2018 AECOM

Technical Leadership

Eleventh International Conference on the Remediation of Chlorinated and Recalcitrant Compounds
Palm Springs, California | April 8-12, 2018

https://www.aecom.com/battelle/
### SHORT COURSES

**SUNDAY, APRIL 8**


**ITRC Training: Managing PFAS Contamination at Your Site: Site Characterization, Sampling, Fate and Transport, along with Remedial Alternatives** - Dora Chiang

### PLATFORM PRESENTATIONS

**MONDAY, APRIL 9**

**D2. Applications of R and Machine Learning to Groundwater Data**
Dustin Bytautas

**B1. In Situ Hydrolysis and Thermal Treatment of 1,1,1-TCA during Electrical Resistance Heating**
Art Taddeo

**TUESDAY, APRIL 10**

**A3. Bioaugmentation to Enhance Biodegradation of 1,4-Dioxane**
Rebecca Mora

**C4. Australia’s First Installation of Horizontal Wells for In Situ Chemical Oxidation (ISCO) and Biosparging: Lessons Learned** - Pedro Balbachevsky

### SESSION CO-CHAIRS

**WEDNESDAY, APRIL 11**

**A6. PFAS Site Characterization**
Dora Chiang

**E7. Cold Region Case Studies**
Bruce Noble

**H5. Improvements in Site Data Collection, Data Management, and Data Visualization**
Junaid Sadeque

### PANELIST

**WEDNESDAY, APRIL 11**

**TRACK A. PFAS Precursors: Is It Too Early or Too Late to Worry About Them?**
Dora Chiang

**TRACK A. PFAS Precursors: Is It Too Early or Too Late to Worry About Them?**
Rachel Casson
# Platform Presentations

**Wednesday, April 11**

**F3. Evaluating LNAPL Mobility and Transmissivity: A Route to Case Closure**  
Sharon Drummond

**F3. Comparison of Laser-Induced Fluorescence Profiles following a Decade of LNAPL Recovery**  
Peter Stumpf

Randy Sillan

**F5. Field-Scale Evaluation of Aerobic Bio-Oxidation to Deplete Groundwater Contaminants from Coal Tar and Creosote**  
Randy Sillan

**A7. What Are Key Considerations for an Approach to Human Health Intake Assessment for PFAS?**  
Amanda Lee

**C6. Opportunities and Limitations of DNAPL Treatment via Injectable ZVI/Carbon: Results of Bench- and Field-Scale Tests**  
Matthias Ohr

**H4. Using Applied Environmental Sequence Stratigraphy to Predict TCE Contaminant Migration Pathways: Air Force Plant 42, Palmdale, California**  
Ryan Samuels

**H4. A Geology-Focused Approach at Three Industrial Sites to Enhance Conceptual Site Models and Remedial Design**  
Katharine Carr

**Thursday, April 12**

**A8. Transformation of PFAS Precursors at an Australian Air Force Base: An Ongoing or Artifact Process?**  
Rachel Casson

**A9. Applications of Electrochemical Oxidation for PFAS Destruction in Water, Liquid, and Solid Wastes**  
Dora Chiang

**A10. Pilot-Scale GAC Filtration Study to Assess Breakthroughs of PFAAs and Precursors**  
Dora Chiang

**B3. Groundwater Recovery to Natural Biodegradation: Demonstrating a Better Remedial Approach to Closure**  
Doug Gray

**B9. PCB Remediation Using an Innovative ISCO Approach: Bench and Pilot Study Results**  
Doug Gray

**C9. Overcoming Challenges and Closure-Strategy Development at a Long-Term, Large-Scale CVOC Bioremediation/Thermal Project**  
Matthew Panciera

**D8. Working on the Railroad: Implementation of Sustainable Remediation at a Programmatic Level**  
Gerlinde Wolf

**F8. Compartmentalized Approach to Bedrock and Overburden Remediation at a Legacy Petroleum Site**  
Brandt Morrow

**H5. Interactive Visualizations of 5 Million Sensor Measurements of the Capillary Fringe Lead to an Optimized Soil Remedy**  
Cameron Dixon
<table>
<thead>
<tr>
<th>POSTERS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MONDAY, APRIL 9</strong></td>
</tr>
<tr>
<td><strong>Testing Commonly Used Insect Repellents for 17 PFAS</strong></td>
</tr>
<tr>
<td><strong>Enhanced Bioremediation in Weathered Bedrock: Modifying ROD Selected Remedy, Design and Implementation</strong></td>
</tr>
<tr>
<td><strong>Summary of State Approaches to Vapor Intrusion – 2018 Update</strong></td>
</tr>
<tr>
<td><strong>Coal Combustion Residual (CCR) Remediation Road Map - How to Get There From Here</strong></td>
</tr>
<tr>
<td><strong>Performance of a Large-Scale Reductant Amended Backfill for Remediation of Hexavalent Chromium Impacted Groundwater</strong></td>
</tr>
<tr>
<td><strong>Enhanced In Situ Bioremediation Pilot Study for Treatment of 1,1,1-TCA</strong></td>
</tr>
<tr>
<td><strong>Passive Hydrocarbon Remediation in a Foreshore Marine Environment</strong></td>
</tr>
<tr>
<td><strong>Large-Scale Remediation of TCE Using Abiotic Degradation with ZVI and Enhanced Biological Degradation</strong></td>
</tr>
<tr>
<td><strong>MNA as an Alternative to the Existing Remedial Approach at a Complex Historic Industrial Site with Multiple COCs</strong></td>
</tr>
<tr>
<td><strong>Assessing NSZD for Creosote DNAPLs</strong></td>
</tr>
<tr>
<td><strong>WEDNESDAY, APRIL 11</strong></td>
</tr>
<tr>
<td><strong>Execution of a Field-Scale Planted Greenhouse PFAS Uptake Study at RAAF Base Williamtown, New South Wales, Australia</strong></td>
</tr>
<tr>
<td><strong>Optimizing Enhanced In Situ Bioremediation of Commingled Chlorinated Ethanes and Ethenes at Two Groundwater Remediation Sites</strong></td>
</tr>
<tr>
<td><strong>Address Long-term Back-diffusion from Low Permeability Zone with Horizontal ISCO Permeable Barriers</strong></td>
</tr>
<tr>
<td><strong>An Accurate and Auditable Cost Estimating Tool for Environmental Remediation Financial Liability</strong></td>
</tr>
<tr>
<td><strong>Roadmap for Ranking PFAS-Contaminated Sites Based on Exposure Pathway Analysis</strong></td>
</tr>
<tr>
<td><strong>Benefits and Limitations of Aggressive Source Removal and Treatment at a Chlorinated Solvent Site</strong></td>
</tr>
<tr>
<td><strong>Mass Discharge Approved as Primary Regulatory Criteria at Two Major Industrial Sites</strong></td>
</tr>
<tr>
<td>POSTERS</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| **Understanding Subsurface Stratigraphy for PFAS Environmental Characterization Using Modern Analogs**  
  Junaid Sadeque                                                        |
| **The Benefits of Acquiring Continuous Cores for Aquifer Characterization: Lessons from Petroleum Industry Best Practices**  
  - Junaid Sadeque                                                      |
| **Leveraging Environmental Sequence Stratigraphy to Refine Mass Discharge Estimates: Magothy Aquifer, New Jersey Coastal Plain**  
  - Ryan Samuels                                                        |
| **Implementation of a Passive DNAPL Recovery Program at a U.S. EPA Region 5 CERCLA Site**  
  Doug Gray                                                             |
| **Optimization of Large-Scale LNAPL Recovery Operations Using a Graphical Analysis Tool**  
  Cynthia Shen                                                          |
| **Combining Multiple Remedial Technologies to Accelerate Property Development and Manage Off-Site Risk**  
  Carol-Anne Taddeo                                                     |
Short Courses
Sequence Stratigraphic Concepts and their Application to Conceptual Site Models and Remedial Strategies: A Hands-On Training

JUNAID SADFEQUE, PH.D. (AECOM), RYAN SAMUELS, MS (AECOM)

This course will provide hands-on training on how to use environmental sequence stratigraphy to develop more accurate conceptual site models (CSMs) and remediation strategies. The potential audience includes environmental professionals and students engaged in remediation projects.

Overview: Sequence stratigraphy has arguably revolutionized stratigraphic analysis in the oil and gas industry since the 1970s, but to date, few environmental companies have utilized this power tool. Although some of us are gradually catching up with sequence stratigraphic concepts, the paradigm of lithostratigraphy is still prevalent in the environmental community. This significantly limits our ability to construct accurate CSMs and develop effective investigation/remedial strategies.

In this course, participants will be made aware of the pitfalls of lithostratigraphy and demonstrate the predictive ability of sequence stratigraphy in accurately determining contamination flow paths.

Besides lecturing on the fundamental concepts, the student will be provided with ample opportunity to try out the techniques of sequence stratigraphy using real data from the environmental industry. At the end of the day, the participant will go home with a better understanding of how sequence stratigraphy can be properly implemented into investigation and remediation projects.

Outline:

Introductions

1. Lecture: Impact of stratigraphy in groundwater modeling
   a. What’s wrong with lithostratigraphy?
   b. Basic definitions and jargons of sequence stratigraphy
   c. Exercise 1

2. Lecture: Stratigraphic surfaces and their recognition criteria in borehole cores and logs
   a. Exercise 2

3. Lecture: Alluvial fans, channels and deltas: how to recognize in subsurface
   a. Exercise 3

4. Special Guest Lecture: The role of Sequence Stratigraphy in Mass Flux calculations

5. Special Guest Lecture: Application of Sequence Stratigraphy in PFAS investigation

6. Lecture: How to correlate? Pitfalls, challenges and solutions

7. Lecture: The role of modern analogs for environmental sequence stratigraphy
   a. Exercise 4

Laptops are not required for this course. Colored pencils and paper for the exercises will be provided.
ITRC Training: Managing PFAS Contamination at Your Site: Site Characterization, Sampling, Fate and Transport, along with Remedial Alternatives

DORA CHIANG, PH.D., P.E. (AECOM) Robert Mueller, M.S. (New Jersey Dept. of Environmental Protection), Christopher Higgins, Ph.D. (Colorado School of Mines), William DiGuiseppi, PG (CH2M Hill), Dora Chiang, Ph.D., P.E. (AECOM), Stewart Abrams, P.E. (Langan Engineering), Virginia Yingling (Minnesota Department of Health)

Objective. Per- and poly-fluoroalkyl substances (PFAS) are an emerging group of contaminants that present unique issues with site characterization, sampling and analysis, fate and transport, and remedial alternatives. Regulators, site managers, facility owners, consultants, technology developers, and other stakeholders will all benefit from this state-of-the-art presentation.

Overview. In 2017, the Interstate Technology and Regulatory Council (ITRC) assembled a team of over 300 PFAS experts drawn from industry, academia, state and federal agencies, consulting, and the U.S. departments of defense and energy. This team developed six fact sheets that provide an overview on PFAS naming conventions, sources and uses, regulatory trends, site characterization, fate and transport, and treatment technologies; these will form the basis of this training. The training will begin with an overview of PFAS in the environment, then will concentrate on three key elements for characterizing and managing PFAS impacted sites—site characterization (including sampling and analysis), complex mechanisms that impact fate and transport, and current and potential remediation technologies. The trainers will present the recommended approaches that should be taken once PFAS contamination is identified.

PFAS in the Environment—PFAS is a family of chemicals that may include as many as 3000+ compounds. The sources and general chemistry of those PFAS thought to be the most environmentally relevant will be highlighted and current knowledge regarding their potential ecological and human health risks will be presented. Precursors that degrade to ecologically important PFAS also will be considered.

Site Characterization—What are the unique aspects of PFAS that pose challenges to getting good site data? This section will cover:

- **Sampling Procedures:** This element introduces state-of-the-art knowledge on proper sampling techniques, sample preparation procedures and transport to the laboratory. The most recent research will be presented to prepare attendees to acquire the best data for their site, while avoiding false positives and false negatives.

- **Laboratory Procedures:** A description of the various laboratory analytical techniques will be presented along with guidance on interpretation of results.

- **Data Accuracy:** Common cross contamination and other issues that can be frequently encountered during sampling and laboratory analysis which unduly bias selection of management actions.

Fate and Transport—How do PFAS move in air, soil, groundwater, and surface water? What are the unique PFAS transport mechanisms that complicate creating a conceptual site model (CSM)? How does the presence of precursors affect the CSM? All of these elements will be presented to help understand these contaminants in the environment.

Treatment & Remediation—Proven treatment and remediation approaches for PFAS are still largely limited to separation and destruction technologies, which will be presented individually. The potential approaches for combining technologies to increase technical and economic feasibility also will be evaluated. Design considerations and performance evaluation will be presented for those technologies that are proven and demonstrated. Current research in emerging (but not yet field-proven) remediation technologies also will be introduced. Case studies will be presented that demonstrate how each of these elements can be applied in the field.

Outline:

1. Overview of the ITRC PFAS team describing the six fact sheets and current team work products in development.
2. Overview of PFAS in the environment
3. Site characterization
4. Sampling of air, water, soil, and biota
5. Laboratory analyses
6. Fate and transport
7. Treatment and remediation technologies
8. Further research needs
Panel Discussion
PFAS Precursors: Is It Too Early or Too Late to Worry About Them?

DORA CHIANG, PH.D., P.E., (AECOM), Ginny Yingling (Minnesota Department of Health), Chris Higgins (Colorado School of Mines), Jennifer Guelfo (Brown University), Rachel Casson (AECOM), Richard Grace (SGS AXYS), Nathan Hagelin (AMEC)

**Background/Objectives.** Per- and polyfluoroalkyl substances (PFASs) have been manufactured and used for the past fifty years as surfactants, processing aids, oil and water repellent coatings and firefighting foams. Perfluoroalkyl acids (PFAAs, which include PFOA and PFOS) are persistent and recalcitrant and have been widely detected in the environment and human sera. Polyfluorinated precursors to PFAAs can biotically and abiotically transform into PFAAs. Although no regulatory criteria have been established for PFAA precursors, concerns regarding their migration and transformation into PFAAs is growing. PFAA precursors include compounds that were the original compositions of PFAS-containing products or intermediate transformation products. The panel will discuss what a practitioner should know about PFAA precursors and what research priorities are essential BEFORE we can properly and reliably determine the data needed for site investigation and remediation.

**Approach/Activities.** The number of precursors measurable with standard analytical methods (typically LC-MS/MS) is very limited. Several methods have been developed to estimate the total fluorine concentrations and results suggest significant mass of PFAA precursors may be present at some sites. Questions and doubts have been raised, beginning with whether precursor concentrations even need to be quantified, but accepting that as important, we should understand how and at what rates these precursors are transformed and transported once released into the environment, and what challenges precursors present for risk and remediation.

**Results/Lessons Learned.** The panel will discuss what a practitioner should know about PFAA precursors and what research priorities are essential BEFORE we can properly and reliably determine the data needed for site investigation and remediation.
Platforms
D2. Applications of R and Machine Learning to Groundwater Data

DUSTIN BYTAUTAS, PE (AECOM, Rocky Hill, Connecticut, USA), Tomasz Kalinowski, Ph.D. (tomasz.kalinowski@aecom.com), (AECOM, Syracuse, New York, USA), Tauhirah Abdul-Matin, Matthew Panciera, PE, Lucas Hellerich, Ph.D., PE

Background/Objectives. Machine Learning is an approach to data analysis and model building where the details and parameters of the model are not explicitly specified by the analyst, but rather, trained by the computer through the use of computational power and large volumes of data. Machine Learning is commonly companion to 'Big Data,' a recently popular term describing datasets that require the use of specialized software because they are too large to analyze using conventional techniques. Driven by advancements in computers, internet technology and field sensors that allow for collection of datasets of unprecedented scale, there is currently a booming ecosystem of new ideas, tools, and techniques for conducting data analysis in the age of “Big Data” and “Machine Learning”. Here we discuss some of the benefits of these modern approaches to data analysis over conventional analysis toolchains, and present case-study examples where the tools have been applied to optimize remediation and monitoring at remediation sites.

Approach/Activities. R is a programming language and statistical data analysis environment where many ‘Big Data’ and ‘Machine Learning’ developments are occurring. Consequently, applications of Machine Learning to groundwater often involve the development of custom software in R. A couple case-studies will be presented of where R software was developed to process and analyze large datasets as part of environmental remediation and monitoring programs.

