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A Regulatory Standard by Any Other Name Would Smell as Sweet

Groundwater Contamination Wars in California – Legal & Technical Issues

Norman Dupont, Ring Bender LLLP, Costa Mesa, CA; Bridgette DeShields, Integral Consulting, Inc., Santa Rosa, CA

The Ignored Path to Reasonable Cleanup

Charles Robinson, SoundEarth Strategies California, Inc., Irvine, CA

Basis for the 0.1 mg/L Water Quality Objective for “Taste and Odor” for Diesel in Groundwater

Dawn Zemo, Zemo & Associates, Inc., Incline Village, NV; Kirk O'Reilly, Exponent, Inc., Bellevue, WA

Turning Contaminated Properties into Profit – A Regulatory Perspective

Nick Amini, Santa Ana Regional Water Quality Control Board, Riverside, CA; Matt Winefield, Winefield & Associates, Inc., Long Beach, CA

Remedy Performance Reporting – Driving Remediation System Optimization and Site Progression

Kevin Lienau, Groundwater & Environmental Services, Inc., Eagan, MN

Cost-Effective Closure Achieved at a TPH- and VOC-Contaminated Site with Vadose Zone Modeling

Tom McDonnell, Brown and Caldwell, Irvine, CA

Groundwater Contamination Wars in California – Legal & Technical Issues

Norman Dupont and Bridgette DeShields

California groundwater contamination and cleanup efforts have now entered a new phase, with public water utilities asserting a right to sue despite having no direct property interest in groundwater. The California State Water Board, flush with funds based on Proposition 1 bond issues, seems willing to support this new wave of groundwater wars. This presentation will address three critical issues for environmental consultants and others:

(1) Who legally owns groundwater in California and why does it matter for cleanup to this key resource?

(2) Recent legal cases involving cleanup proposals to address common contaminants such as VOCs and MTBE in the groundwater, judicial reactions to \$100 million plus "pump-and-treat" at central facility proposals, and the impact for similar efforts throughout California. This will include discussion of specific case studies including: *Orange County Water Dist. v. Alcoa Global Fasteners, Inc.* (4th District Court of Appeal, Division 1, June 1, 2017), *Orange County Water Dist. v. SABIC Innovative Plastics, et.al.* (4th District, Division 1 – oral argument July 26, 2017), and *Orange County Water Dist. v. Exxon Mobil, et. al.* (US District Court, Central District CA, October 2017).

(3) Are there better technical methods of groundwater cleanup beyond the now routine, but sadly out of date pump and treat remedial systems in California and elsewhere? If EPA is now focused more on economic costs, can the costs of decades-long pump and treat remedies with decreasing cleanup impacts over time continue to be sustainable in today's world? Are groundwater cleanup standards based on increasing lower ppb or even ppt action levels or PHGs the true "end goal," or are adjusted technical and legal cleanup standards based on actual use of groundwater resources more realistic? Case studies of southern California Superfund remedies will be addressed.

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The Ignored Path to Reasonable Cleanup

Charles Robinson

The regulatory basis for setting groundwater cleanup levels often seems arbitrary, overly simplified, and inconsistent with State Water Resources Control Board's (SWRCB) resolutions and procedures. Non-petroleum site closure is often not achieved, despite massive and long-term expenditures. This seems contrary to the SWRCB Resolution 92-49 objective that such cleanups be consistent with the maximum benefit to the people of the State. Current cleanup level narratives typically ignore fundamental portions of Resolution 92-49 which provide that cleanup levels are to be based on more than simply Maximum Contaminant Levels. The SWRCB UST Low-Threat Closure Resolution 2012-16, as well as other resolutions and determinations, clarify the Resolution 92-49 basis for alternative cleanup levels for petroleum UST leaks, demonstrating Resolution 92-49's application. However, despite apparent clarity, the 92-49 determinations and methods are seldom applied to other compounds such as chlorinated chemicals. Resolution 92-49 and other SWRCB determinations provide a reasonable, defensible, and legal approach to balance cleanup obligations with resource value which should result in common sense remedial decisions.

This presentation reviews the history of groundwater cleanup levels and common cleanup level setting narratives that often result in never-ending cleanup. Then the salient portions of the SWRCB resolutions and determinations are identified, summarized, and reviewed to show the nature of the decisions which need to be made to arrive at cleanup level determinations that are both reasonable and that fulfill regulatory obligations.

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Basis for the 0.1 mg/L Water Quality Objective for “Taste and Odor” for Diesel in Groundwater

Dawn Zemo and Kirk O'Reilly

California’s State Water Resources Control Board’s Compilation of Water Quality Objectives (WQO) identifies 0.1 milligrams per liter (mg/L) as the “taste and odor” limit for diesel (TPHd/DRO). Several regulatory agencies use this WQO as a groundwater remediation target or effluent discharge limit. It is also used to derive soil cleanup goals that are calculated based on leaching to groundwater, and is responsible for the expenditure of millions of dollars in site assessment, monitoring, and remediation costs. To understand the basis for this WQO, we followed its history through citations to German, USSR, and Polish literature and found that it is poorly supported. The concentration of 0.1 mg/L appears to originate with a 1951 Polish literature summary of a 1948 compilation of fragmented articles on organoleptic limits for “raw crude oil” and “distilled crude oil” from the USSR. Further, it appears that the number may have been impacted by compounding transcription or translation errors over the years. We found no evidence of any separate research conducted by US EPA or any domestic regulatory agency. The detailed history of citations and numerical limits will be provided in the presentation. Given the opaque history of the 0.1 mg/L value, we believe that there is not a sufficient basis for it to serve as a WQO or be used to make management decisions at fuel release sites.

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Turning Contaminated Properties into Profit – A Regulatory Perspective

Nick Amini and Matt Winefield

In 2006, chlorinated solvents were discovered at a former dry cleaning facility in Orange County, California. After performing some limited cleanup, the former facility operator stopped work completely in April 2010. For the next few years, the former operator ignored requests by the Regional Water Board to proceed with investigation and cleanup of the groundwater. In December 2013, the Regional Board issued a Cleanup & Abatement Order (CAO) to the former operator. Despite the issuance of the CAO, both the former operator and the land owner declared that there were no funds available to complete the necessary environmental work at the site. The Water Board Office of Enforcement performed a financial assessment to determine the existence of any viable assets or properties of the former operator, with the intent of placing a lien on those assets or properties; however, it is a lengthy process, subject to legal challenges, and may take years to produce any tangible results. In the meantime, the impacted groundwater plume would have continued to migrate toward an elementary school that is located downgradient of the site. In 2014, a private investor expressed an interest in purchasing the site. The proposed venture was to: buy the impacted property at a price significantly below the market value, work with the regulators to complete the necessary environmental work, and sell the property for a significant profit. The buyer is an environmental engineer with financial backing from investors with sufficient resources, patience, and desire to return the property to productive use – all for an expected profit. This presentation will tell the story of cooperation between the Regional Board and the private investor who, despite a number of obstacles, managed to successfully perform the necessary environmental work at the site to delineate the impacted groundwater plume.

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Remedy Performance Reporting – Driving Remediation System Optimization and Site Progression

Kevin Lienau

Background: Tracking and understanding remediation system performance and safe operation is critical to managing environmental liabilities. Multinational companies and industrial conglomerates often have a diverse environmental liability portfolio consisting of various types of sites across varied geographies, consultant cultures/practices, and regulatory programs. This presents a challenge in centralized portfolio management and optimization. One solution to this challenge is the development of a systematic approach for routine collection and analysis of remediation site data.

Approach: Responsible parties managing these long-term liabilities have developed and deployed various standardized approaches that rapidly assess the performance of a remedy and identify actions to optimize life cycle cost and drive the site to closure. This holistic approach includes not only performance optimization (e.g., by increasing the mass removed over time), but also proactive risk identification and mitigation, optimization of life cycle cost, and steps to drive the site to closure. Remedy performance programs typically include technical practices, standardized field reporting formats, remediation system key performance indicator (KPI) reports, and routine site visits by senior leadership and technical staff.

Lessons Learned: Active and passive remediation remedies need to be evaluated and optimized to ensure regulatory conformance, effectiveness, safe operation, and efficiency. Key learnings include: (1) closure of a site may require more than one remedial method; (2) standardize performance tracking, but allow flexibility in site-level implementation; (3) specialized software applications can be extremely valuable in identifying trends; (4) use independent “fresh eyes” reviews or peer assist reviews to share best practices, highlight innovation, and continuous learning opportunities; (5) strong project management is important to keep the overall project goals on track; and (6) interpretation of remedy data by experienced professionals is vital to delivering implementable improvements. Remedy performance monitoring at remediation projects offers significant opportunities for improving efficiency, enhancing safety, reducing waste, and protecting the environment.

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Cost-Effective Closure Achieved at a TPH- and VOC-Contaminated Site with Vadose Zone Modeling

Tom McDonnell

Vadose zone fate and transport numerical modeling with SESOIL was used to complete the case for site closure. Past industrial activities at this 1-acre site in Los Angeles County resulted in TPH and VOC contamination. Initial remedial efforts included excavation of 3,000 cubic yards of TPH- and VOC-impacted soil. A soil vapor extraction system was used for 1.5 years to reduce the concentrations of TPH-g and PCE in soil and soil gas. The SVE system was discontinued after performance indicators reached asymptotic levels. Bioventing was then used to reduce the concentrations of cis-1,2-DCE and vinyl chloride. Risk assessment estimates for potential future uses of the site were less than applicable thresholds. Residual concentrations of TPH-d, TPH-o, and PCE remained in a 5- to 10-foot thick layer of fine silt/clay at 35 feet bgs depth. A vadose zone fate and transport model was used to demonstrate the protection of groundwater quality and the near absence of mobility of these residual contaminant concentrations. Protection of groundwater quality was corroborated by a 15-year history of groundwater quality monitoring demonstrating the absence of TPH and stable or declining concentrations of PCE and daughter products.

This presentation will review the initial site characterization, the remedial strategies employed, and the vadose zone fate and transport modeling used to achieve final site closure. Schedule and cost savings associated with avoiding the need to remediate the residual TPH and PCE concentrations will also be discussed.

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Bioremediation

Colloidal Activated Carbon as a Treatment Solution for Back Diffusion

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Optimizing a Sorptive Biomatrix MTBE Barrier

Jack Sheldon, Antea Group, West Des Moines, IA; Dacre Bush, Antea Group, Long Beach, CA; Craig Sandefur, Regenesis, San Clemente, CA; Dan Nunez, Regenesis, La Mirada, CA

Comparison of Eight Biotreatment Approaches for Soil Containing TNT and DNT

Alan Seech, PeroxyChem, Corona Del Mar, CA; Ed Meeks, Ashland LLC, Wilmington, DE; Scott Larew, Kennedy/Jenks Consultants, Princeton, NJ; Mitch Wacksman, Arcadis, Portland, ME

Potential Microbial Drivers of Biodegradation of Crude Oil Sludge in Compost

Harrison Atagana, Linda Obi, and Rasheed Adeleke, University of South Africa, Pretoria, Gauteng, South Africa

Colloidal Activated Carbon as a Treatment Solution for Back Diffusion

Dan Nunez, Kristen Thoreson, Stephanie Rittenhouse, and Craig Sandefur

A primary concern in subsurface contaminant hydrology is what can be done to address contaminant storage and release from low permeability (k) layers in plumes, also known as back diffusion. Previous studies that examined various *in situ* treatment options for back diffusion demonstrated an initial decrease in groundwater concentrations, followed by a rebound once the amendment dissipated. These results indicate a necessity for longer-term treatment options to effectively treat the persistent contamination associated with back diffusion. Laboratory studies were performed to evaluate the efficacy of Plumestop[®] (PS), a distributable form of colloidal activated carbon, for removing and degrading common volatile organic compounds (VOCs) in groundwater compared to controls.

A laboratory study was conducted utilizing dual-soil porosity tanks to simulate back diffusion of TCE. The four treatments evaluated in this study were: 1) no-action control, 2) PS-only, 3) *Dehalococcoides* microbial inoculum and lactate (DHC-L), and 4) PS with *Dehalococcoides* microbial inoculum and lactate (PS-DHC-L). Effluent VOC concentrations were monitored throughout the study and microbial analysis was performed at the end of the study. Highlights from the dual-porosity tank study findings include: 1) consequential contaminant storage and release time-frames associated with low k zones; 2) a solution of DHC and lactate will provide reductions in effluent VOC concentrations, but will eventually rebound once the electron donor is exhausted; 3) sorption leading to degradation are the removal mechanisms when PS is applied, and the presence of PS with DHC and lactate increased DHC populations approximately 2 orders of magnitude in both the silts and sands compared to the DHC-L-only treatment; and 4) the migration of the PS throughout the low k soils of the two PS treatment tanks indicates a substantial increase in sweep efficiency compared to a water-only flush, which has far-reaching implications for long-term treatment options.

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Optimizing a Sorptive Biomatrix MTBE Barrier

Jack Sheldon, Dacre Bush, Craig Sandefur, and Dan Nunez

This presentation describes the extended results of a pilot test of a sorptive biomatrix coupled with enhanced aerobic bioremediation at a service station site impacted with methyl tertiary-butyl ether (MTBE) and tertiary butyl alcohol (TBA). More specifically, the amendments PlumeStop[®] Liquid Activated Carbon and Oxygen Release Compound Advanced (ORC Advanced[®]) were applied to address off-site migration of MTBE and TBA in groundwater at a pilot scale and are being scaled up. The site is located in Daly City, California, and historically the on-site area had active remediation that led to significant reduction in gasoline constituents. Biodegradation played a key role in the progress on-site and appears to be key in off-site reduction of MTBE and TBA concentrations. The migration of MTBE off-site is still in question, so control of plume migration remains an issue.

The following aspects of the project will be discussed in this presentation: (1) a summary of on-site and off-site microbial profiling of MTBE-degrading bacteria and gene functions coding for MTBE/TBA biodegradation; (2) the value of in-well microcosms evaluating amendments at individual well locations plus geochemistry, contaminant concentrations, and stable isotope probing using radio-labelled MTBE to differentiate incorporation of ¹³C into biomass and dissolved inorganic carbon as evidence of biodegradation of MTBE; (3) the current results of the pilot test including MTBE/TBA reductions and changes in microbial profile and geochemistry/field parameters; (4) the challenges encountered during the pilot test injection events and the solutions developed; and (5) the impact of new data on the final barrier design configuration.

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Comparison of Eight Biotreatment Approaches for Soil Containing TNT and DNT

Alan Seech, Ed Meeks, Scott Larew, and Mitch Wacksman

Due to base closures and the reduced footprint of the US military, properties once dedicated to supporting the military mission are being converted to other uses. Soil at many military installations and explosives manufacturing facilities have been remediated using a variety of biotreatment approaches. The researchers conducted a controlled, pilot-scale test to evaluate possible approaches to bioremediation of soil containing TNT and DNT using soil excavated from a former organic explosives (OE) manufacturing facility. The study monitored OE reduction over 18 months using eight biotreatment approaches. Objectives included determining the rate and extent of change in concentrations of TNT and breakdown products. Soil was treated in purpose-made 12 y³ open-top steel boxes. The goal of the work was to find a scalable treatment approach while employing minimal physical effort (mixing) and soil amendment. The design included a static control (no mixing or water), a watered control mixed once, and a watered control mixed every 14 days. The treatments included wood mulch (10% w/w) with water and mixed once, the same treatment mixed every 14 days, and six approaches with a reduction-enhancing amendment (40% micro-scale ZVI + 60% comminuted plant fiber), with dosages of 2%, 3%, or 4% (w/w). Three of these treatments received the entire mass of amendment at the start and were mixed only once. The others received the amendment in five smaller doses with mixing, separated by 14 days. Concentrations of TNT and its breakdown products were quite stable in the controls and the wood mulch treatments. Sharp reductions in TNT and breakdown products were observed in response to the reduction-enhancing amendment. In general, greater reductions in all compounds were observed in treatments that received higher doses of the reduction-enhancing amendment. Detailed results will be presented.

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Potential Microbial Drivers of Biodegradation of Crude Oil Sludge in Compost

Linda Obi, Harrison Atagana, and Rasheed Adeleke

Crude oil sludge, which consisted of the 16 priority polycyclic aromatic hydrocarbons (PAH) pollutants, was co-composted for 16 weeks with soybean, horse manure, and surfactants. Microorganisms were isolated and identified using culture dependent and culture independent techniques, respectively. The extent of reduction of the PAH components present in the crude oil sludge was determined by Gas Chromatography–Mass Spectrometer (GC-MS). Isolated fungi were found to belong to different genera such as *Aspergillus*, *Mucor*, *Fusarium*, *Geotrichum*, *Galactomyces*, *Penicillium*, *Doratomyces*, *Bionectria*, *Exophiala*, *Trichoderma* and *Trichurus*, while the bacterial isolates belong to *Stenotrophomonas*, *Pseudomonas*, *Bordetella*, *Brucella*, *Bacillus*, *Achromobacter*, *Ochrobactrum*, *Advenella*, *Mycobacterium*, *Mesorhizobium*, *Klebsiella*, *Pusillimonas* and *Raoultella* after molecular characterisation of the ITS and 16S rRNA genes, respectively. They exhibited hydrocarbon degrading characteristics when inoculated into 2,6-dichlorophenol indophenol culture medium. Analysis of the PAH components of the crude oil sludge present in the composted crude oil sludge showed the absence of 5 and 6 benzene ring PAHs as well as significant differences amongst the treatments ($p < 0.05$) after incubation. Indigenous microorganisms isolated in this study played a crucial role in degrading the PAH components of crude oil sludge as well as resisting the toxicity of the surfactants.

Keywords: fungi, bacteria, PAHs, bioremediation, surfactants, crude oil sludge

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Chemical Analysis

Application of EPA's Triad Methodology for Rapid Arsenic Site Characterization

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Troubleshooting for Total Phosphorous and Ortho-Phosphate Colorimetric Testing

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Dissolve Methane Round Robin Case Study – Regulations Without a Robust Analytical Method

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Application of EPA's Triad Methodology for Rapid Arsenic Site Characterization

Anthony Blake and Meghann Hurt

EPA's Triad Methodology, which consists of systematic planning, dynamic work strategies, and real-time measurement systems, was utilized for a Department of Energy project at the Former Naval Petroleum Reserve Number 1 (NPR-1, also known as Elk Hills), located near Bakersfield, California. One of the areas of concern at the Former NPR-1 consists of former or current oil well pads that may have been impacted by the use of an arsenic-containing corrosion inhibitor. Using innovative investigation, data management, and reporting approaches, over 20,000 samples were collected and analyzed using a mobile X-Ray Fluorescence (XRF) laboratory and 764 well pads were characterized for further action decision making. Attendees will come away with first-hand knowledge regarding how XRF analytical data can be used for supporting dynamic definitive characterization objectives, without reliance on traditional methods of laboratory analysis.

Topics covered in the presentation include: sampling design, geospatial technology applications, sample processing techniques, sample analysis using field laboratory X-Ray Fluorescence, X-Ray Fluorescence method validation for definitive decision making, dynamic sampling approaches, data management, real-time decision making, and results evaluation.

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Troubleshooting for Total Phosphorous and Ortho-Phosphate Colorimetric Testing

Sarah Leibenguth

Total phosphorous and ortho-phosphate are currently tested in many working laboratories. In order to achieve the best results possible for these colorimetric tests, each laboratory should take into consideration chemistry-related issues that may be having an impact on its results. These topics include reagent stability and chemical shelf life, extraction solution considerations, matrix matching of sample preparation, reaction interferences, and chemical contamination. The discussion will also address the importance of the pH of samples and reagents and how it effects the overall color development of each reaction. For total phosphorous, we will discuss the differences in digestion protocols, including acid level considerations and consistency in reconstitution.

