile was covered. Daily aeration was done during the treatment period. After only 12 weeks samples were taken from the bio-pile showing that the remediation of the fuel-oil and PAH contamination was completed to the BC Environmental Standards and safe for reuse on-site”

Tony Robson, Director Mining & Equipment

“We used a combination of Ivey-sol technology and soil excavation. It certainly saved us the headache of having to do more by way of foundation excavation. The result was the important thing. Ivey-sol was a good add-on to the original excavation and we got the results we wanted”

Mike Roy, Senior Claims Adjuster - Plant Hope Adjusters Ltd.

“The name of the game is satisfactory results and closing the file as quickly as possible. Ivey-sol technology is a big help when excavation isn’t an attractive option”

Bill McCann, Senior Claims Adjuster - Halifax Insurance

“Our research has confirmed that the Ivey-sol surfactant technology increases the controlled solubility and rate of MTBE recovery from impacted soil and groundwater by >740%”

Dr. Davis Craft, University of Alberta

“We observed a noticeable drop in the level of contaminants within a two-month period”

Brad Shybunka, S.Sc., P.Ag., Senior Project Manager Operations
Bio-Synergy Resources Inc.

"We used Ivey-sol surfactant technology and experienced greater than 400% enhancement of contaminant mass recovery! This technology significantly sped up remediation saving my clients time and money! We were very pleased with the results and would recommend others to try it"
Dan Smith, Principle Hydrogeologist, Metric Earth Services, LLC

METRIC
EARTH SERVICES

"Our research has shown that the Ivey-sol surfactant technology can increases the controlled solubility rate of PCB into groundwater for mass recovery by >900%"

UNIVERSITY OF
ALBERTA

"We had to evacuate the building after the oil spill, it was a mess. Ivey-sol cleaned up the site up rapidly. It improved the air, soil and groundwater quality"
John Vidditto - Developer/ Property Owner

"I think the future for the Ivey-sol surfactant technology is bright. It's based on sound science and Ivey International Inc. has lots of field application experience"
Lisa Rear, P.Bio., Environmental Consultant

For more information about the Ivey-sol® surfactant technology, and learn about our other innovative remediation technologies, or to find a local distributor or obtain free technical support, please visit www.iveyinternationa.com

AWARDS

Ivey International Inc. has achieved international recognition for the development of several innovative remediation technologies to treat contaminated vapor, soil and groundwater. It has been nominated for and received several national and international environmental awards. A few of these accomplishments have been listed below for your review.

For more information about the company and the products we market globally, please visit www.iveyinternational.com.

2018 2018
The CV Business Awards - **Best Environmental Tech Development Company Award 2018** (February 2018).

2011
The 2011 **MYSTIC Environmental Excellence Award** For Innovative Remediation Technology Development (November 4, 2011).

The 2011 **Roy F. Weston Award** at the 26th International Conference on Solid Waste Technology and Management in Philadelphia, PA, USA. (March 26, 2011).

2008
The 2007 **Environmental Business Journal Bronze Award** Technology Achievement (February 20, 2008).

2007
The 2006 **North American Frost & Sullivan Award** for Technology Innovation (February 7, 2007).

The 2006 **Environmental Business Journal** Remediation Technology Merit Award (February 28, 2007).

2006
The 2006 **Globe Award** for Environmental Innovation and Application (March 31, 2006).

2005
In 2005 George A. Ivey, was inducted as a **Leading Scientist of the World**, in the field of Science & Engineering, by the International Biographical Centre, Cambridge, England.

2004
In 2004, Ivey International Inc. was a **National Finalist** for a National Canadian Urban Institute (CUI) **Brownfield Remediation Award**.

1.0 CHALLENGE & OPPORTUNITY

Normally hydrophobic organic chemicals (HOC), including low (i.e., BTEX and Gasoline), medium (i.e., Diesel and PAH), and high (i.e., Motor Oil, Lubricants, Bunker-C) molecular weight petroleum hydrocarbon contaminants (C_6 to C_{50} range) exhibit limited solubility in groundwater, and as a result, these contaminants tend to partition and sorb (i.e., absorb and/or adsorb) onto the soil or bedrock matrix surfaces, and at high concentrations, they may form a free floating sheen or droplets (NAPL). For the purpose of this proposal HOC will be interchangeable COC.

COC sorption and/or the formation of NAPL (free product) will limit the *‘Availability’* of HOC for in-situ remediation. Hence they are less *‘Physically Available’* for pump and treatment methods; less *‘Biologically Available’* for bioremediation, and less *‘Chemically Available’* for chemical REDOX type chemical treatment. Hence COC’s (i.e., sorbed, dissolved, and/or free phases) can persist in soils, sediments, and fractured bedrock and/or groundwater systems for extended periods of time. This explains why some remediation projects are slow, costly and/or fail to achieve site remediation objectives.

A concern regarding contaminant sorption, and its reduced availability for remediation, has been well cited in literature as demonstrated by the following sample quotation:

> *“During the past decade, much discussion has centered on the unavailability of absorbed compounds to soil microorganisms; it is generally now assumed that desorption and diffusion of bound contaminants to the aqueous phase is required for microbial degradation.”*
>
> *(W.P. Inskeep, J.M. Wraith, C.G. Johnston, Hazardous Substance Research Center, 2005).*

Generally, if we can overcome COC contaminant sorption and/or NAPL formation, we can improve all forms of in-situ and ex-situ physical, biological, and chemical - air (vapor), soil, and groundwater COC remediation.

The application and use of Ivey-sol® surfactant products and processes provided a unique methodology to enhance COC remediation at many sites globally. This is evidenced by many conference paper and poster presentations, peer reviewed journal publications, published case studies, magazine articles, and client testimonials (See Appendix).

1.1 FIELD SCALE OBJECTIVE

The in-situ Ivey-sol® remediation approach would be based on a *'Push-Pull™'* application method (See Section 3.0) to reduce observed petroleum hydrocarbon COC mass in the soil, groundwater table, and within the associated COC smear-zone (to extent present) above and below the static groundwater table elevation. The main focus will be on remediation of COC's to the applicable regulatory (OVAM) clean-up guidelines.

For the observed COC petroleum contamination at the subject site, the Ivey-sol® 103 and 106 formulations (50:50) would be well suited for the proposed in-situ remediation (Assume equal volumes of each product). This recommendation is based on the following IVEY guidance reference table:

Contaminant of Concern (COC)	Ivey-sol® Formulation Required
BTEX, Gasoline, Jet Fuel	**103**
Diesel (Light-Medium Heavy), PAH	**106**
Chlorinated Solvents (DNAPL, API <10)	**106 (CL)**
Motor Oil, Lubricants, Bunker-C	**108**

Note: For contaminants of concern (COC) not listed above contact IVEY directly.

2.0 IVEY-SOL® SURFACTANT TECHNOLOGY

This section will describe the Ivey-sol® surfactant technology and will include a range of in-situ and ex-situ applications, advantages and disadvantages, and the science of how it works.

2.1 IVEY-SOL®

Ivey-sol® Surfactant Technology is comprised of several patented and/or proprietary non-ionic surfactant formulations that have the unique ability to selectively desorb sorbed (i.e., absorbed and/or adsorbed) COC, and make NAPL miscible in the aqueous phase. This includes the broad range of Light Non Aqueous Phase Liquids (LNAPL) like petroleum hydrocarbons (API >10), and the Dense Non Aqueous Phase Liquids (DNAPL) including chlorinated solvents (API <10). Ivey-sol® has also been used for the remediation of recalcitrant compounds within fine to coarse soil textures, marine sediments and fractured bedrock, and within the groundwater table and associated smear-zone, with favorable results.

The three (3) main Ivey-sol® application processes that were developed over two (2) decades for enhancing in-situ and ex-situ remediation of: vapor/VOC, soil/bedrock (sorbed), and groundwater (dissolved, NAPL, smear-zone) COC site remediation, are outlined as follows:

■ **SER®** **Surfactant Enhanced Remediation**

In-situ and ex-situ application processes to liberate sorbed and/or NAPL COC making them more miscible (soluble) and more '*Physically-Available*' for mass removal via '*Push Pull™'* or 'Pump & Treatment' type remediation methods. It is also very effective for ex-situ soil washing of COC for soil texture with >85-90% coarse textures.

■ **SEB®** **Surfactant Enhanced Bioremediation**

In-situ and ex-situ application processes to liberate contaminants making them more '*Biologically Available'* for microbial (bacteria) and associated enzymatic degradation. SEB® improves both in-situ and/or ex-situ bioremediation treatment methods including bio-stimulation, bio-augmentation and newer enhanced biological techniques for aerobic, anaerobic and facultative microorganisms.

■ **SEC®** **Surfactant Enhanced Chemicalization**

In-situ and ex-situ application processes to liberate contaminants making them more *'Chemically-Available'* for chemical REDOX (i.e. Reduction or Oxidation or combined) by chemical agents. SEC**®** improves the availability of the contaminants to the chemical REDOX, facilitating improved contact and reaction kinetics, to enhance the associated in-situ and/or ex-situ chemical reagent degradation of target COC. This process may also be modified for application with chemical REDOX reagents for ex-situ soil applications for a broad range of COC.

2.2 IVEY-SOL® WATER CLUSTER SIZE REDUCTION

Ivey-sol**®** surfactants, when introduced into contaminated soil and groundwater regimes, can reduce the surface tension of water from 73 dynes to <30 dynes. This capacity improves the wetting ability of the water phase in the soil and groundwater (unsaturated and saturated) zones, and improves its relative *'Hydraulic Conductivity*' (K) while Ivey-sol® is present.

The Ivey-sol**®** surfactants accomplished this by reducing the size and formation of large water-clusters to smaller water-clusters (See Figure 2-1). In doing so, the Ivey-sol® allows the water to penetrate into less permeable soils such as: clays, silty-clay, silty-sand, sands with silty and clay content to fractured bedrock, improving COC remediation.

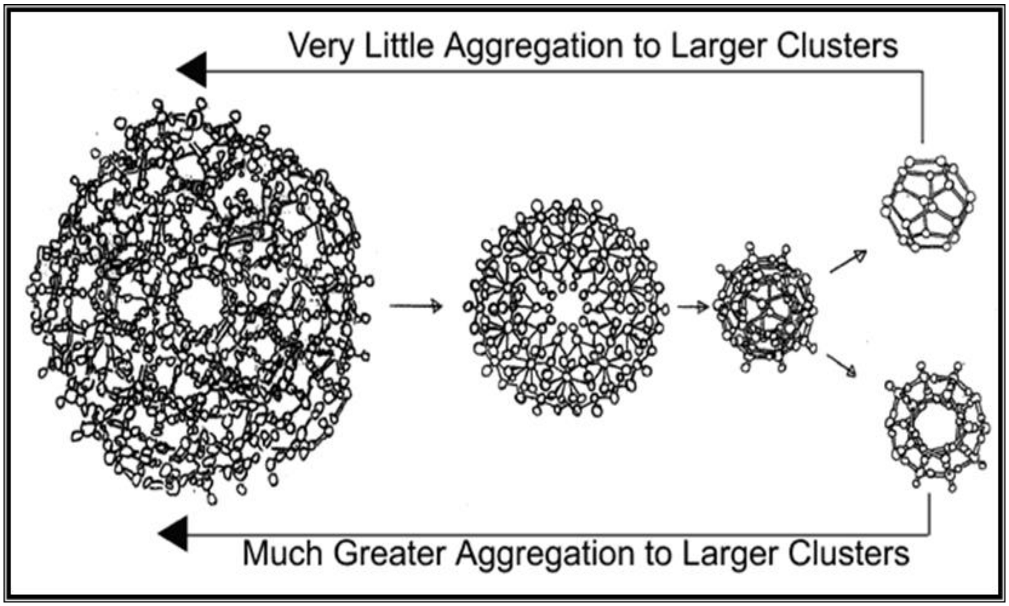


Figure 2-1: **Ivey-sol® reducing water cluster size (Lower surface tension) Improved Injection Penetration Within In Fine Geology**

2.3 ADVANTAGES AND DISADVANTAGES

As detailed in the above sections, Ivey-sol® makes the desorbed contaminants more *'hydraulically-available'* for extraction by in-situ '*Push-PullTM'*, Pump and Treatment and ex-situ Soil Washing; more *'bio-available'* for Bioremediation (in-situ and/or ex-situ); and by increasing the dissolved aqueous-phase contaminant concentrations which improves their *'chemical-availability'* for Reductive-Oxidative (REDOX) chemical treatment (in-situ & ex-situ).

Through scientific product and process design, the Ivey-sol® technology has inherent application flexibility not common to most remediation technologies.

By way of example, TERRACORRECT could commence a physical *'Push-PullTM'* mass recovery approach, and if site conditions permitted, then flexibly modify the remediation strategy to include in-situ SEB® and/or in-situ SEC® and/or conclude site closure by conventional MNA (Monitored Natural Attenuation).

Completing site closure by completing a risk assessment is also an option for site, and may be considered after initial in-situ remediation using Ivey-sol® and the COC concentration have declined significantly.

The following table lists several advantages and disadvantages associated with the Ivey-sol® technology.

Advantages:

i) The Ivey-sol® products are non-toxic and biodegradable, so they do not persist in the environment after application;
ii) Improves contaminant mass recovery for in-situ P&T or *'Push-Pull™'* by > 400 to > 1000%, for LNAPL (LNAPL) and DNAPL contamination;
iii) Improves in-situ and ex-situ soil and water bioremediation by 40-60% or more;
iv) Improves chemicalization (REDOX) so 25% to 75% less chemical reagents are required, saving time and treatment costs;
v) Does not negatively affect water treatments stems (i.e., O/W Separators, GAC, Zeolite, Air Stripping, Membrane Separation, Bio-reactors, Organo-clay, etc.).
vi) Not toxic to bacteria, so can aid and/or improve natural attenuation;
vii) Reduces required treatment times when used in conjunction with other remediation technologies (i.e., P&T, bioremediation, chemical REDOX);
viii) Works well with duel phase extraction, vacuum extraction, and conventional P&T;
ix) Works well in fine grain soil textures (i.e., silty sand, silt, silty clay, clay and fractured bedrock);
x) Does not generate additional O&M issues;
xi) Applicable for the full range of LNAPLs; has been demonstrated to be very effective on most DNAPL contaminants, and several heavy metals (organometallic's);
xii) Can be applied to saturated and/or unsaturated zones.

Disadvantages:

i) Extraction and treatment equipment can be expensive when used with P&T;
ii) If the mixture freezes (below 0 ºC or 32 ºF) during storage and/or handling, it's effectiveness may be reduced;
iii) Generally not intended for NAPL recovery greater than 10 to 12 inches in thickness (25 to 30 cm), as other free product recovery methods are initially more appropriate to implement. [*Note: Ivey-sol has been used on 2 ft. to 4 ft. (0.6 m to 1.2 m) NAPL with success*];
iv) With improved contaminant liberation, the site may go through more GAC or Zeolite or contaminant treatment absorbent than originally planned;
v) If monitoring VOCs during remediation, Ivey-sol® may suppress VOCs, making them less detectable by standard handheld vapor meters. [*This may aid temporary VOC reductions where in-door air quality is a remediation driver];*
vi) When used for SEC®, the Ivey-sol® may consume some of the REDOX reagents being introduced *[Although limited as application concentrations are generally below the CMC - Critical Micelle Concentration];*
vii) During SER®, and effective improvement in mass recovery, bacterial pluming in the soil and groundwater regimes may be observed. When not anticipated it can result in the clogging of well screens, and or bacterial slime buildup in the GAC units lowering the treatment flow rates. This can be resolved using surge block and/or chemical disinfection, if required. [*This may also indicate the opportunity for SEB® and or MNA strategies*].

2.4 IVEY-SOL® MECHANISM

The Ivey-sol® surfactants can selectively desorb and/or dissolve (i.e. make miscible) COC at the molecular level, as microscopic *'surfactant-hydrocarbon-water'* partial non-encapsulations, called partial micelles, well below the critical micelle concentration (CMC).

Through selective desorption and dissolution, below the CMC, Ivey-sol® significantly increases the availability of the subject contaminants for all forms of in-situ or ex-situ remediation. The Ivey-sol® mechanism is illustrated in Figure 2-2 below.

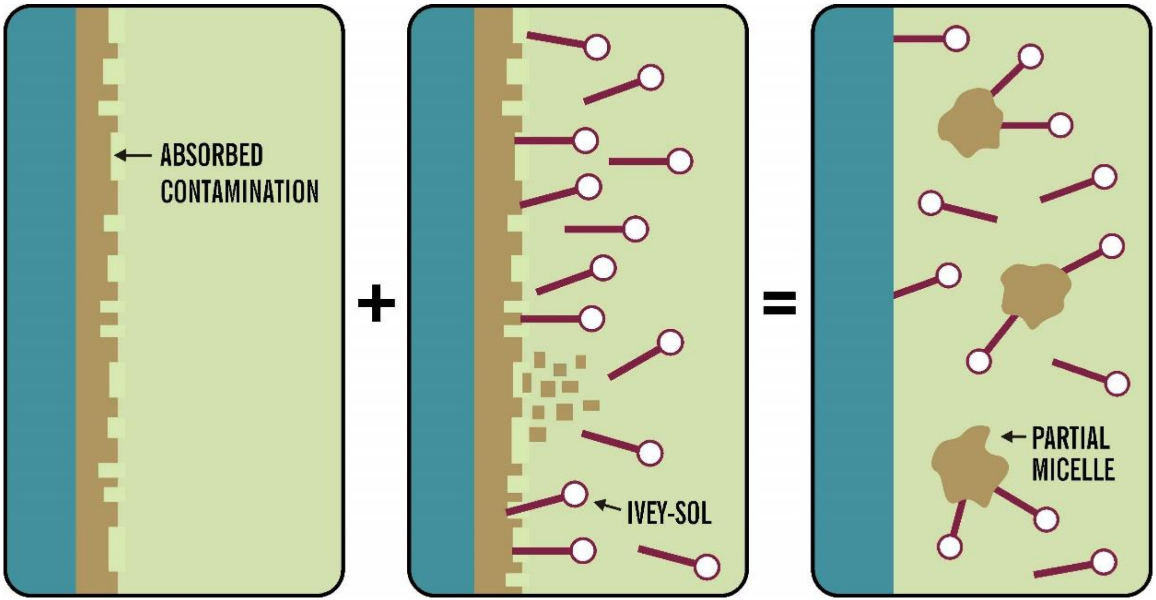


Figure 2-2: Ivey-sol® desorbing contamination off the soil surfaces, or from LNAPL layer making it more 'Available' for in-situ or ex-situ remediation.

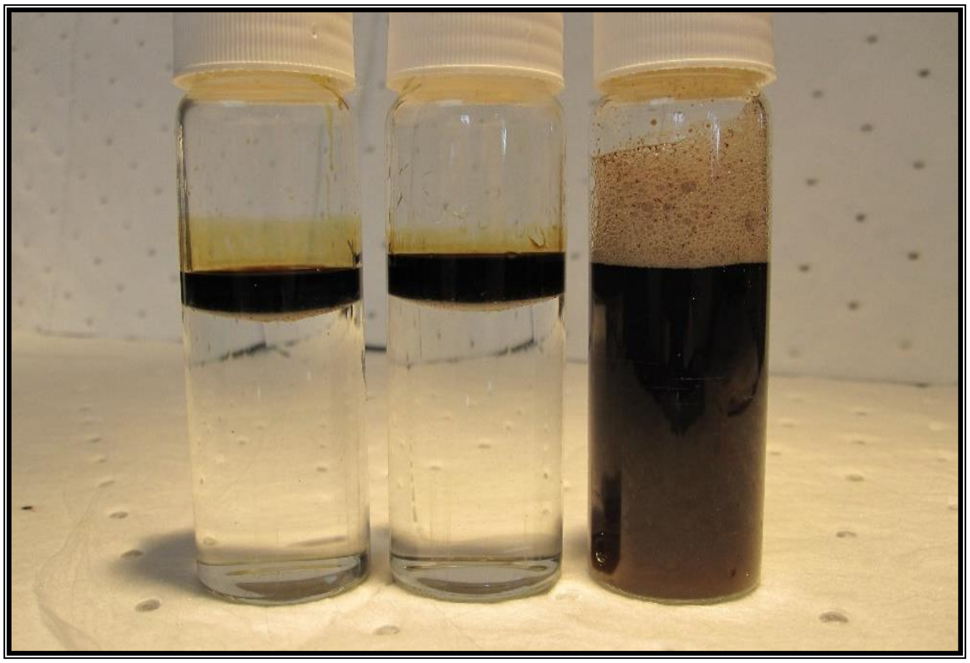
2.5 IVEY-SOL® APPLICATIONS

This section provides a higher level indication of Ivey-sol® effectiveness for treating COC with contaminated soil, bedrock and saturated and groundwater regimes.

Photograph 2-1 below shows contaminated soil from a petroleum refinery site that was treated using Ivey-sol® in an ex-situ soil washing remediation process. The baseline soil concentrations ranged from 30,000 ppm to 40,000 ppm while the post treated soils TPH (C_6 to C_{50}) concentration were consistently <500 ppm after five (5) to seven (7) minutes of treatment.

Photograph 2-1: Pre-post Ivey-sol® Remediation of Refinery Soils

Photograph 2-2 shows free phase product that was treated using Ivey-sol® in an in-situ soil washing *'Push-PullTM'* remediation process. The baseline dissolved concentrations were increased by >1000% following the Ivey-sol® application.



Photograph 2-2: Pre-post Ivey-sol® Free NAPL (LNAPL) Remediation

Photograph 2-3 demonstrates Ivey-sol® increasing the miscibility of DNAPL contamination in groundwater resulting in a greater than 600% increase in DNAPL contaminant mass recovery being observed at the subject site.

Photograph 2-3: Pre-post Ivey-sol® DNAPL Remediation. Increasing the miscibility of the DNAPLs in the groundwater phase for enhanced extraction (i.e., PCE, TCE, CTC, PCB, etc.)

In brief, an Ivey-sol® application accomplishes three (3) feats. First it overcomes the *'Limitation'* challenges associated with contaminant sorption and low solubility. Secondly it lowers the relative surface tension of water improving both its wetting and associated hydraulic conductivity (K) properties, while the Ivey-sol® is present across a broad range of soil textures. Third, through its selective dissolving of contaminants (COC) below the CMC, it broadens the range of contaminants that can be treated and enhances in-situ and ex-situ physical, biological, and chemical remediation methodologies.

3.0 IVEY-SOL® *'PUSH-PULL™'* APPLICATION APPROACH

This section will detail the application of the Ivey-sol® surfactant products, that would be employed in an in-situ *'Push-Pull™'* SER® strategy to help eliminate observed COC soil sorbed and/or dissolved groundwater impacts and/or NAPL within the smear zone localized to groundwater elevation fluctuations at a typical site.

The following image (Figure 3-1) illustrates the *'Push-Pull™'* in-situ approach using Injection Wells (IW) designed and installed to target the Ivey-sol® injections into the subsurface zone(s) of identified. This would make said contaminants more miscible in groundwater, whereby they are more *'Available'* for physical mass extraction at the same IW locations, and/or at nearby Extraction Well/Recovery Well (EW/RW) locations, and/or IW '*Push-Pull*^{TM}*'* well locations (Figure 3-1).

IVEY generally recommends, where existing infrastructure is limited, the installation of 4 inch (100 mm) diameter injection wells (IW), screened across the COC plume, to improve the Ivey-sol® *'Push-Pull*^{TM}*'* applications injection diffusion radius (idr) resulting in improve COC plume contact. Further, these larger diameter IW can serve as multi-purpose wells; used for the Ivey-sol® injections, can be employed as extraction/recovery wells, and later as post-remediation monitoring wells to help facilitate regulatory site closure. This type of IW is referred to as a *Triple-Use* well by IVEY and only cost 10% to 15% to install than 2 inch (50 mm) wells.