The approaches presented will focus on demonstrating how developing novel, quantitative metrics from analytical groundwater data can inform site-management decisions, including remediation technology selection based on past performance, predicting a site-specific likelihood of success of different remediation technologies, identifying opportunities for cost-savings through monitoring optimization, and prioritizing sites within a portfolio for remediation. Site metrics and statistics that allow for this must be unbiased by the overall size of the site, irregularities in the sampling frequency or well network distribution, destruction/creation of well locations over time, and other inconsistencies that typically inhibit cross-site comparisons in analytical groundwater data in environmental remediation applications.

In data-intensive efforts, interactive data visualizations are crucial aids that help both in conducting the data analysis and in communicating the findings. Some examples of interactive data visualizations of remediation-metrics built with R and Shiny are presented.

Results/Lessons. The outcomes of the specific case-studies presented were optimized remediation efforts. The lessons learned were that there are new capabilities to environmental remediation applications due to developments in the “Big Data” ecosystem. Modern development environments like “R” and “Shiny” allow for extremely rapid and low cost development of interactive data visualizations and other data-driven applications. The low-cost of development and deployment enables rapid and frequent rounds of iteration towards greater understanding, efficiency, communication, and automation.

B1. In Situ Hydrolysis and Thermal Treatment of 1,1,1-TCA During Electrical Resistance Heating

ART TADDEO (arthur.taddeo@aecom.com) and Shamim Wright, (AECOM, Chelmsford, MA, USA), Lindsay Mitchell (AECOM, Latham, NY, USA), Paul Dombrowski (ISOTEC, Boston, MA, USA)

Background/Objectives. The site is a former industrial property in southern New York State. Past site activities included an automobile manufacturing plant and a printing/publishing business, both of which used chlorinated solvents. Additionally, a former chemical company operated a warehouse/distribution center on the adjacent property. As a result of a fire at the warehouse in 1963, releases of a number of volatile organic compounds (VOC) occurred. Due to fire-fighting efforts, a large amount of these chemicals impacted the site, which is down-gradient and down-slope from the former warehouse. The principle contaminant is 1,1,1-TCA, together with 1,1-DCA and 1,1-DCE. Dense non-aqueous phase liquids have also been observed. The site is listed as a NYSDEC Superfund Site, and the Record of Decision identified in situ thermal treatment as the selected remedy. Project objectives were to attain, to the extent practicable, the low level Class GA Ambient Water Quality Standards, as well as Protection of Groundwater Soil Objectives.

Approach/Activities. Hydrolysis of 1,1,1-TCA is a common reaction; however it is too slow of a process at ambient temperatures for consideration in environmental applications. With the advent of in situ thermal treatment, increased hydrolysis rates with increased temperatures have allowed this process to assist in site treatment. An electrical resistance heating (ERH) approach was implemented which consisted of 101 single and multi-segmented electrodes designed to treat the saturated overburden aquifer from 5 to 55 feet below ground. Treatment was performed within an existing building as well as outside the building.

Results/Lessons Learned. ERH increased subsurface temperatures in the treatment zone to over 100° C. This increase created steam and volatilized contaminants of interest, which were collected and treated above ground. In addition, in situ hydrolysis occurred. Initial groundwater concentrations of 1,1,1-TCA and 1,1-DCA of 440,000 µg/L and 300,000 µg/L, respectively, were reduced to non-detectable levels. Based on results of pre-design investigations, approximately 13,000 pounds of contaminant mass were estimated to exist in both the sorbed and dissolved phases of the impacted zone. Of that, 9,000 pounds consisted of 1,1,1-TCA, 3,000 pounds were 1,1-DCA, and nearly 1,000 pounds were 1,1-DCE. At the end of ERH treatment, based on both soil and groundwater post-treatment monitoring, only 56 pounds of total contaminant mass remained, for an overall reduction of 99.6%. Of the 9,000 pounds of 1,1,1-TCA initially present, only approximately 900 pounds were recovered in the vapor form. Presumably the remainder was treated via in situ hydrolysis. Acetic acid is a known product from the hydrolysis substitution reaction. Acetic acid concentrations rose from non-detect levels to 620,000 µg/L during treatment. Challenges during treatment to be discussed included encountering shallow bedrock during electrode installation which affected ERH performance.

Future site risk management will be discussed with regard to proposed activities for the site following ERH, together with the adjacent source property.
A3. Bioaugmentation to Enhance Biodegradation of 1,4-Dioxane

REBECCA MORA (Rebecca.Mora@aecom.com) and Holly Holbrook (AECOM, Orange, California), Dora Chiang Ph.D., P.E. (AECOM, Atlanta, Georgia), Shaily Mahendra, Ph.D., and Yu Maio (University of California, Los Angeles, California), Sandra Dworatzek (SiREM, Guelph, Ontario, Canada); Kerry Sublette (University of Tulsa, OK), Adria Bodour, Ph.D. and Hunter Anderson, Ph.D. (Air Force Civil Engineering Center, San Antonio, Texas)

Background/Objectives. 1,4-Dioxane is a probable human carcinogen and an emerging contaminant in groundwater at many military and industrial contaminated sites. Numerous studies provide evidence that 1,4-dioxane can be biodegraded aerobically and several cases have documented both metabolic and cometabolic 1,4-dioxane biodegradation since the early 1990s. However, enhanced in situ biodegradation efforts have been limited by inconsistent microbial performance in the field. Pseudomonadocardia dioxanivorans CB1190 (CB1190) is a monooxygenase-expressing microorganism that has been shown to metabolically degrade 1,4-dioxane as a source of carbon and energy in the laboratory. This technology field demonstration project will evaluate bioaugmentation with CB1190 as a means to enhance in situ biodegradation of 1,4-dioxane.

Approach/Activities. Specific technical objectives for this project include evaluation of 1) growth and distribution of CB1190 in the subsurface, 2) the effect of CB1190 addition on in situ 1,4-dioxane biodegradation, 3) the effect of oxygen and nutrient addition (e.g., nitrogen, phosphorus, and trace elements) on in situ 1,4-dioxane biodegradation kinetics, and 4) the ability of in situ biodegradation of 1,4-dioxane to reduce treatment timeframes and (O&M) costs compared to other remediation technologies currently applied to treat this emerging contaminant. Based on results of the site selection process, the project is being performed in Area of Concern (AOC) 1 at former Air Force Plant 3 (AFP), in Tulsa, Oklahoma. Following site assessment, a microcosm study was performed to optimize the CB1190 culture dosage and nutrient requirements for bioaugmentation in the field. After confirming these requirements, larger volumes of CB1190 were grown for field application. In February 2016, CB1190 was injected into an injection well followed by a robust direct-push sampling event to evaluate distribution of CB1190 in the subsurface. In September 2016, CB1190 was injected into an injection well as well as in four direct push injection points. Groundwater sampling in surrounding wells was performed following bioaugmentation to evaluate in situ biodegradation of 1,4-dioxane. In late 2017, an in situ bioreactor (ISBR) approach will be evaluated. Control and CB1190-baited ISBRs will be deployed in up to two wells following a monitoring program to evaluate the CB1190 population in the ISBR and 1,4-dioxane degradation over time.

Results/Lessons Learned. Three different doses of CB1190 were tested in the microcosm study, both with and without nutrients. 1,4-Dioxane biodegradation was most effective in the mid and high-dose CB1190 bottles that included nutrients. Culture growth to larger volumes was performed by SIREM for field application. Results of the first bioaugmentation event in February 2016 indicated CB1190 was distributed in the subsurface at least 10 feet away from the injection well; however, cell counts were low. Based on these results, SIREM grew a larger volume of culture and maximized the CB1190 cell density to the extent possible for the next injection event. This larger injection volume was injected in early September 2016 and monitoring results showed that CB1190 survived in situ, but the population was still too low to degrade 1,4-dioxane. In 2018, the ISBR approach will be employed to evaluate whether it can help sustain an adequate in situ population of CB1190 and increase effectiveness of in situ biodegradation of 1,4-dioxane.

C4. Australia’s First Installation of Horizontal Wells for In Situ Chemical Oxidation (ISCO) and Biosparging – Lessons Learned

PEDRO BALBACHEVSKY (pedro.balbachevsky@aecom.com), (AECOM, Sydney, NSW, Australia), Will Cadicott (ISOTEC, Newton, MA, USA), Mike Mercuri (Matrix Drilling, Melbourne, VIC, Australia), Mike Sequino (DTI, Wallingford, CT, USA)

Background/Objectives. For the first time in Australia, 288 metres of horizontal wells were installed underneath an operational resin manufacturing facility in Botany Bay, NSW. The wells were installed to enable chemical oxidants and compressed air to be sequentially injected into the local aquifer to degrade contaminants present in the vadose and saturated zones.

A narrow and fast moving plume mainly comprising toluene, ethylbenzene and xylenes was detected at the site in 1999, originating from three above and below ground sources. The plume was migrating offsite, with the potential of reaching sensitive human and ecological receptors, therefore a containment system comprising of an Air Sparging / Soil Vapour Extraction Barrier (AS/SVE) was installed along the downgradient boundary of the site in 2011 and has been operating successfully since then. The next natural step was to treat the contaminant source zones. However, access to those areas was compromised by significant amounts of above and below ground operational infrastructure. To address site access restrictions, a longitudinal horizontal approach was selected as the only effective method to reach and deliver oxidising reagents and compressed air to the whole extent of the contaminant plume, including the target source zones.

Approach/Activities. Groundwater levels within the site range from 4.8 to 5.2 metres below ground level (mbgl) and the plume extends vertically to 8 mbgl. Therefore, the horizontal well screens were installed at around 8 mbgl, longitudinally to the plume movement direction (north-south). Three horizontal wells were installed, with a total combined screen length of 153 metres.

The first ISCO event was completed in August 2017 and comprised the injection of 161,000 litres of reagent. The reagent selected was Modified Fenton Reagent (MFR), a combination of stabilised hydrogen peroxide and chelated ferrous sulphate. The authors believe that this is likely the first time that MFR has been injected through horizontal wells. Three injection events are planned for the site, and will be conducted on a quarterly basis. Each injection event will be followed by a two-week latent period and a performance Groundwater Monitoring Event (GME). Results from the GMEs will be used to assess the efficiency of the treatment in reducing the footprint and magnitude of the subject plume. Three sets of monitoring results will be available by February 2018.

Results/Lessons Learned. The typical equipment setup used in ISCO injections had to be modified to account for the larger-scale of this project. A team comprising local and American companies worked together to complete the job safely and ahead of schedule. Two dedicated progressive cavity pumps transferred the reagent solutions (oxidant and catalyst) from 34,000 litre tanks into each one of the three Ø80 mm injection wells. Permanent dedicated pipework and equipment allowed for a safe operation period. Seven data loggers installed inside nearby vertical wells helped to monitor the process, keeping track of any changes in mounding, temperature and water quality parameters. Mounding peaks of 40 cm and temperature changes of up to 17°C were observed as far as 4 metres away from horizontal well alignments.
F3. Evaluating LNAPL Mobility and Transmissivity: A Route to Case Closure

SHARON DRUMMOND (Sharon.Drummond@aecom.com), (AECOM, Beltsville, MD, USA), Matthew J. Zenker (AECOM, Morrisville, NC, USA)

Background/Objectives. The purpose of this investigation is to demonstrate that removal of light non-aqueous phase liquid (LNAPL; #2 fuel oil and gasoline) at a former manufacturing facility has been completed to the maximum extent practicable and no further action is required. The site is located within the Maryland Coastal Plain Physiographic Province and site sediments consist predominantly of sand and silty sand with discontinuous layers of silts and clays. Environmental investigation and remedial activities began in 1995 when LNAPL was first encountered on the site. A remediation system using vacuum-enhanced groundwater extraction (VEGE) and soil vapor extraction (SVE) began operation in 1998 and was deactivated in 2011 due to diminishing recovery. Manual recovery using sorbent socks/bailers ensued, and from 2013 to 2015 automated LNAPL skimming devices were utilized in several of the on-site monitoring wells to maximize LNAPL recovery. Although LNAPL thicknesses had reduced significantly from 1998 to 2015, measurable quantities were still detected in the on-site monitoring wells. In accordance with the corrective action plan (CAP) developed for the site through the Maryland Department of the Environment (MDE) Oil Control Program (OCP), LNAPL must be removed to the maximum extent possible, which has historically been interpreted by MDE as a non-measurable sheen. In order to achieve case closure, a comprehensive LNAPL mobility study was conducted to provide quantitative evidence that LNAPL has been removed from the site to the maximum extent practicable despite the current and expected long-term presence of measurable LNAPL.

Approach/Activities. The LNAPL mobility study included soil boring advancement, transmissivity testing, analysis of the LNAPL fluid properties, and evaluation of long-term fluid gauging data and volume of LNAPL recovered via the various remedial techniques previously utilized. Skimming tests were completed for all wells containing measurable LNAPL thickness during the study period (November 2015) in order to measure LNAPL transmissivity. Soil cores were collected from eight targeted areas of the site known to contain elevated LNAPL saturation in order to better understand the occurrence, vertical distribution, mobility and recoverability of LNAPL in site soils. Additionally, an undisturbed soil core was collected and immediately frozen with liquid nitrogen to preserve pore structures and fluid saturation, and to minimize movement of liquids within the core. The soil core was photographed under visible and ultraviolet light, and analyzed for several parameters, including fluid saturation, grain size distribution, LNAPL mobility and capillary pressure characteristics. The objectives of these analyses were to obtain quantitative estimates of LNAPL saturation versus depth/grain size, estimate the mobile and residual LNAPL fractions, and measure the capillary pressure parameters of the soil intervals containing the most significant LNAPL impacts.

Results/Lessons Learned. The results of this study indicate through several lines of evidence that the presence of LNAPL poses no significant risk, as transmissivity values are an order of magnitude below the practical recovery range of 0.1 to 0.8 ft²/day (ITRC, 2009), measured soil LNAPL saturation is low and historic gauging and capillary pressure data demonstrate low potential for migration. On the merit of these observations, MDE approved a CAP addendum allowing LNAPL to remain in place. To date, all on-site monitoring wells have been abandoned per MDE approval and the receipt of No Further Action (NFA) letter from MDE is pending. This case study demonstrates the ability to successfully close LNAPL sites despite historically strict requirements regarding the presence of measurable LNAPL.

F3. Comparison of Laser-Induced Fluorescence Profiles following a Decade of LNAPL Recovery

PETER STUMPF (peter.stumpf@aecom.com), Cynthia Shen, Ram Kannappan, (AECOM, Orange, CA, USA), Joseph Lentini (Shell Soil and Groundwater FDG, Carson, CA, USA), Shailendra Ganna (Shell Global Solutions US Inc, Houston, TX, USA)

Background/Objectives. Light nonaqueous phase liquid (LNAPL) recovery operations using skimming and total fluid pumping methods have been occurring at an active petroleum refinery since the 1980s. An investigation of the extent and vertical distribution of LNAPL was performed adjacent to recovery wells in 2005 using laser-induced fluorescence (LIF) combined with cone penetration testing (CPT). Since 2005, the pumping operations have recovered a significant amount of LNAPL and thus resulted in significant decreases in LNAPL recovery rates at several wells. The objective of this work was to investigate changes in the LNAPL saturation profile adjacent to these active LNAPL recovery wells by advancing LIF/CPT borings. Comparison between historic and recent high-resolution borings and analysis of current and cumulative LNAPL recovery were utilized to assist in developing an understanding of progress towards a remediation endpoint of active LNAPL recovery operations.

Approach/Activities. LNAPL recovery began in the 1980s and is ongoing. The LIF borings advanced in 2005 utilized the Rapid Optical Screening Tool (ROST™) were compared to 2017 borings utilized the Ultra-Violet Optical Screening Tool (UVOST®). Three locations were selected for comparison. The ROST™/UVOST® output were compared for both magnitude of fluorescent response and waveform characteristics to estimate changes in LNAPL saturation and composition, respectively.

Results/Lessons Learned. Comparison of the CPT data indicates that the recent boring locations were similar regarding vertical distribution of soil type to previous locations and similar LIF waveforms were seen, which suggests that ROST and UVOST technologies output are similar and the LNAPL has undergone minimal weathering since 2005. A reduction of fluorescence response was observed in proximity to the recovery wells. Certain zones of coarse-grained sediments, where higher transmissivity would be expected, showed little or no reduction in LIF response. Based on information available from the manufacturer, coarse-grained soil can magnify LIF response as much as 10 times compared with finer grained soil. Conversely, reductions in LIF response were seen in several fine grained units within the screened interval. Overall the reductions in LIF response showed that skimming recovery was able to reduce the submerged LNAPL. Calculation of LNAPL transmissivity values and decline curve analysis at each recovery well suggests that LNAPL recovery operations have reached or are approaching an endpoint despite a lack of reduction in LIF response within the coarse-grained unit which may be already at residual saturation in 2005. The comparison indicated that as the recovery system matures and is approaching the end of recovery, recovery well performance history combined with system optimization may be more effective at evaluating recoverability of remaining LNAPL.