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Dissolve Methane Round Robin Case Study – Regulations Without a Robust Analytical Method

Rock Vitale and David Gratson

As the discovery and harvest of fossil fuels from shale formation have increased and provided valued domestic energy reserves, regulations and legal action have followed from the detection of light gases in groundwater used for potable purposes. These actions have proceeded on the basis of an antiquated non-consensus/non-certified analytical procedure. Accordingly, during 2014-2015 the Marcellus Shale Coalition Dissolved Methane Method Workgroup commissioned a round robin study of dissolved light gas analysis. In this initial phase, fourteen commercial laboratories and one government laboratory analyzed blind groundwater samples that had been collected at two locations. The study identified significant variation among the results, with dissolved methane values that varied from 7,400 to 35,000 µg/L. The study showcased the need for a robust consensus analytical procedure and the need for additional work to identify the source of the variability. In 2016 the Marcellus Shale Coalition commissioned a second study, again using fifteen laboratories, that analyzed four reference standards that were submitted blind. The results of this second study will be presented starting with study design, reference standard preparation, data analysis, and the conclusion that calibration is the primary source of error. Techniques within the calibration process will be discussed relative to the source of error for analysis of dissolved methane.

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Emerging Contaminants

The Good, the Bad, the Inevitable: Metabolites During Petroleum Biodegradation

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Reassessment of Ecological Risk at Mature Near-Bay Petroleum Sites Due to Polar Degradation Metabolite Contaminants

Arnab Chakrabarti, Peter Zawislanski, and William Carson, Terraphase Engineering, Oakland, CA

In-Situ Soil Source Removal of PFAS

William Kerfoot, Kerfoot Technologies, Mashpee, MA

Biodegradation of 1,4-Dioxane in a Fixed-Film Bioreactor

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What's Replacing PCE & TCE? Is PCBTF the Next Emerging Contaminant?

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Antimony – A New Emerging Contaminant?

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The Good, the Bad, the Inevitable: Metabolites During Petroleum Biodegradation

Uta Hellmann-Blumberg and Ross Steenson

Biodegradation is an important component of natural attenuation for many environmental contaminants. Degradation of organic chemicals by microorganisms typically involves the production of many intermediates or metabolites. Some of these persist for a long time depending on the compound and conditions at a given site. Although metabolite concentrations at petroleum release sites are not routinely monitored at present, interest in this topic has recently increased. On the one hand metabolites are evidence of biodegradation and can be an important component of site management strategies (the good), on the other there is the potential that some metabolites persist for a significant length of time and have toxic effects when humans or ecological receptors are exposed (the bad). Given the complexity of petroleum hydrocarbon mixtures and the large mass of some releases, it is inevitable that metabolites accumulate during weathering. For much of the first century after it was discovered that microorganisms can attack hydrocarbons it was assumed that oil spills degrade readily and aerobically. However, significant contamination is still present after decades at some petroleum release sites. This should not be surprising because hydrocarbons are chemically very inert; in other words, large amounts of energy and/or catalysts are required for activation and after that it takes many steps to transform a large hydrocarbon into small molecules or carbon dioxide. Enzymes produced by local microbial communities (consortia) provide such catalytic activities. Under aerobic conditions microbial consortia can often degrade most hydrocarbons to levels that no longer cause concern. Metabolites appear to accumulate mostly under anaerobic conditions and often in groundwater. Research on the nature and toxicity of these metabolites is currently in the early stages. Understanding how site-specific microbial consortia and other factors affect the rate and extent of biodegradation may help managing sites with persistent petroleum-related contamination successfully.

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Reassessment of Ecological Risk at Mature Near-Bay Petroleum Sites Due to Polar Degradation Metabolite Contaminants

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Background/Objectives: Polar petroleum degradation metabolites have been identified as an emerging contaminant issue, particularly relevant to the San Francisco Bay region, which contains numerous mature petroleum sites. Select sites with previously established TPH action levels are currently being re-assessed for potential ecological risk attributed to polar compounds. A regulatory screening level for polar compounds has yet to be established due to (a) difficulty in quantifying the complex mixture of degradation metabolites by commercial analytical laboratories and (b) a paucity of toxicological data available for polar compounds.

Approach/Activities: A near-Bay, former 400-acre fuel storage site is currently participating in this process. A previous off-shore ecological risk assessment performed at the site did not find toxicity in off-shore sediments. Per a RWQCB request, groundwater was analyzed without the silica gel cleanup method that selectively removes polar degradation metabolites, starting in 2014. In 2016, ecological risk was assessed by conducting direct aquatic toxicity testing of representative saltwater species (benthic invertebrate, crustacean, and fish) using groundwater that contained polar compounds only and that had been adjusted for estuarine conditions.

Results/Lessons Learned: Results of direct aquatic toxicity testing showed an effect (both acute and chronic growth) from 100% undiluted groundwater for the mysid shrimp receptor only. Toxic effects were not observed for the benthic invertebrate (mussel embryo) or the fish (inland silverside) species. Confounding factors were excluded by sampling a background well and use of reference toxicant tests. Based on these results, serial dilution testing is being conducted using the mysid shrimp to generate a dose-response curve for use in establishing a regulatory point-of-compliance threshold. In the absence of polar-compound-specific regulatory screening levels, other near-Bay sites approaching regulatory closure, or even having obtained regulatory closure, may have to adopt a similar site-specific risk-assessment approach until regulatory screening levels are established.

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In-Situ Soil Source Removal of PFASs

William Kerfoot

Perfluoroalkyl and polyfluoroalkyl substances (PFASs) have been removed from fire training site soils. Expanded range oxidation-reduction allows in-situ soil source removal of PFASs through mineralization. The soils also contain the remnants of the fuels which were ignited and subjected to elevated temperatures. Different tests were carried out on example contaminated peroxide-activated nanobubble ozone slurries. A comparison of released fluoride with PFOS decomposition showed proportional change. The single algorithm can be used to confirm mineralization of PFAS during in-situ treatment. Observed removal during pilot testing ranged from 80 to 98.5%. Fluorotelomer sulfonates of two isotopes, 6:2 and 8:2, showed removal efficiencies over 98%.

Removal raises the question of appropriate endpoints for site soil cleanup. In the U.S. individual states have developed some guidance for groundwater and soil removal. European countries have also adopted certain levels, primarily for PFOS. A discussion of the basis is presented for certain PFASs and normal accompanying residual fuel organics.

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Biodegradation of 1,4-Dioxane in a Fixed-Film Bioreactor

Caitlin Bell, J. Chris Stanfill, Andrew Lorenz, Monica Heintz, and David Favero

Background/Objectives: 1,4-Dioxane is a common co-contaminant with chlorinated solvents. Treatment of 1,4-dioxane via enhanced biodegradation processes provides a viable remedial strategy. Both metabolic (i.e., energy producing) and co-metabolic (i.e., fortuitous) biodegradation of 1,4-dioxane can occur. Metabolic biodegradation occurs under aerobic conditions, and co-metabolic biodegradation must occur in the presence of both oxygen and a primary substrate (e.g., methane or propane) by microorganisms that utilize these primary substrates for growth. At the RACER Trust facility in Lansing, Michigan, historical use of chlorinated solvents resulted in up to approximately 3,300 micrograms per liter of 1,4-dioxane in groundwater. The initial remedial design called for ex-situ treatment via advanced oxidation processes (AOPs), which is relatively expensive for long-term removal of 1,4-dioxane, considering the power and chemical costs for operation. Instead, the RACER Trust is exploring an ex-situ biological treatment approach: using pilot fixed-film bioreactors.

Approach/Activities: Three bioreactors were piloted to treat extracted groundwater with approximately 300 µg/L 1,4-dioxane prior to reinjection: one designed for metabolic biodegradation of 1,4-dioxane and two designed for co-metabolic biodegradation of 1,4-dioxane (for concurrent testing of different conditions). The bioreactor pilot system consisted of an aerated iron oxidation tank and primary clarifier, oxygen and/or propane cylinders, gas injection points, a nutrient feed tank, the three bioreactors filled with approximately 40 percent media in parallel, a biological solids settling tank, an effluent cartridge filter, a lower explosive limit meter, and associated controls. The metabolic bioreactor was seeded with a known 1,4-dioxane degrading organism, *Pseudonocardia dioxanivorans* CB1190 (provided by Dr. Shaily Mahendra, University of California, Los Angeles). The co-metabolic bioreactors were seeded with a propanotrophic culture, *Rhodococcus ruber* ENV425 (provided by EOS Remediation, LLC). ENV425 utilizes propane as its primary substrate and has been used elsewhere to facilitate co-metabolic biodegradation of 1,4-dioxane. The bioreactors also received micro- and macronutrients to promote bacterial colonization.

Results/Lessons Learned: Several challenges were experienced during initial operation of the bioreactors, primarily establishment of a working microbial population. Efforts undertaken to facilitate growth included 1) a period of recirculation and extra nutrient addition after the initial seeding with the microbial cultures, 2) a second seeding of the ENV425 microbial culture, 3) reconfiguration of one of the co-metabolic bioreactors to allow for cycling on and off of the propane, and 4) increasing the hydraulic residence times to mitigate microbial washout. After these efforts, 83% removal of 1,4-dioxane was observed in the co-metabolic bioreactor with cycled propane. However, unforeseen system upsets limited continued performance. A post-mortem evaluation of the microbial population in the bioreactors concluded that the seeded microbial cultures may have been outcompeted by native microorganisms.

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What's Replacing PCE & TCE? Is PCBTF the Next Emerging Contaminant?

Angela Haar and Steve Jones

Perchloroethylene (PCE) and trichloroethylene (TCE) are ubiquitous solvents which have found widespread use in a number of industries, such as plating, dry cleaning, and manufacturing. However, these compounds pose a risk to human health and have therefore seen increasing regulation in recent years. As regulations have stiffened for these and other solvents, we have begun to see replacement compounds showing up in soil and soil gas samples. Parachlorobenzotrifluoride (PCBTF) is an organic solvent that has become a popular alternative to traditional solvents, and since 2005 we have encountered it in an increasing number of environmental samples. Adoption of PCBTF in the automotive, printing, and paint industries has been particularly fast, with its uses extending into a number of other industries.

Touted as a “green” solvent for its low ozone formation and depletion potentials and VOC exempt regulatory status, PCBTF has nonetheless been found to have negative health effects, and the impact of chronic exposure has yet to be fully understood. Our numerous investigations of VOC-impacted sites show that PCBTF is a frequently observed constituent in soil gas throughout Southern California. Furthermore, as it is in current use and is unrestricted, it is often present at exceptionally high levels. While PCBTF is regularly found at sites of industries reliant on high levels of solvent use, it is notably absent from dry cleaners, where different alternatives have been employed. Here we will discuss the prevalence and abundance of PCBTF in the Los Angeles area as well as its behavior at sites under remediation, both with and without current PCBTF use. We will also discuss possible breakdown products and potential health effects associated with environmental PCBTF contamination.

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Antimony – A New Emerging Contaminant?

Jay Clausen and Amanda Barker

Historically, the focus of contaminant transport issues associated with military small arms ranges has been focused on lead. Antimony, in contrast, has received less research scrutiny. However, antimony has a lower action level than lead, is a suspected carcinogen in addition to being toxic, and recent research suggests it has a higher mobility potential. A review of the fate-and-transport observations from a variety of military small arms ranges is presented. In addition, results from laboratory column experiments are presented to quantify the degree of antimony sorption onto soils from an unnamed military site.

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Energy

Microbial Photo-Assisted Energy Conversion for Hydrogen Generation and Wastewater Cleaning

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Decentralized, Energy-Neutral Approach for Onsite Treatment of High-Strength Wastewaters

Orianna Bretschger, Sofia Babanova, Jason Jones, Sujal Phadke, Carlo Angulo, Jaime Garcia, Zach Benavidez, Shirley Chan, Tony Phan, Rachel Cortese, Rafael Calderon, and Mengqian Lu, Aquam LLC, San Diego, CA; Kayla Carpenter, Columbia University, New York, NY

Innovations in Climate Action Planning at the Port of San Diego

Renée Yarmy, Port of San Diego, San Diego, CA

Microbial Photo-Assisted Energy Conversion for Hydrogen Generation and Wastewater Cleaning

Lu Lu, Waltteri Vakki , Jason Ren, and Jing Gu

Sunlight offers an inexhaustible and sustainable source of renewable energy to meet our increasing energy demand. However, direct harvesting of solar energy is still challenging due to the variation of natural sunlight and its intermittent nature. To meet the Terawatt Challenge and harness large quantity of energy, a current artificial photosynthesis system is showing great promise for its capability of imitating natural photosynthesis. Unfortunately, the direct water splitting by artificial photosynthesis requires large energy input. As an alternative, a microbial electrochemical oxidation process could save a lot of energy by recovering electrons and energy from organic matters. In this process, electroactive bacteria capable of extracellular electron transfer are able to oxidize organics and transfer electrons to an electrode, and the electrons can be harvested as direct current or used to reduce protons to H₂ or CO₂ to organic chemicals, respectively. Here we demonstrate a photocathode could couple with the microbial electrochemical oxidation process, which is used to treat wastewater and recover the chemical energy embedded in organics into electricity to convert water into hydrogen.

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Decentralized, Energy-Neutral Approach for Onsite Treatment of High-Strength Wastewaters

Orianna Bretschger, Sofia Babanova, Jason Jones, Sujal Phadke, Carlo Angulo, Jaime Garcia, Zach Benavidez, Shirley Chan, Tony Phan, Kayla Carpenter, Rachel Cortese, Rafael Calderon, and Mengqian Lu

Onsite manure management for confined animal production is typically limited to facultative and/or anaerobic lagoons. These methods are cost-effective; however, they may pose issues with runoff and/or unanticipated storm events that could lead to impacting local water resources. Microbial fuel cells (MFCs) hold the promise for energy-neutral wastewater treatment; however, commercial applications have so far been limited by system costs and scalability. To address this hurdle, several research groups have begun wastewater treatment pilot demonstrations with different waste streams. Here we present a subset of results from a MFC system piloted at a small hog farm to continuously treat swine waste at a scale of 150 gallons per day (0.6 m³/day) for nearly two years. The system was comprised of twelve BioElectrochemical Sanitation Technology (BEST™) reactors operated in hydraulic series with an overall internal volume of 110 liters (29 gal). The system was shaded but otherwise completely exposed to the environment throughout operation.

The system was inoculated with a mixture of swine waste, natural environmental samples, and carbonate buffer (pH 7.5), and operated in a batch mode for the first 30 days with recirculation of the solution at a flow rate of 1.9 lpm. After 30 days, the operation was switched from batch to continuous flow mode (0.4 lpm, 0.1 gpm) and the reactors were fed a continuous supply of swine waste chemical oxygen demand (COD) of approximately 1000 mg-COD/L.

The organic removal rate of the system varied during operation with results between 1-5 kg-COD/m³/d, which is comparable to the removal rates demonstrated by small-scale MFC treating swine manure and current aerobic treatment technologies. These rates are also comparable to standard activated sludge technologies for the treatment of less concentrated human waste. The normalized energy recovery (NER) of the MFC system operated at 330Ω was 0.2 kWh/kg COD, which is a higher instantaneous NER relative to anaerobic digestion with energy recovery from methane. Overall, these data suggest that BEST™ systems can be practically scaled for energy-neutral wastewater treatment. An additional BEST™ demonstration is running in Tijuana, Baja California, Mexico at a scale of 700 gallons per day treatment raw sewage.

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Innovations in Climate Action Planning at the Port of San Diego

Renée Yarmy

The Port of San Diego was one of the first ports in the world to adopt a Climate Action Plan (CAP). The CAP, adopted in 2013, contains both near-term and long-term greenhouse gas (GHG) reduction goals focused on decreasing emissions from energy consumption, transportation, waste generation, and water use. The CAP contains a suite of measures to achieve reduction goals. The Port has since focused efforts to develop policies, create programs, and implement projects aimed at reducing emissions from operations; decrease costs; engage Port tenants; and enhance the San Diego Bayfront. The Port-led presentation will highlight current sustainability and climate planning initiatives aimed at accelerating GHG emissions reductions. These efforts are primarily focused on increasing the use of renewable energy, demonstrating applications for smart port technologies, and fostering the adoption of alternative transportation technologies. In addition, the presentation will provide a high-level summary of other innovative programs currently under development aimed at furthering the Port's role as an environmental champion in the region.

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Environmental Forensics

Environmental Forensics – Past, Present, and Future

Paul Philp, University of Oklahoma, Norman, OK

Combining Isotopes of Chlorine and Oxygen in Dissolved Perchlorate with Stable Isotopes of Oxygen and Hydrogen to Improve Understanding of Perchlorate Sources in Groundwater

Michael Foster, Kleinfelder, San Diego, CA

Metals Forensics at Ghost Factories

Lydia Dorrance and Adam Love, Roux Associates, Inc., Oakland, CA

Data Skewing and Validity – Common Field Methods Influencing Risk, Remedy, and Closure

Joseph Berlin, BLDI Environmental Engineering, Grand Rapids, MI

Temporal and Spatial VOC Distributions in Utility Corridors that Act as Alternative VI Pathways

Yuanming Guo and Paul Dahlen, Arizona State University, Tempe, AZ; Paul Johnson, Colorado School of Mines, Golden, CO

Environmental Forensics – Past, Present, and Future

Paul Philp

Environmental forensics as it is known today has emerged over the past two or three decades and is an important part of any environmental investigation. It is important at the outset of a presentation such as this to point out the basic difference between the environmental forensic approach and the EPA approach in environmental investigations. The EPA approach is basically a monitoring approach to determine changes in concentrations of certain target compounds to determine whether these concentrations are decreasing over time, using very rigid analytical methods. However, such an approach will not determine who was responsible for the release of any contaminants and that is where the environmental forensic approach becomes invaluable. While certain aspects of the analytical techniques in the two approaches may be similar, the way in which the data are acquired and interpreted are different, as will be shown in this presentation.

Environmental forensic investigations may cover contaminants present in samples from air, soil, or water, and the general purpose of the investigation is to determine the source, or point of release, of the contaminants. In this presentation time will permit only a few examples to be discussed. As mentioned above the techniques used for either the EPA approach or forensic approach will be basically the same. However, one significant difference at the outset is that in the forensic approach you may not look for specific target compounds. In other words, if a compound of interest is not in the target list, you will of course not detect it. Furthermore, in the forensic approach individual compounds present below normal detection limits may be invaluable in distinguishing samples from each other.

Another important aspect of any forensic investigation is knowledge of the origin of contaminants. For example, how many people really know how PCE is manufactured and how the process can influence the characteristics of this compound? How do gasolines of the same octane rating but from different refineries differ and why? These are simple questions but if you are simply monitoring concentrations of a specific compound, that type of information may seem irrelevant. However, when trying to determine a specific point of release, or trying to discriminate possible sources for a contaminant, background information on the manufacturing history of a specific contaminant can be crucial.

In brief, this presentation will discuss the basic concept of an environmental forensic investigation and provide a number of different examples specifically designed to show why simply using the standard EPA methods are of little help when trying to determine the source of a contaminant.

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Combining Isotopes of Chlorine and Oxygen in Dissolved Perchlorate with Stable Isotopes of Oxygen and Hydrogen to Improve Understanding of Perchlorate Sources in Groundwater

Michael Foster

Stable isotopes of oxygen and hydrogen in groundwater have been used to help better understand the recharge sources of groundwater downgradient of the Stringfellow Superfund Site in Jurupa Valley, west of the City of Riverside in California. The results indicated that recharge sources varied spatially with some areas having isotopically heavier groundwater as a result of hill-front runoff and recharge of local precipitation. Other areas with isotopically light groundwater reflect a component of recharge from water imported from adjacent basins recharged with water from the San Bernardino and San Gabriel Mountains.

Newly available results for the stable isotopes of chlorine and oxygen in dissolved perchlorate will be combined with the prior stable isotope data to help differentiate perchlorate contaminated groundwater originating from the Stringfellow Superfund Site from other perchlorate present in groundwater in the Jurupa Valley. Other potential sources not from the Stringfellow Superfund Site include perchlorate containing nitrate fertilizers and imported water from other groundwater basins.