The Ivey-sol® '*Push-Pull*^{TM}*'* process is generally easy to apply, and often a very effective method to remove sorbed phase, dissolved phase and free phase (i.e. LNAPL, DNAPL, and PSH) contaminant mass within in-situ environments.

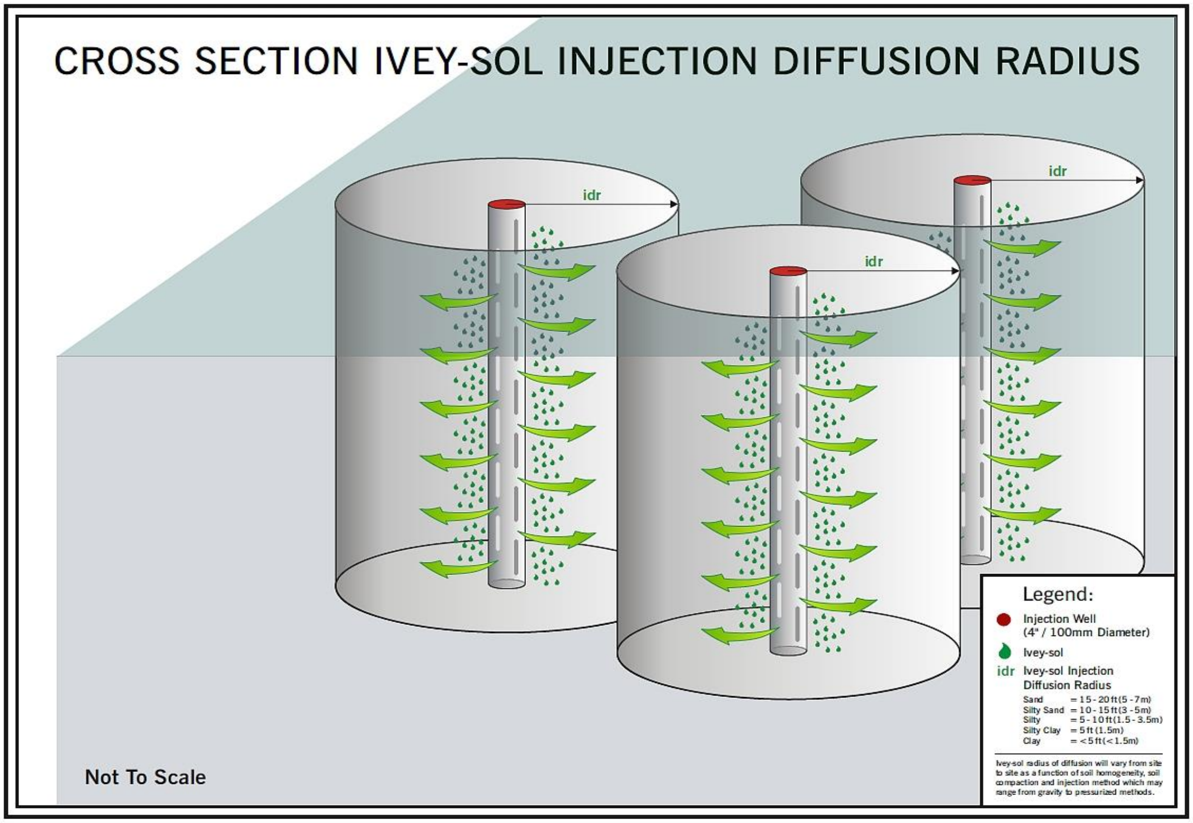


Figure 3-1: **Ivey-sol® *'Push-Pull*^{TM}*'* injection event at IW locations allowing a broad area of remediation application and depth intervals which can be enhanced using low pneumatic I-Packers^{TM} developed by Ivey International Inc.**

Figure 3-2 illustrates a typical field scale Ivey-sol® '*Push-Pull*™' application with anticipated idr shown for the injected Ivey-sol® associated with each injection *'Push'* which after allowing a prescribed *'Contact Time'* is extracted - *'Pull'* - from the IW and RW locations. The idr values shown in the legend are based on 100 mm (4 inch) diameter wells, so should be viewed as conservative, as several site specific variables (i.e. soil texture, compaction, groundwater elevation, K, contaminant type, porosity, etc.) would affect the actual idr realized at different site settings.

When the IW's are 100 mm (4 inch) in diameter, they have a Triple-Use value at the site as detailed above. In addition to making a very good IW, which can be more broadly spaced apart than 50 mm (2 inch) diameter IW's, they can serve as temporary extraction/recovery wells locations allowing for small diameter submersible pumps to easily fit inside the well casings, as well as permitting a standard 50-75 mm (2.5 inch) vacuum truck intake hose entry which is not possible for small diameter wells. Once remediation is concluded, the IW's can be repurposed as MW locations to aid in the final site evaluation and regulatory closure monitoring process of the project.

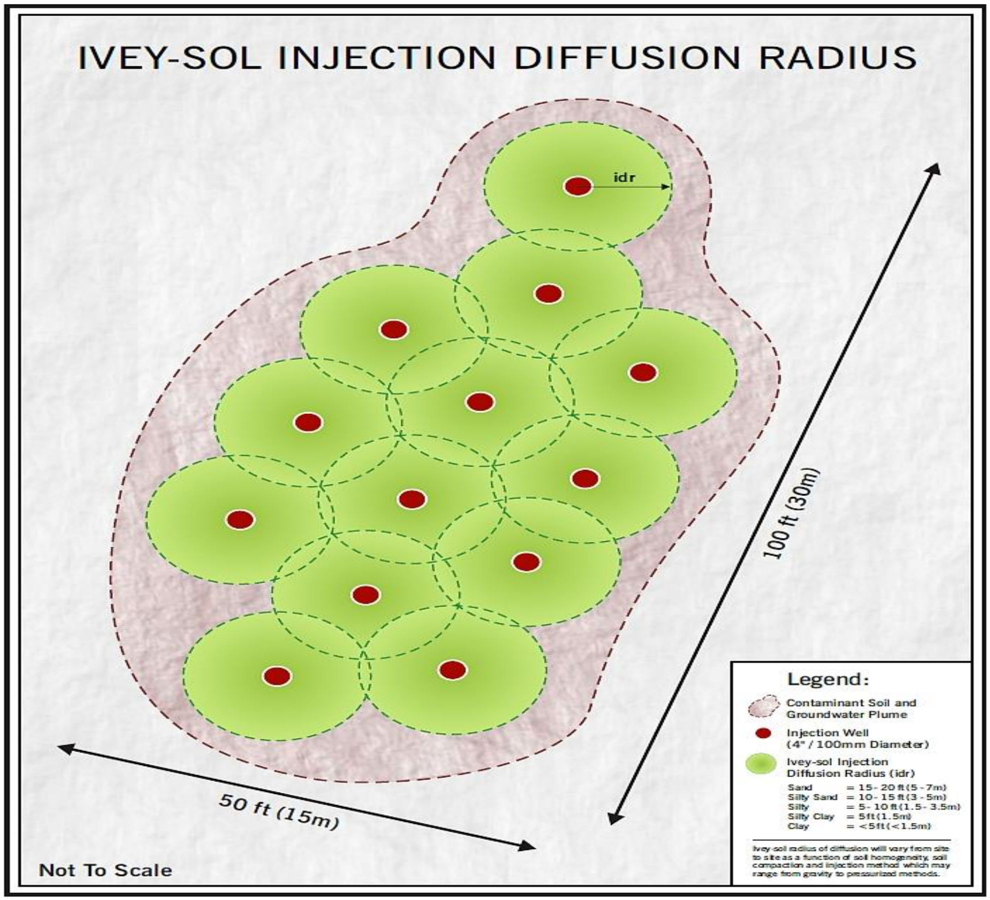


Figure 3-2: **Ivey-sol® *'Push-Pull*™*'* injection event with idr at IW locations that achieve good contact with the contaminant plume.**

3.1 IVEY-SOL® '*PUSH-PULL*™' ANIMATION

Animations depicting typical in-situ Ivey-sol® *'Push-Pull'* applications to desorb COC's sorbed to soil and bedrock surfaces, dissolution of dissolved and free phase (NAPL) contaminants into the groundwater.

This occurs in the vicinity of IW locations, following a '*Push*' injection, and after a brief contact time (hours to days). The liberated contaminants are then extracted at each IW, for the '*Pull'* to recover the liberated contaminant (COC) mass.

For most sites, only a limited number of *'Push-Pull*™*'* events are required to achieve site remediation goals. They can be complete daily, to weekly, to monthly depending on the project logistics. The web based 3-demensional animation link is available as follows:

http://www.iveyinternational.com/videopresentation

For more site application information, complete a site evaluation form and contact Ivey International Inc.

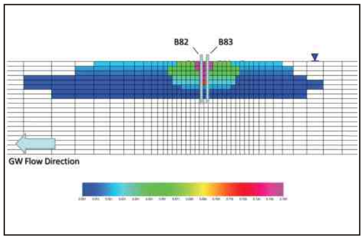
George A. Ivey, B.Sc., CES, CESA, P.Chem, EP
President and Senior Remediation Specialist
Mobile: + 1 250 2033 0867
Email: budivey@iveyinternational.com

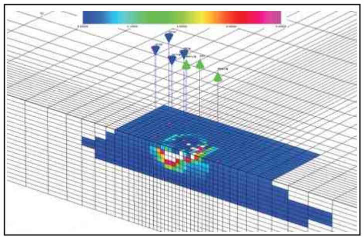
SETUP AND CALIBRATION OF A THREE-DIMENSIONAL NUMERICAL MULTIPHASE MODEL FOR DESIGN OF IN-SITU REMEDIATION OF JET FUEL WITH SURFACTANT

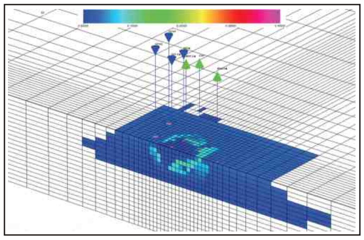
BACKGROUND

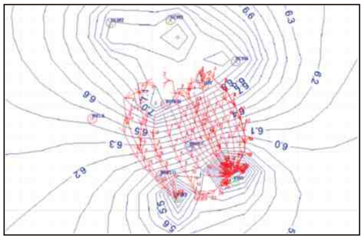
Storage and pumping of jet-fuel have caused a severe contamination of soil and groundwater at a military facility in Denmark. The contamination was detected in 2001. The Danish Defence has conducted a series of investigations and set up a skimmer system, that has recovered approximately 25 m^3 of jet-fuel. In 2005, the recovery stopped, and the remaining jet-fuel is trapped as a residual light non-aqueous phase liquid (LNAPL) comprising approximately 45 m^3 jet-fuel in a 1000 m^2 source area. In the ground water downstream of the source area, there is an extensive diving plume of contaminants.

In part of the source area, the Danish Defence and NIRAS have launched a pilot Scale Surfactant Enhanced Aquifer Remediation (SEAR) in order to demonstrate mobilization of LNAPL from the sediment. The pilot remediation was carried out using non-ionic surfactants (Ivey-sol®) from Ivey International Inc. for injection in a line of injections wells. The mobilized oil and injected surfactants were recovered from a downstream line of extraction wells. The recovered oil/ground water was treated on site, and the treated water was re-injected up-gradient in a line of hydraulic control wells. The effect of the pilot SEAR was monitored by sampling and analyzing the ground water from the extraction wells and by estimation of trapped jet-fuel in an oil-water separator as part of the on-site treatment, supplemented by post soil sampling/analyses from boreholes. The 3 different methods gave different results for the mass balance, and the estimated effect of the pilot remediation ranged from 25 kg to 150 kg of hydrocarbons.









Søren Rygaard Lenschow,
Anders G. Christensen
NIRAS A/S, Allerød,
Denmark

Mette Marie Mygind
Danish Defence, FBE,
Hjørring, Denmark

Ahmad Seyedabbasi,
Phillip C de Blanc
GSI Environmental Inc.,
Houston, TX, USA

George Ivey
Ivey International Inc.
Surrey, BC, Canada

NIRAS

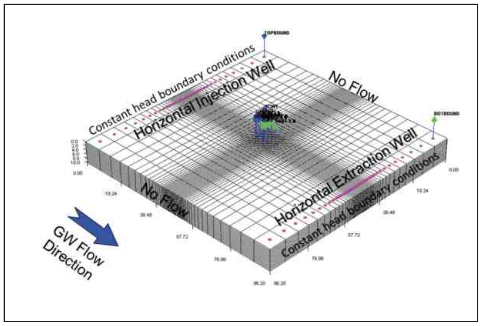
GSI ENVIRONMENTAL

Ivey International Inc.
"Today's Environmental Solutions For A Better Tomorrow"™

WATER BALANCE

- Extraction – 12 m^3/day (0.5 m^3/h)
- Reinfiltration – 8 m^3/day (0.33 m^3/h)
- Injection 0.15 – 1 m^3/day
- Discharge – 4 m^3/day (0.17 m^3/h)
- Hydraulic control – 2 weeks
- 7 injections of Ivey-sol® (0.15 – 1.0 m^3 – 1.3 – 3.0 % surfactants)
- Hydraulic control for 7 weeks post injection

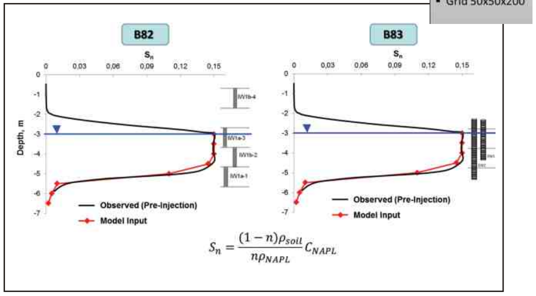
To validate the effect of the Pilot Remediation, GSI Environmental Inc. has set up a three-dimensional numerical multiphase model by using the University of Texas' Chemical Compositional Simulator UTCHEM.



SETUP UTCHEM

- Input – vertical oil saturation based on soil samples

- dx = dy = variable
  - Min = 0,5 m (center)
  - Max = 7,7 m (boundaries)
- dz = 0,5 m
- 100 m x 100 m x 10 m
- Grid 50x50x200



$$S_n = \frac{(1-n)\rho_{soil}}{n\rho_{NAPL}} C_{NAPL}$$

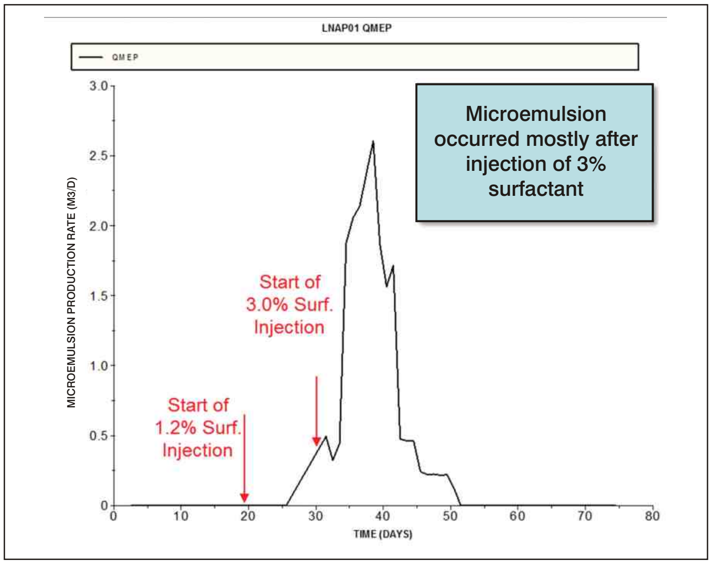
SIMULATIONS UTCHEM

- 70 days – Injections of Ivey-sol® surfactants from day 20 to day 27
- 7 injections of surfactants – 1.3 – 3.0% Ivey-sol®
- Oil saturation as function of time
- Accumulated oil from extraction wells
- Capture of surfactants in extraction wells
- Comparison of simulations with no injection of surfactant

SETUP AND CALIBRATION OF A THREE-DIMENSIONAL NUMERICAL MULTIPHASE MODEL FOR DESIGN OF IN-SITU REMEDIATION OF JET FUEL WITH SURFACTANT

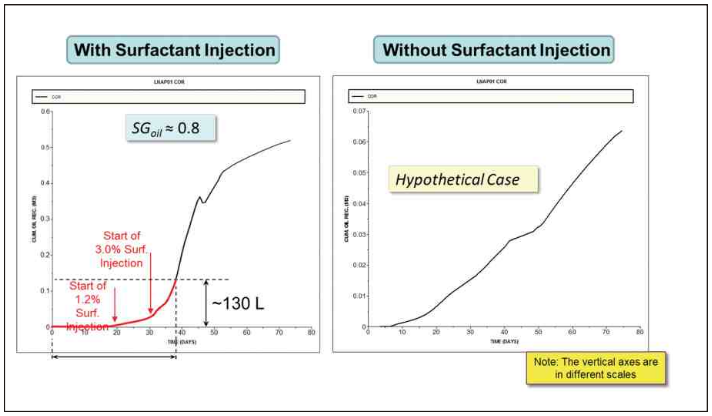
RESULTS

- Formation of micro-emulsion during Pilot SEAR



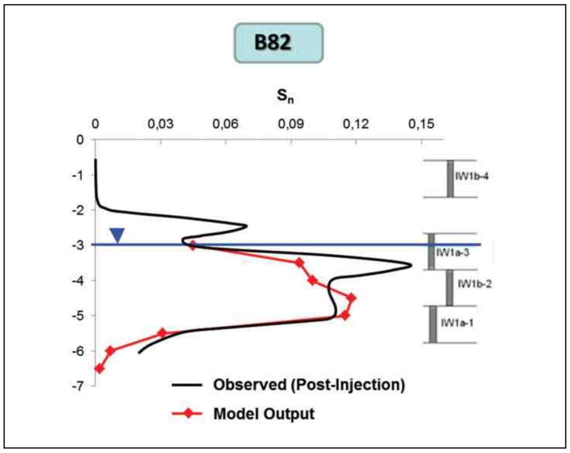
Microemulsion occurred mostly after injection of 3% surfactant

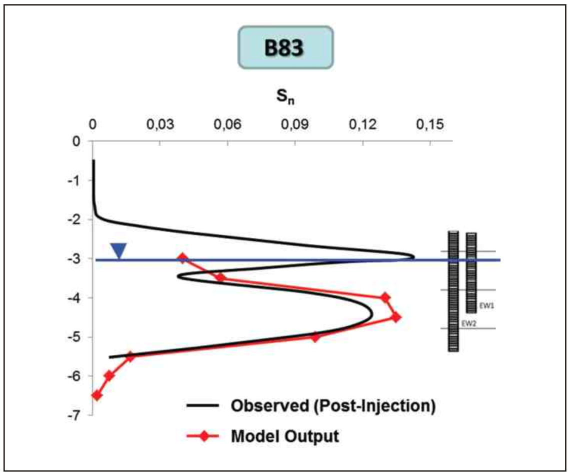
- Accumulated Oil during Pilot SEAR



Note: The vertical axes are in different scales

- Post Oil Saturation in soil





The simulations indicate a removal of 130 kg oil on day 50 and approximately 400 kg after day 70. Simulations without surfactants show a removal of less than 1/10 of the removal achieved when using Ivey-sol® surfactants.

CONCLUSIONS

The UTCHEM model was able to simulate the Pilot SEAR, and injected fluids were contained within the pilot area. Further, the simulations estimated an approximate 10-fold (1000 %) increase of the oil concentration in the extracted ground water relative to a water injection without the use of Ivey-sol® Surfactants. The model also showed that the main process for mass removal during SEAR was production of a micro-emulsion.

The total removal during the Pilot SEAR was by UTCHEM estimated to be 100-400 kg oil compared to 25-50 kg by analysis and measurements of the effluents from the extraction wells, and 50-150 kg based on the change of oil saturation in the soil by analysis of soil samples.

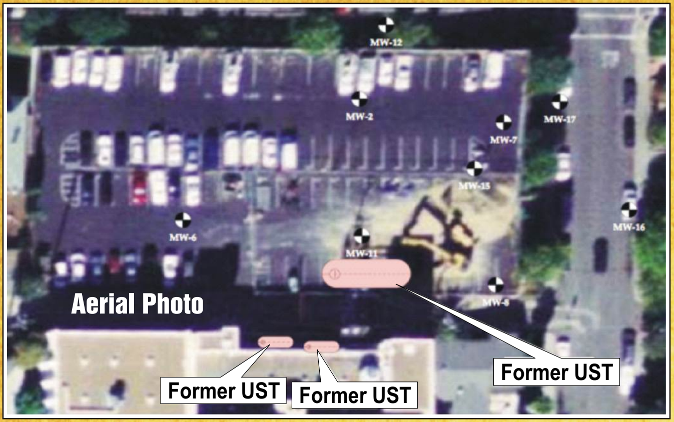
The simulated post-SEAR oil saturation was similar to measured concentrations from post-study soil sampling. The simulations also indicate that most of the Ivey-sol® surfactants was removed during the pilot SEAR and the post pump & treat period.

The setup of the UTCHEM gave an insight into the processes and hydraulics during the pilot SEAR in comparison to a "Black Box" situation, where the remediation technology performance is only evaluated by process and monitoring data, after the remediation is conducted.

The performance of the pilot study provided important lessons of great value for both the design and the documentation of issues in the design and planning of future full-scale remediation.

Surfactant Enhanced HVDPE Remediation of Petroleum Contaminated Soil, Bedrock and Groundwater

Site Conditions

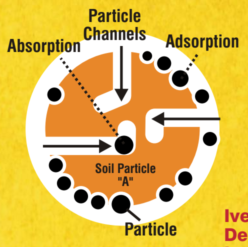


Remediation Challenge

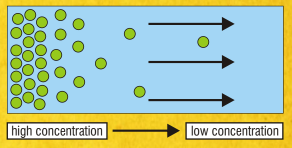
The number one limiting factor for all forms of in-situ remediation is contaminant sorption

Sorption >>>>>Desorption or Diffusion

Absorption vs Adsorption



Diffusion



● **solute**

Solute transport is from the left to the right; movement of the solutes is due to concentration gradient (dC/dx).