RANDALL SILLAN (randy.sillan@aecom.com) (AECOM, Castle Rock, CO, USA)

Background/Objectives. Impacted groundwater at a former chemical facility flows into a tidally-influenced river. Quantifying mass discharge of chemicals of concern (COCs) to the river is critical to the conceptual site model and necessary to meet regulatory requirements. Thus, accurate and defensible estimates of the mass discharge of COCs from groundwater to the surface water are required. However, tidal effects on temporal variability in groundwater flow and spatial variation in groundwater and mass flux make it difficult to accurately estimate mass discharge to the river. Since tidal effects change groundwater flux throughout a day, hydraulic gradients derived from discrete measurements of groundwater levels in monitoring wells did not provide an accurate estimate of the average groundwater discharge to the river. In addition, concentrations of COCs in wells along the river varied significantly with sample depth and well location.

Approach/Activities. Two methods were used to quantify mass discharge to the river. The transect method combined the average Darcy flux and COCs concentrations in wells within a transect parallel to the river. The second method used Passive Flux Meters (PFMs) in wells within the transects to directly measure spatial variability in groundwater and mass flux. The transect method required accurate measurement of groundwater elevations with level sensors and data loggers to estimate the direction and magnitude of the effective hydraulic gradient over several days. Using the effective hydraulic gradient and a homogeneous assumption for hydraulic conductivity, a uniform groundwater flux was estimated for the transect. Mass discharge through the transect was then estimated by multiplying the concentration of each COC to the uniform groundwater flux and the area of the transect represented by each well. Although the transect method is the most common approach to estimating mass discharge through a transect, significant error in the mass discharge estimate is introduced by assuming uniform flow in heterogeneous systems that likely contain preferential flow paths that concentrate mass flux.

In the second approach, PFMs were deployed to measure the vertical variability in groundwater and mass flux at each well within the transect. Results from the PFMs are interpolated across the transect and used to estimate mass discharge to the river that is expected to be more representative and accurate for heterogeneous flow. In addition, the spatial and vertical variability in mass flux with the transect was used to identify likely locations of the upgradient source of COCs.

Results/Lessons Learned. The tidal study revealed the near real-time changes in the magnitude and direction of the hydraulic gradient. The overall effective hydraulic gradient was estimated from high-frequency data collection and improved the estimate of the average uniform groundwater flux in comparison to single snapshots of groundwater elevations. Deployment of PFMs to measure spatial variability in mass flux improved the accuracy and confidence in the estimate of mass discharge to the river. The results from the PFMs were also compared to analytical models of potential mass flux from NAPL dissolution and matrix-back diffusion to evaluate the nature of the COCs source discharging to the river.

F5. Field-Scale Evaluation of Aerobic Biooxidation to Deplete Groundwater Contaminants from Coal Tar and Creosote

RANDALL SILLAN (randy.sillan@aecom.com) (AECOM, Castle Rock, CO, USA)

Background/Objectives. Aerobic biooxidation of dissolved-phase petroleum hydrocarbons (including tar and creosote-related compounds) occurs naturally or via engineered applications when suitable microbial populations and geochemical conditions are present in the aquifer. During aerobic biooxidation, microorganisms utilize hydrocarbons as electron donors in the presence of oxygen as the primary electron acceptor. Biosparging is a proven, effective remediation technology to enhance aerobic biooxidation of dissolved hydrocarbons typically observed in groundwater at coal tar and creosote sites. Enhancing biooxidation in the DNAPL tar source area can enhance dissolution of hydrocarbons from the DNAPL and change the composition of the DNAPL. A NAPL dissolution model that includes a Raoult’s Law solubility model was developed to evaluate the ability to effectively weather hydrocarbons from DNAPL and meet groundwater criteria using biosparging. The Raoult’s Law solubility model is developed from a method that includes laboratory analysis of the NAPL composition and water from NAPL-water equilibrium studies.

Approach/Activities. Engineered applications of biosparging were implemented at a former manufactured gas plant (MGP) site in Florida and a former wood-treating site in Montana. At the Florida site, water-gas tar DNAPL is a source of dissolved-phase VOCs and polycyclic aromatic hydrocarbons (PAHs) to groundwater migrating offsite. Following a 9-month biosparging pilot study at the site boundary to enhance aerobic biooxidation of VOCs and PAHs, the biosparging system was expanded in 2016 to decrease offsite mass flux, and achieve treatment criteria offsite. A portion of the biosparging system that is positioned within the DNAPL tar source area provided data to evaluate DNAPL weathering and use the DNAPL depletion model to estimate the time required effectively weather the groundwater contaminants from the DNAPL.

At the Montana site, creosote DNAPL is primarily a source of dissolved pentachlorophenol (PCP) and PAHs to groundwater. A 10-month biosparging pilot study was completed in 2016 in a portion of the creosote source area to evaluate the ability of biosparging to reduce the mass of PCP and PAHs in soil (DNAPL) and groundwater. The pilot study included baseline and post treatment collection and analysis of soil and groundwater samples to estimate the effective removal of PCP and PAHs from the creosote and mitigate mass discharge of PCP and PAHs to groundwater.

Results/Lessons Learned. At the Florida site, biosparging decreased the mass fraction of isopropylbenzene and naphthalene in the NAPL by 97% and 85%, respectively. To fit the biosparging performance data, the DNAPL depletion model estimated half-lives of 0.1 day for isopropylbenzene and 0.4 days for naphthalene. At the Montana site, biosparging decreased the mass fraction of PCP and naphthalene in the NAPL by 66% and 39%, respectively. The modeled aerobic biooxidation half-lives are 0.7 days for PCP and 0.4 days for naphthalene. The results from the pilot studies and DNAPL depletion modeling showed that enhanced aerobic biooxidation can be an effective strategy to weather contaminants from DNAPL tars and creosotes. In addition, the DNAPL depletion model indicates that the groundwater contaminants can be effectively removed (weathered) from the DNAPL in a reasonable time that ranges from 4 to 6 years.
Approach/Activities. A review of the traditional risk assessment intake calculations used for other persistent organic pollutants was undertaken to determine how applicable they were for PFAS compounds, particularly PFOS, PFOA and PFHxS. The review considered available physical and chemical property information as well as estimation of steady state blood serum calculations and transfer into human breast milk, animal milk, fruit and vegetables, eggs and animal meat.

Results. The review identified that the risk assessment intake equations traditionally used for other persistent organic pollutants cannot be readily applied to PFAS because they rely on chemical and physical parameters which have not been established for PFAS, or are unable to be established. In addition due to rapid absorption of PFAS within blood serum, intake calculations which include consideration of transfer into fat are not relevant.

The review resulted in modifications to the following risk assessment intake estimation specific to PFAS:

- Human breast milk calculation with concentrations in breast milk determined from steady state serum concentration combined with a blood serum to breast milk ratio from published literature.
- Egg ingestion with modifications to include a transfer factor from published literature relating PFAS concentrations in eggs to dietary intake by chickens.
- Livestock meat calculations with concentrations in meat determined from steady state livestock blood serum based on empirical tissue to serum ratios.
- Fruit and vegetable calculations with theoretical soil to plant tissue or water to plant tissue uptake factors based on studies relevant to the edible portion of the plant.
- Livestock milk calculations with concentrations in milk determined from steady state livestock blood serum combined with empirical blood to milk ratios.

These modifications to the intake assessment equations enable a more representative estimate of PFAS intake to be established compared with the risk assessment intake equations traditionally used for other persistent organic pollutants. The reliance on empirical data from published literature emphasises the need for continued international investment in high quality scientific research into these aspects of the environmental chemistry of PFAS. Risk assessment work for these compounds needs to acknowledge the reliance on this ongoing research and that assessments may need to be revisited as new data become available.

C6. Opportunities and Limitations of DNAPL Treatment via Injectable ZVI/Carbon: Results of Bench- and Field- Scale Tests

AMANDA LEE (Amanda.Lee@aecom.com), Michael Archer (AECOM Australia Pty Ltd, Melbourne, Australia)

Overview. Per and poly fluoroalkyl substances (PFAS), particularly perfluorooctanesulfonic acid (PFOS), perfluoroctanoic acid (PFOA) and perfluorohexane sulfonate (PFHxS), are now known to be widely spread all over the world as a contaminant. Due to their unique chemical structure and potential to bioaccumulate the risk assessment intake calculation approach traditionally used for other persistent organic pollutants requires modification.

Approach. A review of the traditional risk assessment intake calculations used for other persistent organic pollutants was undertaken to determine how applicable they were for PFAS compounds, particularly PFOS, PFOA and PFHxS. The review considered available physical and chemical property information as well as estimation of steady state blood serum calculations and transfer into human breast milk, animal milk, fruit and vegetables, eggs and animal meat.

Results. The review identified that the risk assessment intake equations traditionally used for other persistent organic pollutants cannot be readily applied to PFAS because they rely on chemical and physical parameters which have not been established for PFAS, or are unable to be established. In addition due to rapid absorption of PFAS within blood serum, intake calculations which include consideration of transfer into fat are not relevant.

The review resulted in modifications to the following risk assessment intake estimation specific to PFAS:

- Human breast milk calculation with concentrations in breast milk determined from steady state serum concentration combined with a blood serum to breast milk ratio from published literature.
- Egg ingestion with modifications to include a transfer factor from published literature relating PFAS concentrations in eggs to dietary intake by chickens.
- Livestock meat calculations with concentrations in meat determined from steady state livestock blood serum based on empirical tissue to serum ratios.
- Fruit and vegetable calculations with theoretical soil to plant tissue or water to plant tissue uptake factors based on studies relevant to the edible portion of the plant.
- Livestock milk calculations with concentrations in milk determined from steady state livestock blood serum combined with empirical blood to milk ratios.

These modifications to the intake assessment equations enable a more representative estimate of PFAS intake to be established compared with the risk assessment intake equations traditionally used for other persistent organic pollutants. The reliance on empirical data from published literature emphasises the need for continued international investment in high quality scientific research into these aspects of the environmental chemistry of PFAS. Risk assessment work for these compounds needs to acknowledge the reliance on this ongoing research and that assessments may need to be revisited as new data become available.
H4. Using Applied Environmental Sequence Stratigraphy to Predict TCE Contaminant Migration Pathways: Air Force Plant 42, Palmdale, California

RYAN C. SAMUELS (Ryan.Samuels@aecom.com) (AECOM, Arlington, VA, USA), John L. Gillespie (AFCEC, San Antonio, TX, USA)

Background/Objectives. The Antelope Valley (Los Angeles County, California) consists predominantly of unconsolidated alluvially-sourced gravels, sands, silts, and clays that contain an essential source of groundwater for hundreds of thousands of people. Because these sediments can be easily contaminated in the subsurface, they require a comprehensive understanding of stratigraphic constraints on contamination migration pathways in the region. In this study, we examine the regional and site-specific ("plume scale") extent and connectivity of late Pleistocene to Holocene alluvial fan deposits at Air Force Plant 42 (AFP 42), Palmdale, California, by using detailed facies analysis within an environmental sequence stratigraphic framework.

Approach/Activities. We correlate depositional sequences from continuous borehole data and geophysical logs to trace strike and dip cross sections throughout AFP 42. This information is then combined with detailed facies models, developed after examining modern analogs via Google Earth aerial imagery, to allow us to determine the continuity of confining beds/aquifer sands and to predict TCE contaminant migration pathways.

Results/Lessons Learned. Regionally, this study reveals that alluvial fan sediments are sourced from the uplifted San Gabriel Mountains to the south and dip to the north-northeast. Despite variable grain-sizes, all alluvial fan facies have at least some degree of vertical and horizontal transmissivity. On a plume scale, water preferentially flows through coarse-grained channel bar deposits while fine-grained floodplain and interfluve deposits act as flow barriers/baffles. Consequently, channel bar connectivity appears to be the predominant stratigraphic factor affecting the shape of the contaminant plume beneath AFP 42.

H4. A Geology Focused approach at Three Industrial Sites to Enhance Conceptual Site Models and Remedial Design

KATHARINE CARR, PG (katharine.carr@aecom.com) and Assaf A. Rees, PE (AECOM, Long Beach, CA)

Background/Objectives. A geology-focused approach to remediation site management, from the development of the conceptual site model (CSM) to subsequent selection, design and implementation of the remedy, increases the efficiency, reduces uncertainties, and improves the likelihood of achieving site goals. Too often the heterogeneities inherent to the subsurface are not adequately accounted for in the CSM leading to inefficiencies and suboptimal performance of the site remedy. Examples of the effectiveness of the geology-focused approach will be presented for three industrial sites, two in Southern California and one in Minnesota. These sites are impacted with chlorinated solvents, gasoline, and pentachlorophenol/diesel, respectively.

Approach/Activities. At each of these sites, investigation and monitoring activities have been ongoing for extended periods of time, with several pilot tests conducted and full scale remedies at various stages of design implementation. Prior to implementing the remedial design, a geology-based approach was implemented by evaluating a combination of historical boring logs and high-resolution data (CPT, MIP, HPT), which were then verified by detailed geological logging of new cores and environmental sequence stratigraphy (ESS) methods. These were used to create enhanced CSMs and identify high-flux zones in three dimensions. Hydrological and chemical data were then used to develop models of the site contaminant plume and focus the remedial design, technology testing, and full-scale implementation.

Results/Lessons Learned. At the petroleum site, two discrete high-flux zones were identified, corresponding to a continuous geology of fine to medium poorly-graded sand. These are underlain by interbeds of silt, sandy silt, and silty sand, which grade finer with depth. Pilot-scale testing demonstrated the ability of aerobic bioremediation using biosparging to reduce the mass discharge along the boundary by 99%. A full-scale biosparging system, with automated pulsing and flow control, was consequently designed to protect the entire boundary and is currently pending construction.

At the PCP/diesel site, high flux zones and confining layers, corresponding to glacial and fluvial deposits, were delineated at high resolution and the extent of the downgradient plume characterized in three dimensions. Pilot studies evaluating in situ chemical oxidation (ISCO) had previously been conducted. The revised CSM will be utilized in the design of the full scale remedy in late 2017/early 2018.

At the chlorinated site, five discrete high-flux zones were identified corresponding to a geology of estuary, fluvial, and near shore marine deposits of fine to medium sand with occasional coarse sand sequences. Each discrete zone is underlain by a confining unit of 5 to 10 feet in thickness. Many of the historical wells had been installed not with regard to this geological interpretation. New monitoring wells were installed into high-flux zones to characterize each zone’s chemical and hydrological properties, resulting in data that was significantly different with regards to the nature and extent of the groundwater plume and hydraulic conductivities. Hydraulic recirculation was selected as the boundary remedy with enhanced anaerobic bioremediation amendments to treat the source area.
A8. Transformation of PFAS Precursors at an Australian Air Force Base: An Ongoing or Artifact Process?

RACHEL CASSON (Rachael.Casson@aecom.com)(AECOM, Sydney, New South Wales, AU) Vicki Pearce (Department of Defence, PFAS Investigation and Management Program, AU) Dora Chiang (AECOM, Atlanta, Georgia, USA)

Background/Objectives. Knowledge regarding the complexity and mechanisms of fate and transport of Per- and Poly-Fluoro-alkyl Substances (PFAS) in the environment is evolving rapidly. In many instances there is negligible correlation between the findings of published literature, including generic conceptual site models, and ‘real world’ conditions. This uncertainty is further confounded by theories that the presence and transformation of PFAS precursors into Per-Fluoroalkyl acids (PFAAs) can complicate the predictions of PFAS migration through the environment. Understanding the fate and transport of PFAS and which factors affect subsurface mobility is critical. To bridge the gap in understanding, an empirical spatial study has been conducted at an Australian Air Force Base (Study Area) to assess the mobility of precursors in the source area and how aerobic conditions at and near a water retention dam may induce the transformation of PFAS precursors, resulting in elevated concentrations of PFAS down gradient of the primary source. This study also evaluates the usefulness of total oxidisable precursor assay (TOPA) on understanding the precursor behaviours.

