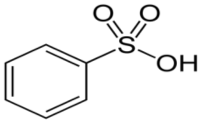
Benzenesulfonic Acid (Surfactant)

1. Submitted by Gary Cronk, JAG Consulting Group, Inc.
2. Benzenesulfonic acid has a chemical formula of C6H5SO3H



Benzene ring with an attached sulfonic acid group.

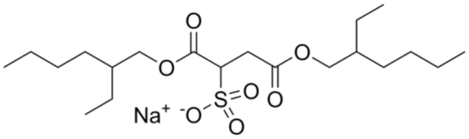
3. MSDS - See attached file
4. Number of Field Applications: 30 (estimated)
5. Case Studies - See attached files
6. Technical Summary: Benzenesulfonic acid is used for surfactant enhanced oil recovery (SEOR), also known as surfactant flushing. Surfactant use allows for enhanced recovery of large volumes of LNAPL (petroleum hydrocarbons). In a typical application, multiple injection wells are installed, as well as multiple hydraulic control wells and multiple recovery wells. Design involves groundwater flow modeling, tracer testing, and establishment of a constant forced-gradient flow field through the NAPL smear zone. A polymer solution (guar gum or xanthum gum) is injected to create a viscous plug flow behind the surfactant for the purpose of improving sweep efficiency and accelerating the recovery of NAPL and surfactant.

   Benzenesulfonic acid is biodegradable and does not degrade into benzene (the benzene ring breaks down first). The surfactant is low in toxicity (LD50 >2000 mg/kg). USEPA has determined that Benzenesulfonic Acid is a Safer Chemical Ingredient for Surfactant use and meets the criteria of the Design for the Environment.

   Benzenesulfonic acid can cause irritation to skin and lungs so use of proper PPE is important when handling the material.

Dioctyl Sodium Sulfosuccinate (Surfactant)

1. Submitted by Gary Cronk, JAG Consulting Group, Inc.
2. Dioctyl Sodium Sulfosuccinate has a chemical formula of $C_{20}H_{37}NaO_7S$. Commonly, a mixture of 75% Sulfosuccinate and 7% ethyl alcohol is used as an anionic surfactant (lowers surface tension of water). Its chemical structure is:



3. MSDS - See attached file
4. Number of Field Applications: 20 (estimated)
5. Case Studies - See attached files
6. Technical Summary: Sodium sulfosuccinate is used for surfactant enhanced oil recovery (SEOR), also known as surfactant flushing. Surfactant use allows for enhanced recovery of large volumes of LNAPL (petroleum hydrocarbons). In a typical application, multiple injection wells are installed, as well as multiple hydraulic control wells and multiple recovery wells. Design involves groundwater flow modeling, tracer testing, and establishment of a constant forced-gradient flow field through the NAPL smear zone. A polymer solution (guar gum or xanthum gum) is injected to create a viscous plug flow behind the surfactant for the purpose of improving sweep efficiency and accelerating the recovery of NAPL and surfactant.

   Sodium sulfosuccinate is biodegradable (ideal for all surfactants). Sodium sulfosuccinate is low in toxicity (LD50 1,900 mg/kg). Sodium sulfosuccinate was used as an oil dispersant in the BP Gulf of Mexico Oil Spill of 2010. It has been used in dozens of groundwater remediation projects.

   Sodium sulfosuccinate can cause irritation to skin and lungs so use of proper PPE is important when handling the material.

Xanthan Gum (Use with Surfactants)

1. Submitted by Gary Cronk, JAG Consulting Group, Inc.
2. Chemically, xanthan gum is a polysaccharide produced by the fermentation of glucose, sucrose, or lactose. Xanthan gum is used as a thickener in various food products.
3. MSDS - See attached file
4. Number of Field Applications: 20 (estimated)
5. Case Studies - See attached files
6. Technical Summary: Xanthan gum is used as a thickener to achieve high sweep and recovery efficiency during a surfactant flush. Xanthan gum is injected to create a viscous plug flow behind the surfactant for the purpose of improving sweep efficiency and accelerating the recovery of NAPL and surfactant.

   Xanthan gum is biodegradable (ideal for all surfactants) and low in toxicity. Xanthan gum has been used in the environmental market for 10 years.

Guar Gum (Use with Surfactants)

1. Submitted by Gary Cronk, JAG Consulting Group, Inc.
2. Chemically, guar gum is a polysaccharide is composed of the sugars galactose and mannose. Guar gum is used as a thickener in various food products.
3. MSDS - See attached file
4. Number of Field Applications: 20 (estimated)
5. Case Studies - See attached files
6. Technical Summary: Guar gum is used as a thickener to achieve high sweep and recovery efficiency during a surfactant flush. Guar gum is injected to create a viscous plug flow behind the surfactant for the purpose of improving sweep efficiency and accelerating the recovery of NAPL and surfactant.

   Guar gum is biodegradable (ideal for all surfactants) and low in toxicity. Guar gum has been used in the environmental market for 10 years.

Evaluation of Surfactants for Inclusion in the General WDR Permit

By: Gary Cronk, P.E.

JAG Consulting Group, Inc.

December 12, 2013

J A G Consulting Group, Inc.

Uses and Types of Surfactants

- Used primarily for surfactant enhanced oil recovery (SEOR), aka surfactant flushing

- Involves a surface-active agent (surfactant) solution to alter the surface chemistry solid surfaces and fluid interfaces to allow for enhanced NAPL flow and/or solubilization of LNAPL components (petroleum hydrocarbons)

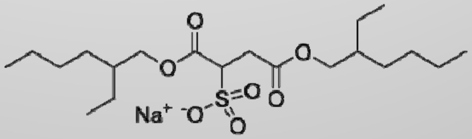
- May be combined with co-solvents (typically alcohols) to create treatment solutions tailored to specific conditions or objectives

- Commonly a polymer solution (Xanthan gum or Guar gum) is injected after the surfactant to achieve high sweep and recovery efficiency

- Recovered fluids are typically treated aboveground to separate contaminants and to recover the surfactant

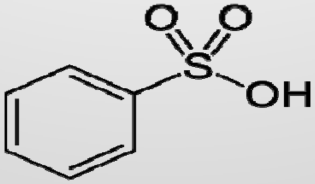
Dioctyl Sodium Sulfosuccinate

- Also Known as Aerosol OT (Brand Name)
- A mixture of 75% Sulfosuccinate and 7% ethyl alcohol
- Chemical structure:



- A component of an oil dispersant used in the BP Gulf of Mexico Oil Spill of 2010
- Low in toxicity (LD50 acute: 1900 mg/kg)
- Biodegradable (ideal for all surfactants)
- Used in dozens of remediation projects

Benzenesulfonic Acid

- Also known as Calfax and Dowfax (Brand names)
- Chemical structure: 
- Benzene ring with sulfonic acid attached
- Material is inherently biodegradable and does not degrade into benzene
- Low in toxicity (LD50 >2000 mg/kg)
- USEPA has determined that Benzenesulfonic Acid is a Safer Chemical Ingredient for Surfactant use and meets the criteria of the Design for the Environment.

JAG Consulting Group, Inc.

Xanthan Gum and Guar Gum

- Food grade products
- Polymers used as a thickener to achieve high sweep and recovery efficiency during surfactant flush
- Gums are biodegradable and low in toxicity

Minimize Health & Safety Issues

- Safe handling surfactants requires close adherence to established safety precautions.
- Surfactants can cause irritation to skin and lungs so use of proper PPE is important.

Case Study No. 1 –
Recovery of Fuel Oil , Coastal New Jersey

- Surfactants used to remove No. 2 Fuel Oil from beneath a sensitive residential structure

- LNAPL was present in 9 monitoring wells with maximum thickness of 2.67 feet. Estimated LNAPL quantity of 391 gallons.

- After extensive Column Bench-ScaleTesting, a design formulation was derived consisting of Sulfosuccinate, Benzenesulfonic acid, Sodium chloride solution, and a Xanthan gum polymer for pushing the surfactant front forward.

- Initial design steps involved groundwater flow modeling, tracer testing, and final design. Tracer testing was used to refine the groundwater model. SEOR emphasized LNAPL mobilization over enhanced solubilization.

- Installed 12 injection wells (2-inch), 10 hydraulic control wells (2-inch), and 4 NAPL recovery wells (4 inch), utilizing existing wells to the greatest extent possible.

Case Study No. 1 – Design Considerations

- Design included establishing a constant forced-gradient flow field through the NAPL smear zone

- Inject surfactant solutions into selected wells and force the solution through the flow field established in the smear zone.

- Inject polymer solution (xanthan gum) to create a viscous plug flow behind the surfactant for the purpose of improving sweep efficiency and accelerating the recovery of NAPL and surfactant

- Inject water and electrolyte (sodium sulfate) to flush the target pore volume of surfactant, polymer, and NAPL and reduce the concentration of dispersed NAPL constituents.

- Capture all treatment fluids and solubilized NAPL constituents as well as any mobilized NAPL using recovery wells located near the barrier wall.

- Remove NAPL, dissolved NAPL constituents, and treatment chemicals from the recovery well effluent so that the groundwater could be discharged the public sanitary sewer.

Case Study No. 1 – Results

- SEOR was operated on a 24-7 basis for 36 days
- Approximately 29,500 gallons of surfactant and 16,700 gallons of polymer were injected over three phases involving 13 individual injection events.
- Estimated 57 gallons of LNAPL was removed by SEOR. LNAPL has not been observed since the SEOR was completed.
- NAPL recovery rates were 3 to 5 times higher using surfactants than conventional pumping methods.
- Over 85% of Surfactant and polymer volume recovered.
- Soil sampling at 12 locations verified that that TPH and benzene levels had been reduced significantly and were below the New Jersey Soil Cleanup Criteria.
- Groundwater samples showed that TPH and target VOCs were below pre-SEOR levels and below New Jersey Groundwater Cleanup Criteria.

Case Study No. 2. Surfactant Flushing of Jet Fuel, Charlotte Air National Guard

- A Pilot Test was performed for removal of Jet Fuel NAPL using two surfactants (sulfosuccinate and benzenesulfonic acid)

- The Hillside Area was a topographic depression in weathered granite rock which was filled with construction debris, trash, and native earth

- During the 7 day pilot test, one injection well and two recovery wells were used to pump four pore volumes through the target sweep zone, using two surfactants, a polymer flush (Xanthan gum), and water flush

- An estimated 106 gallons of Jet Fuel NAPL were removed (68% of total)

- Higher recovery rates (up to 90%) would be expected using an optimized Pilot Test over a longer period.

- Observed 3-orders of magnitude increase in mass removal rate using surfactants than pumping methods

JAG Consulting Group, Inc.

Case Study No. 3. Surfactant Flushing at Alameda Naval Air Station, Alameda, CA

- A Pilot Test for removal of TCA and TCE (DNAPL) using surfactant flush
- Surfactants selected after extensive Column and Batch testing. Final doses determined were 5% sulfosuccinate , 2.5% benzenesulfonic acid, 3% sodium chloride solution, and Polymer flush (Xanthan gum)
- Pilot Test performed on a 20 ft by 20 ft cell. DNAPL well defined by sampling soil cores to just above clay confining layer prior to surfactant flush.
- Surfactant flush performed over a 30 day period
- Over 95% of Surfactant volume recovered within 30 days

Case Study No. 3. Performance Summary

- Sixty five (65) gallons of DNAPL (TCA and TCE) recovered from Groundwater
- Estimated 35 gallons of DNAPL were recovered from MPP
- Estimated 30 gallons of DNAPL in sludge recovered from oil/water separator
- Groundwater contaminant levels (dissolved) decreased by 80%.
- Observed 4-orders of magnitude increase in mass removal rate using surfactants than conventional methods.

Surfactant-Enhanced Recovery of No. 2 Fuel Oil from Beneath a Building Along Coastal New Jersey: A Case Study

James E. Studer, InfraSUR, LLC
Mark A. Hasegawa, Hasegawa Engineering Ltd.
Ed Christine, Ground/Water Treatment & Technology, Inc.
Doug C. Allen, Chris M. Turner, Keith Brodock, John A. Rhodes, Haley & Aldrich, Inc.

Abstract

A surfactant-enhanced oil recovery (SEOR) project was conducted over an approximate 12-month period, starting in June 2003, in a residential neighborhood located within a municipality on a New Jersey barrier island. The goal of the project was to accelerate oil removal and regulatory closure of a property impacted by an underground storage tank (UST) release of No. 2 fuel oil of unknown quantity and believed to have occurred in the late 1990s. The fuel oil release resulted in the migration of lighter-than-water non-aqueous phase liquid (light NAPL or LNAPL) over nearly 0.25 acre, including portions of the subject property and three adjacent properties. The subsurface beneath and around a large residential structure on the subject property was impacted and was the focus of the SEOR project. In 2003, after completion of a string of remedial actions and attainment of closure status for the three surrounding properties, mobile LNAPL was still present within a three feet thick smear zone extending beneath and around the subject foundation. Soil and groundwater impacts exceeded New Jersey Department of Environmental Protection (NJDEP) soil and groundwater cleanup criteria.

Site constraints associated with this project included the presence of LNAPL beneath a sensitive residential structure, limited opportunities to drill and install wells within and around the smear zone, a shallow water table, variable fluid transmissivity across the vertical horizon of soil and groundwater impact, limited working space, a difficult community environment, and a highly aggressive deadline for completion of all SEOR operations, demobilization, and property restoration.

The SEOR design involved a dynamic process of conceptual model building, bench-scale treatability testing, numerical groundwater flow modeling, aquifer and well hydraulics testing, and tracer testing. Results from these activities were integrated with constructability and cost considerations to complete the design. Significant site constraints were addressed and effluent pre-treatment/public-owned treatment works acceptance requirements were negotiated.

Upon completion of tracer testing, final design and construction was completed in an integrated fashion. An injectate sequence consisting of a site-specific binary anionic surfactant solution and a polymer solution was specified to promote LNAPL mobilization primarily and enhanced solubilization secondarily. Supplementary wells were installed and the existing LNAPL and groundwater extraction and pre-treatment system was modified to

allow for LNAPL separation and more aggressive removal of dissolved constituents prior to discharge to the sanitary sewer and POTW.

The SEOR system was operated on a 24/7 basis for approximately 36 days. Approximately 29,500 gal and 16,700 gal of surfactant and polymer solution, respectively, were injected over a sequence of 13 batch injection events. Approximately 57 gallons of LNAPL equivalent were recovered - within the range of recoverable LNAPL estimated during design. Approximately 1500 cubic feet of soil, most beneath the foundation, were treated. Performance assessment involved "before and after" comparisons of off-site analytical results for soil samples and groundwater. Based on the results of a 12-month post-SEOR performance assessment, a combined Soils and Groundwater No Further Action (NFA) proposal was submitted and NJDEP is preparing their final site determination.

Introduction

Surfactant-Enhanced Oil Recovery (SEOR) is an innovative remediation technology that belongs to the general remedial technology category referred to by one or more of the following: in-situ surfactant flushing; surfactant-enhanced aquifer remediation (SEAR); surfactant flooding; surfactant/co-solvent flushing; surfactant-enhanced pump and treat; chemical flooding. The basic technology was first applied in the oil fields decades ago for use in enhanced or tertiary crude oil recovery. In the most basic sense, this technology involves the in-situ application of a **surf**ace-**act**ive agent (surfactant) aqueous solution to alter the surface chemistry of subsurface solid surfaces and fluid interfaces (e.g., interfacial tension or IFT) to achieve conditions conducive to enhanced NAPL flow (i.e., mobilization) and/or solubilization of LNAPL components of petroleum hydrocarbon origin. Efficient and accelerated removal of the contaminants from the subsurface is thus facilitated. Excellent references on the general remedial technology category are available (Wunderlich et al 1992; Pope and Wade 1995; Sabatini et al. 1995; Krebbs-Yuill et al. 1995; Knox et al. 1997; Sabatini et al. 1997; Rao et al. 1997; Sabatini et al. 1998; Falta et al. 1999; Holzmer et al. 2000; Londergan et al. 2001).

Other chemicals such as electrolytes and co-solvents are combined with one or more different surfactants to create treatment solutions (i.e., injectate) tailored to specific site conditions and treatment objectives. For SEOR the surfactant formulation is typically designed to achieve mobilization such that an "oil bank" is formed and pushed to recovery wells. The surfactant solution is injected into a forced gradient flow field and guided through the targeted pore volume containing LNAPL. On the other side of the targeted pore volume, recovery wells or trenches are used to remove the diluted injectate, groundwater, and bulk mobilized NAPL and/or solubilized NAPL components. Water, electrolytic solution, or more commonly polymer solution is always injected after the surfactant solution to achieve high sweep and recovery efficiency. Recovered fluids are typically treated on-site to remove separate and dissolved phase contaminants and in some cases to recover and reuse the surfactant and/or water.

This paper presents a case history of a full scale SEOR design-build-operate subject to extraordinary constraints and pressures not often experienced at other sites involving this or other technology applications. A summary description of key site features including goals and objectives is presented. The design, construction, and operation phases are briefly described followed by discussion of performance assessment measures taken and conclusions.

The SEOR remedial action was performed on behalf of a major insurance company by a team of companies led by Haley & Aldrich, Inc. (H&A). H&A was responsible for regulatory interactions with local and state agencies, communications with stakeholders, establishing the overall goals and objectives to achieve regulatory compliance, coordinating with sub-consultants and subcontractors, and conducting groundwater monitoring and performance assessment sampling. InfraSUR, LLC of Albuquerque, New Mexico with sub-consultant Hasegawa Engineering of Lethbridge, Alberta, Canada (InfraSUR) was retained by H&A to provide technical leadership during the design and execution of the SEOR remedial action. Ground/Water Treatment & Technology, Inc. of New Jersey (GWT&T) provided field services, including equipment procurement, construction, operation and maintenance of the SEOR system.

Site Setting and History

The site is located on a barrier island, approximately 1000 feet from the Atlantic Ocean to the east and 4000 feet from the IntraCoastal Waterway to the west. A plan view of the site as it existed at the conclusion of the SEOR operations is presented as Figure 1.

The source of #2 fuel oil contamination at the site is reportedly a former 750-gallon underground storage tank (UST) previously located in the backyard near the north corner of the property. The UST and distribution pipe were removed by excavation in 1998. The invert depth was approximately 4.5 ft below grade surface (bgs).

General ground surface elevation at the site is seven (7) feet above mean sea level (ft-amsl). However, due to the presence of a soil berm along the west wall of the foundation, the maximum elevation is approximately nine (9) feet ft-amsl.

Shallow native soils are relatively homogeneous fine to medium grained silts and silty sands deposited and reworked as part of the New Jersey barrier island complex. Approximately two feet of granular fill material was placed over what is today an extensive residential area to facilitate construction and occupation of permanent structures. Based on review of available monitoring well data, the nominal elevation of the natural water table at the site is approximately three (3) ft (above mean sea level), or four (4) feet bgs at locations away from the bermed area, with a natural range of vertical fluctuation of approximately two (2) feet. These fluctuations are not tidally influenced. The average linear groundwater velocity is estimated to be 27 ft/day. Estimated values for total porosity, effective porosity, D_{50}, lateral hydraulic conductivity (of the native sands), and Peclet Number are 0.35, 0.27, 0.313 mm, 0.01 cm/sec, and 59, respectively.

Figure 1. Site Plan showing injection, recovery, and monitoring wells as well as multi-level sampling clusters in May 2004. Wells shown in bold were installed after June 2003.

Surface and near-subsurface infiltration of precipitation and utility leakage create a thin lens of fresh water beneath the site. Based on groundwater samples collected in April 2002, approximate values for the geochemical indicators total dissolved solids, pH, temperature, carbonate alkalinity, ferrous iron and sulfate are 200 mg/l, 6.5, 18.7 C, 29 mg/l, 0.3 mg/l, and 47 mg/l, respectively.

After excavation and removal of the UST in 1998, and up to the start of SEOR design activities in July 2003, a series of remedial actions were conducted over the 0.25- acre area including 1) soil excavation and soil removal including extensive sheet pile shoring and dewatering and 2) construction of a LNAPL and groundwater containment system including a subsurface barrier wall and groundwater extraction wells and effluent treatment system.

This containment system, including periodic groundwater monitoring, has been in near continuous operation since installation.

Soil and groundwater contamination was closely associated with the LNAPL smear zone. Based on the estimated smear zone pore volume of 3930 gallons and a reasonable range in average NAPL saturation values across the smear zone (1 to 10 percent), a range in estimated NAPL volume present in June 2003 is 39 to 393 gallons. The range in detected Total Petroleum Hydrocarbon (TPH) soil concentrations was from non-detect to over 32,000 mg/kg. Samples visually observed to contain separate phase were not analyzed but presumably were impacted at even higher TPH concentrations. Groundwater contamination by BTEX or other fuel components was not extensive.

A variety of site constraints and pressures presented a unique challenge to the project team. These included the presence of LNAPL beneath a sensitive residential structure, limited opportunities to drill and install wells within and around the smear zone, a shallow water table, variable fluid transmissivity across the vertical horizon of soil and groundwater impact, limited working space, constraints on allowable periods during which construction related work could be conducted, and a highly aggressive deadline of May 27, 2004 for completion of all SEOR operations and demobilization.

Goals and Objectives

The site falls under the regulatory oversight of the New Jersey Department of Environmental Protection (NJDEP) Division of Remediation Management and Response. The SEOR action was conducted to remove weathered #2 Fuel Oil (LNAPL) from within the site property boundary. The principal goal was to achieve sufficient LNAPL removal to support a Soil No Further Action (NFA) Proposal.

There were five specific objectives of equal importance:

- Remove the separate-phase or non-aqueous phase liquid (LNAPL) #2 heating oil per New Jersey Administrative Code Book 7 (N.J.A.C. 7) Chapter 26E (Technical Requirements for Site Remediation), Subchapter 6.1(d).
- Remove the LNAPL such that post-treatment soil samples meet New Jersey Soil Cleanup Criteria per NJAC 7:26D Residential Direct Contact Soil Cleanup Criteria (RDCSCC) and, if required, Impact to Groundwater Soil Cleanup Criterion (IGWSCC).
- Conduct the SEOR project safely and maintain effective hydraulic control such that uncontrolled release of LNAPL is prevented.
- Avoid adverse impact to the structural stability of the building beneath which LNAPL was to be removed.
- Complete all SEOR operations such that extensive site demobilization and property restoration activities are completed before Memorial Day weekend starting May 28, 2004.

Design, Construction, Operations and Process Monitoring

The SEOR project was designed from the outset to be a conceptual model driven process. From a chronological viewpoint, the SEOR project developed in a general step-wise fashion starting with a feasibility evaluation followed by a bench-scale study. The project continued with design conceptualization, numerical modeling, tracer testing, final design, procurement and finally construction. The tracer-testing program (using three conservative tracers) was designed, in part, through relatively extensive three-dimensional numerical groundwater flow modeling (using Visual MODFLOW, version 3.1.0 from Waterloo Hydrogeologic, Inc.) of steady state and transient flow scenarios. Subsequently, the tracer testing results were used to refine the site conceptual model, numerical model, and ultimately final design and construction details. The treatment solution formulation originally defined through phase behavior and column bench-scale testing was refined and requirements for the full-scale recovery and injection well configuration were changed as well as operational requirements. Also, throughout the design and construction process, as basic information on the site surface and subsurface features became available or conditions changed, the site conceptual model and design basis were strengthened. Once the full-scale operation was underway, new information and insights became available and were used to update the design basis and make changes in the field.

As previously mentioned, the SEOR technology emphasizes LNAPL mobilization over enhanced solubilization. Solubilization depends on formulation designs that optimize around micelle formation. When the aqueous surfactant concentration saturates the interfacial areas, the surfactant molecules self-aggregate into micelles and hydrophobic contaminants preferentially partition into the center of the micelle. On the other hand, mobilization depends on formulations that optimize around middle-phase microemulsions. These are transparent or translucent, thermodynamically stable “emulsion” systems (Griffin, 1949). Forming a middle phase microemulsion requires matching the HLB (hydrophilic-lipophilic balance) of the surfactant system with that of the oil. The HLB number reflects the degree of surfactant partitioning between the water and oil phases; higher HLB values indicate water soluble surfactants while lower values indicate oil soluble surfactants (Kunieda and Shinoda 1980, Abe et al., 1986). Phase behavior changes as the HLB value is systematically adjusted. Three distinct realms of phase behavior have been described and are referred to as Winsor Type I, II, and III (Winsor, 1954). The transitional phase is known as a Winsor Type III middle-phase microemulsion and contains enriched surfactant with solubilized water and oil.

It is widely recognized that the interfacial tension (IFT) between the microemulsion-oil and microemulsion-water both reach a minimum in the middle phase microemulsion region. When equal volumes of water and oil are solubilized in the middle phase, the system is said to be at its optimum state (Bourrel and Schecter, 1988), so defined because IFTs are minimized and thus the optimal oil mobilization occurs. The SEOR design was aimed at achieving maximize contaminant extraction efficiency while optimizing system economics. Since middle phase microemulsions maximize the solubilization while minimizing oil-water interfacial tension, these systems are highly desirable for LNAPLs, where downward migration of released oil is not a concern.

Through relatively extensive bench scale testing using site sediment, groundwater, and LNAPL, a formulation design was derived that achieved a stable Winsor Type III microemulsion. The final formulation, reflecting minor adjustments made after system startup was 1.15 wt% Aerosol OT, 0.27 wt% Calfax, and 2.5 wt% NaCl. A xanthum gum polymer at 50 to 350 ppm was found to be effective in uniformly pushing the surfactant front forward.

With a site-specific surfactant and polymer formulation sequence defined, the basic elements of SEOR implementation were developed for this site:

1) Establish a constant forced-gradient flow field through the NAPL smear zone, and directed towards the subsurface barrier, using existing wells to the extent possible to inject potable water and extract groundwater.
2) Inject surfactant solution into selected injectors and force the treatment solution through the flow field established in the smear zone.
3) Inject polymer solution after surfactant solution to create a viscous plug flow behind the surfactant-groundwater mixing zone for the purpose of improving sweep efficiency and accelerating the recovery of surfactant and NAPL.
4) Inject potable water containing electrolyte to flush the target pore volume of surfactant, polymer, NAPL, and reduce the concentration of dispersed-phase NAPL constituents while minimizing the potential for fines migration.
5) Capture all fluids containing treatment fluids and solubilized NAPL constituents as well as any mobilized NAPL using the recovery wells located near the center of the subsurface barrier wall.
6) Remove NAPL, dissolved NAPL constituents, and treatment chemicals from the recovery well effluent to the extent that the groundwater could be discharged into the public sanitary sewer for primary treatment at the POTW.
7) Monitor the system throughout the process to ensure that measures in place such as the subsurface barrier, hydraulic control wells, and slight over-pumping of recovery wells (relative to injection within the treatment zone) were sufficient to maintain hydraulic capture.
8) Re-establish basic hydraulic control after completion of SEOR operations.
9) Conduct performance assessment soil sampling near pre-SEOR soil sampling locations within and near the residence to evaluate the performance of the SEOR operation. Conduct groundwater sampling using monitoring wells selected by NJDEP to assess impact of SEOR on groundwater quality and determine appropriateness of a No Further Action proposal.

The conceptual model driven, integrated design-construct-operate process successfully elucidated a number of complicating issues that allowed the project team to avoid major set backs and potential failure in executing the basic process steps listed above. As with any subsurface remedial operations, initial subsurface investigations were not adequate to provide a true representation of the subsurface. Using the process described above several issues were revealed and resolution developed. For example as a result of the tracer testing it became apparent that the permeability of the soils increased with depth creating preferential flow paths under the zone impacted by LNAPL. In order to minimize this effect, recovery well design was modified. In addition, polymer was used to promote a more uniform flow of fluids in the subsurface.

Early on it became evident that the pre-existing well pattern configuration was far from ideal. Diverging flow paths were indicated to be the significant factor in promoting dilution and poor injectate sweep coverage. Consequently, the entire treatment zone was divided into three overlapping sub-areas for sequential flushing (Phase 1 with south to north flushing orientation, Phase 2 with west to east flushing orientation, and Phase 3 with north to south flushing orientation). In preparation for tracer testing a limited number of additional wells were installed. However, numerical modeling and tracer testing results continued to highlight the non-optimal nature of the well pattern. Additional hydraulic control, treatment solution injection, and recovery wells (EW-5) were installed in allowable areas but restrictions on drilling locations resulted in only modestly improved capability to establish optimal flow patterns for the SEOR.

The final SEOR system consisted of four main sub-systems: 1) potable water and treatment solution mixing, storage and delivery to wells; 2) groundwater and NAPL recovery; 3) NAPL isolation and recovery; and 4) groundwater treatment and discharge to POTW outfall. Additionally, the collection of observation wells and three multi-level sampling nests (i.e., MLS1, MLS2, and MLS3) as well as the on-site laboratory represented a process monitoring sub-system.

Major components of these sub-systems were:

- Use of nearby fire hydrant for potable water.
- Two 250-gallon potable water totes.
- Two 6000-gallon poly tanks (one for mixing and one for simultaneous staging or temporary storage of treatment solution).
- Two inline static mixers, rated at 300 gpm and connected in series and each having fluid injection ports.
- A gasoline engine driven trash pump rated at 25 hp and 300 gpm for transfer and mixing treatment solution in large tanks.
- An assortment of smaller capacity electrical screw, diaphragm and positive displacement pumps used for batch mixing, large tank transferring and injecting into well manifolds.
- 10 two-inch diameter wells exclusively used for hydraulic control and 12 two-inch wells primarily used as treatment solution injectors with associated flexible delivery hoses and wellhead assembles capable of individual delivery rates of 0.1 to 4 gpm.
- Four – four-inch diameter recovery wells with associated submersible pumps, variable speed controllers, piping and wellhead assemblies capable of individual extraction rates of approximately 0.2 to 5 gpm.
- Several low flow peristaltic pumps and 50 gallon poly barrels used to extract and temporarily contain floating NAPL and emulsion in recovery well casings (above the submersibles).
- Bag filter followed by a series of canisters containing surfactant-modified clay absorber and granular activated carbon (GAC) for removal of particulates, NAPL emulsion, and

dissolved petroleum hydrocarbons from up to 10 or 15 gpm prior to sanitary sewer discharge for primary treatment at POTW.

- 20 wells of various primary functions that were used as observation wells and three (3) multilevel piezometer nests (total of 12 discrete screens) for fluid level gauging and groundwater sampling, and on-site mobile laboratory also used for staging samples for off-site laboratory archiving and analyses.

The site was eligible for and received Permit-by-Rule exemption on UIC Class V well permitting. Thus, the injection wells did not require permitting. System operation resulted in three waste streams: contaminated water; LNAPL, and spent treatment media. Raw effluent could not be sent directly to the sanitary sewer and POTW; pre-treatment of effluent was determined to be necessary. The design included on-site pre-treatment using filtration, phase-separation, and sorption and this facilitated negotiation with the local POTW authorities of reduced pre-treatment requirements to the following: 5-day BOD at or below 300 mg/l and suspended solids at or below 300 mg/l.

The SEOR was initiated on April 6, 2004 and was terminated 36 days later on May 13, 2004 and during this time the system was operated on a 24/7 basis. Hydraulic containment was successfully achieved before, during, and after this period. Approximately 29,500 gallons and 16,700 gallons of surfactant and polymer solution, respectively, were injected over three (3) general phases involving a total of 13 individual batch injection events.

During operations, a number of process monitoring activities were conducted. These activities along with the reason for conducting them are listed as follows:

- On-site testing to ensure injectate formulation was capable of producing a stable middle phase microemulsion with potable water and site LNAPL.
- Visual monitoring and recording of potable water usage as well as potable water and surfactant/polymer injection and recovery flow rates (instantaneous and cumulative) to track volumes for mixing purposes and for estimating pore volume flushing progress.
- Fluid level gauging and construction of potentiometric surface maps to confirm hydraulic containment was being maintained, to track presence of and changes in LNAPL accumulations, and adjust peristaltic pump intake elevation as necessary.
- Visual monitoring and on-site lab testing of bailed groundwater samples for the presence or absence of tracer (which was added to all surfactant injectate), surfactant, of LNAPL or emulsion, and particulates/colloids.
- Effluent sampling between sorption canisters and prior to sewer discharge followed by off-site analysis for TPH to evaluate pre-treatment effectiveness and define progress of surfactant-mobilized LNAPL migration across the swept zone.

The later set of process monitoring data was plotted against time to develop mobilized/solubilized LNAPL breakthrough curves. Figure 2 is an example of one such graph showing TPH versus time for the four recovery wells. Time of zero days coincides with start of Phase I surfactant solution injection. Each of the three phases involved a different well configuration including injection and recovery rates. The recovery wells were operated continuously throughout, however. Centrally located recovery well EW-3r, recovered the most LNAPL and LNAPL constituents. Well EW-1, along the northwest end of the barrier and which was not replaced, recovered the least. All of these TPH values represent diluted concentrations as much of the groundwater pumped from these wells derived from the aquifer below or outside the zone of surfactant injection. The maximum detected TPH value shown in Figure 2 is 480 ppm from a sample collected at EW-3r at day 26.5. In contrast, at observation well IW-6 (beneath the boiler room) the maximum TPH detection was 42,000 ppm at day 33. Elevated TPH was first detected at IW-6 at day 29 and the breakthrough decline was similarly dramatic. The TPH observations at IW-6 compared to the recovery wells point to the slower and less dispersed transit of injectate through the shallow materials of lower permeability. It appears that the recovery well observations shown in Figure 2 are the result of combinations of contributions from complex flow in the shallow and deep horizons and can not be used to estimate overall slug transit times.

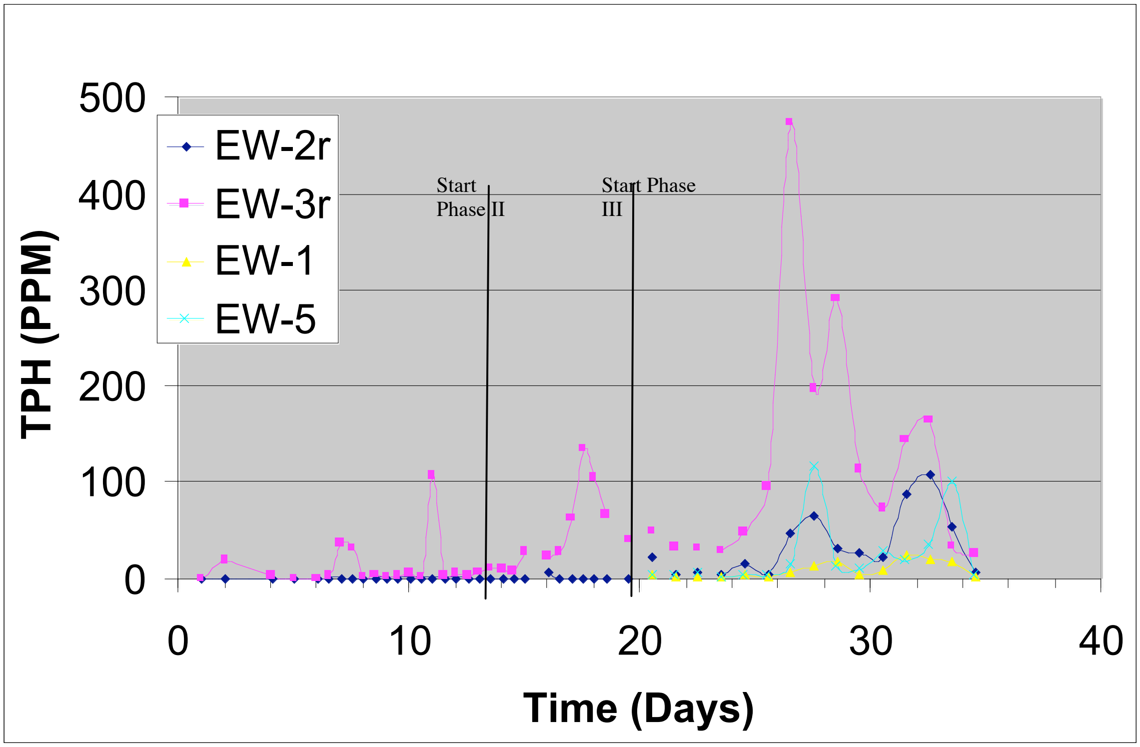


Figure 2. Total Petroleum Hydrocarbon Breakthrough at Recovery Wells due to NAPL Solubilization).

Performance Assessment

The key data required to assess degree of success or failure relative to the first three objectives listed previously were acquired through the following four basic steps:

1. Estimate the volume of LNAPL present at the start of SEOR operations

2. Establish the pre-SEOR nature and extent of soil contamination relative to the NJDEP enforced RDCSSC
3. Estimate the volume of LNAPL removed during the SEOR operation
4. Conduct verification sampling to establish the post-SEOR nature and extent of soil contamination relative to the NJDEP enforced RDCSSC and IGWSCC.

The estimated LNAPL volume present in June 2003 was previously stated to range between 39 and 393 gallons. LNAPL was consistently observed on several wells within the containment system cone of depression near the center of the subsurface barrier. The three-dimensional extent of soil contamination of regulatory interest appeared to be in close association with the geometry of the smear zone and the highest impact was associated with LNAPL presence. The volume of LNAPL removed during the SEOR operation was estimated as an "Equivalent NAPL Volume" to include not only LNAPL recovered using the peristaltic pumps, but also emulsified LNAPL and LNAPL components dissolved in extracted groundwater and captured by the modified clay/GAC media, and dissolved LNAPL components discharged to the POTW. The equivalent NAPL volume recovered was estimated to be 57 gallons. During SEOR operations LNAPL was observed up to 2.67 feet in thickness in nine wells near the subsurface barrier and at termination of the SEOR and thereafter LNAPL has not been observed.

Verification soil sampling was performed after injection operations were terminated at 12 locations and depths corresponding in most cases to pre-SEOR sampling locations. Samples were delivered to an offsite lab for analysis of TPH by Method 418.1M and Total VOCs by Method 8260B. Table 1 summarizes the pre-SEOR and final post-SEOR TPH and Total Organic Compounds (Total OC) results. Significant reductions in TPH and Total OC on the order of one to two orders of magnitude were achieved at all locations. In most cases the TPH limit of 1000 mg/kg continued to be exceeded yet in every case the Total OC limit of 10,000 mg/kg was not and no individual Method 8260B constituent limits for groundwater protection (e.g., benzene at 1.0 mg/kg) were exceeded. Conditions for a soils NFA determination were achieved.

Groundwater was sampled at NJDEP designated observation wells PZ-D and EW-4 on multiple occasions during the 12-month period after SEOR termination. The samples were analyzed for TPH, VOCs, and SVOCs. Post-SEOR, the TPH, target VOC and target SVOC concentrations were at or below levels observed pre-SEOR and below groundwater quality standards. However, detected Tentatively Identified Compounds (TICs), mostly semi-volatile in nature, increased as a result of the SEOR. The TIC increase was temporary at PZ-D and TIC concentrations are declining at EW-4. These elevated TIC were of concern to NJDEP and delayed the soils NFA process. However, evidence indicates the TICs are primarily related to residual surfactant biodegradation and is not a long-term concern. Consequently, NJDEP requested the submittal of a combined soil and groundwater NFA request (as opposed to only a soils NFA request). The combined submittal was made and NJDEP is conducting their review.