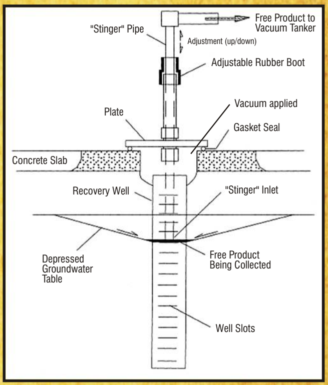
Ivey-sol® Overcomes Sorption Improving Desorption & Diffusion of Contaminants Increasing Their 'Availability' for Remediation

- ★ Recalcitrant petroleum product residuals sorbed in fine grain soils and fractured bedrock
- ★ Persistent concentrations in groundwater after 12 years of remediation – including pumping, HVDPE
- ★ Obtained regulatory approval for Ivey-sol® surfactant application in spring 2009

Pilot Test Approach

Focused Short-Term Surfactant Injection/Extraction to Maximize Recovery

- ☐ Ivey-sol® 106 pilot scale injection undertaken over 5 days in July 2009
- ☐ Four injection events, one injection well (MW15) and four extraction HVDPE wells (MW2, 7, 8 and 11)
- ☐ Five surrounding monitoring wells sampled during pilot
- ☐ Mobile HVDPE system capable of 28 inch Hg vacuum and 800 SCFM
- ☐ Groundwater HVDPE average recovery rate of 0.24 ppm



HVDPE Extraction Well

Diagram shows radius of influence and potential LNAPL collection

- ☐ Recalcitrant petroleum product residuals in fractured bedrock
- ☐ Persistent concentrations in groundwater after 12 years of remediation – including pumping, HVDPE

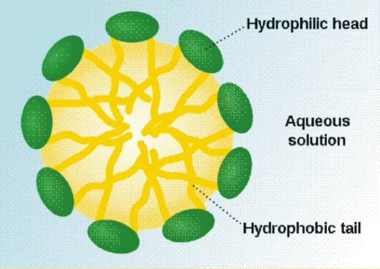
Ivey International Inc.
"Today's Environmental Solutions For A Better Tomorrow"™
www.iveyinternational.com

RMT

Galen Kenoyer | Tel. 1-213-700-8704 | E: galen.kenoyer@rmtinc.com
Chris D'Sa | Tel. 1.310.570.7069 | E: Chris.dSa@rmtinc.com

Surfactant Chemistry

Surfactant Structure



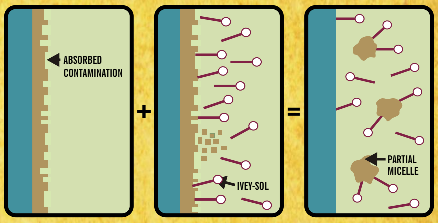
Hydrophilic (water loving) and Hydrophobic (water hating oil-liking) Groupings allow for Mobilization of many Organic Contaminants

Classes of Surfactants

- ☐ Anionic: Have one or more negatively (-) charged groupings; commonly used in laundry detergent
- ☐ Cationic: Have one or more positively (+) charged groupings, typically poor detergents but well suited for use as germicides, fabric softeners and emulsifiers.
- ☐ Amphoteric: Contains both anionic and cationic groupings; prefer neutral pH and found in products such as hair shampoo, skin cleaners and carpet shampoo.
  - *Ionic Surfactants make up >95% of the surfactant used around the world.*
- ☐ Non-ionic: Have no ionic constituents or groupings; largest single group of SAA (Surface Active Agent) and have a correspondingly wide range of chemical characteristics. Ivey-sol® surfactant mixtures are non-ionic and have the unique ability to selectively desorb contamination (LNAPL, DNAPL's, PAH, PCB, DCE, TCE, PCE), etc.

Why Ivey-sol® Surfactants?

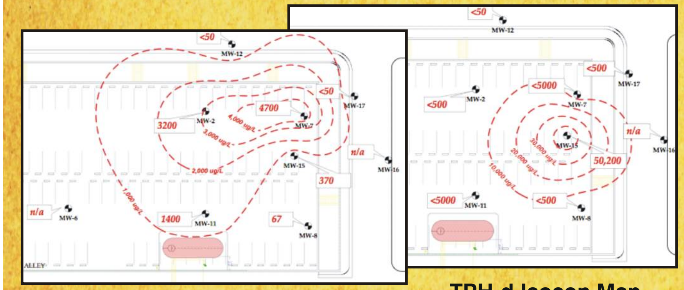
- ☐ Improves desorption of target contaminants in soil and groundwater
- ☐ Lowers the surface tension of water improving both its wetting and associated permeability (K) properties
- ☐ Effective as a stand alone technology for soil and groundwater remediation
- ☐ Effective to improve other remediation techniques (i.e., P&T, Soil Washing, Bioremediation, Chemical Oxidation/Reduction)



Ivey-sol® desorbing NAPL mass for increased 'availability' for remediation

Results

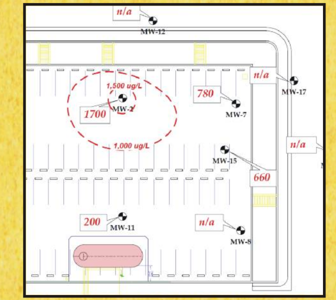
Before and During Test



TPH-d Isocon Map
before Pilot Test

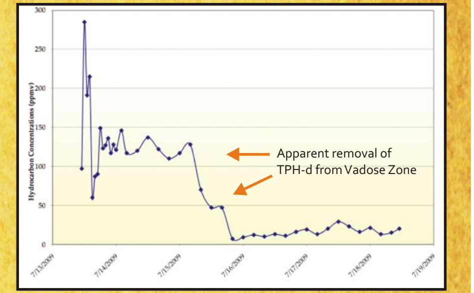
TPH-d Isocon Map
2 hrs after Pilot Test

Post Pilot Test Results



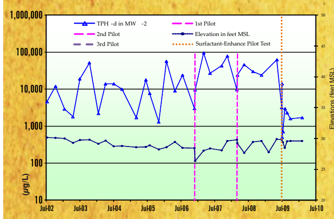
TPH-d Isocon Map
7 months after Pilot Test

HVDPE Vapor Concentrations



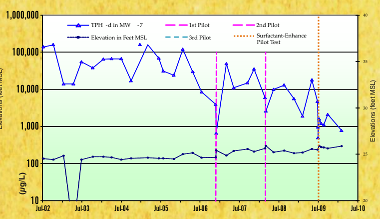
MW-2

$[9.169 \times 10^3 \text{mg/day} \div 1.5551 \times 10^3 \text{mg/day}] \times 100\% =$ **590%**



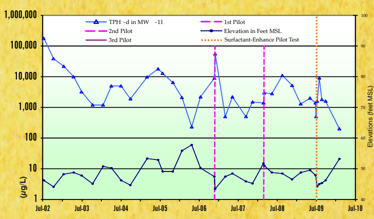
MW-7

$[2.1754 \times 10^4 \text{mg/day} \div 3.1918 \times 10^3 \text{mg/day}] \times 100\% =$ **682%**



MW-11

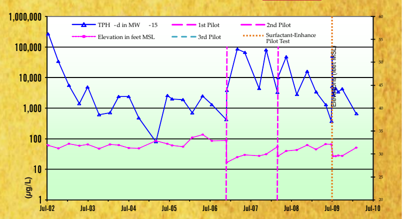
$[1.678 \times 10^4 \text{mg/day} \div 1.7579 \times 10^3 \text{mg/day}] \times 100\% =$ **955%**



MW-15

$[4.4107 \times 10^4 \text{mg/day} \div 2.7603 \times 10^3 \text{mg/day}] \times 100\% =$ **1,598%** Standard Pilot

$[3.875 \times 10^4 \text{mg/day} - 2.014 \times 10^3 \text{mg/day}] \times 100\% =$ **1,924%** Push-Pull



Conclusions: We increased the TPH$_d$ Mass Recovery Rate by 10x !!!

- Removed TPH-d from vadose zone
- Lowered groundwater concentrations
- Regulatory Agency agree to risk-based closure if concentrations continue to decrease
- Pilot Application was a Success!

Ivey International Inc.
"Today's Environmental Solutions For A Better Tomorrow"™
www.iveyinternational.com

RMT

Galen Kenoyer | Tel. 1-213-700-8704 | E: galen.kenoyer@rmtinc.com
Chris D'Sa | Tel. 1.310.570.7069 | E: Chris.dSa@rmtinc.com

Surfactant Enhanced Extraction of Carbon Tetrachloride at an Active Grain Elevator

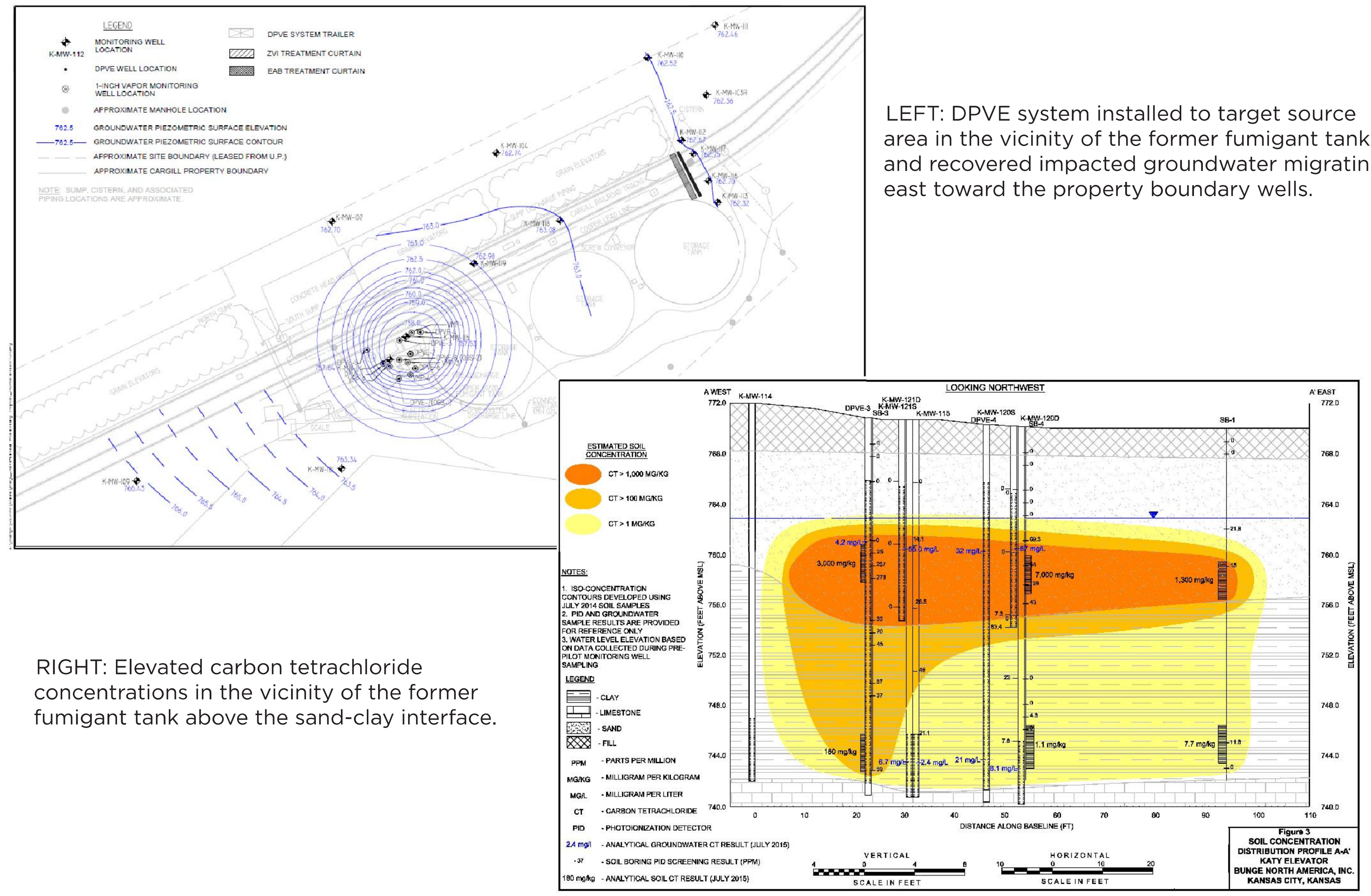
Eric Dulle (edulle@burnsmcd.com)
Bud Ivey (budivey@iveyinternational.com)

Current Site Conditions

- Groundwater and soil data indicate impacts of fumigant constituents of concern (COCs), primarily carbon tetrachloride, resulting from historical operations associated with fumigant storage tanks and application.
- Groundwater is encountered at the site approximately 7 to 8 feet below ground surface (bgs). Lithology within the source zone generally consists of well-sorted, loose, silty sand to depths ranging from approximately 13 to 17 feet bgs, underlain by silty clay.
- Dual-phase vacuum extraction (DPVE) was implemented in the source area for hydraulic control and source area remediation.
- Since implementation, more than 10,000 pounds of total volatile organic compounds (VOCs) have been removed, and concentrations, downgradient of the source area, have been reduced to below cleanup goals.

Site Challenges

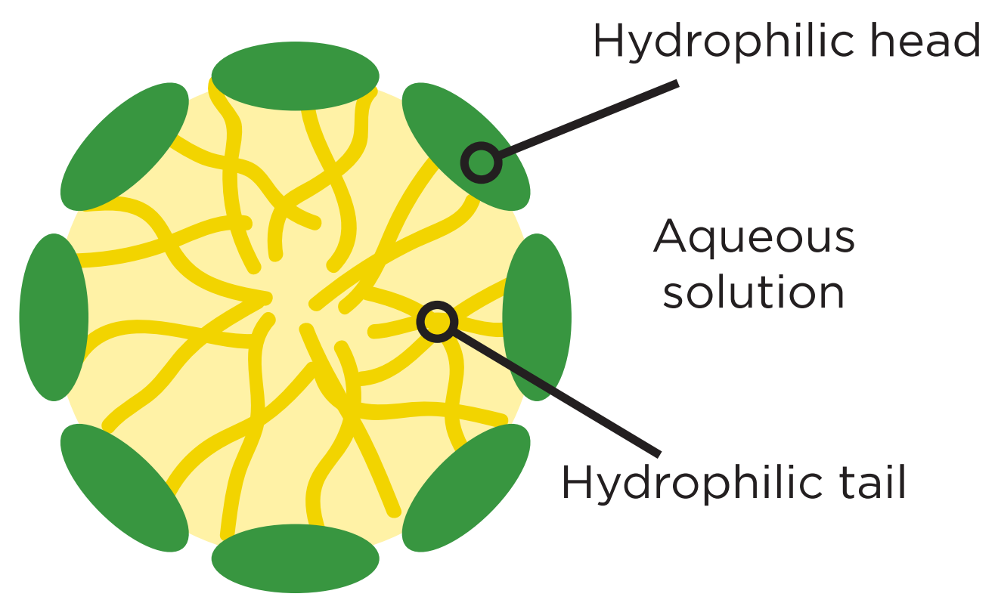
- Elevated and persistent source area COC groundwater concentrations observed during groundwater monitoring events.
- Supplemental source area soil investigation results indicated significant sorbed-phase COC mass, generally limited to the shallow, sandy interval of an area bound by the DPVE wells exhibiting elevated COC concentrations.
- Light nonaqueous phase liquid (LNAPL) heavily impacted with the site COCs also was identified.
- Surfactant enhanced extraction (SEE) was subsequently identified as the optimal source zone remedial alternative because of the technology's ability to quickly and efficiently remove a concentrated but relatively isolated and shallow zone of contaminant mass with relatively low surfactant application concentrations. In addition, the existing DPVE infrastructure could be utilized to implement SEE at the site, minimizing intrusive activities and cost.



LEFT: DPVE system installed to target source area in the vicinity of the former fumigant tank, and recovered impacted groundwater migrating east toward the property boundary wells.

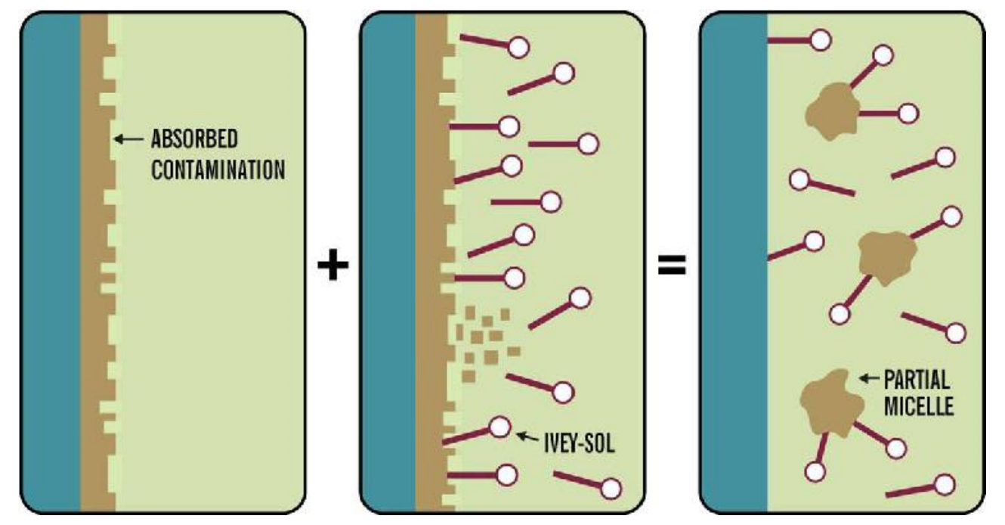
RIGHT: Elevated carbon tetrachloride concentrations in the vicinity of the former fumigant tank above the sand-clay interface.

Surfactant Structure



Hydrophilic (water-loving) and Hydrophobic (water-hating, oil-liking) groupings allow for mobilization of many organic contaminants.

NAPL vs. DNAPL



Classes of Surfactants

- Anionic: Have one or more negatively (-) charged groupings; commonly used in laundry detergent.
- Cationic: Have one or more positively (+) charged groupings; typically poor detergents but well-suited for use as germicides, fabric softeners and emulsifiers.
- Amphoteric: Contain both anionic and cationic groupings; prefer neutral pH and found in products such as hair shampoo, skin cleaners and carpet shampoo.

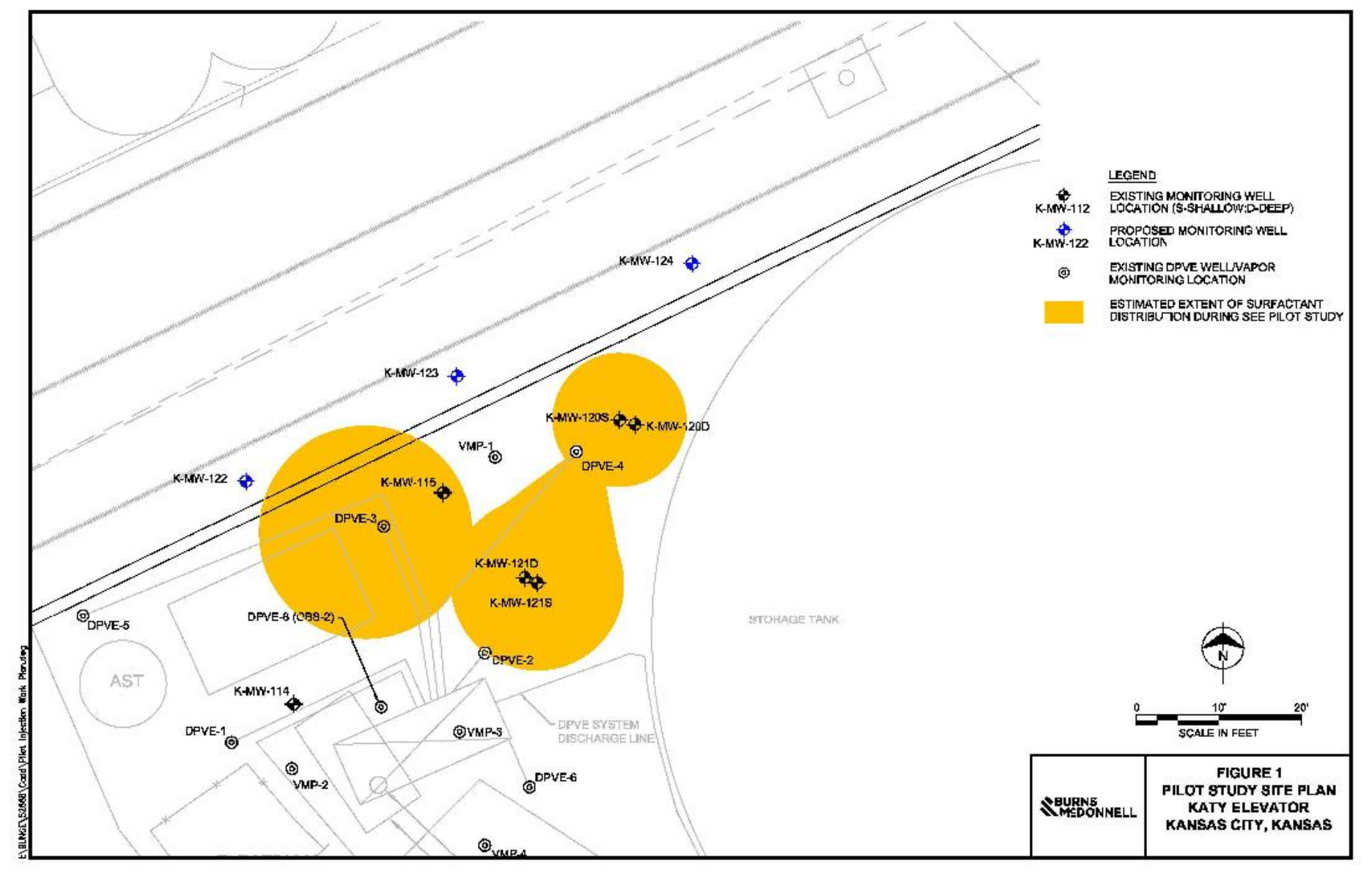
  ** Ionic surfactants make up >99% of the surfactant used around the world.*
- Nonionic: No ionic constituents or groupings; largest single group of SAA and have a correspondingly wide range of chemical characteristics. Ivey-sol® surfactant mixtures are nonionic and have the unique ability to selectively desorb contamination (LNAPL, DNAPLs, PAH, PCB, DCE, TCE, PCE, etc.).

Why Ivey-sol Surfactants?

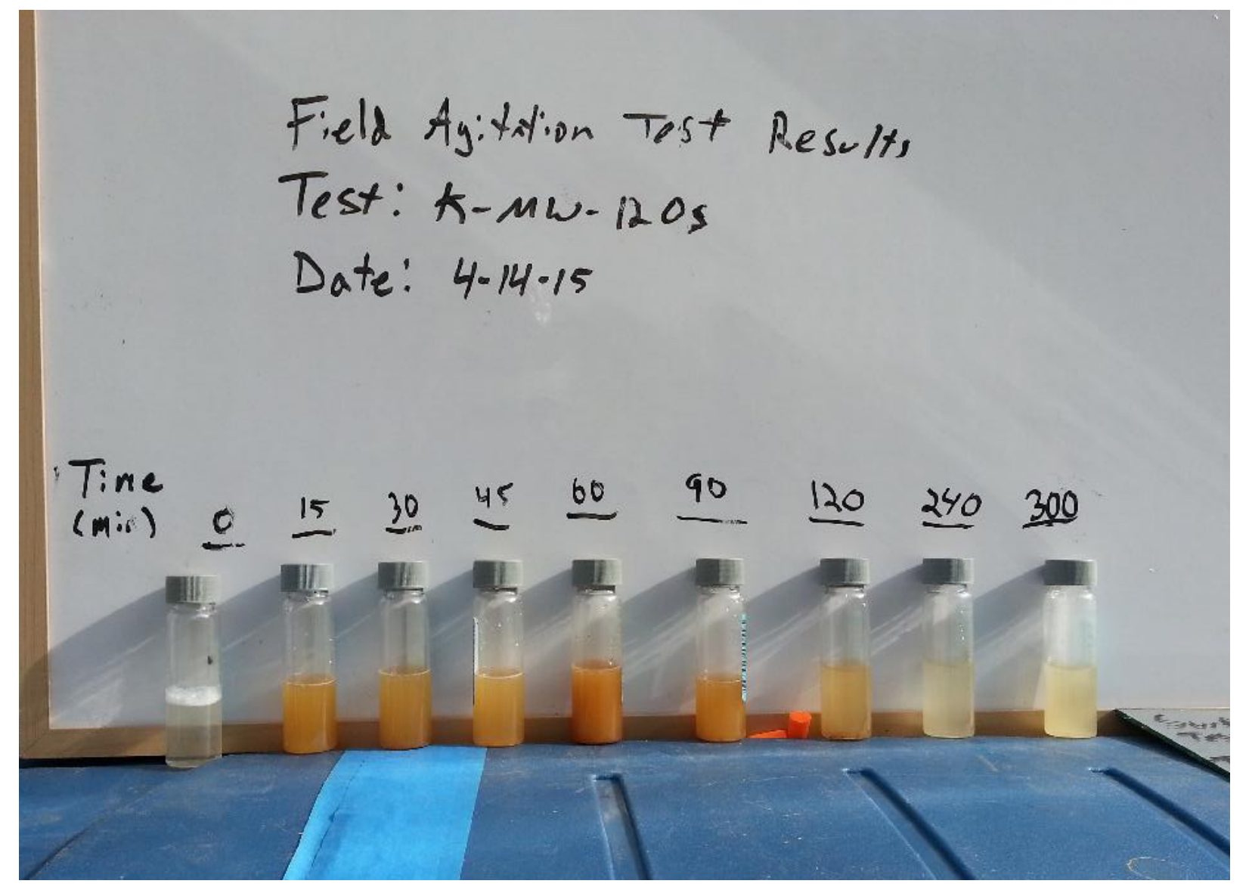
- Improves desorption of target contaminants from soil.
- Lowers the surface tension of water, improving its wetting and associated permeability properties.
- Effective as a stand-alone technology for soil washing.
- Effective to improve other remediation techniques (i.e., P&T, soil washing, bioremediation and chemical oxidation/reduction).