Approach/Activities. The Study Area forms part of a larger investigation area (50 km2) across the entire Base and coastal neighbouring land. The Study Area is located on highly permeable sandy soils; a shallow groundwater table with complex migration pathways; dynamic interaction between rainfall, surface water and groundwater; and runoff draining through extensively modified networks to two separate marine environments, containing wetlands and commercial fishing. Off-Base the surface water and groundwater is extensively used for residential and agricultural purposes. Soil, groundwater, surface water and sediment were collected in winter from a north – south transect (direction of groundwater flow) and were analysed for 28 – 31 different PFAS using a high resolution Quadrupole Time of Flight Mass Spectrometry (Q-TOF /MS) and Liquid Chromatography (LC – MS/MS). The same samples were tested using the Total Oxidisable PFAS (TOP) Assay; cations / anions; Total Organic Carbon (TOC); and Dissolved Organic Carbon (DOC). Geochemical parameters including pH, temperature, oxidation-reduction potential, dissolved oxygen and conductivity, were measured for groundwater and surface water. In addition, bench scale column trials have been commenced to further understand transformation factors and whether transformation is an ongoing or artefact process.

Results. Results to date have indicated that:

- 27 different PFAS including six PFAS precursors/intermediates were identified in soil in the source area, 19 different PFAS were identified in the groundwater, 10 in the sediment and 12 different PFAS in the surface water.
- After TOPA, perfluoroalkyl carboxylic acids (PFCAs) concentrations in the soil and sediment at the primary source area significantly increased. The PFCA concentration delta before and after TOPA suggest the abundance of PFAS precursors that are not analysable before TOPA. However, the study found very little to no oxidisable precursor mass in groundwater and surface water, suggesting that the precursors are relatively immobile in the soil and sediment of source area. Correlations between geochemical parameters and potential PFAS precursor transformation will be made and the significance between surface water and groundwater interactions will also be discussed.


DORA CHIANG PH.D., P.E. (dora.chiang@aecom.com, AECOM, Atlanta, Georgia), Shangtao Liang, Ph.D. (University of Georgia, Griffin, Georgia, USA), Rachael Casson (AECOM, Sydney Australia), Rebecca Mora (AECOM, Orange, CA, USA), Qingguo (Jack) Huang, Ph.D. (University of Georgia, USA)

Background/Objectives. PFAS compounds have been ubiquitous in the environment because they have been used in industrial and consumer applications for more than six decades. Once releases, PFAAs as subclass of PFAS are persistent and do not biodegrade in the environment. PFAS also bioaccumulates in the biological tissues with potential adverse impact to human health and the environment. Current practice of treating PFAS in water is to separate PFAS from the environmental media using granular activated carbons or ion exchange resin (IX-R). IX-R has gained increased attention because it treats wider range of PFAS and can be regenerated on site. Destruction of PFAS has been developed in recent years for mass removal (not mass transfer) and for achieving the ultimate risk reduction. The destruction technologies such as electrochemical oxidation (EO), plasma technology and sonochemistry have demonstrated degradation and mineralization of PFAS in the laboratory environment. The promising results have led to field scale demonstrations. This paper presents the latest progress on scaling up EO technology for water treatment and its applications for destroying PFAS in the PFAS concentrates including liquid and solid wastes.

Approach/Activities. The approach of studies is built upon a series of effective treatment of spiked PFAAs in the water solutions using low-cost titanium based electrodes. The spiked solutions were originally used to account for the mass balance before and after the PFAS destruction and to understand complete destruction kinetics and mechanisms. Laterally, this EO technology has been applied to treat (1) low ppb to high ppm of PFAAs and PFAS precursors; (2) PFAS impacted groundwater; (3) PFAS concentrate in liquid waste generated from ion exchange resin regeneration processes; (4) PFAS concentrate in liquid waste from a proprietary treatment waste stream; (4) pretreatment sludge containing PFAS; and (5) PFAS impacted soil. Additionally, pilot scale reactors were built to treat wastewater in a semi-continuous flow process.

Results/Lessons Learned. The PFAS contaminated industrial wastewater and groundwater are commonly require pre-treatment or post-treatment processes for removing other co-contaminants (including organic and inorganic contaminants); these pre- and post-treatment processes generate solid and liquid wastes containing PFAS. We realize the need of developing PFAS destruction technologies for not only water solutions but also waste streams in order to provide a total solution of leaving no PFAS waste behind. The EO studies have successfully demonstrated the treatment of PFAS from low to high concentration ranges and PFAS concentrates in liquid waste. We have found 100% removal of measurable PFAS and 300+% of fluoride concentrations as end product in the IX-R waste. This finding suggests (1) the loading of non-measurable PFAA precursors to the IX-R; and (2) Successful mineralization of PFAS including PFAA and PFAS precursors. The EO technology is also found effective on decomposing 8000 ppm TOC together with mineralization of PFAS. When high TOC is encountered, coupling EO with pre-treatment technologies may be needed to reduce energy consumption. The presentation will also discuss the progress of reducing perchlorate as unwanted byproducts.
A10. A Pilot-Scale GAC Filtration Study to Assess Breakthroughs of PFAAs and Precursors

DORA CHIANG Ph.D., P.E. (dora.chiang@aecom.com, AECOM, Atlanta, Georgia), Alix Elizabeth Robel and Jennifer Field, Ph.D. (Oregon State University), Qingguo (Jack) Huang, Ph.D. (University of Georgia, Griffin, Georgia), Adria Bodour, Ph.D. and Catharine Varley, Ph.D. (AFCEC, San Antonio, TX)

Background/Objectives. Granular activated carbon (GAC) treatment for per- and polyfluoroalkyl substances (PFAS), including perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS), impacted water is currently a presumptive remedy in the United States. However, recent studies suggest GAC may not be effective for short chain PFAS and precursors, which can result in some PFAS discharging back into the environment. The Air Force Civil Engineer Center (AFCEC) Broad Agency Announcement (BAA) program funded a pilot-scale field demonstration project to monitor and assess breakthrough of 11 perfluoroalkyl acids (PFAAs) and 43 precursors. Additionally, Total Oxidizable Precursors (TOP) assay was used to estimate the removal of some missing precursors (i.e., precursors that are non-identifiable and non-analyzable using standard LC/MS/MS procedures). Findings provided site remediation managers with justification for frequent GAC changeouts, and design considerations for GAC filtration and alternative remediation systems (i.e., remediation systems need to address PFAS, rather than solely PFOS and PFOA).

Approach/Activities. Since 2015, a full-scale GAC filtration system has been operated at Wurtsmith Air Force Base (WAFB) to treat PFAS impacted groundwater extracted from a former fire training area. WAFB was selected as the BAA pilot demonstration site because the groundwater quality has been well characterized and the full scale system has experienced more frequent GAC changeouts than expected. The pilot treatment system was an exact scale-down version of the full-scale system. One lead vessel and one lag vessel were connected sequentially and received the split groundwater flow that fed into the full-scale GAC system. The pilot study was conducted from November 2016 through August 2017 without changeout of GAC vessels allowing a long-term monitoring of PFAS breakthroughs. Water samples were collected from 4 sampling ports on a weekly basis for the analysis of 54 PFAS. Selected samples were also analyzed for TOP assay.

Results/Lessons Learned. 18 out of 54 PFAS were frequently detected. The total PFAS concentrations in the influent ranged from 20-25 nM and 30-40 nM before and after the TOP assay, respectively. During the TOP assay process, significant amount of precursors were oxidized and transformed into perfluoroalkyl carboxylates (particularly perfluorohexanoic acid [PFHxA]) and PFHxA increased approximately 10-15 nM after TOP assay. For the samples collected from the lead vessel, short chain perfluoroalkyl acids (PFAAs) breakthrough faster than long chain, perfluoroalkyl carboxylates breakthrough faster than sulfonates. Among the detectable precursors, 6:2-Fluortelomersulfonate (6:2-FTS) broke through first while perfluorooctane sulfonamide (FOSA) showed very minimum breakthrough after 10 months of GAC operation. The pilot study demonstrates the need of high resolution characterization of PFAS in the influent. The current analytical method cannot fully identify or quantify PFAA precursors in the influent; however, TOP assay provides indirect information about the presence of other precursors. And these precursors can be as high as 30% based on the site specific data. This is the first field study that comprehensively assesses the breakthroughs of a wide range of PFAS from a GAC treatment system.


DOUG GRAY (doug.gray@aecom.com) (AECOM, Cleveland, Ohio, USA)

Overview. In a portion of a refinery site located in the Upper Midwest, groundwater has been historically impacted with free product and dissolved phase pentachlorophenol (PCP). A groundwater recovery system, placed in operation in 1996, was designed to provide hydraulic control and prevent PCP migration. Beginning in 2015, a review of existing data indicated that the groundwater recovery system was exacerbating dissolved phase PCP concentrations and subsurface conditions were conducive to natural biodegradation. The pilot study demonstrates the need of high resolution characterization of PCP in the influent. The current analytical method cannot fully identify or quantify PCP precursors in the influent; however, TOP assay provides indirect information about the presence of other precursors. And these precursors can be as high as 30% based on the site specific data. This is the first field study that comprehensively assesses the breakthroughs of a wide range of PCP from a GAC treatment system.
B9. PCB Remediation Using an Innovative ISCO Approach: Bench and Pilot Study Results

DOUG GRAY (doug.gray@aecom.com) (AECOM, Cleveland, Ohio, USA), Francisco Barajas (AECOM, Austin, Texas, USA)

Overview. Anecdotal evidence from a proof-of-concept bench-scale study indicated that an activated carbon peroxide-based chemical oxidant exhibited the ability to significantly reduce the concentrations of soil impacted with polychlorinated biphenyls (PCBs) and volatile chlorinated organics. These results were intriguing, especially given that PCBs have generally been considered fairly recalcitrant with limited in-situ remedial options. The successful demonstration of a potential in-situ remedy that can be readily implemented would provide an innovative and cost effective approach to addressing sites impacted with PCBs. As a result, a bench-scale study was developed and completed in order to provide for a proof-of-concept. Concurrently, and in anticipation of positive results, a pilot-scale study was designed such that implementation could begin immediately following the completion of the laboratory bench-scale study.

Background/Objectives. Soils in an area of a former steel manufacturing site, located in the Upper Midwest, were identified as being impacted by both volatile chlorinated organics and PCBs. The impacted soils were delineated from depths ranging from approximately 6 to 20 feet below ground surface (ft-bgs), and covering an area of approximately 20,000 ft². The site is currently undergoing remediation as part of brownfield efforts, and the identification of cost effective and implementable remedies is paramount in keeping the overall site development moving forward. In order to address the identified the identified soil impacts excavation and thermal treatment remedies were being contemplated. However, a preliminary test of an in-situ chemical oxidant indicated that significant reductions in PCB soil concentrations were possible and could provide a means to treat the impacted soils in-place and potentially provide a significant cost savings.

Approach/Activities. In order to verify the preliminary information, a bench-scale study was implemented to demonstrate the efficacy of the chemical oxidant to effectively treat both the volatile chlorinated organics and PCB impacts. The bench-scale study involved the collection of site soils and the completion of a bench-scale treatability study using a control and two duplicate reactors. The reactors were set up to provide for multiple time point sampling to monitor soils conditions and oxidant performance over the course of a 30 day testing period. While the bench-scale study was underway, a pilot-scale study was designed such that implementation could be initiated in short order. The purpose of the pilot-scale study will be to determine the field-scale deliverability of the oxidant and to further verify the efficacy and performance of the oxidant over a larger area.

Results/Lessons Learned. The results of the bench-scale study will be available in November 2017 and the results of at least one round of performance monitoring from the pilot-scale study are anticipated to be available for presentation at the time of the conference. Additionally, lessons learned from both the bench- and pilot-scale studies will be provided in order to disseminate information for use at other similarly impacted sites.

C9. Overcoming Challenges and Closure-Strategy Development at a Long-Term Large-Scale CVOC Bioremediation/Thermal Project

MATTHEW A. PANCIERA, P.E., L.E.P. (matthew.pancriera@aecom.com), Dustin Bytautas, P.E., Tomasz Kalinowski, Ph.D., and Lucas A. Hellerich, Ph.D., P.E., L.E.P. (AECOM, Rocky Hill, CT, USA), Rory Henderson (AECOM, Providence, RI, USA)

Background/Objectives. Historical releases of chlorinated solvents occurred from a former manufacturing facility in Connecticut resulting in concentrations of chlorinated volatile organic compounds (CVOCs) in source zone groundwater of up to 780 ppm and concentrations of over 20 ppm in the resulting 15-acre downgradient groundwater plume. Source area residual dense non-aqueous phase liquid (DNAPL) and CVOCs were situated in tight soils (till) and weathered bedrock. The majority of the off-site CVOC groundwater plume is located within a forested wetland where the soils are more permeable than in the source area. The primary contaminant of concern was trichloroethylene (TCE) although other CVOCs persisted in groundwater. The final multi-faceted remedial solution was a large-scale project incorporating limited source zone excavation followed by source zone in situ electrical resistance heating (ERH), and extensive plume-wide in situ bioremediation utilizing enhanced reductive dechlorination (ERD) and bioaugmentation. Remediation has been ongoing since 2009.

Approach/Activities. In situ thermal treatment of the saturated zone was proposed as the remedy for the source area combined with in situ bioremediation via ERD and bioaugmentation, followed by monitored natural attenuation to address the migrating groundwater plume. The bioremediation system consisted of approximately 600 injection wells installed across multiple biobarriers installed to a maximum depth of 40-feet. Approximately 20,000 gallons of emulsified vegetable oil substrate (EVO) were injected between June 2010 and October 2015. Bioaugmentation followed the 2010 injections. Beginning in Spring 2017, approximately seven years following the initial phase of treatment, targeted injections were undertaken at approximately 200 locations spread across several areas within the original biobarriers. Approximately 3,500 gallons of EVO were injected with the goal of reducing recalcitrant pockets of CVOCs and accelerating remedial completion. The 2017 injections are expected to be the final round of injections at the site. The ERH system operated from October 2010 through July 2011 and was comprised of 89 electrodes installed in the source area overburden and weathered bedrock. Approximately seven years of remediation performance monitoring data has been collected and evaluated. The monitoring well network has been evaluated for locations where compliance has been attained and where pockets of recalcitrant CVOCs remain.

Results/Lessons Learned. After seven years following initial substrate injections, the combined ERD/ERH remedial approach is progressing well despite challenges encountered at each injection event. It is anticipated that the 2017 targeted substrate injections will be the last. The exact locations for substrate addition were chosen based on past performance data and biogeochemical parameters collected through December 2016. Data analytics were used to target injection locations and maximize injection efficiency. This abstract focuses on the evaluation, design, and implementation of year-seven supplemental substrate injections and will highlight the basis for the design approach, challenges encountered, lessons learned, and deviations from the initial three injection programs. This abstract will also discuss the closure-strategy development following this last round of injections and how regulatory compliance will be achieved.
D8. Working on the Railroad - Implementation of Sustainable Remediation at a Programmatic Level

GERLINDE WOLF (gerlinde.wolf@aecom.com) (AECOM, Latham, NY, USA), Scott Pittenger (scott.pittenger@nscorp.com) (Norfolk Southern Railway Corporation, Atlanta, GA, USA)

Background/Objectives. Over the past decade, the concept of sustainable remediation (SR), which incorporates environmental, social and economic considerations on a holistic basis when selecting, designing or implementing a remedial approach, has emerged as an integral part of many site cleanup projects. The Norfolk Southern Railway Company (NSRC) SR program was established in 2016 in order to provide a framework for implementing SR practices at the entire Portfolio of NSRC environmentally impacted sites. Objectives of the SR program include providing a transparent framework for incorporating sustainability into remediation projects, providing a metric tracking system in order to document benefits and value of the program, and increase remediation project efficiency. This presentation will discuss implementation of the SR program at NSRC sites that are managed by AECOM.

Approach/Activities. The NSRC SR program includes three levels of evaluation which are defined by tiers and include different levels of evaluation ranging from qualitative selection, implementation, and documentation of best management practices (BMPs) to quantitative assessments using various footprint calculation tools.

During the inaugural year of the program, SR evaluations were completed at 11 environmentally impacted sites. The nature of the work that is performed at many sites requires that various types of contractors and subcontractors are involved (i.e. construction crews, waste haulers, material suppliers). Therefore, the NSRC SR program is incorporated into project specific planning and bidding documents and subcontractor crews are integrated into the SR program. Details on the subcontractor engagement aspect and the process for conducting quantitative and qualitative assessments will be discussed during the presentation.