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Metals Forensics at Ghost Factories

Lydia Dorrance and Adam Love

Hundreds of industrial facilities abandoned or demolished prior to property transaction environmental due diligence – so-called “ghost factories” – exist throughout the United States. The legacy of these facilities often remains in the form of soil contamination on the historical parcel and adjacent properties. Increasing attention is currently being placed on such parcels, as in subsequent years residential and municipal development has occurred on land where soil levels can exceed the hazardous waste criteria for metals and pose a health risk for those who inhabit or frequent the former industrial site. While these ghost facilities often stand as the most obvious source of elevated soil metals concentrations, additional consideration of other potential sources such as other industrial/commercial facilities, regional anthropogenic background, historic automobile contributions, natural background, and historical fill materials is necessary in order to avoid oversimplified conceptual models. A wide range of potential environmental forensic tools are available to help with such distinctions, such as ratio comparisons, isotopic analyses, and single and multi-variate statistical techniques. The value of these forensic tools at a given site will depend on multiple factors, including data availability and the uniqueness of the contributing sources.

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Data Skewing and Validity – Common Field Methods Influencing Risk, Remedy and Closure

Joseph Berlin

Data validity is critical to conducting environmental assessments, feasibility studies, risk assessments, cleanups, and site reuse. To assert that sample collection methods should be conducted consistent with agency and industry guidance and best practices is an understatement. Peer reviews, discussions, and field observations regarding the relatively common use of “non-standard” sampling practices puts data validity and reliance into question.

The research was conducted to assess historic and current field soil sampling practices influencing volatile organic compound (VOC) results. Although field preservation using US EPA Method 5035 (i.e., Method A) is presumed to mitigate soil sample VOC losses, upstream sample handling practices, including collection of the VOC sample from field screening aliquot (i.e., Method B), are common and significantly impact outcomes. Survey data was collected demonstrating that in over 20% of sample events, soil samples were collected using Method B. Further, over the 2015 to 2017 period, peer review and field observations identified multiple other common data skewing methods influencing all soil sampling results. To demonstrate the impact of the use of the most common soil sample skewing method (Method B), multiple co-located samples were collected using both Method A and Method B collection methods. Significant VOC losses were experienced in all sample sets ranging from 50% to over 90% VOC losses.

The presentation will discuss the variance between Method A and Method B results on the Conceptual Site Model for a large gasoline tanker spill, including standardized corrections to Method B results.

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Temporal and Spatial VOC Distributions in Utility Corridors that Act as Alternative VI Pathways

Yuanming Guo, Paul Dahlen, and Paul Johnson

Subsurface utilities can act as significant alternative vapor intrusion (VI) pathways. These subsurface corridors, such as sewer lines, may distribute VOCs beyond groundwater plume and directly link VOC source to building interior. Several data sets have been published in the recent years to review the spatial and temporal characteristics of VOCs in utility systems; however, no studies addressed long term VOCs spatial and temporal changes in utility systems. The objectives of this research are to understand the long-term VOCs' behavior more comprehensively in the utility lines and to examine the correlations between VOC utility distributions and VI impacted houses.

Five quarterly surveys on VOC distributions in subsurface utilities were conducted at a neighborhood sitting on a chlorinate solvent groundwater plume. Over 270 air samples were collected during each survey event. Spatial and temporal characteristics are analyzed and compared to historical indoor air monitoring results. TCE vapors were detected in about 50% of manhole samples across the test area with greatest concentrations over 500 ppbv. Different TCE temporal changes were discovered at different locations; TCE varied less than x10 in more than 55% of manholes, whereas more than x10 TCE vapor variations were found in 38% of sampled manholes. The study on historical indoor air VOC record versus utility VOC distributions are being conducting and will be updated.

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Innovative Remedial Technologies

Innovative and Cost Saving Solutions Derived from Sustainable Remediation Thinking

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The Effect of Particle Size and Surface Composition on ZVI Reaction Kinetics

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Quantifying the Thermal Desorption Effect During ISCO Injections

Gary Cronk, JAG Consulting Group, Inc., Santa Ana, CA; Greg Sounhein, SounPacific Environmental Services, Eureka, CA

A Novel Technology for Removal of Metal from Solvents

Roger Acey, California State University, Long Beach, CA; Gwen Jordeen, MGP Biotechnologies, Irvine, CA

Diverse Settings for Natural and Anthropogenic Pyrite Oxidation and Selected Mitigation Strategies

James Jacobs, Clearwater Group, Point Richmond, CA

A Rigorous Demonstration of Permeability Enhancement Technology for In Situ Remediation of Low Permeability Media: Final Results

Ryan Wymore, Kent Sorenson, Nathan Smith, and Dung Nguyen, CDM Smith, Denver, CO

Innovative and Cost Saving Solutions Derived from Sustainable Remediation Thinking

Paul Favara and Jeff Gamlin

There are numerous examples of remedies that continue to operate “indefinitely,” resulting in “time of remediation” and costs far exceeding any planned schedule and budgets. What is not often addressed are the increased burdens to the environment, society, and economy of these inefficient systems. By looking at a project through a sustainability lens, we can increase the opportunity to develop more sustainable remedies while providing greater confidence in schedule and costs. One strategy used to identify more sustainable remedies is called a “bottom-up” approach and involves sustainability objectives underpinning all aspects of the technology solution that will be used to clean up the site. “Systems thinking” – an approach that considers externalities of the cleanup process – can also be leveraged to help project teams identify sustainability opportunities.

The use of Life Cycle Assessment (LCA) can help practitioners better integrate systems thinking into remedial planning and shine a light on the opportunity to reduce those impacts through material substitution and optimization while improving the effectiveness of the remedy. The design of an insitu solar powered biogeochemical reactor (SBGR) to treat chlorinated ethenes in groundwater is used as an example to demonstrate how systems thinking can be used to identify sustainability impacts and minimize their negative impacts. The SBGR technology is also compared to a recognized sustainable remediation technology, enhanced insitu bioremediation (EISB), to demonstrate the sustainability benefits of system thinking.

The approaches presented in this presentation indicate the promise of developing zero, or near zero, sustainability footprint treatment technologies.

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The Effect of Particle Size and Surface Composition on ZVI Reaction Kinetics

John Freim

Zero valent iron (ZVI) is a powerful reductant that reacts with and eliminates trichloroethylene (TCE) and other groundwater contaminants. All ZVI powders are not the same and reactivity can vary greatly with both particle size and composition. This work investigated the effect of several variables on reactivity with TCE, perchloroethylene (PCE), and carbon tetrachloride (CT). Material properties studied included particle sizes that ranged from nanoscale to over 100 micrometers. Also studied was the effect of passivating surface layers that result from exposure to air. Additionally, the effect of an iron sulfide surface layer on reactivity was evaluated. Kinetics were evaluated by adding 2 to 50 g/L of ZVI to tap water containing 50 mg/L TCE, 5 g/L PCE, and 5 g/L CT and using gas chromatography to measure reaction progress. Each iron product exhibited first order reaction kinetics with correlation coefficients generally greater than 0.95. While particle size had a modest effect on reactivity, surface composition was far more significant with mass adjusted rate constants for TCE and PCE degradation 10 to 50 times greater when 2% sulfide was added to the particle surface. Qualitative experiments also showed that sulfide additions had the positive effect of inhibiting the production of hydrogen gas produced by the reaction of ZVI and water, potentially improving the material's reactive capacity and extending its reactive lifetime.

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Quantifying the Thermal Desorption Effect During ISCO Injections

Gary Cronk and Greg Sounhein

Thermal desorption is a widely recognized environmental remediation technology that utilizes heat to increase the volatility of VOC contaminants so they can be removed (desorbed) from the soil matrix. However, in contrast to most thermal technologies, the heat given off during the Fenton's ISCO reaction has seldom been quantified or recognized as a significant contributor in VOC destruction. This probably is due to the generation of high strength hydroxyl radicals that provide excellent VOC destruction without even considering the thermal desorption effect. Due to the large number of ISCO sites that experience VOC rebound from matrix diffusion, there is a significant need to quantify the effectiveness of thermal desorption occurring during the Fenton's ISCO reaction. Hydrogen peroxide possesses tremendous exothermic potential. In the field, groundwater temperatures generated by the Fenton's reaction have often been measured in the range of 120 to 140 degrees Fahrenheit (F) (based on 10% and 12% peroxide injections). However, this temperature increase cannot be duplicated in the lab environment due to the small size of the testing vessels typically used (one liter or smaller). The Fenton's reaction is most evident and measurable in a field injection, where the heterogeneous soils cause semi-confining conditions which temporarily trap the heat released by the Fenton's reaction while simultaneously increasing subsurface pressures due to rapid release of oxygen gas. JAG designed several Bench-Scale Treatability Tests which simulated the thermal effect from the Fenton's reaction. JAG tested separate peroxide reactor vessels in laboratory tests by heating vessels to 110 degrees and 130 degrees F, respectively. Using a mass balance approach, these tests confirmed that 30% more thermal desorption from the soil occurs at 110 degrees F and 55% more desorption at 130 degrees F (in relation to a control vessel). Peroxide oxidation is a two-step process that involves desorption of VOCs and subsequent destruction of dissolved VOCs.

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A Novel Technology for Removal of Metal from Solvents

Roger Acey and Gwen Jordeen

The technology described here for removal and recovery of toxic/precious metals is based on a unique metal binding protein known as metallothionein (MT). MT has the ability to selective bind heavy metals, e.g., lead, arsenic, methyl mercury, and uranium. We have cloned the gene for MT from the brine shrimp *Artemia*. In order to enhance expression levels of the protein, we generated a SUMO-MT chimeric. The SUMO-MT is isolated from cell homogenates using Ni-NTA. The chimeric protein shows the same metal binding capability as the monomeric MT. Both are active at extreme pH (4 to 10) and temperature (4°C to 100°C). In addition, SUMO-MT is capable of efficiently extracting water insoluble metal complexes from organic solvents. This includes removal of palladium and gold nanoparticles and chloro [1,3 bis(2,6-diisopropylphenyl)imidazole-2-ylidene]copper(I) from chloroform. The metal or metal complexes can be released from the SUMO-MT-metal by addition of acid. In order to simplify the removal and recovery of metal from a solution, we placed the SUMO-MT on a solid support. We also have covalently coupled SUMO-MT to polystyrene beads where the protein retains its biological activity. We refer to the material as a "heavy metal sponge." Passing a solution of copper sulfate through a column of the material results in metal binding to the SUMO-MT. Subsequently, the copper can be recovered by washing the column with acid. The column can be regenerated up to four times without loss of metal binding efficiency. In order to increase the efficiency of the technology, we cloned a SUMO dimeric MT. The construct is capable of binding metal like SUMO MT.

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Diverse Settings for Natural and Anthropogenic Pyrite Oxidation and Selected Mitigation Strategies

James Jacobs

Oxidation of pyrite-rich rocks in diverse settings contributes to the formation of sulfuric acid drainage and the release of metals such as arsenic, chromium, copper, iron, nickel, zinc, and lead, among others in the presence of acidophilic microbial communities. This paper describes four case studies from different geographic areas illustrating similar biogeochemical conditions which release acidic drainage containing soluble metals. The first case study illustrates natural glacier melt impacts in lake water in an area of pyrite-rich rocks in the tropical high-mountain Pastoruri Glacier in the Peruvian Andes. A second case study is located in an area undergoing glacier retreat in the northern Italian Alps where water samples from high-altitude Lake Rasass and three creeks contain elevated sulfate and metal concentrations. The anthropogenic disturbance described in the third case study features the historic releases of acid mine drainage at the infamous Iron Mountain Mine Superfund site in northern California where negative pH waters were documented by the USGS. Although continued work is needed, significant efforts over the past three decades at Iron Mountain Mine have controlled acid drainage, repaired ecosystem damage, and stopped fish kills. The fourth case study features similar biogeochemical changes in a south Florida aquifer as a result of an innovative water recycling project; the reinjection of oxygen-rich treated wastewater initiated pyrite oxidation and the unintended release of soluble arsenic into the aquifer. All four sites have similar biogeochemistry. Site-specific mitigation strategies to address acidic drainage containing soluble metals at these types of sites include chemical reduction processes, passive acid drainage treatments, and surface capping and water diversion.

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A Rigorous Demonstration of Permeability Enhancement Technology for In Situ Remediation of Low Permeability Media: Final Results

Ryan Wymore, Kent Sorenson, Nathan Smith, and Dung Nguyen

At sites with low hydraulic conductivity (10^{-5} cm/sec or lower), specialized injection techniques are required to distribute amendments effectively. The three most prevalent methods in use today are pressurized direct-push injection (DPI), hydraulic fracturing, and pneumatic fracturing. Pressurized DPI is commonly used because of its low initial cost. However, distribution of amendments using this technique is often uncontrolled and unverified. Unfortunately, the high life cycle cost of poor amendment distribution is seldom considered when selecting an injection strategy, and rapid diagnostic tools for assessing amendment distribution to facilitate real-time optimization of that strategy have not yet been well documented. In recent years, a number of technologies have been developed in an attempt to address the challenge of achieving an effective amendment distribution in low permeability and fractured media. These advances include permeability enhancement technologies (hydraulic and pneumatic fracturing), both of which are able to emplace amendments into low permeability media. In addition, significant advances have been made in technologies that can provide high resolution mapping of the subsurface distribution of amendments. Despite these advances, a rigorous comparison of amendment distribution using such methods in different low hydraulic conductivity geologies has never been made.

This project attempts to address these challenges by providing a rigorous demonstration of costs and benefits of permeability enhancement technology for amendment distribution in low permeability media in different geologic settings at three Department of Defense sites. Based on state-of-the-art tiltmeter monitoring (as well as conventional borehole logging and/or trenching), the results of amendment delivery using different approaches will be used to develop guidance that outlines the pros and cons, as well as the costs, of each of the technologies. This talk will present final results and conclusions from all three field sites and will offer preliminary guidance regarding the effectiveness of each injection approach.

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NAPL

ITRC LNAPL Update

Randy Chapman, Virginia Department of Environmental Quality, Woodbridge, VA; Erik Gessert, Terracon, Wheat Ridge, CO

High Resolution Mobile NAPL Interval Identification and Transmissivity Calculations for DNAPL

Lisa Reyenga, GEI Consultants, Denver, CO; J. Michael Hawthorne, GEI Consultants, Keller, TX; Derek Tomlinson, GEI Consultants, Exton, PA

Achievements of Bioventing Relative to NSZD and LNAPL Recovery

Andrew Kirkman, BP, Naperville, IL

Temporal Variability in Natural Source Zone Depletion Rates Based on Analysis of Empirical Soil-Gas Data

Matthew Lahvis, Shell, Spring, TX

A Method to Estimate Historical LNAPL Volume and Mass Losses from Composition Changes

Don Lundy, Groundwater & Environmental Services, Inc., Tucson, AZ; John Dowd, University of Georgia, Athens, GA

UVOST-CPT Profiling, LNAPL Transmissivity Testing, and Skimming Recovery: Comparison and Implications for Plume Management

James Studer, InfraSUR LLC, Albuquerque, NM; Neil Irish and Paul Parmentier, Apex, Signal Hill, CA; Carol Devier-Heeney, Defense Logistics Agency, Fort Belvoir, VA

ITRC LNAPL Update

Erik Gessert and Randy Chapman

Since 2007, ITRC has been a national leader in producing technical and regulatory guidance documents and training courses on light non-aqueous phase liquids (LNAPL). These efforts have been instrumental in: advancing modern LNAPL conceptual site models; identifying specific LNAPL concerns and addressing them through the use of LNAPL saturation-based and composition-based remediation objectives; selecting established LNAPL remedial technologies to achieve remediation objectives; and implementing remedial technologies to achieve quantifiable goals and endpoints.

The LNAPL courses provided by ITRC have trained over 15,000 participants since 2009. In 2016, the ITRC LNAPL team took on the task of developing a comprehensive web-based guidance that captures the fundamentals presented in the original documents, internet-based training, and classroom training. This guidance also incorporates new science and enhanced understanding that have emerged in the last decade. *LNAPL Site Management: LCSM Evolution, Decision Process, and Remedial Technologies* was published in March 2018. The presentation will highlight the content of this comprehensive LNAPL guidance.

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High Resolution Mobile NAPL Interval Identification and Transmissivity Calculations for DNAPL

Lisa Reyenga, J. Michael Hawthorne, and Derek Tomlinson

Dense non-aqueous phase liquid (DNAPL) can be persistent in the saturated zone and complex in terms of its distribution with multiple mobile NAPL intervals (MNIs) separated by lenses of lower permeability soils. These multiple MNIs can result in perched DNAPL that yields exaggerated thicknesses of DNAPL in wells relative to the actual MNI thicknesses in the formation. To date, no method has satisfactorily accounted for these complexities in the measurement of DNAPL transmissivity, thus yielding artificially low DNAPL transmissivity values due to falsely large assumed drawdowns. The authors have developed patent pending procedures to identify each individual MNI across a given well screened interval and to accurately calculate DNAPL transmissivity values for each MNI and for the well in the aggregate. The resulting information provides precise determination of the elevation and thickness of each MNI as well as the associated DNAPL transmissivity value for each MNI. This information can be used in a variety of ways to augment the conceptual site model (CSM) to better quantify potential DNAPL migration risk and pathway identification and design improved remedies. Perhaps more importantly, this information can be used to justify cessation of DNAPL recovery and site closure where no other risk driver exists and DNAPL recovery is the only driver for continued work.

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Achievements of Bioventing Relative to NSZD and LNAPL Recovery

Andrew Kirkman

LNAPL remediation has been challenged by the natural laws of the universe and remedy selection. LNAPL recovery has historically been selected for gauged LNAPL thickness in wells. A pilot study was initiated in 2nd quarter 2017 and run through 1st quarter in 2018 to evaluate the efficacy of bioventing at treating the mobile LNAPL interval near the water table. The pilot study utilizes past knowledge from US EPA and Airforce Center of Environmental Excellence publications as well as improved understanding on LNAPL degradation, natural source zone depletion, and LNAPL mobility. A discussion of respiration rates near the capillary fringe (i.e., the water table and air/LNAPL interface) will be provided. This discussion will include challenges of NSZD and respiration testing under non-ideal conditions to provide insight into realities. Many sites are referencing an LNAPL recovery endpoint of 0.1 to 0.8 ft²/day for maximum extent practicable. How does a change in technology affect the achievable endpoint? A discussion of bioventing versus LNAPL recovery endpoints will be provided as well as how those could apply to site management.

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Natural Source Zone Depletion Rates Based on Analyses of Empirical Soil-Gas Data

Matthew Lahvis

Spatio-temporal and other site-specific factors that affect rates of natural source-zone depletion (NSZD) remain uncertain. Most measurements and assessments of NSZD spatio-temporal variability have been conducted at large petroleum industrial sites using carbon traps or surface-flux chambers installed over open ground. In this study, rates of NSZD were estimated by calibrating a reactive transport model (BioVapor) to total petroleum hydrocarbon (TPH) and benzene soil-gas concentration data compiled by the US EPA Office of Underground Storage Tanks. The analysis included 75 analyses from 17 sites and 45 locations. TPH and benzene transport was simulated assuming conservative transport assumptions and default soil properties defined in US EPA guidance in the absence of site-specific data. Model results indicate that NSZD rates increase increasing source concentration and decreasing source depth. These results are consistent with a rate dependent on oxygen availability. Assessments of temporal variability from single locations imply that NSZD rates are generally stable or increase over time.

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A Method to Estimate Historical LNAPL Volume and Mass Losses from Composition Changes

Don Lundy and John Dowd

The volume and mass of LNAPL that reached the water table from a historical release is often not known, even when a previous sudden release date is known and the volume is approximated from available records. But if the starting composition of the lost LNAPL is known or assumed based on previous analyses, it can be used as a reference to quantify composition changes and relative mass losses inferred from compositions of LNAPL samples collected later from monitoring wells in the resulting LNAPL body in contact with groundwater. If the extent and volume of free and residual LNAPL resulting from the release can be delineated and estimated with sufficient random sampling and core analyses, then summed to a total LNAPL volume for a date following the release, it can be used to back-calculate the volume reaching the water table after the release. An eight-step algorithm to estimate the starting volume at a well-studied crude oil release site near Bemidji, Minnesota, was developed and used to infer a first-order decay trend of the starting LNAPL mass over three decades of contact with groundwater. The derivative of the first-order function represents the rate of mass depletion with time since the LNAPL reached the water table. Those rates fall within the range of independently measured rates of mass depletion based on different methods of measuring and quantifying rates of CO₂ production resulting from biodegradation of a broad range of hydrocarbons partitioned to the groundwater and vadose zones. The agreement between the rates of mass loss based both compositional changes and indirect field measurements of CO₂ production lend credence to the proposed method. It can be used to evaluate the stability of the LNAPL body using a simple mass balance between mass spreading and mass depletion rates.