SEE Pilot Study — Spring 2015

- A SEE pilot study was conducted in spring 2015 to assess the efficacy of the technology under site-specific conditions.
- 50 gallons of Ivey-sol 106 surfactant was mixed with water to achieve 1-2% mixture and injected into several source area wells.
- Both push-pull and point-to-point tests were conducted to evaluate aquifer-surfactant mixing and mass removal.
- During the pilot study, the highest total VOC dissolved-phase concentrations (8,100 ug/L) ever reported were observed from water recovered by the DPVE system.
- Following the pilot, 99% reduction in groundwater concentrations were observed in two shallow source area monitoring wells.



Most impacted portion of the source area, including area where historic LNAPL has been observed, targeted for the pilot study. Radius of influences greater than 10 feet observed.



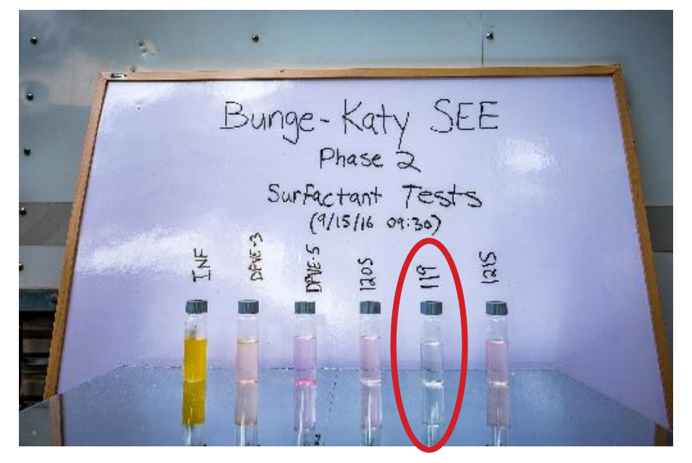
Groundwater recovered from the DPVE system becomes clear once depletion of surfactant is observed.

Full-Scale SEE — Fall 2016

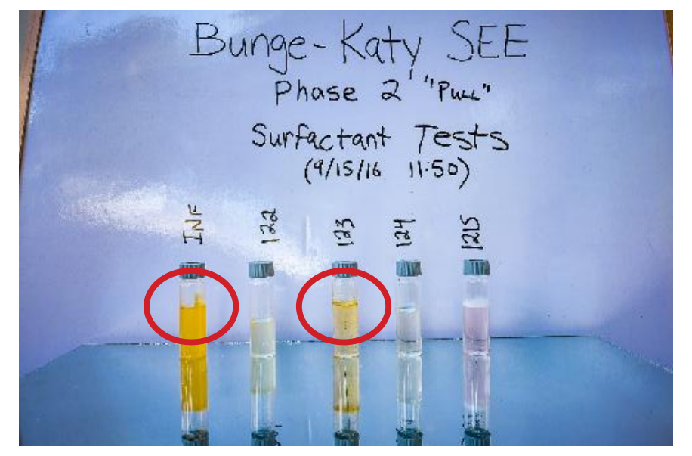
- Based on the results of the SEE pilot study, full-scale SEE remediation activities were conducted in fall 2016.
- Three additional shall monitoring wells were installed to facilitate surfactant delivery along the northern portion of the source area.
- 275 gallons of Ivey-sol 106 surfactant was mixed with water to achieve 1-2% mixture and injected into several source area wells.
- Both push-pull and point-to-point test were conducted based on the results of the pilot study.
- During full-scale SEE, significantly elevated dissolved and vapor-phase mass removal and carbon tetrachloride-impacted LNAPL was observed.

Tracer dye was mixed with the surfactant water mixture to further assess injection distribution.

Surfactant, water and tracer dye were mixed at the surface and gravity fed into the targeted well.

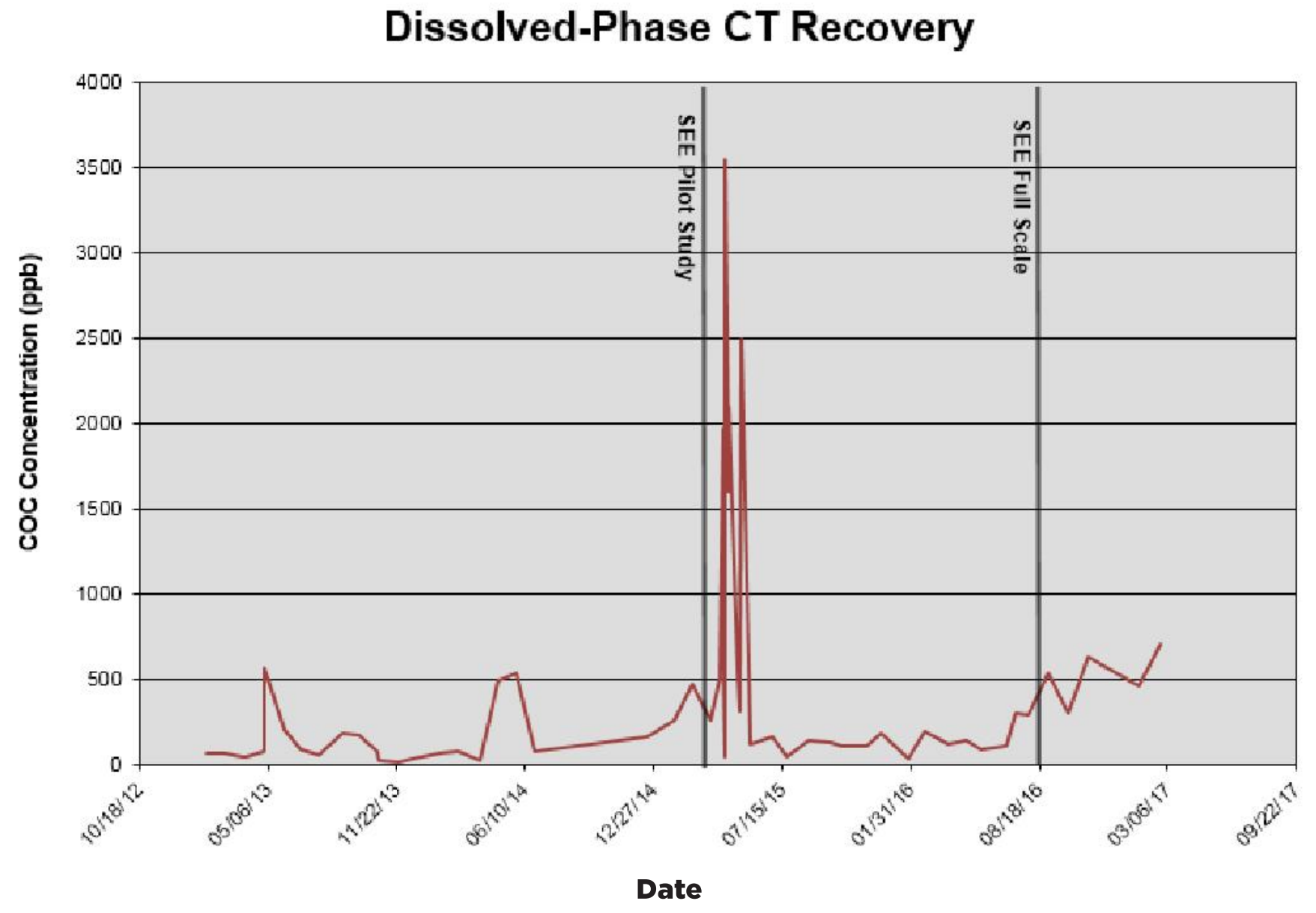


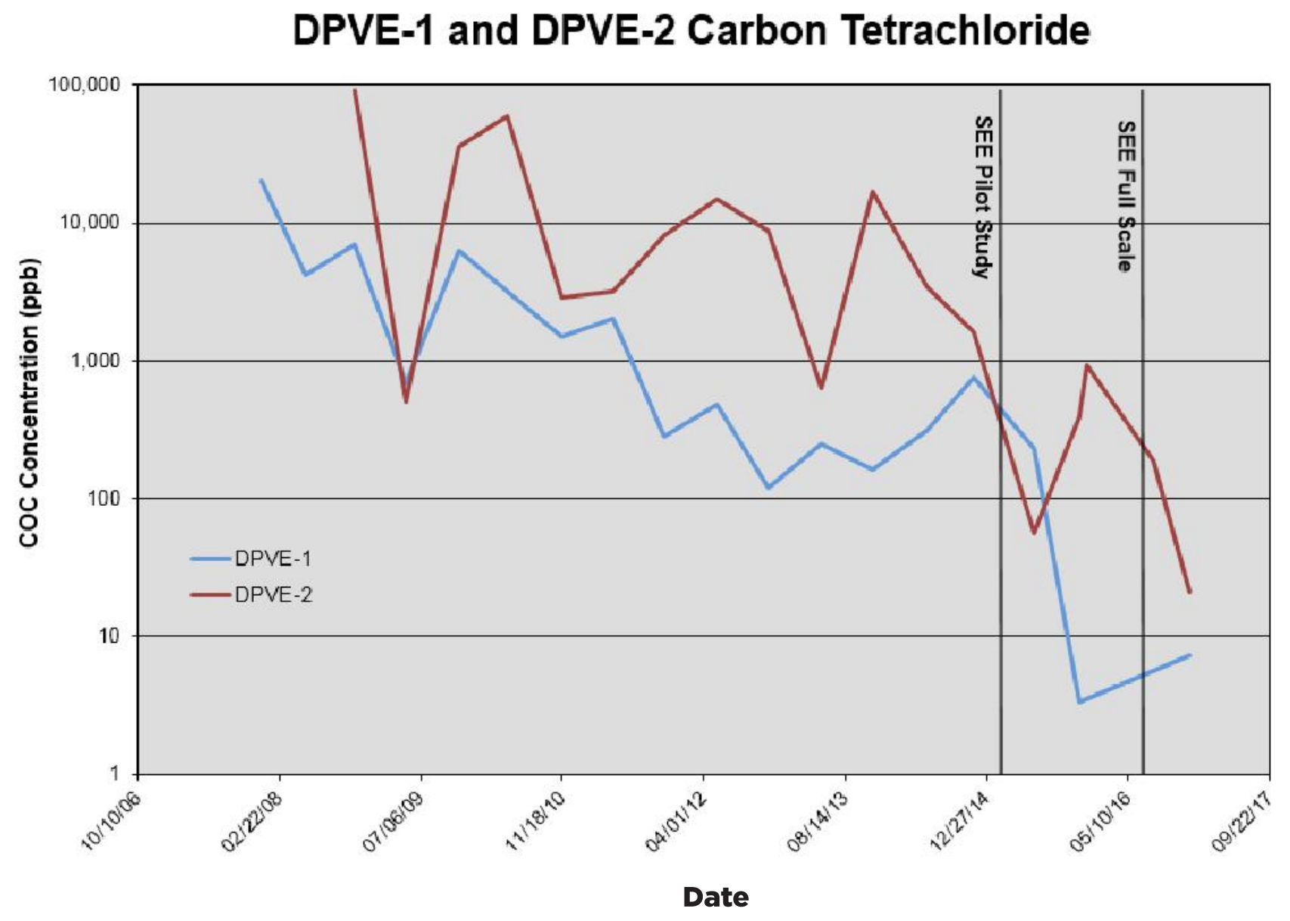
Water samples were collected from observation wells to estimate radius of influence. No dye is observed at 119 (downgradient of the source area), indicating adequate hydraulic control over the treatment area to prevent unanticipated contaminant mobilization.

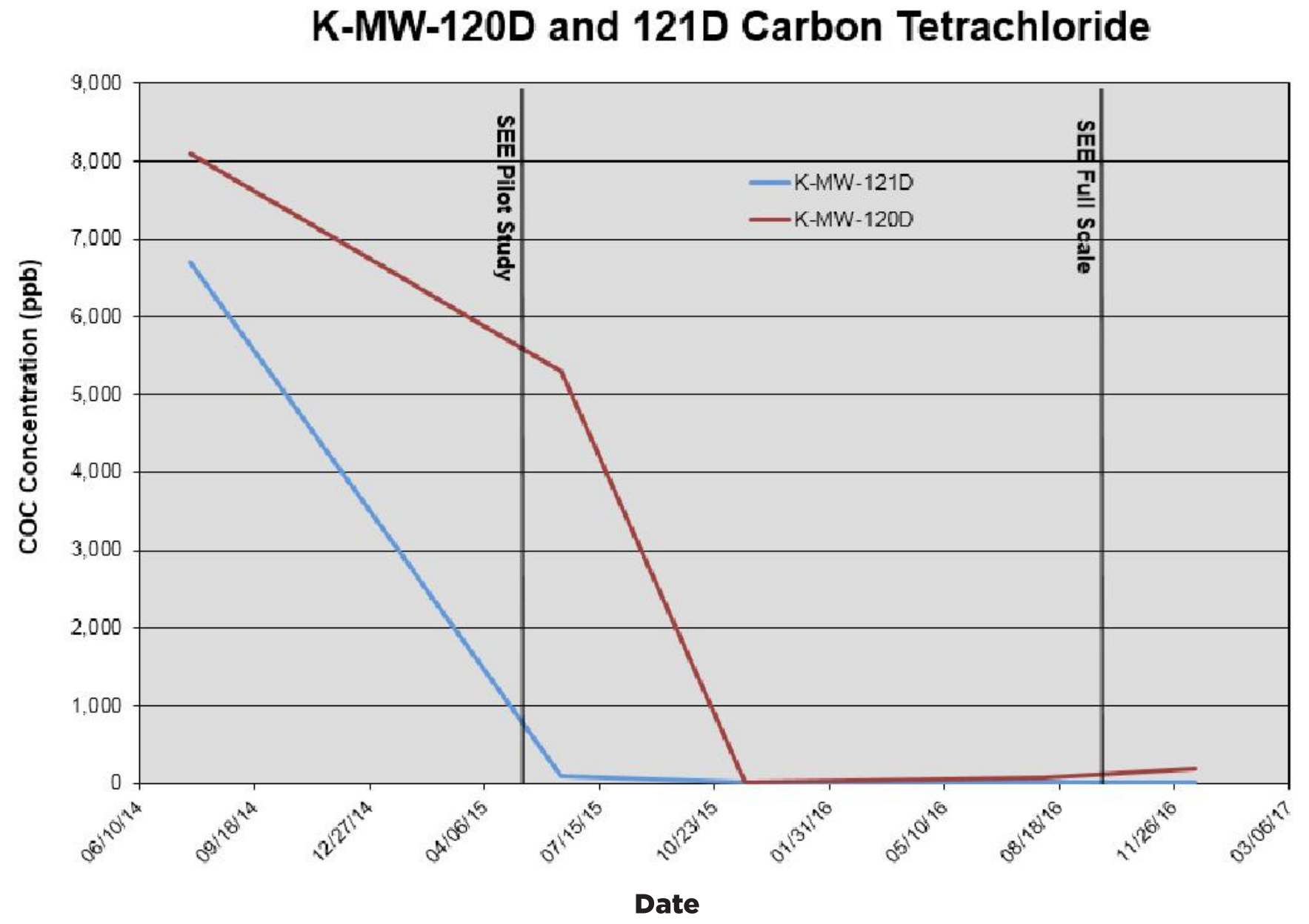


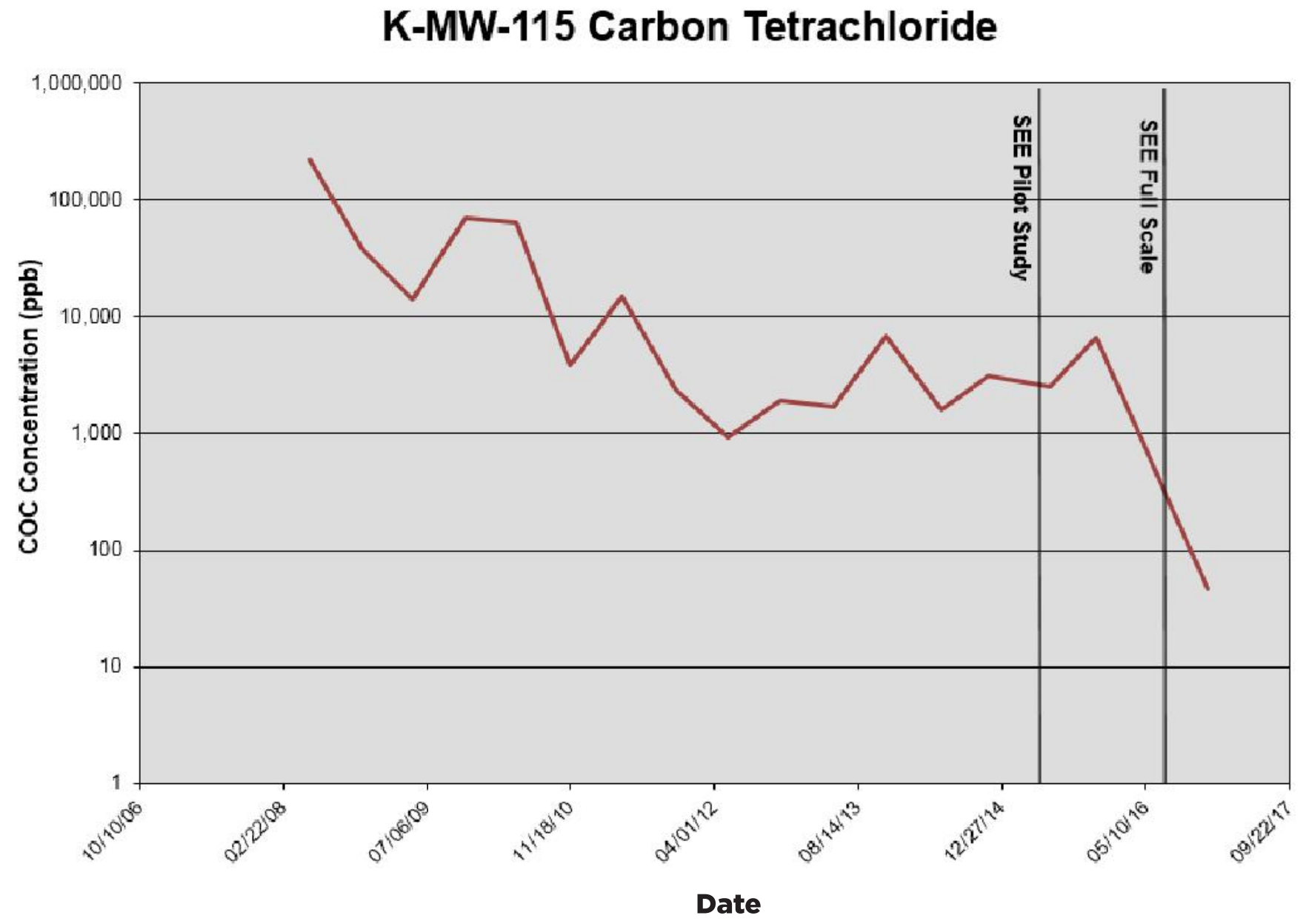
Groundwater samples from DPVE influent and monitoring well 123 indicate mobilization and subsequent recovery of LNAPL.

Results







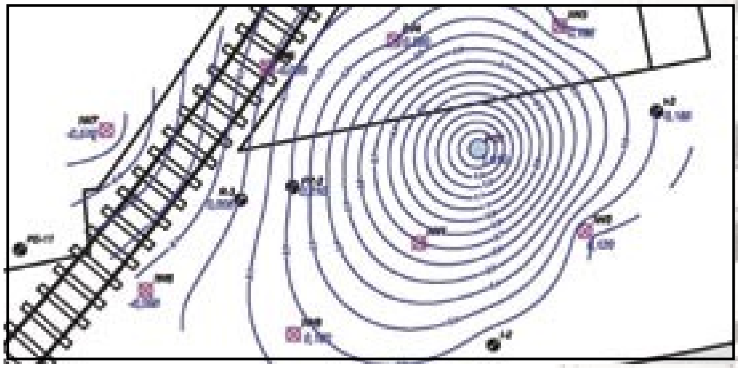


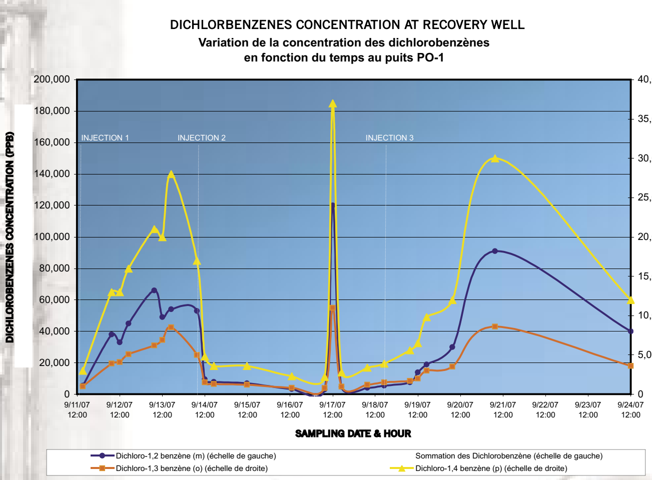
IVEY INTERNATIONAL INC.

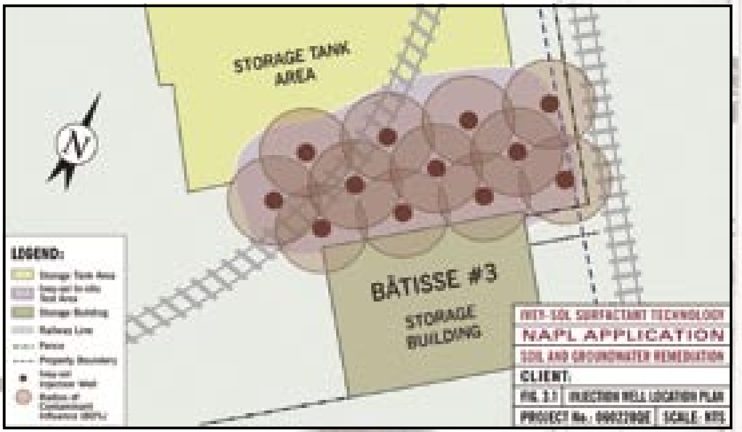
Case Study: In-situ Surfactant Enhanced DNAPL Recovery Pilot Project - Refinery Site Montreal Canada

PROJECT FACTS:

- Active chemical refinery (20 acre site)
- Several DNAPL (chlorobenzene and dichlorobenzenes) and BTEX stored on-site
- Multiple DNAPL and BTEX spill events reported over a site history extending back to the 1950's.
- DNAPL and BTEX impacts to both the local soil and groundwater covering an 8 acre (+) area
- Risk: potential risk for impacting the near-by municipal groundwater aquifer
- Soil comprised of glacial till
- Property owner tried several different in-situ remediation technologies over the past 3 years without success, at a considerable cost.
- Ivey-sol 106 pilot scale injection program between September 11 - 24, 2007
- Pump and treatment system installed and operating with 3 inch Hg vacuum
- Pilot scale results demonstrated significant ability to improve contaminant recovery and potential to clean up the site in a rapid and cost effective manner.