Results/Lessons Learned. Implementation of the SR program has already resulted in sustainability benefits for stakeholders and the environment. For example, sustainability BMPs related to use of local resources and carpooling were able to save approximately 2,175 vehicle miles traveled for one particular project, resulting in emissions reductions and decreased trucking traffic. Other BMPs identified for the project put an emphasis on recycling of disposal materials which enabled the recycling of approximately 92 tons of material and provided an estimated transportation and disposal cost savings of approximately $3,700. As program implementation continues, we expect to provide a dashboard showing quantitative results on additional sustainability metrics and benefits on both a site specific basis, as well as at the program level.

Lessons learned about programmatic SR implementation will be presented which will benefit remediation practitioners who are thinking about incorporating similar SR programs for their portfolios or undertaking SR practices for their projects. Examples of how sustainability has been incorporated into remedy decision making will also be discussed.

F8. Compartmentalized Approach to Bedrock and Overburden Remediation at a Legacy Petroleum Site

BRANDT MORROW (brandt.morrow@aecom.com) (AECOM, Inc., Charlotte, NC, USA), Gary Simpson (AST Environmental, Inc., Midway, KY, USA)

Background/Objectives. The site was formerly a general store with two 1,000-gallon UST’s with primary constituents of concern being benzene, toluene, ethylbenzene, and xylenes (BTEX). Historic monitoring wells already installed at the site were screened at various depths in the overburden, bedrock, and across the overburden/bedrock interface. The shallow, highly fractured schist bedrock is approximately 10 feet (ft) below ground surface (bgs) with groundwater observed within the overburden and bedrock wells. The conceptual model theorized that hydrocarbon mass resided at the overburden/bedrock interface and was contributing to groundwater exceedances in bedrock.

Approach/Activities. Based on the limited historical soil and groundwater data, and the multiple zones that were represented in the monitoring well network, additional investigation was warranted to characterize the mass present in the overburden and the bedrock. The characterization of the bedrock consisted of identification of fractures/weathered zones within the bedrock using a downhole camera, discrete groundwater sampling from identified fractures/bedding planes using a custom designed straddle packer assembly with an eighteen-inch sample interval, and high resolution water level monitoring of the surrounding well network during groundwater sampling using pressure transducers to define the horizontal connectivity between existing monitoring wells and the vertical connection between formations. To investigate the overburden, five overburden soil borings were completed with soil samples collected every 2 feet to quantify the saturated soil mass contributing to groundwater impacts in the overburden and bedrock. The soil borings were converted to temporary piezometers to obtain groundwater samples and to evaluate the connection of the overburden with the bedrock during the bedrock injections. The piezometers confirmed that the overburden was contributing to the impacts identified in the bedrock monitoring wells.

Based on the data collected from the RDC, a clear picture of the subsurface lithology and hydrological connectivity between the overburden and bedrock was confirmed. The data collected from the discrete groundwater sampling, provided information to assist in injection location and remediation product loading. Injections began in the bedrock and targeted four fractures identified in the RDC sampling event. Injections were completed using a truck mounted custom injection system containing a 165 HP triplex positive displacement pump and a custom straddle packer allowing precise product placement in the formation. During injections, groundwater levels were constantly monitored to determine well connection and radius of influence. Approximately six months after the bedrock injections were completed, the overburden was treated via a similar high pressure/high flow injection system.

Results/Lessons Learned. After the first injection event, the compliance bedrock well achieved cleanup standards and 75% reduction of BTEX concentrations was demonstrated in the wells screened across the soil/bedrock interface. Upon completion of the second injection event (overburden only), all compliance wells achieved cleanup standards. Quarterly sampling events confirmed the initial post injection results and a No Further Action letter was issued in December 2014.
H5. Interactive Visualizations of 5 Million Sensor Measurements of the Capillary Fringe Lead to an Optimized Soil Remedy

CAMERON DIXON, PE (cameron.dixon@aecom.com), (AECOM, Boston, Massachusetts, USA), Tomasz Kalinowski, Ph.D. (AECOM, Syracuse, New York, USA), Christopher Brownfield, PE (AECOM, Morrisville, North Carolina, USA); Scott Mikaelian, PE (AECOM, Piscataway, NJ, USA), Mark Terril, PE (PPG, Pittsburg, PA)

Background/Objectives. Concerns of contaminated groundwater impacting clean soils through capillary rise, and the appropriate mitigation measures to address them, were a point of contention between numerous site-stakeholders. To help address concerns, a study was undertaken to characterize capillary rise in site materials, as well as test some candidate mitigation technologies.

Approach/Activities. A year-long high-resolution field study was undertaken with approximately 200 soil and groundwater sensors collecting hourly measurements. Sensor data was paired with an on-site meteorological station recording weather conditions in 15-minute intervals. The study focused on understanding the range of elevations where contamination from groundwater may be present in the future. Findings from the high-resolution year-long field study were then integrated with a complementary analysis of the relatively sparser historic site dataset going back 14 years, as well as meteorological data over the past century.

The datasets were too large to analyze using conventional techniques, and consequently custom analytics and visualization software was developed to perform the analysis and communicate findings from the data. The R environment was used to develop a custom data-analysis pipeline which featured novel visualizations and statistical workflows, and heavy use of automation and report reproducibility. Additionally, custom interactive data visualization and reporting tools were built, allowing the project team to interactively explore visualizations of up-to-date data through a web-browser based “data explorer.”

Results/Lessons Learned. The results of the study were used in remedial design to determine an appropriate final ground surface elevation, and to identify site areas where construction of a mitigation measure for capillary rise was appropriate. The interactive data visualizations facilitated communication among the stakeholders, which led to greater understanding and ultimately, consensus about the best path forward. The outcome of the study was a highly data-driven, optimized, and efficient site remedy.
Posters
Testing Commonly Used Insect Repellents for 17 PFAS

SAM BARTLETT (sam.bartlett@aecom.com), (AECOM, Providence, RI, USA), Kathy Davis (katherine.l.davis@aecom.com), AECOM, Newark, DE, USA, Robert Kennedy (robert.kennedy@aecom.com), (AECOM, Chelmsford, MA, USA)

Background/Objectives. An AECOM project team encountered a health and safety concern during preparations for a sampling event for Per- and Polyfluoroalkyl Substances (PFAS) in groundwater in the town of Portsmouth, RI. Current PFAS sampling guidance provides suggested personal protective equipment (PPE) alternatives to minimize PFAS cross-contamination that may result from using PPE with known or suspected PFAS content. The Portsmouth site was known to have an elevated tick population and ticks had already been observed during brush clearing and pre-mobilization site visits. Permethrin and N,N-Diethyl-m-toluamide (DEET) are highly effective for protecting against ticks, but these products were suspected of containing PFAS. To better protect the field team and ensure generation of reliable PFAS data, a study was completed to determine if commonly used insect repellents containing permethrin or DEET presented a concern for PFAS cross-contamination.

Approach/Activities. AECOM tested three commonly used insect repellent products to determine if the products presented a potential for PFAS cross-contamination. The products were selected based on what was commonly provided to the field teams and are as follows: Sawyer Premium Insect Repellent Clothing treatment: a do-it-yourself permethrin treatment for clothing, EPA Registration Number: 50404-3-58188; OFF! Deep Woods Insect Repellent: a DEET based spray for skin and clothing, EPA Registration Number: 4822-167; and Insect Shield Insect Repellent Apparel: clothing that is pre-treated with permethrin, EPA Registration Number: 74843-2. The Sawyer and OFF! sprays were applied as directed to strips of fabric from a well-worn t-shirt for testing and an Insect Shield hat was tested. The treated fabrics were exposed to lab-certified PFAS-free water with a 30-second contact time. The water was then containerized and analyzed. Additionally, two blanks were collected for quality control: a blank of the lab-certified PFAS-free water and a water rinse sample of the untreated t-shirt fabric. Samples were preserved on ice, packaged, and delivered to Vista Analytical Laboratory for analysis by the EPA 537 Modified method. The Vista method uses solid phase extraction of aqueous samples followed by UPLC/MS/MS analysis and isotope dilution quantitation for target analytes.

Results/Lessons Learned. All samples analyzed were reported as non-detect (<2.5 ng/L) for the following 17 PFAS compounds: PFBA, PFPeA, PFBS, PFHxS, PFHpA, PFHpS, PFOA, PFNA, PFDA, PFOS, PFDA, PFDoA, PFT rDA, and PFT eDA. The results showed the tested formulations of these products did not present a risk of PFAS cross-contamination and may be used for PFAS investigations. This project also reinforced the benefit of collecting equipment blanks prior to initiating an investigation in order to better understand cross-contamination concerns and generate reliable PFAS data, and further support the health and safety of your field team. Many products once suspected of containing PFAS compounds may not pose a real significant risk of contamination during field sampling. Prudent testing before use can verify specific commercial products are free of PFAS target analytes. Analytical results and information on the product formulations that were tested will be provided at the time of the presentation.

Enhanced Bioremediation in in Weathered Bedrock: Modifying ROD Selected Remedy, Design and Implementation

DUSTIN BYTAUTAS, P.E. (dustin.bytautas@aecom.com), (AECOM, Rocky Hill, CT), Paul M. Dombrowski, P.E. (ISOTEC Remedial Technologies, Lawrenceville, NJ), Michelle Snyder, Curt Weeden (AECOM, Chelmsford, MA), Curt Weeden (AECOM, Manchester, NH)

Background/Objectives. At a former Department of Defense base, tetrachloroethene (PCE) impacts groundwater within a multi-acre plume at an undeveloped site consisting of a heavily wooded wetland. Like many sites, the Remedial Investigation focused on impacts in overburden and in competent bedrock. The selected remedy in the Record of Decision (ROD) consisted of enhanced biodegradation injections and the installation of mulch permeable reactive barriers (PRBs). Biodegradation was chosen for the treatment of bedrock and overburden source area Target Treatment Zones (TTZs). Two mulch PRBs were designed to intercept PCE in overburden at the downgradient edge of the plume before discharging to a surface water feature. Overburden soils at the site consist primarily of glacial till composed of densely compacted sand, silt, gravel, and clay, which is underlain by granite bedrock. During installation of monitoring wells to evaluate performance of enhanced biodegradation injections, weathered bedrock zones and highly fractured bedrock zones were identified with thicknesses ranging from 5 to 60+ feet where PCE was present.

Approach/Activities. Additional investigation was performed of the weathered bedrock layer across the site, including thickness of the weathered layer and nature and extent of PCE concentrations within it. Notably, in the area of the proposed mulch PRBs the additional investigation indicated that refusal was shallower than assumed (5 to 9 feet lbs compared with 15 feet assumed in the ROD), that PCE in overburden groundwater was below site-specific site cleanup levels, and detected PCE concentrations in weathered bedrock were over double the concentrations observed in overburden and above clean-up levels. As a result of the weathered bedrock investigation, the Remedial Design (RD) was modified to replace the downgradient mulch PRBs in overburden with biobarriers established with a network of injection wells screened in the weathered layer to apply emulsified vegetable oil as a longer persistent electron donor. In addition, due to the extent of PCE impacts in groundwater identified during the investigation, the RD was enhanced to include an upgradient weathered bedrock TTZ and an additional weathered bedrock biobarrier.

Results/Lessons Learned. Injections of emulsified vegetable oil and sodium lactate with bioaugmentation were completed during Summer 2017. In the three biobarriers, injection wells were spaced approximately 10 to 15 feet apart to establish a PRB. In the TTZ, a network of injection wells screened in weathered bedrock and highly fractured bedrock were used to apply electron donor solutions to areas of higher PCE concentrations, including injections as deep as 60+ feet below ground surface. During injection, water level rises and detection of substrate were measured in monitoring wells approximately 40 feet from the injection points as well as in adjacent injection wells indicating influence of injected solutions and connectivity of the weathered bedrock fractures. Groundwater performance monitoring will be conducted to evaluate distribution of injected electron donor, establishment of reductive dechlorination reactive zones, and the successful reduction in concentrations of CVOCs.
Summary of State Approaches to Vapor Intrusion – 2018 Update

BART EKLUND (bart.eklund@aecom.com) (AECOM, Austin, TX), Lila Beckley (lmbeckley@gsi-net.com) (GSI Environmental, Austin, TX), Rich Rago (RRago@haleyinside.com) (Haley & Aldrich, Glastonbury, CT)

Background/Objectives. Regulatory requirements for the evaluation of vapor intrusion (VI) vary significantly among states. For site owners and responsible parties that have sites in different regulatory jurisdictions, one challenge is to know and understand how the requirements or expectations for vapor intrusion (VI) differ from one jurisdiction to the next. Differences in requirements can make it difficult to manage sites in a consistent manner between jurisdictions. Eklund, Folkes, Kabel and Farnum published an overview of state guidance for VI in 2007 that provided a useful summary of pathway screening values and other key VI policies. An update by Eklund, Beckley, Yates, and McHugh was published in 2012. Since that time, numerous states have revised their guidance and some states that did not have VI-specific guidance have issued new guidance. This paper provides an update to the 2012 study.

Approach/Activities. For each State, the review includes tabulations of the types of screening values included (e.g., groundwater, soil, soil gas, indoor air), the screening values for selected chemicals that commonly drive VI investigations (i.e., TCE, PCE, and benzene), and the risk levels used for cancer and non-cancer risk. Federal values are included for comparison. In addition, for each state, we summarize a number of key policy decisions that are important for the investigation of VI including: distance screening criteria, default subsurface to indoor air attenuation factors, policies for evaluation of petroleum VI, and policies for evaluation of indoor sources of VOCs.

Results/Lessons Learned. States continue to use dramatically different screening values for evaluation of the VI pathway. Screening concentrations for groundwater and soil gas may vary by >100x for key VI compounds such as PCE and TCE. These differences reflect variation in default risk limits, default attenuation factors, and differences in toxicity factors for some VOCs. The review also highlights topics where there is a wide divergence in approach from State to State, such as exclusion distances for petroleum VI and significance of very short-term exposure to TCE.

Coal Combustion Residual (CCR) Remediation Road Map - How to Get There From Here

DOUG GRAY (doug.gray@aecom.com) (AECOM, Cleveland, Ohio, USA), Byron Dahlgren (AECOM, Atlanta, Georgia, USA)

Overview. Abraham Lincoln is quoted as saying, “If I had eight hours to chop down a tree, I’d spend six hours sharpening my axe.” With the implementation of the CCR Rule and the looming potential for future remediation activities at CCR sites, a streamlined road map for working through the remedial alternative selection process is presented to highlight critical milestones and key steps required to optimize the overall process. Accurate site characterization, the development of a robust site conceptual model (SCM), effective data visualization tools, and the identification of potentially viable remedial technologies are paramount with regard to the completion of feasibility evaluations, remedial alternative designs and the implementation of efficient and cost-effective remedial solutions for the clean-up of impacted CCR sites.

Background/Objectives. As work progresses implementing the CCR Rule, related to the gathering of groundwater data from coal ash facilities, the time frame is quickly approaching when remedial efforts will be mandated based on criteria outlined in the CCR Rule. This presents a number of challenges with respect to remediation. First, the sheer size of many of the impoundments presents significant challenges with respect to the scale and costs associated with any required remediation. Second, the constituents of interest at CCR sites are primarily metals, some of which are difficult to treat and are recalcitrant to conventional remedial technologies. Finally, because the CCR Rule is a rule, and not a regulation, the technical merits of implemented remedial efforts is likely to be subject to increased challenges from environmental groups and the general public; thus thorough documentation and evaluation is warranted to support these future corrective actions.

Approach/Activities. In essence, a “CCR Remediation Road Map” designed to identify and elucidate the steps required to provide a strategy to focus on areas that significantly impact the SCM, provide specific data useful in targeting remedial efforts, and collect data essential in the evaluation of potential remedial alternatives is akin to “sharpening the axe”. The various components of the outline process provide details on approaches, along with the use of relatively new and innovative methods, to work through the development of technically defensible corrective action despite the complicating factors associated with CCR facilities.