Table 1. Comparison of Baseline to Final Verification Sampling Results - Soil

Soil Sampling ID (Prior / Post)	Pre-SEOR (2002) TPH and Total OC	Post-SEOR (2004) TPH and Total OC
BOIL1/ BOIL1A	17,300 17,300	2320 2320
BOIL2/ BOIL2A	NA (visible sheen)	9190 9261
F(-1) / F(-1)A-r	NA (visible sheen)	4840 4840
F(-1) / F(-1)B	NA (visible sheen)	6190 6205
G(0) / G(0)A	20,700 21.003	9840 9869
J(0) / J(0)A	17,800 18,274	359 359
J(1) / J(1)A	32,200 32,931	2920 3084
HALL2 / HALL2A	NA (visible sheen)	35 35
SIT2 / SIT2A	NA (visible sheen)	6150 6364
KITCH1 / KITCH1A	NA (visible sheen)	8190 8424
KITCH2 / KITCH2A	NA (visible sheen)	33 33
None / KITCH4B	No sample	6210 6354

Notes: 1) First sample ID relates to 2002 sampling and second to 2004 performance assessment sampling
2) Values are reported in mg/kg. Regulatory limits: 1000 mg/kg for TPH and 10,000 mg/kg for Total OC.
3) KITCH4B sample collected from a location beneath foundation not sampled prior to SEOR

Conclusions

By utilizing surfactant-enhanced oil recovery technology, the project team achieved the overall goal of removing the weathered #2 fuel oil NAPL to an acceptable regulatory level, as well as the five specific project objectives previously listed. The project was conducted safely, there were no adverse impacts, demobilization and site restoration were complete prior to Memorial Day weekend 2004. LNAPL has not been observed since the completion of the SEOR action. Post-treatment soil sample analytical results were compared to New Jersey Soil Cleanup Criteria per NJAC 7:26D Residential Direct Contact Soil Cleanup Criteria (RDCSCC) and Impact to Groundwater Soil Cleanup Criterion (IGWSCC). The only lingering concern one year after the completion of LNAPL removal was elevated TICs in groundwater and these have been for the most part ascribed to surfactant biodegradation. TICs concentrations have declined significantly since the first post-SEOR groundwater-sampling event and are expected to completely disappear in the near future by natural biotic and abiotic pathways. Consequently, NJDEP requested the submittal of a combined Soils and Groundwater NFA Proposal for review and approval.

The SEOR technology was specified for this site to remove difficult-to-extract NAPL in a matter of weeks and accelerate soils remediation. Because NAPL contains the vast majority of contaminant mass when and where it is present at a site, removal of most of the NAPL translates into dramatically reduced TPH and VOC concentrations as observed through analysis of soil samples from the immediate area of NAPL impact. Maximum benefit from NAPL removal is typically observed after a period of adsorbed and dissolved contaminant mass redistribution (during which time surfactant-enhanced biodegradation may be significant). Because removal of heating oil constituents adsorbed to soil surfaces and dissolved in groundwater was not a goal of the SEOR action, flushing of the treated subsurface volume by groundwater using the groundwater containment system was anticipated for approximately one year beyond the end of the SEOR. One year of flushing did in fact occur, however, during the initial approximately six months of this one-year period the groundwater containment P&T system was operated at approximately 1 gpm while during the latter six-month period it was operated at approximately 5 to 6 gpm. Visual observations and sample analytical results demonstrated that the latter operating conditions promoted more groundwater flushing and concomitant lowering of TICs concentrations in groundwater – the only lingering concern from a regulatory perspective. Through enhanced LNAPL removal, the SEOR technology application achieved the desired soils treatment and as an additional benefit established the opportunity for full site closure based on groundwater sampling and analysis data collected over a twelve-month period.

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Keith P. Brodock is an engineer with Haley & Aldrich, Inc., 299 Cherry Hill Road, Suite 105, Parsippany, New Jersey 07054-1124. Email: kbrodock@haleyaldrich.com. He provides task management and professional support on numerous environmental projects. Project experience includes phase I assessments, phase II investigations, environmental site characterizations, remedial investigations, and Monte Carlo simulations for environmental liability management. Keith earned a Bachelors of Science degree in Chemical Engineering from Clarkson University in 2002.

John A. Rhodes is Senior Vice President for Haley & Aldrich, Inc. Based in New Jersey, John has over 28 years of experience in environmental engineering related to property, air, surface water and groundwater. He is an expert in investigative and remedial engineering and management decision analysis including economic risk assessment and risk reduction. John received a B.A. from Bowdoin College, Physics 1972, an M.S. from Massachusetts Institute of Technology (MIT), Civil Engineering 1979, and a Degree of Civil Engineer from MIT, Water Resources and Environmental Engineering Division 1979. He is a licensed Professional Engineer in New Jersey, Pennsylvania and Connecticut.

ABSTRACT FOR AIR FORCE PRESENTATION

Remediation Pilot Testing: Surfactant Flushing of Jet Fuel Free Product in a Debris Fill Unit, Charlotte Air National Guard (Helen Corley, AMEC Earth & Environmental; Jim Studer, InfraSUR LLC; Mark Hasagawa, Hasagawa Engineering)

The Charlotte Air National Guard facility is located next to the Charlotte Douglass international airport. In the 1950s, what is now the Hillside area was a topographic depression in partially weathered rock of dioritic granite. As part of an apron expansion project this depression was filled with construction debris, trash, and some native earth materials to a thickness of two to fourteen feet and this layer was buried under silty clay fill. Materials identified in the debris fill have included wood, glass, concrete, paper and miscellaneous metallic debris. AMEC has periodically detected free product, termed light non-aqueous phase liquid (LNAPL) in several monitoring wells screened across the debris fill. The LNAPL is dominated by petroleum hydrocarbons but also contains TCE and at some locations is quite black and sticky in character. The depth to water table within the Hill Slope area is approximately 27 to 33 feet below grade. Groundwater discharges to a local stream that exits the property, thus surface water is the receptor being protected. This Hillside is not an active part of the Base but is located between two critical operations: Flight line and POL.

Surfactant flushing, also referred to as Surfactant Enhanced Oil Recovery (SEOR), is a technology that can rapidly remove a large percentage of the NAPL present within the swept pore volume. AMEC retained InfraSUR LLC (including subconsultant Hasagawa Engineering Ltd.) to assist in evaluating the feasibility of conducting a surfactant flush pilot test and subsequently to assist in the design, execution and evaluation of such test. Two test plots were created (Plot A and Plot B) in areas with differing debris fill saturated thicknesses. Each test plot included two recovery wells, one injection well, one multi-level sampling well and varying monitoring wells. A rough estimate of the LNAPL present in each plot prior to SEOR flushing was calculated to be 84 gallons. During seven days and nights of pilot testing, the one injection and two recovery wells per Plot forced 4 pore volumes of the following fluids through the target swept zone: potable water; two surfactants in a salt solution; polymer; and water again. Success was to be measured not only in enhanced recoverability of LNAPL, but in achieving technical goals while not interfering with the mission's operations.

A relatively comprehensive program of performance-assessment monitoring including a field laboratory was implemented to discern effectiveness during testing and allow for mass balance calculations upon completion. Samples of the effluent exhibited interesting changes in color, opacity, and fraction as micro-emulsion. The percentages of surfactant and chloride recovered were calculated to be approximately 78 and 81, respectively. Offsite laboratory analyses coupled with field analyses allowed for the use of four methods of measuring petroleum hydrocarbon recovery. The resultant calculations estimated that a combined 106 gallons of LNAPL was removed from the two Plots with 168 gallons as the pre-test estimate of quantity present; thus it is estimated that 63 percent of the LNAPL in the Plots was removed. This is an outstanding outcome considering the non-optimized nature of the pilot test and the fact that the test was terminated early to accommodate a special event at the base. LNAPL recovery on the order of 90 percent is possible at this site. Logistics, regulatory, and base concerns were managed and quality information for full scale up was obtained. SEOR has subsequently been selected for full-scale implementation during Hillside remediation expected to commence in 2011.

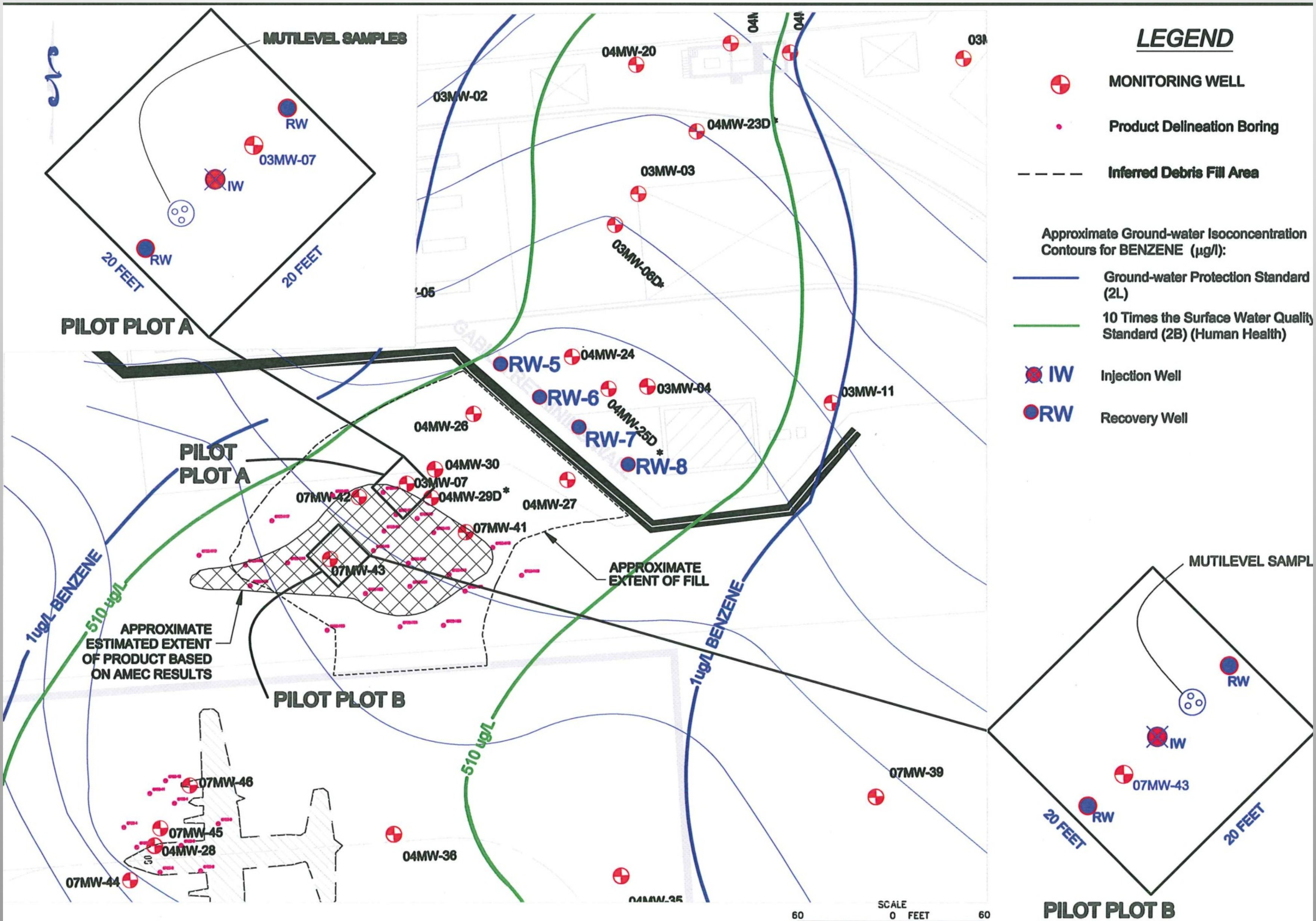
Case Study:
Surfactant & Polymer Enhanced NAPL Recovery
North Carolina Air National Guard

Contact: Jim Studer
505-858-3136
Jstuder@infrasur-llc.com

InfraSUR LLC
Albuquerque New Mexico

North Carolina Air National Guard

- Remediation of fuel oil plume adjacent the tarmac
- Water table 30’ below grade
- Product thickness ranges from several feet to a sheen
- InfraSUR technical lead assisting AMEC with pilot
- Treated two 20’ x 20’ plots in a larger plume
- Very limited working space
- Timeline requirements extremely stringent
- Designed surfactant, delivery and treatment system for site specific use.



LEGEND
MONITORING WELL
Product Delineation Boring
Inferred Debris Fill Area
Approximate Ground-water Isoconcentration Contours for BENZENE (µg/l):
Ground-water Protection Standard (2L)
10 Times the Surface Water Quality Standard (2B) (Human Health)
IW Injection Well
RW Recovery Well
MUTILEVEL SAMPLES
RW
03MW-07
IW
RW
20 FEET
20 FEET
PILOT PLOT A
03MW-02
04MW-20
04MW-23D*
03MW-03
03MW-06D*
RW-5
04MW-24
RW-6
03MW-04
04MW-25D
RW-7
RW-8
03MW-11
04MW-26
PILOT PLOT A
04MW-30
03MW-07
07MW-42
04MW-29D*
04MW-27
07MW-41
07MW-43
APPROXIMATE EXTENT OF FILL
1ug/L BENZENE
510 ug/L
APPROXIMATE ESTIMATED EXTENT OF PRODUCT BASED ON AMEC RESULTS
PILOT PLOT B
1ug/L BENZENE
510 ug/L
07MW-39
07MW-46
07MW-45
04MW-28
07MW-44
04MW-36
04MW-35
MUTILEVEL SAMPL
RW
IW
07MW-43
RW
20 FEET
20 FEET
PILOT PLOT B
SCALE
60
0 FEET
60

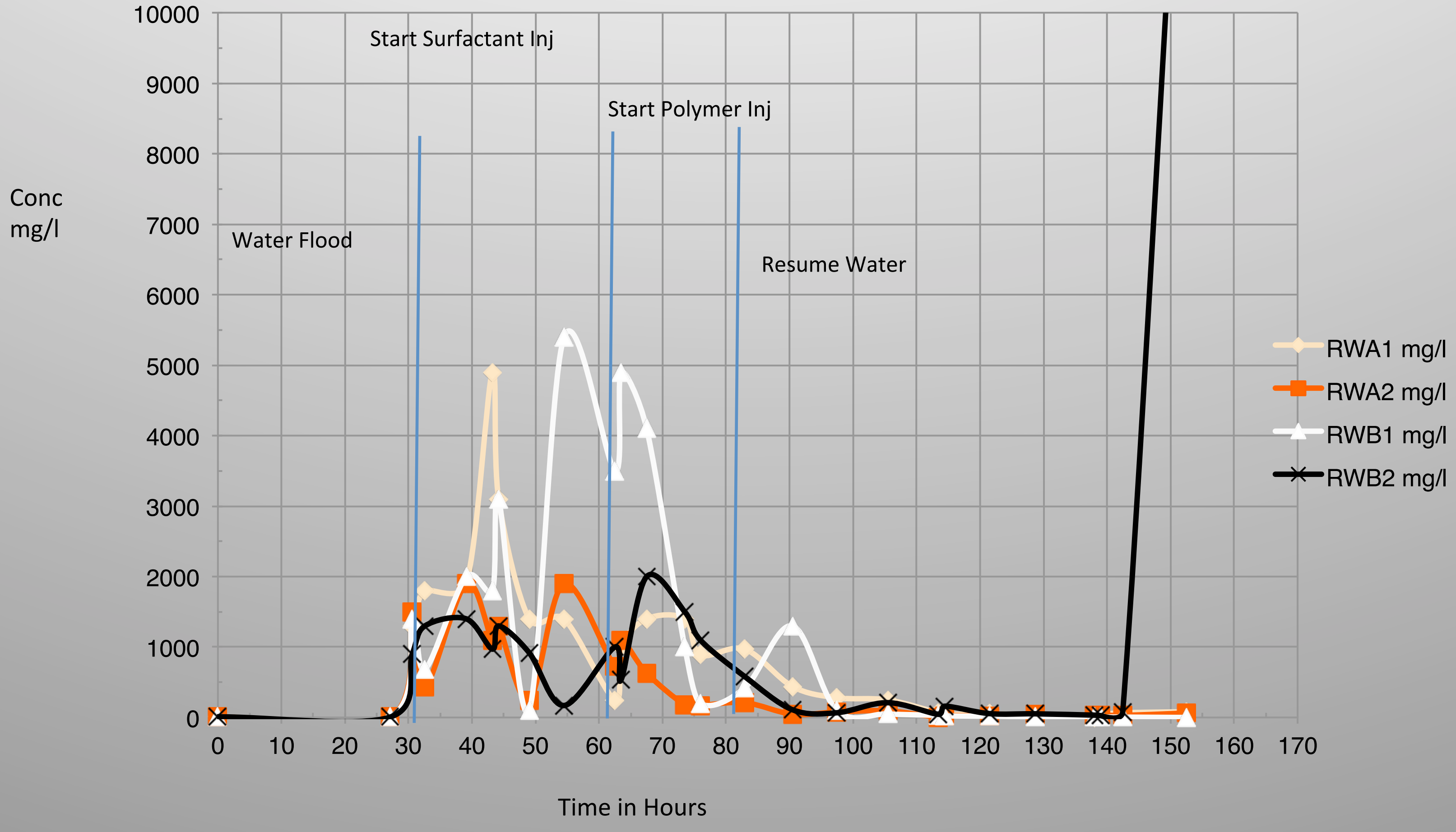
Project Objectives

- Evaluate removal of the separate-phase or non-aqueous phase liquid (LNAPL) complex Jet fuel in a fixed duration of time
- Evaluate the technology for application on the entire plume

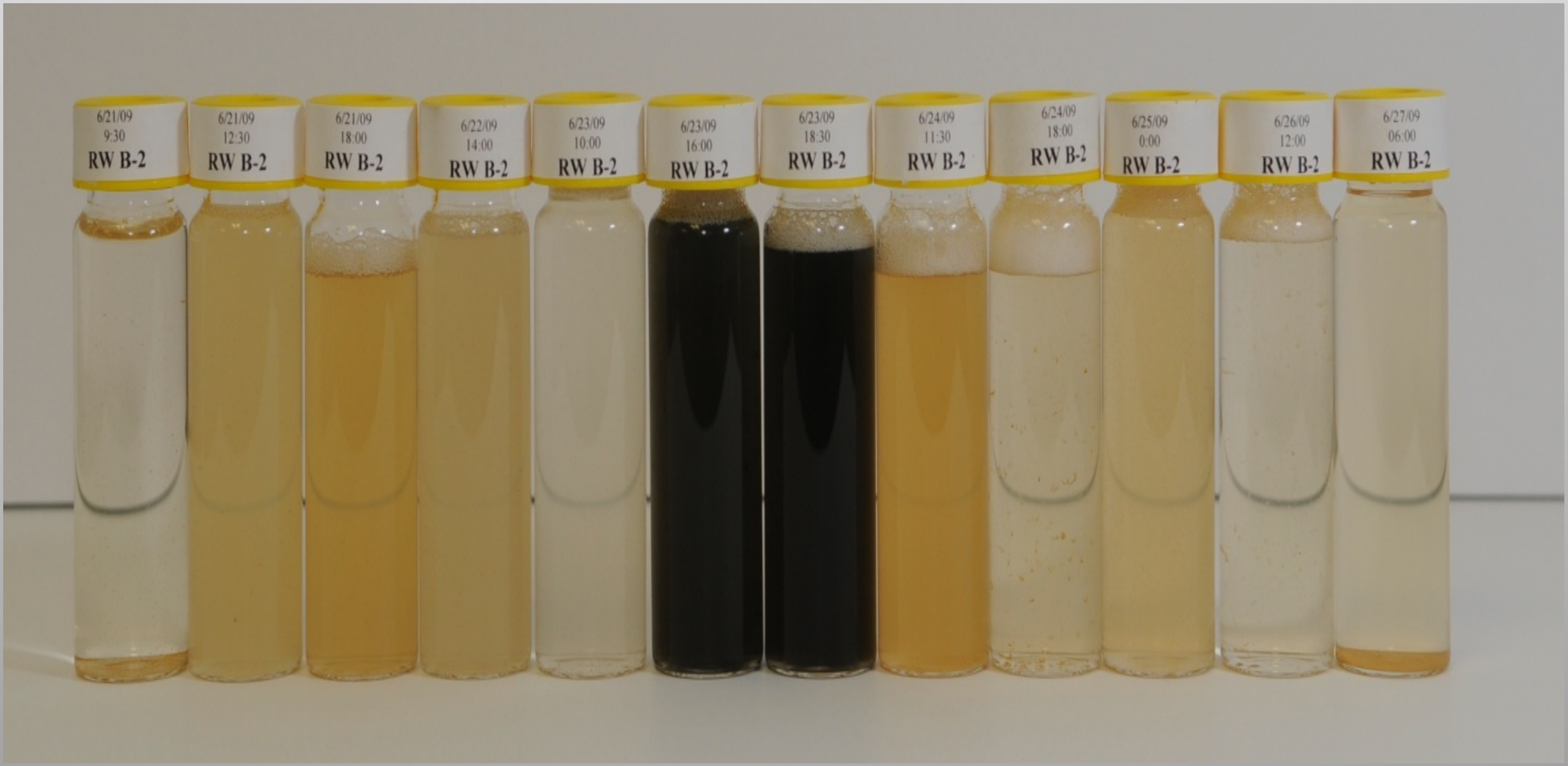
Results

- Created a forced flow gradient system with 79% capture of injected fluids
- Observed 3 order of magnitude increase in mass removal rate
- Removed 100 gallons of product in 3 days
- No evidence of free phase NAPL in test area after the project.

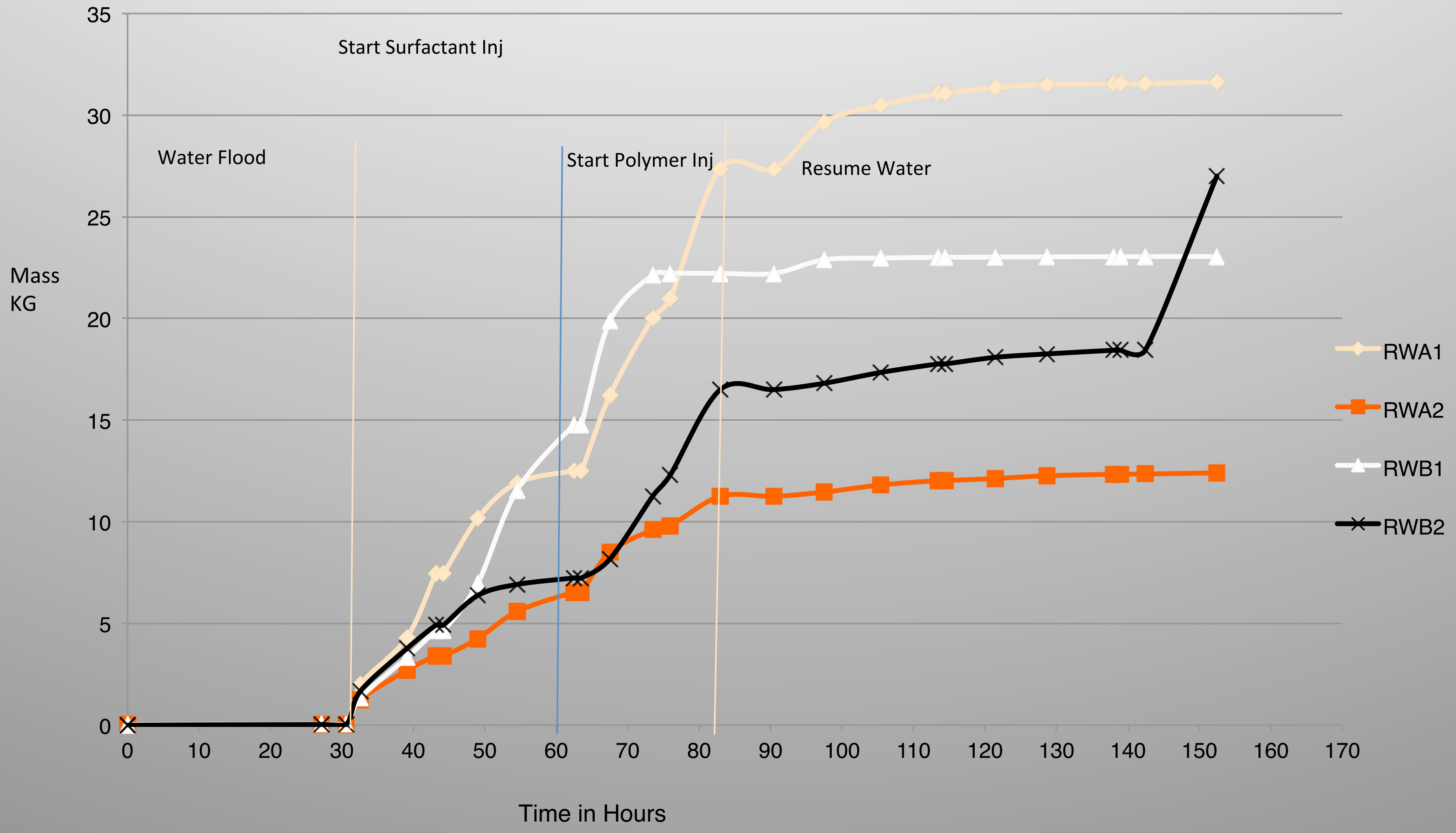
GRO Breakthrough Curve



Pictorial Breakthrough at RW-B2



Cumulative GRO Recovery



Overview

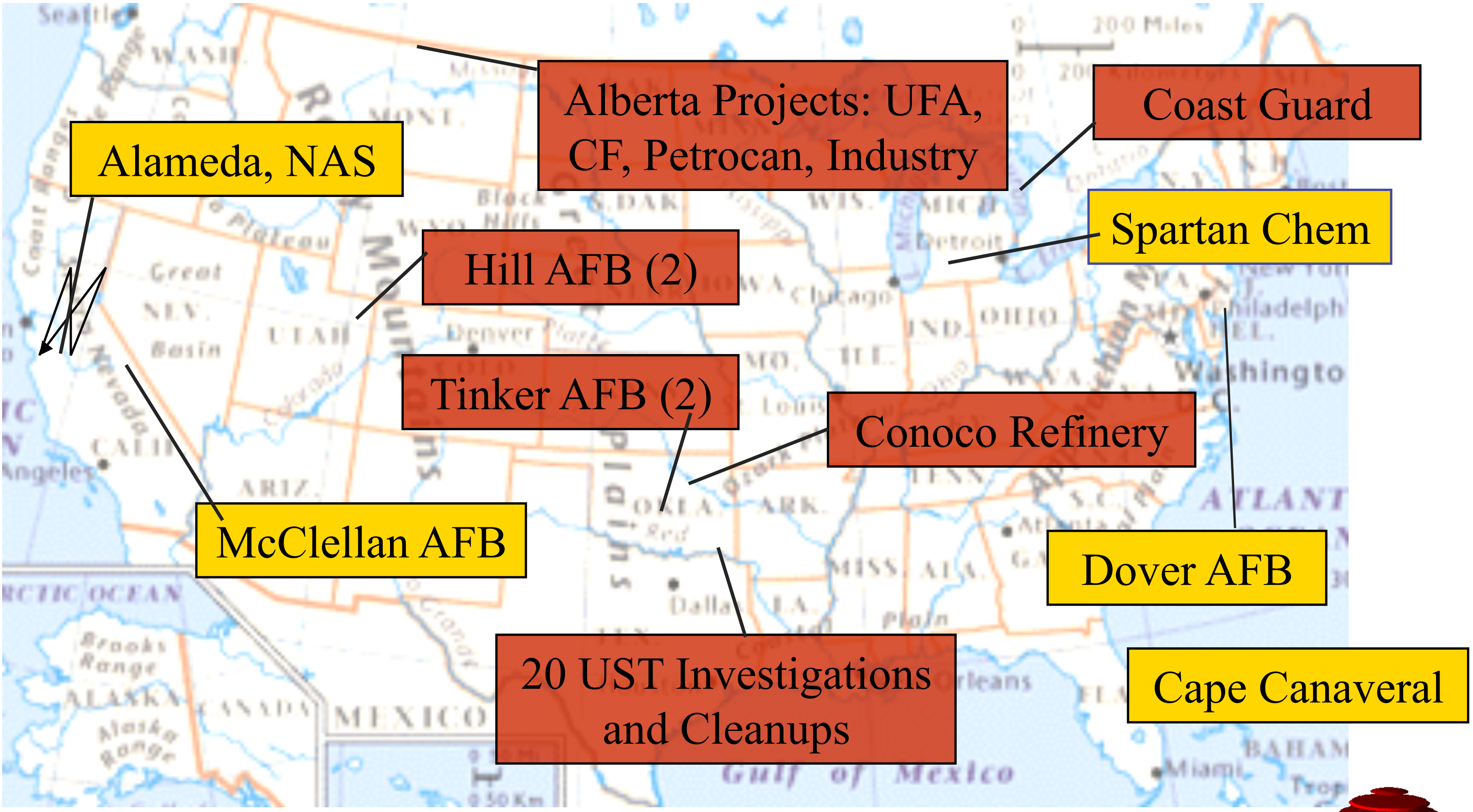
- Flushing applies to all sites where advection or fluid flow plays a role in remediation (ie)
- Overcoming preferential flow, heterogeneities major issue overcoming recalcitrant problems
- Mobility control can help all sites
- Flushing agents such as surfactants/ colsovents improve effectiveness of flushing
- If properly implemented at the right sites flushing can be very effective risk reducer
- Low hanging fruit is focusing on recalcitrant sites with infratructure in place

Case Studies

InfraSUR

H-E

Surfactant Projects



Alberta Projects: UFA, CF, Petrocan, Industry

Coast Guard

Alameda, NAS

Spartan Chem

Hill AFB (2)

Tinker AFB (2)

Conoco Refinery

McClellan AFB

Dover AFB

20 UST Investigations and Cleanups

Cape Canaveral

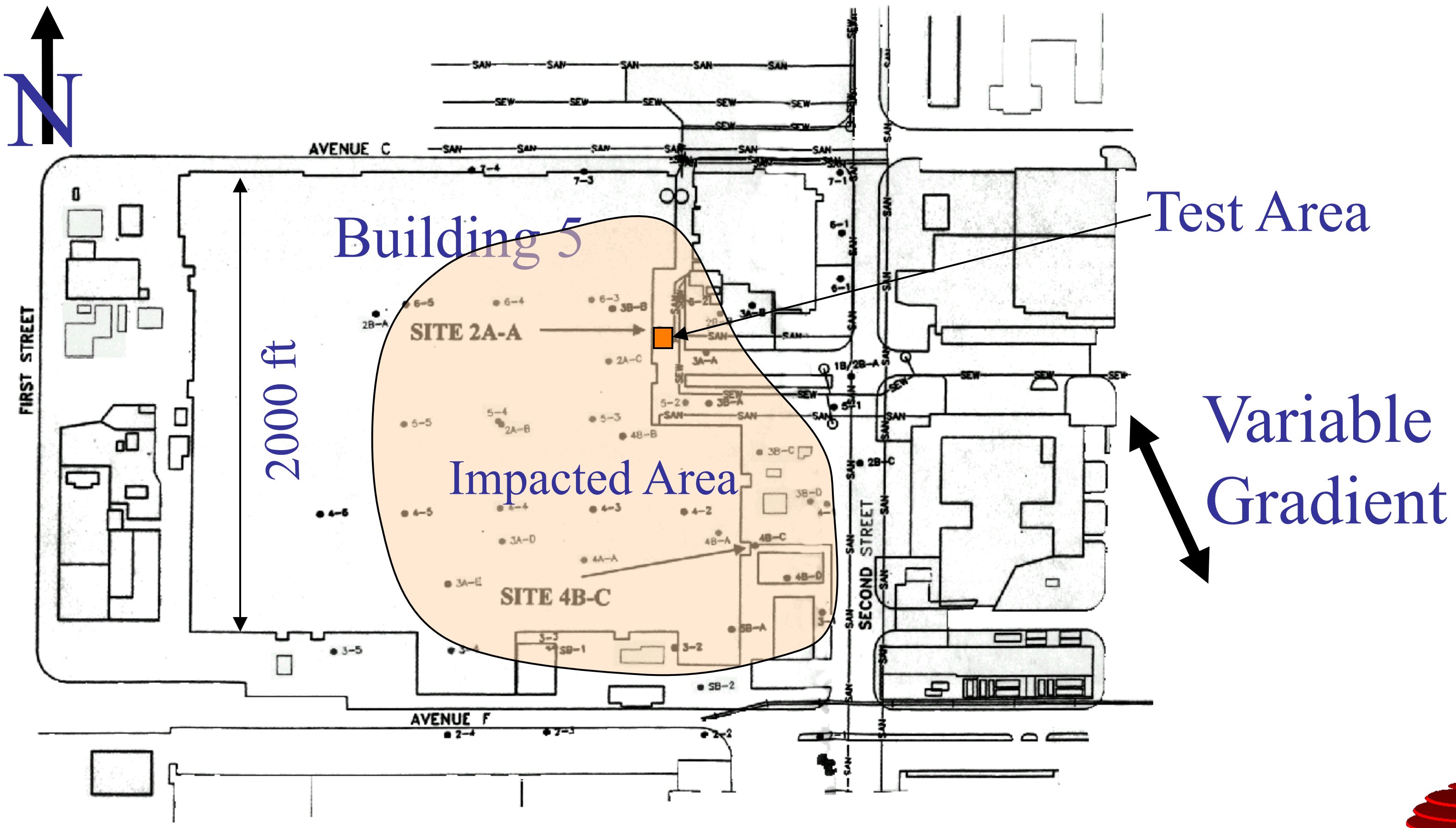
🟦 DNAPL 🟥 LNAPL

SESR Project Summary
Alameda Point

Alameda site

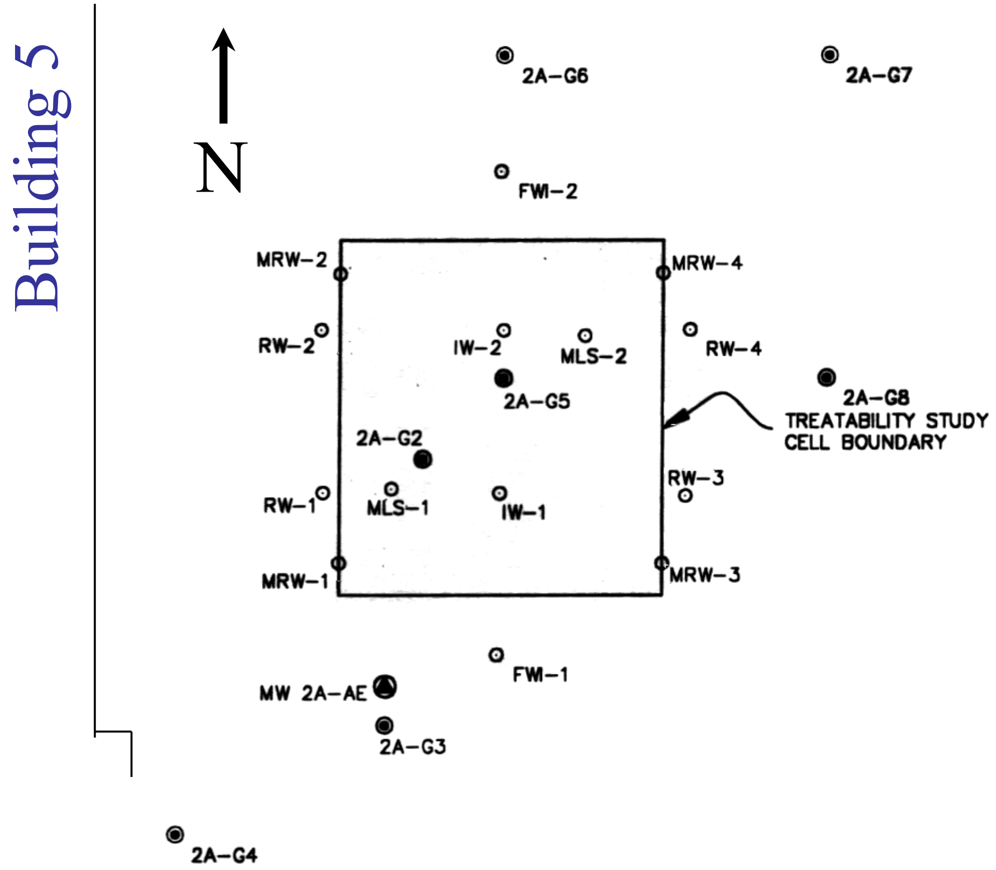
- Client: TetraTech/US Navy
- Facility: BRAC
- Scope: DNAPL remediation
- Approach: SESR
- Performance: Self
- Dates: July-Oct 1999
- DNAPL: TCA, TCE, DCE, DCA
- Sand Aquifer K=20 ft/d
- Water table at 10 feet

Alameda Point Site



Site Investigation

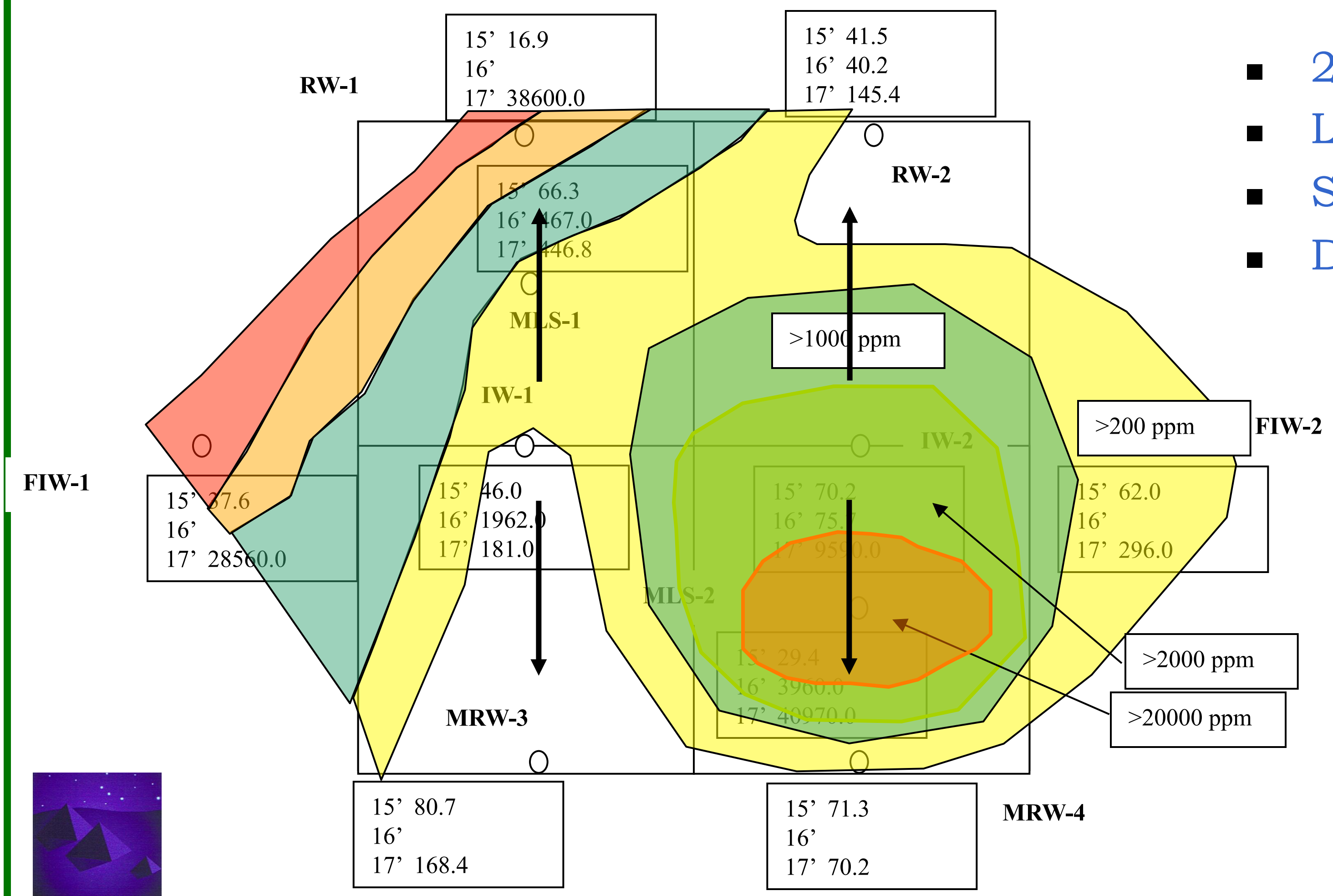
- Finding DNAPL
- Soil Coring/ Geoprobes
- Methanol preservation
- Aquifer testing
- Groundwater modeling