RESULTS:

Mass Recovery (mg/day) = Flow Rate (L/min) x Concentration (mg/L) x Time (T) min/day
Over the course of the Pilot Scale Application the increase in DNAPL Mass Recovery was 549%, and BTEX Mass Recovery was 303%, based on a real time calculation.
Increases of >800% to > 1200% in individual DNAPL and BTEX contaminant parameters were observed.

"The in-situ application of the Ivey-sol surfactant technology significantly increased the DNAPL and BTEX mass recovery form the impacted soil and groundwater on-site. We were very pleased by these results leading to our recommending a full scale site application as a rapid and cost effective method to achieve site clean up"

- Martin Beaudoin, Project Engineer with Sanexen Environmental Services Inc.

'Today's Environmental Solutions For A Better Tomorrow'

Contact: Ivey International Inc. Tel: 250.923.6326 Fax: 1.888.640.3622 Email: budivey@iveyinternational.com Web: www.iveyinternational.com

Ivey-sol • SPTT

Ivey International Inc.

Case Study: Monroe, Connecticut, USA

Monroe Facts:

- Former heating oil terminal from the mid-1950's to the late 1970's
- No. 2 fuel oil was stored at the site
- Multiple releases occurred over time
- Site and surrounding area are wetlands, with the former terminal area elevated with fill material for commercial use
- Irregular fill consisting of sand, silt, gravel and boulders with some timbers and metal buried throughout the site
- Sensitive receptors are adjacent stream and down-gradient potable wells
- High vacuum (dual phase) extraction system in use at the site since late 1999
- Selective Phase Transfer Technology (SPTT) system installed in May 2002
- Monthly SPTT injections commenced in May 2002

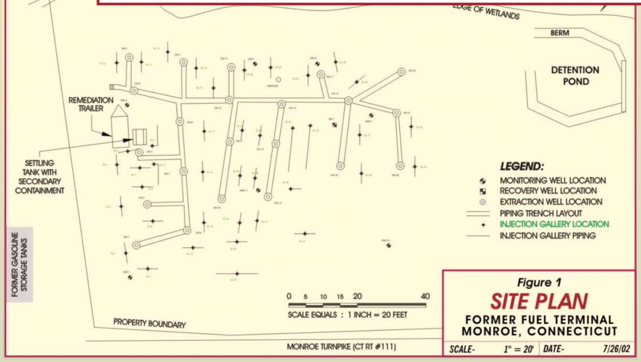


Figure 1

SITE PLAN

FORMER FUEL TERMINAL
MONROE, CONNECTICUT

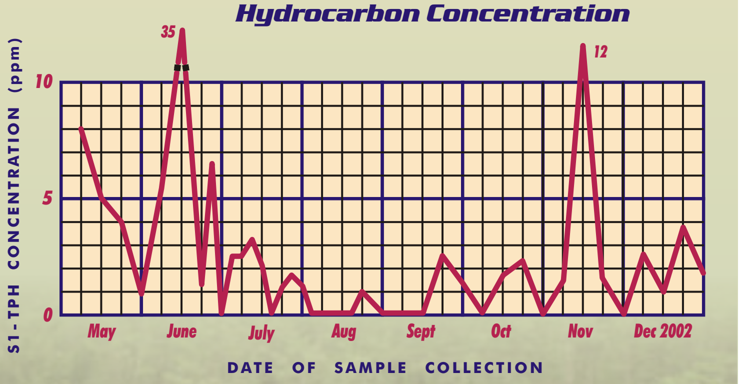
SCALE- 1" = 20' DATE- 7/26/02

Conclusions:

- Mass Recovery = Flow Rate x Concentration
- Mass Recovery (pounds per day) = gallons per minute (gpm) x mg/l X 0.012
- 3.785 l/gal x 1 lb/454,000 mg x 1440 minutes/day = 0.012
- Mass Recovery prior to the injection period is based on an average influent concentration of 0.75 mg/l
- 8 gpm x .075 mg/l x 0.012 = 0.072 lbs/day = 3.269 x 10^4 mg/day (prior to SPTT use)
- Mass Recovery during the injection period is based on a concentration average calculated using the post injection peak concentrations of 3.07 mg/l
- 8 gpm x 3.07 mg/l x 0.012 = 0.29472 lbs/day = 13.38 x 10^4 mg/day (during SPTT use)
- **Pre vs. post injection mass removal rates show an increase of 409.3%**

Site Images

Influent Total Petroleum Hydrocarbon Concentration



Handex Environmental, Inc.
PRACTICAL ENVIRONMENTAL SOLUTIONS

Today's Environmental Solutions For a Better Tomorrow.™

> “ The Ivey-sol surfactant products significantly enhanced our contaminant mass recovery by >400%, and put a rapid end to a 5 year plus remediation project in less than 9 months. We were very pleased with the results and would recommend it's use to enhancing site remediation. ”
>
> *Dan Smith, Project Manager – Handex Environmental, Inc.*

Ivey-Sol® 103 Successfully Treats Free-Phase Impacted Shale Via On-Site Washing

CASE SUMMARY

Undisclosed Site, Ontario, 2008

Environmental investigation of a grass-covered area uncovered free phase petroleum (F3-F4 fraction heavy oils) in fractured, weathered shale. A pilot project was undertaken by **Terratechnik Ltd**. to excavate the shale and treat it by washing with a non-ionic surfactant, Ivey-Sol® 103.

Ivey-Sol® Benefits

- Operates below the critical micelle concentration facilitating low application rates
- Strongly enhances the solubility of hydrophobic compounds
- Does not cause emulsification of oils
- Does not foul traditional wastewater treatment systems (i.e. organoclays, GAC, etc.)
- Unlike ionic surfactants Ivey-Sol® does not disperse in the aqueous phase
- There are various formulations (103, 106, 108) designed for specific types of contaminants

Pilot Study

Washing was first conducted using just water, as a baseline for washing efficiency. Washing time was the only variable. Results are reported qualitatively.

Wash Solution	Total Time	Ratio Material: Wash-Solution (V:V)	Visual Observations of Treated Shale
H_2O	< 1 min	0.05	Free Product, Sheen and Strong Odour
H_20	2 min	0.10	Free Product, Sheen and Strong Odour
H_20	3 min	0.15	Sheen and Strong Odour
H_20	5 min	0.25	Sheen and Strong Odour
H_20	8 min	0.40	Sheen and Strong Odour

Based on the results of washing with only water, it appeared that the addition of a surfactant to facilitate the desorption of the contaminant was necessary. The shale was subsequently washed using various concentrations of Ivey-sol® 103 to determine the most efficient combination of washing time and surfactant concentration.

The results are reported below:

Wash Solution	Conc. (ml/L)	Total Time	Ratio Material: Wash-Solution (V:V)	Visual Observations of Treated Shale
Ivey-Sol® 103	1	1 min	0.05	Free Product, Sheen and Strong Odour
Ivey-Sol® 103	1	3 min	0.15	Sheen and Strong Odour
Ivey-Sol® 103	1	5 min	0.25	Sheen and Moderate Odour
Ivey-Sol® 103	4	1 min	0.05	Sheen and Strong Odour
Ivey-Sol® 103	4	3 min	0.15	No Sheen, Slight Odour
Ivey-Sol® 103	**4**	**5 min**	**0.25**	**No Sheen, No Odour**
Ivey-Sol® 103	8	1 min	0.05	Sheen and Strong Odour
Ivey-Sol® 103	**8**	**3 min**	**0.15**	**No Sheen, No Odour**
Ivey-Sol® 103	**8**	**5 min**	**0.25**	**No Sheen, No Odour**

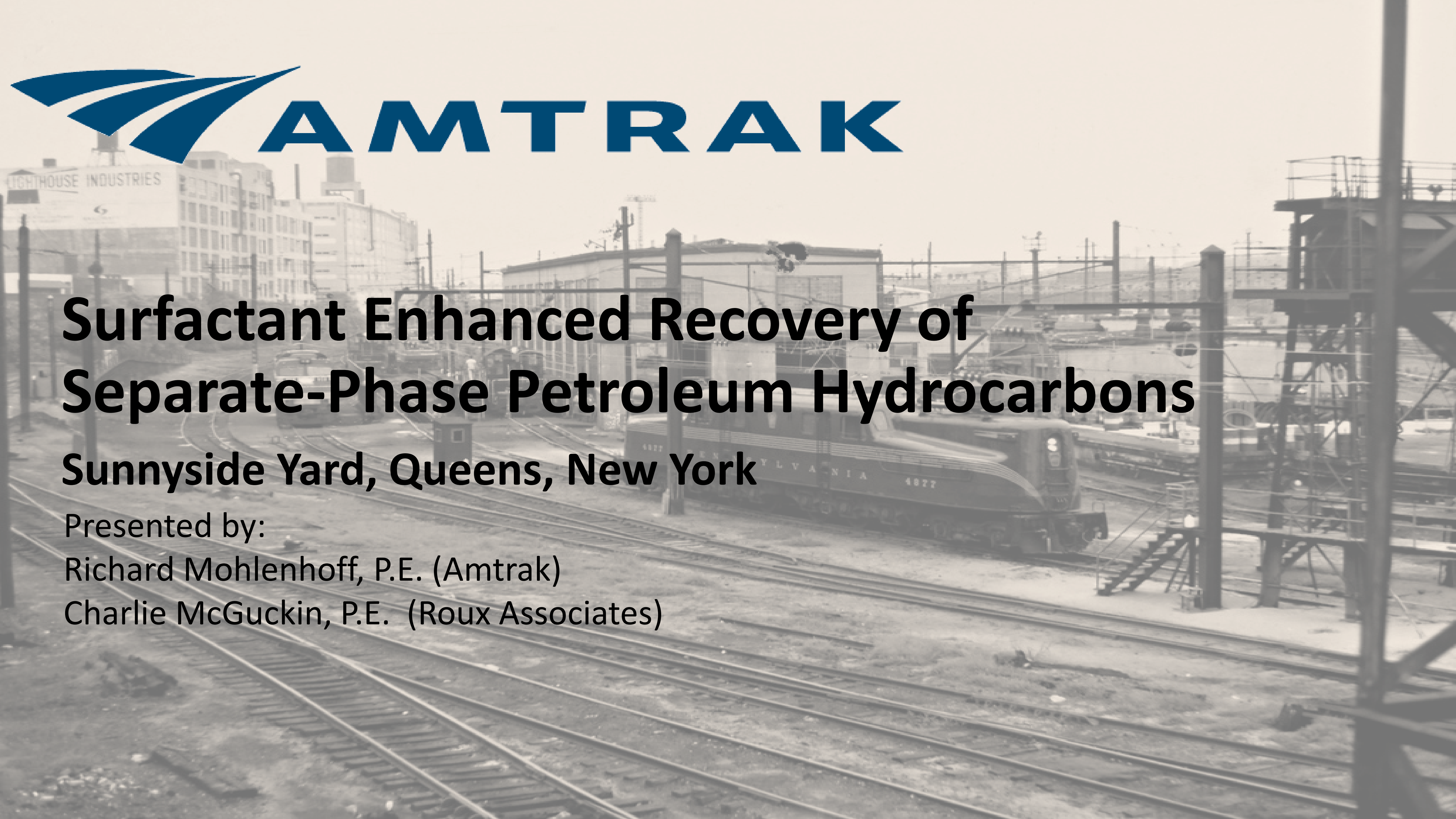
After several iterations, it was found that the most efficient combination was a surfactant concentration of between 0.4% to 0.8% and washing for 3-5 minutes per cubic metre of shale.

Conclusions

Using low concentrations of Ivey-Sol® solution, free product was successfully removed from shale. Soil/shale washing with Ivey-Sol® is a cost-effective technology for on-site treatment of impacted soils.

Based on the parameters above, projected treatment price for a small scale project (< 2,000 tonnes) would be $35 per tonne, which is currently less expensive than disposing of the impacted material at a landfill and replacement with clean fill. Obviously, with larger projects, the economies of scale will drive the price down even lower.

Canada Colors & Chemicals (CCC) is the exclusive distributor of Ivey-Sol® products in Canada as well as many other remediation products. ***Terratechnik Environmental Ltd*** holds MOE issued Certificates of Approval for the application of Ivey-Sol® products along with a wealth of remediation experience. Please call Leonard Chan of CCC at 416-346-5130 to discuss specific approaches and products suitable to your needs.



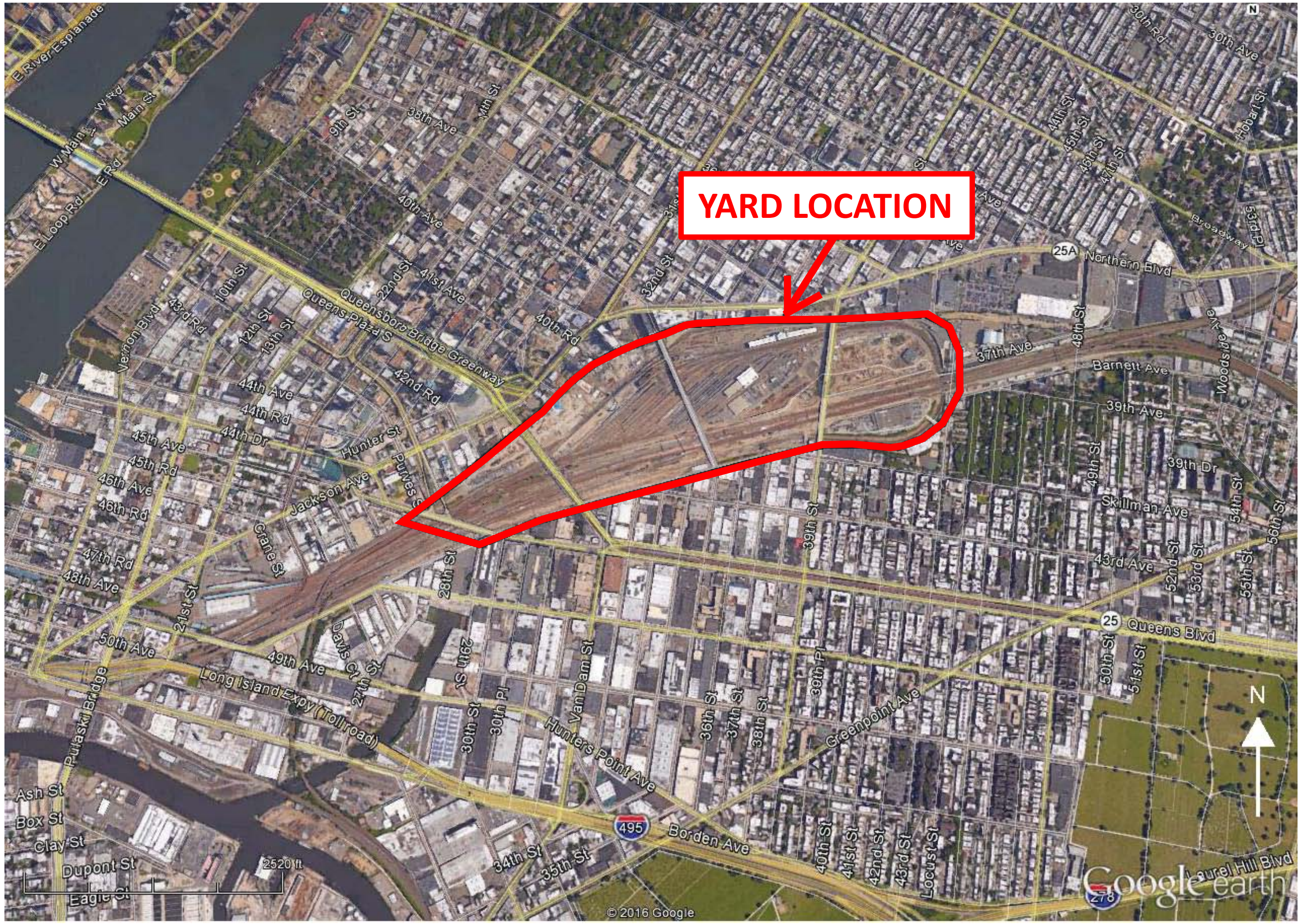
Surfactant Enhanced Recovery of Separate-Phase Petroleum Hydrocarbons

Sunnyside Yard, Queens, New York

Presented by:
Richard Mohlenhoff, P.E. (Amtrak)
Charlie McGuckin, P.E. (Roux Associates)

Site History

- Located in Sunnyside Yard, Queens, New York
- Over 100 years of service
- State Superfund Site
- Six Operable Units (OUs)
- 130 acre Site
- OU-3 LNAPL and PCB Plume



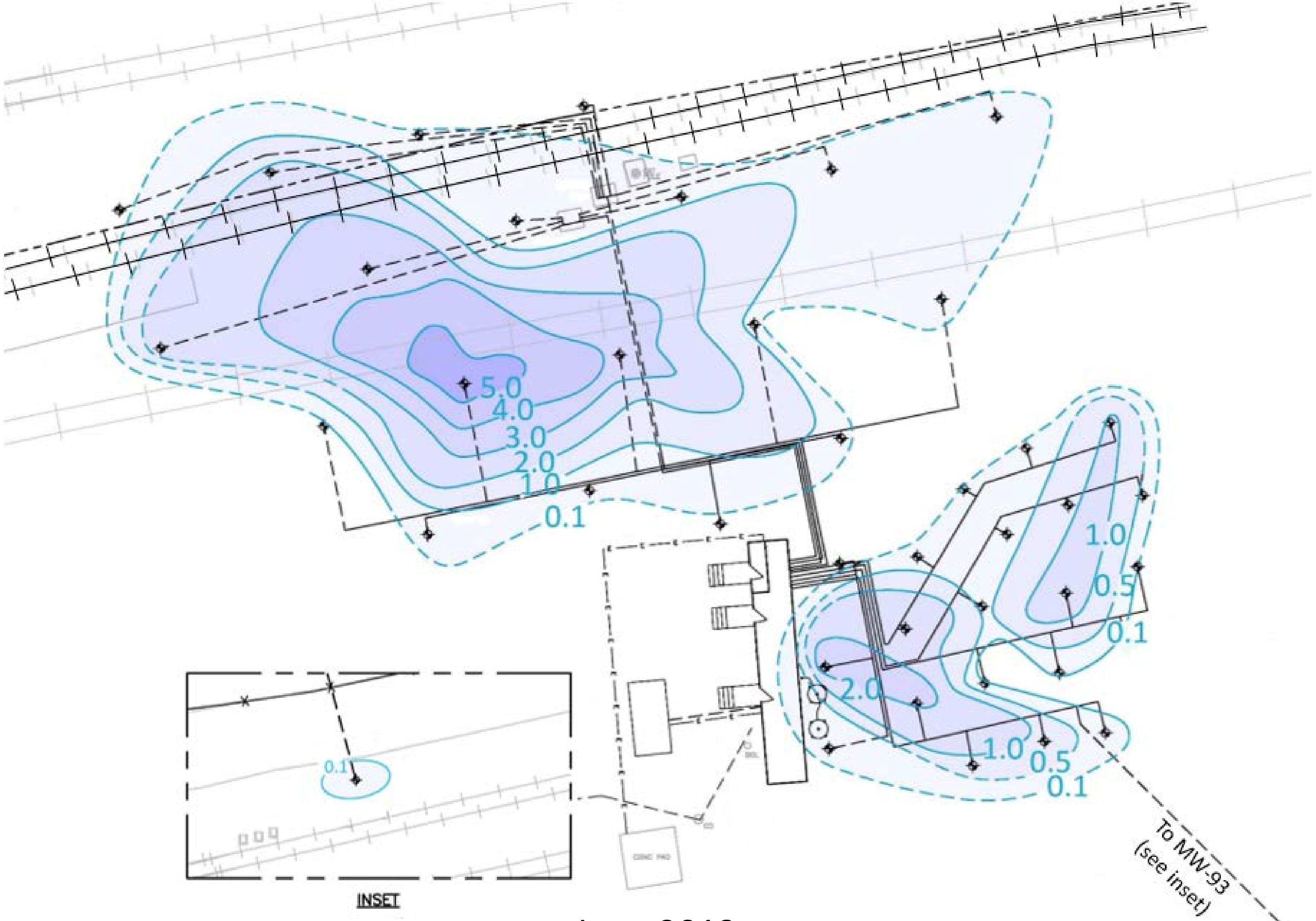
YARD LOCATION

OU-3 Record of Decision

Cleanup Standards

- PCBs < 25ppm
- Lead < 3,900 ppm
- cPAHs < 25 ppm (total of 7 compounds)
- SVOCs < 500 ppm
- LNAPL thickness < 0.1 foot