Results/Lessons Learned. Through the development of the “CCR Remediation Road Map”, this process will provide for the evaluation and development of cost effective and technically defensible corrective action approaches at CCR sites. The various components of the “Road Map”, while not atypical to approaches implemented for more conventional contaminants, when combined with innovative methodologies and properly implemented evaluation will prove beneficial to complex CCR sites. The “Road Map” and associated specialized evaluation techniques have been used in the completion of a corrective measures/feasibility evaluation, and the preliminary results will be available for presentation.
Performance of a Large-Scale Reductant Amended Backfill for Remediation of Hexavalent Chromium Impacted Groundwater

LUCAS HELLERICH, PHD, PE, LEP (AECOM, Rocky Hill, Connecticut, USA), lucas.hellerich@aecom.com (mailto:lucas.hellerich@aecom.com); Sachin Sharma, PE (AECOM, Piscataway, New Jersey, USA); Shree Ravi (AECOM, Piscataway, New Jersey, USA); Scott Mikaelian, PE (AECOM, Piscataway, N.J., USA); Mark Terrill (PPG, Pittsburgh, PA)

Background/Objectives. Over an area of approximately 15 acres and 20 feet deep, soils containing chromium ore processing residue (COPR) have been excavated and the excavations have been backfilled with fill amended (mixed) with FerroBlack-H reductant (a reductant mixture of insoluble ferrous sulfide and soluble hydrogen sulfide) at a former COPR facility located in New Jersey. The soluble hydrogen sulfide reacts rapidly with residual hexavalent chromium (Cr6+) present in the groundwater, reducing it to trivalent chromium, which forms an immobile and relatively insoluble hydroxide precipitate. The reductant also immobilizes other metals present in groundwater. The insoluble ferrous sulfide provides a longer term source of reductants that will continue to reduce Cr6+ over many years.

The application of the amended backfill is also remediating shallow groundwater, as well as serving as a safeguard against recontamination from contaminated groundwater entering the site from deeper impacted groundwater and adjacent residual sources. The longevity of the reductant in the amended backfill is a function of the dosing of the reductant, amount of chromium in the subsurface, site geochemistry, and rate of exposure of the reductant to rainfall-induced infiltration and groundwater flow.

Approach/Activities. The dosage and placement of the amended backfill was selected depending on the concentration of Cr6+ in groundwater and the results of bench- and field-scale testing. The performance assessment of the amended backfill included quarterly groundwater sampling of chromium species, metals, and geochemical parameters. The data were evaluated and geochemical/concentration trends were analyzed; reductive capacity calculations of the amended backfill were performed.

Results/Lessons Learned. Evaluation of groundwater data indicates that negative oxidation-reduction potential conditions have been sustained following placement of the amended backfill. Groundwater pH has also moderated in areas where amended backfill was placed. Concentrations of Cr6+ and total chromium have reduced and continue to reduce over time. Reductions in metals concentrations have also been observed. FerroBlack-H activity and longevity is a function of the dosing of the reductant, and site-specific geochemical and contaminant/geochemical loading conditions. A quantitative assessment of the longevity and reducing capacity of the reductant amended backfill will be presented. Lessons learned related to the application of the amended backfill, including sampling and analysis procedures will be discussed.

Enhanced In Situ Bioremediation Pilot Study for Treatment of 1,1,1-TCA

LINDSAY MITCHELL (lindsay.mitchell@aecom.com) and Mark J. Howard (AECOM, Latham, New York, USA), Art Taddeo (AECOM, Chelmsford, MA, USA), Paul Dombrowski (ISOTEC, Boston, MA, USA)

Background/Objectives. The subject site is located in southern New York State, which was occupied by a chemical company operating as a distributor of bulk chemicals from 1950 to 1963. Operations were halted in 1963 when a fire released a number of volatile organic compounds (VOCs) from an on-site warehouse. During firefighting efforts, a large amount of chemicals impacted the subject site, including 1,1,1-TCA, 1,1-DCA and 1,1-DCE. The site is listed as a NYSDEC Superfund Site, and the Record of Decision identified enhanced in situ bioremediation (EISB) as the selected remedy. Project objectives were to attain, to the extent practicable, Class GA Ambient Water Quality Standards and Protection of Groundwater Soil Cleanup Objectives.

Approach/Activities. To evaluate the potential of an enhanced in situ bioremediation approach, an anaerobic bench-scale pre-design test was performed on soils and groundwater from the site. The electron donor used was Emulsified Oil Substrate (EOS). Results indicated that intrinsic bioremediation at the site was limited by the lack of an electron donor since indigenous bacteria were present at moderate levels. Addition of EOS alone (no supplemental microbes) generated favorable geochemical conditions, increased degrading microbes to high levels, and completely treated chlorinated ethenes to ethene and TCA/DCA to chloroethane. The conclusion of the bench-scale test was that the site could undergo EISB through the addition of an electron donor. Implementation of the EISB pilot study included; characterization of groundwater geochemistry, oxidation-reduction conditions, and bacterial populations; direct-push injections of soluble electron donors (emulsified vegetable oil [EVO] and EHC® with zero valent iron [ZVI]) in areas with CVOC concentrations greater than 100,000 micrograms per liter; and evaluation of EISB performance via post-injection groundwater monitoring. The total injection quantities applied to the subject site during the pilot study were 4,152 gallons of 60% EVO and 7,825 pounds of EHC.

Results/Lessons Learned. Over the four to 16 months following injections, pH decreased in several monitoring wells; however, by October 2016, pH was within a favorable range in all but three of the 16 wells. Oxidation-reduction potential (ORP) decreased to less than -75 mV in all on-site wells. Injected carbon substrate was successfully distributed throughout the pilot study area, and total organic carbon (TOC) increased by two to three orders of magnitude in several wells. Results indicate that there is evidence of reductive dechlorination conditions and biodegradation within the groundwater at the subject site. The concentrations of parent compounds (1,1,1-TCA, PCE, TCE, and 1,1-DCA) decreased, and temporary increases in daughter products (chloroethane, cis-1,2-DCE, vinyl chloride, and ethene) were observed. Dechlorinating microbial analysis indicated healthy, thriving populations of dechlorinating bacteria. Additionally, remaining TOC, methane generation, increasing molar concentrations of degradation byproducts, and negative ORP were favorable. With these parameters in place, a successful dechlorinating environment is expected to persist.
Passive Hydrocarbon Remediation in a Foreshore Marine Environment

RAM KANNAPPAN (ram.kannappan@aecom.com) (AECOM, Orange, CA, USA)
Chris Boys (Christopher.Boys@parkland.ca) (Parkland Refining (B.C.) Ltd, Burnaby, BC, Canada)
Robert Horwath (robert.horwath@aecom.com) (AECOM, Oakland, CA, USA)
Michael Gill (mgill@slrconsulting.com), Cindy Ott (cott@slrconsulting.com) and James Malick (jmalick@slrconsulting.com) (SLR Consulting (Canada) Ltd., Vancouver, BC, Canada)

Background/Objectives. Non-aqueous phase liquid (NAPL) seeps were observed along the southern foreshore of Burrard Inlet, down slope of the Chevron Burnaby Refinery, British Columbia, Canada in April 2010. Chevron responded immediately with soaker pads and booms to mitigate the effects of the NAPL seeps. In the spring of 2011, 10 and 30 metre long Interim Remedial Action (IRA) Barriers were constructed. The IRA Barriers consisted of sand and organoclay trenches and CETCO® Reactive Core Material (RCM) mats along the high tide line. The trench was extended in 2012 because NAPL was seen down slope of the IRA Barriers. The objectives of this work were to assess the performance of these barriers and to assess new technologies for the design of a comprehensive multicomponent foreshore final remedy.

Approach/Activities. The performance of the IRA Barriers and the assessment of the mobility and petroleum flux onto the foreshore were completed through traditional soil and porewater field sampling and laboratory analysis and through porewater extraction testing. Two-dimensional gas chromatography with mass spectrometry (GCxGC-MS) analysis was utilized to better identify the petroleum hydrocarbons and the polar metabolites present, and microbial DNA/RNA analysis was completed to probe for the presence and activity of petroleum hydrocarbons degrading organisms. As part of final remedy design, treatability studies were performed on Aquagate+Powdered Activated Carbon® (AG+PAC) with light extractable petroleum hydrocarbons (LEPH) from up gradient refinery groundwater to determine AG+PAC loading capacity.

Results/Lessons Learned. The IRA successfully mitigated NAPL impacts to the foreshore for six years and will be replaced by a multicomponent final remedy in 2017. The permeability of the sand and organoclay mixture decreased over time and necessitated a different flow design for the final remedy. LEPH was determined to be the controlling aqueous contaminant which required inclusion of activated carbon as an adsorbent. To better control sheens, an oleophilic biobarrier (OBB) was added to the final remedy. Delivery piping was placed for the addition of amendments to stimulate microbial degradation of petroleum hydrocarbons. The combination of the organoclay, activated carbon and OBB provides a robust multilayer approach to limiting exposure of surface water to contaminants. The materials were structured to address the daily tidal changes in water level and long term impacts of coastal erosion. This multicomponent remediation approach is unique in its design and applicability in a marine foreshore environment.

Large-Scale Remediation of TCE Using Abiotic Degradation with ZVI and Enhanced Biological Degradation

Mark Wichman, United States Army Corps of Engineers, Omaha, Nebraska, USA, Brian Wight and RYAN MOWAN (AECOM, Omaha, NE, USA), Eric Moskal and Robert Kelley (Cascade Technical Services, Inc., Jackson, NJ, USA)

Background/Objectives. As part of an environmental remediation effort at the McConnell Air Force Base in Wichita, KS, a pneumatic emplacement technology (Ferox™) has been used for in situ ZVI injections on six sites. Treatment was applied to chlorinated solvent contaminated soils and groundwater. At some sites, there has been an increase in daughter products including vinyl chloride and high levels of methane. However, the contribution of biological activities and the role of the levels of carbon (electron donor) to these increases was not clear.

Approach: Over 3,000 tons of ZVI was injected during four campaigns between 2014 and 2017. All the sites treated with ZVI saw a greater than 100 mV decrease in ORP as reductive conditions were established. The pH slightly increased and methane, ethane and ethene concentrations increased. On average at most sites, the TCE concentrations were below USEPA MCL and KDHE Risk levels within a couple of months. The Ferox™ patent is based on the results that less iron distributed better through the formation give a better result. Pneumatic emplacement of in situ amendments increased contact and permeability within the contaminated zones in order to achieve treatment goals within a short period of time. Experience has also shown that too much carbon in the system can lead to methanogenic conditions and less reductive dechlorination. A variety of products and techniques have been used to determine the optimum balance of ZVI and carbon to produce degradation of the TCE at several sites on base. In some areas, more ZVI was injected, and in other area a molasses-base product or a nutrient blend product was added.

Lessons Learned. A wide range of biogeochemical conditions were detected throughout the base. Each of these conditions required a different approach. The results of these different approaches and how each approach was selected will be presented.
MNA as an Alternative to the Existing Remedial Approach at a Complex Historic Industrial Site with Multiple COCs

MATTHEW A. PANCIERA, P.E., L.E.P. (matthew.panciera@aecom.com), Zackary Smith, L.E.P., and Dustin Bytautas, P.E. (AECOM, Rocky Hill, CT, USA), William E. Penn (United Technologies Corporation, Farmington, CT, USA)

Background/Objectives. Historic releases of multiple contaminants of concern (COCs) occurred at a 15-acre site used for various manufacturing operations for nearly the past 180 years. Historical operations included a woolen mill and tannery with coal fired boilers and a coal gas manufacturing plant, electro-plating operations, boron filament manufacturing, and various associated wastewater treatment operations. For the most part, the extent and degree of impacts to soil, sediment, and groundwater have been identified; COCs include semi-volatile organic compounds (SVOCs), volatile organic compounds (VOCs), total petroleum hydrocarbons (TPH), and chromium impacts. Federal and state Applicable or Relevant and Appropriate Requirements (ARARs) were developed for the Site and a proposed remedial action plan (RAP) was prepared and approved by regulatory agencies. The current objective, and subject of this abstract, is to present recent evaluations performed at the site, namely inclusion of monitored natural attenuation (MNA), as a way to modify and streamline the approved remedial approach to minimize active remediation and long term Operation, Monitoring, and Maintenance (OMM).

Approach/Activities. The current approved remedial approach was designed to address sediment, soil, and groundwater impacts through excavation, an engineered soil cap, air sparge/soil vapor extraction (AS/SVE), bioventing/biosparging (BV/BS), and targeted injections of calcium polysulfide (CPS). Historic site data (pre-RAP) and more recent groundwater monitoring data (post-RAP) were reviewed and evaluated against the selected remedial approaches. It was determined that the current remedial approach could be significantly reduced through additional data gap sampling and by leveraging MNA to a greater extent. The data gap sampling effort was conducted during late 2015/early 2016, targeting soil and groundwater with the goal of eliminating the AS/SVE, BV/BS systems, and CPS injections entirely.

Results/Lessons Learned. The subsequent data collected was combined with the historic data set and ongoing groundwater monitoring data to redefine, and significantly reduce, areas requiring active remediation at the site. The outcome of this analysis was a transition to predominately MNA for areas where active remedial systems were previously proposed. When the RAP was prepared, MNA was not considered a viable remedial approach, but over five years of recent groundwater monitoring data indicates it may be very effective for large portions of the site. This abstract will present the results of the data gap sampling in the context of the original remedial approach and will detail how the MNA evaluation was performed. It will discuss the inputs/objectives, the techniques used for the MNA evaluation, and the output and final conclusions. Finally, this abstract will summarize how the data gap sampling and MNA evaluation impacted the active remediation planned for this site from a technical and financial perspective.

Assessing NSZD for Creosote DNAPLs

JONATHON SMITH (jonathon.smith@aecom.com) (AECOM, Southfield, Michigan), Brad Koons (brad.koons@aecom.com) (AECOM, Minneapolis, Minnesota), Ron Holm (ron.holm@aecom.com) (AECOM, Minneapolis, Minnesota), Randy Sillan (randy.sillan@aecom.com) (AECOM, Castle Rock, Colorado), Steven Gaito (steven.gaito@aecom.com) (AECOM, Providence, Rhode Island), Greg Jeffries (gregory.jeffries@bsnfrail.com) (BNSF Railway, Minneapolis, Minnesota)

Background/Objectives. Research on natural source zone depletion (NSZD) processes at petroleum, light nonaqueous-phase liquid (LNAPL) sites has led to the development of several industry-accepted methods for quantifying natural LNAPL depletion rates in the subsurface. Like petroleum LNAPLs, coal tar and wood creosotes are composed of complex mixtures of hydrocarbon compounds. Unlike petroleum LNAPLs, creosotes are denser than water and are classified as dense nonaqueous-phase liquids (DNAPLs). Creosotes are subject to the same natural depletion mechanisms (i.e., volatilization, dissolution, and biodegradation) as petroleum hydrocarbons and methods that have been developed for quantifying NSZD rates at petroleum LNAPL sites are applicable for creosote DNAPL sites.

Approach/Activities. NSZD assessments were completed at a former tie treatment facility where creosote is present in the subsurface related to historical wood treating operations. NSZD rates were assessed using a multiple lines of evidence approach to evaluate and quantify NSZD rates. The lines of evidence included 1) collection of groundwater data to assess NAPL depletion in the groundwater saturated zone; 2) measurement of carbon dioxide flux at ground surface, 3) Measurements of oxygen utilization and carbon dioxide production from nested soil gas probes, and 4) temperature profiling using existing wells and buried thermistors to identify thermal anomalies associated with NSZD.

Results/Lessons Learned. Preliminary results of the assessment indicate that NSZD rates are significant compared to active remediation approaches for creosote. The NSZD study will be described with a focus on highlighting similarities and differences in NSZD evaluations for petroleum LNAPLs and creosote DNAPLs. The results of the evaluation will be presented along with a discussion on the lower bounds of what can be detected using current NSZD measurement methods.
Execution of a Field-Scale Planted Greenhouse PFAS Uptake Study at RAAF Base Williamtown, New South Wales, Australia

BARRY J. HARDING (barry.harding@aecom.com) (AECOM, Grand Rapids, MI), Rachael Casson (AECOM, Sydney, New South Wales, AU), Michael McLaughlin, PhD (CSIRO/University of Adelaide, Adelaide, AU)

Background/Objectives. Historical use and discharge of Aqueous Film Forming Foam (AFF) by the Australian Department of Defence at the Royal Australian Air Force (RAAF) Base Williamtown (Base), has resulted in legacy Per- and Poly-Fluoroalkyl Substances (PFAS) impact both on and off the base. Investigations undertaken at and near the Base have identified PFAS contamination in various media including soil, sediment, surface water, groundwater and biota including plants, fish and birds. Extensive use was historically made of surface water and groundwater for residential and agricultural purposes in the areas surrounding the Base, including, but not limited to, irrigating edible fruits and vegetables.