Surfactant Selection

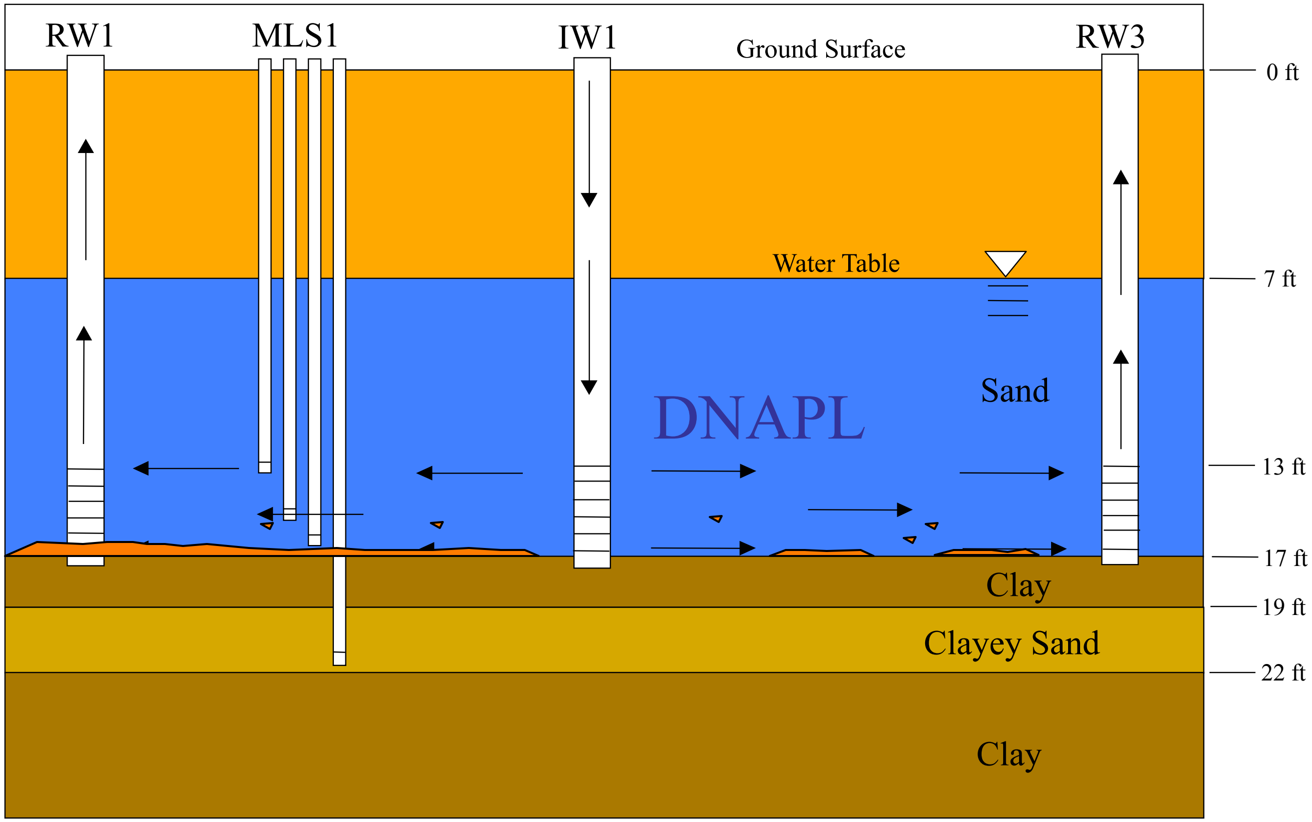
- Site soil and groundwater
- Batch/column tests
- Ultrasolubilization
- Mobilization testing
- Air stripping/MEUF tests
- DF/AMA/NaCl selected
  - TCA/TCE solubility at 10 wt %
  - >99% TCA removal

Cell Layout/Soil Coring Results



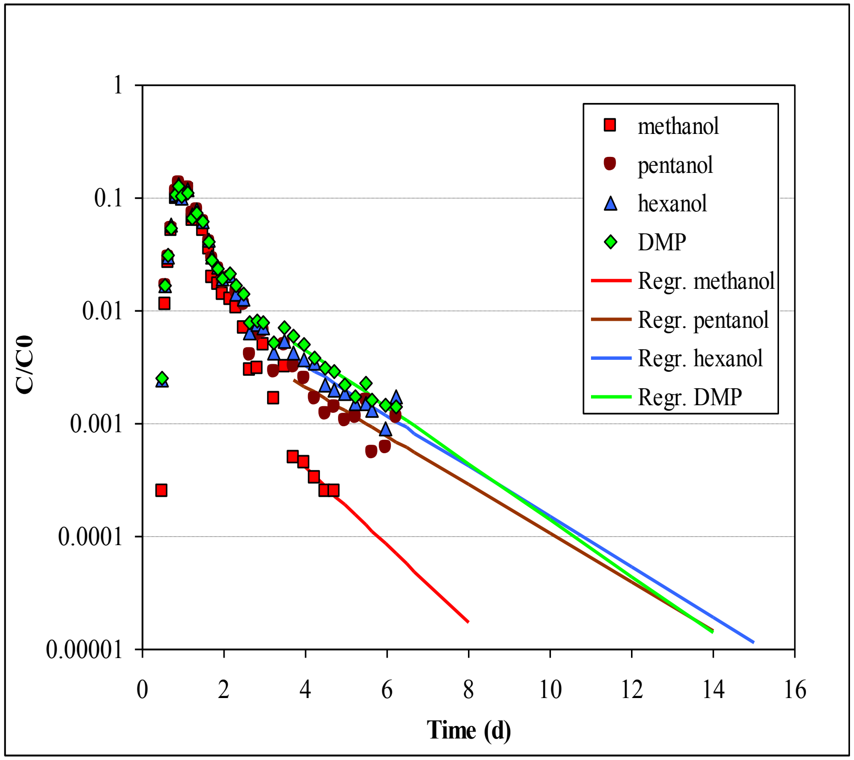
- 20’ x 20’ Cell
- Line drive
- Soil Sampling
- DNAPL dist.
  - 34 gallons

Cell Cross-Section



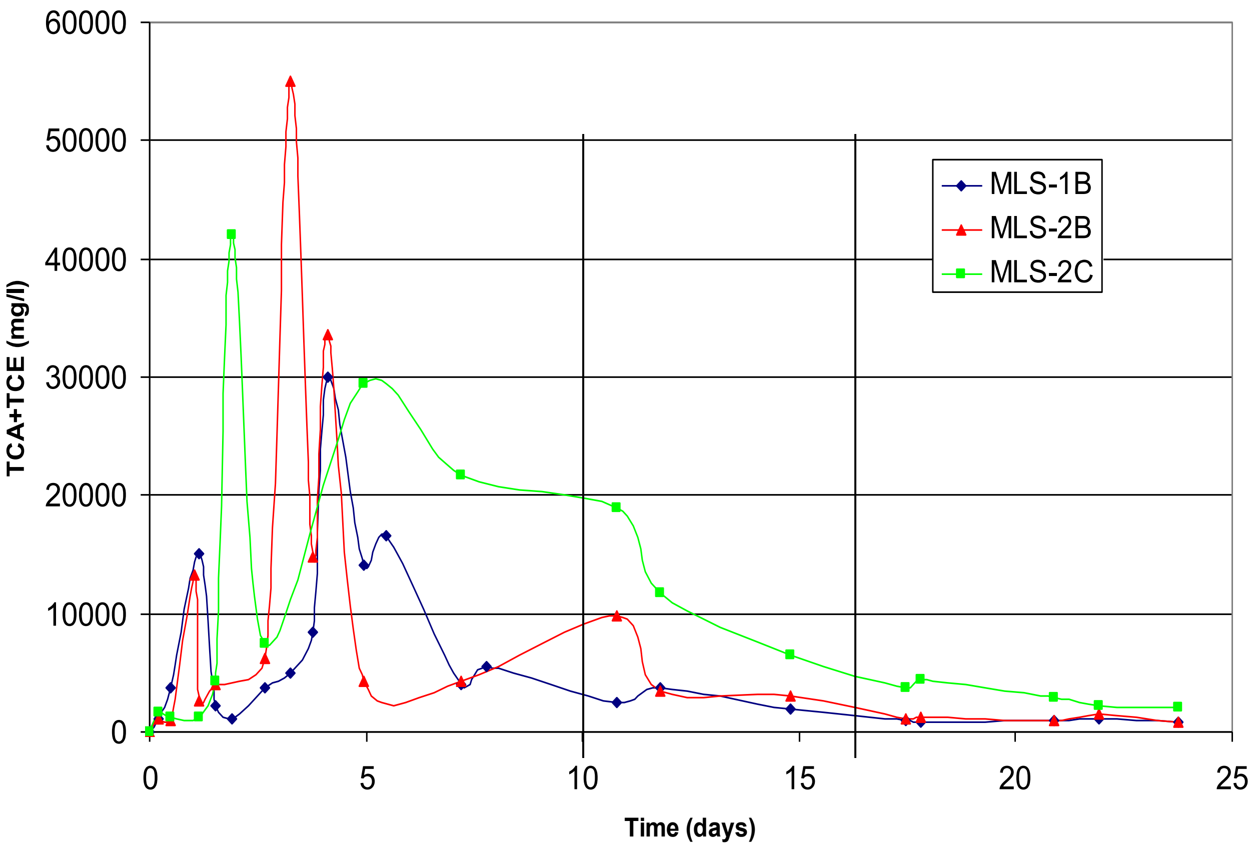
Pre-PITT

- Show capture and NAPL volume
- Tracers:
  - bromide/methanol
  - Hexanol, pentanol 2,4-dimethyl-3-pentanol
- 1000 gallons injected
- 8 pv of water flood
- DNAPL volume
  - 2-4 DMP -100 gal
  - Hexanol -169 gal

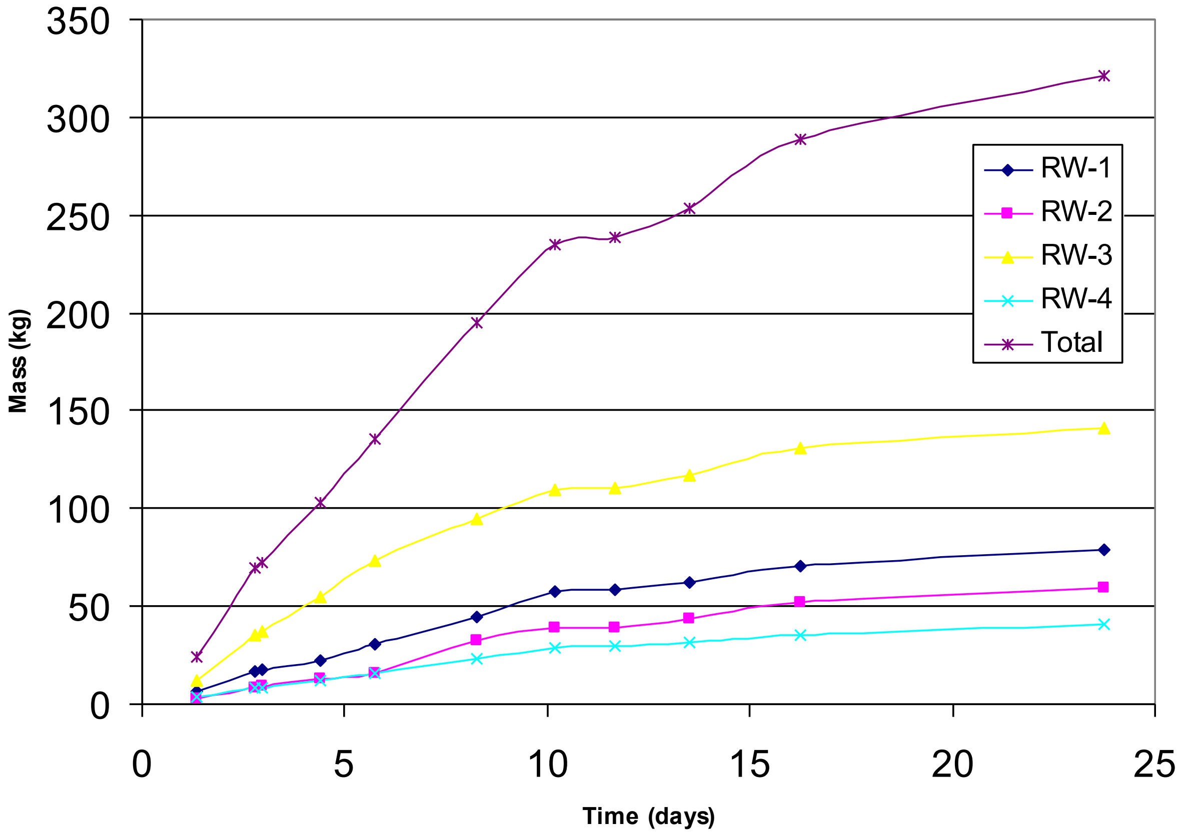


Implementation

TCA+TCE Breakthrough in MLS



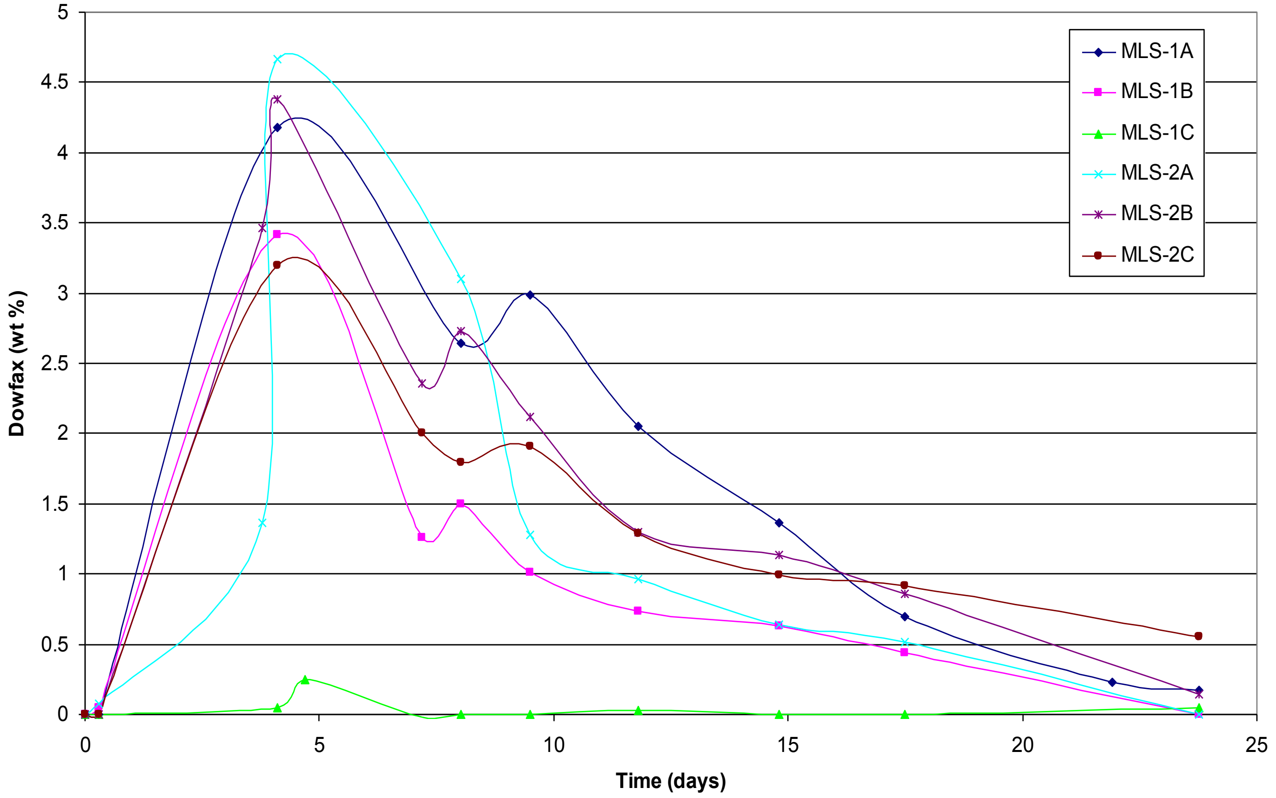
TCA+TCE Recovery from GW



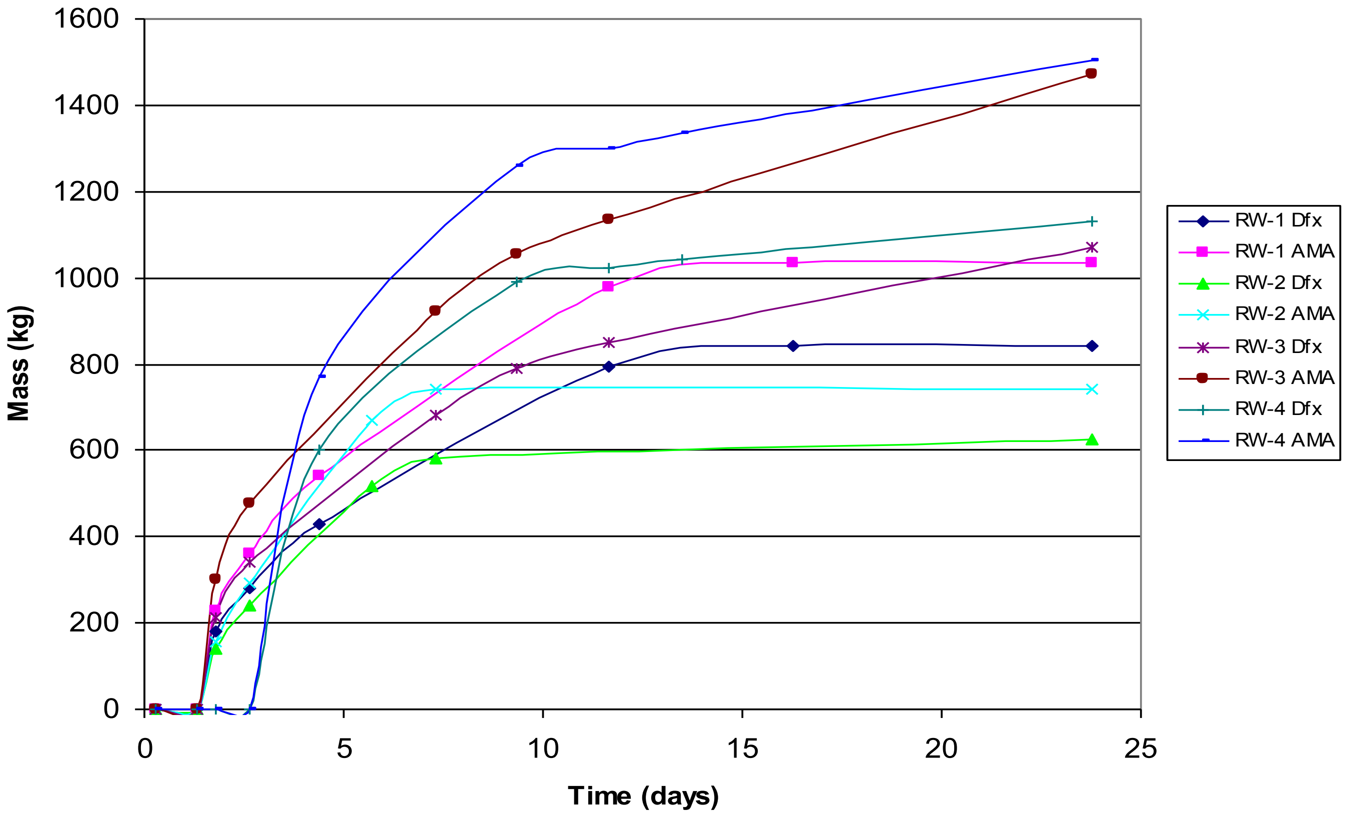
InfraSUR

H-E

Dowfax Breakthrough in MLS



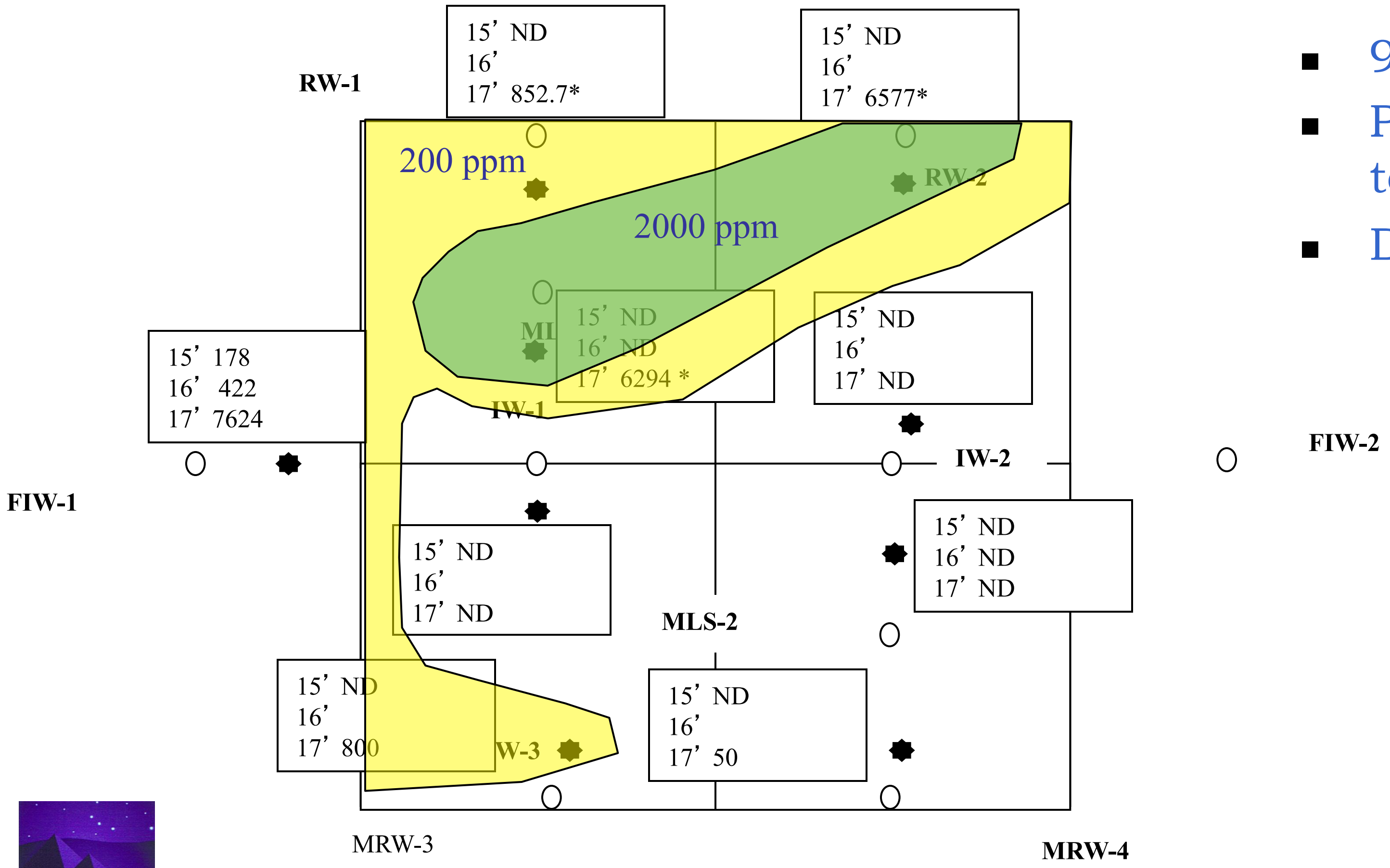
Surfactant Recovery from RW



Waste Disposal

- Used MPP, air stripping and activated carbon in series to remove VOCs
- Discharge to EBMUD
- Regulated parameters included metals and chlorinated solvents
- Metals (Zinc) problematic
- Offsite disposal of NAPL, carbon, and GW

Post Test Coring



- 9 soil cores
- Placed near pre-test cores
- DNAPL dist.
  - <1 gallon

Performance Summary

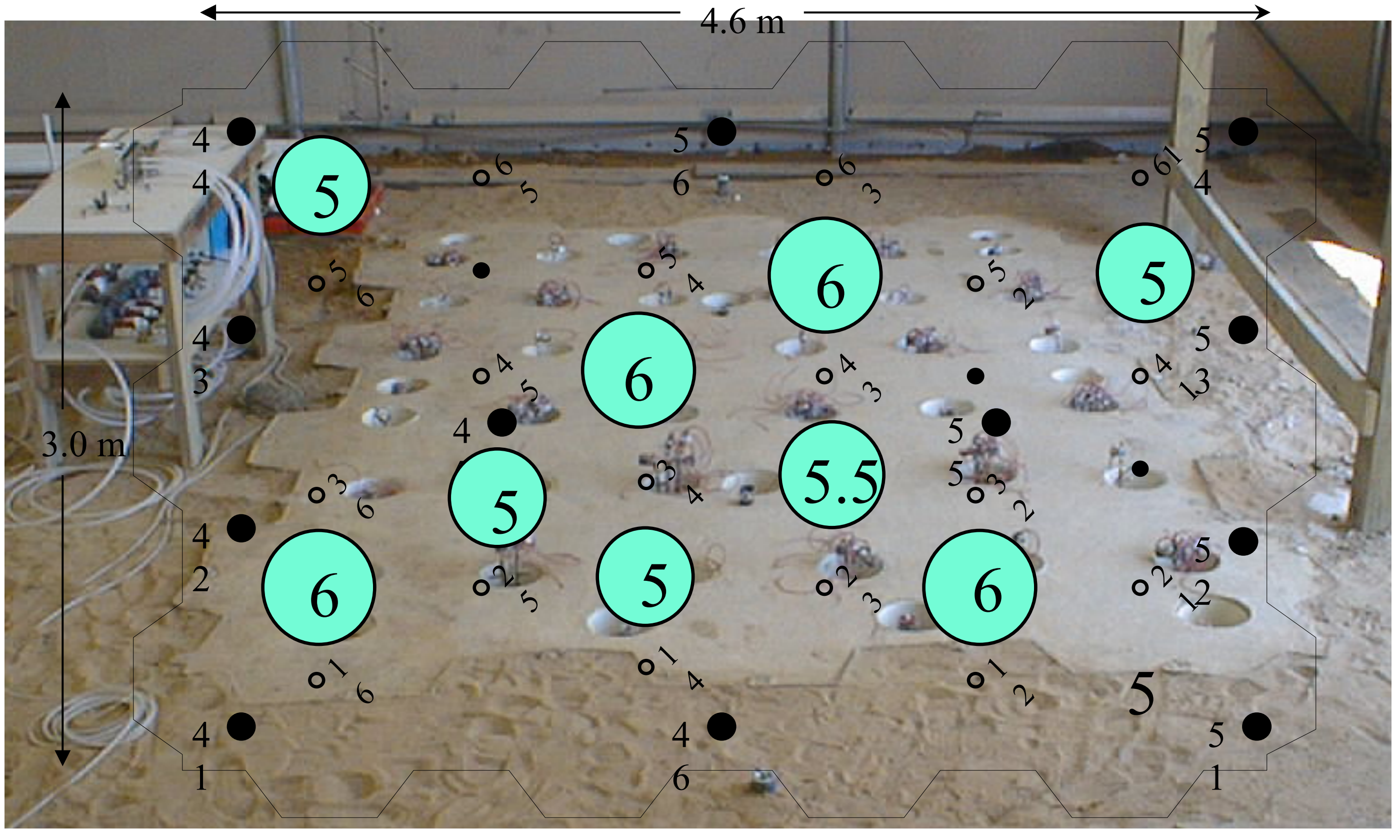
Evaluation Methodology	Pre-test Volume (gal)	Post-test Volume (gal)	Percent Removal
PITT			
2,4-DMP	100	<1.0	>99%
Hexanol	169	<1.0	>99%
Pentanol/ Heptanol	NA	3.17	>99%
Coring	34.0	<1.0	>97%

- Sixty-five (65) gallons of DNAPL (TCA and TCE) were recovered in GW
- 35 gallons of DNAPL was recovered from the MPP system
- 30 gallons of DNAPL in sludge from oil/water separator
- TCA/TCE GW concentration decrease 80% & 56%, respectively.

Dover National Test Site

- Primary Objective: Remove PCE (79 liters) from closed cell
- Process steps
  - Surfactant selection, design (bench scale), modeling
  - Tracer testing and baseline contaminant level quantification
  - Surfactant flooding
  - Post test tracer testing and contaminant evaluation

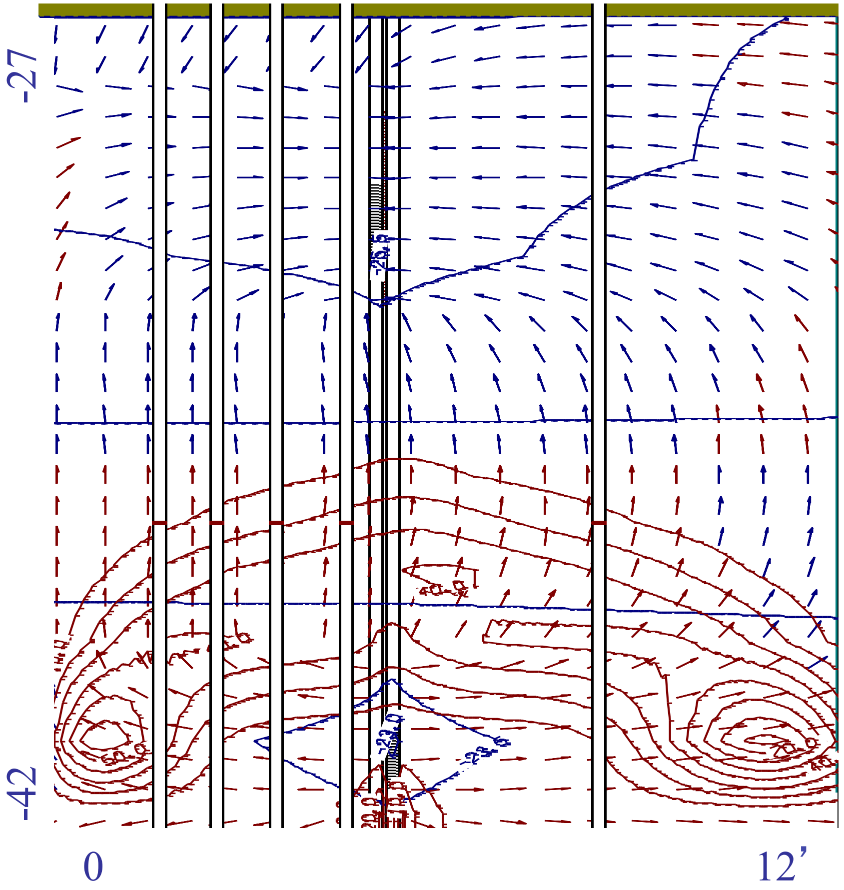
Site Layout



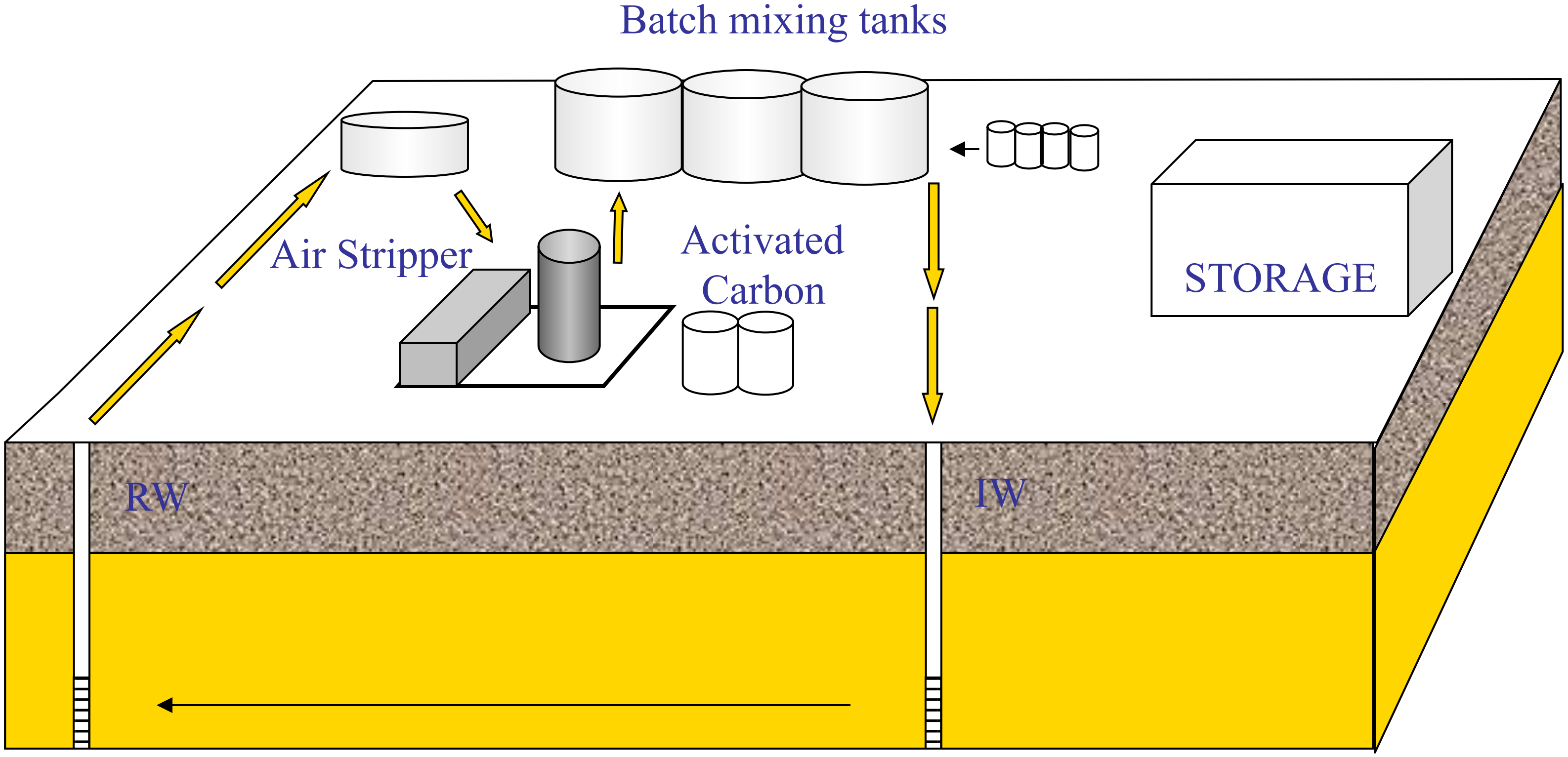
● Injection or Extraction Well ○ MLS • Release point

General Site Information

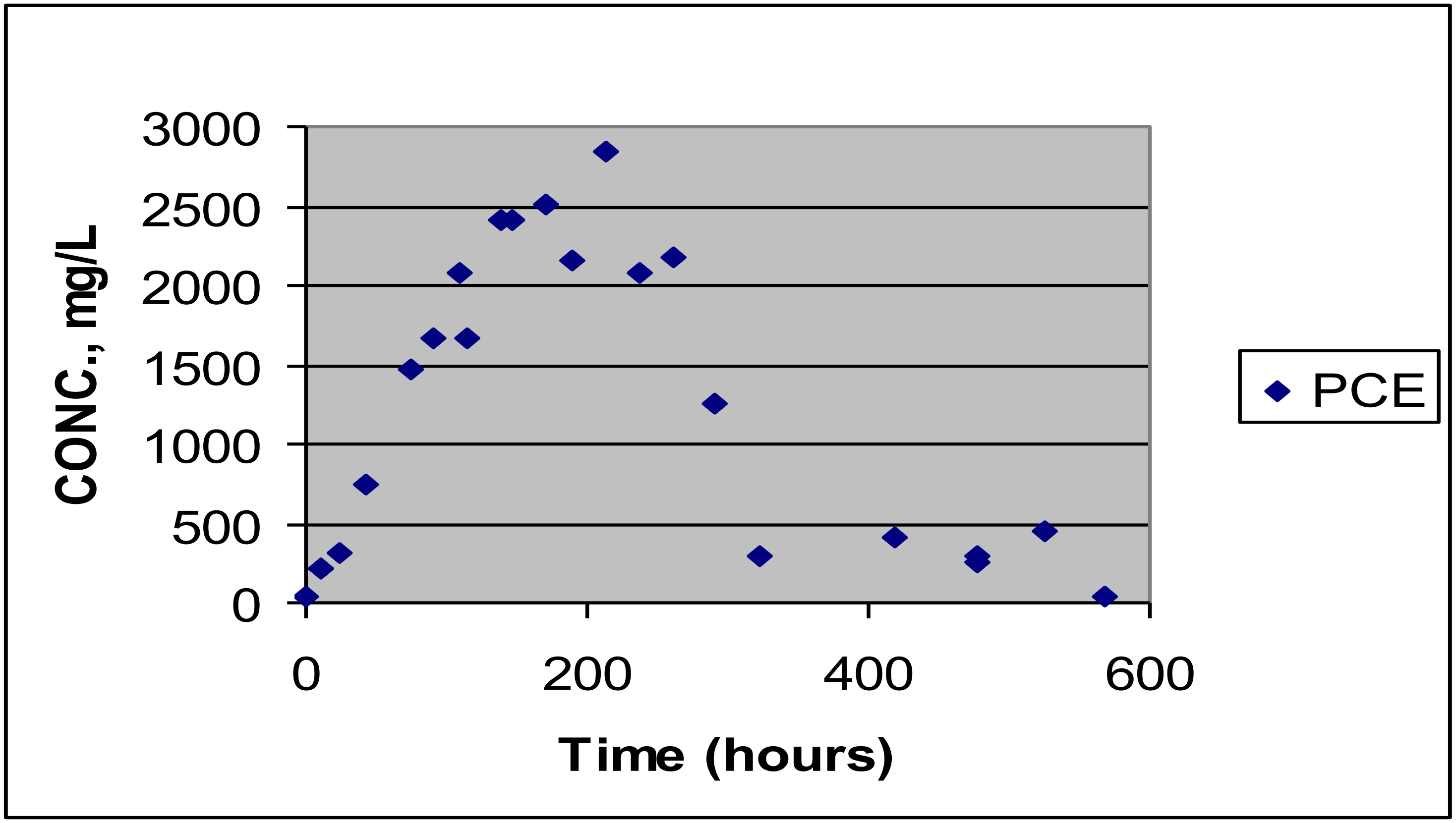
- Low permeability soils with interbedded silts and sands
- Vertical circulation followed by line drive
- Recirculated surfactant solution 34 days
- AMA/IPA surfactant