Dual Phase Vacuum Extraction (DPVE) System



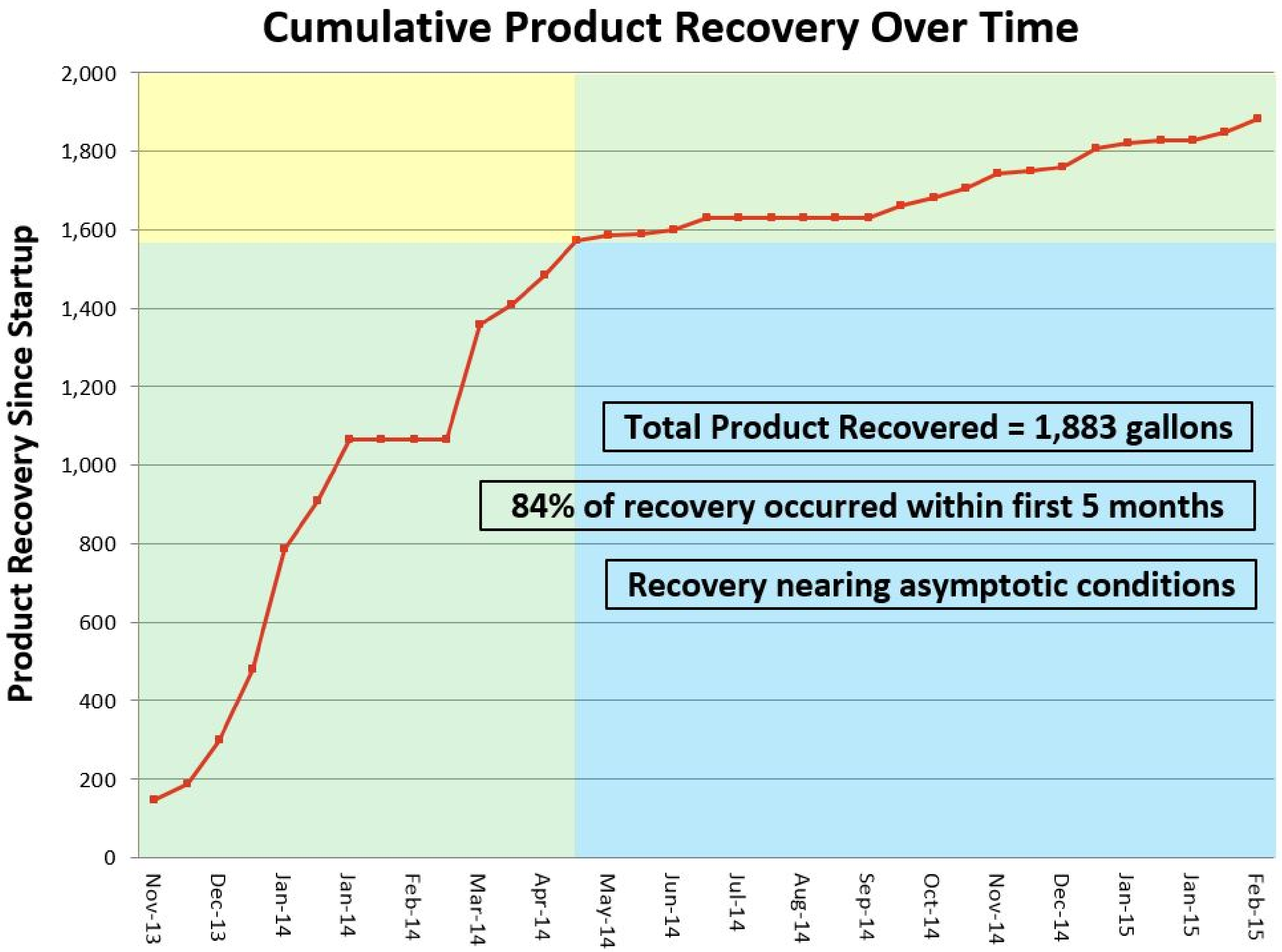
June 2013

ROUX

AMTRAK

Dual Phase Vacuum Extraction (DPVE) System

DPVE System Performance

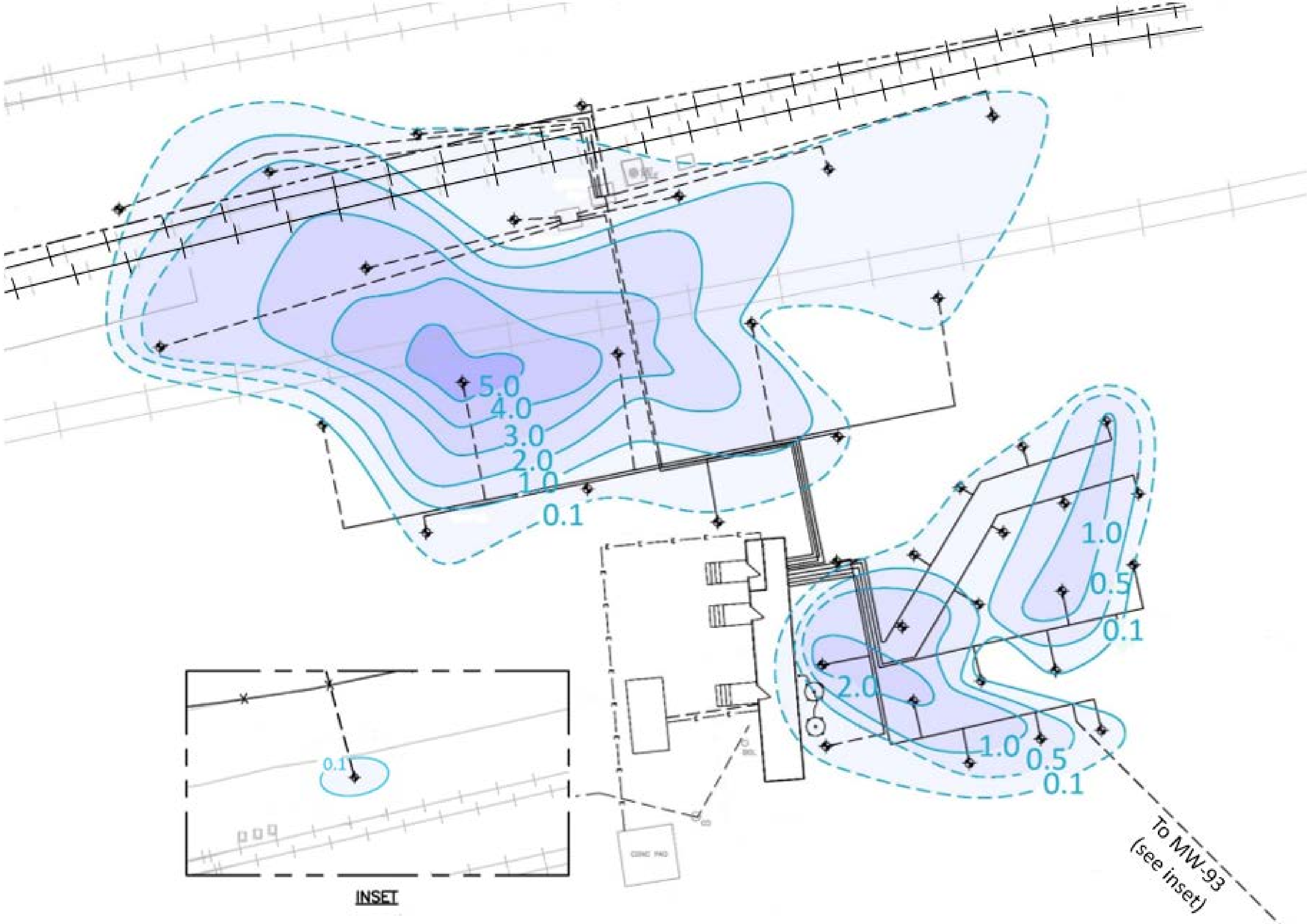


Total Product Recovered = 1,883 gallons

84% of recovery occurred within first 5 months

Recovery nearing asymptotic conditions

DPVE System Performance



June 2013

High Speed Rail Building Design

High Speed Rail Building Design

Evaluate Technologies to Accelerate Remediation

- Source zone excavation
- Activated persulfate injections
- Catalyzed hydrogen peroxide injections
- Surfactant injections
- Thermal enhancement

Ivey-sol® Surfactant Technology

- Composition
  - Several patented non-ionic surfactant formulations
- Applications
  - Desorb and liberate free-phase LNAPL and/or sorbed petroleum hydrocarbons
- Mechanism
  - Makes the contaminants more miscible in the aqueous phase, increasing the "physical availability"
- Additional Uses
  - Enhances bioremediation

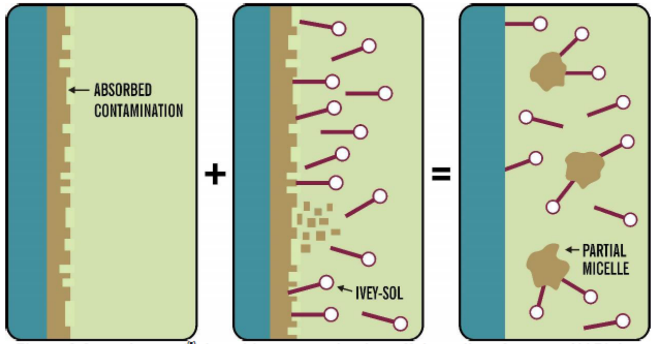
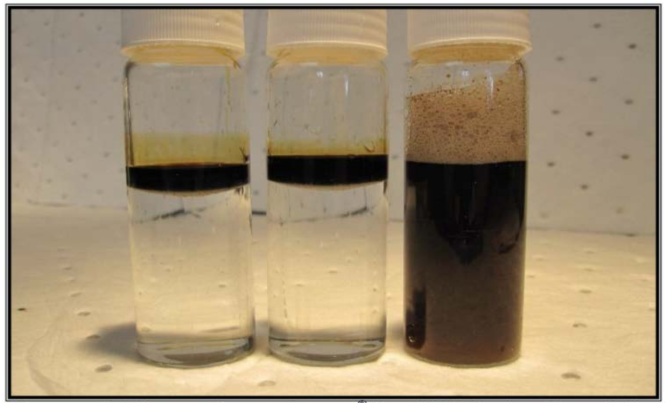


Figure 2-2: Ivey-sol® desorbing contamination off the soil surfaces, or NAPL layer making it more 'Available' for in-situ or ex-situ remediation.



Photograph 2-2: Pre-post Ivey-sol® Free NAPL Product Remediation

Ivey International Inc.

"Today's Environmental Solutions For A Better Tomorrow"™

ROUX

AMTRAK

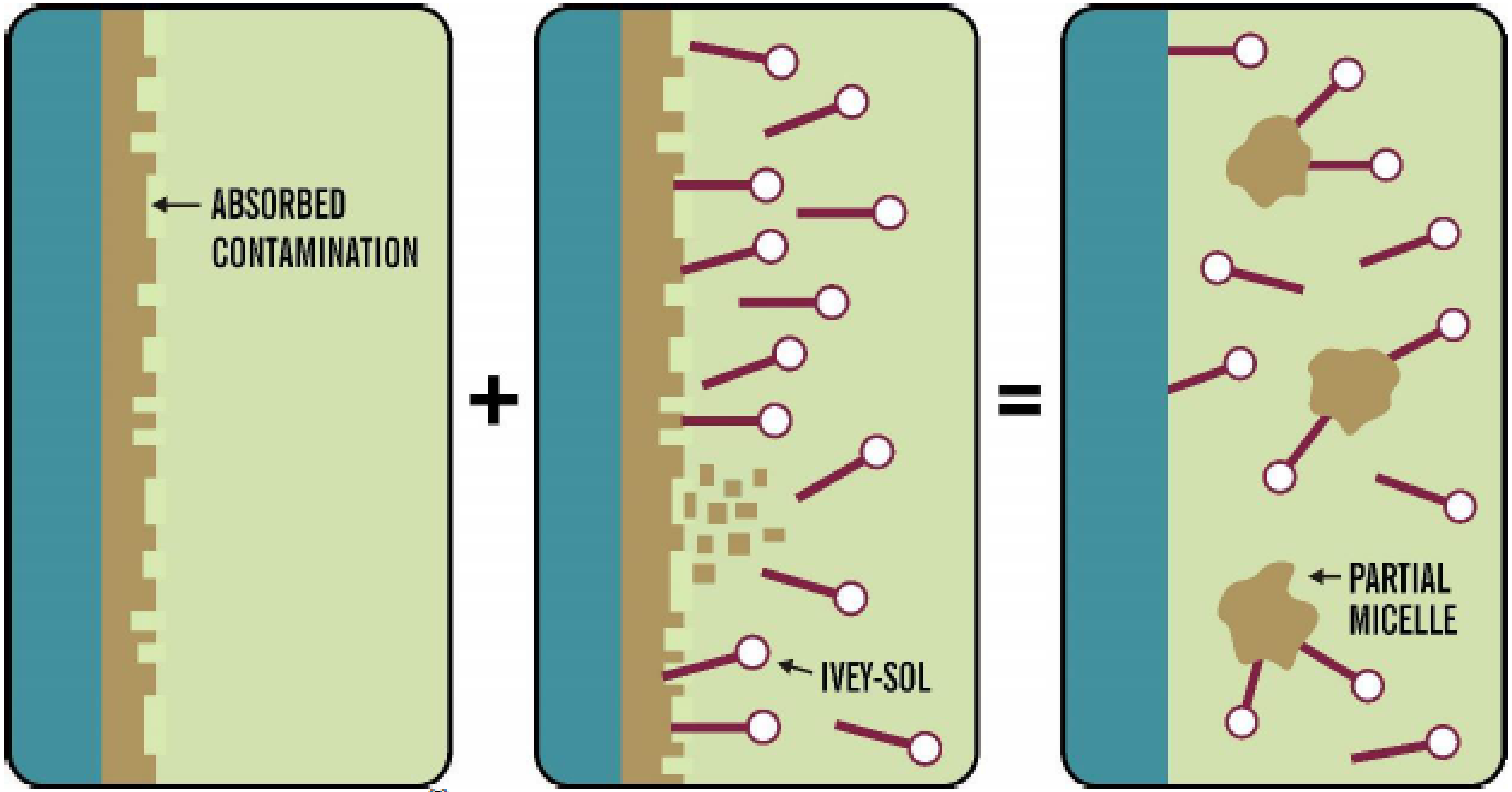
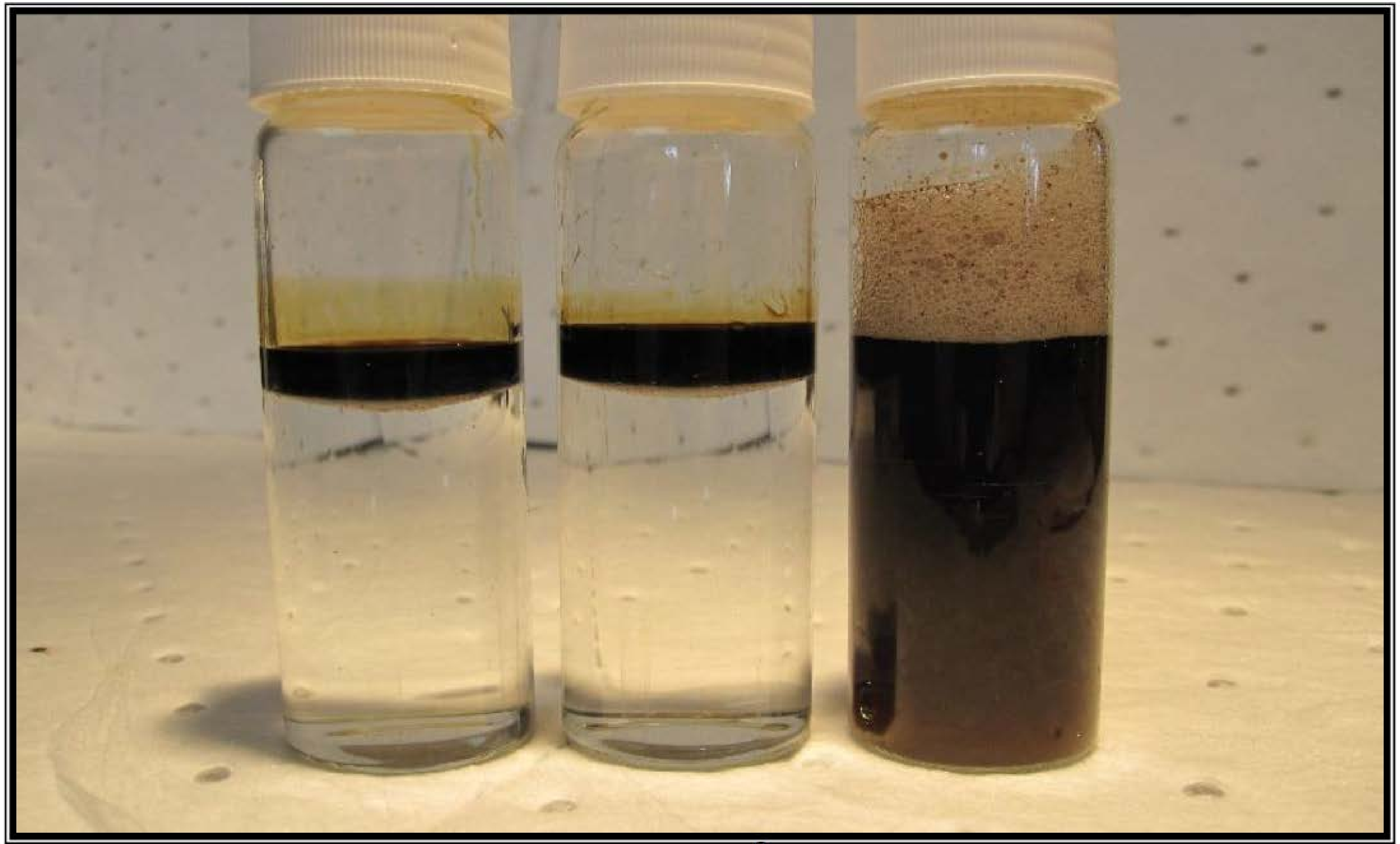


Figure 2-2: Ivey-sol® desorbing contamination off the soil surfaces, or NAPL layer making it more 'Available' for in-situ or ex-situ remediation.



Photograph 2-2: Pre-post Ivey-sol® Free NAPL Product Remediation

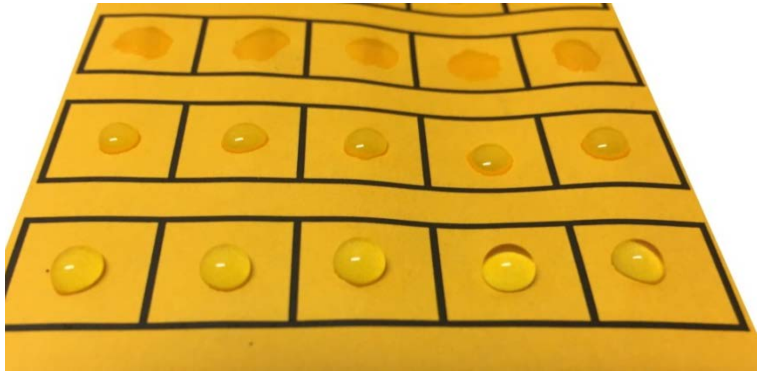
Injection Areas

ROUX

AMTRAK

Pilot Study Methods

1. Injection (gravity fed/geoprobe)
    - Experimented with surfactant to water ratios
    - Experimented with volumes of total mixture
2. Extraction (DPVE system)
    - Removed at least 3x the injection volume
    - Continued extraction until no surfactant was present
3. Extract from injection point or nearby extraction well