In 2017, a plant PFAS uptake study was requested to allow Defence and others to advise on fruit and vegetable irrigation practices and consumption to the local community. The data was used to refine plant uptake factors and exposure point concentrations utilised in the Human Health Risk Assessment (HHRA, 2016 and 2017), which in turn was employed to evaluate risk to human health. The objective of this study was to collect a statistically reliable and robust data set of PFAS uptake into fruit and vegetables that could be utilised to refine the uptake factors and exposure concentrations employed in the HHRA. The findings of the study were used to understand how different contaminated water concentrations affected uptake of PFAS in various species of fruit and vegetables.

Approach/Activities. The field-scale uptake study was novel in being executed at the Base, within four constructed greenhouse enclosures, using PFAS-impacted groundwater derived from RAAF Bases at Williamtown and the Army Aviation Centre Oakey (AAOCO), Queensland, and separate drip-irrigation trials using prepared groundwater dosages of 1 µg/L, 10 µg/L and 100 µg/L total Perfluoroalkanoic acids (PFOA), Perfluorooctanesulfonic acid (PFOS), Perfluorohexanoic acid (PFHxS) and Perfluorohexane sulfonate (PFHxS). A control consisted of plants irrigated with clean groundwater derived from a groundwater well located in the Williamtown region. A total of seven test crops were studied: lettuce, tomato, cucumber, alfalfa, beet, radish, and strawberry. Tomato failed to produce during the study.

The uptake study was phased with four primary stages of activity, which included: 1) Pre-Design, 2) Design, 3) Implementation of a 90-120 day Plant Uptake Study, and 4) Harvesting, Analysis and Assessment of Data.

Results/Lessons Learned. Transfer Factors (TF) were reliably derived for radish, radish leaf, beet leaf, and lettuce and compare to previously reported TF. Cucumber and strawberry represented statistically significant population pools and derived TF are less reliable. Initial and ongoing hurdles included maintaining consistent environmental conditions within four separate greenhouses, plant tolerances to high-salinity groundwater derived from AAOCO, maintaining consistent irrigate flow, to over 250 potted plants, leachate recovery, plant pest and pathogen management, plant nutrient requirements, and laboratory quality assurance and quality control. Various tips and lessons learned will be presented in the final deliverable.

Optimizing Enhanced In Situ Bioremediation of Commingled Chlorinated Ethanes and Ethenes at Two Groundwater Remediation Sites

LUCAS HELLERICH (lucas.hellerich@aecom.com) (mailto:lucas.hellerich@aecom.com) (AECOM, Rocky Hill, CT, USA), Tomasz Kalinowski (AECOM, Rocky Hill, CT), Patrick Gratton (AECOM, Rocky Hill, CT, USA), Francisco Barajas (AECOM, Austin, Texas), Keith Ryan, (AECOM, Piscataway, NJ, USA), Carl Shuman, (AECOM, Piscataway, NJ, USA), Sachin Sharma, (AECOM, Piscataway, NJ, USA)

Background/Objectives. Enhanced in situ bioremediation was implemented at two sites in the northeast United States to address commingled chlorinated ethanes, primarily 1,1,1-trichloroethane (1,1,1-TCA) and ethenes, primarily tetrachloroethene (PCE), in groundwater. At Site A, treatment was targeted in impacted overburden and intensely weathered bedrock within approximately 40,000 SF and a depth interval from 8 to 35 ft bgs. Site B had an impacted overburden treatment area of approximately 4,200 SF, with a depth interval of 6 to 31 ft bgs. The primary remediation objective at both sites was aggressive reduction of chlorinated volatile organic compound (CVOC) impacts and mitigation of off-site migration of degradation products.

Approach/Activities. At Site A, the groundwater remediation was initiated in 2014, and employed a combination of fast and slow release carbon sources to enhance bioremediation via enhanced reductive dechlorination (ERD) in combination with bioaugmentation. Sequenced injections of lactate and emulsified vegetable oil (EVO), followed by anaerobic chase water and a bioaugmentation culture, were accomplished through a network of overburden and bedrock wells. The distribution of amendments in the bedrock was optimized through simultaneous extraction (recirculation) of groundwater from wells around the point of injection.

At Site B, the groundwater remediation was initiated in 2012, and consisted of the injection of zero valent iron (ZVI), pH buffer, lactate, EVO, and bioaugmentation culture through a grid of direct-push injection points. As a secondary measure, an aerobic barrier zone was established near the downgradient property boundary to further reduce vinyl chloride and mobilized metals.

Supplemental sampling and analysis of groundwater for a suite of non-traditional nutrient and microbial parameters was performed at both sites to understand the differences in the extent of degradation observed between the sites. A set of bench-scale tests, using groundwater and soil from Site B, was also conducted to attempt to enhance the complete degradation of 1,1,1-TCA.

Results/Lessons Learned. At Site A, the amendments were optimally distributed in the treatment zone. An evaluation of 36 months of performance monitoring data showed near complete degradation of 1,1,1-TCA, following some intermediate buildup in chloroethane. At Site B, an evaluation of approximately 54 months of performance monitoring data indicated: distribution of amendments and established reducing conditions in the injection zone; significant reduction of CVOCs within the treatment volume; no production of vinyl chloride; and effective establishment of oxidizing, co-metabolic conditions in the vicinity of the down-gradient aeration barrier. CVOC and geochemical temporal trends within and downgradient of the source area varied. The reduction kinetics for chlorinated ethenes were faster than for the chlorinated ethanes. The buildup of chloroethane at Site B was greater than at Site A. The performance, operational, and supplemental monitoring results will be interpreted to explain the differences in the degradation behavior of the commingled CVOCs between the two sites. An initial finding of the bench-scale testing for Site B is that the rate of chloroethane biodegradation may be able to be enhanced.
Address Long-term Back-diffusion from Low Permeability Zone with Horizontal ISCO Permeable Barriers

HECTOR HUANG (hector.huang@aecom.com), Jim Fenstermacher (jim.fenstermacher@aecom.com), David Kistner (david.kistner@aecom.com), Johanna Moreskog (Johanna.moreskog@aecom.com) (AECOM, Conshohocken, PA, USA)

Background/Objectives. Back-diffusion of contaminants of concern (COCs) from low permeability zones is often a long term source impacting groundwater for extended time periods. In the situation where the low permeability unit is difficult to reach by excavation or in situ mixing, options for source zone remediation are very limited and plume remediation options usually require long term operation and maintenance due to the nature of the slow-releasing source. The objective of this study was to explore the concept of horizontal long-term permeable oxidation zones embedded into the low permeability zone to reduce back-diffusion mass flux of COCs and mitigate the impact to the overlying groundwater.

Approach/Activities. The concept of horizontal permeable oxidation zones was implemented in the field by emplacing horizontal KMnO4 lenses into a low permeability unit. KMnO4 was selected as the oxidant mainly because KMnO4 has greater longevity than other oxidant options and can be injected as slurry. The lenses were emplaced by horizontal hydraulic fracturing from injection wells that were installed into the top of the low permeability unit. KMnO4 slurry was propagated in horizontal fractures within a dense, saprolitic weathered bedrock formation. Thus, the KMnO4 lenses were physically inserted into the COC back-diffusion pathway. Furthermore, it is anticipated that dissolved KMnO4 will diffuse into the low permeability unit above and below the lenses to remove more COC mass and create thicker oxidation reactive zones. Over the long term, the COC mass flux from the impacted zone beneath the KMnO4 lenses will be oxidized and decreased when it diffuses through the oxidation barriers. Intensive remedial investigation and bench-scale studies were conducted to evaluate critical information for design and implementation of these horizontal oxidation barriers. A simplified mathematical model based on one-dimensional diffusion and first-order decay of the COC was constructed to provide estimates on the performance of the barriers and identify key parameters that affect the performance.

Results/Lessons Learned. A detailed conceptual site model is essential for the design and implementation of the horizontal oxidation barriers. The vertical distribution of COC mass within the low permeability unit was used to understand the depths at which the KMnO4 lenses should be emplaced. The amount of KMnO4 required to establish the lenses and the oxidation barriers was estimated based on the total mass of COCs present and the native oxidant demand of the formation. The mathematical mass balance yielded a generalized equation used to calculate the theoretical effectiveness of the oxidation barriers. The model indicated that the performance of the oxidation barrier is mainly a function of the thickness of the barrier, the effective diffusion coefficient of the COC within the barrier, and the first-order decay constant of the COC within the barrier. Field performance of the remediation will be evaluated by confirmatory soil borings and groundwater monitoring program.

An Accurate and Auditable Cost Estimating Tool for Environmental Remediation Financial Liability

ANNA KAKAI (Anna.Kakai@aecom.com) (AECOM, Greenwood Village, Colorado, USA)

Background/Objectives. Federal Government Congressional mandates requiring identification of financial liability makes environmental liability (EL) cost estimating an important effort. Financial liability reporting, on corporate balance sheets (Sarbanes-Oxley [SOX] compliance), is a requirement for the private sector. The federal government also requires each Department and Agency of the Executive Branch to prepare and submit an annual financial statement (AFS) for the preceding fiscal year. Both Department of Defense (DoD) Financial Management Regulation (FMR) and Defense Environmental Restoration Program (DERP) guidance provides for the use of electronic cost estimating software in most EL estimating situations.

One of the primary estimating software programs used by the DoD is the Remedial Action Cost Engineering and Requirements (RACER) application. RACER is a cost estimating software that was developed in 1992 under the direction of the U.S. Air Force as a uniform, repeatable, audit tool for estimating environmental investigation and cleanup costs for the annual budgeting and appropriations process. RACER is used currently to develop major parts of estimates for annual budgets, prepare individual project cost estimates, and to evaluate the reasonableness of cost estimates and proposals.

Approach/Activities. RACER is a budgetary level cost estimating tool that includes programmed cost models for environmental investigations and remediation projects. With over 110 models in 13 different categories, RACER offers a unique way to generate cost estimates for a wide range of complex remediation projects, including but not limited to: in situ bioremediation, pump and treat, free product removal, phyto remediation, oxidation processes and customized/user defined projects. Ongoing RACER enhancement efforts will be discussed and include: creation of a new ISCO model for estimating remediation costs via chemical oxidation or chemical reduction, AST Model for closure or removal of above ground storage tanks, and mining enhancements for large hard rock mining sites. A new cost model is being developed for decommissioning remediation systems once remediation goals have been achieved or when systems/components have reached the end of their useful service lives. RACER is also used to create EL estimating documentation trails to meet audit requirements, and for cost budgeting and forecasting of costs over time.

Results/Lessons Learned. RACER uses industry recognized risk analysis processes, is quick and easy-to-use, comprehensive, audit tool and allows the estimator the ability to verify the level of scope definition and understand the cost drivers. It also allows for quality assurance and the ability to benchmark the estimate cost and schedule against similar already completed, projects thereby allowing for identification of any final areas of concern. While RACER continues to meet the estimating needs of its users, it is a legacy system that requires enhancements to remain current with industry standards and best practices. Detailed documentation of assumptions and reference information is required. Due to the lack of sufficient environmental remediation information, emerging contaminants remain difficult to estimate.
Roadmap for Ranking PFAS-Contaminated Sites Based on Exposure Pathway Analysis

AMANDA LEE (Amanda.Lee@aecom.com), Michael Archer (AECOM Australia Pty Ltd, Melbourne, Australia), Gemma Williams (Peter J Ramsay and Associates, Melbourne, Australia)

Overview. Per and poly fluoroalkyl substances (PFAS), particularly perfluorooctanesulfonic acid (PFOS), perfluorooctanoic acid (PFOA) and perfluorohexane sulfonate (PFHxS) are now known to be widely spread all over the world as an environmental contaminant. For land owners and companies who have multiple sites with numerous sources, more tools are needed to enable sites to be ranked based on exposure pathways for both human and ecological receptors. Using real world data from numerous Australian sites, a ranking roadmap tool based on high to low exposure risk pathways has been developed enabling a cost-effective approach to management.

Approach. A review of numerous environmental investigations based in different geological regions was undertaken. The investigations included the collection of a wide range of environmental media to enable detailed conceptual site models to be established. The outcomes of the review were the identification of potential exposure pathways which, if complete, would categorize a site to have a higher risk ranking.

Results. The tool incorporates available data on PFAS environmental fate and transport with exposure assessment variables to provide a roadmap for ranking sites for investigation or management actions.

Benefits and Limitations of Aggressive Source Removal and Treatment at a Chlorinated Solvent Site

CRAIG W. MACPHEE, PE (AECOM, Chelmsford, MA, USA)

Background/Objectives. Many state and federal regulatory agencies in the US acknowledge that groundwater remediation to achieve drinking water standards is not practical at some sites. Although it is acknowledged that achieving the drinking water quality goals is not possible, active remediation is typically required to reduce the source of contamination. The extent of source reduction and the benefits of source reduction are debated among regulators and those responsible for the clean-up. To provide some insight into this debate, this paper examines a specific chlorinated solvent site where aggressive source removal/treatment measures were completed. The benefits and limitations of aggressive source removal/treatment are presented.

The project is in Rhode Island. Chlorinated solvents (primarily 1,1,1, trichloroethane) were present in soil, overburden groundwater, and in deep (greater than 400 feet) bedrock groundwater. Groundwater concentrations of chlorinated solvents exceeded 600,000 micrograms per liter (ug/l). 1,4 dioxane was present at 2,500 ug/l. Light non-aqueous phase liquid (LNAPL) was present (two foot thickness) in the overburden and shallow bedrock. Dense non-aqueous phase liquid (DNAPL) was also believed to be present. The source area is 50 feet by 200 feet in size. The depth to bedrock is 2 feet. Depth to bedrock ranges from one to ten feet. Clean-up to the drinking water criteria was determined to be impractical. Source removal to the extent practical is required for regulatory closure. A downgradient pump and treat system is in place to prevent spread of the groundwater plume.

Approach/Activities. Source removal included excavation of all overburden soils, removal of loose fractured bedrock, pressure washing of bedrock, extended pumping of open excavations, and use of an amendment in the backfill to provide on-going treatment of groundwater. The development and testing of backfill amendments to treat both chlorinated solvents and 1,4 dioxane will be presented. In total, 2,500 tons of soil/rock was removed and 80,000 gallons oil/water was treated. The backfill amendment was zero valent iron and a specialty product (activated carbon with a surface coating). Following source removal, four quarters of groundwater monitoring were completed.

Results/Lessons Learned. Details and results of the full-scale source excavation/treatment effort will be presented. Results include trend analysis of one year of post-excavation/treatment groundwater monitoring. The source removal/treatment had the following benefits:

1. The full-scale remedial action lowered chlorinated solvents and 1,4 dioxane levels in the overburden groundwater by more than 90%.
2. LNAPL has not been detected since source removal.
3. Potential risks were eliminated for utility workers coming into contact with soil, LNAPL and groundwater.
4. Air testing in a nearby utility tunnel indicates improvement.

Groundwater concentrations of chlorinated solvents reached below drinking water standards.

Details and results of the full-scale source excavation/treatment effort will be presented. Results include trend analysis of one year of post-excavation/treatment groundwater monitoring. The source removal/treatment had the following benefits:

1. The full-scale remedial action lowered chlorinated solvents and 1,4 dioxane levels in the overburden groundwater by more than 90%.
2. LNAPL has not been detected since source removal.
3. Potential risks were eliminated for utility workers coming into contact with soil, LNAPL and groundwater.
4. Air testing in a nearby utility tunnel indicates improvement.

Groundwater concentrations of chlorinated solvents reached below drinking water standards.

Further reduction by natural processes is expected but will be very slow. Use of groundwater will remain prohibited in the immediate area. The down gradient pump and treat system will have to remain operational for the foreseeable future. Regulatory closure with application of a Residual Zone is anticipated.
Background/Objectives. The concept of utilizing mass flux/mass discharge (MF/MD) to improve site characterization, risk assessments, and remediation design and performance has been well established over the past decade, in published guidance documents, articles, and computer-generated models. However, the application of MF/MD as a remedial metric and regulatory criteria has lagged behind the science and very few sites have had MF/MD as an alternative goal to groundwater concentrations to achieve regulatory standards. Two major industrial sites in Southern California, one impacted by gasoline and one by chlorinated solvents, have had MF/MD implemented as a remedial action objective and regulatory criteria. These sites help to set a precedence for future applications of MF/MD concepts for protection of groundwater resources and human health.