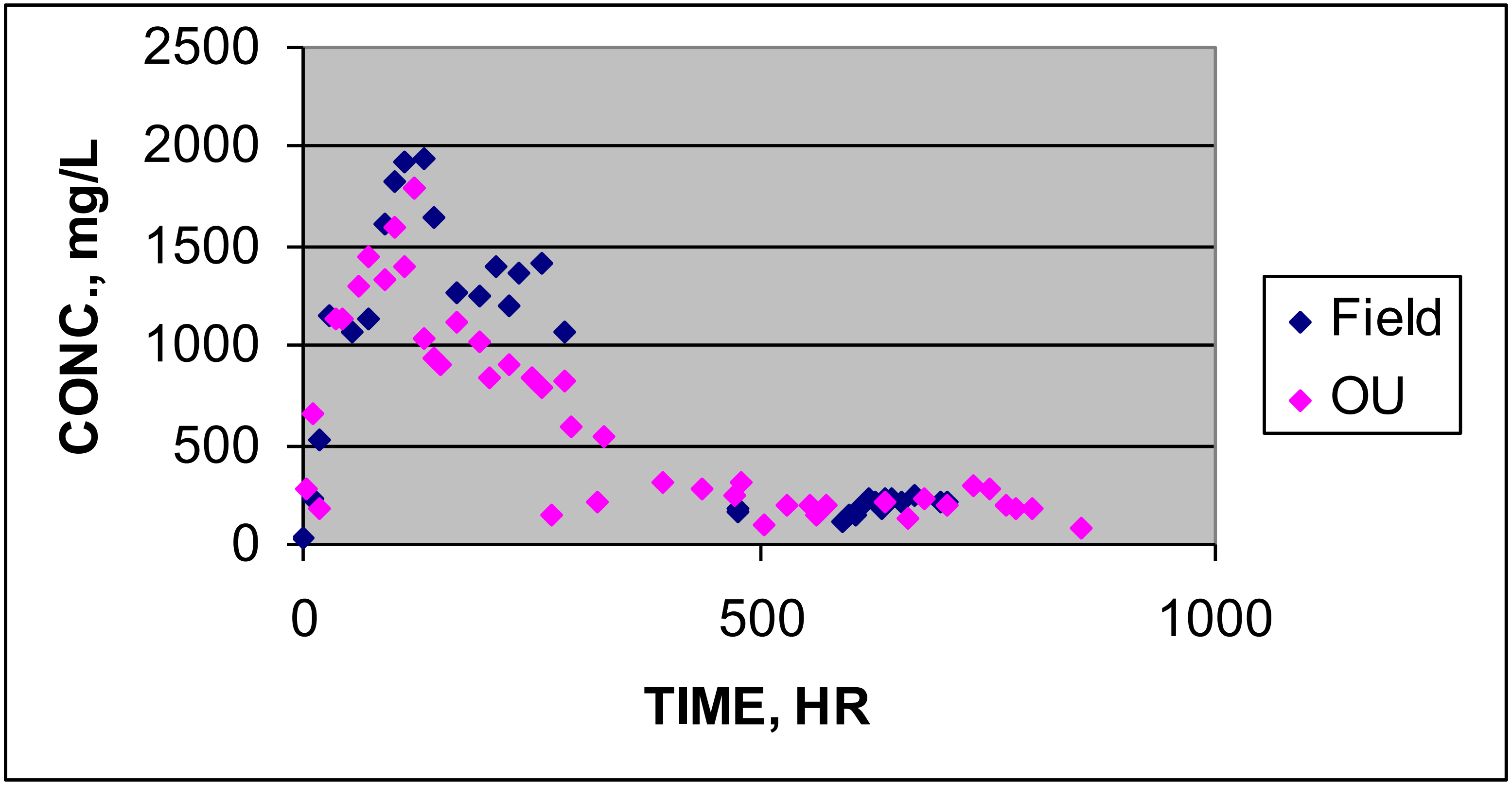
Process Flow Diagram



PCE Breakthrough at EW-46



Combined PCE Breakthrough



Results and Conclusions

- Estimated 58 liters of PCE recovered in effluent
- Observed 70% - 95% reduction in groundwater concentrations in 8 wells
- 95% removal of PCE using air stripping and only 3000 gallons fluids disposed
- Remaining mass may be trapped in clays

Surfactant Flushing

A NAPL Remediation Technology
Case Study: Fort Drum

Jeffrey H. Harwell, Ph.D.
University of Oklahoma/Surbec Environmental

Surbec is a collaborative member of the InfraSUR Team

Hot Fueling Point
Fort Drum, New York

Fall 2009

- Jet fuel spill discovered in 2006
- Probably happened in 2001
- Depth to water 44 ft
- Sandy aquifer - 20% silt
- Drinking water wells in deeper aquifer
- Estimated 350,000 to 700,000 gal spill

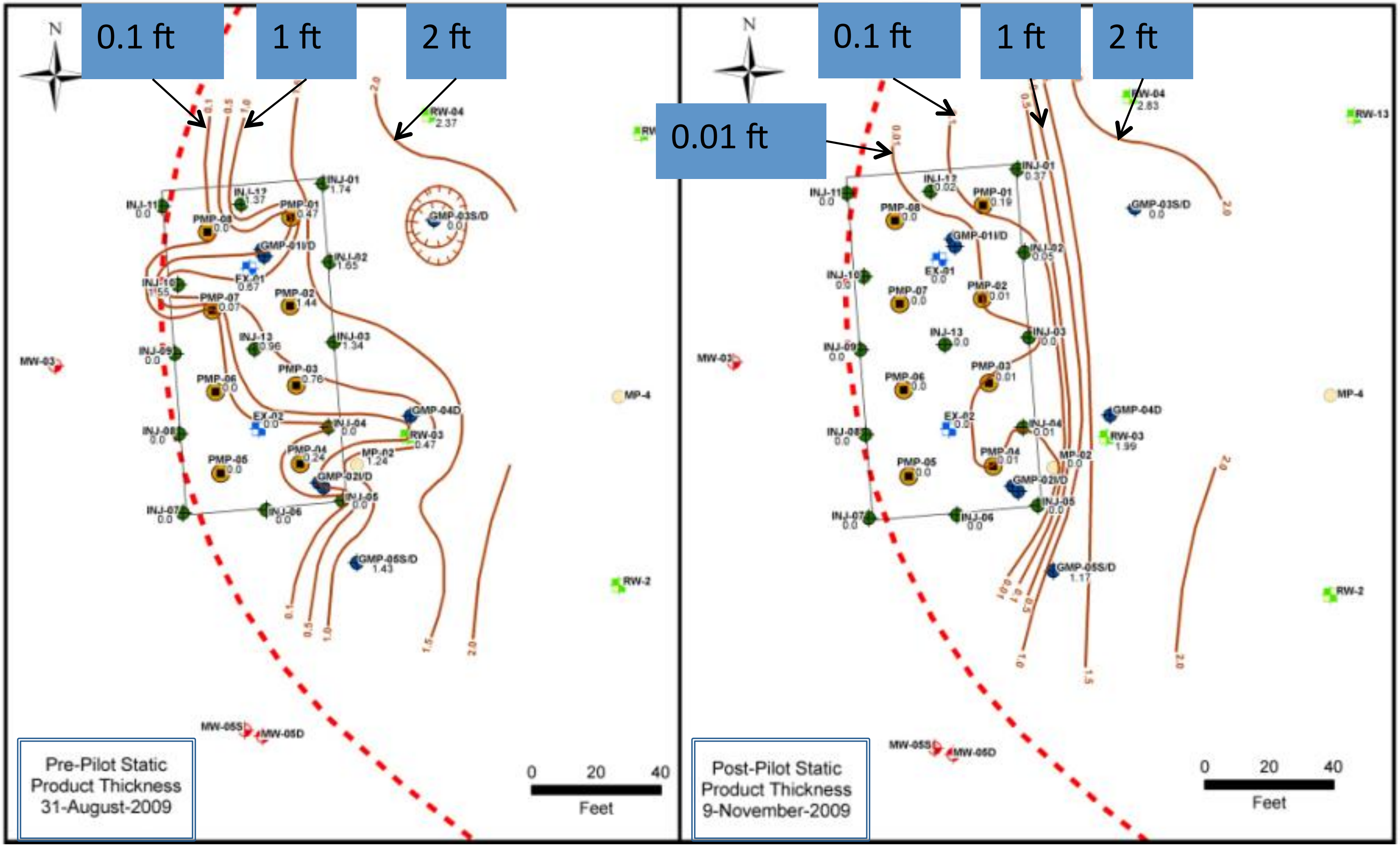
Project Overview

- Worked with consultant on characterization
- Selected effective surfactant through bench scale testing
- Designed injection / recovery system
- Used polymers for flow control
- Treated fluids

Step 1: Formulate Microemulsion

Increasing Salinity

LNAPL Thickness/Distribution



0.1 ft

1 ft

2 ft

Pre-Pilot Static
Product Thickness
31-August-2009

0.1 ft

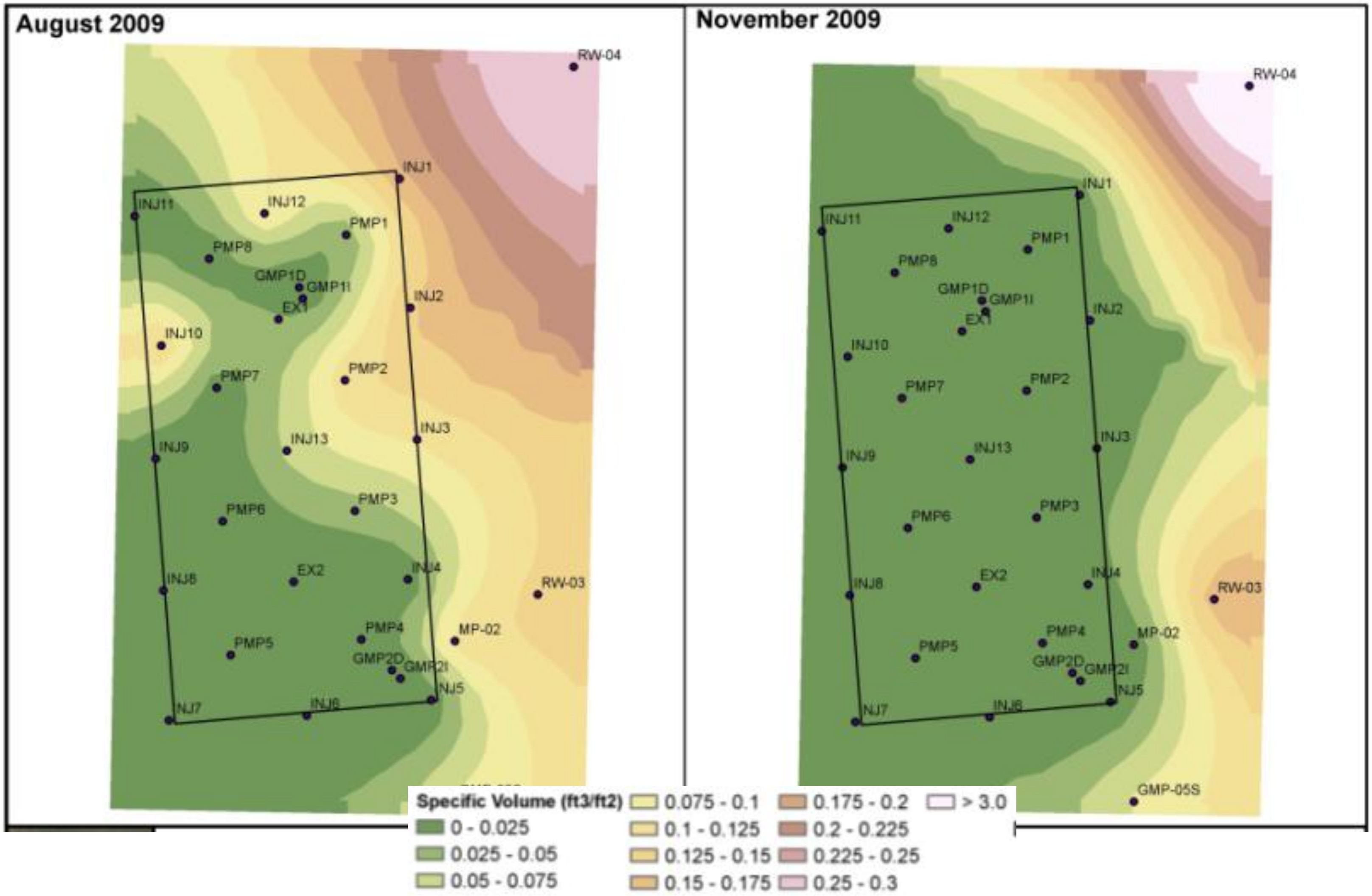
1 ft

2 ft

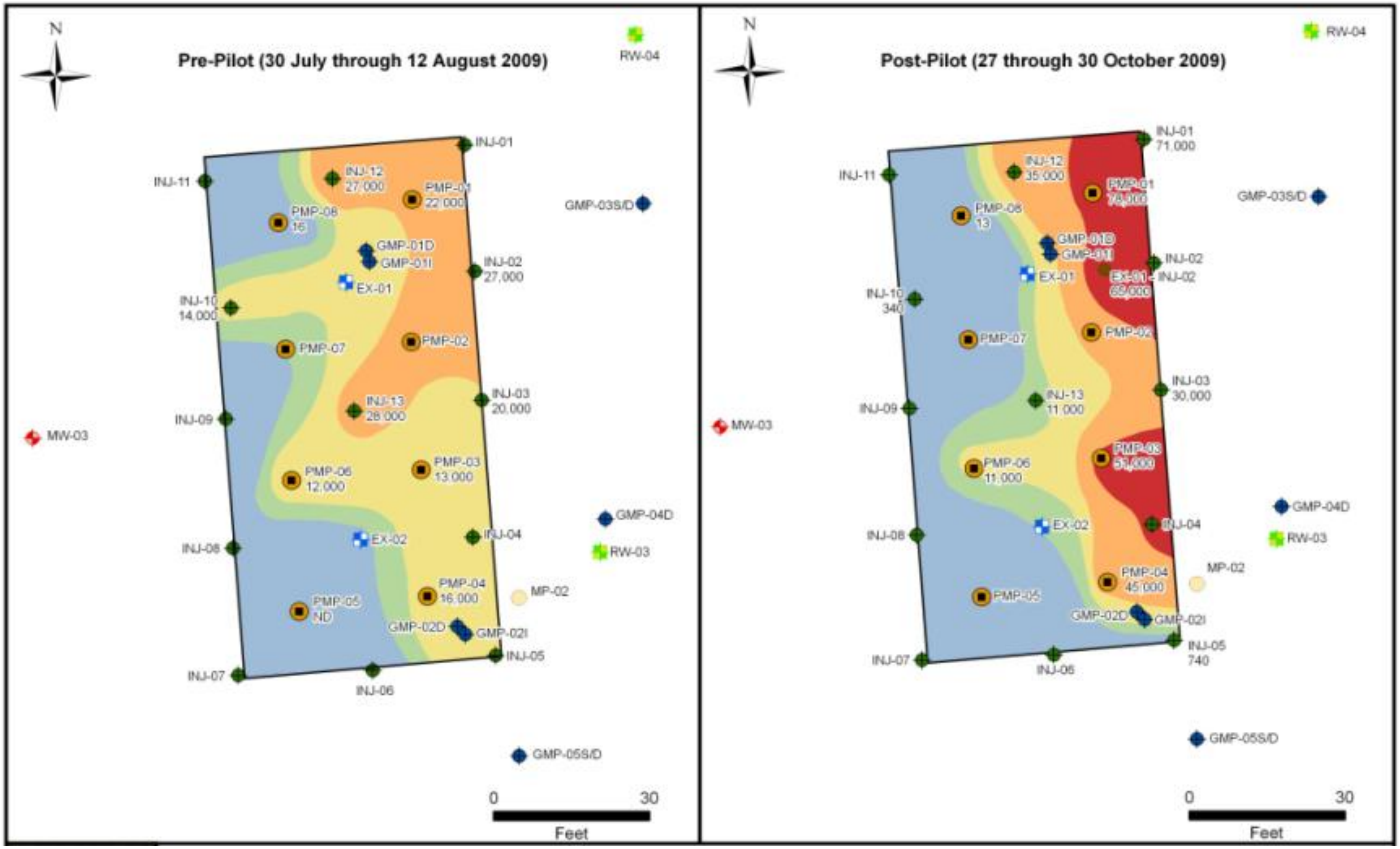
0.01 ft

Post-Pilot Static
Product Thickness
9-November-2009

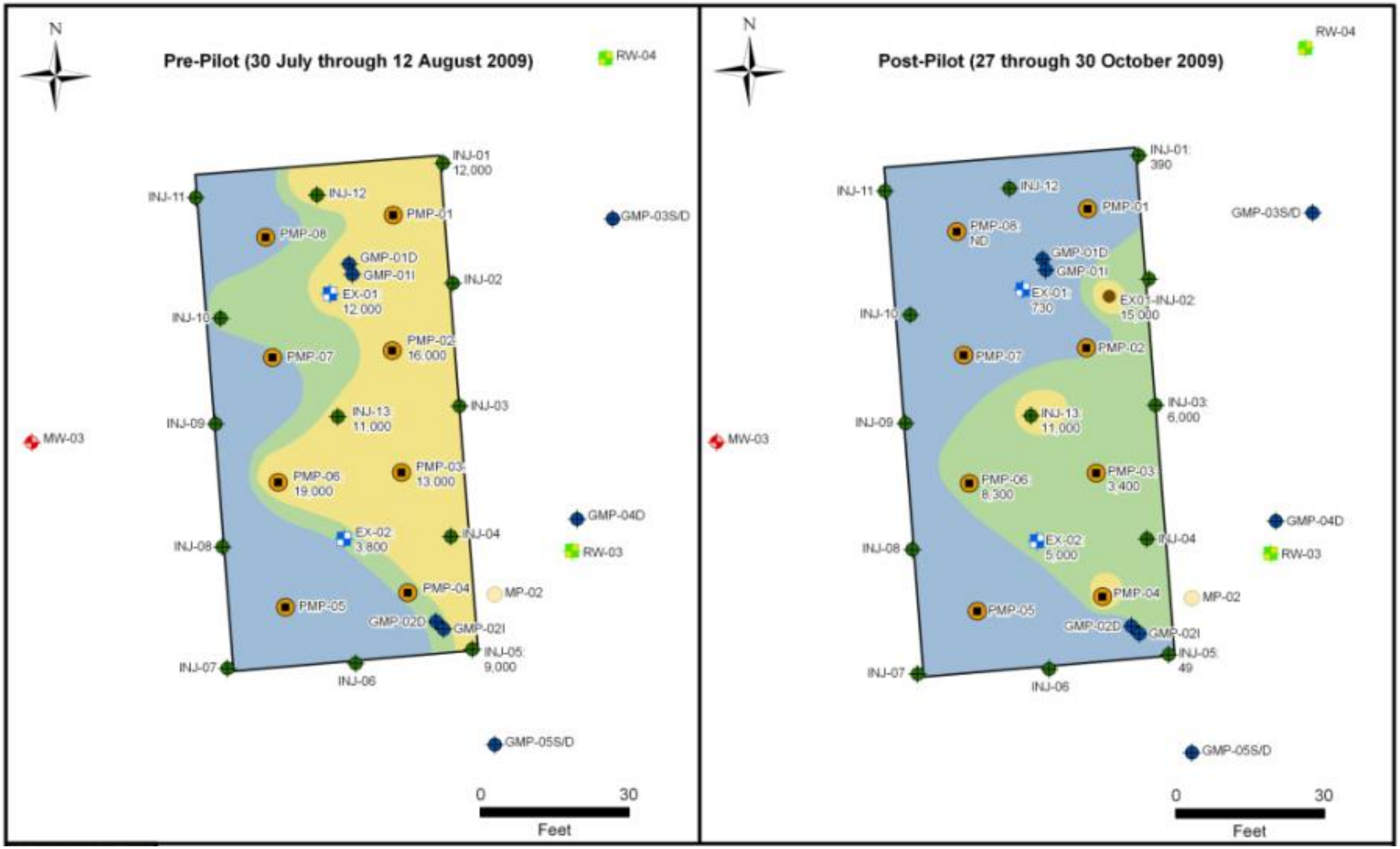
API Model


August 2009
November 2009
RW-04
INJ1
INJ11
INJ12
PMP1
PMP8
GMP1D
GMP1I
EX1
INJ2
INJ10
PMP7
PMP2
INJ3
INJ9
INJ13
PMP6
PMP3
INJ8
EX2
INJ4
RW-03
PMP4
MP-02
PMP5
GMP2D
GMP2I
INJ5
INJ7
INJ6
GMP-05S
Specific Volume (ft3/ft2)
0 - 0.025
0.025 - 0.05
0.05 - 0.075
0.075 - 0.1
0.1 - 0.125
0.125 - 0.15
0.15 - 0.175
0.175 - 0.2
0.2 - 0.225
0.225 - 0.25
0.25 - 0.3
> 3.0

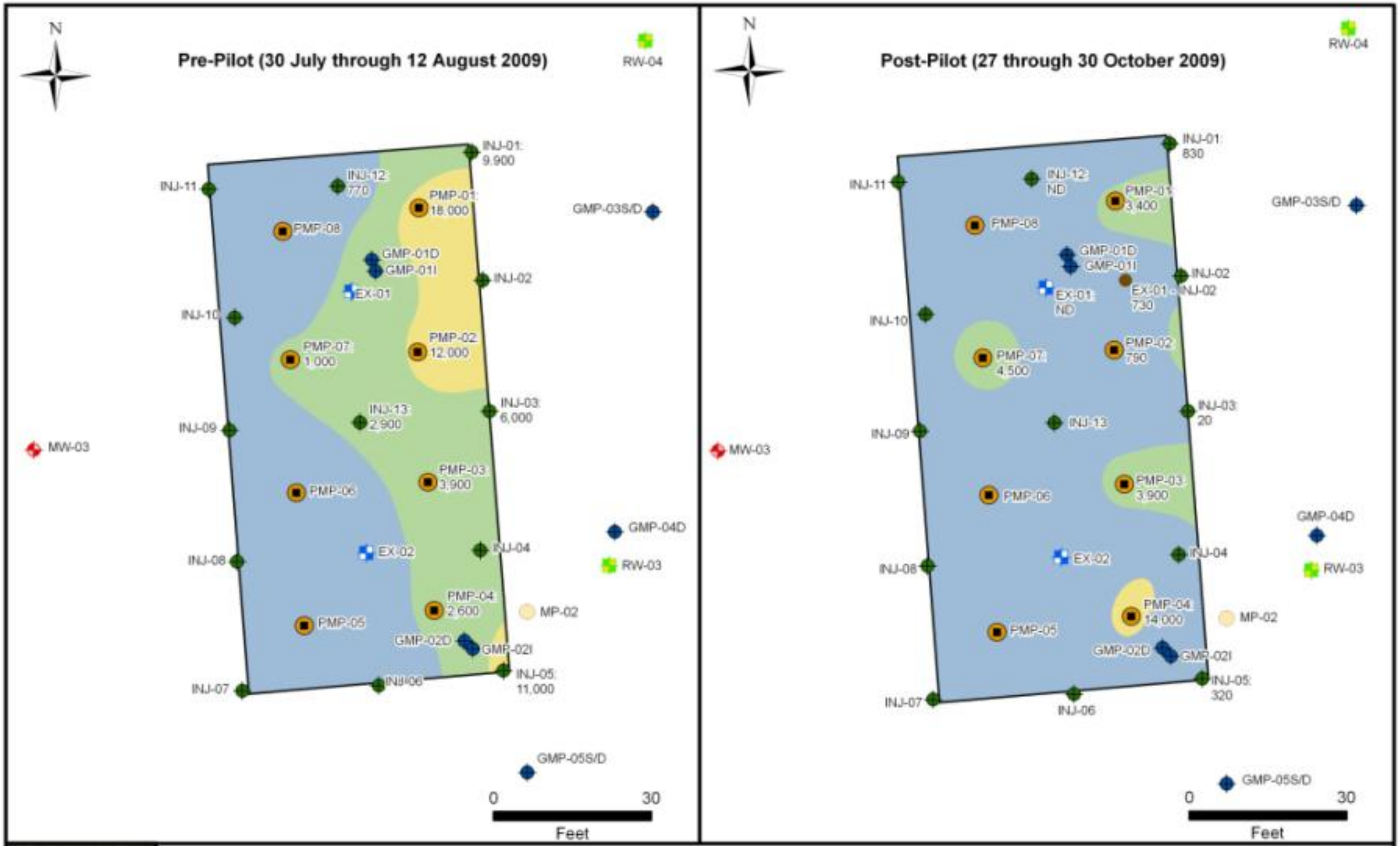
Soil Sampling Results – Upper (water table)



Soil Sampling Results – Middle (just below water table)



Soil Sampling Results – Lower (below screens)



Pre-Pilot (30 July through 12 August 2009)

Post-Pilot (27 through 30 October 2009)

NAVAL FACILITIES ENGINEERING COMMAND
Washington, DC 20374-5065

NFESC
Technical Report
TR-2219-ENV

Surfactant-Enhanced Aquifer Remediation (SEAR) Implementation Manual

Prepared by:

Intera Inc. (formerly Duke Engineering & Services)

and

Naval Facilities Engineering Service Center

April 2003

ACKNOWLEDGEMENTS

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CONTENTS

FIGURES

TABLES

ACRONYMS AND ABBREVIATIONS

CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
cP	centipoise
DAS	data acquisition system
DNAPL	dense nonaqueous phase liquid
DQO	data quality objective
FID	flame ionization detector
GC	gas chromatograph(y)
GFI	ground fault interruptors
HDPE	high density polyethylene
HPLC	high performance liquid chromatography
ICP	inductively coupled plasma
IFT	interfacial tension
LNAPL	light nonaqueous phase liquid
MCL	maximum contaminant levels
mL	milliliter
MLS	multi-level sampler
NaCl	sodium chloride
NAPL	nonaqueous phase liquid
NPDES	National Pollutant Discharge Elimination System
PCE	tetrachloroethylene or perchloroethylene
PITT	partitioning interwell tracer tests
POTW	public-owned treatment works
PPE	personal protective equipment
RCRA	Resource Conservation and Recovery Act
RFP	request for proposal
SCADA	Supervisory Control and Data Acquisition
SDWA	Safe Drinking Water Act
SEAR	Surfactant-enhanced aquifer remediation
SOW	Statement of Work
TCD	thermal conductivity detector
TCE	trichloroethylene
UIC	Underground Injection Control
USDW	underground sources of drinking water
UTCHEM	University of Texas Chemical Flooding Simulator
VOC	volatile organic compound
wt%	weight percent

Section 1.0: INTRODUCTION

1.1 Objective and Scope

The objective of this implementation manual is to familiarize remedial project managers and engineers and scientists affiliated with environmental remediation projects on the major tasks and planning parameters involved with implementing an in-situ surfactant flood or surfactant-enhanced aquifer remediation (SEAR) project to remove dense non-aqueous phase liquids (DNAPLs). A companion technical manual has been produced on SEAR design focusing on removal of DNAPLs. It is hoped that in combination, the guiding principles presented in these two manuals will assist users in understanding basic design and implementation issues for attaining remedial objectives and in following risk management methodologies and approaches for avoiding misapplication of surfactant flooding for DNAPL removal. Cost-effective surfactant flooding performance demands recognition of the chemical flooding process, system specifications, and design and operational limitations, in order to secure the appropriate level of services and performance for the site.

This manual acknowledges that most key design parameters for surfactant flooding operations have been determined with earlier process design (as covered in the *SEAR Design Manual*) and that technology implementation on a full-scale is intended, or that a requirement for a pilot-scale study exists to fully specify design parameters. Planning and field preparation aspects, general system component specifications, and performance-related issues will be detailed. As can be discerned from the design criteria introduced within the *SEAR Design Manual*, surfactant flooding mandates expertise in many diverse areas inclusive of DNAPL source zone characterization technologies, aquifer and aquitard testing methods, and the chemical and multi-phase fluid flow properties of pumped surfactant solutions. Field implementation will furthermore require skilled knowledge of field-scale chemical preparation methods and remediation engineering resources for controlled injection and extraction of chemical solutions throughout the contaminated aquifer zones, and decontamination of the remedial fluids.

1.2 Technology Review

SEAR is a technology addressing the removal of immiscible-phase liquid contaminants, also termed nonaqueous phase liquids (NAPLs), from the saturated zone. In recent years, it has been further developed to be applicable to the removal of dense NAPL contaminants or DNAPLs such as TCE and PCE, which are amongst the most recalcitrant groundwater contaminants to be addressed in source zones or contamination source areas. Often likened as a chemical enhancement to pump and treat operations, aggressive source reduction technologies such as SEAR will typically be used in conjunction with conventional dissolved-phase remediation methodologies to restore groundwater quality to drinking water standards. The use of surfactants in a flooding configuration enhances the solubility and mobility of NAPL trapped in pore spaces to greatly increase the removal rate achievable with pumped groundwater. By promoting the rapid removal of these non-aqueous phase contaminants, groundwater cleanup goals may be accomplished more quickly.

Surfactant flooding involves the preparation of low viscosity surfactant solutions that are pumped through the DNAPL contaminated zone by introduction at injection points and removal from extraction points. Polymer amendment that will increase the viscosity of the surfactant solution may be required for higher viscosity contaminants (e.g., creosote) when temperature augmentation for viscosity reduction is not otherwise feasible. The surfactant flooding wellfield will generally be composed of dedicated surfactant injection and extraction points, and 'water' injection points for hydraulic control. Detailed site characterization is necessary to define DNAPL zone boundaries, and to elucidate the associated hydrostratigraphy of the zones to be flooded, both to optimize remedial design and to minimize the risk of unintended DNAPL migration. Hydraulic continuity between the injection and extraction points is required to recover contaminated fluids and injectants, and such should be verified before injecting surfactants. When present, free-phase or mobile DNAPL[1] will be evacuated through pumping and water flooding operations prior to surfactant solution injection to minimize the possibility of vertical DNAPL mobilization with interfacial tension reduction of the surfactant. The more tightly held DNAPL, also termed residual DNAPL, will then be removed through sweeping of the surfactant solution across the DNAPL source zone. A post surfactant-injection water flood is finally conducted to recover injected chemicals and solubilized or mobilized DNAPL remaining in the aquifer. Extracted fluids are treated above ground to remove free-product DNAPL, dissolved-phase contamination and cosolvent or alcohol injected with surfactants. Upon contaminant removal, the surfactant and cosolvent (usually residual from earlier treatment) can be recovered for reinjection, as desirable.

The greater the interfacial tension (IFT) requirements (i.e., low IFT value to be obtained with the surfactant system from a high IFT value without surfactants present) to accomplish surfactant-enhanced recovery of DNAPL, such as decreasing system permeability with greater capillary forces, the greater the necessity for appropriate hydraulic gradients to ensure recovery of DNAPL. Similarly, as contaminants are more readily mobilized in a permeable aquifer (e.g., requires less IFT reduction), high pumping rates and gradients that are also more easily accomplished in a permeable aquifer, will still be required to capture any mobilized DNAPL fluids. Field testing of interwell pumping rates for injection and extraction is required ahead of surfactant injection to verify sustainable pumping gradients.

1.3 Document Organization

The design manual includes issues related to technology applicability, design concepts and terminology, DNAPL source zone characterization, surfactant selection, wastewater treatment technologies, wellfield configuration and optimizing key flooding parameters for fluids delivery and recovery. This manual highlights project management planning issues, post-process design or field preparation and system construction requirements, system construction components, and major injection and extraction operational requirements. Following this overview section, surfactant flooding implementation topics are organized as follows: Section 2.0 describes field planning activities and issues, such as performance assessment, site logistics and the benefits of pilot-scale studies. Section 3.0 details the primary system components and assembly issues organized by major field task. Section 4.0 covers flooding operations, including preparation, monitoring and chemical analysis of SEAR fluids, and system shutdown. References, citations and miscellaneous details are footnoted throughout the document. Detailed specifications, methods and examples, including contracting guidance, may be viewed in the Appendices. The Figure 1-1 flowchart illustrates the basic decision steps for guiding field implementation of surfactant flooding projects.

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[1] United States Environmental Protection Agency. 1993. Appendix D – Glossary. *Groundwater Sampling – A Workshop Summary*. EPA/600/R-94/205. Robert S. Kerr Research Laboratory, Ada, OK.

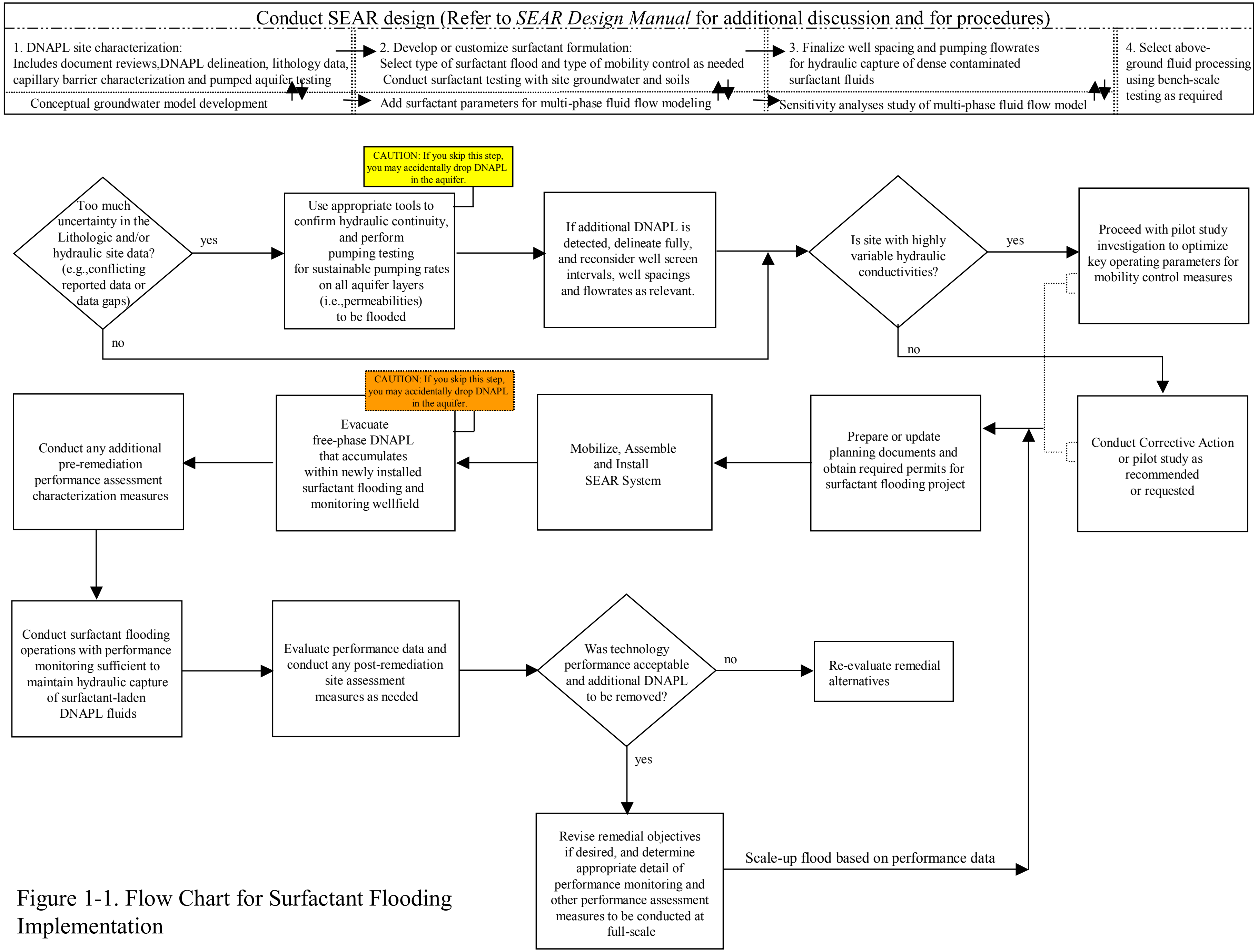

Figure 1-1. Flow Chart for Surfactant Flooding Implementation

Section 2.0: FIELD PLANNING ACTIVITIES

2.1 Teaming

Due to the multi-disciplinary nature of field activities, the technical team composition should include: geologists/hydrogeologists with groundwater remediation and modeling experience; environmental engineers with backgrounds in pumping systems, piping and instrumentation, wastewater treatment processes, power systems, and construction; chemical or petroleum engineers that are knowledgeable in surfactant chemistry, soil and groundwater physical and chemical properties, and the design of flooding remediation processes involving multi-phase fluid flow; and analytical chemists familiar with surfactant analytical techniques. For custom surfactant requirements, microbiologists, toxicologists, and process chemists should be included on the team to ensure food-grade or biodegradability requirements are being met, alongside consistent chemical delivery quality. The installed surfactant flooding system should have a high reliability in maintaining a constant quality of delivered surfactant solutions, continuous injection and extraction rates meeting required forced gradients for hydraulic capture, and treatment of extracted solutions to comply with discharge and reinjection requirements. Such will require a thorough understanding of the aquifer system in which the flooding system is emplaced, leading to proper location and installation of all wells for high efficiency pumping[2,3] and DNAPL removal operations, as well as knowledge of positive and negative surfactant interactions within the contaminated aquifer environment and indicators of both responses for controlling and monitoring field operations appropriately.

2.2 Health & Safety

The primary hazard of SEAR operational activities is associated with the large quantities of DNAPL-contaminated fluids being extracted from the subsurface. Piping, hosing, and other plumbing lines that carry DNAPL-contaminated fluids should be chemically compatible with handled fluids so as to not leak during operations. Proper safety precautions will be required for handling these fluids during daily operations. Secondary containment is required of DNAPL storage tanks and all chemical waste and storage tanks. Air emissions monitoring may be required for volatile contaminants, e.g., chlorinated solvents and fuel components. A secondary chemical hazard is related to the transport, storage and handling of alcohol that will be used as cosolvent in the surfactant solution. Fire and explosion hazards exist due to the flammability of the alcohol. Alcohol drums should be properly grounded to avoid static electricity hazards. Compliance with OSHA and local regulations for work on hazardous waste sites will be appropriate for surfactant flooding projects.

2.3 Regulatory/Permitting Issues

Injection wells are regulated by the underground injection control (UIC) program under the federal Safe Drinking Water Act (SDWA). The purpose of the UIC program is to protect underground sources of drinking water (USDWs). Under the UIC program, injection of any fluid into a well is prohibited, except as authorized by permit or rule. Injection wells incidental to aquifer remediation and

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[2] United States Environmental Protection Agency. 1991. Seminar Publication: Site Characterization for Subsurface Remediation. EPA/625/4-91/026. Center of Environmental Research Information. Office of Research and Development. Cincinnati, OH.

[3] United States Environmental Protection Agency. 1993. *Suggested Operating Procedures for Aquifer Pumping Tests.* EPA/540/S-93/503. Technology Innovation Office, Washington DC.

experimental technologies are distinguished from hazardous waste injection wells and are designated as Class V wells under the UIC program. Class V wells covered by the federal UIC program are authorized by rule and do not require a separate UIC permit. A Class V well regulated by a state may require a permit. Application of UIC requirements depends on the regulatory framework controlling the cleanup with fewer restrictions expected for cleanup activities conducted under CERCLA authority (United States Environmental Protection Agency {U.S. EPA}, 1995[4]). UIC requirements are regularly implemented for RCRA corrective action cleanup projects, but may not be as consistently applied to CERCLA sites.

It is essential that the injection permit documentation list both principal compounds and any unreacted compounds or impurities. One example of this point is the use of sodium chloride (NaCl) as an electrolyte. Most sources of NaCl (including food grade material) will list arsenic as a potential impurity. Hence, the potential arsenic concentration in the injectate (or injected solution) must be considered.

Conducting SEAR requires the recovery of injected solutions containing high concentrations of dissolved or mobilized contaminant and surfactant chemicals. On-site treatment of the extracted groundwater will typically be needed to reduce contaminant concentrations to levels consistent with the permit requirements of the publicly-owned treatment works (POTW), other discharge requirements such as the National Pollutant Discharge Elimination System (NPDES) permit, or for chemical recovery and reuse requirements. Management of other waste streams resulting from wastewater treatment (e.g., DNAPL separated by decanting or air discharged from a stripper) must comply with all applicable federal, state, and local requirements.