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UVOST-CPT Profiling, LNAPL Transmissivity Testing, and Skimming Recovery: Comparison and Implications for Plume Management

James Studer, Paul Parmentier, Neil Irish, and Carol Devier-Heeney

Light Non-Aqueous Phase Liquids (LNAPL) comprised of petroleum hydrocarbon (PHC) jet fuel of variable grades and weathering is present in the subsurface at a Department of Defense fuel storage transportation facility in Southern California. LNAPL, sorbed, and dissolved-phase PHC mass reside in sandy fluvial sediment at a depth of 30 to 40 feet below grade. Efforts have accelerated to define the current extent and volume of LNAPL, determine LNAPL migration potential and degree of LNAPL recoverability via conventional and enhanced recovery approaches, and establish final remedial action details. Continuous cone penetrometer and ultraviolet optical screening tool (UVOST-CPT) profiling refined three-dimensional understanding of lithology and presence/absence of LNAPL. A total of 54 UVOST-CPT soundings have been performed with 45% inferring presence of LNAPL. These supplement data from 130 borings (most completed as wells) including information on LNAPL presence/characteristics for 90 (40 of these documenting presence of LNAPL). Total volume of LNAPL was estimated from these data, with heavy reliance placed on the UVOST-CPT profile data indicating LNAPL smear zone thickness with estimated saturation values. Recent LNAPL skimming operations have focused on six recovery wells in a test plot with areal dimensions of 200 feet by 80 feet. LNAPL recovery per well has ranged from less than one to five gallons per day over nearly a two-year period. Shortly after skimming operations began, a standardized (ASTM) bail-down method was followed to estimate LNAPL transmissivity (T_n) for the recovery wells. Estimated average T_n values ranged from 0.3 to 15.1 ft^2/day . The T_n values were compared to the UVOST-CPT profiles to develop predictions on the rate of early stage conventional LNAPL recovery. Comparisons of predicted values to actual skimming recovery data were made. Prediction reliability appears low. Sources of prediction error are identified as well as implications for LNAPL plume management.

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Per- and Polyfluoroalkyl Substances (PFAS)

Technical Evaluation of Poly/Perfluorinated Alkylated Substance (PFAS) Methods and Data Quality

David Gratson, Environmental Standards, Santa Fe, NM; Rock Vitale, Environmental Standards, Valley Forge, PA

PFAS Site Characterization Techniques

Erica Kalve, Arcadis, San Rafael, CA; Erika Houtz, Arcadis, San Francisco, CA; Jeff McDonough, Arcadis, Newtown, PA; Ian Ross, Arcadis, Cheshire, United Kingdom

Atmospheric Long-Range Transport of PFAS

Laura Trozzolo, TRC Solutions, Fort Collins, CO

A Technique for Determining Total Oxidizable Precursors (TOP) of Perfluoroalkyl Compounds

Charles Neslund, Eurofins Lancaster Laboratories Environmental, LLC, Lancaster, PA

Closing the PFAS Mass Balance: The Total Oxidizable Precursor (TOP) Assay

Karla Buechler, TestAmerica, West Sacramento, CA

Per- and Polyfluoroalkyl Substances (PFAS): Treatment Options

Gary Birk and David Alden, Tersus Environmental, Wake Forest, NC; John Archibald, Tersus Environmental, Grimsby, ON, Canada

Technical Evaluation of Poly/Perfluorinated Alkylated Substance (PFAS) Methods and Data Quality

David Gratson and Rock Vitale

Poly- and perfluorinated alkylated substances (PFASs, also known as PFCs) are identified as contaminants/chemicals of an emerging concern by the US EPA and the State of California. The number of PFAS substances that have been identified in ground and drinking water has grown considerably and is now considered to include almost 1,000 different analogs and telomers, yet the EPA, DOD, and ASTM published methods account for only a small subset of potential contaminants of concern at any particular site. In addition, the published EPA Method (537, ver. 1.1) was prepared for drinking water matrix, yet it has been modified by most laboratories and extended to general groundwater, surface water, and soils/sediments. Significant differences have been identified in how the commercial laboratory community has modified this method. The presenter will provide an overview on the analytical methods for PFASs with focus on the use of LC/MS-MS. Method details and how they can impact data quality and comparability will be described. The importance of data assessment via verification and validation will also be presented.

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PFAS Site Characterization Techniques

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Per- and polyfluoroalkyl substances (PFASs) are used in a wide range of industrial applications and commercial products due to their unique surface tension reducing and levelling properties. Commonly associated with aqueous film forming foams used to suppress Class B fires, PFASs are also used in metal plating and cleaning; electronics; performance plastics; stain-, oil-, and water-resistant coatings for furnishings, clothing, and food packaging; and several other products. Due to their wide-spread use, PFASs have been globally distributed in the environment at low concentrations, and some forms are known to be toxic to humans. Source areas typically exhibit higher PFAS concentrations and resultant PFAS groundwater plumes from source zones may require active management. As community and environmental awareness and regulations continue to evolve, sites with historical uses will likely be required to initiate the site investigation process to evaluate potential risk to receptors. The general approach to any contaminated site characterization includes developing a conceptual site model (CSM) that provides the basis for the investigation, risk assessment, and, if an unacceptable exposure pathway is complete, a remediation approach. Typical sampling protocols designed to inform the CSM need to be adapted for PFAS-specific considerations. This presentation will provide a review of the state of the science for PFAS site characterization, a case study using SMART Characterization® techniques for PFASs, and practical considerations for developing a streamlined approach to the site assessment process.

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Atmospheric Long-Range Transport of PFAS

Laura Trozzolo

PFAS are ubiquitous in ambient (outdoor) air, with elevated concentrations observed in urbanized areas nearest to emission sources such as manufacturing facilities, wastewater treatment plants, and landfills. Long-range transport (LRT) processes are responsible for the wide distribution of PFAS across the globe, as evidenced by their occurrence in surface snow, ice cores, seawater, and other environmental media in remote regions as far as the Arctic and Antarctic. This presentation will discuss LRT as well as factors that influence atmospheric fate and transport of PFAS.

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A Technique for Determining Total Oxidizable Precursors (TOP) of Perfluoroalkyl Compounds

Charles Neslund

PFAS compounds have been manufactured and in use for many years. Over that time and due to variables in the production processes like electrofluorination, many different chemistries of PFAS compounds have been produced and used. Many of these compounds have not yet been fully characterized and, therefore, analytical standards are typically not available. This presents a challenge for the accurate assessment of PFAS contamination at environmental sites. A new method, developed by Houtz and co-workers, can be set up and commercialized to convert polyfluorinated precursor compounds to more studied and analyzable perfluorinated chemistries such as PFOA and PFOS and, therefore, allows for a way to determine the total PFAS content of an environmental sample. This presentation will discuss the set-up and application of this technique and its utility for risk assessment.

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Closing the PFAS Mass Balance: The Total Oxidizable Precursor (TOP) Assay

Karla Buechler

Current methodologies for the analysis of per and polyfluoroalkyl substances (PFAS) are designed to measure a discrete list of ~20 compounds. There are many additional PFAS compounds that are not determined as discrete compounds by existing analytical methods, including Method 537. Hence, we may be underestimating the PFAS risk potential present in the environment. There is significant pressure from the public, environmental agencies, and others to apply methodologies that more closely measure the full extent of PFAS contamination.

TestAmerica Sacramento implemented the Total Oxidizable Precursor (TOP) assay as a solution to this complex problem. The TOP assay rapidly converts polyfluorinated PFAA precursors into PFAAs including PFOA using a hydroxyl radical-based chemical oxidation method. The TOP assay replicates what micro-organisms in the environment would achieve after many years. The TOP assay quantifies the sum of PFAS that could be converted to PFAAs in the environment. The TOP methodology has revealed that for AFFF-impacted sites, the existing analytical LCMSMS methods are only detecting an estimated 30% to 50% of the total PFAA mass present as PFAA precursors.

Topics the presentation will cover include:

(1) A brief PFAS introduction, including:

- Nomenclature
- Chemical structure
- Formation, transport, and risk
- Analytical methodology and current regulatory guidance

(2) In depth explanation of the TOP assay

- Background
- What is the TOP assay?
- How does it work?
- The TOP assay chemical reaction
- What do the results mean?
- What are the limitations of the assay?

(3) Future concerns

(4) Capabilities and questions?

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Per- and Polyfluoroalkyl Substances (PFAS): Treatment Options

Gary Birk, John Archibald, and David Alden

Background/Objectives: Per- and polyfluoroalkyl substances (PFASs) are surfactants, polymers, and other substances that are widely distributed across the higher trophic levels and are found in air, soil, and groundwater at sites across the U.S. (US EPA, NSCEP, 2014). This diverse group of compounds is resistant to heat and repels water and oil. For decades, they have been used in hundreds of industrial applications and consumer products such as carpeting, apparels, upholstery, food paper wrappings, and metal plating. Surfactant applications used heavily in the military include aqueous film-forming foams (AFFFs) used to extinguish fires involving highly flammable liquids.

The toxicity, mobility, and bioaccumulation potential of PFASs pose potential adverse effects for the environment and human health. PFASs have been found at very low levels both in the environment and in the blood samples of the general U.S. population. To provide a margin of protection from a lifetime of exposure to perfluorooctanoic acid (PFOA) and perfluorooctyl sulfonate (PFOS) from drinking water, EPA has established the health advisory levels at 70 parts per trillion (EPA 800-F-16-003).

PFASs are fluorinated organic compounds in which the hydrogen atoms of the hydrocarbon skeleton are substituted fully or partially by fluorine atoms. In view of the strong covalent bond between the fluorine and the carbon atoms, these compounds are considered non-degradable and they persist in the environment. Practitioners have difficulty remediating these compounds at a reasonable cost because PFASs are extremely resistant to thermal, chemical, and biological degradation processes. Literature shows that PFOS (potassium salt) is substantially non-volatile.

Approach/Activities: The current state of the practice for addressing highly concentrated source zones, mitigating mass flux of impacts to aquifers, or PFAS in extracted water includes the use of granular activated carbon (GAC). Unfortunately, GAC is only a temporary solution as it is effective at removing only a portion of PFAS from groundwater (Ross et al., 2017). This is due to GAC's low binding capacity for PFOS as compared to nonpolar organic hydrocarbons and the low effective removal of shorter chain perfluoroalkyl acids (PFAAs), the daughter products resulting from biotransformation of polyfluorinated precursor compounds. As the PFAS family of compounds includes anions, cations, and zwitterions, new sorbent media are being developed to remove both long- and short-chain PFASs that combine hydrophobic interactions with electrostatic interactions.

Liquid surface-active reagents are also being developed for use as an initial pretreatment. In the pretreatment phase, dissolved PFASs are precipitated as micro-flocs by metering the liquid active compound into a stirring tank. With removal efficiencies of 96 to 98 percent, the precipitants can be

concentrated to a very high degree, and the life of sorbent media is significantly extended. This constitutes a considerably more sustainable approach.

Results/Lessons learned: The presentation will include results and lessons learned from the latest laboratory and field implementation for the treatment of PFAS impacted soil and groundwater. The presentation will also provide an update on advances in Point-of-Entry (POE) systems.

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Petroleum Biodegradation Metabolites in Groundwater Research Update

Life Cycle of Fuel Biodegradation Metabolites Plumes

Dawn Zemo, Zemo & Associates, Inc., Incline Village, NV; Kirk O'Reilly, Sungwoo Ahn, and Asheesh Tiwary, Exponent, Inc., Bellevue, WA; Rachel Mohler, Renae Magaw, and Catalina Espino Devine, Chevron Energy Technology Company, San Ramon, CA

Potential Human and Aquatic Toxicity of Petroleum Biodegradation Metabolites

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Use of Two-Dimensional Gas Chromatography (GCxGC) to Supplement the Evaluation of Natural Attenuation at Petroleum Release Sites

Catalina Espino Devine, Renae Magaw, and Rachel Mohler, Chevron Energy Technology Company, San Ramon, CA; Dawn Zemo, Zemo & Associates, Inc., Incline Village, NV; Kirk O'Reilly and Sungwoo Ahn, Exponent, Inc., Bellevue, WA

Composition of Extractable Organics in Groundwater at Biodegrading Crude Oil Release Sites

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Return to the Biosphere: A Metabolomics Evaluation of Oxygen-Containing Organics in Groundwater from Petroleum Release Sites

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Life Cycle of Fuel Biodegradation Metabolites Plumes

Dawn Zemo, Kirk O'Reilly, Rachel Mohler, Renae Magaw, Catalina Espino Devine, Sungwoo Ahn, and Asheesh Tiwary

This presentation demonstrates the life-cycle of “extractable organics” groundwater plumes at sites with biodegrading fuel sources. Groundwater samples collected from source and downgradient areas from 22 upland fuel release sites were extracted using methylene chloride and extracts were analyzed using targeted (GC-FID and GC-MS) and non-targeted (GC-MS and GCxGC-TOFMS) methods. Identified metabolites were classified according to molecular structural class and assigned an oral reference dose-based toxicity ranking. If a petroleum source is still an active source of dissolved hydrocarbons (e.g., GRO is also present), the associated “Stage 1” extractable organics plume consists of dissolved C10+ hydrocarbons and biodegradation metabolites, dominated by ketones (32%) and alcohols (36%). For sources weathered such that dissolved hydrocarbons are no longer present, the “Stage 2” extractable organics plume within the smear zone consists of 100% metabolites, dominated by acids/esters (42%) followed by alcohols (26%) and ketones (25%), with very few aldehydes or phenols. The “Stage 3” plume, which is the combination of smear zone and downgradient areas, consists of 100% metabolites, dominated by acids/esters (64%). The “Stage 4” plume, downgradient of the smear zone, is composed of 100% metabolites dominated by organic acids/esters (about 75%), with n- and alkyl- structures the most commonly identified. Very few saturated cyclic acid structures were identified. The identified metabolites naturally attenuate in a predictable manner with an overall trend toward simpler molecular structures and a higher proportion of organic acids/esters. The overall human toxicity ranking of metabolites identified in these plumes is Low with an increasingly lower profile seen as the plumes biodegrade from Stage 1 (78% Low) to Stage 4 (95% Low). These findings are consistent with the natural attenuation paradigm adopted by many regulatory agencies for petroleum release sites. A separate presentation discusses results from testing of whole groundwater samples for aquatic toxicity and for in-vitro screening for genotoxic and estrogenic effects.

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Potential Human and Aquatic Toxicity of Petroleum Biodegradation Metabolites

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and Catalina Espino Devine

Non-targeted GCxGC-MS analyses of groundwater samples from historic fuel release sites have tentatively identified more than 1,000 unique polar metabolites representing many distinct structural classes of chemicals including acids/esters, alcohols, phenols, ketones, and aldehydes. The potential toxicity of these metabolites to aquatic and human receptors has been investigated. To evaluate the potential aquatic toxicity of these metabolites, upgradient (representing local background conditions) and downgradient groundwater samples (intended to contain metabolites but not hydrocarbons) were collected from 14 representative biodegrading fuel sites and submitted to a laboratory for chronic aquatic toxicity testing using EPA test methods 1000 (Fathead Minnow), 1002 (Daphnid) and 1003 (Green Algae). Test results show that there is generally no difference in observed toxicity between upgradient groundwater samples free of polar metabolites and downgradient samples containing polar metabolites. This result suggests that any aquatic toxicity observed in these samples primarily arose from background water quality and not from metabolites. Evaluation of potential human toxicity of the metabolites was initially assessed by reviewing available agency-derived Reference Doses (RfDs) for individual potential metabolites, and then developing an RfD-based toxicity ranking system for each structural class of potential metabolites. This ranking system was applied to all metabolites identified in each groundwater sample, and the results show that the vast majority of the metabolites are in structural classes that are ranked "low" toxicity to humans (RfDs \geq 0.1 mg/kg/day). Results of in-vitro testing of upgradient and downgradient groundwater samples from 12 representative sites using the gamma-H2AX assay and the ERTA assay indicate the metabolite mixtures do not appear to have the potential to cause significant genotoxic or endocrine disruption effects. Overall, the complex mixtures of polar metabolites identified in groundwater are unlikely to present a significant risk to human health or aquatic life.

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Use of Two-Dimensional Gas Chromatography (GCxGC) to Supplement the Evaluation of Natural Attenuation at Petroleum Release Sites

Catalina Espino Devine, Renae Magaw, Rachel Mohler, Dawn Zemo, Kirk O'Reilly, and Sungwoo Ahn

Petroleum releases are complex mixtures that contain hundreds to thousands of individual petroleum hydrocarbon compounds. In the subsurface, as soon as physical (e.g., volatilization, dispersion) and biochemical natural attenuation processes take hold (e.g., biodegradation), the organic mixture begins to change. Metabolites from biodegradation of petroleum (i.e., polar oxygenated compounds such as organic acids, esters, aldehydes, ketones, and phenols) start to form in groundwater, soil, and even in Light Non-Aqueous Phase Liquid (LNAPL). Over the years there has been a great deal of interest in analyzing the organic metabolite mixture to identify the intermediates and products of biodegradation. Two-dimensional gas chromatography (GCxGC) allows for structural class identification of chemical compounds which is particularly useful for identifying the polar metabolites that are products of petroleum biodegradation in the organic mixture. In our study we used traditional analytical methods used for advanced chemical fingerprinting such as high resolution GC Flame Ionization Detection (FID) and GC Mass Spectrometry (MS) to confirm natural attenuation and track it along space and time. We applied GCxGC as a supplemental analytical tool to document changes in the chemical structural class of petroleum and metabolite mixtures. GCxGC data in groundwater, soil, and LNAPL phases were compared to traditional analytical methods to confirm natural attenuation. We will present compiled data and conclusions from biodegrading petroleum release sites where natural attenuation has been documented. We will discuss changes in the structural classes of chemical compounds using GCxGC analysis and compare the results to GC-FID and GC-MS in groundwater, soil, and LNAPL phases in the source area as well as downgradient from source areas. We will also discuss the implications of this in depth understanding of monitored natural attenuation, including the chemistry transformations in the metabolite plume, for risk management decisions.

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Composition of Extractable Organics in Groundwater at Biodegrading Crude Oil Release Sites

Rachel Mohler, Catalina Espino Devine, Sungwoo Ahn, Kirk O'Reilly, Dawn Zemo, Renae Magaw, and Natasha Sihota

Crude oil releases, like refined petroleum fuel releases, undergo biodegradation in the environment. During these processes the constituents are transformed from the original hydrocarbons into polar biodegradation metabolites (polars), which can be measured as extractable organics in groundwater at these sites. There is little data in the scientific literature on the detailed composition of the complex mixture of polars actually present in groundwater at biodegrading crude oil sites, and there is uncertainty about the potential polar compounds that could be formed at these sites as compared to those that are formed at fuel release sites. Differences could occur due to the composition (i.e., PAHs and cyclic biomarkers) and complexity of crude oil. We have studied the detailed composition of extractable organic plumes at multiple biodegrading fuel release sites and have published those results. Recently, we have begun studying the polar compounds detected as extractable “diesel-range” and “oil-range” total petroleum hydrocarbons at crude oil release sites using comprehensive two-dimensional gas chromatography with time of flight mass spectrometry (GCxGC-TOFMS). Results to date indicate that the nature and distribution of the compound molecular classes present in downgradient wells at crude oil sites are quite consistent with those from downgradient locations at biodegrading fuel release sites, with the n and alkyl organic acids/esters dominating the percentage of tentatively identified compounds. Cycloalkyl (pentyl or hexyl) acids were only detected in two source zone wells to date. The specifics on the analytical approach, the results from one (or more) biodegrading crude oil releases, and a comparison to the results from multiple fuel release sites will be presented.