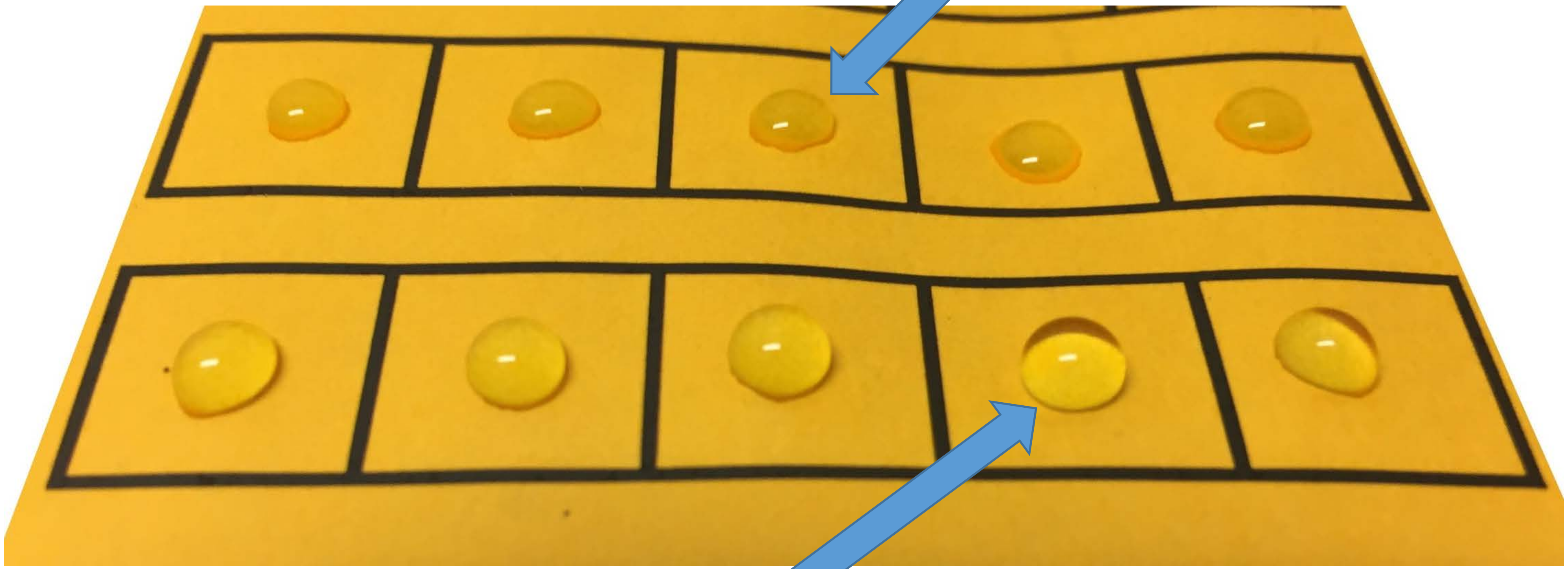


Water mixed with Surfactant

Irregular edges

Loses its beading

Absorbed by the paper



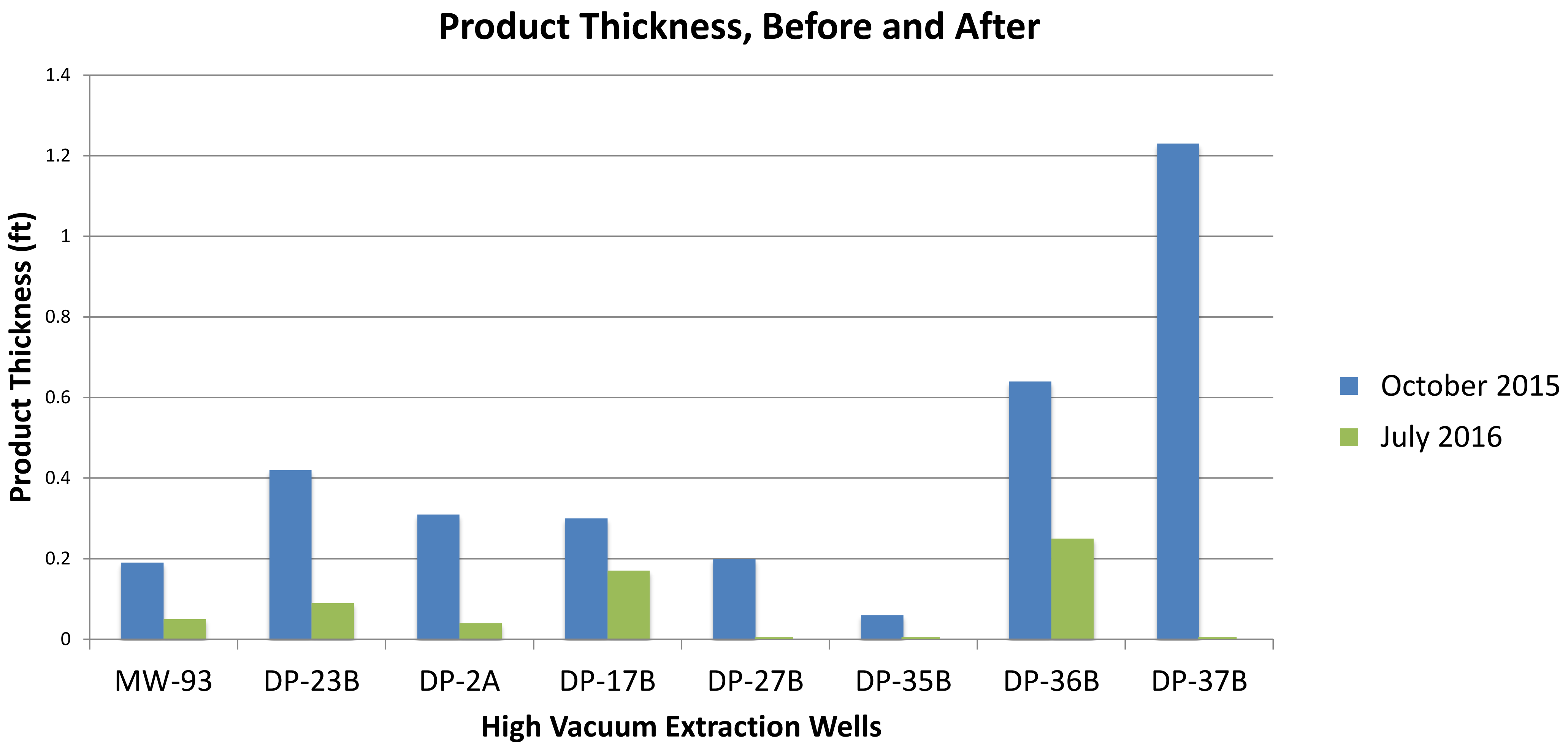
Water free of Surfactant

Forms near-perfect circles

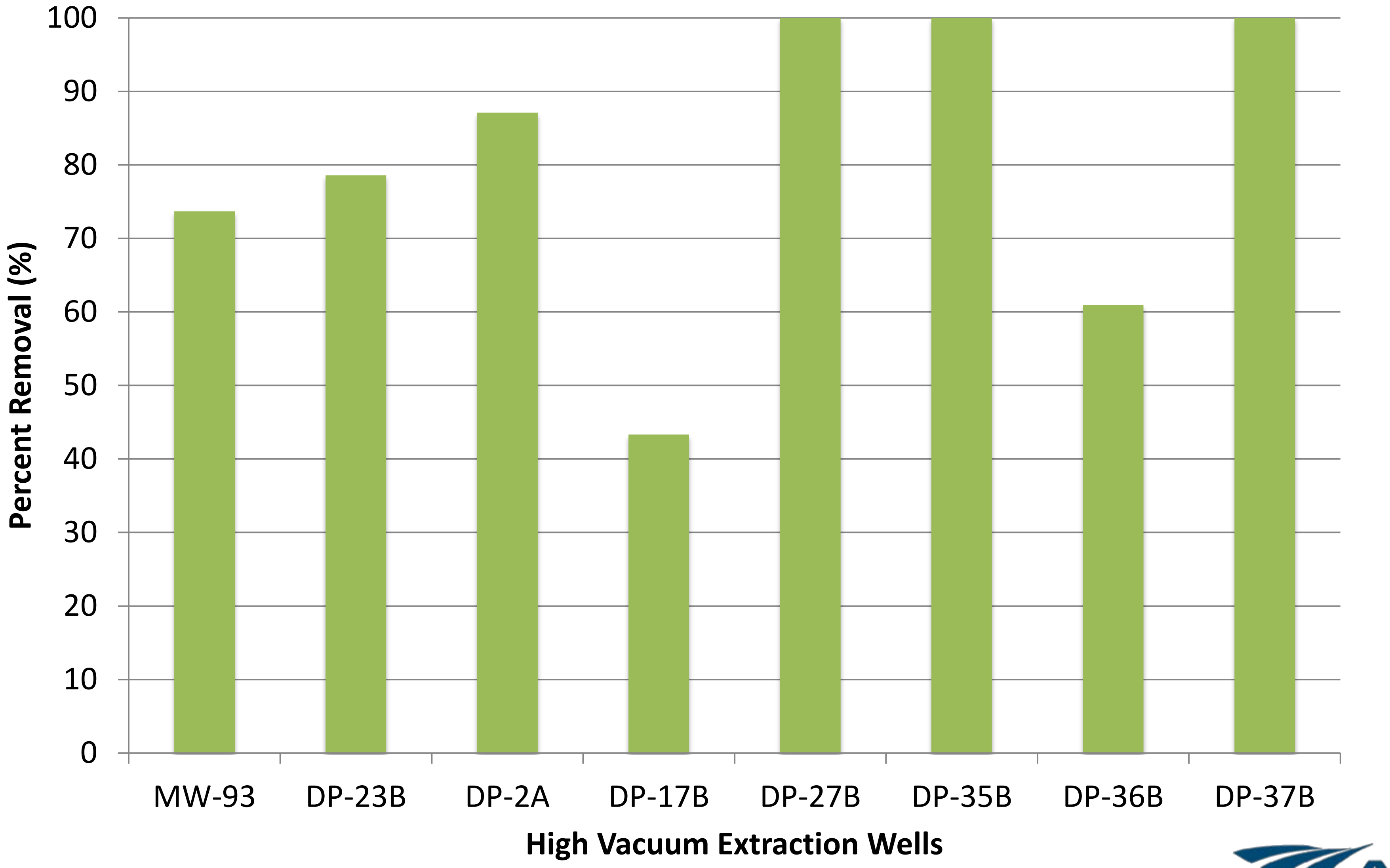
Retains its beading

Does not absorb into the paper

Pilot Study Results



SPH Percent Removal



ROUX

AMTRAK

Conclusions

- SHP recovery was enhanced by the increase of SPH solubility
- Free product was not observed in the extracted groundwater
- Reduction of SPH thickness was usually observed within 24 hours of surfactant injection and persisted for several weeks or longer
- Low concentration ratios of surfactant (1:20) are effective and higher concentrations do not increase effectiveness
- Low injection volumes or injection rates were generally needed in OU-3 due to the low permeability soil conditions and high groundwater table

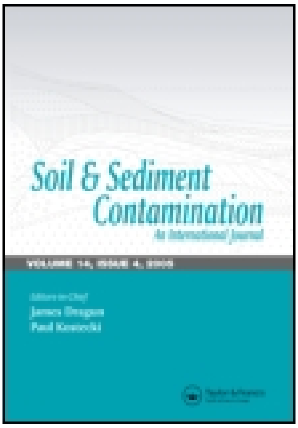
Recommendations

- Future applications of surfactant should be aimed at treating areas exterior of the proposed excavation but impacted by measurable impacts of SPH > 0.1 foot

- A Geoprobe® should be used to facilitate injections of a surfactant solution using a 5% Ivey-sol® to potable water ratio (i.e., 10:200 v/v or similar) under pressure

- Extraction should commence approximately 48 hours after injection and expect to conclude after removing 30 to 70 times the injection volume.

Questions



Soil and Sediment Contamination: An International Journal
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/bssc20

Mobilization Assessment and Possibility of Increased Availability of PAHs in Contaminated Soil Using Column Tests

F. J. García Frutos [a], O. Escolano [a], S. García [a] & G. A. Ivey [b]
[a] CIEMAT, Madrid, Spain
[b] Ivey International Inc., Campbell River, BC, Canada

To cite this article: F. J. García Frutos, O. Escolano, S. García & G. A. Ivey (2011): Mobilization Assessment and Possibility of Increased Availability of PAHs in Contaminated Soil Using Column Tests, Soil and Sediment Contamination: An International Journal, 20:5, 581-591

To link to this article: http://dx.doi.org/10.1080/15320383.2011.587046

Soil and Sediment Contamination, 20:581–591, 2011
Copyright © Taylor & Francis Group, LLC
ISSN: 1532-0383 print / 1549-7887 online
DOI: 10.1080/15320383.2011.587046

Mobilization Assessment and Possibility of Increased Availability of PAHs in Contaminated Soil Using Column Tests

F. J. GARCÍA FRUTOS,[1] O. ESCOLANO,[1] S. GARCÍA,[1]
AND G. A. IVEY[2]

[1]CIEMAT, Madrid, Spain
[2]Ivey International Inc., Campbell River, BC, Canada

Surfactants are well known to increase solubility/mobility of hydrocarbons and can be used to remediate contaminated water and soil. We wanted to explore if Ivey sol® 106 used at less than the critical micelle concentration (CMC) could effectively mobilize PAH (polycyclic aromatic hydrocarbons) from contaminated soil. The first step was to establish a measurement technique. Hence, a column leaching method was undertaken to investigate mobility of PAH-contaminated soil from a former gaswork facility. The methodology was based on a recycled flow of aqueous solution containing $CaCl_2$ 0.01M through two different soil columns. In the first column test, the free desorption of hydrocarbons was studied by recycling the solution through the soil column with a peristaltic pump and with a liquid/solid ratio of 2, based on ISO/DIS 18772. The solution was replaced with new solution every three days to aid desorption.

In the second column test, the set-up was similar with the exception of the aforementioned recycling solution. In this case, a second column was filled with a resin, Amberlite XAD-2, which captures PAHs entering the solution through the soil column, cleaning it of hydrocarbons (induced desorption). The results obtained for induced desorption and free desorption with reposition showed that liberation of PAHs in the presence of resins was higher (7%) as opposed to free desorption (below 0.3%). These two experiments demonstrated low mobilization of PAHs.

A third column test was performed using a non ionic surfactant, Ivey-sol® 106, 100 $\mu g\ g^{-1}$ of soil below the CMC in the recycling solution. The introduction of Ivey-sol® 106 at 0.005%w/v increased desorption of PAHs to 32%, thus demonstrating the potential for increased bioavailability of the PAHs for bioremediation of the soil.

Keywords Hydrocarbons, non-ionic surfactant, bioremediation

Introduction

Industrial activities have led to the deposition and discharge of a number of pollutants in soils. Many of these organic pollutants are persistent in contaminated sites. Among the most widespread, persistent organic pollutants are polycyclic aromatic hydrocarbons (PAHs), which originated from several pyrolysis processes. Due to the persistence of such compounds, the remediation of these sites is an important environmental issue.

Address correspondence to F. J. García Frutos, CIEMAT, Avda. Complutense 22, 28040 Madrid, Spain. E-mail: garcia.frutos@ciemat.es

The high hydrophobicity of these compounds results in strong sorption to the soil matrix, hence reducing availability for microorganisms and limiting the rate of their biodegradation (Di Gennaro et al., 2008). Typically, it is assumed that the slow biodegradation of such compounds in soils is caused by the extremely slow desorption or dissolution rates of these hydrophobic organic contaminants. In other words, these hydrophobic organic compounds have low bioavailability for bacteria.

Several different approaches to determine desorption and leaching of hydrophobic organic compounds have been reported. Stirred aqueous batch tests can increase the desorption rate of contaminants. The introduction of a third phase as an adsorbent to the soil/water system is another method, but if it is done in a stirred reactor, over-estimations of desorption rate can take place. To overcome some of these drawbacks, mobility assessment can be determined with the use of column leaching methods (Enell et al., 2004).

Column leaching methods have been thought to be more realistic in simulating the leaching processes occurring in the field. Existing column leaching procedures for organic compounds are often modified standard leaching tests for inorganic compounds. Standard procedures for the determination of leaching of organic compounds from contaminated soil such as the German column leaching test DIN V 19736 (DIN, 1998) are commonly used. Research has been conducted on the PAHs solubilization, mobilization, and biodegradation based on column tests (Hack and Selenka, 1996; Tiehm et al., 1997; Berger et al., 2005).

The use of resins as adsorbents of a hydrophobic organic compound is a well-known practice (Yang et al., 2001; Dongye and Pignatello, 2004; Huesemann et al., 2000). Amberlite XAD-2 is a resin-type styrene-divinylbenzene, which has shown strong affinity to aromatic compounds. The introduction of this resin as a third phase provides an infinite sorption sink to maintain near-zero aqueous-phase PAH compound concentrations, in order to maximize the rate of PAH compound mass transfer out of soil particles (Lei et al., 2004).

Surfactant-enhanced ground water remediation and soil washing are technologies previously shown to enhance the removal of organic contaminants (Yeom et al., 1995). The use of surfactants should therefore be considered as a possible solution in an experimental and modelling study of washing organic contaminated soil (Mulligan et al., 2001). Liu et al. (1991) and Yeom et al. (1996) have previously demonstrated the use of anionic and non-ionic surfactants as washing solutions, resulting in increasing the PAH desorption rate and mass transfer from soil. The application of many types of surfactants on PAH has been reported (Zheng and Obbard, 2002; Zhou and Lizbong, 2007, 2008). Ivey-sol® 106 surfactant is a proprietary, non-ionic formulation that has been used successfully in various situations (Ivey and Craft, 2005; Ivey, 2006).

Volkering et al. (1995) described using non-ionic surfactants for the solubilization of PAHs and demonstrated that if the substrate was in the micellar phase it was not available for degradation by microorganisms, thus causing inhibition. In a separate study by Laha and Luthy (1991), the use of non-ionic surfactants below the CMC demonstrated no inhibitory effects during biodegradation. These are two examples for specific analytes, surfactants, and microorganisms demonstrating the advantages of working below the CMC. Other advantages of working below surfactant CMC would include cost of remediation as well as compatibility with analytical testing procedures used to measure the effluent. In this study, we used an optimized formulation of Ivey-sol® 106 at 0.005%w/v below the CMC of 0.02%w/v (pure surfactant) to investigate its ability to mobilize PAH contamination. We used a column leaching method to measure mobility of PAHs from contaminated soil that originated from an old gaswork facility based on ISO 18772 (International Standard, 2008).

Comparative column free desorption, induced desorption (using resin Amberlite XAD-2), and surfactant desorption tests (using a non-ionic surfactant, Ivey-sol® 106), were studied with the objectives of evaluating the mobility of PAHs or quantification of the desorbable PAHs and the possibilities to increase desorption and bioavailability.

Materials and Methodology

Design of Column Leaching Tests

The method set-up is based on a recycled flow of an aqueous solution of $CaCl_2$ 0.01 M through three soil columns with different leaching procedures.

In the first column test, free desorption of hydrocarbons was studied by recycling the solution through the soil column with a peristaltic pump (Watson-Marlow) and with a Liquid:Solid ratio of 2 L/kg. The solution was replaced daily with a new solution during duration of test to aid desorption (Figure 1a).

In the second column test, the set-up is similar, with the exception of the previously used recycling solution. In this test, a second column was filled with resin Amberlite XAD-2 that captures PAHs, which enter the solution as it passes through the soil column and removes the hydrocarbons (induced desorption) from the soil (Figure 1b).

In the third column, the set-up was the same as with the free desorption, but the leaching media now contained a non-ionic surfactant formulation, Ivey-sol® 106 in an optimal concentration, that was determined by a previous stirred desorption test. This test was carried out, varying the Ivey-sol® 106 surfactant concentration in solution from 0–1000 $\mu g\ g^{-1}$ of soil (0–0.05%w/v). Samples of 2 g of soil were put in contact with 40 mL of Ivey-sol® 106 surfactant solutions in 50-mL Teflon-lined screw-cap glass centrifuge tubes and stirred. The test lasted four days. At the end of the test, samples were centrifuged, the supernatant solution was retired, and a new solution of only fresh water was introduced and

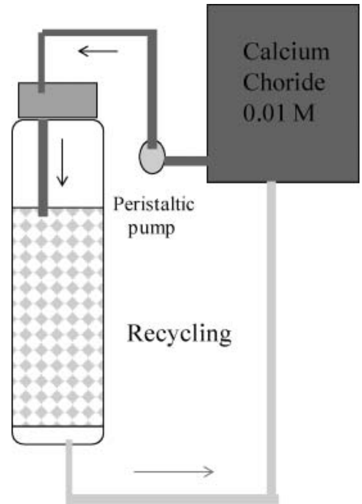


Figure 1a. Desorption in free column.

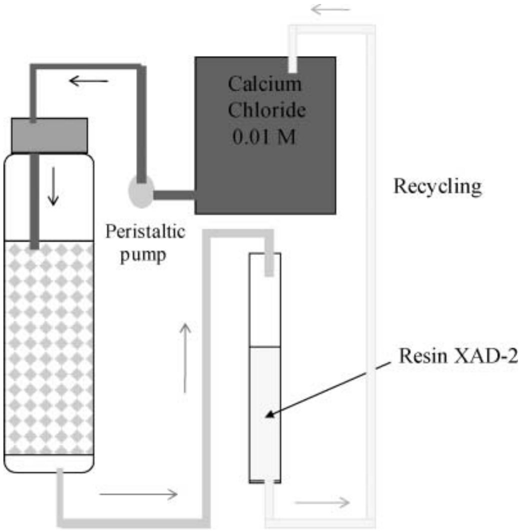


Figure 1b. Desorption in column with resin.

stirred over 24 hours. At the end of the test, the initial washing solutions were analyzed for PAHs to determine the optimal Ivey-sol® 106 surfactant concentration. The tests were performed in a thermostatic chamber at 25°C and under darkness. An additional desorption test was carried out using only water for comparison with the surfactant-aided desorption process.

In the surfactant desorption column test, two cycles of conducting included one leaching step (4 days of leaching) plus one washing step (4 days of washing). In the washing steps, the washing solution (aqueous solution of $CaCl_2$ 0.01 M) was changed daily.

The three soil-containing columns were identical, with their characteristics summarized in Table 1. The column containing the resin was smaller, with a diameter of 25 mm and a height of 40 cm. The quantity of resin Amberlite XAD-2 used was half of the soil sample, therefore the resin:soil weight ratio was 1:2.

Table 1
Column test conditions

Material of column	Glass
Diameter of column (mm)	75
Filling heights (cm)	35
Tubing materials	Viton
Flow rate (ml/min)	0.46
Test conditions	Room temperature
Leaching solution (mL)	500
Soil sample (g)	250
Duration of test (days)	16

Table 2
Main physical-chemical characteristics of soil samples. In Table 2, it takes in all values, the points corresponding to decimals.

Parameter		Value
Humidity	(%)	0.92
Water holding capacity	g H_2O 100 g $^{-1}$	23.06
pH H_2O		8.3
Hydraulic conductivity	cm h^{-1}	20.1
Porosity		0.46
Conductivity	μS cm^{-1}	390
Carbon	Total C (%)	19.1
	Black C (%)	7.7
	Total Organic C (%)	5.7
	Total Inorganic C (%)	5.7
Nitrogen	(%)	0.35
Phosphorus	mg/Kg	210

Soil Sample

Contaminated soil samples were extracted from an old gaswork facility. For the column test, a size fraction of less than 4 mm was used. The soil was saturated into the column and a bulk density of 1.2 g/cm^3 (porosity of 0.46) was achieved. The main physical-chemical characteristics of the soil prior to testing were performed following standard procedures (Guitián-Ojea and Carballas, 1976), with black carbon (Oen et al., 2006) and hydraulic conductivity applying (U.S. EPA Method 9100, 2008). These results are summarized in Table 2.

PAHs analyses were carried out by HPLC (high performance liquid chromatography) with a fluorescence detector. The conditions of the fluorescence detector and analytical procedure have been previously reported (García-Alonso et al., 2008). Briefly, solid samples were previously homogenized by grinding followed by extraction with methylene chloride and sonication. Extraction was carried out using sub-samples of 0.5 g and 20 mL of dichloromethane for 20 minutes twice to assure maximum extraction efficiency. Extracts were separated by centrifugation and then concentrated under nitrogen stream to adjust the final volume to 1 or 10 mL (acetonitrile) according to the level of concentration sample. An Agilent series 1200 chromatograph equipped with a C18 supelcosil thermostated column (250 × 4.6 mm) at 37°C and a series 1100 fluorescence detector were used for analysis. The operating conditions were gradient-mode starting with acetonitrile/water (45:55) at 1.5 mL.min^{-1}, programmed up to 100% of acetonitrile over 23 minutes, and holding for 10 minutes for column washing. The column was equilibrated for 6 minutes at the starting conditions prior to each injection. PAH concentrations of initial samples are displayed in Table 3.

Liquid Sampling Collecting

Samples of the supernatant and washing solutions in the tubes (desorption test), as well as leaching samples, were taken during the column tests. All samples were analyzed for PAHs

Table 3

PAHs content of initial soil sample

PAH	Content (mg/kg soil)
Fluorene	29
Phenanthrene	139
Anthracene	36
Fluoranthene	156
Pyrene	224
Benzoanthracene	66
Chrysene	69
Benzo(b)fluoranthene	61
Benzo(k)fluoranthene	38
Benzo(a)pyrene	58
Dibenzo (a,h)anthracene	8
Benzo (g,h,i)perylene	47
Σ PAHs	**931**

by HPLC solvent extraction with methylene chloride. During column tests, liquid samples were taken from the leaching media daily.

PAH Desorption Yield

PAH desorption yields were calculated based on analysis of final solid samples from columns after desorption tests, which are compared with the content of the initial sample, as described by the following equation:

$$\text{PAHs desorption (\%)} = [(\mathrm{I} - \mathrm{F})^{*}100]/\mathrm{I}$$

being

I: PAH concentration (mg kg^{-1}) in initial sample.
F: PAH concentration (mg kg^{-1}) in final solid residues from column desorption tests.

Results and Discussion

Surfactant Aided Desorption

Preliminary testing of the Ivey sol® 106 was required to obtain the optimized concentration for PAH desorption. The results obtained using a range of Ivey-sol® 106 surfactant concentrations by batch desorption test in tubes are represented in Figure 2. It was observed that PAH solubilization is diminishing at concentrations greater than 100 μg g^{-1} of soil. This may be explained by the surfactant approaching the effective critical micelle concentration. Taking into account these results, a concentration of 100 μg g^{-1} of soil was chosen as optimal and was applied in the leaching media for surfactant-aided desorption.

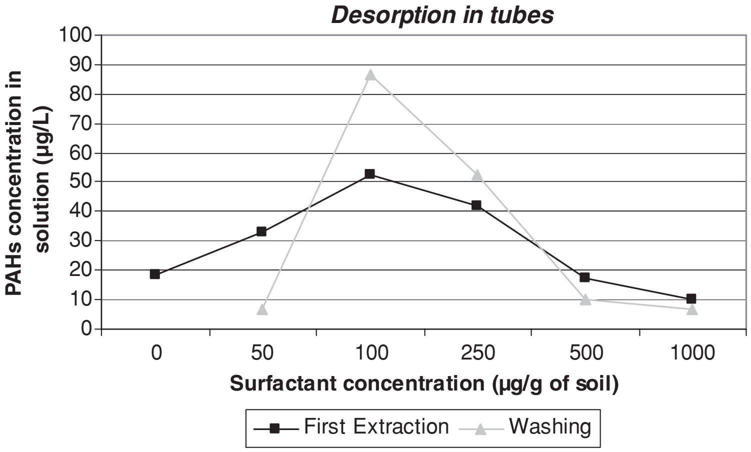


Figure 2. Optimization of dose of Ivey-sol® 106 surfactant by batch desorption in tubes.

Free and Induced Desorption

Figure 3 represents a graphical display of the results for each soil sample after free desorption, induced desorption, Ivey sol 106®, and initial PAH measurements. This data was used in the equation previously mentioned, to calculate percent desorption, displayed in Figure 4.

Minimal desorption rates for individual PAHs were observed in the case of free desorption; only chrysene and benzo(k)fluoranthene showed significant mobility at approximately

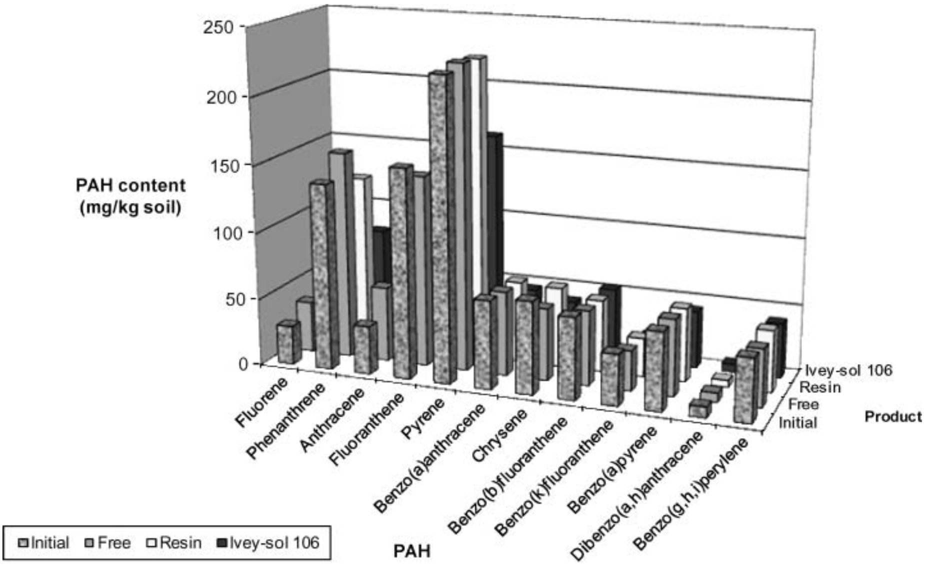


Figure 3. Comparative results of analysis of PAHs (final solids) for desorption column tests.