Should it prove economical to recycle compounds such as the surfactant and alcohol, regulatory permission for reinjection must be gained. The recycling process involves concentration of surfactant chemicals for reuse and an undesirable effect is the simultaneous concentration of other compounds that may impact surfactant performance (Battelle/DE&S, 2001a[5]). The feasibility of surfactant reuse is strongly dependent on site-specific regulations, as contaminant removal to maximum contaminant levels (MCLs) prior to surfactant reinjection is cost-prohibitive. Recently completed surfactant floods at former Naval Air Station Alameda Point, CA, and Marine Corps Base (MCB) Camp Lejeune, NC, where permission was granted to reinject surfactant without requiring contaminant removal to MCLs (because hydraulic control of injected fluids had been demonstrated), indicates that controlled reinjection of surfactants may gain widespread regulatory acceptance. As regulatory interpretations allowing the use of injectants have recently become more flexible (U.S.EPA, 2002[6], 2000[7]), it is possible that a similar trend will follow for the reinjection of SEAR process chemicals.

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[4] United States Environmental Protection Agency. 1995. *Surfactant Injection for Ground Water Remediation: State Regulators' Perspectives and Experiences*. EPA/542/R-95/011. Technology Innovation Office, Washington, DC.

[5] Battelle and Duke Engineering & Services. 2001a. Final Technical Report for Surfactant-Enhanced DNAPL Removal at Site 88 Marine Corps Base Camp Lejeune, North Carolina. Prepared on behalf of the Naval Facilities Engineering Service Center for the Environmental Security Technology Certification Program, Arlington, VA.

[6] United States Environmental Protection Agency. 2002. Handbook of Groundwater Protection and Cleanup Policies for RCRA Corrective Action. EPA/530/R-01/015. Office of Solid Waste and Emergency Response, Washington D.C.

[7] United States Environmental Protection Agency. 2000. *Applicability of RCRA section 3020 to In-Situ Treatment of Groundwater*. Letter Memorandum, Office of Solid Waste and Emergency Response, Washington D.C.

Vertical gradients in the subsurface system and recoverability of DNAPL fluids may be of concern to regulators at some sites. This may dictate a more conservative design approach, to mitigate potential loss of hydraulic control vertically, as well as to prevent the ultra-reductions of interfacial tension that may result in a mobile DNAPL front (i.e., DNAPL mobilization). Similarly very dense surfactant-DNAPL solutions (e.g., solubilizing 25% or more of DNAPL by weight) may not be permitted, with lesser leeway being given to more dense contaminants, discontinuous and other such complicated lithologies, leaky or fluctuating groundwater conditions and weak capillary barriers.

2.4 Risk Management Issues

Education of technical and project managers is a key factor in reducing misapplication of technology, probable errors in implementation, and for resolving contracting performance issues. For a DNAPL site, the more simple, or homogeneous, the hydrogeology, the more permeable the media to be flooded, and the more competent the underlying capillary barrier, the lower the risk of technology failure. At more complex sites with significant heterogeneities, low permeabilities ($< 10^{-3}$ cm/sec), or vertical gradient systems, greater expertise is required for comparable performance to the simpler low risk sites. At the time of this publication, it is not recommended to use surfactant flooding on DNAPL sites with fractured media or those without a continuous and relatively impermeable capillary barrier. This includes locations where earlier site investigation activities may have compromised the integrity of the capillary barrier beyond feasible repair. Such sites may result in insufficient hydraulic capture of contaminated fluids regardless of imposed gradients.

Generally, proper recovery and targeting of flooding chemicals necessitates hydraulic continuity of the zones to be flooded under pumping gradients, well-defined vertical and horizontal extent of contamination with the associated permeabilities of these zones, natural and external gradients and any fluctuations of such quantified, and integrity measurements of the underlying and supporting low permeability media that has arrested DNAPL movement downwards. As explained in the *SEAR Design Manual*, attentive logging and capillary barrier testing procedures, using the appropriate equipment for retrieval of completely intact core samples, can provide valuable information on the integrity of the less permeable layers or aquitard maintaining DNAPL above it. Due to flowing sands conditions often encountered during retrieval of soil samples, direct measurement methods (e.g., CPT sensor equipment) may support refined vertical profiling of soil lithology and DNAPL saturations, if both can be obtained real-time simultaneously, to avoid pushing through a formation that is preventing DNAPL movement downwards. Water level data from multiple locations, collected at discrete depth intervals per location, may also indicate confining zone integrity, and geophysical methods used in determining hydrogeologic zone boundaries.[2] These procedures, alongside other field design characterization activities, may be best delegated to the vendor contracted to perform the flood for reasons of liability and design aspects. As mentioned above, the breaching of a capillary barrier supporting DNAPL is a concern to be avoided in all cases. More conservative flooding approaches, resulting in less dense DNAPL solutions to be transported through the aquifer, may be indicated by capillary barrier testing results and other DNAPL site characteristics, as mentioned above. Similarly, pumping rate pulsing or pulsing of injectants, which has been investigated, may be unfavorable due to vertical gradients created with significant variability (e.g., turnoff and turn on) of injection pumping rates. Finally, free-phase DNAPL should be removed to the extent feasible prior to introduction of surfactants to reduce unintended mobilization concerns. It may be noted that the above-mentioned admonitions do not apply equally to LNAPL sites with LNAPL contaminants only, as these contaminants will not be mobilized downwards due to gravity. Additional risk management measures not involving issues for design are discussed in the following on sections.

2.5 Performance Assessment

Performance assessment as a concept has typically been applied to small-scale technology demonstration projects, to provide a benchmark with which to compare, on an even basis, competing innovative technology alternatives. For larger-scale projects, there is usually a trade-off between devoting additional budget dollars towards 'post-mortem' site characterization analysis, and operating the remedial system for an extended period with any possible in-the-field system optimization. For contractual purposes, the former may be recommended, to be protective of the environment at a site that poses significant risk if DNAPL becomes mobilized in unwanted directions. This contracting approach would preferably stipulate that the vendor is liable for the uncontrolled DNAPL migration and additionally nonattainment of specific performance objectives (as explained in the paragraph below), akin to an extended service warranty on a consumer product[8]. As surfactant flooding has seldom been used to address remediation of entire DNAPL source zones impacting a particular contaminant plume, the longevity of a surfactant flooding remediation on the overall plume size has yet to be directly observed, and has thus been the forum of groundwater modeling, which is yet another motivation for the emphasis that has been placed upon accurate and correctly applied baseline and post-remediation performance assessment measures. When a site has already been thoroughly characterized for remediation design as recommended for high performance, the additional investment for post-DNAPL characterization may not be as significant. In all cases, sampling media (i.e., soil to soil or groundwater to groundwater) and sampling intervals (e.g., 6 in. to 6 in. core samples or 2 in. screen to 2 in. screen groundwater samples, all at similar depths) should be comparable for pre- and post- events. An exception is to prevent the hydraulic breaching of a confining layer within a DNAPL zone, most critically prior to remediation; thus, it may be difficult to characterize safely DNAPL distribution in confining zones.

In recent projects, the performance of a SEAR flood has been evaluated primarily by obtaining initial and final DNAPL mass estimates to determine whether percent DNAPL removal objectives have been achieved, as well as by comparing the mass of chemicals injected to the mass recovered to evaluate attainment of chemical recovery (or hydraulic fluid control) objectives. Such has required relatively detailed monitoring operations in tandem with detailed pre- and post-remediation site characterization. The performance (or design) targets for technology demonstrations are often established at over 90% for both contaminant and chemical recovery design parameters. While the former criteria may be relaxed somewhat, the latter pertaining to recovery of injected surfactant chemicals should not be due to the significant increase in contaminant mobility in the presence of surfactant chemicals. Numerous soil samples (sampling volume, locations and depth intervals for accurate parameter estimates as determinable or validatable by geostatistical kriging methods), partitioning interwell tracer test (PITT) data, or a combination of these and other approaches may be necessary to obtain quantitative and validated pre- and post- DNAPL soil estimates. (Recommended DNAPL soil sampling procedures and a discussion of PITTs can be found in the *SEAR Design Manual*.) Vertical profiling to determine the lithologic layer in which the contaminant continues to be lodged is necessary to determine the remaining risk of DNAPL unremoved following treatment. For example, contaminant remaining lodged in a low permeability clay-containing layer tends to provide a persistent long-term but relatively low-level (i.e., slower mass transfer) contamination source, while contaminant left behind in more permeable and transmissive layers will serve as a greater (i.e., faster mass transfer) but less persistent contamination source.

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[8] Minimally, certain stated design parameters would have to be attained, such as specified pumping rates, monitoring schedules, and contaminant recovery levels, all over a priorly designated duration.

Whether or not it is possible to determine the error associated with a given DNAPL mass removal estimate, the cumulative DNAPL recovered from each extraction well, in a separate or free-phase, and solubilized forms, can be calculated to estimate the total mass of DNAPL recovered from the subsurface with flooding operations. The accuracy of the mass extraction curve will increase with the number of samples collected and the clarity of resolution within the aquifer will rely as well upon the number of extraction wells selected for detailed sampling. The recovery of DNAPL from selected aquifer strata can also be determined from vertical contaminant recovery distribution profiles obtained from multi—level sampling (MLS) data. As briefly mentioned in the *SEAR Design Manual* and as further described in Appendix B, multi-level sampling devices permit the collection of numerous depth discrete samples in contrast to those from regular monitoring wells that provide averaged samples from groundwater drawn in over the length of the exposed well screen. If contaminant recovery as observed at the extraction wells is poor, then the surfactant levels in the discrete sampling zones may also provide information about the efficiency of chemical flooding (i.e., effectiveness of chemical penetration into all zones to be remediated). A running estimate of the percentage of chemicals removed from the aquifer with post-surfactant water flooding operations may also be obtained and correspondingly the mass of injected chemicals remaining in the aquifer following flooding operations can usually be obtained of mass recovery curves composed of a sufficient number of samples to appear continuous.

Given that the entire DNAPL source has been treated, which includes the assumption that the source zone has been delineated well enough for remediation of the entire source zone, post-treatment conventional groundwater monitoring in the downgradient or other compliance boundary direction, may supplement other performance data directly from the treatment zone. This may entail encircling the perimeter of the original source zone with wells for a site with variable hydraulic gradients. In the meantime, new technology continues to evolve towards more cost-effective DNAPL detection, and measurement technologies in the subsurface and improved tools for determining the mobility of contaminant away from the source at a selected boundary zone (or contaminant mass flux measurements) continue to be investigated. Currently under evaluation are a variety of pumping, passive diffusion, and other innovative borehole methods to determine whether source reduction measures have impacted dissipation of contaminant from the source zone.

From an operational viewpoint, meeting SEAR performance criteria is dependent on the following:

- ☐ Proper wellfield installation, inclusive of well construction and development methods,
- ☐ maintaining the quality of injected surfactant chemicals,
- ☐ maintaining design flowrates in the SEAR wellfield,
- ☐ maintaining a sufficient extent of surfactant flooding and post-surfactant injection water flooding operations, and
- ☐ monitoring system parameters and recording monitoring data to validate that SEAR performance criteria have been met.

These topics are the subject of Section 4.0. To be protective, monitoring activities to maintain and document system integrity and performance should receive thorough treatment in project planning documents subject to approval by regulatory agencies. These include the workplan as well as sampling & analysis plan.

In summary, it may be noted that performance assessment measures are inclusive of detailed performance monitoring activities to ensure that the surfactant flooding remediation system will operate properly and as designed. Sampling monitoring and system operational data, juxtaposed with initial design detail, inclusive of modeling simulation predictions, may be used to determine whether the remediation has been successful in achieving design objectives, and in reducing risk to the environment and receptors, subject to confirmation by post-treatment performance assessment characterization, as deemed desirable, feasible, or worthwhile. As emphasized in the *SEAR Design Manual* and as reiterated here, much will hinge on the initial design characterization, as proper system monitoring itself may not be possible without sufficient information and interpretive expertise from earlier completed stages of the project.

2.6. Site Coordination Requirements

There will be a number of issues to discuss with the facility in order to properly specify site mobilization and system construction requirements, including the availability of local equipment and on-site operators. This will require coordination on items ranging from utilities needs to delivery of bulk items, to community public relations and hazardous waste removal from the site.

2.6.1 Water and Utilities

SEAR operations will require a potable water source, electricity, compressed air and in some instances, natural gas or propane for the operation of heated wastewater equipment. If compressed air (for pneumatic equipment) is not available, on-site generation of compressed air by an electric-powered compressor is an alternative. Therefore the basic utility requirements are a reliable source of potable water and electricity to sustain injection and extraction operations for the duration of the project. Water in sufficient quantities is generally available, but for large-scale projects (e.g. > 50 gallons per minute system) may require notifying the utility supplier to install larger diameter lines and to ensure a continuous supply of water for the project duration. With respect to electricity, the proper phase, amperage, and voltage must be available. If sufficient power is available from the public supply company, it can still often mean that a line or lines must be dropped into the site and transformers installed. One advantage of connecting to a public supply network is that it can be a more reliable source, than portable generators. When comparing the relative costs of a public supply versus on-site generation of electricity, the reliability of the source may add value to the public supply network. In either case, a contingency power source may be necessary if power outages are expected.

If electric power is to be supplied by generators, it will be necessary to locate a provider. It is generally prudent to have extra generation capacity on-site in case of mechanical device failure. The generators will be supplying power on a continuous basis, 24 hours per day, for the duration of the project and the vendor from which the generators are to be rented should be informed that the generators will be operated more than 8 hours per day. This fact will alter the maintenance and replacement schedule the vendor has for the generators. The method used to refuel portable generators is an additional consideration. Hauling fuel to the site daily in 5-gallon cans is the least desirable option. Contracting with a local fuel supply company to bring a fuel truck to the on either a set schedule or on an on-call basis is often the most attractive option. Refueling considerations will also be applicable to fuel-powered compressors if used. Finally, the power generated by portable generators is often not “clean” enough to operate sensitive equipment such as gas chromatographs without line filters added; however this may also apply to existing utility lines which require transformer devices.

2.6.2 Miscellaneous Logistics Coordination

It will be necessary to coordinate with local wastewater treatment facilities or waste contractors to determine the available capacity and costs of discharging to their facility relative to onsite wastewater treatment processing. Additionally, particularly with oily combustible mixtures, there may be a resale value associated with reuse of recovered NAPL liquids; therefore, such opportunities should be investigated in advance. Used chemical drums may be recycled.

Project scheduling will require arrangements with local staff members to avoid interfering with operating facilities and existing activities. During surfactant flooding remediation, vicinity pumping should be reduced to avoid any additional gradients to the areas being treated by surfactants. Arrival of rental equipment, equipment trailers, piping/hosing, bulk chemicals (e.g., drummed, palleted, and tankered) as well as miscellaneous delivered hardware components, will require facility coordination to arrange paved road accessibility rights and receiving locations for air-shipped items. Anticipated chemical storage and trailer areas should be coordinated with local authorities ahead of arrival so that designated areas may be appropriately delineated and labeled with placarding and project notification signs. Local authorities and residents should be notified of the anticipated project duration and 24 hour per day nature of flooding operations.

2.7. Pilot-Scale Investigations

Pilot-scale studies may be desirable to investigate system performance and cost feasibility prior to a full-scale effort or when a risky situation is encountered, such that difficulty exists for maintaining hydraulic control over surfactant laden DNAPL contaminated fluids (e.g., tidal fluxes or other vertical gradients in the vicinity of the treatment zone), or when a weak capillary barrier system exists. The chemical compatibility of surfactant for the contaminant(s) and aquifer formation may also be confirmed during a pilot-scale study; however, bench-scale surfactant selection testing with site groundwater and soils can be performed in place of more expensive field testing if this is the only requirement. Recoverability of surfactant laden with DNAPL fluids can be somewhat gauged by a conservative tracer test under a given set of design pumping rates (i.e., injection and extraction rates) through examination of tracer recoveries. However, only a surfactant injection (with extraction) test will provide information about recoverability of surfactant-laden solutions under pumping conditions. Finally, flooding variants such as the use of polymer and/or surfactant foam for even fluid propagation across a heterogeneously composed aquifer stratigraphy will be the greatest benefit of pilot testing to refine design injection and extraction parameters. When sufficient injection pressures and/or hydraulic gradients can be maintained, most sites will exhibit improved flooding efficiency with the addition of mobility control refinement to circumvent preferential flow in the vicinity of low permeability silty layers commonly sinks for DNAPL.

Surfactant foam flooding mobility control design will require specifying a design pulsing rate of air to create foam within the desirable (and clean) layers. While laboratory-based foam formation studies (AATDF, 1997)[9] will be needed to evaluate the influence of contaminant and surfactant formulation properties on foaming mobility and stability, only a field foam propagation study[9,10] will reveal whether horizontal traverse of foam under specified air pressures is sufficient to divert surfactant fluids through lower permeability zones for the air pressures applied. Thus, a pilot investigation may be helpful in examining the feasibility of foam propagation when mobility control is to be used. On the

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[9] AATDF. 1997. *AATDF Surfactant/Foam Process for Aquifer Remediation*. Prepared for The Advanced Applied Technology Demonstration Facility, Houston, TX by Intera Inc.

[10] Hirasaki, G.J., Jackson, R.E., Jin, M., Lawson, J.W., Londergan, J., Meinardus, H., Miller, C.A., Pope, G.A., Szafranski, R., and Tanzil, D., 2000. "Field Demonstration of the Surfactant/Foam Process for Remediation of a Heterogeneous Aquifer Contaminated with DNAPL," *NAPL Removal: Surfactants, Foams, and Microemulsions*. Fiorenza, S., Miller, C.A., Oubre, C.L., and Ward, C.H. Editors. Lewis Publishers, Boca Raton, (2000), 1-166.

other hand, polymer addition for mobility control, particularly for removal of contaminants of greater viscosity than water, increases the viscosity of the flooding solution and will require higher induced gradients for capture of contaminated and remedial fluids. Pilot testing can determine whether the gradients necessary for capturing DNAPL and polymer-surfactant fluids can be maintained for improved contaminant contact and recovery compared to an unamended (without polymer mobility control) system. Similarly, if heating is deemed necessary to assist in mobilizing a viscous contaminant, pilot testing can assist in feasibility evaluations.

When intended only for a portion of the entire source zone area, a pilot-scale investigation should occur ideally in the upgradient portions of the source zone area. This will ensure minimum disturbance of streamlines within the test zone caused by any existing containment pumping that can not be turned down, and protect the zone being flooded from subsequent recontamination by DNAPL outside of the treated zone to maximize the benefit of the pilot study remediation effort. As earlier mentioned, as much free-phase NAPL should be removed from zones adjacent to the targeted remediation zones as possible to facilitate meaningful collection of any post-treatment monitoring data, as well as for the longevity of remedial efforts. When inaccessibility issues arise, such as DNAPL located beneath a building in use, remediation efforts should consider hydraulic isolation of these zones. The above issues apply equally to a full-scale remediation that is performed in a modular fashion to reduce equipment capital costs.

Section 3.0: SEAR SYSTEM COMPONENTS

This section seeks to clarify the major equipment items in use with and components of in-situ surfactant flooding operations. Following the process design and initial planning stages, design operating parameters such as the durations of flooding phases (i.e., aquifer preparation flooding, surfactant flooding and post-surfactant water flooding), required chemical quantities, and individual well pumping rates, will be specified for a given estimate of DNAPL mass and distribution. Implementation of surfactant flooding remediation will require further engineering design and construction of the flooding system components to allow continuous delivery of enhancing or remedial fluids and recovery and handling of spent surfactant solution and contaminants. The sizing of field equipment may occur once the available capacity of on-site or vicinity wastewater treatment facilities has been evaluated and confirmed. It may thus be more feasible to address the source zone in sections proceeding from upgradient to downgradient portions as recommended, to reduce any treatment plant construction costs as well as the cost of any additional fluids processing to recycle surfactant chemicals. Administrative or management constraints may also influence the scale of flooding system construction activities. The major surfactant-enhanced flooding system components are introduced below.

3.1 Component Description

A SEAR project requires equipment and components to conduct the following major field tasks:

- ☐ Preparation of surfactant solution and other injected chemical solutions;
- ☐ Injection and extraction operations;
- ☐ Monitoring of system parameters;
- ☐ Maintenance of critical system design parameters;
- ☐ Wastewater treatment.

The operational criteria for these tasks and their associated equipment, hardware and materials of construction where relevant (e.g., for chemical compatibility) are discussed in the sections that follow.

3.1.1 Chemicals Preparation.

There are in general three options for preparing chemical solutions for delivery on a SEAR project:

- ☐ Batch (tank) mixing;
- ☐ In-line mixing; and
- ☐ Pre-mixing or off-site preparation.

These options may be applied to the preparation of two types or compositions of solutions that are injected during SEAR flooding operations: surfactant solutions and water flood or hydraulic control solutions. Surfactant solutions are commonly comprised of a surfactant, salts of sodium and/or calcium, and a cosolvent. Occasionally, a polymer may be added as well. Water flooding and hydraulic control solutions consist of potable water mixed with the same electrolyte at the same or lower concentrations as used for the surfactant mixture, and will be referred to in further discussion as electrolyte solution.

3.1.1.1 Batch Preparation Method. Batch preparation methods are the most common method of preparing chemical solutions in the field for small-scale surfactant flooding projects. Mixing conditions within tanks can be created with recirculation pumps that draw fluid from the bottom of the tank for discharge at the top of the tank. The tanks will require fittings for drawing fluids in this manner. To decrease the amount of time required to mix the injected batch, a mixing pump should be obtained that provides for a flowrate capacity sufficient to ensure adequate time to prepare additional batches such that only well-mixed fluids, passing quality standards (to be discussed in Section 4), are delivered for injection. The viscosity and composition of the unmixed injectate must also be considered in selecting recirculation pumps for mixing. A pump and tank configuration is shown in Figure 3-1.

Fiberglass or composite plastic tanks can be used for blending and storage of the surfactant, alcohol, and electrolyte solutions. The specification of the tank materials should be based on an evaluation of the chemicals that will be stored in the tanks to ensure that the tank materials are compatible. An array of high density polypropylene (HDPE) tanks used for blending electrolyte solutions is shown in Figure 3-1. Composite plastic materials are generally chemically compatible and resistant to most of the chemicals used on SEAR projects and are easier to handle when empty because of their relatively low weight. For mixing and storage of the injectates or solutions to be injected, multiple tanks will be necessary to allow for the injection of a mixed batch and the concurrent mixing of additional batches. A minimum of two tanks is recommended for surfactant preparation with one tank for mixing and the other tank for storage of the mixed solution. This ensures that sufficient injectate quantities are continuously available for injection. In general, the minimum capacity of the storage tanks should be at least 150% of the expected volume of chemical solution delivery. For injectate preparation on SEAR projects, tank volumes of 6,000 gallons or less, consisting of composite plastic materials are commonly used.

Figure 3-1. HDPE Storage Tanks Used for Blending Electrolyte Solutions

Surfactant and cosolvent chemicals are usually delivered to the site in drums or in bulk tank cars and will need to be transferred to tanks for batch mixing. The viscosity of most surfactants used in SEAR projects is in the range of 40 to 1000 centipoise (cP), (depending on the purity of the surfactant preparation from the manufacturer that can be variable), which is significantly more resistant to flow than water that possesses a viscosity of 1 cp. When transferring viscous surfactants and surfactant solutions through hoses and tubing, additional head losses will be encountered, which should be accounted for in specifying the pumping capacity and line diameters. When transferring alcohol on-site, extreme caution must be taken to ensure that the pump type and construction materials do not create a flammable or explosive situation during the transfer process.

3.1.1.2 In-Line Mixing Method. To mix chemical solutions in-line, hydrodynamic mixers installed in the injection line are used in lieu of batch mixing tanks and recirculation pumps. This method of mixing is an innovation derived from the food industry and requires less tankage than the batch mixing method for supplying high flow volumes of surfactant solutions and to accommodate relatively small footprints. In-line mixing requires that injectate components be accurately metered into a potable water stream so that the mixture contains the appropriate chemical concentrations. The chemicals are staged in relatively small tanks in pure form or high concentrations and then metered into the injectate stream for mixing at the hydrodynamic mixer. Properly selected chemical transfer pumps and flowmeters or metering pumps can be used for chemical metering. This method greatly reduces injectate mixing time, but relies heavily on the accurate metering and performance of the equipment items, which will be operated 24 hours per day during flooding operations.

3.1.1.3 Pre-mixing or Offsite Chemical Preparation. When it can be arranged with a chemical manufacturer, pre-mixing of supplied chemicals may prove to be the most cost-effective option for preparing surfactant solutions. This will provide the most consistent quality of surfactant solution for flooding operations. Surfactant, cosolvent (if used) and electrolyte are pre-mixed at the vendor facility for delivery to the site. Electrolyte solutions for hydraulic control wells will still require batch mixing preparation. For premade solutions delivered to the site, the storage volume should be based upon the turnover or use of the chemicals with a storage capacity for a one-week or a one-month supply being desirable depending on the environmental stability of the chemical compound solutions to be stored.

3.1.2 Injection and Extraction Operations.

A simplified process flow diagram of injection and extraction operations with control instrumentation is provided in Figure 3-2. Water injection or hydraulic control wells supplement extraction wells for maximum containment and recovery of injected fluids. Automated process control and data acquisition for continuously monitored pumping operations is addressed further in Section 3.1.4.

Injection and extraction operations require properly constructed injection and extraction wells alongside standard equipment items that include injection and extraction pumps and controllers, flowmeters and a combination of hoses, tubing, pipes and valves for carrying fluids to and away from the treatment zone. In-line filters will be needed upstream of pumps and flowmeters to protect against damage and poor performance from particulate materials, such as any undissolved impurities from chemical solution tanks and soil fines removed from extraction wells. Reformulation of recovered surfactant fluids for reinjection may result in precipitation of iron and cationic species from solution and require additional filtration prior to reintroduction to the aquifer. Backup power generation equipment is suggested for continuous pumping operations, and pumping power hookup should consider minimizing the time to switch to a backup power source when a power-out alarm is sounded.

3.1.2.1 Injection and Extraction Wells. Proper well construction is perhaps one of the most important, yet often poorly accomplished, aspects of addressing NAPL remediation. It is a major component in the success of a SEAR project, as maximizing the available pumping gradients is

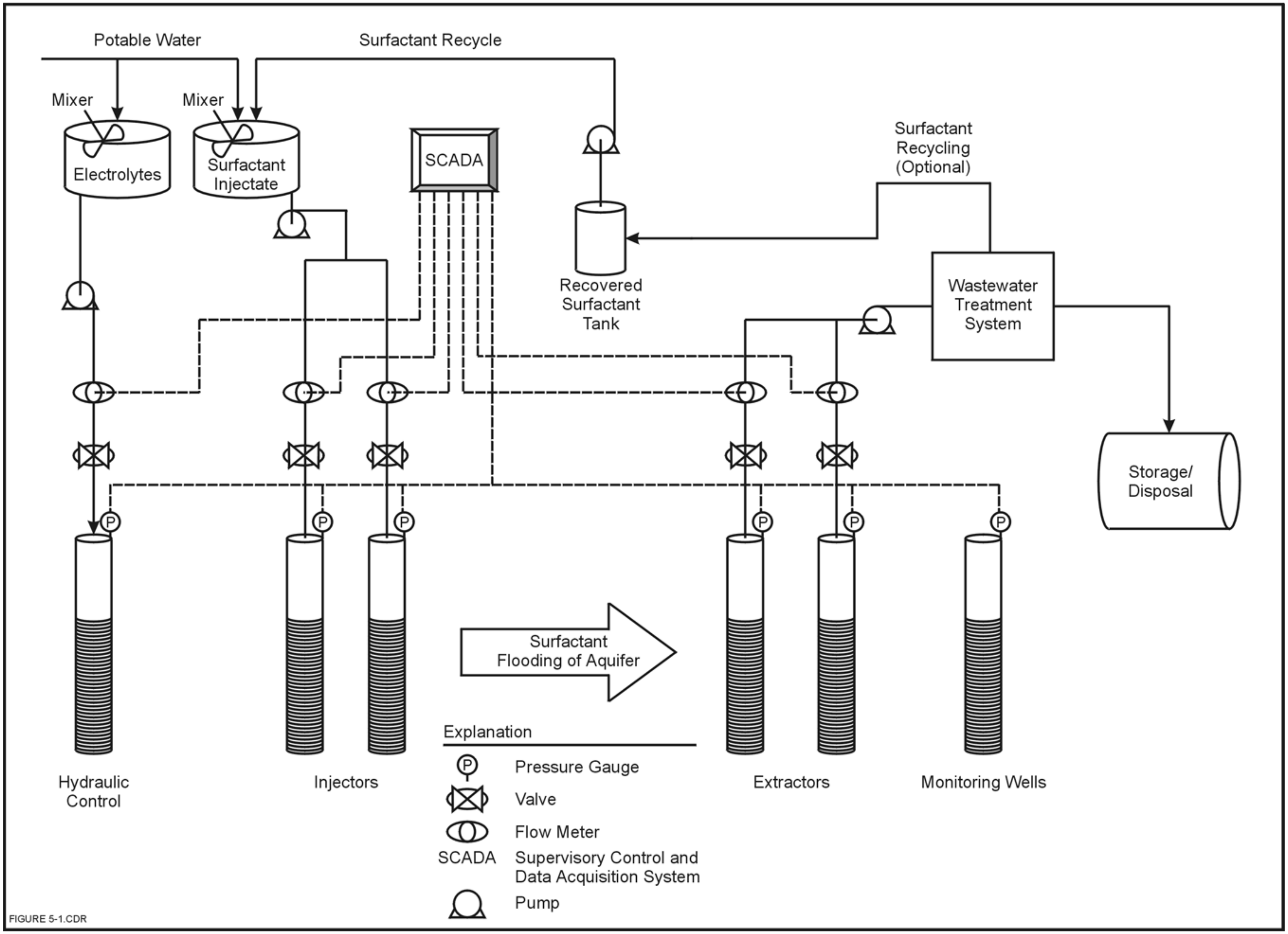

Figure 3-2. Basic Surfactant Flooding Components

critical to recovering contaminated fluids of elevated density and viscosity relative to water. For this reason, well construction methods used for SEAR wells, are more detailed and demanding than for conventional groundwater monitoring wells. Existing wells pre-dating discovery of DNAPL zones may best be used to supplement surfactant flooding operations as groundwater sampling and water level monitoring locations, as relevant.

Following SEAR design, the well locations and screen intervals and depths will be known and well construction can begin. To ensure that well construction is consistent with the stratigraphy and contamination at the site, the following should occur:

- ☐ Screen placement across the contaminated stratigraphy of interest. Furthermore, at DNAPL sites, the bottom of the well screens in recovery wells should be installed across the lower capillary barrier/aquifer interface (this allows for uninhibited DNAPL migration into the well). At LNAPL sites, the screens should span the oil/water interface and be long enough to meet the demands of the SEAR design. Well construction should not allow cross contamination between aquifers.
- ☐ Well screen and filter pack sizes should be properly selected based upon the particle size of the aquifer material.
- ☐ Well materials should be chosen based on their chemical compatibility with the contaminant(s) and other SEAR chemicals as well as their physical compatibility with pressure or heat stresses that may be exerted.
- ☐ Injection and recovery well screens should be continuous wire wrap (this improves well efficiency and allows for superior well development).
- ☐ Wells must be accurately placed within the desired depth interval and not offset by conditions such as flowing sand.
- ☐ Wells should be installed using centralizers to ensure placement in the middle of the borehole.
- ☐ Drilling fluids should be selected that do not inhibit well development, thereby decreasing well efficiency.
- ☐ The volumes used and placement of the sand/gravel filter pack should be carefully monitored to insure that the filter pack fully surrounds the well screen.

Detailed recovery well construction specifications intended for duplicate use in DNAPL site characterization and surfactant flooding remediation were provided in the design manual and have been included as Appendix A within this document. Occasionally, wells installed during the DNAPL investigation phase are screened over the improper depth intervals, or demonstrate poor efficiency. If the well is screened to the appropriate final depth, it may still be used for mobile DNAPL removal, and perhaps for injection activities with the use of an inflatable packer to modify the screen interval as applicable. Wells that perform poorly during tracer injection or extraction activities should be redeveloped and replaced if feasible.

3.1.2.2 Pumps and Plumbing. With the completion of design simulations, the required flowrates and head differential for establishing hydraulic control will be known. This information is used to select pumping equipment. The optimum pump configuration to maximize well fluid recovery uses dedicated extraction pumps for each well. When selecting downhole submersible pumps, such as those used frequently for recovery operations, consideration must be given to the diameter of the well, the number of pumping zones per well, the lift and flowrate required under maximum viscosity conditions, and the chemical compatibility of the pump materials with the effluent. In practice, even if the mobilization of NAPL is not anticipated during surfactant flooding, it is recommended to design for this possibility. As 24 hour per day operation will be required, equipment reliability will also be a major criterion of all pumps selected. Finally, spare pumps should be readily available for contingency use.

The plumbing conduits of a SEAR system for injection and extraction operations include pipes, tubing and hoses. Selection of appropriate materials, such as steel or polyvinyl chloride, should be based on factors including cost, pressure rating, and chemical compatibility with surfactant fluids and NAPL[11] (in the recovery lines). Manifolding of injection or extraction lines requires piping material construction. Otherwise where possible, flexible tubing or hoses are more convenient for mobility and construction.

Valves are used to control the movement of fluids through pipes, tubing, and hoses, such as for sampling fluids and flowrate measurement and control. Valve types used on a SEAR project include ball, gate and needle valves. Ball and gate valves are commonly used for on/off control of fluids, and can also be used for rough flowrate control. Needle valves are used for more precision in flowrate control. Valves that are electronically actuated will be required for automated flowrate and pressure regulation. As with other plumbing material types, cost, pressure rating, and chemical compatibility with fluids should be considered when selecting valve material types.

3.1.3 Monitoring System Parameters.

Monitoring equipment is used to collect data to gauge SEAR progress and to maintain and refine SEAR system operating parameters. Throughout a SEAR project, fluid chemistry, fluid flow properties and aquifer properties are regularly monitored. Table 3-1 shows the most important system monitoring parameters and common monitoring locations. For performance monitoring of a surfactant flooding operation, groundwater samples are most easily collected from extraction wells. However, groundwater samples collected at these locations will not provide vertical performance data. A multi-level sampler (MLS) network within the extraction wells can provide undiluted groundwater samples at depth discrete intervals, more accurately reflecting the capacity of the surfactant formulation and contact of discrete aquifer zones through a heterogeneous aquifer. Appendix B discusses MLS devices in further detail.

Specific conductance, temperature and pH can be measured with manually operated meters or using in-line probes, particularly for process monitoring of effluent fluids. Flowrates and system pressure can be measured using calibrated in-line flowmeters and pressure instruments. Electronic pressure transducers or transmitters and manual water level meters can be used to determine the elevation of the water surface within and adjacent to the treatment zone.[2,12] Interface probes can determine the in situ depth and corresponding volume of DNAPL within a well. DNAPL volume may also be determined using a graduated glass cylinder or similar device after pumping or bailing from a well. Sampling of monitoring points can occur either intermittently, whenever a sample is scheduled for collection, or continuously (i.e., with continuous pumping) at low flowrates. Intermittent sampling of wells or multilevel samplers is typically conducted using surface pumps, while continuous sampling

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[11] United States Environmental Protection Agency. 1995. *Nonaqueous Phase Liquids Compatibility with Materials Used in Well Construction, Sampling and Remediation.* EPA/540/S-95/503. Technology Innovation Office. Washington DC.

[12] United States Environmental Protection Agency. 1985. *Practical Guide for Ground Water Sampling*. EPA# CR-809966-1. Illinois State Water Survey Contract Report #374. Prepared in cooperation with Robert S. Kerr Environmental Research Laboratory, the Environmental Monitoring Systems Laboratory, Las Vegas, Nevada, and the Illinois State Water Survey.

Table 3-1. SEAR System Monitoring Parameters

Category	Monitoring Parameter	Monitoring Location
Fluid chemistry	Temperature, pH Specific conductance Electrolyte Cosolvent Surfactant	Mixed injectate (tank or injection line), extraction wells and monitoring points[(a)]
	Contaminant (NAPL volume and dissolved concentration of each component)	Extraction wells and monitoring points[(a)]
Fluid flow properties	Pumping flowrates	All pumping locations
	Pressure	Injection, extraction and wastewater processing fluid lines
Aquifer Properties	Water levels	Injection and extraction wells and monitoring wells
	Free-phase NAPL levels	Check for in all wells being monitored during flooding operations

[(a)] Refers to monitoring wells, multi-level samplers (MLS), and monitoring points for wastewater treatment processes

often utilizes submersible pumps. Low flowrate pumps such as peristaltic and bladder pumps are commonly used for sampling purposes. Sampling pumps, filter devices, tubing points and materials, as well as sampling well points, should be chemically compatible with NAPL in the aquifer.

Extraction well line sample retrieval can be accomplished using in-line sampling equipment that can be electronically actuated. With appropriate well sampling accessories, in-line sampling devices can be used in tandem with autosampler equipment and gas chromatography (GC) components adapted for surfactant solutions and high organic compound loading to quantify cosolvent and solubilized contaminant concentrations. This type of system can provide near real-time concentration data for monitoring of multiple effluent lines. Monitoring of surfactant concentrations, such as for maintaining injectate quality and performance capabilities of wastewater treatment processes, will require titration or HPLC equipment. Alternatively, a surrogate organic compound, such as the cosolvent co-eluting with the surfactant, which requires only appropriately fitted GC equipment for measurement, may be used to estimate surfactant concentrations. Analytical methods are discussed in Section 4.2.3. Surfactant titration equipment is detailed further in Appendix C.

3.1.4 Process Control System.

Due to the extent of data collection activities for system monitoring on SEAR projects, automated data recording devices are suggested. Electronic monitoring equipment for injection and extraction operations can be incorporated into a data acquisition system (DAS) for automated data logging and feedback process control. A centralized user interface may be attached for data access and viewing. Such is known as a Supervisory Control and Data Acquisition system (SCADA). A SCADA system for SEAR incorporates electronic monitoring and control devices for automated measurement and regulation of flowrates, system pressure, water levels and other parameters as desired. An assembly of SEAR components that includes SCADA control features is displayed in Figure 3-2. Aboveground treatment operations will typically require separate control systems and displays for different monitoring features.

System software is used for interactive control of SCADA components and must be customized for each project to address the site-specific number of items such as injection wells, extraction wells, sampling parameters and sampling frequencies. Automatic shut-off devices and alarming features may also be incorporated with the inclusion of a SCADA system. Most SCADA components are integrated within a system control trailer that is plumbed to injection and extraction lines. Although a SCADA system will still require periodic calibration using manual measurements and more hardware to assemble, there can be a significant reduction in the labor requirements that attend 24-hour field operations. Continuous system monitoring will generate a much higher volume of data for SEAR documentation and performance evaluation, and this data can be efficiently collected and viewed in electronic format.

3.1.5 Wastewater Treatment.

The principal unit operations for a SEAR wastewater treatment system and selection criteria, including commercial availability of separation systems developed and tested for surfactant/cosolvent flooding wastewaters, are described in the design manual. Technologies for contaminant removal may include conventional processes such as air-stripping and steam-stripping, or innovative processes such as liquid-liquid extraction and pervaporation, depending on surfactant chemical recovery requirements and contaminant effluent properties. Once the bulk of strippable or contaminated compounds are removed, biological treatment may be used with a sufficient residence time for surfactant degradation. However, more typically, surfactant may be allowably discharged (under permit) into another off-site wastestream, and as such it will often contain foam suppressing chemicals; on the other hand, it may also be concentrated for reuse on-site by filtration and foaming methods both necessitating the absence of foam suppressants.

In addition to aqueous-phase organic compound removal equipment, pretreatment and auxiliary equipment will frequently include:

- ☐ Decanting equipment (or separators) to remove free-phase NAPL;
- ☐ Chemical metering equipment to adjust pH and dispense antifoaming agent;
- ☐ Surge/Process storage tanks; and
- ☐ Contingency storage tanks.

A UV sterilization or chemical amendment unit to destroy microorganisms in the process water may be necessary if biofouling is anticipated to adversely affect the treatment process. Similarly, additional filtration devices may be required to capture suspended particulates (i.e., fines and precipitates) that may cause fouling of thermal treatment lines and membrane modules when used.