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Return to the Biosphere: A Metabolomics Evaluation of Oxygen-Containing Organics in Groundwater from Petroleum Release Sites

Kirk O'Reilly, Dawn Zemo, Rachel Mohler, Sungwoo Ahn, Renae Magaw, and Catalina Espino Devine

Petroleum was formed through the reduction of compounds synthesized by living organisms. Biodegradation returns carbon to the biosphere through oxidative processes. A goal of this study was to compare extractable oxygen-containing compounds identified in groundwater from petroleum fuel release sites with chemicals in the biosphere that were not derived from hydrocarbons. Site groundwater was collected upgradient of the release, within the source area, and downgradient of the hydrocarbon source but within the presumed "metabolites plume." Sample extracts were analyzed using targeted (GC-FID and GC-MS) and non-targeted (GC-MS and GCxGC-TOFMS) methods. Two types of evaluations will be discussed. In the first, compounds identified in downgradient wells were compared to those identified in upgradient wells. In the second, compounds in each type of well were matched against those in the metabolomics database, FooDB. Of the 345 compounds identified in the 46 downgradient samples, only 44 were detected four or more times, and about 60% of these were also detected in upgradient wells. A majority of compounds found in both upgradient or downgradient wells were fatty acids or esters of fatty acids. Of those commonly detected in downgradient but not upgradient wells, over half were alcohols. Principal component analysis indicated a continuum of biodegradation between the source area and downgradient samples with the latter becoming more consistent with upgradient samples. About 98% of the chemical formulas identified in downgradient wells were in the FooDB. Using the more specific chemical structure, about 24% of the downgradient compounds and 43% of the upgradient compounds were in the FooDB. This experimental program was built on the hypothesis that the compounds identified in downgradient wells are intermediates of petroleum biodegradation. Based on the analyses presented, an alternative hypothesis that the compounds are consistent with the products of microbial growth on non-hydrocarbon substrates will be discussed.

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Petroleum Hydrocarbon Vapor Intrusion

Summary of State Approaches to Vapor Intrusion – 2018 Update

Bart Eklund, AECOM, Austin, TX; Lila Beckley, GSI Environmental, Inc., Austin, TX; Richard Rago, Haley & Aldrich, Inc., Rocky Hill, CT

Vapor Intrusion at Former MGP Sites: Do the UST-Based Petroleum Vapor Intrusion Criteria Apply?

Diana Marquez, Burns & McDonnell Engineering Company, Inc., Kansas City, MO; Aaron Christensen, Burns & McDonnell Engineering Company, Inc., Pasadena, CA

Temporal Variability of Soil Gas Concentrations and Pressure Under Natural Weather Conditions at Petroleum Hydrocarbon Impacted Sites

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Results of Field-Based Research Study to Support Screening Approaches for Vapor Intrusion Risk from Lead Scavengers

Ian Hers, Golder Associates Ltd., Richmond, BC, Canada; Parisa Jourabchi, Golder Associates Ltd., Vancouver, BC, Canada; John Wilson, Scissortail Environmental Solutions, Ada, OK; Matthew Lahvis, Shell, Spring, TX; Emma Hong Luo and Ravi Kolhatkar, Chevron Energy Technology Company, Houston, TX

Small Purge Method to Sample Vapor from Groundwater Monitoring Wells to Assess Hydrocarbon Vapor Risk

Todd Ririe, BP (retired), Chino Hills, CA; Robert E. Sweeney, Exploration and Petroleum Geochemistry, Etna, CA

Unintentional Discharges of Industrial Compounds into and out of Sanitary or Stormwater Drainage Systems in Urban Settings

Olivia Jacobs and James Jacobs, Clearwater Group, Point Richmond, CA; Harry O'Neill, Beacon Environmental Services, Inc., Forest Hill, MD; Ryan Schneider, Beacon Environmental Services, Inc., Bel Air, MD

Summary of State Approaches to Vapor Intrusion – 2018 Update

Bart Eklund, Lila Beckley, and Richard Rago

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 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 presentation provides an update to the 2012 study.

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.

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Vapor Intrusion at Former MGP Sites: Do the UST-Based Petroleum Vapor Intrusion Criteria Apply?

Diana Marquez and Aaron Christensen

Thousands of former manufactured gas plant (MGP) sites exist throughout the country, often in urban settings or similarly developed communities. Many of these sites are currently being used for residential or industrial purposes, and still others are located in areas that are desirable for future development. Typical contaminants of concern at MGP sites include benzene and naphthalene, the volatility and toxicity of which have fueled increasing concerns about potential vapor intrusion issues both with existing buildings and potential future construction. Historically, vapor intrusion at MGP sites has been evaluated using some variation on the screening and sampling process set forth by the US EPA's Office of Solid Waste and Emergency Response in their 2002 draft guidance document and subsequent state guidance documents that are based on the same principles. Since 2009, data gathered from hundreds of underground storage tank sites has demonstrated that petroleum-related constituents show predictable patterns when evaluating vapor intrusion. Guidance documents based on this research include the Interstate Technology and Regulatory Council's (ITRC) Petroleum Vapor Intrusion (October 2014), and US EPA Office of Underground Storage Tanks' Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites (June 2015). These guidance documents describe a method for evaluating vapor intrusion based on distance between the source of contamination and a building. Most of the published data and guidance relate specifically to UST sites, which prompts the question of whether the petroleum vapor intrusion principles and separation distances apply to MGP sites. To address this question, soil, groundwater, soil gas, and/or sub-slab soil gas data from multiple MGP sites located throughout the Midwest have been compiled and reviewed relative to the petroleum vapor intrusion principles set forth in current research and guidance. The following paper presents the results of this review.

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Temporal Variability of Soil Gas Concentrations and Pressure Under Natural Weather Conditions at Petroleum Hydrocarbon Impacted Sites

Emma Hong Luo

It is believed that at petroleum hydrocarbon (PHC) impacted sites, there is a temporal variability in soil gas concentrations and pressure induced by changes in natural weather conditions, especially at shallow depths, typically less than 5 feet below ground surface. It is also believed there is a potential change in soil vapor intrusion risk due to that temporal change. Therefore, some researchers proposed that real-time monitoring should be done at PHC vapor intrusion sites and others, such as regulators, require multiple rounds (at least two rounds) of soil gas sampling to demonstrate its “temporal trends,” as is a normal practice for groundwater plume as a way of resolving the assumed temporal changes in soil gas.

In this presentation, simulated and field soil gas pressure and concentration data collected from petroleum hydrocarbon spill sites under natural weather conditions will be presented with the goal of providing a better understanding of existence and magnitude of the temporal variability in soil gas. The results show that the assumed temporal variability in soil gas concentration, at either deep or shallow depth, is minimal even under some extreme weather conditions. The exhibited temporal concentration changes, if any, are not significant enough to change the vapor intrusion risk profile. Soil gas pressure changes at shallow depths only change with extreme weather conditions, and the magnitude of temporal variability is highly dependent on site-specific conditions such as soil permeability.

The results of this study show that at PHC sites, under natural weather conditions, multiple rounds of soil gas sampling are not necessary because the temporal changes in soil gas concentrations and pressure are usually not significant enough to change the risk profile.

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Results of Field-Based Research Study to Support Screening Approaches for Vapor Intrusion Risk from Lead Scavengers

Ian Hers, Parisa Jourabchi, John Wilson, Emma Hong Luo, Ravi Kolhatkar, and Matthew Lahvis

Guidance issued by the US EPA and ITRC recommend the use of source-building separation distances for screening petroleum vapor intrusion risks. A data gap identified in these guidance is whether the vertical screening distances can be applied to 1,2-dibromoethane (EDB) and 1,2-dichloroethane (EDC). These compounds were used as lead scavengers in leaded gasoline until 1996 (in US) when use of leaded gasoline for on-road use was banned. The objective of the broader API study is to promote an improved knowledge of vertical screening distances for EDB and EDC through existing literature on fate and transport, an empirical database, an improved analytical protocol, and a detailed field-based study. This study presents results of detailed field-based research where new analytical methods with lower reporting limits were utilized. Field research was conducted at a site in Sobieski, Minnesota, where a historical gasoline release occurred. The depth to water table ranged from 2.96 to 4.57 m and soils consist of sand to silty sand. For soil vapor, recently developed modified US EPA Method TO-14m with reporting limits of 0.16 $\mu\text{g}/\text{m}^3$ for EDB and 3.6 $\mu\text{g}/\text{m}^3$ for EDC was employed. Within the LNAPL source zone, the maximum groundwater concentrations of EDB and EDC were 175 and ³, respectively. EDB and EDC vapor concentrations decreased to less than the reporting limit within 1.1 m vertical distance of the source. The dissolved plume EDB and EDC concentrations were much lower (maximum of 3.5 mg/L) with a soil vapor EDB concentration of 1 mg/m^3 in one sample and non-detect EDC soil vapor concentrations. Vadose zone biodegradation rates are estimated from EDB, EDC, and benzene soil vapor profiles using the BioVapor model. The results of this detailed field-based study are consistent with other research that suggests the vertical distances for benzene are protective for EDB and EDC.

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Small Purge Method to Sample Vapor from Groundwater Monitoring Wells to Assess Hydrocarbon Vapor Risk

Todd Ririe and Robert E. Sweeney

Groundwater monitoring wells are present at most hydrocarbon release sites that are being assessed for cleanup. If screened across the vadose zone, these wells provide an opportunity to rapidly collect vapor samples that can be used in the evaluation of vapor movement and biodegradation processes occurring at such sites. A low purge volume method (modified after that developed by the US EPA) was developed for sampling vapor from monitoring wells that is easy to implement and can provide an assessment of the soil gas TPH and O₂ concentrations at the base of the vadose zone. This assessment can be done in the field using a portable field gas analyzer so that if a risk is present, action can be taken quickly.

Several case studies will be presented to demonstrate that the approach is easily implemented and can provide results that are consistent with accepted models for hydrocarbon vapor intrusion transport processes. The method uses a small purge method that is particularly useful for screening those sites with LNAPL plumes that may not meet the 15 foot depth to source screening criteria recommended by ITRC and the US EPA OUST guidance documents. This method can provide a more rapid and cost-effective approach compared to installation of deep gas sampling probes at a site. The small purge volume method has also been successfully used for sampling monitoring wells at sites with low permeability soils.

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Unintentional Discharges of Industrial Compounds into and out of Sanitary or Stormwater Drainage Systems in Urban Settings

Olivia Jacobs, James Jacobs, Harry O'Neill, and Ryan Schneider

Modern sanitary sewer systems and storm drain sewer systems have fluid exfiltration by design and failure. Plumbing systems are designed to prevent sewer gases from entering habitable spaces; vapor seals (P-traps, wax rings, vent lines, etc.) minimize the risk of vapor exposures and explosions. Plumbing vapor traps and seals can be compromised, allowing vapor intrusion of sewer air into indoor air. Sanitary sewers convey liquid and semi-solid wastes to the wastewater treatment plant. Storm drains are designed to carry rainwater from the stormwater drain to an outfall location. In both sanitary and storm drain systems, as subsurface pipes settle, crack, and break, industrial chemicals in shallow groundwater contaminant plumes at elevations at or above sewer system pipes infiltrate into the sewer systems and are transported. The infiltration of contaminants like volatile organic compounds (VOCs) into sewer pipes creates the potential for generating contaminant vapors within sewer air. Although several well-known studies have collected data on trichloroethylene (TCE) releases and dry cleaner sites where tetrachloroethylene (PCE) was the primary contaminant, other contaminants such as petroleum hydrocarbons have not been widely reported. The results of a limited passive sewer air sampling project where time-integrated samples collected over periods of one to two weeks to report time-weighted average concentrations will be presented. The passive samplers are designed to adsorb compounds in the vapor phase over an extended time period at predictable rates. The validated sampling rates along with the time of exposure are used to convert the mass measured on the adsorbent (i.e., nanograms) to a concentration (i.e., $\mu\text{g}/\text{m}^3$ or ppbv). Analyses of the samples are by US EPA Method TO-17 to target a range of petroleum hydrocarbons in sanitary and stormwater sewers. The implications of petroleum hydrocarbons in sewer air as it relates to potential health risks from vapor intrusion will be discussed.

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Regulatory Programs and Policies

Current State of Cleanup Levels and Approaches for Petroleum-Contaminated Sites

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San Francisco Bay Water Board's Approach to Evaluating Contaminated Groundwater Discharges to Surface Water

Ross Steenson and Alec Naugle, San Francisco Bay Regional Water Quality Control Board, Oakland, CA

Orange County North Basin Plume – Navigating the Multi-Agency Oversight Process to Protect Groundwater Quality

Maile Gee and Nick Amini, Santa Ana Regional Water Quality Control Board, Riverside, CA

A Tale of Two Cleanup Programs, Part 1 – California's Leaking Underground Storage Tank (LUST) Program

Matthew Cohen, State Water Resources Control Board, Sacramento, CA

A Tale of Two Cleanup Programs, Part 2 – California's Site Cleanup Program (SCP)

Steven McMasters, State Water Resources Control Board, Sacramento, CA

State of California Funding Sources for Site Cleanup Actions

Jessica Law, Santa Ana Regional Water Quality Control Board, Riverside, CA

Current State of Cleanup Levels and Approaches for Petroleum-Contaminated Sites

Mala Pattanayek

Risk evaluations for petroleum release sites present complex and unique challenges to site managers, risk assessors, regulators, and other stakeholders. Risk characterization based on total petroleum hydrocarbon (TPH) concentration measurements in different environmental media may be used for risk-based corrective actions at petroleum release sites. However, chemical compositions of petroleum hydrocarbon mixtures are complex and subject to change over time due to fate and transport processes. While methods to characterize risk for individual constituents are well accepted, methods to assess cumulative risk posed by the multitude of petroleum-related compounds typically included under the term “TPH” have yet to be widely accepted and employed. This is compounded by inconsistencies between published guidance for the risk-based assessment of TPH-related compounds and requirements for expensive laboratory tests that might not be available in many areas of the country. Better guidance is needed to help states develop consistent methodology for establishing risk-based cleanup levels and for establishing and approving methods for risk-based corrective action.

A state survey was conducted by the Interstate Technology and Regulatory Council (ITRC) TPH Risk Evaluation at Petroleum-Contaminated Sites Team. A total of 53 complete responses were recorded from 44 states (a few with multiple programs); Washington, D.C.; and Puerto Rico. The goal of the survey was to collect information on state agencies’ use of TPH data within their regulatory programs and to help develop the ITRC technical and regulatory (Tech Reg) guidance that describes best practices for evaluating TPH risk. This presentation will highlight the various approaches used by different states and programs, analysis of the survey results, and its implementation in the ITRC Tech Reg guidance.

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San Francisco Bay Water Board's Approach to Evaluating Contaminated Groundwater Discharges to Surface Water

Ross Steenson and Alec Naugle

During groundwater investigations near surface water bodies, potential contaminant discharge to surface water is often addressed as part of an ecological risk assessment for sediment, or overlooked altogether. Ecological risk assessments typically utilize sediment/porewater data at the point of exposure. This is fraught with uncertainty due to the variable nature of groundwater-surface water interaction including discharge location, timing, and contaminant toxicity. Furthermore, it is analogous to using contaminant concentrations in a drinking water well at a cleanup site to assess human health risk. Under the California Water Code there is no right to discharge toxic substances in toxic amounts. The Water Boards can control toxic discharges to surface water under National Pollutant Discharge Elimination System (NPDES) permitting authority. NPDES-influenced approaches to evaluating such discharges have utilized groundwater monitoring wells, modeling, and less frequently, whole effluent toxicity (WET) testing. The San Francisco Bay Water Board is currently refining its approach to evaluating these contaminated groundwater discharges considering groundwater-surface water interaction (e.g., function of the hyporheic zone); appropriate locations for points of compliance; sampling methodologies (e.g., sediment porewater); more recent exposure testing endpoints (e.g., finfish swimming performance); recognition of the toxicity contribution from the partial breakdown products of contaminants; limitations of conventional analytical technologies (e.g., extraction techniques); and adapting WET testing methods for groundwater matrices. This will emphasize the need for an empirical approach with the routine integration of porewater sampling and aquatic toxicity testing in addition to modeling. This presentation work presents examples of situations where these aspects are included.

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Orange County North Basin Plume – Navigating the Multi-Agency Oversight Process to Protect Groundwater Quality

Maile Gee and Nick Amini

The Orange County North Basin Plume is a large-scale, regional, and complex volatile organic compounds (VOC) plume located beneath the cities of Placentia, Anaheim, and Fullerton in northern Orange County, California. The plume is the result of discharges into groundwater during several decades of operations by aerospace, plating, and other manufacturing facilities in the area, and it has impacted drinking water production wells in the cities of Anaheim and Fullerton. Efforts have been made by the State regulatory agencies to remediate the known source areas; however, remediation of the larger co-mingled plume has been a technical, legal, regulatory, and political challenge. The Orange County Water District, United States Environmental Protection Agency (US EPA), Santa Ana Regional Water Quality Control Board, Department of Toxic Substances Control, State Water Resources Control Board Division of Drinking Water, and the Department of Financial Services have all joined together to address this regional groundwater challenge. This presentation will provide an overview of the evolution of the project throughout the past 30 years as well as the regulatory process hurdles encountered along the way. The presentation will also include an update on the project's US EPA National Priority Listing and its qualification for funding through the State of California's Groundwater Grant Program (a.k.a. Proposition 1).

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A Tale of Two Cleanup Programs, Part 1 – California’s Leaking Underground Storage Tank (LUST) Program

Matthew Cohen

The California State Water Resources Control Board (State Water Board) administers groundwater cleanup primarily through two programs. One has had decades of robust funding to assist with cleanup and oversight. The other has had fewer resources even though the sites are often more complex and have had a greater impact on water resources. The more well-funded program is the Leaking Underground Storage Tank (LUST) Program, which has been funded from a gasoline storage fee since 1991.

The contaminant plumes emanating from LUST sites consist of petroleum products and have a higher propensity to naturally biodegrade. This factor – along with the readily available funding for most cleanup and oversight – has resulted in LUST cases moving through cleanup more quickly, the number of open cases declining, and fewer impacts to water supply wells. These factors have also led to the development of the “low threat closure policy” in California, which has helped further reduce the LUST caseload.

One of the striking elements of California’s LUST Program is the abundance of groundwater, remediation, and case management data that has been generated and stored in the state’s GeoTracker database during the cleanup of over 35,000 LUST cases. The availability and analysis of this data sheds light on a wealth of cleanup experience, and it can offer many valuable lessons in remediation and case management.

As the State Water Board’s LUST Program matures, and as leak prevention measures improve, fewer new LUST cases are reported each year, and the number of existing LUST cases has now fallen below 4,000 cases statewide. The steady reduction in LUST caseload, along with the need to transition resources to higher risk sites, will cause the LUST Program to evolve in coming years.

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A Tale of Two Cleanup Programs, Part 2 – California’s Site Cleanup Program (SCP)

Steven McMasters

The California State Water Resources Control Board (State Water Board) administers groundwater cleanup primarily through two programs; the Leaking Underground Storage Tank (LUST) Program, which has been funded from a gasoline storage fee since 1991, and the Site Cleanup Program (SCP), which has had fewer revenues to assist with cleanup and oversight. For the vast majority of SCP cases, the discharger is required to finance the cleanup of the site in its entirety and pay for agency oversight under the State Water Board’s Cost Recovery Program.

SCP cases are typically more complex and higher risk than LUST cases, in part due to the high variability of contaminants (chlorinated hydrocarbons, metals, PCBs, etc.), the wide variability in cleanup cost, the higher propensity for vapor intrusion, and the lower propensity for biodegradation, resulting in legacy groundwater plumes that are more likely to impact water supply wells. The State Water Board promotes collaboration with sister agencies and water districts to identify and capture groundwater contaminant plumes, identify unreported sources of contamination, and manage and treat contaminated groundwater to clean up California’s groundwater.

The impacts to groundwater from non-petroleum contaminants have not gone unnoticed in California. The Department of Water Resources’ California Water Plan, Update 2013, estimates groundwater cleanup cost for industrial contaminants could approach \$20 billion in the next 25 years. The California legislature passed – and the Governor signed – Senate Bill 445 which provides revenues to the Site Cleanup Subaccount, and the public passed Proposition 1, Water Quality, Supply, and Infrastructure Improvement Act of 2014. These funding sources give promise for stimulating a more aggressive cleanup of California’s groundwater.