Approach/Activities. The two sites have a downgradient property boundary of approximately 1,000 feet where groundwater impacts originating at the site have migrated and formed off-site plumes. To prevent the migration of chemicals of concern (COCs) in groundwater and protect off-site receptors, a mass discharge goal was set so that to focus site characterization and remediation efforts on the mobile portion of COC mass. A combination of high-resolution tools (CPT, MIP, HPT) were utilized at the sites and verified by detailed geological logging and environmental sequence stratigraphy methods. These were used to create an enhanced conceptual site model of the sites and identify the high-flux zones in three dimensions. Hydrological and chemical data were then used to develop a MF/MD model of the sites boundary to focus the remedial design and technology testing.

Results/Lessons Learned. At the petroleum site, two discrete high-flux zones were identified between 19 and 37 feet below ground surface (ft bgs), corresponding to a continuous geology of fine to medium poorly-graded sand. These are underlain by interbeds of silt, sandy silt, and silty sand, which grade finer with depth and where the presence of COCs dissipate to non-detect. Earth Volumetric Studio modeling helped to visualize and present the correspondence between geology and COC mass. Pilot-scale testing demonstrated the ability of aerobic bioremediation using biosparging to reduce the mass discharge along the boundary by 99%. A full-scale biosparging system, with automated pulsing and flow control, was consequently designed to protect the entire boundary and is currently pending construction.

At the chlorinated site, five discrete high-flux zones were identified between 25 and 90 ft bgs, corresponding to a geology of estuary, fluvial, and near shore marine deposits of fine to medium sand with occasional coarse sand sequences. Each discrete zone is underlain by a confining silty unit of 5 to 10 feet in thickness and all are underlain by a laterally-continuous aquitard consisting of marsh land deposits with glacial deposits. The base of the incised valley was then partially infilled by fluvial channels during Lowstand. Subsequently, with rising lake-level, the valley was subject to inundation and a muddy estuarine condition established within the valley. By the end of this transgression, sedimentation started to keep pace with a relatively stable lake-level. As a result, fluvial channels, lagoons, wave-dominated strand-plains and other deltaic deposits accumulated at the Site. This new approach demonstrates that using modern analogs in conjunction with lithologic data can be an effective tool that helps us to visualize the subsurface at a high resolution, even with very limited data. Eventually this approach could be used to refine remedial strategies based on better informed conceptual site models.

Understanding Subsurface Stratigraphy for PFAS Environmental Characterization Using Modern Analogs

JUNAID SADEQUE (junaid.sadeque@aecom.com) (AECOM, Arlington, VA, USA), John Cuthbertson (John.Cuthbertson@aecom.com) (AECOM, Grand Rapids, MI, USA)

Background/Objectives. Understanding the subsurface stratigraphy and facies architecture of a contaminated Site is essential to determining preferential contaminant flow pathways. However, limited or low-confidence borehole information in absence of continuous geophysical logs often presents a major challenge in accurately delineating the subsurface. In this study, we test if modern analogs from DEM and Google Earth images can effectively supplement subsurface interpretations where bore-hole information is insufficient.

Approach/Activities. We produce stratigraphic cross-sections at the subject site that combine bore-hole information with modern analogs (DEM and Google earth images), as well as other areas with similar geological settings. Results of the study are then compared to previous lithostratigraphic interpretations at the Site.

Results/Lessons Learned. While previous studies in the area treated the deposits as simple glacioluvial sediments of gravels, sands and clay, our investigation indicates a more complex and heterogeneous facies architecture for the region. A conspicuous lake-level fall of the proto Lake Huron controlled by a Pleistocene glacial event lead to the development of an incised valley that down-cut into the previous glacial deposits. The base of the incised valley was then partially infilled by fluvial channels during Lowstand. Subsequently, with rising lake-level, the valley was subject to inundation and a muddy estuarine condition established within the valley. By the end of this transgression, sedimentation started to keep pace with a relatively stable lake-level. As a result, fluvial channels, lagoons, wave-dominated strand-plains and other deltaic deposits accumulated at the Site. This new approach demonstrates that using modern analogs in conjunction with lithologic data can be an effective tool that helps us to visualize the subsurface at a high resolution, even with very limited data. Eventually this approach could be used to refine remedial strategies based on better informed conceptual site models.
The Benefits of Acquiring Continuous Cores for Aquifer Characterization: Lessons from Petroleum Industry Best Practices

JUNAID SADEQUE (junaid.sadeque@aecom.com)

Background/Objectives. Since the underlying geology of a site is the primary control of groundwater flow and contaminant pathways, it is essential that we develop Conceptual Site Models (CSMs) based on robust subsurface data. Borehole information in the form of core materials and well-logs provide the ground-truth for such stratigraphic frameworks. However, in the environmental industry, continuous cores are seldom obtained for investigations because of cost considerations. Most environmental studies thus typically rely upon discontinuous core samples and cuttings for direct lithologic information, resulting in stratigraphic interpretations that are often challenged with uncertainties. This shortcoming is further exacerbated by the lack of any standardized workflow for recording lithologic information derived from those discontinuous cores. The purpose of this paper is to highlight the benefit of utilizing continuous cores and applying standardized sedimentological methods for recording grain size, texture, lithology and facies.

Approach/Activities. Recently conducted subsurface stratigraphic investigations in the Niger Delta, using continuous core and associated well-log data, are presented here as best practice examples from the petroleum industry. The standard workflow of core-description and facies analysis is also shared for comparison.

Results/Lessons Learned. Observations of slabbed continuous cores provide a unique opportunity to implement grain size information, sedimentary structures, lithology data, and fossils/trace fossils for facies analysis. Applying this approach to the proto-Niger Delta shows valuable stratigraphic details that can help to identify the heterogeneity of permeable and non-permeable rocks. Logging the grainsize using a standardized scale and keeping the textural information separate from grain size information helps us see the stratigraphic trends of the deposits and determine their depositional environments. Furthermore, calibration of well-logs with core-data offers a reliable tool for inferring lithology and depositional environment in intervals/locations without cores. Finally, directly measured saturation data from core plugs helps us to correctly determine the porosity-permeability of the studied rocks and recognize different flow units. The environmental industry can benefit significantly by taking a similar approach in data acquisition and interpretation.

Leveraging Environmental Sequence Stratigraphy to Refine Mass Discharge Estimates: Magothy Aquifer, New Jersey Coastal Plain

RYAN C. SAMUELS (ryan.samuels@aecom.com) and Junaid Sadeque, (junaid.sadeque@aecom.com) (AECOM, Arlington, VA, USA), Matthias Ohr (matthias.ohr@aecom.com) (AECOM, Conshohocken, PA, USA), Shannon D. Lloyd (Ashland LLC, Dublin, OH, USA)

Background/Objectives. Sound conceptual site models (CSMs) and estimates of mass discharge (mass/time) are essential for developing a comprehensive understanding of natural attenuation processes and preferential groundwater flow pathways at contaminated sites. However, as groundwater remediation projects are commonly challenged by inherent geologic complexity in the subsurface, the development of CSMs and a quantification of the associated uncertainties often tend to be less accurate than desired. In this study, we use detailed facies analysis within an environmental sequence stratigraphic framework to better understand the subsurface geology and define preferential flow pathways within a complex groundwater remediation site. This information is then used to refine contaminant mass discharge estimates with the goal of optimizing remediation strategies at both the source and the dilute fringe of a tert-butyl alcohol (TBA)-impacted groundwater plume.

Approach/Activities. We correlate depositional sequences from continuous geophysical data to trace strike and dip cross sections throughout the subject site (Hercules LLC, Parlin, New Jersey). This information is then combined with detailed facies models, developed within the context of modern analogs, whereby the Site data is recognized to be fully consistent with regional-scale facies interpretations of the Turonian sequence.

Results/Lessons Learned. Correlation of existing CPT and complementary well logs from the Site reveals four high-frequency, depositional sequences of the Turonian Magothy Formation, consisting of fluvial and deltaic deposits during an overall fall of the sea-level. Each sequence boundary is marked by subaerial exposure (paleosol) or fluvial incision in a coastal setting. A detailed analysis of the facies architecture within the established sequence stratigraphic framework indicates a seaward progradation of channel bars and muddy bay-fill deposits behind wave-dominated deltaic deposits (mouthbars and/or barrier bars). In light of this high resolution stratigraphic interpretation, re-examination of the impacted groundwater data shows significant stratigraphic constraints on the plume migration pathway and corresponding contaminant mass discharge. Although the basic geometry of groundwater flow and contaminant transport was recognized previously through conventional investigative approaches, the present study reveals important and unique new insights into the dependencies between groundwater contamination and facies architecture within the Magothy aquifer.
Implementation of a Passive DNAPL Recovery Program at a U.S. EPA Region 5 CERCLA Site

DOUG GRAY (douggray@aecom.com) (AECOM, Cleveland, Ohio, USA), Marty Schmidt (AECOM, Cleveland, Ohio, USA), Anton Heitger (AECOM, Cleveland, OH, USA), Tom Steib (Detrex Corporation, Ashtabula, OH USA)

Background/Objectives. A former chlorinated solvent manufacturing facility used a series of unlined ponds for separation of process solids circa 1950-1972. In 1986, the site was designated as a CERCLA Site within the United States Environmental Protection Agency (USEPA) Region 5. From 1992 to 2002, the facility completed the Remedial Investigation / Feasibility Study, Remedial Design, Remedial Action and Record of Decision (ROD) process. High vacuum, dual phase groundwater and DNAPL extraction was used for site remediation from 2002 to 2014. During a span of 12 years, approximately 6,000 gallons of DNAPL was recovered. Also, the Site Conceptual Model (SCM) was updated using MIP investigations, pilot studies and continuously sampled soil borings. Based on recovery operations and the updated SCM, it was determined that high vacuum extraction was ineffective for DNAPL removal as it required extensive OMM and not cost effective.

Approach Activities. Considering operational issues and the updated SCM, a request was submitted for USEPA to consider an Explanation of Significant Difference (ESD) to modify the ROD and change the DNAPL recovery method. The ESD was issued in January 2014 and changed the DNAPL recovery method to passive recovery using drop tube vacuum extraction from recovery wells. The ESD program required the installation of 180, 4-inch diameter, HDPE wells on 45 ft. spacings in the source area. A Mobile DNAPL Recovery Unit (MDRU), consisting of a 25 ft. trailer, dual double diaphragm pumps, conical separation tank, and activated carbon air treatment, was designed and built for DNAPL recovery. Monthly recovery was required for any well with greater than 1 ft. of DNAPL. Installation of the passive recovery system was completed in 2014 and the MDRU program became fully operational in September 2014.

Results/Lessons Learned. In June 2017, USEPA Region 5 approved the ESD Construction Completion Report and indicated that all requirements were achieved. Recoverable DNAPL (>1 ft.) has been identified in approximately 75 of the 180 recovery wells. During the past three years, more than 27,000 gallons of DNAPL have been recovered and treated offsite. Currently, approximately 208 gallons are recovered monthly. The former high vacuum operation recovered 8,000 gallons in 12 years and required extensive OMM, due to corrosion of materials and vapor phase treatment. Annual OMM costs ranged from $300,000-$325,000/yr. The current passive operation has minimal OMM (annual well cleanout, vacuum pump repair and drop tube adjustments). Annual OMM costs range from $90,000-$125,000/yr. Including monitoring and reporting to USEPA. It is expected that the passive DNAPL recovery operation will continue for the next 30-50 years, if not longer. The use of an ESD has provided a cost effective, reliable, and sustainable method of DNAPL recovery.

Optimization of Large-Scale LNAPL Recovery Operations Using a Graphical Analysis Tool

CYNTHIA SHEN (Cynthia.Shen@aecom.com), Peter Stumpf, Ram Kannapan, (AECOM, Orange, CA, USA), Joseph Lentini (Shell Soil and Groundwater FDG, Carson, CA, USA), Shailendra Ganna (Shell Global Solutions US Inc, Houston, TX, USA)

Background/Objectives. Light nonaqueous phase liquid (LNAPL) recovery operations using total fluid pumping methods have been occurring at an active petroleum refinery since the 1980s. Current LNAPL recovery operations include up to 28 vertical extraction wells that operate via total fluid recovery. The geology and hydrogeology of the site is complex. Interbedded sand and silt layers are present. Seawater intrusion management activities since 1971 have resulted in approximately 40 feet increase in potentiometric surface elevation. The LNAPL distribution is therefore highly variable and is present above and below static water level. Many existing recovery wells also have screens that have become submerged. The variability of LNAPL distribution and submerged screen recovery wells create difficulty when attempting to optimize LNAPL recovery operations. The objective of this study was to develop an efficient method to utilize a large amount of existing and current investigation and operational data to optimize LNAPL recovery operations under the site-specific condition.

Approach/Activities. Skimming method may not be the most effective at removing submerged LNAPL as well as from wells with submerged screens. Recovery under this condition should consider not just the screen interval but also the subsurface LNAPL distribution. Therefore, recovery pumps inlets were adjusted to maximize LNAPL recovery based on nearby laser-induced fluorescence (LIF) data and actual LNAPL recovery. By lowering the recovery zone, this study also seeks to lower the water level locally to potentially mobilize previously “trapped” LNAPL to enhance LNAPL recovery. To study the effects of the enhanced LNAPL recovery, individual graphics were created for each well by combining a variety of historical data including LIF and cone penetrometer testing (CPT) logs, well construction details, fluid gauging data, fluid recovery rates and LNAPL transmissivity. All data were referenced to a common vertical scale (when applicable) to allow for ease of interpretation.

Results/Lessons Learned. The creation of individual graphics allowed for rapid analysis and decisions regarding system operation throughout the project team. Specifically, graphics were utilized to adjust extraction well pump placement for LNAPL recovery optimization and determine for each well the optimal operating conditions.
Combining Multiple Remedial Technologies to Accelerate Property Development and Manage Off-Site Risk

CAROL-ANNE TADDEO (carol-anne.taddeo@aecom.com) and Dan Taylor, (AECOM, Chelmsford, MA, USA), Mike Mazzarese (AST Environmental, Inc., Denver, CO, USA), Paul Dombrowski (ISOTEC, Boston, MA USA)

Background/Objectives. This property in a residential community was contaminated through the discharge of chlorinated solvents (primarily trichloroethene or TCE) from buried drums and surface dumping. The resultant solvent plume migrated through the sandy shallow soils and deeper glacial till over time in the direction of off-site residences with private wells.

Approach/Activities. A remedial approach was adopted which combined two treatment technologies to facilitate residential property development by accelerating source reduction and minimizing the potential for off-site migration. In the 1,200 square foot source area, which had concentrations of up to 23,800 µg/L TCE, in situ chemical oxidation (ISCO) was implemented using sodium permanganate. ISCO was selected for its rapid reduction in contaminant concentration and to minimize creation of daughter products. One round of injection was completed in November 2014 with injection focused at the interface between the sand and till. TCE concentrations were reduced to below the regulatory standard of 5 µg/L. Permanganate is still visibly present, suggesting the potential for rebound is minimal.

The downgradient plume edge is 500 feet from the source, and off-site migration toward downgradient private wells was a second concern. Concentrations of up to 241 µg/L TCE have been detected near the downgradient edge of the plume. Creation of an injected permeable reactive barrier using BOS100®, activated carbon impregnated with reduced metallic iron, was selected for long-term prevention of off-site migration. Injections to install the reactive barrier were performed in October 2016. Significant decreases in TCE concentrations have been measured in groundwater samples collected since injection (4 to 8 months after injection), with the immediate downgradient well decreasing from 122 µg/L to 5.47 µg/L and a well 15 feet downgradient declining from 134 to 21.2 µg/L.

Results/Lessons Learned. Tailoring the remedial approach to the project/client goals is critical to managing risk, cost, and client satisfaction. In a sensitive residential area served by private wells, we were able to show both impressive source reduction with a "big hammer", and provide a longer term protection to downgradient properties. Additional investigations of the two treatment areas for groundwater and soil TCE concentrations as well as geologic stratigraphy focused the treatment strategy and was critical to achieving rapid reductions in TCE concentrations in both areas. The remaining goal for the property is to achieve at least a temporary solution (closure) within the next 1-2 years to allow the dormant property to be developed for residential use, so the client can recoup his investment.
About AECOM

AECOM is built to deliver a better world. We design, build, finance and operate infrastructure assets for governments, businesses and organizations in more than 150 countries. As a fully integrated firm, we connect knowledge and experience across our global network of experts to help clients solve their most complex challenges. From high-performance buildings and infrastructure, to resilient communities and environments, to stable and secure nations, our work is transformative, differentiated and vital. A Fortune 500 firm, AECOM had revenue of approximately $18.2 billion during fiscal year 2017.

See how we deliver what others can only imagine at aecom.com and @AECOM.