Bag filters (i.e., 1 to 25 μm filters)[13] are effective in removing such particulate matter without pressure drop concerns. Appropriately rated pumps will be required to move fluids from one process unit to another. Plumbing networks of piping, tubing and hoses with valves and gauges of compatible and process-rated materials will provide controlled fluid movement throughout the system.

Additional tankage to accommodate possible system modifications (such as increased pumping rates) as well as effluent streams which fail discharge permit limits should be readily available. For surge/process storage tankage, chemically compatible thermoplastic storage tanks can be used once DNAPL is mainly removed. Metallic or stainless steel tanks and drums are commonly used for storing DNAPL fluids. For contingency tankage, oil-field frac tanks or tractor-trailer tanker trucks are generally used given their larger capacities, rental availability, and trailer mobility. Secondary containment will be necessary for tanks and plumbing containing chemical solutions, as further discussed in the next section. As shown in Figure 3-3, wastewater treatment equipment may be contained within a tented facility with plumbing to wastewater discharge tankers, including bypass hosing to the tankers for emergency operations. Containment lining can be constructed during tent installation using wood berming about the perimeter of the tent frame to elevate the flooring edges of an appropriate liner material.

Figure 3-3. Temporary Tented Wastewater Treatment Facility

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[13] Vane, L.M., Hitchens, L., Alvarez, F.R., and E.L. Giroux. 2001. "Field demonstration of pervaporation for the separation of volatile organic compounds from a surfactant-based soil remediation fluid." *Journal of Hazardous Materials,* B81 (2001), 141-166.

3.2 Systems Components Preparation

During system mobilization and assembly, some components will require calibration, leak and failure checking, and conditioning against inclement weather and potential system failures. Appropriate calibration and testing equipment will be needed to maintain operability of pumping equipment and data logging devices both within specified ranges. Components that fail calibration testing should be repaired or substituted prior to initiating flooding operations; this applies particularly to commonly rented equipment such as water quality measurement probes and pumps. If used for on-site operations, GC equipment, i.e., detectors, and any transducing equipment, such as actuated sensors and other automated devices, will also require calibration. Health and safety instruments, such as a combustible gas indicator, should be periodically calibrated prior to use.

Flowmeters and metering devices can be calibrated by taking an average of several manual flowrate or fluid delivery measurements (e.g. bucket tests). Of particular importance is that the flowmeter be rated for the viscosity of the fluid it is intended to monitor and that the fluid being monitored itself is used during the calibration process. Water quality probes and pressure transducers should be calibrated in accordance with the manufacturer's guidance. Pumps should be individually checked for leaks and malfunctions. Potable water should be used to test system components for proper flow routing and leaky connections. Flow-related devices should be tested at the highest and lowest anticipated flowrates to verify that all valves, flowmeters, pressure gauges, and plumbing will operate as designed and not malfunction.

Some equipment may require protection from inclement weather to avoid unexpected system failures and operational complications. Pumps and other outdoor electric equipment should be weatherized (with appropriate covers) and be properly grounded with ground fault interruptors (GFI). Sensitive electronic equipment should be safeguarded against exposure to heat, light and moisture and be equipped with properly conditioned power sources where relevant (e.g. GC equipment). Any SCADA and DAS components should be equipped to minimize the impact of potential power interruptions.

Tank storage areas will require secondary containment that can hold a volume equal to 110% of the largest tank contained, unless otherwise stipulated by local regulatory authorities. High density polyethylene (HDPE) landfill liner can be used to construct most secondary containment. Experience has shown that the HDPE liner should be at least 20 mils thick and of the 'cross-linked' variety. For effluent tanks, it should be noted that HDPE is not compatible with chlorinated solvents, but there are few acceptable materials that can be otherwise used. Sheets of plywood can be laid over or under the liner to reduce puncturing. The walls of the secondary containment system are often constructed with straw bales or with fencing materials. A secondary containment liner is shown in Figure 3-1. Site drainage should be directed away from wells and drum storage areas as much as possible using appropriately constructed drainage diversion and/or collection systems.

Section 4.0: FIELD OPERATIONS

This section discusses surfactant flooding operations, beginning with startup of the fully assembled system. Detailed procedures have been provided below for chemicals preparation, inclusive of quality control procedures, monitoring operations and analytical methods. With wellfield installation, free-phase DNAPL may be indicated in additional wells, and DNAPL recovery operations must occur to evacuate as much DNAPL as feasible prior to surfactant injection activities. Depending on the duration of free product removal required, some of these activities, such as water flooding, may be coordinated with other SEAR aquifer preparation activities (as described further in this section) or any additional tracer testing recommended during groundwater pumping (i.e., extraction) activities, once it is deemed safe to inject fluids under pressure.

4.1 System Initiation

During the initiation of operations (injection and extraction), the objectives are to establish the flow field and to verify the system integrity and stability. Pre-remediation verification of system equipment requires startup of the effluent treatment system. Specific tasks include:

- ☐ Rechecking the system for leaks and adjusting flowrate equipment operation under actual system pressures;
- ☐ Verifying that hydraulic control of injected fluids has been established;
- ☐ Ensuring that the effluent treatment system is functioning properly and permitted discharge limits are being met;
- ☐ Testing the accuracy of all automated data recording and display features of any data acquisition system; and
- ☐ Testing alarms and automatic equipment shut-off features.

System testing should continue until all of the injection and extraction rates and water levels are stable, indicating that the flowfield has been established, and at a minimum a pore volume of water flooding solution has been delivered through the treatment zone.

4.2 Flooding Operations

Surfactant flooding operations can begin once the system operation is stable. In total, there are three stages of surfactant flooding operations. The first stage is to establish the flow field and aquifer preparation for surfactant injection. An electrolyte solution that will not induce permeability reduction due to soil ion exchange interactions, is injected to prepare the aquifer for optimum performance of the surfactant. (Additional details on the influences of electrolyte upon anionic surfactant behavior and soil minerals can be found in the *SEAR Design Manual*.) The second stage is to flood the targeted treatment zone with the surfactant formulation. The surfactant solution designed for the site contaminant and soils is delivered to the treatment zones to enhance the removal of contaminants. The final stage is to remove the injected surfactant solution chemicals and associated DNAPL. Water is injected to continue the movement of the surfactant solution with the solubilized and/or mobilized contamination through the subsurface to the extraction wells for recovery. An electrolyte may still be added to the injectate during this period to maintain optimum aquifer conditions for continued flooding.

4.2.1 Injectate Preparation and Quality.

4.2.1.2 Surfactant Injectate Preparation. When preparing surfactant solutions by either batch or in-line mixing, the electrolyte (calcium or sodium chloride) must be dissolved in water before the surfactant is added. Otherwise, the surfactant may not remain soluble in solution when salt is added. Cosolvent is best mixed in following surfactant, as it will assist in removing any residual surfactant from transfer lines and pumps. As a rule of thumb, a surfactant batch should be prepared with the following sequence:

1. Partially fill the mixing/holding tank with potable water;
2. Add the amount of salt required for the total batch, mix until all salt is dissolved;
3. Add the required amount of surfactant to the tank;
4. Add the required volume of cosolvent (if applicable) to the tank;
5. Fill tank to the desired volume with potable water;
6. Continue to mix the contents.

When transferring flammable chemicals such as cosolvent, the drums or other metallic containers as well as all equipment items used should be grounded to reduce possibility of a static discharge. Appropriate personal protective equipment (PPE) should also be used when handling these materials. It is important to keep tanks and piping clean to avoid fouling or plugging of the chemical lines. Solutions with high alcohol content should be stored and handled appropriately to avoid any chemical hazards.

4.2.1.3 Injectate Quality Control Measures. The simplest method of verifying the quality of a surfactant solution is to perform phase behavior testing of the surfactant solution in the field. The purity of surfactants, i.e., active wt%, as supplied by the manufacturer, may vary with shipment, so phase behavior trials should be conducted with the mixed injectate before it is injected. For batch mixing, samples should be taken from the top and bottom of the tank of each surfactant batch to confirm that the solution is uniformly mixed. For in-line mixing, routine sampling of the downstream injectate concentration should be used for verification. The phase behavior test will demonstrate whether the surfactant chemicals have been mixed in the proper quantities and detect any variability in water hardness that may affect surfactant performance. Equal volumes of the mixed surfactant injectate and preferably site (D)NAPL are combined in a sealed pipette, and the equilibrated pipette can be compared to laboratory phase behavior standards. A detailed description of the interpretation of phase behavior testing results is given in the *SEAR Design Manual*. Phase behavior tests are usually supplemented with chemical analyses for surfactant, alcohol and electrolyte for precise information on the surfactant injectate composition. With sufficient batch tank storage capacity, quick-turn around analytical results will allow for unsatisfactory mixes to be adjusted. Any surfactant recycle activities will require analysis of the recovered surfactant solution for amendment, and preferably analysis of the amended surfactant solution, including residual contamination concentration, prior to reinjection.

When analyzing water flood or hydraulic control injectate mixture for uniformity, the specific conductance of the mixture is commonly used to verify uniform mixture of the added salts. The conductivities obtained from the top and bottom samples will not vary by more than 10% when adequately mixed. For conductivity measurements within surfactant batches, the measurement will require calibration to a surfactant mixture containing the correct salt concentration. In this way, a determination of the salt content and homogeneity of the surfactant batch mixture can be made.

Finally, it is important to maintain a log of the mass quantities of injected chemicals. A detailed account of the quantity (volumetric and/or weight measurement) of all chemicals added to each surfactant batch or staged in tanks for in-line mixing should be recorded in a field logbook or on uniform field forms and compared to the expected quantities as determined from the design. Flowrates of metering devices used for in-line mixing should be confirmed periodically as well. In all, these procedures will help ensure that the correct mass/volume of the specific chemical has been meted out before mixing. Records should also be kept on the chemical composition of the injectate as reference information to maintain fluid quality.

4.2.2 Monitoring Evaluation of Flooding Operations.

System monitoring is necessary to maintain control over injected fluids and to track the progress of the remediation effort. The data collected is used to adjust system performance as needed. Pumping flowrates and treatment duration are typically constrained by the available head with drawdown at the recovery wells, bulk chemical cost and field budgets. As described in the *SEAR Design Manual*, multi-phase fluid flow design simulations conducted with appropriate design data can provide estimates of flooding duration required to meet a given budget and specified target remediation goals. For reasons of cost, performance monitoring will usually not dictate flooding duration, except with real-time performance data and flexible contracting to allow immediate extensions in surfactant flooding duration and any concomitant increases in post-water flooding duration. Common debugging issues in field implementation that require system monitoring include: errors in chemical purity and surfactant formulation preparation, failure to maintain adequate injection or extraction rates, unexpected aquifer conditions and data gaps (e.g., incomplete stratigraphic data leading to poorly chosen well construction materials and unstable performance).

4.2.2.1 Flowrate, Water Level and DNAPL Level Monitoring. Once surfactants have been injected, frequent monitoring of the system is usually undertaken to maintain hydraulic control of the swept zone, even if conducting the source removal from within a barrier wall. If hydraulic control of the treatment zone is not maintained, the swept areas intended for treatment may not be effectively flushed and the recovery of the surfactant/NAPL mixture may be lower than anticipated or required. Regulating injection and recovery flowrates is vital to maintaining hydraulic control. The magnitude of the injection and recovery flowrates will govern the rate at which the surfactant solution is transported through the subsurface as well as the size of the aquifer pore volume that is swept by the surfactant solution; therefore, hydraulic control can not be maintained simply by turning down injection flowrates without altering the duration of the surfactant flooding operations and possibly the volume of the treatment zone. The flowrates should be monitored as often as practical at each of the injection and extraction wells, and at any hydraulic control wells. Adjustments to the flowrates can then be made on a timely basis if they are out of the specified design range.

Flowrate monitoring is accomplished most simply by basic manual 'bucket' tests with a graduated container and timer. However, manually-read volumetric totalizers and timers or manually-read electronic rate meters can also be used. Electronic flowmeters and a DAS may be most convenient for constant flowrate monitoring, but electronic flowrate equipment will require regular calibration against manual measurements. With the capability of electronic monitoring and alarm system with off-site notification procedures, hydraulic control of the flow field can be closely monitored around the clock to ensure the source zone is effectively swept and that the recovery of the injectate and NAPL is maximized.

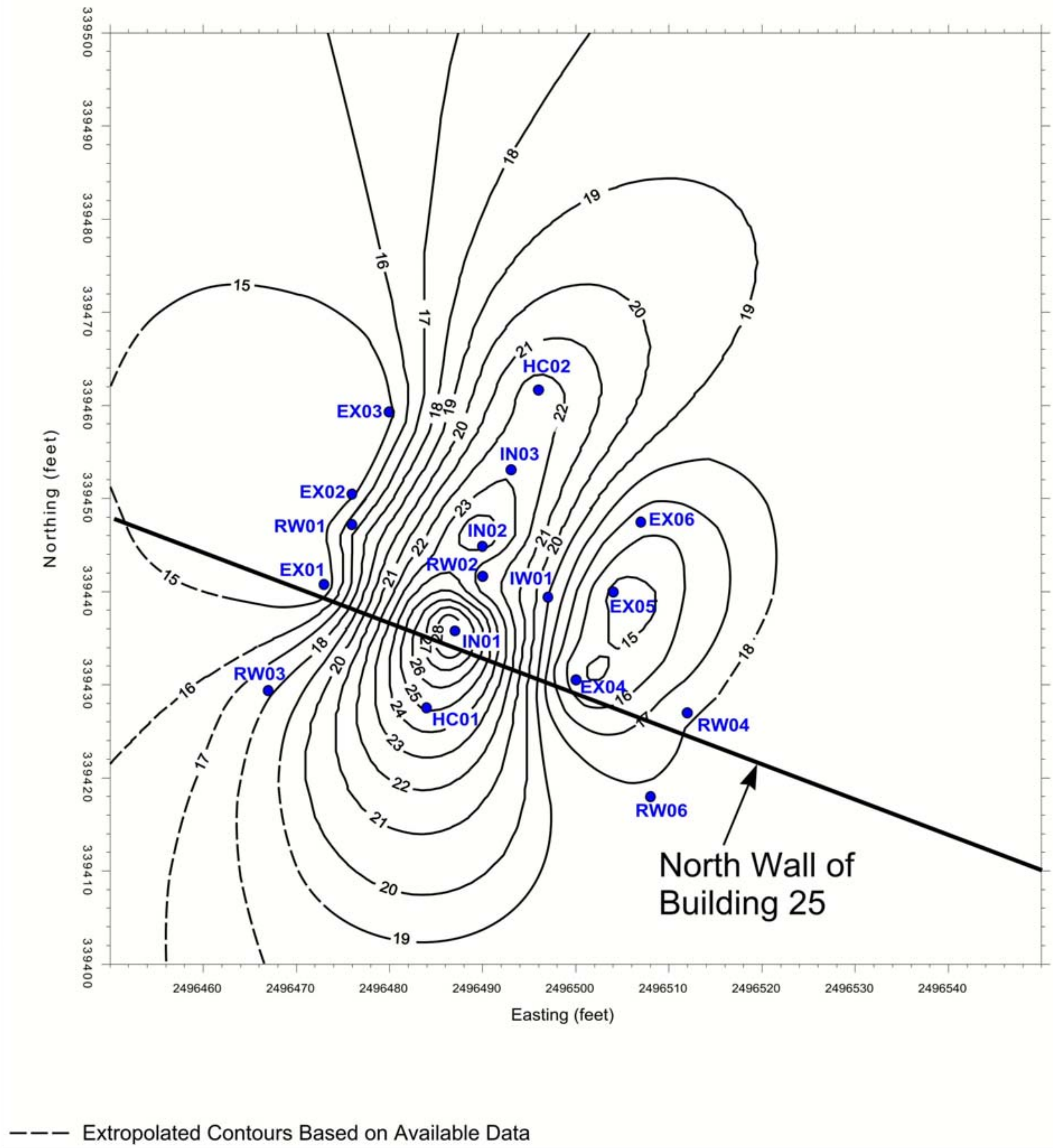
With improperly formulated surfactant injectate or poorly designed surfactant solutions, permeability reduction can sometimes result. If injection/recovery flowrates are continued in the presence of permeability reduction, water levels will rise in the injection wells and fall in the recovery wells. An off-calibration pump or inclement weather may result in an increasing water level in a recovery well. Frequent water level monitoring can immediately detect such situations so that they can be corrected. More complex situations may be introduced in the presence of tidal fluctuations or other vertical groundwater gradients. Therefore, diligent monitoring of water levels influencing the SEAR capture zone may also be responsive to fluctuations in the field environment.

Manual monitoring by standard metered contact tapes is the most common method of recording water level data. However, in order to capture a meaningful hydrostatic pressure surface map, a sufficient number of wells must be simultaneously monitored for water levels with each round. Ideally, water levels are simultaneously measured in as many well as possible, inclusive of injection, extraction, hydraulic control and surrounding monitoring and pumping wells. Electronic transducer measurements amplify the quantity of water level data that can be collected simultaneously. However, electronic sensing will require regularly scheduled manual measurements to ensure that the pressure transducer or transmitter is measuring accurately.

Electronically recorded flowrate and water level data should be checked regularly to ensure that the data is being recorded properly and that the specified monitoring frequencies are maintained. Flowrate and water level data should be plotted regularly to note any trends. Gradual or abrupt changes in water levels that are not intended can provide information on changing subsurface conditions or system malfunctions. Offtrending flowrates may indicate equipment malfunction or off-calibration. Maintaining a constant watch on water levels and flowrates can alert site personnel to potential problems to be handled in a timely manner. A potentiometric surface map derived from plotting water level data collected during a surfactant flood is shown in Figure 4-1. Plotting water level data can demonstrate hydraulic closure of orthogonal streamlines, i.e., the direction and path of water flow is assumed orthogonal to the hydrostatic pressure gradient. It should be compared to monitoring well sampling results to verify that injected fluids are being captured.

Finally, as discussed in Table 3-1, free-phase NAPL levels should be recorded in all wells being monitored. Simultaneous measurement is not as critical, and manually operated interface probes are typically used for this purpose. These measurements will provide an indication of the extent to which the surfactant solution is mobilizing DNAPL as a separate phase, and/or the efficiency of the hydraulic system in capturing free-phase DNAPL. When not under the influence of sufficient hydraulic gradients for removal, such as DNAPL accumulating in wells (i.e., well screens and/or sumps), bailing or pumping of these wells individually should be undertaken as immediately as possible.

4.2.2.2 Effluent and Monitoring Well Sampling. Sampling of SEAR fluids is conducted to track the progress of injected fluid and DNAPL fluids during flooding operations. The primary monitoring points are the extraction or recovery wells and/or multi-level sampling points located just inside the target treatment area. Secondary monitoring points are monitoring wells beyond the SEAR wellfield. Effluent sampling of the target treatment zone, that includes the extraction well lines and near-extraction well monitoring points (wells or multilevel samplers), provides real-time information on the effectiveness of the surfactant flood in removing contaminant based on visual and quantitative evidence of surfactant progress through the aquifer. Ultimately, mass balance data will be obtained for the contaminant(s) and each chemical injected into the aquifer. Monitoring well sampling adjacent to the SEAR wellfield provides additional verification that containment of SEAR fluids is being accomplished when no sudden increases in the concentrations of injected fluids or solubilized contaminants beyond steady-state values are observed. Effluent and monitoring well sampling documents system performance, can be used to shift pumping gradients to the portions of the aquifer



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Potentiometric Surface During Surfactant Flooding Operations

Site 88, MCB Camp Lejeune, NC

Figure 4-1

Figure 4-1. Potentiometric Surface Map of Water Levels During Surfactant Flooding Operations

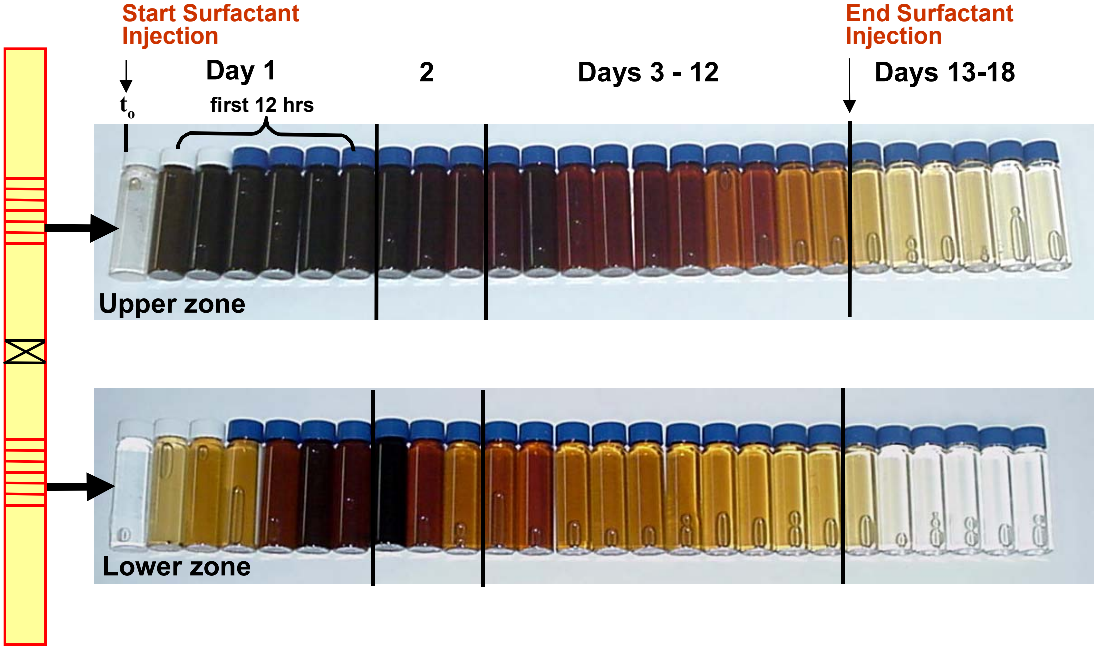

Figure 4-2. Visual Monitoring Samples Collected from a SEAR Pilot Test

that require further remediation, as well as to improve hydraulic control performance, and may dictate the duration of flooding phases when initial DNAPL estimates are undeterminable. With effluent sampling activities, a relatively large number of samples will be necessary, given the number of sampling locations and analysis parameters. A mass balance comparison metric requires quantification of the mass of surfactant and cosolvent recovered from the subsurface. A determination of the DNAPL mass recovered will similarly require solubilized contaminant mass estimates to be obtained, in addition to the quantity of any free-phase product recovered (mobilized).

To obtain an accurate mass recovery curve, approximately thirty samples is usually sufficient, although under tidal fluxes and to meet higher resolution data requirements, continuous monitoring is recommended. When the risk is lower (e.g., LNAPL sites), fewer samples may be collected with proper sample spacing that captures the peak breakthrough curve and tailing concentrations caused by post-surfactant water flooding. UTCHEM design simulation data can assist in developing an appropriate sampling strategy. Mass breakthrough curves based on each sampling location will provide detailed resolution on the subsurface distribution of surfactant solution and the spatial distribution of DNAPL recovery, to include vertical profiling when MLS devices are used. The impact of any hitherto undetected heterogeneities can be determined to correct operating parameters (such as foam addition parameters). Monitoring well samples collected for the purpose of monitoring hydraulic control should be maintained at a lower frequency, but should preferably accompany any change in an individual well pumping rate or with a change in flooding phase. In either circumstance, monitoring sample collection should span the entire flooding duration to reflect conditions prior to and following surfactant flooding. This includes monitoring locations within and beyond the contaminated aquifer.

Visual inspection of treatment fluids or effluent samples can provide real-time qualitative information on when the breakthrough of surfactant mixture has occurred at the extraction well or intermediate sample recovery locations which can then be compared to the designed predictions. Figure 4-2 shows a set of near-extraction well monitoring samples taken at various time intervals during a pilot test conducted to remove a high viscosity NAPL (1000 cp at 23 degrees C), Navy Special Fuel Oil, from two contaminated zones of the aquifer with surfactant solution heating. The procession from light to dark back to light indicates the breakthrough of surfactant solution with contaminant. Indicators of poor surfactant sweep efficiency across (D)NAPL zones can be evident within the first pore volume of surfactant flooding, if not by visual samples and observations at the extraction wells, then by verification of analytical concentrations at extraction wells. Analytical concentration data for contaminants and chemicals in the surfactant solution may be compared to design simulation predictions, allowing for immediate adjustments or corrections to the makeup of the surfactant formulation as required. In the flooding of a layered permeability saturated zone, poor sweep efficiency may not be readily detected unless multilevel sampling devices are used. Appendix D provides examples of comparison data with a discussion of modeling issues.

A variety of methods can be used for sampling and analysis. An auto-sampling system is usually preferred, given the large number of samples to be collected for sample analysis. Sampling procedures should be developed which will ensure the integrity of the samples taken and the subsequent sample analysis. When samples are downloaded from auto-sampling systems, care must be taken to ensure that the samples are properly labeled and that sample control logs and chain of custody forms are correctly filled out.

Experience has shown that continuous low flow sampling of aquifer monitoring locations generally results in less variation in concentrations sample to sample, producing a much smoother data set of concentrations versus time. The recommended monitoring sampling procedure is to push the sample to the surface using either a downhole pump such as a bladder pump, which does not allow the driving air to contact the sample or a tubing/check valve configuration that achieves the same end. This avoids common issues associated with suction pumping of surfactant-laden samples that includes sample foaming and volatile losses of contaminant and cosolvent. Intermittent samples may be acceptable for low frequency sampling of groundwater outside of the swept treatment volume where low surfactant concentrations may be anticipated. This will reduce the requirement for dedicated sampling pumps but will increase required decontamination activities; therefore, the cost requirements of each approach should be considered alongside the benefits of each sampling technique.

As mentioned in Section 3.1.3, equipment is available for automated sampling and in-line GC analysis. Back up samples should be collected at a lower frequency and stored under required conditions in case of GC malfunctions. A minimum 40 milliliter (mL) aqueous sample volume should be collected for surfactant titrimetric analysis; carouseled automated high volume sampling devices can assist in avoiding sampling redundancy in this endeavor. Analytical methods used in SEAR are described in Section 4.2.3.

4.2.2.3. Wastewater Treatment Monitoring. Wastewater treatment monitoring is conducted to confirm that contamination levels stipulated under regulatory permits for air and wastewater discharge are being met, and that violations are not impending with in specification wastewater treatment system operation. Gravity separator monitoring will also provide information as to the extent of DNAPL mobilization being effected by subsurface treatment operations. More heed to system parameters and sample collection will be needed at peak surfactant concentrations, which should coincide with peak concentrations of contaminant and cosolvent (the latter if used). Improper handling of surfactant-laden wastewater streams can cause serious operational difficulties such as poor contaminant removal efficiency, foam leakage from the system, and in the worst case, complete shutdown of the wastewater treatment system. Common system monitoring parameters include: temperature, pressure, flowrates, and pH, all in addition to tracking contaminant removal efficiencies frequently. Predicted effluent composition data from numerical design simulations as well as any bench- or pilot-scale testing data may assist with monitoring operations.

4.2.3 Sample Analysis.

Various laboratory techniques currently exist and have been used for the analysis of concentrations of surfactants, contaminants, cosolvents and electrolytes in recent field projects.[4,14] However, the presence of all these components in a single phase makes accurate detection and quantification difficult. This section briefly discusses laboratory techniques required to analyze injectate and effluent samples during surfactant flooding. Available methods exist for surfactant identification within organic-rich fluids, and organic compound analysis within surfactant-rich effluents.

4.2.3.1 Surfactant Analysis. Techniques for the analysis of surfactant concentrations are described in detail in current literature (Schmitt, 1992[15]; Cullum, 1994[16]). The potential techniques include potentiometric titration, HPLC (high performance liquid chromatography), evaporative light scattering detection, and ultraviolet or fluorescence detection.

Potentiometric titration is perhaps the simplest method to use for contaminated surfactant-laden groundwater samples. Surfactants typically used in SEAR are alcohol ether sulfates, alkane sulfonates, and sulfosuccinates. To determine anionic surfactant concentrations by potentiometric titration, one precipitates the surfactant with a cationic surfactant titrant. An electrode combination that responds to anionic surfactant in solution serves as an indicator. The indicating electrode is a combination electrode pair consisting of an Ag/AgCl (silver/silver chloride) reference cell and a PVC membrane cell. A nitrate or sulfate sensing electrode may be used for sensing anionic surfactants. A dilute solution of benzethonium chloride (hyamine) is used as the titrant. The titrations should always be evaluated using the inflection point of the sigmoidal titration curve, which corresponds to the reaction equivalence point. This should preferably be done with an autotitrator or a pH meter capable of measuring potential and a burette. Typically buffering is not recommended for solutions with near neutral pHs. However, if the pH of the effluent is either acidic or alkaline, buffering is highly recommended. The exact hyamine titration technique should be tailored for each surfactant by running test titrations with known standards. An example of the hyamine titration technique to determine the concentration of sodium dihexyl sulfosuccinate is given in Appendix C.

HPLC techniques can provide more detailed resolution for surfactants with numerous isomers and can be applied to detect uncharged impurities in an anionic surfactant mixture. They are generally more robust, but may require greater skill to implement. The stationary phase in the HPLC column should be compatible with the surfactant being used and identifying an optimal organic mobile phase for a specific surfactant formulation in a contaminated solution will require methods development. With a conductivity detector, the possibility of interference caused by miscellaneous solubilized ions and contaminants that can co-elute with the surfactant should be addressed during methods development. The presence of dissolved humic matter may interfere with light scattering and UV and fluorescence HPLC detectors.

Both the hyamine titration and the HPLC techniques can detect sulfate surfactants down to 0.01 weight percent. The titration techniques are generally much easier to perform and interpret and require less time for equipment setup and methods development. HPLC techniques may be used to assess surfactant degradability and impurity issues that may be relevant for surfactant flooding.

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[14] U.S. Environmental Protection Agency. 1999. *In Situ Enhanced Source Removal*. EPA/600/C-99/002. Office of Research and Development, National Risk Management Research Laboratory, Subsurface Protection and Remediation Division, Ada, OK.

[15] Schmitt, T.M. *Analysis of Surfactants.* Surfactant Science Series, Vol. 40; Marcel Dekker, Inc., New York, 1992. ISBN 0-8247-8580-2.

[16] Cullum, D.C. (Ed.). *Introduction to Surfactant Analysis.* Blackie Academic, London, 1994. ISBN 0-7514-0025-4.

The methods detailed above are generally useful for surfactant detection within aqueous samples containing other organic compounds. When cosolvent is not used in the surfactant formulation, simple methods that may be used for surfactant detection include examination of the foaming nature and interfacial tension properties of a liquid sample. Foam suppressing compounds and any other IFT reducing agents present will interfere to some extent with these methods.

4.2.3.2 Analysis of Organics in the Presence of Surfactants. The quantification of organic contaminants such as solubilized tetrachloroethylene and trichloroethylene during SEAR is complicated by the presence of high cosolvent and surfactant concentrations. Surfactants can plug capillary columns, whereas high cosolvent concentrations generally overwhelm capillary columns and cause problems such as carry over. The preferred technique is to use a column that can take high sample loading and exhibit minimal plugging due to surfactant. Surfactant plugging can also be minimized with use of a precolumn, but such a device can cause greater dispersion and spreading of the sample peaks. Under these conditions, a modified EPA Method 8021B can be used to detect chlorinated VOCs and cosolvent using the flame ionization detector (FID). In general, this approach uses a packed stainless steel or glass column with direct injection onto the column using an autosampler (connected to in-line sampling device) and autoinjector. The advantage of using a packed column is that it can take much higher sample loading and the effects of surfactant plugging are usually not observed until after the injection of more than 300 samples or so. This technique is suitable for detecting PCE and TCE between 50 and 10,000 mg/L and cosolvent between 0 and 0.5%. Higher cosolvent (between 1% and 18%) and contaminant concentrations (between 10,000 mg/L and 50,000 mg/L) may be quantified using a thermal conductivity detector (TCD) in series with a FID. Using this setup, contaminant concentrations between 50 and 10,000 mg/L, and cosolvent concentrations between 0 and 0.5% will be quantified by the FID. The higher cosolvent and contaminant concentrations will be quantified using the TCD.

An alternative to addressing the presence of surfactant in contaminant samples is to use a purge and trap method of sample injection. This technique is useful when a range of halogenated and nonhalogenated compounds are being detected, such analysis of VOCs by EPA Method 8260. Significant sample dilution is required as well as the addition of anti-foam agent to avoid surfactant foaming problems. Therefore, this technique may not be economical for handling large sample volumes that may result from a short duration surfactant flood. It is most simple to use for monitoring well samples beyond the treatment zone and when organic compound concentrations lower than 50 mg/l are anticipated.

4.2.3.3 Other Sample Analysis. To accurately quantify the concentration of divalent and metal cations in extracted surfactant solutions, chemical analysis is necessary. It may also be necessary to confirm the sodium or calcium concentration in the injected solution after conductivity measurements are taken. This should be done using an inductively coupled plasma (ICP) detection technique such as EPA Method 6010B. ICP techniques are extremely robust, detect the total cations in solution (e.g. Fe,Mn,Cr), have few interference problems from other cations, and show linear calibration curves through several orders of magnitude.

4.2.4 Equipment Maintenance.

The following maintenance checks should occur on a frequent basis during the operation of the SEAR flood. These checks provide information about flow conditions and impending system failures and are listed below in approximate order of importance.

- ☐ Check graphical or numerical data displays (e.g., pressure, flowrate, conductance) on the SCADA and DAS systems if such capability is being used. This is an efficient way of looking at the behavior of numerous system components in a short amount of time.

- ☐ Check all of the tank levels to avoid low level tank pumping and any overfull waste tankage.
- ☐ Check flowmeter readings on injection and recovery systems to verify flowrates are within the desired ranges.
- ☐ Check temperature and pressure gauges to see if readings are within desired ranges.
- ☐ Check for water or air leaks.
- ☐ Check for unusual noises (especially with pumps or sticky solenoid valves or flowmeters).
- ☐ Check the placement of well covers and when raining, sandbag as necessary to prevent sediment and debris from entering wells.
- ☐ Clean or replace all filters, particularly those on recovery and injection lines.
- ☐ Compare transducer readings to manual water-level measurements taken with a water-level probe. If the two do not compare favorably to one another, the transducer should be adjusted, recalibrated, or replaced.
- ☐ Check for frayed or damaged electric cords and loose connections.

Flowmeters should be checked periodically for accuracy by performing bucket tests. This will ensure that flowmeters remain calibrated to within specified limits (such as ±10%). Flowmeters that are found to be out of range due to drifting or damage can be recalibrated or replaced as needed. Each downhole meter or probe should always be calibrated before use. If readings drift or are erratic, a probe may require replacement. The owner's manual should be consulted when troubleshooting or calibrating a meter.

Besides daily checks, some other system components need periodic checks during a SEAR flood. Whenever necessary, in-line injection filters should be cleaned or replaced, particularly if pumping from a near-empty tank. Conditions where high particulate contents are produced or where free-phase NAPL is frequently present will require frequent filter maintenance. Scaling or solids buildup may occur with some system components during the course of the SEAR. This usually occurs where components are exposed to oxidation during the surfactant flooding operations or where the orifice size is reduced, such as at valves. Valves that have suspected solids buildup should be replaced with backup valves. The valve requiring replacement can often be restored to optimum working condition by soaking in a weak acid solution to remove the scaling.

When calibration parameters are changed or a component is replaced, the corrective action and the time of action should be noted in the field log so that corrections to data can be made if applicable. Additionally, any parts that are replaced should be noted so that spare parts of critical components are always immediately available.

4.3 System Shutdown

Typically, shutdown of a surfactant flooding operation is based upon the conclusion of post-surfactant injection water flooding to remove residual injected chemicals and contaminants from the aquifer. The duration of surfactant flooding and other flooding phases is based on initial DNAPL estimates, and multi-phase flow modeling with input of surfactant, hydrogeological and (field-)validated pumping parameters. Operating durations for a well-designed surfactant flooding system are often very short relative to alternative approaches that use vapor extraction contaminant recovery systems. With a properly designed and installed surfactant flooding system for aggressive DNAPL recovery (referred to as high performance design in Appendix E), long flooding durations (i.e. greater than 2 months) are not usual. If not demonstrating effective DNAPL recovery during this period, significant redesign is necessitated. Thus, system shutdown can occur once significant quantities of injected chemicals have been removed from the subsurface during post-surfactant injection water flooding. Unless surfactant has become sorbed to the point where reduced aquifer permeability makes further DNAPL pumping impossible (i.e., disastrous failure of surfactant formulation design), surfactant-laden fluids will always require removal from the aquifer. In general, if hydraulic control over the treatment zone is maintained, it is recommended that DNAPL pumping be continued until asymptotic dissolved-phase concentrations have been maintained for several fluid pore volumes to capture the majority of surfactant and cosolvent before the system is shutdown. Elevated dissolved-phase concentrations measured while injection and extraction pumping of the flooding wellfield is still maintaining hydraulic capture (e.g., exceeding the 1% rule of thumb) is indicative of a residual DNAPL saturation in the treatment zone or swept pore volume, but concentrations should in all cases (excepting disasters) be measurably lower than the initial dissolved concentrations observed. The permanence of such a concentration reduction will depend upon lack of recontamination, particularly absence of free product intrusion, from adjacent untreated zones; therefore, a repeat reminder to evacuate free-product DNAPL from all portions of the source zone prior to surfactant flooding operations.

The primary task during system shutdown is to decontaminate system flow components, particularly effluent pumps and lines carrying contaminated groundwater, while still interconnected. This typically involves pumping a decontamination fluid through these lines. When disassembling system equipment and plumbing, leaving elements of the treatment system in place as long as practical to treat the decontamination fluids developed may be cost effective. Precautions must be taken to contain any fluid release from the system as it is being disassembled. Installing valves at the ends of runs of tubing or piping during the initial assembly process will allow the sections of hose/pipe to be removed with both ends closed to facilitate control of the fluids contained within. Health and safety-related equipment that has been in use throughout surfactant flooding operations should be readily available for waste handling activities.

APPENDICES

APPENDIX A. SURFACTANT FLOODING WELL CONSTRUCTION SPECIFICATIONS

The minimum diameter for recovery wells is generally four inches, as the effluent flow tubing, as well as any monitoring equipment that may be added to these wells will compete with each other for space in a two-inch well, a situation magnified as the depth increases. The cost savings of two-inch wells versus four-inch wells is also not considerable. At DNAPL sites, the base of the screen in the recovery wells should span the aquitard/aquifer interface. Placing the screen in this fashion is a generally recommended practice for all wells installed at DNAPL sites as it will allow mobile DNAPL to flow into the well if present. A solid screw-on sump should be attached to the bottom of the screen to collect mobile DNAPL. Under no circumstances however, should a competent aquitard be compromised in constructing a well to collect DNAPL at the aquifer/aquitard interface. Stainless steel screens are preferred for DNAPL recovery operations, but PVC risers can be acceptable if the sediments they will contact do not contain DNAPL. The well casing and screen should be placed using centralizers. Centralizers will help ensure that the well is centered in the borehole during the placement of the sand/gravel pack. If the well screen is not centered and comes into contact with the formation, this may have a detrimental effect on the flow efficiency of the well due to plugging. In addition, the introduction of formation material into a well may damage pumps and produce additional problems such as "locking" submersible pumps in place. The filter pack should be placed a minimum of 2 feet above the well screens, with the depth to the top of the filter packs being determined by measurements with a weighted calibrated tape. A thin layer of fine sand (approximately 6 inches) should be placed on top of the coarser sand of the filter pack. A bentonite seal at least 2 ft thick can then be placed on top of the fine filter pack and hydrated. The cement mixture that fills the remainder of the annulus to the completion surface can be formulated to minimize grout loss to the formation. An airtight wellhead that can withstand injection pressures will be needed to inject air at design pressures for surfactant foam formation, when desired for mobility control. The wellhead cap should have fittings to feed through injection tubing and compressed air as well as any necessary electronic monitoring devices.