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State of California Funding Sources for Site Cleanup Actions

Jessica Law

An unknown quantity of tetrachloroethene (PCE) was released to the subsurface by a leak from a 5,000-gallon aboveground storage tank. The release has impacted soil and groundwater, and concentrations of PCE in soil gas at the site indicate a risk to human health. Due to very high concentrations of chlorinated solvents in soil and particularly in the soil gas, it was imperative that the risk to human health be investigated and addressed efficiently. However, due to lack of cooperation from the responsible party (RP), a Cleanup and Abatement Order (CAO) was issued to motivate the RP under monetary penalties. The CAO for the site set forth the requirements needed to assess and remediate the release at the site and protect human health. Even under a CAO, a financial hardship was claimed by the RP for not proceeding with the necessary environmental work. The process of enforcement under the CAO was not moving forward efficiently and the very high concentrations of PCE in all media beneath the site were disconcerting to the Water Board staff.

In 2014, the California State legislature approved the establishment of a fund to assist the RPs with limited financial resources for the cleanup of contaminated properties under SB445. Board staff informed the RP about this source of funding and encouraged them to apply for it. In order to move site investigations and cleanup forward, the RP, their consultant, and Board staff worked together to complete an application and obtain SB445 funding. This presentation will elaborate on the program priorities, requirements, and preferences.

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Remediation

Stabilization of Lead at a Former Gulf Oil Refinery

Christa Bucior, Donald Pope, Sophia Dore, Ryan Thomas, and Alan Weston,
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Application of ISCO at a Former Petroleum Refinery

Scott Blaha, Parsons Corporation, Saratoga Springs, NY

Taking Advantage of the Drought – Optimizing Secondary Source Removal at LUFT Sites

Thomas Rejzek and Steve Nailor, Santa Barbara County, Santa Maria, CA

Stabilization of Lead at a Former Gulf Oil Refinery

Christa Bucior, Donald Pope, Sophia Dore, Ryan Thomas, and Alan Weston

Lead is a highly poisonous metal, affecting almost every organ and system in the body. People can be exposed to lead by breathing it in, swallowing it, skin contact, and eye contact. Soil impacted by lead is often present on industrial sites associated with oil refineries, smelters, and other manufacturing. Impacted soil is usually excavated and disposed of. Soil from which lead leaches at greater than 5 mg/L as measured by the Toxicity Characteristic Leaching Procedure (TCLP) must be disposed of as hazardous; however, if leaching can be controlled it can be disposed of as non-hazardous material.

Different technologies exist to prevent lead leaching. One such technology is Stabilization/Solidification (S/S). S/S converts soil into a less soluble form and prevents leaching. Solidifying agents and/or bulking agents are added to treat the soil. The solid matrix encapsulates any metals present within the solid matrix where they are no longer available and cannot leach out. In this way, the metals are immobilized and are no longer considered a risk.

Inorganic lead was detected in the soil at a former Gulf oil refinery in Texas at concentrations up to 84,500 mg/kg. The soil that exceeded regulatory requirements was excavated and disposed at an off-site landfill. A treatability study was performed to test the ability of S/S to reduce the lead leaching from the soil to meet the TCLP standard of 5 mg/L. Screening of many different solidification reagents including Portland cement, Fly Ash, and several proprietary products was performed to determine whether leaching of lead could be controlled. Different mixing times, mixing methods, moisture contents, and curing times were also tested to determine the most effective dose to prevent leaching of lead. The design, performance, and results of the treatability study will be discussed in this presentation.

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Application of ISCO at a Former Petroleum Refinery

Scott Blaha

In Situ Chemical Oxidation (ISCO) is being applied to treat hydrocarbons in groundwater and the shallow soil at a former refinery site. ISCO was identified as the corrective measure for several Solid Waste Management Units (SWMUs) and Areas of Concern (AOC) in a RCRA Corrective Measures Study. The implementation of this technology is being coordinated with light non-aqueous phase liquid (LNAPL) recovery, *in situ* stabilization, *ex situ* stabilization, *in situ* chemical fixation, and enhanced *in situ* bioremediation, depending on the chemicals of concern (CoCs) and site characteristics. ISCO is targeted in areas with relatively high BTEX concentrations, after LNAPL recovery has taken place.

Base activated sodium persulfate is being applied as the oxidant by injection or soil mixing. Sodium persulfate and sodium hydroxide have been injected into the aquifer in liquid form. In some cases, the high water table (typically 1-5 feet below surface grade) allows the chemicals to be applied in a dry form and “slurried” with the saturated soils down to a depth of approximately 8 to 10 feet.

This presentation will discuss the corrective measure objectives, describe the site conditions where ISCO has been applied, and present treatment effectiveness based on soil cores and groundwater trends. Factors that influence performance such as soil and groundwater characteristics, CoC concentrations, mass loading on soil, and persulfate dose will be discussed. A comparison of ISCO performance at the former refinery site with performance from other sites may be elucidated.

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Taking Advantage of the Drought – Optimizing Secondary Source Removal at LUFT Sites

Thomas Rejzek and Steve Nailor

The recent California drought altered subsurface conditions, resulting in decreased water tables and drier soil conditions. These conditions exposed a significant mass of previously submerged petroleum hydrocarbons at multiple sites in Santa Barbara County. The Santa Barbara County Environmental Health Services Leaking Underground Fuel Tank (LUFT) Program directed responsible parties to implement Soil Vapor Extraction (SVE), taking advantage of the conditions to enhance mass removal. This presentation describes several case studies that demonstrate the effectiveness of implementing SVE at these sites.

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Risk Assessment

Human Health Risk Assessment of Synthetic Turf Field Materials

Kathy Phillips and Ruth Custance, Geosyntec Consultants, Santa Barbara, CA

An Algorithm for Engineering Human Health Risk Attenuation

John Sepich, Brownfield Subslab, Westlake Village, CA

Human Health and Ecological Risk Communication: Translating Environmental Data for the Public Through Media Sources

Eric Cherry, Hexagon Environmental Solutions LLC, Westerville, OH; Jane Dailey, Indiana University Southeast, New Albany, IN

Use of Relative Oral Bioavailability in Site-Specific Risk Assessment

Ann Verwiel, ToxStrategies, Inc., Richmond, CA; Deborah Proctor and Mina Suh, ToxStrategies, Inc., Mission Viejo, CA

Incremental Sampling Methodology Triplicates: Use of 95UCL Calculations in Risk Assessment and Site Characterization

Jason Brodersen, Tetra Tech, Oakland, CA; Rob Tisdale, Tetra Tech, Denver, CO; Marvin Heskett, Element Environmental, Aiea, HI

Human Health Risk Assessment of Synthetic Turf Field Materials

Kathy Phillips and Ruth Custance

Synthetic turf has been used on athletic and recreational fields since the 1960s, with approximately 13,000 such fields currently in use in the United States and up to 1,500 new fields installed each year. The number of people potentially using these fields is estimated to be in the millions. While the construction of synthetic turf fields varies, an installation typically includes a multilayered polymer backing material into which plastic fiber “grass” blades are imbedded. To support the blade structure and to provide cushioning for field users, an infill material – which often includes pieces of “crumb rubber” produced from recycled tires – is typically installed between the blades. Crumb rubber has the potential to contain toxic chemicals including heavy metals, volatile organic compounds, and polycyclic aromatic hydrocarbons.

Public concerns over potential health effects associated with the use of synthetic turf fields have led to assessments by various government and other organizations. The conclusions of limited studies have not identified an elevated health risk; however, data gaps remain and additional assessment is needed. At the federal level, the United States Environmental Protection Agency (US EPA) initiated a research project in 2016 to evaluate human exposures associated with the use of crumb rubber in fields. In California, the Office of Environmental Health Hazard Assessment (OEHHA) has been investigating potential health effects associated with the use of recycled tires in recreational and athletic surfaces since at least 2007, and their newest study on the potential human health effects of synthetic turf commenced in 2015. The US EPA, OEHHA, and other studies are ongoing.

This presentation will combine our experience in assessing synthetic turf field materials with information gleaned from a variety of public studies to summarize the current understanding of potential human health risks associated with the use of synthetic turf fields.

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An Algorithm for Engineering Human Health Risk Attenuation

John Sepich

Issues: The environmental community faces challenges related to Human Health Risk (HHR) mitigation and the design of volatile organic compound (VOC) soil vapor control systems. The public must be protected against sometimes not well defined hazards. The costs for arbitrary mitigation and long-term monitoring can be high.

HHR versus Vapor Attenuation: An attenuation factor (AF) quantifies the diminishment of chemical concentrations from a source to a secondary point of measurement. Current industry practice defines a linear relationship between HHR and VOC concentrations. Attenuation of soil vapor concentrations by an order of magnitude decreases HHR by an order of magnitude. If modeling shows health risk from soil vapors to not meet goals -- i.e., target risk normally 10^{-5} or 10^{-6} -- by, say, several orders of magnitude, then engineered mitigation measures must attenuate soil vapor concentrations by several orders of magnitude.

Engineered Attenuation: Calculations and field measurements suggest that passive sub-slab venting may provide AFs of one to several orders of magnitude, and active systems may provide additional AFs. AFs for membranes may be two to several orders of magnitude in practice, and theoretically much more. Although seldom considered, soil bio-attenuation may provide AFs up to several orders of magnitude. Building ventilation and other mitigation measures add additional attenuation.

Design Details: The presentation discusses specific design elements and techniques to optimize engineered AFs, including materials, methods, and layout for venting and membrane, and design and operational techniques for fans and active systems. Much science is yet to be developed in this arena. Current knowledge is a combination of theory and empirical measurements, and not all influences of AFs are known or quantified.

Regulatory Possibilities: AF standards should be considered a legitimate engineering design tool. Mitigation costs and effectiveness would be optimized by engineering design based upon scientific principles, and greater reliance upon construction phase deputy inspection. All stakeholders would benefit.

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Human Health and Ecological Risk Communication: Translating Environmental Data for the Public Through Media Sources

Eric Cherry and Jane Dailey

Whether it is an emergency response situation or an ongoing environmental issue related to surface water or drinking water supplies, environmental professionals frequently need to accurately and effectively communicate with the public through the media. We may be engineers, toxicologists, hydrogeologists, or environmental chemists who have extensive experience in our specialties and who are well aware of both the accuracy and limitations of our knowledge related to a given situation. However, if we cannot effectively communicate this information because we are being overly technical or using the jargon of our professions, then we are doing a disservice to the public.

To improve our communication skills, we need to understand the “news value” of a given event: Is it timely, is it proximal to populations, what are the potential impacts or consequences, is this situation novel or rare, and finally, is there potential good-guy/bad-guy conflict in the situation? We also need to understand how the environmental story can be presented to the public through Framing Theory and Prospect Theory. Framing Theory deals with how the information is presented to suggest context, and Prospect Theory shows how we need to consider the public's concept of their current situation.

As environmental professionals, we deal with concentrations, ratios, time, and distance. We may understand the consequences of a spill or release, but to the public, “perception is reality.” Hence, it is our obligation to translate our knowledge and understanding of uncertainty to the public through media outlets so that the public and their governmental representatives can make informed decisions. This presentation highlights three nationally recognized case studies associated with water quality issues where outcomes could have been improved by a better implementation of accurate and effective risk communication efforts by the science community and its interaction with the press.

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Use of Relative Oral Bioavailability in Site-Specific Risk Assessment

Ann Verwiel, Deborah Proctor, and Mina Suh

In health risk assessment for metals, a default assumption of 100% relative oral bioavailability is commonly applied. However, as has been demonstrated for arsenic and lead in media such as mine tailings and slag (Diamond et al., 2016; US EPA, 2012), the relative bioavailability of metals is often less than 100% because of poor solubility in the gastrointestinal tract. Metal alloys used for critical components (e.g., aircraft engine parts) are designed to be corrosion resistant and thus expected to have significantly reduced bioavailability. Accounting for the relative bioavailability of metals in alloys can be critical for accurately assessing the potential human health risk.

In our case study, the bioaccessibility and relative oral bioavailability of key metals, cobalt and nickel, in soil and dust were investigated to refine risk assessment of the ingestion exposure pathway. Samples of soil and dust were collected within a block of an operating metal forge, which historically emitted metals as alloys from grinding. Measures of *in vivo* bioaccessibility for both nickel and cobalt in soil and dust averaged 1-2%. The *in vivo* relative bioavailability in a juvenile swine model for cobalt ranged from 0.2 to 11% and from 1 to 2% for nickel. To be health-protective and address uncertainty in the underlying data, DTSC recommended using 25% relative bioavailability for soil and 10% for dust for both metals. These assumptions significantly reduced calculated hazard indices, resulting in values less than 1 for soil, and for dust in most areas.

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Incremental Sampling Methodology Triplicates: Use of 95UCL Calculations in Risk Assessment and Site Characterization

Jason Brodersen, Rob Tisdale, and Marvin Heskett

Increased use of incremental sampling methodology (ISM) has resulted in increased application of this sampling technique across the U.S. A challenge of ISM is the desire, need, or requirement to apply a 95 upper confidence level (95UCL) of the mean for risk assessments, characterization, or confirmation sampling. The 2012 Interstate Technology Regulatory Council (ITRC) ISM Guidance Document provides information on the calculation of a 95UCL using triplicate results; however, the specific use, application, or interpretation of this 95UCL is not defined. This is important because the calculation of the ISM 95UCL does not address the same confidence factors or variabilities as the 95UCL calculated from traditional discrete samples.

Agencies, owners, and consultants are calculating this new ISM 95UCL, but is it clear what those results represent or how they should be applied? The ISM 95UCL estimates the confidence interval of the central limit theorem, which is not addressed at all through the calculation of discrete 95UCLs. The ISM 95UCL also incorporates laboratory error and variability, which are also not addressed in the discrete 95UCL. The discrete 95UCL provides a confidence interval in the mean of the data set collected – but in ISM, the confidence in the mean has theoretically already been minimized through the proper collection of the 30, 50, or 5-75 point incremental sample, as supported through references in EPA guidance regarding confidence in the mean when more than 30 discrete samples have been collected.

As a result, it is likely that applying the ISM 95UCL overestimates the confidence interval and variability as compared to the discrete 95UCL. This would result in ISM site decisions more conservative than those with a discrete sampling approach. Similarly, the ISM 95UCL highlights the variabilities not included in discrete 95UCL calculations, which could undermine the confidence in decisions supported by discrete 95UCL calculations.

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Site Investigation

Real-Time Measurements of Hydrocarbon Concentrations in Soils

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X-Ray Fluorescence for Cost-Effective Site Characterization and Metals Remediation

Zachary Salin and Bruce Castle, EKI Environment & Water, Burlingame, CA

Deep Groundwater Investigation for Tunnel Feasibility in Igneous and Metamorphic Bedrock, Los Angeles County, CA

Jim Finegan, Kleinfelder, Riverside, CA

Real-Time Measurements of Hydrocarbon Concentrations in Soils

Natasha Sihota and Toni Miao

Portable field instruments can enable time and cost efficiencies in site investigation and monitoring. For example, total petroleum hydrocarbon (TPH) measurements in soils and groundwater are necessary to delineate hydrocarbon impacts, evaluate remedial endpoints, and satisfy regulatory requirements. These measurements can be obtained in analytical laboratories; however, lengthy turnaround times (weeks - months) can cause significant delays in field operations, and per-sample costs may limit the number of samples analyzed.

To address need for field measurements of TPH in soils, a field-portable IR device (“IR gun”) using attenuated total reflectance was evaluated at multiple sites impacted with crude oil. Reflectance IR spectra can be acquired easily and rapidly because of the high sensitivity of alkyl-CH₃ vibrational group. Partial least squares and cross validation techniques were used to develop equations for TPH quantification. The impacts of soil moisture, grain size, and hydrocarbon type on the accuracy of reported results were evaluated.

Results show that, following site-specific calibration, the device can provide TPH measurements in minutes for significantly less cost than laboratory methods. Our data show that soils with water contents up to 30 wt% can be measured without significant loss of accuracy in reported TPH. Results also show that the lower detection threshold is sensitive to soil grain size. The small contact window of the IR gun results in an elevated lower detection threshold for sites with larger grain sizes. In contrast, variability in crude oil did not have an impact on the readings for the sites tested in this study. Overall, results show that the IR gun can deliver real-time results for field screening of hydrocarbon-impacted soils when calibrated with a site-specific model. This approach can potentially lead to significant time and cost savings and increase decision making efficiency through reducing the need for laboratory analytical techniques.

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X-Ray Fluorescence for Cost-Effective Site Characterization and Metals Remediation

Zachary Salin and Bruce Castle

X-Ray Fluorescence (XRF) is an attractive choice over traditional analytical methods for site assessment, site characterization, and performance sampling for sites with known or suspected metals contamination. Paired with new methods for telemetry and field data acquisition, XRF offers several cost-effective advantages to conventional methods for metals characterization. This presentation will describe a case study with over 200 soil boreholes for site characterization and remediation including more than 13,000 individual XRF confirmation soil samples for arsenic and lead across approximately 100 acres of project area. Design of successful XRF investigations requires knowledge of both applicable guidance, i.e., U.S. EPA Method 6200, as well as equipment limitations. Calibration standards must be selected based on contaminants; awareness of common interferences due to spectral overlap (i.e., lead and arsenic) is particularly critical in sites with more than one metal contaminant. The advantages of XRF over traditional fixed laboratory-based sample analysis from several different perspectives will be presented. Projects requiring a high volume of soil samples see cost savings over laboratory-based methods, and XRF allows the user to measure metals concentrations within minutes, reducing reliance on expedited laboratory analysis and providing real-time data to guide characterization and remediation extents. XRF can be used to quickly provide answers to contractors in the field, or it can be used to guide excavation in areas with more than one contaminant, allowing same-day confirmation sampling, selectivity in analytes, and per-sample costs approximately 60% below laboratory-based methods. XRF is capable of delineating soil zones with different waste characterization prior to remediation, helping clients minimize excavated soil volumes. Low-cost, mapping-grade GPS and cloud-based tools for input of field data make data management and completion tracking easier, and are especially suited for the rapid data collection possible using XRF.

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Deep Groundwater Investigation for Tunnel Feasibility in Igneous and Metamorphic Bedrock, Los Angeles County, CA

Jim Finegan

An investigation was performed in the San Gabriel Mountains in Southern California to evaluate hydrogeologic conditions and the potential impact of tunneling on groundwater and surface water resources. Five rock core holes were advanced to investigate parameters affecting tunnel feasibility including water pressure, hydraulic conductivity, water flow, ground conditions at significant fault zones, ground temperatures, and groundwater chemistry. The core holes were drilled to depths of 1,000 to 2,700 feet, dipping from 90 to 67 degrees. Hydrogeologic testing included in-situ hydraulic conductivity testing using packers, groundwater sampling, geophysical logging, and installation/monitoring of vibrating wire piezometers (VWPs).

The San Gabriel Mountains have experienced a complex tectonic history and are bounded by the San Andreas Fault to the north and the San Gabriel Fault to the south; several other faults traverse the investigation area. Investigation area rocks are Proterozoic to Miocene metamorphic and intrusive-igneous. The margin of the mountains is mantled with Tertiary-age sedimentary rocks (siltstone and sandstone). The hydrogeology of the study area is dominated by fracture flow, with little to no porosity within the rock mass. However, the mountains have been subjected to numerous episodes of deformation, including faulting and uplift, which has fractured the bedrock.

Five to fifteen packer tests were performed in each core hole. Hydraulic conductivity values were generally low, but ranged from 1.2×10^{-7} to 1.8×10^{-4} cm/sec. Deep groundwater samples were collected from four of the core holes at depths of 190 to 2,400 feet. Samples were analyzed for geochemistry, metals, radionuclides, and isotopes to evaluate groundwater age, chemistry, and the isotopic signature of groundwater with depth. Estimated groundwater ages were up to 4,500 years. Measured in-situ groundwater pressures indicate hydraulic barriers to vertical flow at some locations based on non-linear hydrostatic trends. 3-D numerical modeling is being performed to evaluate the effects of tunneling on groundwater and surface water resources.