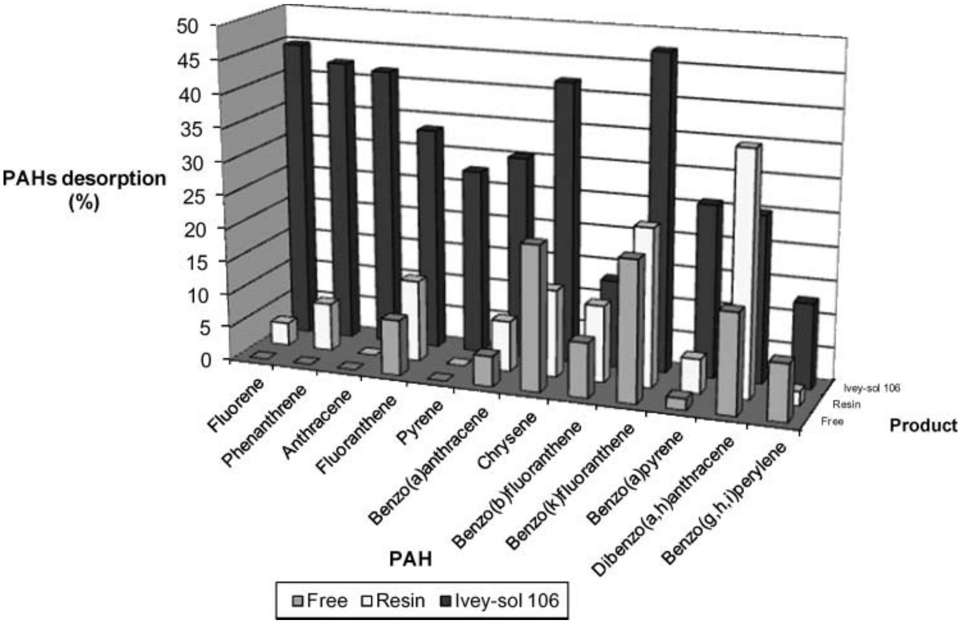


Figure 4. Comparative desorption (%) for PAHs in all tests.

20%. The desorbable fraction obtained with free desorption showed very low mobility (below 0.3%) of contaminants in this soil.

The desorption rates for individual PAHs obtained in the induced desorption test were higher than free desorption mainly for phenanthrene, fluoranthene, and dibenzo(a,h)anthracene. Although the desorbable fraction was increased, PAH mobility only increased a further 7%. This data is consistent with prior literature confirming the inefficient mobilization of these contaminants in soil (Hong et al., 2003; Johnsen et al., 2005). The result is very limited availability of PAHs and consequently unlikely positive remediation.

Figure 3 also contains the comparative results of analysis for PAHs (final solids) and for Ivey-sol® 106 surfactant desorption. Figure 4 displays desorption rates for all tests.

Figure 4 shows that surfactant-aided desorption clearly increased desorption yields for almost all PAHs. Specifically, anthracene and pyrene went from close to zero up to 42 and 27% desorption, respectively. The PAHs can be classified according to benzene ring number. When this ring number increases more difficult is to degrade the compound and consequentely it is more persistent in environment. Grouping aromatic compounds by ring numbers, Figure 5 compares desorption of PAHs for all tests. These results show that there is a notable increase in all PAH desorption rates with respect to free and induced desorption (desorption being higher for 3- and 4-ring PAHs).

The sum of PAHs for initial conditions was 931 μg.g^{-1}, whereas soil, post-free, resin and surfactant treatment were 929 μg.g^{-1}, 869 μg.g^{-1}, and 632 μg.g^{-1}, respectively. These results indicate that free desorption was only 0.24% and induced desorption was 6.7%.

The use of Ivey-sol® 106 surfactant at 4 times below the CMC of 0.02%w/v resulted in a 32% desorption rate, thus significantly increasing the bioavailability.

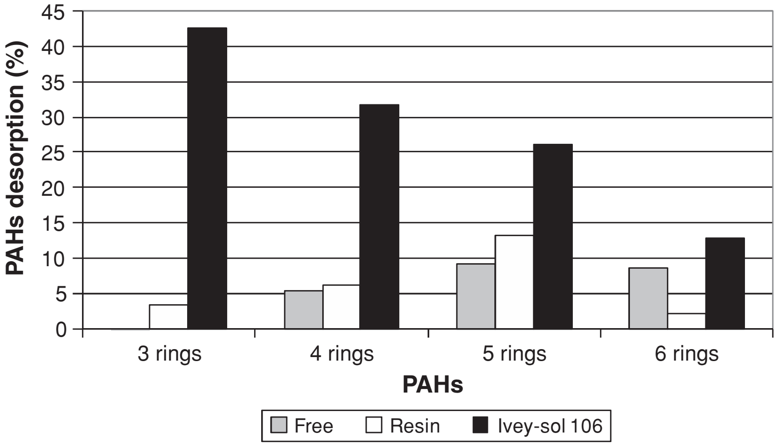


Figure 5. Comparative desorption (%) for PAHs grouping by ring numbers in all tests.

Conclusions

The column leaching method was an appropriate means to measure mobility of organic pollutants in soil. This methodology is also adequate to select optimal conditions to increase availability and consequently bioavailability of contaminants such as PAHs.

The use of this non-ionic surfactant Ivey sol® 106 below the CMC increased desorption yield of t-PAHs by 32% compared to free and induced desorption techniques at 0.3 and 7%, respectively. This significant increase in PAH desorption yields for Ivey-sol® 106 make it promising for improving bioremediation of contaminated soil. Taking into account the results of the bioremediation tests of contaminated soil (in which the PAH contaminants are desorbed and made more bioavailable), it is possible to conclude that applying adequate conditions of humidity, nutrients, Ivey-sol® 106 surfactant, and aeration would improve the efficacy and enhance bioremediation processes. Future work will involve using this column method to optimize real-world testing of Ivey-sol® 106 surfactant in conjunction with bioremediation.

Acknowledgments

This work has been carried out in the framework of a project funded by the Spanish Ministry of Science and Education (Plan Nacional I+D+I, CTM2004-05832-C02-01).

We wish to acknowledge the technical support of J.C. Díaz Reyes and M.L. Sevillano. We also wish to thank the inestimable comments and help of Dr. David Craft.

References

Berger, W., Kalbe, U., Eckardt, J., Christoph, G., and Walzel, H. 2005. Column tests for studying leaching behaviour of PAH's in soil. *Consoil 2005*. Proceedings, 827–832.

Di Gennaro, P., Franzetti, A., Bestetti, G., Lasagni, M., Pitea, D., and Collina. E. 2008. Slurry phase bioremediation of PAHs in industrial landfill samples at laboratory scale. *Waste Management.* **28**, 1338–1345.

DIN V 19736. 1998. Soil quality -Derivation of concentrations of organic pollutants in soil water. *Ableitung von Konzentrationen organischer Stoffe im Bodenwasser.- Normenausschuß Wasserwesen (NAW)*, Berlin: Deutsches Institut für Normung.

Dongye, Z., and Pignatello, J. 2004. Model-aided characterization of Tenax®-TA for aromatic compound uptake from water. *Environmental Toxicology and Chemistry.* **7**, 1592–1599.

Enell, A., Reichenberg F., Warfvinge, P., and Ewal G. 2004. A column method for determination of leaching of polycyclic aromatic hydrocarbons from aged contaminated soil. *Chemosphere.* **54**, 707–715.

Garcia-Alonso, S., Pérez, R., Sevillano, M. L., Escolano, O., and García Frutos, F. J. 2008. Influence of particle size on the quality of PAH concentration measurements in a contaminated soil. *Polycyclic Aromatic Compounds.* **28**, 67–83.

Guitián-Ojea, F., and Carballas, T. 1976. *Técnicas de Análisis de Suelos*Ed. Pico Sacro, Santiago de Compostela, Spain.

Hack, A., and Selenka, F. 1996. Mobilization of PAH and PCB from contaminated soil using a digestive tract model. *Toxicol. Lett.* **88**, 199–210.

Hong, L., Ghosh, U., Mahajan, T., Zare, R. N., and Luthy, R. G. 2003. PAH sorption mechanism and partitioning behavior in lampblack-impacted soils from former oil-gas plant sites. *Environ. Sci. Technol.* **37** (16), 3625–3634.

Huesemann, M.H., Hausmann, T. S., and Fortman T. 2000. Comparison of PAH biodegradation and desorption kinetics during bioremediation of aged petroleum hydrocarbon contaminated soils. In: Wickramanayake, G. B., Gavaskar, A. R., Gibbs, J. T., and Means, J. L. (eds.), *Case Studies in the Remediation of Chlorinated and Recalcitrant Compounds*. Batelle Press, Columbus, OH, pp. 181–188.

International Standard ISO 18722. 2008. Soil quality–Guidance on leaching procedures for subsequent chemical and ecotoxicological testing of soils and soil materials. Geneva: ISO Copyright office. CH-1211.

Ivey, G. A., and Craft, D. 2005. In-situ & Ex-situ Remediation of LNAPL and DNAPL Contamination. Presented at AEHS Conference, San Diego, CA.

Ivey, G. A. 2006. Surfactant Enhanced Aquifer Remediation (SEAR) Using Ivey-sol® Surfactant Technology. Presented at ENVIRO 2006, Melbourne, Australia (Enviro 06 Conference & Exhibition).

Johnsen, A. R., Wick, L. Y., and Harms, H. 2005. Principles of microbial PAH-degradation in soil. *Environmental Pollution.* **133**, 71–84.

Laha, S., and Luthy, R. G. 1991. Inhibition of phenanthrene mineralization by nonionic surfactants in soil-water systems. *Environ. Sci. Technol.* **25** (11), 1920–1930.

Lei Li, S., Makram, T., Khodaoust, A. P., and Tabak, H. H. 2004. Assessing the bioavailability of PAHs in field-contaminated sediment using XAD-2 assisted desorption. *Environ. Sci. Technol.* **38**, 1786–1793.

Liu, Z., Laha, S., and Luthy, R. G. 1991. Surfactant solubilization of polycyclic aromatic hydrocarbon compound in soil-water suspensions. *Water Sci. Technol.* **23**, 475–485.

Mulligan, C. N., Young, R. N., and Gibbs, B. F. 2001. Surfactant-enhanced remediation of contaminated soil: a review. *Engineering Geology.* **60**, 317–380.

Oen, A. M. P., Cornelissen, G., and Breedveld, G. D. 2006. Relation between PAH and black carbon contents in size fractions of Norwegian harbor sediments. *Environmental Pollution.* **141**, 370–380.

Saponaro, S., Bonomo, L., Barbafieri, M., and Petruzzelli, G. 2002. Soil washing feasibility at a manufacturing gas plant site. *Soil and Sediment Contamination*, **11**(5), 751–767.

Tiehm, A., Stieber, M., Werner, P., and Frimmel, F. H. 1997. Surfactant-enhanced mobilization and biodegradation of polycyclic aromatic hydrocarbons in manufactured gas plant soil. *Environ. Sci. Technol.* **31**, 2570–2576.

U. S. EPA Method 9100. 2008. *Saturated Hydraulic Conductivity, Saturated Leachate Conductivity, and Intrinsic Permeability*, Cincinnati, OH: U.S. Environmental Protection Agency.

Volkering, F., Breure, A. M., van Andel, J. G., and Rulkens, W. H. 1995. Influence of nonionic surfactants on bioavailability and biodegradation of polycyclic aromatic hydrocarbons. *Applied and Environmental Microbiology.* **61**(5), 1699–1705.

Yang, Y., Ratté, D., Smets, B. F., Pignatello, J. J., and Grasso, D. 2001. Mobilization of soil organic matter by complexing agents and implications for polycyclic aromatic hydrocarbon desorption. *Chemosphere.* **43**, 1013–1021.

Yeom, I.T., Ghosh, M. M., Cox, C. D., and Robinson, K. G. 1995. Micellar solubilisation of polycyclic aromatic hydrocarbons in coal-tar contaminated soils. *Env. Sci Tech.* **29**, 3015–3021.

Yeom, I. T., Ghosh, M. M., and Cox, C. D. 1996. Kinetic aspects of surfactants solubilisation of soil bound polycyclic aromatic hydrocarbons. *Env. Sci. Tech.* **30**. 1589–1595.

Zheng, Z., and Obbard, J. P. 2002. Polycyclic aromatic hydrocarbon removal from soil by surfactant solubilisation and *Phanerochaete chrysosporium* oxidation. *J. Environ Qual.* **31**, 1842–1847.

Zhou, W., and Lizbong, Z. 2007. Efficiency of surfactant-enhanced desorption for contaminated soils depending on the component characteristics of soil-surfactant-PAHs system. *Environmental Pollution.* **147**(1), 66–73.

Zhou, W., and Lizbong, Z. 2008. Influence of surfactant sorption on the removal of phenanthrene from contaminated soils. *Environmental Pollution.* **152**, 99–105.

Section 1 IDENTIFICATION OF THE SUBSTANCE/MIXTURE AND OF THE COMPANY/UNDERTAKING

1.1 Product identifier:

Identification on the label/Trade name: Ivey-sol®
CAS: See section 3 EC: See section 3
Index Number: N/A
REACH Pre-registration No.: N/A
Additional identification: Ivey-sol® 103, Ivey-sol® 106, and Ivey-sol® 108

1.2 Relevant identified uses of the substance and uses advised against:

1.2.1 Identified uses:

Ivey-sol® can be used for cleaning gasoline, diesel and bunker fuel spills through direct application to the spill site. This product is also effective on chlorinated solvent spills.

1.2.2 Uses advised against:

Not available.

1.3 Details of the supplier of the safety data sheet:

Ivey International Inc.
Unit 7, 19122-27 Ave,
Surrey, BC, Canada V3Z 5T1
Phone:+1.604.538.1168 (Direct)
Toll free : +1.800.246.2477
Fax: +1.888.640.3622

Supplier are avalable in: Canada, Europe, United States, and South East Asia.

1.4 Emergency telephone Number: (+1) 604 538 1168 or (+1) 250 203 0867

Available 24 hours? YES ☐ NO ☒

Section 2 HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

2.1.1 Classification:

Classification in according to EU CLP 1272/2008	
Hazard classes/Hazard categories	Hazard statement
N/A	N/A

For full text of H- phrases: see section 2.2.

Classification in according to 1999/45/EC(DSD)	
Hazards characteristics	R-Phrases
N/A	N/A

For full text of R- phrases: see section 16.

2.1.2 The most important adverse effects

2.1.2.1 The most important adverse physicochemical effects:

Not available.

2.1.2.2 The most important adverse human health effects:

Not available.

2.1.2.3 The most important adverse environmental effects:

Not available.

2.2 Label elements

Hazard Pictograms:	No hazard pictogram is used.
Signal Word(S):	No signal word is used.
Hazard Statement:	Not applicable.
Precautionary Statement:	Not applicable.

2.3 Other hazards

Not applicable.

Section 3 COMPOSITION/INFORMATION ON INGREDIENTS

Substance/Mixture:	Mixture
Ingredient(s):	Biodegradable non-ionic surfactant formulation

Section 4 FIRST AID MEASURES

4.1 Description of first aid measures:

4.1.1 In case of inhalation:

No adverse health effects anticipated by this route during proper industrial handling. However, if necessary, move person into fresh air.

4.1.2 In case of skin contact:

Generally the product does not irritate the skin. If necessary, wash contact areas with soap and water.

4.1.3 In case of eyes contact:

Flush eyes with plenty of water for at least 15 minutes. If necessary, consult a physician.

4.1.4 In case of ingestion:

Not expected to be a problem. However, if ingested, do not induce vomiting. Rinse mouth with water. Seek medical attention.

4.2 Most important symptoms and effects, both acute and delayed

The product is not classified as harmful to human health effect.

4.3 Indication of any immediate medical attention and special treatment needed

Immediately call a POISON CENTER or doctor/physician.

Section 5 FIRE-FIGHTING MEASURES

5.1 Extinguishing media:

Suitable extinguishing media: The product is not flammable. Use extinguishing agent suitable for surrounding fire. Water spray, foam, dry chemical or carbon dioxide.

Unsuitable extinguishing media: Not available.

5.2 Special hazards arising from the substance or mixture

Not available.

5.3 Advice for fire-fighters:

In any fire, fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

Section 6 ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures:

Observe good industrial hygiene practices. Use personal protective equipment recommended in Section 8. Avoid breathing vapors, mist or gas. Ensure adequate ventilation.

6.2 Environmental precautions:

No special environmental precautions required.

6.3 Methods for containment and cleaning up:

Eliminate and/or contain source with inert material (sand, earth, absorbent pads, etc.). Wear basic eye and skin protection. Floor may be slightly slippery; so use care to avoid falling. Avoid discharge to natural waters, and/or dilute with water. Transfer liquids to suitable containers for recovery, re-use or disposal. Contact Ivey International Inc. for technical assistance if required.

6.4 Reference to other sections:

Refer to section 8 of the SDS.

6.5 Additional information:

Not available.

Section 7 HANDLING AND STORAGE

7.1 Precautions for safe handling:

7.1.1 Protective measures:

Practice good housekeeping. Avoid breathing excessive vapors. Avoid contact with skin and eyes. Use personal protective equipment. Ensure adequate ventilation. Wash thoroughly after handling.

7.1.2 Advice on general occupational hygiene:

Do not eat, drink or smoke when using this product. Wash hands thoroughly after handling. Remove contaminated clothing and protective equipment before entering eating areas.

7.2 Conditions for safe storage, including any incompatibilities:

Keep the product in dry containers tightly closed when not in use. Containers which are opened must be carefully resealed and kept upright to prevent leakage. Do not allow to freeze, keep > 0°C.

7.3 Specific end use(s):

Not available.

Section 8 EXPOSURE CONTROL/PERSONAL PROTECTION

8.1 Control parameters:

8.1.1 Occupational exposure limits: Not available.

8.1.2 Additional exposure limits under the conditions of use: Not available.

8.1.3 DNEL/DMEL and PNEC-Values: Not available.

8.2 Exposure controls

8.2.1 Appropriate engineering controls:

Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

8.2.2 Individual protection measures, such as personal protective equipment:

Eye/face protection: Not required under normal conditions of use. Goggles or face shield, if splashes or contact with eyes is possible.
Hand protection: Latex, or similar would be sufficient.
Body protection: None required for normal recommended use. Wear normal work clothing.
Respiratory protection: Not necessary if room is well-ventilated.

8.2.3 Environmental exposure controls:

Avoid discharge into the environment.

Section 9 PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

Appearance:	Water based liquid
Physical state:	Liquid
Colour:	Clear to slightly cloudy white color
Odour:	Mild
Odour threshold:	No data available
pH:	Not Available (Typically 6.5-7.5 Range)
Melting point/range:	Approx. 0°C
Boiling point/range (°C):	No data available
Flash point (°C):	No data available
Evaporation rate:	<0.01
Flammability (solid, gas):	No data available
Ignition temperature (°C):	No data available
Upper/lower flammability/explosive limits:	No data available
Vapour pressure :	<0.01 mm Hg
Vapour density:	> 1 (Air = 1.00)
Density (20°C):	No data available
Water solubility (g/l):	Completely miscible
n-Octanol/Water (log Po/w) :	No data available
Auto-ignition temperature:	No data available
Decomposition temperature:	No data available
Viscosity, dynamic:	No data available

9.2 Physical hazards:

Not classified.

9.3 Other information:

Fat solubility (solvent– oil to be specified) etc	Not available
Bulk Density:	Not available
Dissociation constant in water (pKa):	Not available
Oxidation-reduction Potential:	Not available
Surface tension:	Not available
Molecular Formula:	Mixture (Not Applicable)
Molecular Weight:	Mixture (Not Applicable)
Specific Gravity:	0.99-1.04 (Water = 1.0)

Section 10 STABILITY AND RELIABILITY

10.1 Reactivity:

Stable under recommended transport or storage conditions.

10.2 Chemical stability:

Stable under normal temperatures and pressures.

10.3 Possibility of hazardous reactions:

No dangerous reactions known.

10.4 Conditions to avoid:

Prolonged excessive heat may cause product decomposition. Freezing should also be avoided as it may cause product decomposition. In some cases it may cause irreversible changes.

10.5 Incompatible materials:

Normally un-reactive; however avoid strong bases at high temperatures, strong acids, strong oxidizing agents, and materials with reactive hydroxyl compounds. These compounds would damage the mixture and reduce its effectiveness during application.

10.6 Hazardous decomposition products:

Not available.

Section 11 TOXICOLOGICAL INFORMATION

11.1 Toxicokinetics, metabolism and distribution

Not available.

11.2 Information on toxicological effects

Acute toxicity:	
LD50 (Oral, Rat):	Not available.
LD50 (Dermal, Rabbit):	Not available.
LC50 (Inhalation, Rat):	Not available.
Skin corrosion/Irritation:	No data available.
Serious eye damage/irritation:	No data available.
Respiratory or skin sensitization:	No data available.
Germ cell mutagenicity:	No data available.
Carcinogenicity:	No data available.
Reproductive toxicity:	No data available.
STOT- single exposure:	No data available.
STOT-repeated exposure:	No data available.
Aspiration hazard:	No data available.

Section 12 ECOLOGICAL INFORMATION

Toxicity:

Acute toxicity		*Time*	*Species*	*Method*	*Evaluation*	*Remarks*
LC50	0.07695%	96h	Fish	OECD 203	N/A	N/A
EC50	0.11%	48h	Daphnia	OECD 202	N/A	N/A
EC50	N/A	72h	Algae	OECD 201	N/A	N/A

Persistence and degradability:	>90% biodegradable in < 28 days.
Bioaccumulative potential:	No data available.
Mobility in soil:	Completely miscible with water.
Results of PBT & vPvB assessment:	No data available.
Other adverse effects:	No data available.

Section 13 DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

For aqueous Ivey-sol® mixture solutions; aerobic biological wastewater treatment systems are effective in treating said mixtures. Ivey-sol does not have any known negative affect on coagulant or flocculent water treatment processes.

Section 14 TRANSPORT INFORMATION

	Land transport (ADR/RID)	**Sea transport (IMDG)**	**Air transport (ICAO/IATA)**
UN-Number:	Not regulated	Not regulated	Not regulated
UN Proper shipping name:	Not regulated	Not regulated	Not regulated
Transport hazard Class:	Not regulated	Not regulated	Not regulated
Packaging group:	Not regulated	Not regulated	Not regulated
Environmental hazards:	No	No	No
Special precautions for user:	See section 2.2	See section 2.2	See section 2.2
Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code	Not regulated	Not regulated	Not regulated

Section 15 REGULATORY INFORMATION

15.1 Safety, health and environmental regulations/legislation specific for the substance or mixture

Relevant regulations: No data available.

Chemical Safety Assessment Carried Out? YES ☐ NO ☒

Section 16 OTHER INFORMATION

16.1 Indication of changes

Version 2.1 amended by EU No 453/2010

16.2 Relevant R- phrases (number and full text):

Not applicable.

16.3 Legal Disclaimer:

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The company shall not be held liable for any damage resulting from handling or from contact with the above product.

- End -