Whenever a well is to pass through a competent capillary barrier, such as for the installation of a deep monitoring well, care must be taken to ensure that the competency of the barrier is not degraded. Installing the wells through properly installed surface casings is one way of achieving this. Proper grouting and sealing procedures should also be used for all borings not completed as wells penetrating clay containing zones, although these should be avoided as much as possible when working in a DNAPL-contaminated aquifer. Since DNAPL flows in response to gravity, any opening in the capillary barrier at DNAPL sites may provide a conduit for the downward migration of free-phase contaminant. In addition, in areas where groundwater is utilized as a resource, vertical downward flow gradients are common. Even if NAPL is not present, an opening in the aquitard may provide a pathway for the downward migration of dissolved phase contamination. An additional precaution is to prevent cross contamination resulting from the drilling process. This is especially the case for drilling into a DNAPL-contaminated ground-water system where the NAPL can migrate downward solely as a result of gravity. However, when care is taken to review previous nearby soil boring logs and to slow the drilling process by applying continuous logging and core sampling methodology[17] with short run drilling (e.g., 6 inches to 2 feet intervals applied for core retrieval)[18], the danger of cross contamination can be minimized.

After a well has been properly installed, a vigorous well development process should be employed to maximize the flow efficiency of the well. The development process is the last step in

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[17] NAVFAC 1998. *RITS 1998: Surfactant Enhanced Aquifer Remediation (SEAR) Part I: Characterization of DNAPL Zones.* Prepared for Naval Facilities Engineering Service Center, Port Hueneme, CA.

[18] See Appendix A of the *SEAR Design Manual*.

constructing a SEAR well that, when placed into operation, will provide the maximum injection or recovery flowrates and will provide full accessibility to the contaminated zones of interest. Proper development involves the use of surge blocks or similar devices and methods to effectively move fine-grained sediments from the filter pack and even the aquifer itself into the well bore where they are evacuated with a pump or bailer. Surging should be conducted in stages across successively lower segments of the screen, while periodically removing the sediment-laden water in the well bore. Surging should be conducted using properly sized surge blocks. If bailing or pumping is the sole method of well development, sufficient flow is required for proper flushing.

APPENDIX B. MULTI-LEVEL SAMPLERS

Multi-level samplers (MLSs) are a useful and recommended tool for monitoring chemical flooding operations. An MLS device allows the collection of numerous vertically discrete groundwater samples at a single location. These samples are in contrast to those from regular monitoring wells that provide groundwater drawn in over the length of the entire well screen. Additionally, when situated within the injection and extraction wellfield, samples from MLSs installed over the screen depths of extraction wells are relatively undiluted, as samples collected at the extraction wells will also contain groundwater not containing flooding agents. Therefore, MLS devices are most often installed within the injection/extraction wellfield, to elucidate the impact of vertical heterogeneity on the surfactant solution sweep efficiency.

MLSs may be installed in various configurations. Some may consist of no more than bundles of metal tubing, each tube of a different length, with a porous frit sampler device attached at the tubing ends at depth. Installation generally takes place inside a hollow stem auger or geoprobe casing. Once the boring is completed, the filter sampler is lowered to the desired depth of installation and held in place as the hollow stem auger or geoprobe casing is retracted, allowing the formation to collapse around the sampler. Samples are then collected at the surface. Since the samples are most often drawn to the surface via suction lift, this type of sampler is generally only applicable for shallow applications. Using porous frit sampling devices, a depth resolution of 1 foot or greater can be obtained depending on the formation being sampled and the sampling rate. The formation sampled should have sufficient conductivity to produce enough sample volume in a reasonable period of time, and the recommended hydraulic conductivity is 10^{-4} cm/sec or greater. With excessive vacuum pressures, volatile contaminant losses and surfactant foaming are likely to occur.

Other MLS designs consist of interconnected assemblies. Depending on the configuration, the suction or pressure may be applied either at the surface[19] or through pneumatic pumps (i.e. bladder pumps) installed at depth as part of the assembly[20], therefore extending usefulness to deeper depths. However it should be noted that when fitted with pumps as part of the assembly, the spacing required for installation of MLS assemblies will most likely be greater than without pumps. Materials of the appropriate compatibility will be required, as before. When installed within a well boring, MLS devices and well packers may not be as accurate as needed, as the filter pack around the well screen may act as a high permeability conduit. For example, during pumping for sample collection, the filter pack can allow samples to be drawn to sample inlets from higher permeability zones in the formation intercepted by it and not from the aquifer immediately adjacent to the sample inlet. Externally influenced pumping can also exacerbate this sampling issue. Thus, contact of the sampler device to the formation is the most preferred configuration, with hydraulic isolation between the sampling ports included within the design. Partitioning of aquifer zones may also be obtained through more sophisticated well construction techniques, such as the use of bentonite plugs in the well annulus to separate discrete sampling zones, but depth resolution required may not be achievable in this design. Passive diffusion-based sampling devices may also provide inexpensive discrete groundwater sampling capabilities; however, due to the relatively long equilibration times relative to the more frequent sampling activities during surfactant flooding operations, (that may be multiple events in a single 24-hour period at the peak of operation), their use may be limited to longer period and less intensive monitoring operations beyond the target treatment area. Finally, the graphics below illustrate the general concept of the multi-level sampler installation as well as a passive sample collection inlet design that incorporates a positive pressure pumping mechanism (not shown) for sample retrieval.

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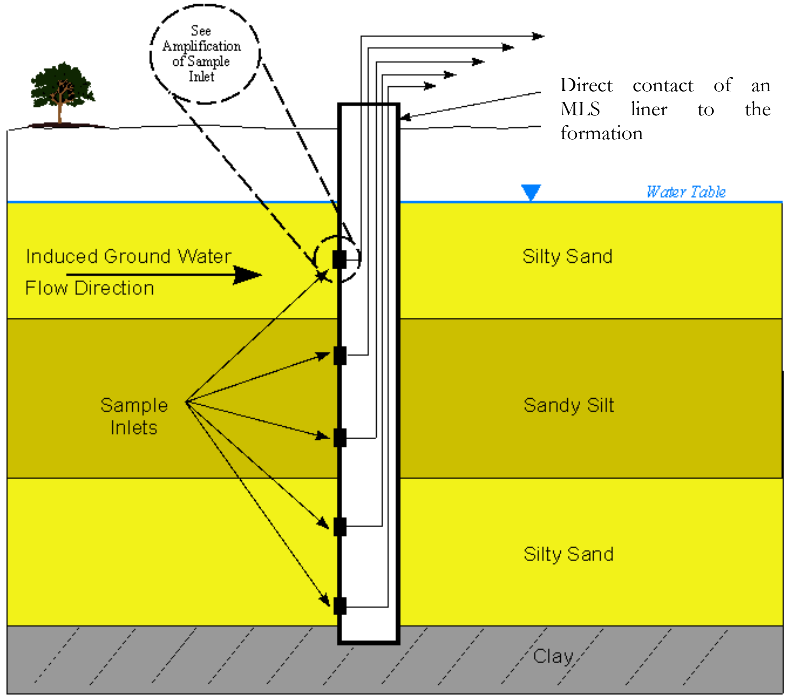
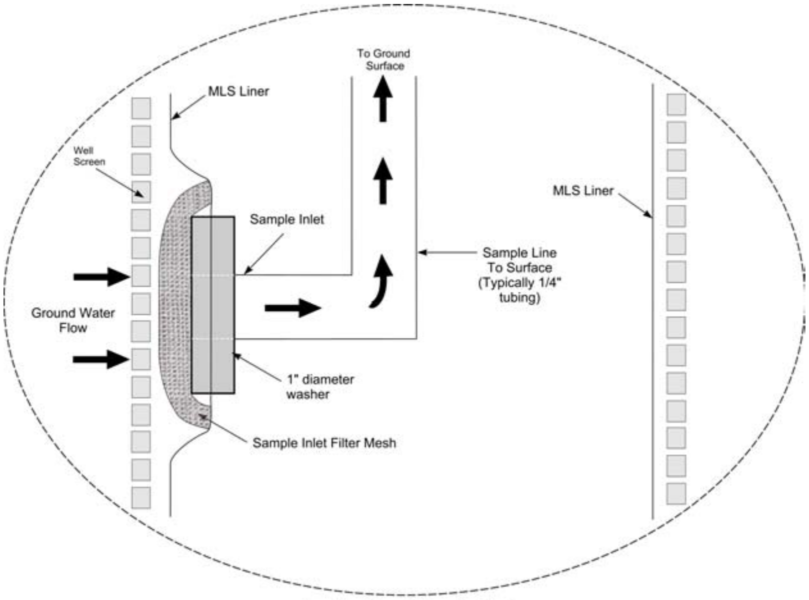
[19] NAVFAC 2001. "A Demonstration of the Continuous Multichannel Tubing (CMT®) System." NFESC TDS-2073-ENV. Port Hueneme, CA.

[20] NAVFAC 2003. *RITS Spring 2003: DNAPL Detection and Characterization Techniques*. Prepared for Naval Facilities Engineering Service Center, Port Hueneme, CA.



Cross-Section of a Multi-level Sampler Installation



Amplification of Sample Inlet

Figure B-1. An Example of a Semi-Passive Multi-Level Sampler Installation Design

APPENDIX C. SURFACTANT TITRATION PROCEDURES FOR SODIUM DIHEXYL SULFOSUCCINATE

Included herein are the equipment and procedures for automated titration of sodium dihexyl sulfosuccinate surfactant solutions to determine the surfactant concentration.

Apparatus

- ☐ Beakers for titration,
- ☐ Magnetic stirrer,
- ☐ Combination anionic surfactant specific electrode,
- ☐ An automatic titrator, and a burette,
- ☐ A balance capable of accurate weight to at least 2 decimal places, and
- ☐ A combination of a top loading electronic balance, accurate to 2 decimal places and an analytical balance accurate to 4 decimal places is best.

Procedure

1. Since the sodium dihexyl sulfosuccinate produces a very weak signal, initialize the probe using sodium dodecyl sulfate. Prepare a standard solution of sodium dodecyl sulfate, approximately 0.004 M/L or 0.004 M/1000 g.

2. Prepare a solution of benzethonium chloride, approximately 0.004 M. This concentration is somewhat arbitrary. A titrant should be dilute enough to yield a measurable titration volume with a reasonable sample of unknown. That is the only constraint.

3. The procedure outlined here is based on using an automatic titrator with a 10 mL burette. Titrant will be standardized in M/L. Weigh accurately, approximately 5 g of standard sodium dodecyl sulfate into a 100 mL beaker and dilute to approximately 60 mL with deionized water.

4. Immerse the surfactant specific electrode in the solution of analyte. Add one or two drops of a 1% solution of Triton X-100. Commence stirring using a magnetic stirrer.

5. Begin adding titrant in small increments. The automatic titrator records voltage changes.

6. Continue titrating past the maximum rate of voltage change.

7. Locate the titration end point by drawing a tangent to the inflection portion of the curve and calculating a mid-point, or accept the end-point calculated by the automatic titrator.

8. Calculate the normality of the benzethonium chloride according to the following: Nt = meq/g*wt(sodium dodecyl sulfate)/mL titrant.

9. For unknown determinations, weigh enough sample into a 100 mL beaker to provide approximately 0.02 meq surfactant for titration. Dilute to approximately 60 mL with deionized water.

10. Repeat steps 3 through 7 for the anionic surfactant of interest. Calculate surfactant concentration according to:

Cs = Nt*Vol titrant/wt sample. An automatic titrator can provide a calculation of surfactant concentration if programed to do so.

Notes on the above method:

A blank, a known sample, and an unknown to which a known quantity of sodium dodecyl sulfate has been added should be run after every twenty samples to determine if the electrode is being affected by the contaminant.

APPENDIX D. COMPARISON OF FIELD DATA TO PREDICTED SEAR SIMULATION RESULTS

The figures below show examples of field performance data relative to final field design simulation predictions. Assuming that the surfactant has been chosen using appropriate testing procedures (using site DNAPL or an appropriate substitute, and soils and groundwater collected from the relevant interval of the aquifer), and the numerical model has three-dimensional multi-phase flow modeling capabilities, inaccurate modeling predictions are typically the result of inadequate or insufficient characterization data or bias and error in rejecting unfavorable values or hypotheses. Additionally, the design modeling, focused on the source zone area, may not incorporate periodic variability in hydraulic gradients in the surrounding adjacent regions. These types of variables will require user judgement to impose appropriate modeling constraints for observing the impact of periodic phenomenon and/or uncertainty variables on the robustness of chosen design parameters. Preventable but common poor data quality can result from careless drilling procedures (thus miscalculating contamination depths or not recording soil data information), as well as from flowing sands conditions encountered in retrieving samples (no sample interval data available, hence other characterization tools needed).

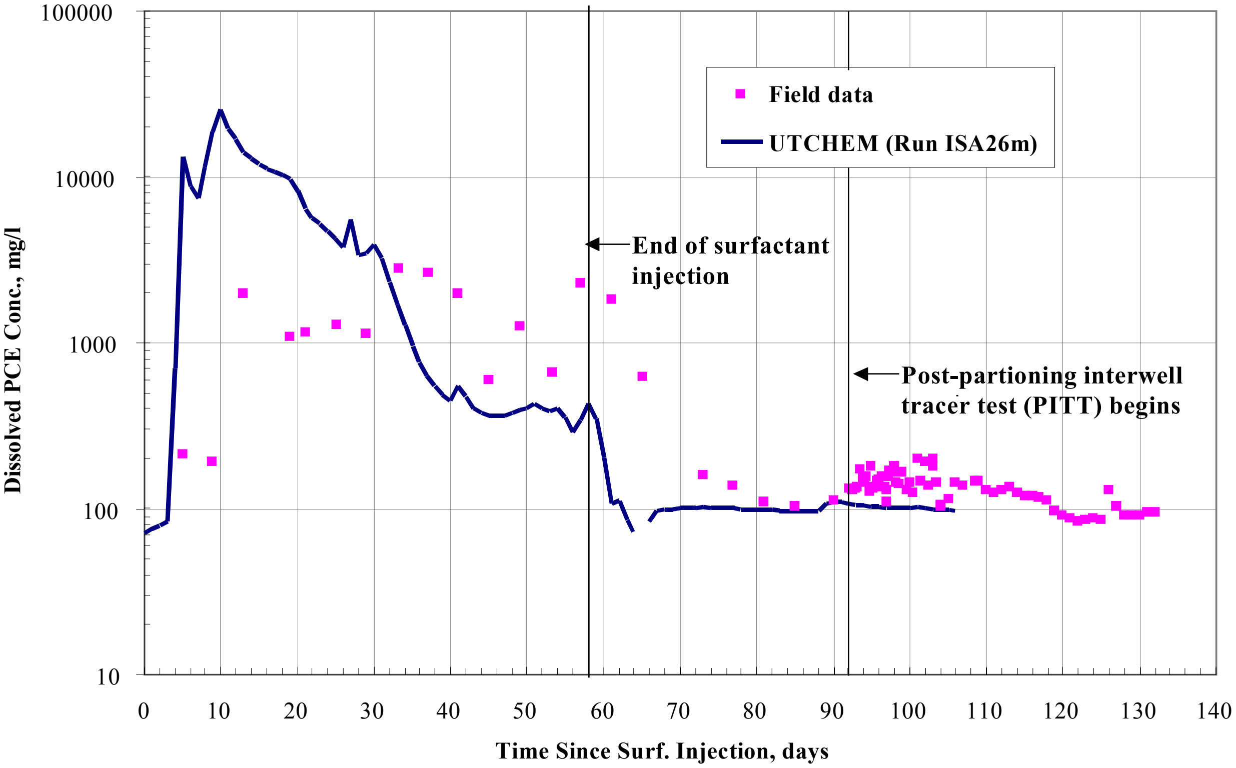


Figure D-1: Comparison of field and predicted dissolved PCE concentration at extraction well Surfactant flooding demonstration at Site 88, Marine Corps Base Camp Lejeune, North Carolina

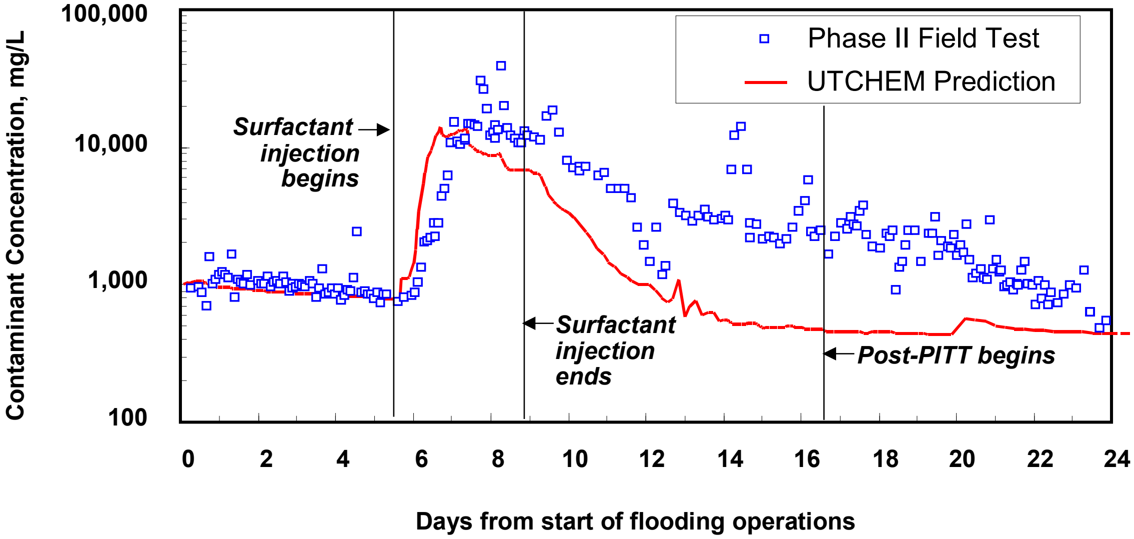


Figure D-2. Comparison of field to predicted effluent contaminant concentrations Phase II test data for surfactant demonstration at Hill AFB, Operable Unit 2

Figure D-1[5,21] illustrates poor field performance when juxtaposed to design predictions, while Figure D-2 [22,23] shows good performance in keeping with field modeling predictions. Post remedial site observations illustrate that the former was caused by poor sweep or bypass of the low permeability DNAPL zones. The deviation in coincidence of the actual field data to predicted concentrations that can be observed in the Hill AFB OU2 data may be attributed to a larger DNAPL volume than originally predicted. It may be noted that when uncertainty or doubt exists about design parameters obtained from numerical simulation results and/or the input data, a properly conceived pilot study is required to recommend more accurate full-scale parameters for effective surfactant flooding operations.

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[21] Duke Engineering and Services. 2000. *Surfactant Enhanced Aquifer Remediation Demonstration at Site 88, Marine Corps Base, Camp Lejeune, North Carolina*. Report prepared for Naval Facilities Engineering Service Center, Port Hueneme, CA.

[22] NAVFAC 1998. *RITS 1998: Surfactant-Enhanced Aquifer Remediation (SEAR) Part II*. Prepared for Naval Facilities Engineering Service Center, Port Hueneme, CA.

[23] Delshad, M. *et al*. 2000. *Technical Documentation for UTCHEM 9.0, A Three-Dimensional Chemical Flooding Simulator, Volume II.* Center for Petroleum and Geosystems Engineering, University of Texas at Austin, TX.

APPENDIX E. CONTRACTING GUIDANCE FOR REMEDIAL PROJECT MANAGERS

Generally speaking, the more detailed the solicitation package requirements for the work to be performed, the more accurate the cost estimate retained for selecting the best qualified vendor for services. An often-encountered weakness with the solicitation of innovative remedial technology services is very broad design and/or performance specifications that leave much open to interpretation by the solicitees or their contracting agents, and reliance on good will contracting that may not always provide the desired security or liability protection when contingencies occur. Even though the relationship between client and vendor relies on mutual understanding of issues that may be hard to stipulate fully in writing, every attempt should be made to provide specific details on every item to be costed, whether it be equipment specifications, requirements for continuous operation and monitoring, and/or required extracted contaminant concentrations. Such will require the requesting party to do thoughtful advance research as to the level of data that must pre-exist in order to accurately design a properly scaled system to achieve a given quantity of removal within a designated period of time, and to budget and schedule the necessary advance activities accordingly, such as to obtain meaningful cost and design proposals, i.e., relying on few assumptions. Such would also promote shifting the viewpoint of the vendor from a research-oriented approach, even while the technology continues to evolve to newer design practices, to a relatively standardized operations approach that may be successfully applied at the majority of sites. By the same token, responding vendors would be enabled to identify sites that do not meet certain minimal background criteria for flooding application to recommend additional design characterization studies or alternative approaches as appropriate. Therefore, included below is a suggested outline for primary elements of a surfactant flooding remediation solicitation or request for proposal (RFP) package, that has the stated objective of obtaining contracting options for maintaining design flexibility and management predictability, with tangible costs associated with all of these options.

Generally, the evaluation of surfactant flooding solicitations should be based upon the following criteria:

1) Staffing qualifications, emphasizing field experience of specifically assigned personnel
2) Technical quality of baseline design as well as design options
3) Quality of monitoring plan
4) Performance guarantee options
5) Any site closeout options
6) Past vendor performance on similar projects

Technical Skill Requirements

A successful SEAR application requires individuals with the following skills and proficiencies:

- Hydrogeology
- Groundwater and surfactant chemistry
- DNAPL site characterization
- Chemical and/or petroleum engineering for process development and construction
- Multi-phase flow modeling
- Electronic data collection including basic software development
- Analysis of highly contaminated samples containing surfactant and co-solvent as present
- Environmental remediation projects for groundwater and NAPL removal.

An experienced field remediation crew with readily available home office technical support can avoid costly and critical field errors in implementing surfactant flooding remediation projects.

Statement of Work and Cost Estimate Preparation Considerations

Prior to developing the statement of work requirements and government cost estimate for surfactant flooding field implementation activities, DNAPL site investigations should be completed. Probably the largest ticket item to be negotiated amongst the project team of regulators and community, inclusive of the vendor to be contracted, is the design scoping of the monitoring plan for zones within and adjacent to the treatment zone, i.e., performance monitoring locations and sampling frequencies per location. Much will depend upon the confidence in the environmental protectiveness of the surfactant flooding remediation design submitted by the contractor, and prior performance of the contractor on similar sites. Vendor capabilities for automation (Section 3.1.3) will also play a role in selecting the scope of the monitoring plan. For example, the number of manual versus automated sampling locations, sampling methods and frequencies, with the total number of samples will also need to be determined. Any requirements for higher data quality objective QA/QC, requiring periodic monitoring of the on-site laboratory by specialists or the additional use of commercial off-site laboratory services capable of using analytical methods adapted for highly contaminated surfactant-rich samples, should be determined as soon as possible, if not prior to, sending out the RFP requirements package. For a contaminant mixture, lead time for analytical methods development may also be required. A summary table of direct cost and labor categories associated with a surfactant flooding remediation project, (however excluding pre-remediation design and field characterization study cost categories), that may be used in facilitating contracting discussions and cost estimate development is provided in Table E-1. Well specifications may have been modified with the results of the completed process design (e.g., aquifer characterization testing) studies at the site, but with either circumstance, if an interwell tracer test was earlier completed, a full complement of injection and extraction wells may not be required to be costed for the surfactant flooding remediation portion (as already installed). Budgeting considerations should incorporate provisions for removal of any DNAPL free product encountered during installation of the flooding wellfield and the performance monitoring points. When costing labor requirements, the 24-hour nature of operations should be considered, along with monitoring of required pumping rates to maintain hydraulic capture on fluids.

Detailed Format for Evaluation of RFP Submission

As mentioned earlier, the quality and content of the cost proposal as well as the subsequent evaluation criteria will vary depending upon the level of effort dedicated towards earlier characterization studies in following with the breadth of investigations recommended in the *SEAR Design Manual* and as briefly gone over in this section and elsewhere in this document. Characterization of the underlying capillary barrier should be remembered, as well as attention to earlier investigation data that may have indicated a breach did occur in the capillary barrier, for further investigation studies to confirm locations and repair as necessary and feasible. Nevertheless, particularly for higher performance flooding operations to be performed (as described in Item 6b), detailed capillary barrier characterization and conservative interwell tracer testing should be tasked to the flooding vendor for design protectiveness of the aquifer system. The proposed format below for cost submission assumes that the contaminant hydrogeology is fairly well understood and that DNAPL delineation has occurred, such that sufficient data exists for a baseline design cost estimate plus any recommended design activities. This includes knowledge of whether pooled or free-phase DNAPL may exist at the site, requiring pre-removal. Most cost-relevant details will be summarized within the Statement of Work (SOW), such as the findings of earlier site characterization activities and performance requirements, with original reports available upon request by the contractor. Detailed equipment specifications, such as the requirement to use only stainless steel materials in contact with DNAPL, or equipment and devices with a given rating and/or accuracy range, may be incorporated with the SOW, but usually should be provided as a separate design specifications package. The evaluation of the submitted RFP package should involve selective weighting of the following criteria:

1) Staffing skills, with equal if not greater weight placed on the field experience of the field crew as with the reputation of the technical design experts back in the office. Project history of proposed or assigned field crew and managers to be evaluated;
2) Staffing continuity (as opposed to change of staff) over the fielding duration;
3) Round the clock monitoring capabilities;
4) Ability to meet specified, if any, project completion schedules to be included with the RFP requirements package, without any sacrifice in performance quality;
5) Quality and cost of any proposed pre-treatment mobile DNAPL removal activities requested of the surfactant flooding vendor, if not already designated for a separate contractor;
6) Preparation of a baseline design cost estimate based on the site information provided or made available with the RFP, that would optimally include data such as the onsite wastewater treatment capabilities and capacities, or stipulation of approved discharge limits (volume and concentration limits), as well as a low and average estimate of DNAPL contamination and distribution within the aquifer (hydrogeologic model already constructed); any available government furnished equipment and/or labor should also be so stated. Cost of any vendor proposed wastewater treatment upgrade and/or onsite wastewater treatment lease costs should be itemized separately from the remainder of the subsurface treatment equipment items provided for design packages. The technical quality of the vendor submitted design proposal package, such as the design specifications for hydraulic control (e.g., well spacing and pumping) parameters, as well as contingency planning for maintaining hydraulic control under usual and inclement conditions, should be evaluated.

    a. Baseline design costs will be for the baseline extraction effluent (or low performance enhanced contaminant recovery) scenario that includes contingency operations costs and minimum specified operational monitoring requirements, including each contaminant species to be monitored, as well as for any additional aquifer monitoring requested (such as for tracking biotransformation etc.) and quality control testing of injected surfactant solutions. The site owner stipulates the minimum solubility enhancement to be accomplished, over a given duration of time, averaged over all extraction wells. Effluent concentrations will be evaluated over the maximum screened intervals of the extraction wells, from initial pre-treatment to final post-treatment extracted groundwater values.

    N.B. Government or client uses contaminant volume or mass estimate and applies 5 to 10x (times) the solubility limit of the primary contaminant (an assumed increase in the solubility limit effected by introduction of surfactant that also depends on the well placement within the contamination zone, average residual DNAPL saturation (or contamination "density"[24]) of the targeted treatment zone, and the screening interval or contaminated thickness), the expected average pumping rate, and generates the expected treatment duration (of surfactant flooding phase operations) for cost preparation purposes. For chemical requirements, a hypothetical surfactant composition (such as the use of one already applied in the field for a similar contaminant, see Table 2-1 of the *SEAR Design Manual*) may be used with relative accuracy. Detailed costing information for a surfactant flooding pilot-scale study may be found in the Section 4 tables of Battelle/DE&S (2001b)[25].

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[24] Take contamination volume estimate, and divide by anticipated swept pore volume of the aquifer. As roughly depicted in the SEAR Design Manual, liquid-phase surfactant testing is conducted with 50% DNAPL phase by volume, with the remainder comprised of surfactant solution. The solubility enhancement in the field will be reduced by the relative amount of DNAPL contamination that the surfactant "sees" in the swept pore volume of the aquifer, or by a dilution factor.

[25] Battelle/DE&S, 2001b. Final Cost & Performance Report for Surfactant Enhanced DNAPL Removal at Site 88, Camp Lejeune, North Carolina. Prepared on behalf of the Naval Facilities Engineering Service Center for the Environmental Security Technology Certification Program, Arlington, VA.

    b. Costs for optional higher surfactant performance scenario(s): shortened treatment duration (with potential cost savings), usually requiring mobility control enhancement, but that will achieve a consistently higher solubilization performance up to 20x the aqueous solubility limit as observed in the extracted groundwater. All added costs for any additional field or capillary barrier characterization studies, bench-scale studies and wastewater treatment should be included herein. Question to the vendor is: IS THERE A REASONABLE TRADEOFF IN TERMS OF COST SAVINGS TO CUSTOMER FOR HIGHER PERFORMANCE OF CONTAMINANT REMOVAL?

    c. WITH THE SUBMITTED DESIGN PACKAGE, THE VENDOR MUST QUALIFY ALL ASSUMPTIONS AND RECOMMEND ANY REQUIRED FIELD AND LABORATORY CHARACTERIZATION STUDIES TO OBTAIN ADDITIONAL DATA FOR REFINING BASELINE DESIGN ESTIMATES. IF THE ADDITIONAL FIELDWORK IS NOT PERFORMED AS RECOMMENDED, THE CONSEQUENCES SHOULD BE CLEARLY STIPULATED. The vendor shall also state any lead time required for surfactant in the proper quantities to become available, and whether any customized surfactant development is required; any impact of additionally proposed field and design optimization activities (inclusive of modeling etc.) on the stipulated schedule should also be addressed.

7) Scope of monitoring plan for operations and performance – the government or site owner should stipulate whether the vendor is responsible for monitoring point installation, inclusive of multilevel sampler installation, for a complete cost submission.

8) Quality of data plan – must include the configuration of all unprocessed data to be submitted, or basically the form of all operations and performance monitoring data that will be reported.

9) Quality and cost of any warranty service plan provided – based on pre- and post- (or post-only) performance assessment data for flooding remediation, and conditions for re- flooding treatment of the targeted zone should occur under circumstances to be stated by vendor as the warrantied service; vendor shall provide the cost of this service plan, inclusive of the performance assessment used in the service plan.

10) Closeout option package: availability, cost-effectiveness and quality of site closeout option packages tailored to site contamination conditions
    a. Cost option of extended pumping operations – under water flooding, contaminant concentrations averaged in extraction wells must be less than one-hundredth the solubility limit of all primary components (such indicating likely removal of residual saturation DNAPL) or a less stringent reduction of dissolved contaminant concentrations to satisfy alternative mass removal requirements.
    b. And/or cost of alternative treatment services following treatment of preferably an entire source zone area and upon attainment of asymptotic conditions (as discussed in Section 4.3) to terminate continued hydraulic control measures, for remediation by chemical oxidation, vacuum-enhanced pumping, enhanced bioremediation and so forth, with targeted compliance concentrations to be met.

Table E-1. Direct Cost Items Table for Surfactant Flooding Projects

Direct Cost Item	Required Labor Skill Category	Points of coordination for cost savings, including quality improvements
Project Management tasks (assigning and coordinating project staffing, coordinating field planning and remediation, developing cost estimate and other project requirements, contract negotiation and ratification, cost and schedule management, field data compilation and coordination of project documentation, technical presentations and client meetings)	Senior-Level Project Manager Mid-Level Scientist/Engineer Junior-level Scientist/Engineer Contracting specialists Word processing/Graphics personnel	Discuss field personnel requirements to maximize field expertise and minimize staff rotations during the project Minimize project reporting requirements to reduce unnecessary paperwork Discuss electronic data recording formatting inclusive of individual cost tracking (e.g. spreadsheets and databases) to maximize data organization and availability and minimize data losses Discuss contracting format requirements that can suitably meet any additional treatment duration possibly needed to accomplish target remediation objectives Discuss any potential barriers to timely and in-budget project execution (i.e. seasonal hurricanes etc.)
Field planning activities (field personnel staffing, lodging and transportation, site coordination issues, equipment purchase/rental, chemical purchase and delivery, planning documentation and permitting, and community presentations as needed)	Mid to Senior-Level Scientist/Engineer "technical specialists and decision-makers" Junior-level Scientist/Engineer "data gatherer"	Assist contractor with points of contacts list and own arrangements to reduce time and labor requirements Determine whether boiler plate document formats can be used in place of any "special" document formats and agree upon scope of documenting monitoring activities Inform contractor of any site-specific requirements Discuss project staffing with respect to continuity in field operations, project timetable and anticipated field duration Compare relative costs of planned lodging or housing relative to use of Navy Officer Quarters if available for contractor usage

Table E-1. (cont.)

Direct Cost Item	Required Labor Skill Category	Points of coordination for cost savings, including quality improvements
System components and equipment, including rental equipment and trailers but excluding well installation and materials (costs usually include delivery)	Mid to Senior-Level Scientist/Engineer "technical specialists and decision-makers"	Pros/cons of using rental versus purchased equipment as well as for any innovative equipment items (e.g., newly marketed pump or sampler device) versus alternatives Arranging use of existing facilities for office space, wastewater treatment, etc. Discuss the use of automated inline sampling devices for more frequent sample collection capabilities attending 24 hour operations Does the contractor have adequate staff to support construction and operation of a SCADA for continuous flowrate and aquifer monitoring?
Additional well installation & development, including injection/extraction wells, monitoring wells and multilevel sampler (MLS) installation	Mid to Senior-Level Scientist/Engineer (Hydrogeologist)	Detailed well specifications should be obtainable for any subcontract requirements, as outlined in Appendix A Discuss optimum number of monitoring points, inclusive of MLS points, to meet technology performance evaluation objectives Require field project manager be on site for well installation – experienced field hands are a must to ensure careful well installation and development Be prepared to extend contractor field stay if free-phase DNAPL accumulates in wells Assist with coordinating waste management
DNAPL recovery operations as needed (individual well pumping and water flooding prior to any pre-performance assessment)	Mid-Level Scientist/Engineer (Hydrogeologist)	Arrange use of existing wastewater treatment services as appropriate Carefully quantify free product removal efficiencies

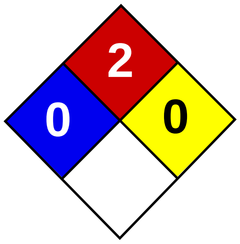
Table E-1. (cont.)

Direct Cost Item	**Required Labor Skill Category**	**Points of coordination for cost savings, including quality improvements**
Pre SEAR performance assessment sampling and any other background sampling requirements	Mid -Level Scientist/Engineer (Hydrogeologist)	Discuss optimum number of soil samples and sampling locations for DQOs– consider use of composite soil samples for DNAPL mass estimates and minimize soil sampling locations when flowing sands conditions exist; note that given the heterogeneity of the DNAPL environment, detailed logging of soil types encountered should always occur while soil sampling Groundwater sampling measures may be coordinated with MLS and well installation
Surfactant injection chemicals, analytical equipment chemicals, as well as any needed wastewater treatment process chemicals, e.g. anti-foam agent	Mid to Senior-Level Scientist/Engineer "technical specialists and decision-makers"	Determine whether a discount volume exists for bulk purchasing of chemicals, as well as delivery method and shipped volume of a bulk container
Site setup/Components assembly/Shakedown testing labor	Senior-Level Scientist/Engineer (field technical backup support) Mid -Level Scientist/Engineer (field manager and experienced field personnel) Junior–Level Scientist/Engineer (field assistant and technician)	Coordinate with any local construction personnel for use of forklifts, shipping vehicles, and equipment operators as necessary
Operations monitoring labor, including sampling and analytical labor	Senior-Level Scientist/Engineer (real-time review of data for recommended design adjustments) Mid –Level Scientist/Engineer (field manager, experienced field personnel, and chemist as required) Junior–Level Scientist/Engineer (field assistant and technician)	Determine the quantity of automated sampling and monitoring and requirements for off-site analyses

Table E-1. (cont.)

Direct Cost Item	Required Labor Skill Category	Points of coordination for cost savings, including quality improvements
Miscellaneous spare/replacement parts, and expendable materials including filters, sampling vials, glassware, GC supplies, officeware, including packing and shipping materials	Junior–Level Scientist/Engineer (field assistant and technician)	Equipment reliability and spare part requirements should be discussed with system component selection costs to avoid costly equipment maintenance
Disassembly and Demobilization	Mid –Level Scientist/Engineer (experienced field personnel) Junior–Level Scientist/Engineer (field assistant and technician)	Coordinate with any local construction personnel for use of forklifts, shipping vehicles, and equipment operators as necessary
Post-SEAR Performance Assessment	Mid -Level Scientist/Engineer (Hydrogeologist)	Discuss criteria for determining when post-treatment PA may be conducted, and parallel methods to be used for data comparable to the baseline conditions.
Lodging, Per Diem and Transportation Costs	N/A	Minimize travel to and from field for the duration of the remediation effort; onsite housing rental may be desirable to minimize lodging costs
Sample shipment and contingency equipment parts shipment	N/A	Use of well-packed, labeled and manifested coolers can reduce number of sample shipments and sample breakage
Waste disposal fees, including wastewater disposal fees if onsite treatment is not occurring	N/A	Is there a reuse possibility for wastes recovered? It is not advisable to use filtration to reduce the volume of untreated SEAR effluent wastewater
Final Summary Report, which typically encompasses design details, discussion of field operations, and data analysis	Senior-Level Scientist/Engineer Mid-Level Scientist/Engineer Junior-level Scientist/Engineer Word processing/Graphics personnel	Specify intended audience from the outset An outline document format supplied in advance will be helpful for customized or streamlined reporting requirements

ScienceLab.com
Chemicals & Laboratory Equipment



Health	2
Fire	3
Reactivity	0
Personal Protection	H

Material Safety Data Sheet

Aerosol OT-75% MSDS

Section 1: Chemical Product and Company Identification

Product Name: Aerosol OT-75%

Catalog Codes: SLA4807

CAS#: Mixture.

RTECS: Not applicable.

TSCA: TSCA 8(b) inventory: Ethyl alcohol 200 Proof; Dioctyl Sodium Sulfosucccinate

CI#: Not applicable.

Synonym: Aerosol OT-75% Surfactant

Chemical Name: Not applicable.

Chemical Formula: Not applicable.

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Ethyl alcohol 200 Proof	64-17-5	6-7
Dioctyl Sodium Sulfosucccinate	577-11-7	73-75

Toxicological Data on Ingredients: Ethyl alcohol 200 Proof: ORAL (LD50): Acute: 7060 mg/kg [Rat.]. 3450 mg/kg [Mouse]. VAPOR (LC50): Acute: 20000 ppm 8 hours [Rat]. 39000 mg/m 4 hours [Mouse]. Dioctyl Sodium Sulfosucccinate: ORAL (LD50): Acute: 1900 mg/kg [Rat]. 2643 mg/kg [Mouse].

Section 3: Hazards Identification

Potential Acute Health Effects: Hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Classified PROVEN by State of California Proposition 65 [Ethyl alcohol 200 Proof]. Classified A4 (Not classifiable for human or animal.) by ACGIH [Ethyl alcohol 200 Proof]. MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. [Ethyl alcohol 200 Proof]. Mutagenic for bacteria and/or yeast. [Ethyl alcohol 200 Proof]. TERATOGENIC EFFECTS: Classified PROVEN for human [Ethyl alcohol 200 Proof]. DEVELOPMENTAL TOXICITY: Classified Development toxin [PROVEN] [Ethyl alcohol 200 Proof]. Classified Reproductive system/toxin/male [POSSIBLE] [Ethyl alcohol 200 Proof]. The substance is toxic to blood, the reproductive system, liver, upper respiratory tract, skin, central nervous system (CNS). Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. Immediately flush eyes with running water for at least 15 minutes, keeping eyelids open. Cold water may be used. Get medical attention.