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State of the Practice: Advances in In-Situ Remediation

Proper Pilot Test Design and Successful In-Situ Anaerobic Biotreatment of PCE and TCE Using EHC-L

Kevin White, Brown and Caldwell, Irvine, CA; Karnam Ramanand, Brown and Caldwell, Cherry Hill, NJ; James Claffey, Brown and Caldwell, Upper Saddle River, NJ

An Approach with Synergistic Advantages of Combining Colloidal Activated Carbon and Zero Valent Iron

Katherine Pappano and Kristen Thoreson, Regenesys, San Clemente, CA

Controlled Release Environmental Reactants – In-Situ Soil and Groundwater Remediation of Recalcitrant Compounds and Emerging Contaminants of Concern

Lindsay Swearingen, Specialty Earth Sciences, New Albany, IN

Combining Persulfate, In-Situ Ferrate Generation and Enhanced Bioremediation for Safer, More Effective Remedial Actions

Jim Mueller, Provectus Environmental Products, Freeport, IL; Kevin Finneran, Clemson University, Anderson, SC; Mike Scalzi, IET, Inc., Toledo, OH; Chris Carey, ppB EnviroSolutions, LLC, Topeka, KS

Lessons Learned from ERD Implementation at a CVOC Contaminated Site in Monterey, CA

Andrew Halmstad, Integral Consulting, Inc., Portland, OR; Avram Frankel, Integral Consulting, Inc., San Francisco, CA; Craig Sandefur, Regenesys, San Clemente, CA; Debra Moser, Trinity Source Group, Inc., Santa Cruz, CA; Tricia Wotan, City of Monterey, Monterey, CA

Proper Pilot Test Design and Successful In-Situ Anaerobic Biotreatment of PCE and TCE Using EHC-L

Kevin White, Karnam Ramanand, and James Claffey

Groundwater at a Site in the Los Angeles area is impacted with perchloroethene (PCE) from former releases at the Site and trichloroethene (TCE) from upgradient source(s). A pilot test was conducted to evaluate the performance of in-situ anaerobic biotreatment to degrade the contaminants. There are several key design elements that can affect the performance of the anaerobic biotreatment including selecting the right electron donor and amendments to promote dechlorination. The pilot test that was employed consisted of one injection point with five monitoring wells within 15 feet of the injection point to monitor the injected reagent's performance on contaminant dechlorination, with EHC-L serving as a long-term electron donor source.

A case study will be presented showing the successful implementation of the pilot test and treatment of groundwater contaminants at the Site. Concentrations of PCE and TCE decreased from approximately 600-800 µg/L to less than the groundwater standard of 5 µg/L within 10 feet of the injection and have remained that way for over a year. This confirmed efficient distribution of the reagents and provided a key design parameter (injection spacing) for the potential full-scale remedy. Other indicators such as the presence of tracers, total organic carbon, methane, and ferrous iron reaffirmed the case for future injection spacing. In addition, the concentrations of by-products, such as vinyl chloride that initially increased and pH which declined due to the dechlorination process, have shown a positive trend towards baseline. The bacterial culture added during injection is helping to control the initial increase of vinyl chloride to 17 µg/L, which has now decreased to approximately 5 µg/L. The pH initially dropped to as low as 5.2, but has since rebounded to baseline near 7. Based on this successful pilot test proof-of-concept, a full-scale remedy is being planned to address groundwater contamination at the Site.

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An Approach with Synergistic Advantages of Combining Colloidal Activated Carbon and Zero Valent Iron

Katherine Pappano and Kristen Thoreson

This presentation explores combining the sorptive properties of colloidal activated carbon with the reductive properties of colloidal zero valent iron (ZVI) to remediate contaminated soil and groundwater. The combined approach allows the rapid removal of contaminants and provides long-term treatment with a single application of product. The colloidal nature of the activated carbon and ZVI allows the materials to be co-applied at low pressure with uniform distribution in the subsurface to ensure contact with contaminants.

The sorption and degradation of PCE by activated carbon and ZVI was analyzed in batch and column laboratory studies. Colloidal activated carbon and colloidal ZVI were studied in combination under abiotic conditions, as well as in the presence of a chlorinated solvent degrading bacteria inoculum. To monitor both the sorption of PCE onto activated carbon as well as any degradation, the PCE and daughter product concentrations in the aqueous solution were monitored, and organic extractions were also performed to measure the total mass balance across all phases (water, soil, colloidal activated carbon). A separate sand column study was conducted to test the transport properties of these colloidal agents.

The laboratory studies demonstrated that the combination of colloidal activated carbon, ZVI, and contaminant degrading bacteria resulted in a synergistic performance. These studies suggested that PCE is sorbed to activated carbon within one day and, once sorbed, the PCE remains available to be degraded. As PCE is degraded, the activated carbon is regenerated, providing a mechanism for long-term treatment by controlling rebound due to back diffusion. PCE and daughter products can also be degraded by the ZVI in this system. Column studies demonstrated that the colloidal activated carbon and the colloidal ZVI are readily transported through sand. The co-application of colloidal activated carbon and ZVI does not show competition or diminished performance of either technology.

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Controlled Release Environmental Reactants – In-Situ Soil and Groundwater Remediation of Recalcitrant Compounds and Emerging Contaminants of Concern

Lindsay Swearingen

The environmental science community has a collective interest in identifying viable and sustainable remedial solutions for groundwater contaminant plumes, seeking out remedies which reduce carbon footprint, minimize waste generation, and limit energy inputs required for remediation implementation, operations, and ongoing maintenance at sites impacted by CVOCs, PAHs, BTEX constituents, and heavy metals. Stakeholders could benefit from greener cleanup technologies, especially in light of future requirements to remediate vast dissolved phase plumes of emerging contaminants of concern such as 1,4-dioxane.

Sustained and controlled release reactant technology involves coating or encapsulating environmental reactant materials to facilitate a more user-friendly in-situ remediation implementation. The result is an efficient approach to soil and groundwater remediation which addresses the common challenges encountered with traditional liquid injection applications. Challenges include contaminant rebound, plume migration, and the need for multiple mobilizations. Rather than pressurized liquid injection, the energy of concentration gradient driven diffusion as well as natural groundwater movement is used to deliver oxidants in the subsurface without the need for specialized injection equipment or expensive injection field services providers.

Sustained and controlled release reactant materials can be applied to the subsurface in a number of forms and methods. Multiple remediation practitioners have applied these materials at sites across the U.S. and Europe and in Canada and Brazil. Current and updated site examples will be presented including site selection, implementation design, cost, and monitoring data.

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Combining Persulfate, In-Situ Ferrate Generation and Enhanced Bioremediation for Safer, More Effective Remedial Actions

Jim Mueller, Kevin Finneran, Mike Scalzi, and Chris Carey

Background/Objectives: Ideally, ISCO rapidly oxidizes/mineralizes organic contaminants in a safe and effective manner (i.e., materials easy to handle on site, no extreme activation chemistries such as heat or grossly elevated pH, no generation of secondary contaminants). And – importantly – remedial actions are completed via a one-time application event. However, with essentially all conventional ISCO technologies, the oxidation reactions are partially incomplete and contaminant desorption/rebound is a very common problem.

Approach/Activities: When ferric oxide is used to activate persulfate the process quickly yields ferrate (tetraoxy iron or FeO_4^{2-} or Fe(VI)) in addition to the standard persulfate radicals (SO_4^\bullet , $E_0 = 2.600 \text{ V}$). Ferrate functions both as an oxidant and subsequent coagulant in the form of Fe(III) (hydro)oxides that can immobilize heavy metals. Ferric iron activation of persulfate also enhances subsequent utilization of sulfate and iron as terminal electron acceptors for facultative redox reactions that sustain bioremediation of residual contaminants and partially oxidized compounds. This combination of chemical and biological treatment mechanisms allows for more cost-efficient treatment while supporting long-term, sustained, secondary bioremediation processes to manage residuals and prevent contaminant rebound.

Results/Lessons Learned: Provect-OX® is a pre-mixed, dry powder containing both sodium/potassium persulfate and ferric oxide that can be easily applied into a subsurface environment via direct mixing, hydraulic fracturing, pneumatic fracturing, and direct push injection of slurries. Ferrate will be continuously generated in-situ to support extended oxidation of persistent compounds, provided that persulfate is maintained with iron as an activator. Thereafter, the residual iron and sulfate will support bioremediation processes to manage partially oxidized compounds and residual contaminants that continually desorb from the matrix over time (c. 3 to 5 years). This presentation will outline parameters considered for calculating material requirements, discuss field application considerations (material handling and implementation guidelines), and summarize performance data and costs from various projects.

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Lessons Learned from ERD Implementation at a CVOC Contaminated Site in Monterey, CA

Andrew Halmstad, Avram Frankel, Debra Moser, Tricia Wotan, and Craig Sandefur

As the implementation of enhanced reductive dechlorination (ERD) for chlorinated volatile organic compounds (CVOCs) evolves, new approaches that leverage a well-developed conceptual site model (CSM), remediation hydraulics best practices, and next generation reagents are yielding efficiencies. Data gathered from a recently initiated and ongoing ERD project in Monterey, California, have demonstrated excellent ERD performance after one injection event, and have contributed to the CSM by refining the source area locations and requirements for treatment. After a single injection event, the current program is successfully remediating zones of significantly elevated CVOC concentrations indicative of adsorbed phase and non-aqueous phase material. Overall, the program is being implemented in a conductive, sandy, yet heterogeneous aquifer setting with a nearly flat potentiometric surface. This combination of aquifer characteristics presents unique opportunities and challenges in design and application. Past experience and careful consideration of the CSM resulted in real-time integrated pilot testing that was completed as part of the initial injection program in a single mobilization. A robust injection monitoring program and pre-planned implementation flexibility facilitated program optimization through real-time decision making and field adjustments. Post-injection monitoring results illustrate the need for a thorough understanding of pre- and post-injection site conditions for all remedial steps. The lessons learned during design, field application, and post-injection monitoring have implications for the future ERD applications. These include in-the-field adaptive management approaches for ERD applications, the importance/utility of near-real-time data collection efforts, and the benefit of close coordination between injection design and implementation stages; each will be discussed.

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Sustainability Considerations in Remediation and Restoration

Remedy Resiliency to Extreme Weather Events

Roy Thun, GHD, Santa Clarita, CA

Time, Technology, and Sustainable Remediation

Paul Hadley, DTSC (Retired), Davis, CA; William Butler, Environmental Resources Management, Atlanta, GA

Engineered Phytoremediation of Aquifers Impacted by High Contaminant Levels and Emerging Contaminants: Lessons Learned

Ron Gestler, Geosyntec Consultants, Benicia, CA; Karen Berry-Spark, Geosyntec Consultants, Waterloo, ON, Canada; James Linton, Geosyntec Consultants, Clearwater, FL; Edward Gatliff and Paul Thomas, Applied Natural Sciences, Inc., Hamilton, OH

Applying Lean to Optimize Project Strategies, Create Team Alignment, and Develop Sustainable Remedial Approaches

William Kay, Haley & Aldrich, Costa Mesa, CA; Bethany Brooks, Haley & Aldrich, Rochester, NY

Remedy Resiliency to Extreme Weather Events

Roy Thun

The National Contingency Plan (NCP) utilizes long-term effectiveness and permanence as one of the primary balancing criteria in the selection of a remedy. To achieve satisfactory long-term effectiveness and permanence, remedial designs often rely on a 1% probability event occurrence. This is a 1 in 100 chance of an event (e.g., flood) being equaled or exceeded in any 1 year, and an average recurrence interval of 100 years. This is often referred to as the “100-year event.”

In March 2016, the National Academy of Sciences (NAS) released a report, *Attribution of Extreme Weather Events in the Context of Climate Change*. NAS findings denote an increase in the severity and frequency of extreme weather events. Scientific evidence shows temperature extremes have shifted the mean and the low-probability tails toward more frequent and intense heat events. In 2011, Texas reached drought status while the Midwest recorded unprecedented precipitation. In 2014, a team of more than 300 experts guided by a 60-member Federal Advisory Committee produced the National Climate Assessment report. This report evidences an increase in precipitation during very heavy rainfall events.

With all the evidence, the question arises as to whether existing and future remedy designs are satisfactory when accounting for changes in frequency and severity of extreme weather events. This presentation will look at remedial design factors in the context of long-term resiliency to extreme weather events, and recommend a process to assist in the evaluation of long-term effectiveness and permanence.

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Time, Technology and Sustainable Remediation

Paul Hadley and William Butler

The remediation industry has been implementing groundwater cleanup technologies since at least the early 1980s, sometimes continuously since that time at certain sites. Metrics to track progress of such cleanups based on mass flux have long been suggested for implementation and are beginning to find broader acceptance and application. Along the way, the concepts of sustainable remediation have been introduced and applied to groundwater remediation projects as well. By considering the time-history of a “typical” groundwater remediation project, the advantages of implementing mass flux-based metrics for tracking cleanup – as well as for evaluating risk – become apparent. Equally apparent are opportunities for improving the sustainability of groundwater projects beyond traditional remedial optimization processes. The coordinated integration of mass flux-based metrics and sustainability principles and practices to groundwater remediation projects are presented through examples available in the literature, guidance documents, and projects known to the authors. Collectively, the integration of improved use of mass flux-based metrics with sustainability principles and practices offers a clearer lens through which to view and evaluate groundwater cleanup technologies, as well as for remediation decision making in general.

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Engineered Phytoremediation of Aquifers Impacted by High Contaminant Levels and Emerging Contaminants: Lessons Learned

Ron Gestler, Karen Berry-Spark, James Linton, Edward Gatliff, and Paul Thomas

Phytoremediation – plant-based remediation technology – has gained increasing interest in recent decades as an effective, low-cost, green, and sustainable approach to site cleanup. Geosyntec has successfully applied phytoremediation at multiple sites to address impacts from a wide range of environmental contaminants under diverse hydrogeologic conditions, including sites impacted by high levels of volatile organic compounds and emerging contaminants such as 1,4-dioxane. For many of these sites, phytoremediation was selected as an alternative to or replacement for more costly groundwater pump-and-treat systems.

This presentation will review several phytoremediation case studies at various stages of deployment, from recently implemented to more mature systems, including a site where phytoremediation was directly combined with in-situ chemical treatment technologies to address high levels of chlorinated solvent contamination. For all case studies presented, designed and engineered phytoremediation systems have been utilized to achieve both contaminant treatment and hydraulic control of impacted groundwater horizons. Lessons learned from these implementations and data supporting conclusions regarding contaminant degradation and hydraulic control will be discussed, along with details of the modelling performed beforehand that helped ensure successful system designs.

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Applying Lean to Optimize Project Strategies, Create Team Alignment and Develop Sustainable Remedial Approaches

Bethany Brooks and William Kay

Site reviews are a standard practice for many of our clients. General feedback from the industry has highlighted a need to better optimize investigative and remedial strategies (including O&M) to ultimately support closure and/or long-term site management goals. While these reviews are intended to optimize strategy and management practices, feedback indicates that reviews, particularly when done independently from the project team, are expensive and do not produce actionable improvements.

Lean principles focus on increasing value (e.g., achieving desired outcomes), reducing waste (e.g., optimizing use of resources), and respecting people (e.g., team alignment). Through a facilitated, Lean-based approach, in as little as 1.5 days, a project team can develop a stronger understanding of the current state, site-specific risk drivers, and desired outcomes. This shared perspective results in rapid development and alignment on an actionable path forward. The team develops a strategy-based action plan, implemented with Lean-based support, including responsibilities and a short-term execution schedule, thereby reducing waste and adding significant value to the project.

This presentation will share case studies demonstrating how applying Lean to optimize site reviews is ultimately a better management practice resulting in more sustainable remediation approaches.

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Sustainability in Emerging Remediation Markets

A Zero Energy-Consuming Tool for Treating Petroleum Contaminants in Tight Formations

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Strategies for Rehabilitating Mercury-Contaminated Mining Lands in Colombia for Renewable Energy and Other Sustainable Reuse

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Sustainable Remediation in China: Challenges and Opportunities

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A Zero Energy-Consuming Tool for Treating Petroleum Contaminants in Tight Formations

Song Jin, Paul Fallgren, Matthew Larsen, and Jennifer Strauss

A bioelectrochemical technology has been recently developed, patented, and applied on multiple underground storage tank (UST) and petroleum terminal sites for treating petroleum compounds in groundwater and saturated soils, with no energy input or consumable materials. The so trademarked E-Redox[®] technology stimulates biodegradation essentially by “pulling” electrons from the impacted matrix to the terminal electron acceptor of oxygen in the ambient air and consuming no energy, and for the same mechanism, it is not limited by low permeability formations such as clay. Rather, higher conductivity in clay favors the E-Redox[®] operation and performance.

Case studies to date have demonstrated significant enhancement of petroleum-hydrocarbon degradation rates in groundwater and soil. Field applications were conducted at leaking underground storage tank UST sites in Colorado, where the main contaminants of concern included benzene and total petroleum hydrocarbons (TPH) and the subsurface formation was clay-dominant. Data indicated that the E-Redox[®] treatment achieved up to 5x the benzene degradation rates, exceeding that from aerobic biodegradation and substantially higher than that from remedies of amending other alternative electron acceptors such as nitrate and sulfate. In a recent full-scale field implementation of E-Redox[®] technology, benzene concentrations in the groundwater decreased by more than 90% within three months. Additionally, over 50% reductions in other petroleum hydrocarbon concentrations were observed in conjunction with the benzene degradation. Overall, the field case studies have demonstrated that the E-Redox[®] technology is effective in enhancing biodegradation of petroleum compounds in tight formations, with zero energy and consumable material input, achieving a truly sustainable remediation.

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Strategies for Rehabilitating Mercury-Contaminated Mining Lands in Colombia for Renewable Energy and Other Sustainable Reuse

Barbara Maco, Paul Bardos, Alfonso Rodríguez, Euan Hall, Tony Hutchings, and Andrew Cundy

Background/Objectives: Gold mining using mercury recovery techniques has resulted in severe health and environmental impacts in large areas of Colombia. With approximately 4,200 active and abandoned gold mines and some 3,000 additional artisanal locations, 80,000 hectares are estimated to be contaminated with mercury in Colombia, especially by artisanal methods. Focusing on the triple bottom line, a range of science-based gentle remediation strategies was considered to rehabilitate land affected by soil mercury pollution in disadvantaged areas in Colombia and bring it back into productive use focusing on renewable energy generation.

Approach/Activities: With strategic funding from the United Kingdom and closely partnering with Colombian federal, state, and local entities, an international consortium transferred state of the art sustainable remediation knowledge and successful implementation from the UK, EU, and North America, adapting it to the local situation. Specific activities included: (1) Technology evaluations and bench-scale test work including biochar for mercury stabilization that will form an on-site field testing plan for techniques that promises to be replicable to other similarly contaminated sites, and (2) Adaptation of international project decision support tools (EU GREENLAND and HOMBRE Brownfields Opportunity matrix, and U.S. RE-Powering America) to conditions in Colombia.

Results/Lessons Learned: (1) Experimental findings for mercury immobilisation using chars. (2) Site specific feasibility evaluations for mercury stabilisation and renewable energy production. (3) High level review of brownfield land reuse potential for renewable energy identifying opportunities for community and/or Colombian commercial enterprise. (4) Broader guidance (including policy briefs and stakeholder engagement) on maximising the sustainability and value of restoring mining land for renewables and other non-built reuses in Colombia. These project results have wider relevance to other forms of degraded land in Colombia as well as in neighbouring countries and emerging economies globally.

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Sustainable Remediation in China: Challenges and Opportunities

Jun Lu and Qingbao Gu

Decades of rapid industrialization have left China with vast areas of contaminated lands. Chinese authorities recognize the problem, and The Prevention and Control of Soil Pollution Action Plan (also known as “Soil Ten”), released in 2016, targets soil deterioration. Numerous guidance documents were released to facilitate execution of the plan. As with what happened in the U.S. remediation industries in early 1980s to mid-1990s (i.e., use of high energy techniques such as dig, pump, bury, and burn), the Chinese have taken similar paths in remediation in the last decade. The Chinese have taken these paths for different reasons in that remediation has been primarily associated with property development and the value of the land affords the cost of remediation. However, the high energy approach is certainly not sustainable with the large scale of remediation soon approaching. Thankfully, more than forty years of remediation experience from the developed countries (especially the United States) will present ample opportunities for Chinese practitioners to overcome the problems faced. This presentation will address the status of soil remediation in China including scale of problem, regulations, current practices, and risk-based sustainable remediation opportunities.