Skin Contact:
In case of contact, immediately flush skin with plenty of water. Cover the irritated skin with an emollient. Remove contaminated clothing and shoes. Cold water may be used.Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek immediate medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention if symptoms appear.

Serious Inhalation:
Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. Seek medical attention.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. If large quantities of this material are swallowed, call a physician immediately. Loosen tight clothing such as a collar, tie, belt or waistband.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Flammable.

Auto-Ignition Temperature: The lowest known value is 363°C (685.4°F) (Ethyl alcohol 200 Proof).

Flash Points: CLOSED CUP: 29°C (84.2°F). (Pensky-Martens.)

Flammable Limits: LOWER: 3.3% UPPER: 19%

Products of Combustion: These products are carbon oxides (CO, CO2), sulfur oxides (SO2, SO3...).

Fire Hazards in Presence of Various Substances:
Highly flammable in presence of open flames and sparks, of heat. Non-flammable in presence of shocks, of reducing materials, of combustible materials, of organic materials, of metals, of acids, of alkalis, of moisture.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available.

Fire Fighting Media and Instructions:
Flammable liquid, soluble or dispersed in water. SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use alcohol foam, water spray or fog. Cool containing vessels with water jet in order to prevent pressure build-up, autoignition or explosion.

Special Remarks on Fire Hazards:
Containers should be grounded. CAUTION: MAY BURN WITH NEAR INVISIBLE FLAME Vapor may travel considerable distance to source of ignition and flash back. (Ethyl alcohol 200 Proof)

Special Remarks on Explosion Hazards:
Ethanol has an explosive reaction with the oxidized coating around potassium metal. Ethanol ignites and then explodes on contact with acetic anhydride + sodium hydrosulfate (ignites and may explode), disulfuric acid + nitric acid, phosphorous(III) oxide platinum, potassium-tert-butoxide+ acids. Ethanol forms explosive products in reaction with the following compound :

ammonia + silver nitrate (forms silver nitride and silver fulminate), iodine + phosphorus (forms ethane iodide), magnesium perchlorate (forms ethyl perchlorate), mercuric nitrate, nitric acid + silver (forms silver fulminate) silver nitrate (forms ethyl nitrate) silver(I) oxide + ammonia or hydrazine (forms silver nitride and silver fulminate), sodium (evolves hydrogen gas). (Ethyl alcohol 200 Proof)

Section 6: Accidental Release Measures

Small Spill:
Dilute with water and mop up, or absorb with an inert dry material and place in an appropriate waste disposal container.

Large Spill:
Flammable liquid. Keep away from heat. Keep away from sources of ignition. Stop leak if without risk. Absorb with DRY earth, sand or other non-combustible material. Do not touch spilled material. Prevent entry into sewers, basements or confined areas; dike if needed. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep locked up.. Keep away from heat. Keep away from sources of ignition. Ground all equipment containing material. Do not ingest. Do not breathe gas/fumes/ vapor/spray. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents, acids, alkalis.

Storage:
Store in a segregated and approved area. Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame).

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors below their respective threshold limit value. Ensure that eyewash stations and safety showers are proximal to the work-station location.

Personal Protection:
Splash goggles. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Vapor respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
Ethyl alcohol 200 Proof TWA: 1000 (ppm) from ACGIH (TLV) [United States] [1999] TWA: 1000 (ppm) from OSHA (PEL) [United States] TWA: 1900 (mg/m3) from OSHA (PEL) [United States] TWA: 1000 (ppm) from NIOSH TWA: 1000 (ppm) [United Kingdom (UK)] TWA: 1920 (mg/m3) [United Kingdom (UK)] TWA: 1000 STEL: 1250 (ppm) [Canada] Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid.

Odor: Slight.

Taste: Not available.

Molecular Weight: Not applicable.

Color: Clear. Water-white

pH (1% soln/water): 6 [Acidic.]

Boiling Point: 78°C (172.4°F)

Melting Point: May start to solidify at -114.1°C (-173.4°F) based on data for: Ethyl alcohol 200 Proof.

Critical Temperature: The lowest known value is 243°C (469.4°F) (Ethyl alcohol 200 Proof).

Specific Gravity: 1.09 (Water = 1)

Vapor Pressure: The highest known value is 5.7 kPa (@ 20°C) (Ethyl alcohol 200 Proof).

Vapor Density: The highest known value is 1.59 (Air = 1) (Ethyl alcohol 200 Proof).

Volatility: Not available.

Odor Threshold: The highest known value is 100 ppm (Ethyl alcohol 200 Proof)

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water, methanol, diethyl ether, acetone.

Solubility: Soluble in cold water, hot water, methanol, diethyl ether, acetone.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Heat, ignition sources, incompatible materials.

Incompatibility with various substances: Reactive with oxidizing agents, acids, alkalis.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity: Incompatiable with strong acids, strong bases, strong oxidizers. (Dioctyl Sodium Sulfosucccinate)

Special Remarks on Corrosivity: Aqueous solutions of this product corrode steel.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Eye contact. Inhalation. Ingestion.

Toxicity to Animals: Acute oral toxicity (LD50): 1900 mg/kg [Rat]. (Dioctyl Sodium Sulfosucccinate).

Chronic Effects on Humans:
CARCINOGENIC EFFECTS: Classified PROVEN by State of California Proposition 65 [Ethyl alcohol 200 Proof]. Classified A4 (Not classifiable for human or animal.) by ACGIH [Ethyl alcohol 200 Proof]. MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. [Ethyl alcohol 200 Proof]. Mutagenic for bacteria and/or yeast. [Ethyl alcohol 200 Proof]. TERATOGENIC EFFECTS: Classified PROVEN for human [Ethyl alcohol 200 Proof]. DEVELOPMENTAL TOXICITY: Classified Development toxin [PROVEN] [Ethyl alcohol 200 Proof]. Classified Reproductive system/toxin/male [POSSIBLE] [Ethyl alcohol 200 Proof].

Other Toxic Effects on Humans: Hazardous in case of skin contact (irritant), of ingestion, of inhalation.

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans:

May affect genetic material (mutagenic). May cause adverse reproductive effects and birth defects (teratogenic). May cause cancer based on animal test data.

Special Remarks on other Toxic Effects on Humans:

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are less toxic than the product itself.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: CLASS 3: Flammable liquid.

Identification: : Ethanol Solution (Ethyl alcohol 200 Proof) UNNA: 1170 PG: III

Special Provisions for Transport: Not available.

Section 15: Other Regulatory Information

Federal and State Regulations:
California prop. 65: This product contains the following ingredients for which the State of California has found to cause cancer, birth defects or other reproductive harm, which would require a warning under the statute: Ethyl alcohol 200 Proof California prop. 65: This product contains the following ingredients for which the State of California has found to cause birth defects which would require a warning under the statute: Ethyl alcohol 200 Proof California prop. 65: This product contains the following ingredients for which the State of California has found to cause cancer which would require a warning under the statute: Ethyl alcohol 200 Proof Rhode Island RTK hazardous substances: Ethyl alcohol 200 Proof Pennsylvania RTK: Ethyl alcohol 200 Proof Florida: Ethyl alcohol 200 Proof

Other Regulations: OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200).

Other Classifications:

WHMIS (Canada):
CLASS B-2: Flammable liquid with a flash point lower than 37.8°C (100°F). CLASS D-2A: Material causing other toxic effects (VERY TOXIC).

DSCL (EEC):
R10- Flammable. R22- Harmful if swallowed. R36/38- Irritating to eyes and skin. S2- Keep out of the reach of children. S46- If swallowed, seek medical advice immediately and show this container or label.

HMIS (U.S.A.):

Health Hazard: 2

Fire Hazard: 3

Reactivity: 0

Personal Protection: h

National Fire Protection Association (U.S.A.):

Health: 0

Flammability: 2

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate. Splash goggles.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

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Last Updated: 06/09/2012 12:00 PM

PILOT CHEMICAL COMPANY

MATERIAL SAFETY DATA SHEET

2744 East Kemper Road • Cincinnati, OH 45241

www.pilotchemical.com • 1-800-70-PILOT

CALFAX® 16L-35

1. PRODUCT AND COMPANY IDENTIFICATION

Product name	CALFAXœ 16L-35
Company Address	2744 East Kemper Road Cincinnati, Ohio 45241
Emergency Telephone Number	Chemtrec 1-800-424-9300 Pilot Chemical Corporate Office 1-513-326-0600

2. COMPOSITION/INFORMATION ON INGREDIENTS

Component	CAS-No	Weight %	OSHA PEL
Benzenesulfonic acid, hexadecyl(sulfophenoxy)-, disodium salt	65143-89-7	35-36	-
Benzenesulfonic acid, oxybis[hexadecyl-, disodium salt	70191-76-3	5-10	-
Sodium sulfate	7757-82-6	0-2	-
Water	7732-18-5	56-57	-

3. HAZARDS IDENTIFICATION

Emergency Overview	Irritant
Potential Health Effects	
Eyes	Contact with eyes may cause irritation.
Skin	Substance may cause slight skin irritation.
Inhalation	May cause irritation of respiratory tract
Ingestion	Ingestion may cause gastrointestinal irritation, nausea, vomiting and diarrhea
Chronic effects	No information available

4. FIRST AID MEASURES

Eye Contact	Rinse thoroughly with plenty of water, also under the eyelids. If symptoms persist, call a physician
Skin Contact	Wash off immediately with soap and plenty of water removing all contaminated clothes and shoes. If symptoms persist, call a physician
Inhalation	Move to fresh air. If symptoms persist, call a physician
Ingestion	Drink 1 or 2 glasses of water. Consult a physician. Do not induce vomiting without medical advice.

5. FIRE-FIGHTING MEASURES

Flammable Properties	Non-flammable water solution.
Flammable Limits	Not Determined.
Hazardous Combustion Products	Oxides of carbon and sulfur.
SPECIAL FIRE FIGHTING PROCEDURES	
Method	Water mist may be used to cool closed containers.
Suitable Extinguishing Media	Water spray. Carbon dioxide (CO2). Foam. Dry chemical.

Unusual Fire & Explosive Hazards	None

6. ACCIDENTAL RELEASE MEASURES

Small Spillages	Recover all usable material. Soak up balance with sand or dirt.
Large Spillages	In case of a large spill by truck, use small spill procedure and a vacuum truck. Call CHEMTREC at 1-800-424-9300.

7. HANDLING AND STORAGE

Handling	Wear personal protective equipment. Avoid contact with skin, eyes and clothing.
Storage	Containers should be tightly closed and stored between 60°F and 100°F and away from strong oxidizing agents.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

Engineering measures	Ensure adequate ventilation, especially in confined areas
Eye/Face Protection	Tightly fitting safety goggles. If splashes are likely to occur, wear a face-shield
Skin Protection	Wear protective gloves/clothing .
Respiratory Protection	No special protective equipment required, unless workers are exposed to concentrations above the exposure limit

9. PHYSICAL AND CHEMICAL PROPERTIES

Boiling Point/Range	100°C
Vapor Pressure	17.8 mm Hg @ 20 °C
Volatile Weight %	56 (as Water)
Water Solubility	Soluble in water
Specific Gravity	1.13
pH	8-10
Odor	Mild detergent odor
Appearance	Colorless to pale yellow
Physical State	Liquid

10. STABILITY AND REACTIVITY

Chemical Stability	Stable under normal conditions.
Unsuitable Materials	Strong oxidizing agents and strong acids.
Conditions to Avoid	Do not mix with strong oxidizing agents or strong acids.
Hazardous Decomposition Products	None under normal use
Hazardous Polymerization	No information available

11. TOXICOLOGICAL INFORMATION

Component	LD50 Oral	LC50 Inhalation	LD50 Dermal
Sodium sulfate	10000 mg/kg (Rat)	-	-

Eyes Eye Irritation

Skin Skin Irritation

Ingestion Unknown

Inhalation Unknown

Chronic Toxicity No information available

Carcinogenicity Product is not listed.

Hazard Type Skin/Eye Irritant.

12. ECOLOGICAL INFORMATION

Component	Freshwater Algae	Freshwater Fish	Microtox	Water Flea
Sodium sulfate	-	-	-	EC50 = 2564 mg/L 48 h EC50 = 4547 mg/L 96 h
Benzenesulfonic acid, hexadecyl(sulfophenoxy)-, disodium salt	EC50 = 42 mg/L 72 h EC50 = 100 mg/L 72 h	LC50 = 0.42 mg/L 96 h LC50 = 0.86 mg/L 96 h	-	EC50 = 6.95 mg/L 48 h

Ecotoxicity effects Harmful to aquatic organisms, may cause long-term adverse effects in the aquatic environment

Chemical Fate Material is not readily biodegradable.

13. DISPOSAL CONSIDERATIONS

Waste Disposal Methods Dispose of contents/container in accordance with local regulation.

14. TRANSPORT INFORMATION

The following transportation descriptions are for bulk transport and international shipments. Materials in non-bulk quantities shipped domestically within the United States are non-regulated.

DOT

Proper shipping name	Environmentally hazardous substances, liquid, n.o.s. (mono-and-dihexadecyl disulfonated diphenyl oxide, disodium salt), Marine Pollutant
Hazard class	9
UN-No	UN3082
Packing Group	III
Description	UN3082, Environmentally hazardous substances, liquid, n.o.s. (mono-and-dihexadecyl disulphonated diphenyl oxide, disodium salt), 9, III, Marine Pollutant

ICAO

UN-No	3082
Proper shipping name	Environmentally hazardous substances, liquid, n.o.s. (mono-and-dihexadecyl disulphonated diphenyl oxide, disodium salt), Marine Pollutant
Hazard Class	9
Packing Group	III
Description	UN3082, Environmentally hazardous substances, liquid, n.o.s. (mono-and-dihexadecyl disulphonated diphenyl oxide, disodium salt), 9, III, Marine Pollutant

IATA

UN-No	3082
Proper shipping name	Environmentally hazardous substances, liquid, n.o.s. (mono-and-dihexadecyl disulphonated diphenyl oxide, disodium salt), Marine Pollutant
Hazard Class	9
Packing Group	III
Description	UN3082, Environmentally hazardous substances, liquid, n.o.s. (mono-and-dihexadecyl disulphonated diphenyl oxide, disodium salt), 9, III, Marine Pollutant

IMDG/IMO

Proper shipping name	Environmentally hazardous substances, liquid, n.o.s. (mono-and-dihexadecyl disulphonated diphenyl oxide, disodium salt), Marine Pollutant
Hazard Class	9
UN-No	3082
Packing Group	III
Description	UN3082, Environmentally hazardous substances, liquid, n.o.s. (mono-and-dihexadecyl disulphonated diphenyl oxide, disodium salt), 9, III, Marine Pollutant

RID

Proper shipping name	Environmentally hazardous substances, liquid, n.o.s. (mono-and-dihexadecyl disulphonated diphenyl oxide, disodium salt), Marine Pollutant
Hazard Class	9
UN-No	3082
Packing Group	III
Description	UN3082, Environmentally hazardous substances, liquid, n.o.s. (mono-and-dihexadecyl disulphonated diphenyl oxide, disodium salt), 9, III, Marine Pollutant

ADR

Proper shipping name	Environmentally hazardous substances, liquid, n.o.s. (mono-and-dihexadecyl disulphonated diphenyl oxide, disodium salt), Marine Pollutant
Hazard Class	9
UN-No	3082
Packing Group	III
Description	UN3082, Environmentally hazardous substances, liquid, n.o.s. (mono-and-dihexadecyl disulphonated diphenyl oxide, disodium salt), 9, III, Marine Pollutant

ADN

Proper shipping name	Environmentally hazardous substances, liquid, n.o.s. (mono-and-dihexadecyl disulphonated diphenyl oxide, disodium salt), Marine Pollutant
Hazard Class	9
UN-No	3082
Packing Group	III
Description	UN3082, Environmentally hazardous substances, liquid, n.o.s. (mono-and-dihexadecyl disulphonated diphenyl oxide, disodium salt), 9, III, Marine Pollutant

15. REGULATORY INFORMATION

International Inventories

Component	TSCA	DSL	NDSL	EINECS	ELINCS	ENCS	CHINA	KECL	PICCS	AICS
Benzenesulfonic acid, hexadecyl(sulfophenoxy)-, disodium salt	X	X	-	-	-	-	X	-	X	X
Benzenesulfonic acid, oxybis[hexadecyl-, disodium salt	X	X	-	-	-	-	X	-	X	X
Sodium sulfate	X	X	-	X	-	X	X	X	X	X
Water	X	X	-	X	-	X	X	X	X	X

USA

Federal Regulations

SARA 313

Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA). This product does not contain any chemicals which are subject to the reporting requirements of the Act and Title 40 of the Code of Federal Regulations, Part 372.

SARA 311/312 Hazardous Categorization

Acute Health Hazard	Yes
Chronic Health Hazard	No
Fire Hazard	No
Sudden Release of Pressure Hazard	No
Reactive Hazard	No

Clean Air Act, Section 112 Hazardous Air Pollutants (HAPs) (see 40 CFR 61)

This product does not contain any HAPs.

16. OTHER INFORMATION

Revision Date	01/04/2012
Prepared by	David A. Pollard

Disclaimer

The information provided on this MSDS is correct to the best of our knowledge, information and belief at the date of its publication. The information given is designed only as a guide for safe handling, use, processing, storage, transportation, disposal and release and is not to be considered as a warranty or quality specification. The information relates only to the specific material designated and may not be valid for such material used in combination with any other material or in any process, unless specified in the text.

Material Safety Data Sheet

1. CHEMICAL PRODUCT & COMPANY IDENTIFICATION

24-Hour Emergency Phone Number: 989-636-4400

Product: DOWFAX* 3B2 SOLUTION SURFACTANT

Product Code: 23261

Effective Date: 11/21/02   Date Printed: 12/26/02   MSD: 000005

The Dow Chemical Company, Midland, MI 48674

Customer Information Center: 800-258-2436

2. COMPOSITION/INFORMATION ON INGREDIENTS

Decyl(sulfophenoxy)benzenesulfonic acid, disodium salt,	CAS# 036445-71-3	30-45%
Oxybis(decylbenzenesulfonic acid), disodium salt	CAS# 070146-13-3	7-13%
Sodium sulfate	CAS# 007757-82-6	1.5% Max.
Sodium chloride	CAS# 007647-14-5	< 1%
Water	CAS# 007732-18-5	Balance

3. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

```
***********************************************************************
*  Yellow to light brown liquid.  Disinfectant odor.  Causes eye burns.*
*  Toxic fumes are released in fire situations.                       *
***********************************************************************
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POTENTIAL HEALTH EFFECTS (See Section 11 for toxicological data.)

EYE: May cause moderate eye irritation which may be slow to heal. May cause moderate corneal injury. May cause permanent impairment of vision, even blindness.

SKIN: Prolonged or repeated exposure not likely to cause significant skin irritation. May cause more severe response if skin is abraded (scratched or cut). A single prolonged skin exposure is not likely to result in the material being absorbed through skin in harmful amounts.

INGESTION: Single dose oral toxicity is considered to be low.

(Continued on page 2 , over)

* OR (R) INDICATES A TRADEMARK OF THE DOW CHEMICAL COMPANY

Small amounts swallowed incidental to normal handling operations are not likely to cause injury; swallowing amounts larger than that may cause injury.

INHALATION: Excessive exposure may cause irritation to upper respiratory tract.

SYSTEMIC (OTHER TARGET ORGAN) EFFECTS: Repeated excessive exposures to high amounts may cause liver and kidney effects (based on similar material).

CANCER INFORMATION: Did not cause cancer in long-term animal studies. (product similar to active ingredient)

4. FIRST AID

EYE: Immediate and continuous irrigation with flowing water for at least 30 minutes is imperative. Prompt medical consultation is essential.

SKIN: Wash off in flowing water or shower.

INGESTION: If swallowed, seek medical attention. Do not induce vomiting unless directed to do so by medical personnel.

INHALATION: Remove to fresh air if effects occur. Consult a physician.

NOTE TO PHYSICIAN: No specific antidote. Supportive care. Treatment based on judgment of the physician in response to reactions of the patient.

5. FIRE FIGHTING MEASURES

FLAMMABLE PROPERTIES
FLASH POINT: Flame extinguished; none to boiling.
METHOD USED: Closed Cup; Open Cup.
AUTOIGNITION TEMPERATURE: > 550 C

FLAMMABILITY LIMITS
LFL: Not applicable
UFL: Not applicable

HAZARDOUS COMBUSTION PRODUCTS: Hazardous combustion products may include and are not limited to sulfur oxides.

(Continued on page 3)

EXTINGUISHING MEDIA: To extinguish combustible residues of this product use water fog, carbon dioxide, dry chemical or foam.

FIRE FIGHTING INSTRUCTIONS: Hand held carbon dioxide, dry chemical or water extinguishers may be used for small fires.

PROTECTIVE EQUIPMENT FOR FIRE FIGHTERS: Wear positive pressure self-contained breathing apparatus (SCBA) and protective fire fighting clothing (includes fire fighting helmet, coat, pants, boots, and gloves).

6. ACCIDENTAL RELEASE MEASURES (See Section 15 for Regulatory Information)

PROTECT PEOPLE: Use appropriate safety equipment. For additional information, refer to "Exposure Controls/Personal Protection", MSDS Section 8.

PROTECT THE ENVIRONMENT: Spills should be collected to prevent contamination of waterways.

CLEANUP: For small spills absorb with material such as: sawdust, kob grit, Zorb-all(R).

7. HANDLING AND STORAGE

HANDLING: Refer to Exposure Controls/Personal Protection, Section 8, of the MSDS.

STORAGE: Product may become a solid at temperatures below 32 deg. F (0 deg. C).

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

ENGINEERING CONTROLS: Provide general and/or local exhaust ventilation to control airborne levels below the exposure guidelines.

PERSONAL PROTECTIVE EQUIPMENT

EYE/FACE PROTECTION: Use chemical goggles. Eye wash fountain should be located in immediate work area.

SKIN PROTECTION: Use gloves impervious to this material when prolonged or frequently repeated contact could occur. If hands are cut or scratched, use gloves impervious to this material even for brief exposures.

(Continued on page 4 , over)

RESPIRATORY PROTECTION: Atmospheric levels should be maintained below the exposure guideline. When respiratory protection is required for certain operations, use an approved air-purifying respirator.

EXPOSURE GUIDELINE(S): Sodium sulfate: Dow IHG is 10 mg/m3.

Benzene, 1,1-oxybis,tetrapropylene derivatives, sulfonated, sodium salts: Dow IHG is 5 mg/m3.

9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE/PHYSICAL STATE: Yellow to light brown liquid (aqueous solution).
ODOR: Disinfectant - type odor.
VAPOR PRESSURE: 17.8 mmHg @ 20C
VAPOR DENSITY: Not available
BOILING POINT: 100C, 212F
SOLUBILITY IN WATER/MISCIBILITY: Completely miscible.
SPECIFIC GRAVITY OR DENSITY: 1.12-1.16

10. STABILITY AND REACTIVITY

CHEMICAL STABILITY: Stable at ambient temperatures.

CONDITIONS TO AVOID: None known.

INCOMPATIBILITY WITH OTHER MATERIALS: Avoid unintended contact with strong acids.

HAZARDOUS DECOMPOSITION PRODUCTS: Hazardous decomposition products may include and are not limited to surfur oxides.

HAZARDOUS POLYMERIZATION: Will not occur.

11. TOXICOLOGICAL INFORMATION (See Section 3 for Potential Health Effects. For detailed toxicological data, write or call the address or non-emergency number shown in Section 1)

SKIN: The LD50 for skin absorption in rabbits is > 2000 mg/kg.

INGESTION: The oral LD50 for rats is > 2000 mg/kg.

12. ECOLOGICAL INFORMATION (For detailed Ecological data, write or call the address or non-emergency number shown in Section 1)

(Continued on page 5)

ENVIRONMENTAL FATE

MOVEMENT & PARTITIONING: No bioconcentration is expected because of the relatively high water solubility. May foam in water.

DEGRADATION & PERSISTENCE: Material is biodegradable according to SDA Semi-Continuous Activated Sludge (SCAS) confirming test to anionic surfactants.

ECOTOXICITY: Material is moderately toxic to aquatic organisms on and acute basis (LC50 or EC50 between 1 and 10 mg/L in the most sensitive species tested). Acute LC50 in water flea Daphnia magna is 1.50 mg/L. Acute LC50 in fathead minnow (Pimephales promelas) is 3.66 mg/L. Acute LC50 in bluegill (Lepomis machrochirus) is 4.99 mg/L. Acute LC50 in rainbow trout (Oncorhynchus mykiss) is 5.02 mg/L.

13. DISPOSAL CONSIDERATIONS (See Section 15 for Regulatory Information)

DISPOSAL: DO NOT DUMP INTO ANY SEWERS, ON THE GROUND, OR INTO ANY BODY OF WATER. All disposal methods must be in compliance with all Federal, State/Provincial and local laws and regulations. Regulations may vary in different locations. Waste characterizations and compliance with applicable laws are the responsibility solely of the waste generator. THE DOW CHEMICAL COMPANY HAS NO CONTROL OVER THE MANAGEMENT PRACTICES OR MANUFACTURING PROCESSES OF PARTIES HANDLING OR USING THIS MATERIAL. THE INFORMATION PRESENTED HERE PERTAINS ONLY TO THE PRODUCT AS SHIPPED IN ITS INTENDED CONDITION AS DESCRIBED IN MSDS SECTION 2 (Composition/Information On Ingredients).

FOR UNUSED & UNCONTAMINATED PRODUCT, the preferred options include sending to a licensed, permitted: incinerator or other thermal destruction device.

As a service to its customers, Dow can provide names of information resources to help identify waste management companies and other facilities which recycle, reprocess or manage chemicals or plastics, and that manage used drums. Telephone Dow's Customer Information Center at 800-258-2436 or 989-832-1556 for further details.

14. TRANSPORT INFORMATION

(Continued on page 6 , over)

DEPARTMENT OF TRANSPORTATION (D.O.T.): This product is not regulated by D.O.T. when shipped domestically by land.

CANADIAN TDG INFORMATION: For TDG regulatory information, if required, consult transportation regulations, product shipping papers or contact your Dow representative.

15. REGULATORY INFORMATION (Not meant to be all-inclusive--selected regulations represented)

NOTICE: The information herein is presented in good faith and believed to be accurate as of the effective date shown above. However, no warranty, express or implied is given. Regulatory requirements are subject to change and may differ from one location to another; it is the buyer's responsibility to ensure that its activities comply with federal, state or provincial, and local laws. The following specific information is made for the purpose of complying with numerous federal, state or provincial, and local laws and regulations. See other sections for health and safety information.

U.S. REGULATIONS

SARA 313 INFORMATION: To the best of our knowledge, this product contains no chemical subject to SARA Title III Section 313 supplier notification requirements.

SARA HAZARD CATEGORY: This product has been reviewed according to the EPA "Hazard Categories" promulgated under Sections 311 and 312 of the Superfund Amendment and Reauthorization Act of 1986 (SARA Title III) and is considered, under applicable definitions, to meet the following categories:

An immediate health hazard
A delayed health hazard

TOXIC SUBSTANCES CONTROL ACT (TSCA):

All ingredients are on the TSCA inventory or are not required to be listed on the TSCA inventory.

(Continued on page 7)

REGULATORY INFORMATION (CONTINUED)

STATE RIGHT-TO-KNOW: The following product components are cited on certain state lists as mentioned. Non-listed components may be shown in the composition section of the MSDS.

CHEMICAL NAME	CAS NUMBER	LIST
SODIUM SULFATE (SOLUTION)	007757-82-6	PA1 PA3

PA1=Pennsylvania Hazardous Substance (present at greater than or equal to 1.0%).
PA3=Pennsylvania Environmental Hazardous Substance (present at greater than or equal to 1.0%).

OSHA HAZARD COMMUNICATION STANDARD:

This product is a "Hazardous Chemical" as defined by the OSHA Hazard Communication Standard, 29 CFR 1910.1200.

CANADIAN REGULATIONS

WHMIS INFORMATION: The Canadian Workplace Hazardous Materials Information System (WHMIS) Classification for this product is:

D2B - eye or skin irritant
Refer elsewhere in the MSDS for specific warnings and safe handling information. Refer to the employer's workplace education program.

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CPR STATEMENT: This product has been classified in accordance with the hazard criteria of the Canadian Controlled Products Regulations (CPR) and the MSDS contains all the information required by the CPR.

\- - - - -

HAZARDOUS PRODUCTS ACT INFORMATION: This product contains the following ingredients which are Controlled Products and/or on the Ingredient Disclosure List (Canadian HPA section 13 and 14):

COMPONENTS:	CAS #	AMOUNT(%w/w)
DECYL (SULFOPHENOXY) BENZENESULFONIC ACID, DISODIUM SALT	036445-71-3	30-45%

(Continued on page 8 , over)

REGULATORY INFORMATION (CONTINUED)

OXYBIS (DECYLBENZENESULFONIC ACID), DISODIUM SALT	070146-13-3	7-13%

CANADIAN ENVIRONMENTAL PROTECTION ACT (CEPA):

All substances in this product are listed on the Canadian Domestic Substances List (DSL) or are not required to be listed.

16. OTHER INFORMATION

HAZARD RATING SYSTEM

NATIONAL FIRE PROTECTION ASSOCIATION (NFPA) RATINGS:

Health	3
Flammability	0
Reactivity	0

MSDS STATUS: Revised Section 16, NFPA.

ASTRO PRODUCT CODE # 6450

MATERIAL SAFETY DATA SHEET

JUNGBUNZLAUER INC. Page 1 of 4

Product: Xanthan Gum Food Grade Revision Date: 8/19/96 Print Date: 4/30/97

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

COMMERCIAL PRODUCT NAME	Xanthan Gum, Various suffixes such as FNA, FNB, FAS, FS, FF, FED
COMPANY/SUPPLIER	Jungbunzlauer Inc. 75 Wells Avenue Newton Centre, MA 02159
Emergency Phone	1- 617-969-0900; 8:30 - 5:00 M-F Eastern Time
24 Hour Emergency Phone Number	**CHEMTREC 1-800-424-9300**
PRODUCT USE	Multipurpose thickener and viscofier for food and pharmaceutical systems, emulsion stabilizer.

2. COMPOSITION, INFORMATION ON INGREDIENTS

CHEMICAL NAME OF THE MATERIAL	Xanthan gum
CHEMICAL CHARACTERIZATION	Polysaccharide (C35H49O29)n
SYNONYMS	none
CAS Reg. No.	11138-66-2
EINECS- Nr.	234-394-2
HAZARDOUS IMPURITIES	None

3. HAZARDS IDENTIFICATION

Most important Hazard	Spilled material, when wet, forms very slippery mass.
Emergency Overview	Fine white to yellowish powder with slight odor.
Inhalation	Dust may cause irritation of mucous membrane and respiratory tract.
Eye contact	May cause irritation
Skin contact	No data available
Ingestion	No data available
Chronic	No data available
Carcinogen status	None

4. FIRST AID MEASURES

General advice	No hazards which require special first aid measures. If you feel unwell, seek medical advice.
Inhalation	Move to fresh air. If symptoms persist, call a physician.
Skin contact	Wash off with soap and plenty of water. If skin irritation persists, call a physician.
Eye contact	Flush eyes with water as a precaution. If eye irritation persists, consult a specialist.
Ingestion	Drink water as a precaution. Consult a physician if necessary
Protection of first-aiders	No hazards which require special first aid measures.

5. FIRE FIGHTING MEASURES

FLASH POINT	no data available
FLAMMABLE LIMITS	no data available
Autoignition temperature	>200°C
Special characteristics	Power forms slippery mass when wet.
Suitable extinguishing media	water, water spray, dry powder, foam, carbon dioxide (CO2)
Extinguishing media which must not be used for safety reasons	None
Hazardous decomposition products	carbon oxides
Special protective equipment	Use personal protective equipment including self-contained breathing apparatus when fighting fire in enclosed area.
Specific methods	Standard procedure for chemical fires.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions	Use personal protective equipment. Avoid dust formation.
Environmental precautions	Dispose according to federal, state and local authorities.
Methods for cleaning up	Sweep up and shovel. After cleaning, flush away traces with copious amounts of water.

7. HANDLING AND STORAGE

HANDLING

Technical measures/Precautions	No special technical protective measures required.
Safe handling advice	Immediately sweep up spills. If possible avoid wetting spilled material. If spilled material must be washed down, then copious amounts of water will be necessary. Avoid walking on wet spilled material which will be very slippery.

STORAGE

Technical measures/Storage conditions	Keep tightly closed in a dry and cool place.
Incompatible products	No special restrictions on storage with other products.
Packaging material	Store in original container.

8. EXPOSURE CONTROLS, PERSONAL PROTECTION

Engineering measures	Provide general dilute ventilation.
Exposure limit(s)	None established
Personal protection equipment	
Respiratory protection	NIOSH approved dust respirator
Hand protection	Gloves
Eye Protection	Safety glasses
Skin and body protection	Lightweight protective clothing
Hygiene measures	Handle in accordance with good industrial hygiene and safety practice

9. PHYSICAL AND CHEMICAL PROPERTIES

Form		powder
Color		white/beige
Odor		slight
pH	solution (1%)	6.0-8.0
Vapor pressure		not applicable
Vapor density		not applicable
Boiling point		not applicable
Evaporation rate		not applicable
Coefficient of water/oil distribution		not applicable
Melting point/range		not applicable
Decomposition temperature		no data available
Relative density		not available
Bulk density		650-850 kg/m3 all grades except ED /FED grades FED & ED grades approximately 400 kg/m3
Explosive properties		no data available
Water solubility	g/kg	forms colloidal sol - "completely soluble."

10. STABILITY AND REACTIVITY

Stability	Stable at normal conditions
Conditions to avoid	Keep containers dry and tightly closed to avoid moisture absorption and contamination.
Materials to avoid	Strong oxidizers.
Hazardous polymerization	Does not occur.

11. TOXICOLOGICAL INFORMATION

Acute toxicity	LD50/o.o./rat= 45,000 mg/kg
Local effects	no data available
Chronic toxicity	no data available
Human experience	Health injuries are not known or expected under normal use.

12. ECOLOGICAL INFORMATION

Mobility	completely soluble
Persistence and degradability	
Chemical oxygen demand	Unknown
Biochemical oxygen demand within 5 days	(BOD5) = 250 mg O2/ g
Readily biodegradable	> 98% after 2 days (OECD 302B)
Bioaccumulation	no data available
Ecotoxicity effects	no data available

13. DISPOSAL CONSIDERATIONS

Waste from residues/unused products	Any disposal practice must be in compliance with local, state and federal laws and regulations (contact local or state environmental agency for specific rules).

14. TRANSPORT INFORMATION

Not regulated.

15. REGULATORY INFORMATION

is approved by the FDA as a food additive.
Listed European Food Additive E415
The material is listed on the TSCA Inventory List.

CERCLA (Comprehensive Response Compensation, and Liability Act):
Not hazardous

SARA Title III (Superfund Amendments and Reauthorization Bill): Not Considered Hazardous
Foreign Inventory Status
Canadian DSL (Domestic Substance List)

16. OTHER INFORMATION

HMIS* Rating Health =0, Fire = 0, Reactivity =0
*Hazardous Material Information System of the National Paint and Coating Association

MSDS Status: Revised 8/19/1996 by the Technical Service Department of Jungbunzlauer Inc.

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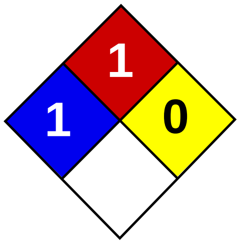
Chemicals & Laboratory Equipment



Health	1
Fire	1
Reactivity	0
Personal Protection	E

Material Safety Data Sheet

Guar gum MSDS

Section 1: Chemical Product and Company Identification

Product Name: Guar gum

Catalog Codes: SLG1537, SLG2035

CAS#: 9000-30-0

RTECS: MG0185000

TSCA: TSCA 8(b) inventory: Guar gum

CI#: Not available.

Synonym:

Chemical Name: Not available.

Chemical Formula: Not available.

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Guar gum	9000-30-0	100

Toxicological Data on Ingredients: Not applicable.

Section 3: Hazards Identification

Potential Acute Health Effects: Slightly hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. Repeated or prolonged exposure is not known to aggravate medical condition.

Section 4: First Aid Measures

Eye Contact: No known effect on eye contact, rinse with water for a few minutes.

Skin Contact:
After contact with skin, wash immediately with plenty of water. Gently and thoroughly wash the contaminated skin with running water and non-abrasive soap. Be particularly careful to clean folds, crevices, creases and groin. Cover the irritated skin with an emollient. If irritation persists, seek medical attention. Wash contaminated clothing before reusing.

Serious Skin Contact: Not available.

Inhalation: Allow the victim to rest in a well ventilated area. Seek immediate medical attention.

Serious Inhalation: Not available.

Ingestion:
Do not induce vomiting. Loosen tight clothing such as a collar, tie, belt or waistband. If the victim is not breathing, perform mouth-to-mouth resuscitation. Seek immediate medical attention.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: May be combustible at high temperature.

Auto-Ignition Temperature: Not available.

Flash Points: Not available.

Flammable Limits: Not available.

Products of Combustion: Not available.

Fire Hazards in Presence of Various Substances: Not available.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available.

Fire Fighting Media and Instructions:
SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use water spray, fog or foam. Do not use water jet.

Special Remarks on Fire Hazards: Not available.

Special Remarks on Explosion Hazards: Not available.

Section 6: Accidental Release Measures

Small Spill:
Use appropriate tools to put the spilled solid in a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements.

Large Spill:
Use a shovel to put the material into a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and allow to evacuate through the sanitary system.

Section 7: Handling and Storage

Precautions:
Keep away from heat. Keep away from sources of ignition. Empty containers pose a fire risk, evaporate the residue under a fume hood. Ground all equipment containing material. Do not ingest. Do not breathe dust. If ingested, seek medical advice immediately and show the container or the label.

Storage:
Keep container dry. Keep in a cool place. Ground all equipment containing material. Keep container tightly closed. Keep in a cool, well-ventilated place. Combustible materials should be stored away from extreme heat and away from strong oxidizing agents.

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

Personal Protection: Safety glasses. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits: Not available.

Section 9: Physical and Chemical Properties

Physical state and appearance: Solid.

Odor: Not available.

Taste: Not available.

Molecular Weight: Not available.

Color: Not available.

pH (1% soln/water): Not available.

Boiling Point: Not available.

Melting Point: Decomposes.

Critical Temperature: Not available.

Specific Gravity: Not available.

Vapor Pressure: Not applicable.

Vapor Density: Not available.

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: Not available.

Solubility: Not available.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Not available.

Incompatibility with various substances: Not available.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity: Not available.

Special Remarks on Corrosivity: Not available.

Polymerization: No.

Section 11: Toxicological Information

Routes of Entry: Not available.

Toxicity to Animals: Acute oral toxicity (LD50): 6770 mg/kg [Rat].

Chronic Effects on Humans: Not available.

Other Toxic Effects on Humans: Slightly hazardous in case of skin contact (irritant), of ingestion, of inhalation.

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans: Not available.

Special Remarks on other Toxic Effects on Humans: Nuisance dust.

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are more toxic.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:

Section 14: Transport Information

DOT Classification: Not a DOT controlled material (United States).

Identification: Not applicable.

Special Provisions for Transport: Not applicable.

Section 15: Other Regulatory Information

Federal and State Regulations: TSCA 8(b) inventory: Guar gum

Other Regulations: Not available..

Other Classifications:

WHMIS (Canada): Not controlled under WHMIS (Canada).

DSCL (EEC):
This product is not classified according to the EU regulations.

HMIS (U.S.A.):

Health Hazard: 1

Fire Hazard: 1

Reactivity: 0

Personal Protection: E

National Fire Protection Association (U.S.A.):

Health: 1

Flammability: 1

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Safety glasses.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

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Last Updated: 06/09/2012 12:00 PM