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The Evolving Risk Assessment Landscape in California

The Ongoing Controversy Surrounding the Effects of Short-Term Exposure to Trichloroethene

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Updating the Regulatory Risk Assessment for Hexavalent Chromium in California: Implications for Regulatory Standards

Deborah Proctor, ToxStrategies, Inc., Mission Viejo, CA

Department of Toxic Substances Control Toxicity Criteria for Human Health Risk Assessments, Screening Levels and Remediation Goals Rule

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Updates to the Hazard and Dose Response Assessment for 1,1-Dichloroethylene

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The Ongoing Controversy Surrounding the Effects of Short-Term Exposure to Trichloroethene

Gregory Brorby

Trichloroethylene (TCE) has long been an important environmental contaminant, but as a result of recent information regarding TCE's toxicity and regulatory action, there has been increased scrutiny on sites with TCE in soil, soil gas, or groundwater. The toxicity criteria changed significantly in 2011 when EPA's Integrated Risk Information Service (IRIS) updated their Toxicological Profile, with additional implications in 2014 when EPA Region 9 issued their response action levels based on short-term exposures. However, the primary TCE toxicology study (Johnson et al., 2003) at the center of the concern over short-term exposures is controversial, at least in part because the TCE literature does not support the findings, including studies of superior design that have been unable to reproduce the effects. Despite the ongoing controversy, many federal and state agencies have followed Region 9's lead to regulate short-term exposure to TCE using the IRIS toxicity value for chronic exposures. Further evaluation of TCE toxicity continues, including as part of the amended TSCA risk evaluation program. The scientific interpretation underpinning Region 9's action levels, the attendant controversy, and ongoing activities will be presented and discussed.

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Updating the Regulatory Risk Assessment for Hexavalent Chromium in California: Implications for Regulatory Standards

Deborah Proctor

Since the movie *Erin Brockovich*, the presence of hexavalent chromium in groundwater—though mostly naturally occurring—has sparked concern that existing drinking water standards are not sufficiently protective. In 2016, California's newly set Maximum Contaminant Level (MCL) for hexavalent chromium in drinking water of 10 ppb was nullified due to an appellate court's finding that the economic feasibility analysis was inadequate. In addition, the 2011 Public Health Goal of 0.02 ppb is currently under review to determine the need for a reassessment based on updated science. As such, the California risk assessment for hexavalent chromium in drinking water and associated guidance values are yet unresolved. This talk presents the results of a seven-year toxicology research effort to evaluate the mode of action of hexavalent chromium carcinogenicity following oral exposure, and the development of toxicity criteria protective of cancer and non-cancer effects. The research included PBPK modeling to quantify reduction kinetics in the gut of rodents and that of humans including sensitive subpopulations. The findings of the evaluation are that hexavalent chromium causes cancer in the mouse small intestine by repeated wound and healing, which is an effect only expected at high doses. Based on the new research, a reference protective of both cancer and non-cancer effects has been developed and supports that the current total chromium MCL is protective of adverse health effects associated with ingestion of hexavalent chromium, including sensitive subpopulations.

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Department of Toxic Substances Control Toxicity Criteria for Human Health Risk Assessments, Screening Levels and Remediation Goals Rule

Kimberly Gettmann

The California Department of Toxic Substances Control (DTSC) is promulgating a new rule to adopt specified, peer-reviewed, Office of Environmental Health Hazard Assessment (OEHHA) toxicity criteria, and require their use in all human health risk assessments, for human health risk-based screening levels, and for human health risk-based remediation goals at hazardous waste and hazardous substance release sites in California. The rule will apply to the characterization and cleanup of those sites under Health and Safety Code, Division 20 Chapters 6.5, 6.8, and 6.82 including sites/facilities subject to CERCLA and RCRA corrective action. The rule will formalize DTSC's existing practice, applied since 1994, of using certain OEHHA toxicity criteria that incorporate California-specific health and safety considerations. The OEHHA criteria specified in the new rule afford a greater level of protection than their equivalent U.S. Environmental Protection Agency criteria for human health, safety, and the environment. DTSC will explain the rule, its basis, and its applications to cleanup sites in California.

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Updates to the Hazard and Dose Response Assessment for 1,1-Dichloroethylene

Efrem Neuwirth

1,1-Dichloroethylene (synonyms 1,1-DCE, vinylidene chloride) is primarily used as a monomer in the production of polyvinylidene chloride (PVDC) copolymers. 1,1-DCE is also commonly found at solvent release sites as an environmental breakdown product of other chlorinated VOCs. Since the 2002 risk assessment when US EPA withdrew previously developed cancer toxicity factors, this chemical has been a relatively low risk chemical, with risk assessments based upon the non-cancer health effects. The completion of new lifetime inhalation cancer studies by the National Toxicology Program in 2015 and recent reevaluation of the cancer hazard by an international body suggest that this chemical may again become a chemical which may drive remediation and mitigation. The changing regulatory status, cancer potency, and implications will be discussed.

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Vapor Intrusion: Cal/EPA Focus on Protecting Current and Future Building Occupants

E Pluribus Unum: A Cal/EPA Unified Approach to Evaluating and Managing Vapor Intrusion Risk

Claudio Sorrentino, Dan Gallagher, and Barbara Renzi, Cal/EPA, Department of Toxic Substances Control, Sacramento, CA; Ross Steenson, Nicole Fry, and Cheryl Prowell, San Francisco Bay Regional Water Quality Control Board, Oakland, CA; Steven McMasters, State Water Resources Control Board, Sacramento, CA

Where the Rubber Meets the Road: How to Use the 2018 Cal/EPA VI Supplement

Nicole Fry, San Francisco Bay Regional Water Quality Control Board, Oakland, CA

Considerations for Evaluating Alternative Pathways as Part of Vapor Intrusion Assessments

Kelly Pennell, University of Kentucky, Lexington, KY

Communities' Role in Vapor Intrusion Management

Lenny Siegel, City of Mountain View, Mountain View, CA

Another Tool in the Toolbox – Practitioners' Perspectives on the New Cal/EPA VI Guidance Supplement

Gina Plantz and David Molmen, Haley & Aldrich, Oakland, CA; Adrienne LaPierre, RPS Environmental, Oakland, CA

E Pluribus Unum: A Cal/EPA Unified Approach to Evaluating and Managing Vapor Intrusion Risk

Claudio Sorrentino, Nicole Fry, Dan Gallagher, Steven McMasters, Cheryl Prowell, Barbara Renzi, and Ross Steenson

The numerous challenges of vapor intrusion have brought State government together. Faced with spatial and temporary variability of data, sewers as a preferential pathway, and uncertainty concerning attenuation factors, the Department of Toxic Substances Control (DTSC), the San Francisco Bay Regional Water Quality Control Board (RWQCB), and the State Water Resources Control Board (SWRCB) have joined forces to develop supplement VI guidance. Our workgroup developed a 4-step process to protect current occupants of buildings near known or suspected releases of VFCs during a site investigation and future occupants after the site is fully characterized. This will bring state-wide consistency and improve risk management.

Step 1 (Identification and Prioritization): developing an initial conceptual site model (CSM), and using proximity to the release, occupancy, and preferential pathways as criteria to identify which building should be evaluated first. *Step 2 (Soil Gas Screening):* soil gas sampling near the building to decide if threat to occupants warrants further investigation. For Step 2, we recommend using the US EPA default attenuation factor (AF) of 0.03 for soil gas to indoor air. *Step 3:* inside the building with multiple rounds of paired indoor air and sub-slab vapor sampling, and concurrent outdoor air sampling. Sub-slab and outdoor air data are used to identify confounding factors. *Step 4:* a framework for when to manage risk (mitigate and/or remediate). We recommend a sub-slab to indoor air AF=0.03 for future exposure to ensure long-term protection of human health because sub-surface and building conditions may change over time. This proposed step-wise process streamlines the currently recommended approach in existing State guidance. DTSC, SWRCB, and RWQCBs will use the VI data collected using the recommended approach to generate a California-specific empirical database. The database will help us reduce the uncertainty and improve how we evaluate risk associated with the VI pathway.

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Where the Rubber Meets the Road: How to Use the 2018 Cal/EPA VI Supplement

Nicole Fry

The 2018 Cal/EPA Vapor Intrusion (VI) Supplement describes a 4-step process for evaluating the potential vapor intrusion threat to occupants of buildings near known or suspected subsurface contamination by Vapor Forming Chemicals (VFCs). The document includes specific sampling and risk assessment recommendations. This presentation will include a hypothetical case study to illustrate how and when the recommendations from this guidance can be applied to protect current and future buildings' occupants from exposure to VFCs reaching the indoor air through the vapor intrusion pathway at cleanup sites. The case study will also demonstrate how application of this process will promote consistent vapor intrusion risk assessment at all buildings located on or near California cleanup sites.

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Considerations for Evaluating Alternative Pathways as Part of Vapor Intrusion Assessments

Kelly Pennell

Volatile organic compounds (VOCs) have been the focus of hazardous waste investigations for many decades. Over the past several years, improved science-based understanding of VOC vapor intrusion into indoor air spaces through foundation cracks have informed state and federal regulatory guidance for assessing and mitigating exposure risks. Several recent reports of VOC vapors entering buildings through alternative pathways (i.e., plumbing fixtures, land drains, etc.) have challenged the conventional conceptual model of vapor intrusion occurring predominantly through foundation cracks, and call for new perspectives to inform vapor intrusion exposure assessments. This presentation will include a discussion of field data that show spatial and temporal variability of VOC concentrations in sewer systems located near hazardous waste sites. In addition, geospatial evaluation methods using city and regulatory databases will also be presented to screen locations where preferential pathways may be important for vapor intrusion into buildings. This screening method provides insight into which sites may have increased exposure risks for populations living nearby. Lastly, the presentation will highlight advanced characterizations methods – including high-frequency sampling, passive sampling, and tracer gas testing – and will also discuss several mitigation techniques that may be appropriate to reduce exposure risks associated with vapor intrusion through alternative pathways.

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Communities' Role in Vapor Intrusion Management

Lenny Siegel

California communities where vapor intrusion is being investigated or addressed are likely to consider Cal/EPA's 2018 Supplemental "Approach to Screening and Evaluating Vapor Intrusion" a step forward. The Supplemental Guidance: 1) brings recent research and field experience into Cal/EPA's approach; 2) recommends a more conservative approach by encouraging the use of default attenuation factor based on an empirical database over theoretical modeling; and 3) is likely to further harmonize the practices of the Department of Toxic Substances Control and the Regional Water Boards. Hopefully, this new Guidance will discourage responsible parties and developers from conducting investigations designed to understate risk with the goal of minimizing expenditures on mitigation or even remediation. The Supplemental Guidance illustrates also the need for more research within California on the temporal variability of indoor air contamination. Some of these information gaps could be filled by the introduction of new generation of near-real-time sampling techniques.

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Another Tool in the Toolbox – Practitioners’ Perspectives on the New Cal/EPA VI Guidance Supplement

Gina Plantz, David Molmen, and Adrienne LaPierre

It is understandable that the Cal/EPA wants a consistent approach for evaluating the vapor intrusion pathway (VI) throughout California, and the goal is to be protective of human health. However, the new Cal/EPA VI Guidance Supplement has recommendations that may lead to a significant amount of unnecessary data collection and decisions which may not be representative of actual risk from VI.

This presentation will focus on two specific areas which should be thoughtfully considered before developing site VI evaluation work plans and decisions: the applicability and use of the US EPA generic attenuation factors (AFs), and understanding typical indoor air background.

The US EPA generic AFs are based upon the 2010 US EPA VI database. The AFs calculated are specific to chlorinated hydrocarbons in residential buildings. This included screening out any chemicals labeled as a petroleum hydrocarbon (i.e., benzene, toluene, ethylbenzene, xylenes) and any buildings labeled as “commercial,” “commercial/residential,” “residential/commercial,” and “multi-use.” The database was also screened to exclude data that fell within the range of background. While it is necessary to understand background during VI evaluations, excluding datasets that had indoor air within background likely compromised the representativeness of the database by not including data from sites where VI is not occurring. It is important to understand the data and quality within the database and to consider that the database represents only a very small subset of data and it may not be technically justified to apply the outputs to other sites.

The presence of volatile organic compounds (VOCs) as a background condition in residential and non-residential indoor air has been well documented. Although consumer product formulations and building materials have changed, recent studies confirm that many volatile compounds, including tetrachloroethene (PCE), benzene, and naphthalene, are still commonly encountered in indoor air background. The Guidance Supplement recommendations will lead to more indoor air investigations where VI screening and risk management decisions focus on levels well within or below background. Understanding typical indoor air concentrations will be critical in making risk management decisions for the VI pathway.

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Vapor Intrusion I

A Dirty Secret: Causes of Duplicate Variability in Summa Canister Samples for Vapor Intrusion Investigations

Lila Beckley, GSI Environmental, Inc., Austin, TX; Carlyssa Villarreal, Sharon Rauch, and Thomas McHugh, GSI Environmental, Inc., Houston, TX

Rapid, Real-Time TCE Measurements of Sewer Headspace: Characterizing Spatial and Temporal Variability

Bruce Richman, C. Ricardo Viteri, Michael A. Armen, Artyom Vitouchkine, Gunnar Skulason, and Anthony E. Miller, Entanglement Technologies, Inc., Burlingame, CA

Multiple Lines of Evidence, Including CSIA, to Differentiate an Indoor Source from Vapor Intrusion

Safaa Dergham and Carol Serlin, Ramboll Environ, Irvine, CA; Devon Rowe, Ramboll Environ, Vancouver, WA; Blayne Hartman, Hartman Environmental Geoscience, Solana Beach, CA

Recent Developments in Quantitative Passive Soil Gas Sampling for VOCs

Hester Groenevelt, Geosyntec Consultants, Guelph, ON, Canada; Todd McAlary, Geosyntec Consultants, Toronto, ON, Canada; Robert Ettinger, Geosyntec Consultants, Santa Barbara, CA; Tadeusz Górecki, Marios Ionnadis, and Faten Salim, University of Waterloo, Waterloo, ON, Canada

Resolving Vapor Intrusion Challenges via Automated Continuous Real-Time Monitoring and Response

Blayne Hartman, Hartman Environmental Geoscience, Solana Beach, CA; Mark Kram, Groundswell Technologies, Santa Barbara, CA; Cliff Frescura, Groundswell Technologies, Inc., Goleta, CA

A Dirty Secret: Causes of Duplicate Variability in Summa Canister Samples for Vapor Intrusion Investigations

Carlyssa Villarreal, Sharon Rauch, Lila Beckley, and Thomas McHugh

For vapor intrusion (VI) investigations, most samples are collected using Summa canisters. Unlike the disposable containers used for most environmental samples, Summa canisters are reused many times. As a result, proper cleaning of these canisters is critical for attainment of accurate investigation results, particularly for samples used to define clean locations and boundaries.

We have utilized field duplicates in the California GeoTracker database to evaluate variability in vapor samples and whether the reuse of Summa canisters is a common source of errors in VI investigations. We extracted normal and duplicate vapor sample pairs from 400 sites covering a timeframe from 2003 to 2016. For each sample, we retained results for target analytes that were detected in one or both of the paired samples. For reference, we compiled a similar dataset for groundwater field duplicates. This resulted in more than 7,000 and 5,900 vapor and groundwater analyte-sample pairs, respectively.

Our analysis indicates that vapor field duplicate samples exhibit much higher variability than groundwater field duplicate samples. For example, the difference between duplicate vapor results was greater than a factor of four in 20% of paired samples. In contrast, only 3% of results were more than a factor of four different in the groundwater dataset. For both datasets, the largest differences were observed in sample pairs with one detection and one non-detect result. For groundwater samples, these artifacts were mostly limited to common laboratory contaminants (e.g., acetone). However, for vapor samples, these artifacts were also observed for VOCs specific to contaminated sites such as cis-1,2-dichloroethene. One important difference between the collection of water and vapor samples is the use of disposable glass vials for water samples and reusable containers for vapor samples. For vapor samples, incomplete cleaning of the reusable canisters is a possible source of false-positive VOC detections.

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Rapid, Real-Time TCE Measurements of Sewer Headspace: Characterizing Spatial and Temporal Variability

Bruce A. Richman, C. Ricardo Viteri, Michael A. Armen, Artyom Vitouchkine, Gunnar Skulason, and Anthony E. Miller

Historically, the study of the risk of vapor intrusion (VI) has considered the direct pathway from contaminated soil into indoor space (e.g., through slab or foundation). Recently, the pathway through sewer or other utility lines, bypassing the building exterior barrier, was shown to be potentially at least as common as the direct pathway. Chlorinated volatiles (cVOCs) in the soil or water can enter the underground sewer lines through leaks, cracks, or displacements, or through direct discharge into the sewer system. cVOCs then enter the indoor space through leaks, failed seals, or dry U-traps. TCE concentration in sewer headspace is highly variable in both space and time. Understanding this variability is crucial to evaluating the health risk of VI.

We report measurements of TCE concentration in sewer headspace by the Autonomous Rugged Optical Multigas Analyzer (AROMA) developed by Entanglement Technologies. Sewer headspace is measured in manholes in the San Francisco Bay Area in and near sites with known groundwater contamination. Measurements were performed over a variety of timescales including continuously (15-minute intervals) for hours at a time, and periodically over several days and over the course of a year. Observed concentrations display significant variability on all timescales, with fluctuations in excess of 100x over one-week intervals. Elevated concentrations of TCE were found in sewer systems well outside known groundwater plume boundaries. Several factors were observed to correlate with the variability and mean concentration within the sewer system, including the age of the sewer and maintenance activity such as flushing.

The AROMA technology combines cavity ring-down spectroscopy (CRDS) with proprietary separation techniques to provide rapid, real-time, multi-species analysis. Its operation requires minimal expertise. It provides measurements every 15 minutes and limits of detection for TCE and cis-DCE of $0.01 \mu\text{m}^3$ and $0.1 \mu\text{m}^3$, respectively. Dynamic range extends to 100,000s μm^3 .

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Multiple Lines of Evidence, Including CSIA, to Differentiate an Indoor Source from Vapor Intrusion

Safaa Dergham, Devon Rowe, Blayne Hartman, and Carol Serlin

A residential community sits downgradient from a former industrial site in southern California where active remediation to address TCE in groundwater is ongoing. As a precautionary measure to mitigate potential vapor intrusion, DTSC requested that homes overlying the plume be offered sub-slab depressurization systems (SSDSs). At one homeowner's request, an SSDS was installed shortly after purchasing the home. While historical IAQ sampling in that home did not indicate vapor intrusion, IAQ sampling after SSDS installation showed a sudden increase in TCE concentrations in indoor air.

The unhappy homeowner needed an answer: what was the source of the TCE – vapor intrusion, entrainment from the SSDS, and/or an indoor source? An indoor evaluation using portable monitoring equipment failed to provide an answer. Consequently, Ramboll Environ developed a multiple lines of evidence approach, in conjunction with the regulatory agency and the homeowner, that resulted in conclusive determination of the source. The approach involved multi-depth soil gas sampling around the perimeter of the home; continuous IAQ and sub-slab differential pressure monitoring in multiple rooms inside the home while changing SSDS operation; seven day passive IAQ sampling; continuous weather monitoring; and CSIA of groundwater, soil gas, and indoor air. Using these multiple lines of evidence, Ramboll Environ concluded that the TCE in indoor air was not due to vapor intrusion.

This presentation presents a summary of the multiple lines of evidence investigation methods; the real-time implementation of the approved scope of work; the resulting IAQ, sub-slab differential pressure, weather, soil gas, and CSIA results; and the detailed analysis that resulted in the determination that the TCE in indoor air likely results from a consumer product located within the home.

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Recent Developments in Quantitative Passive Soil Gas Sampling for VOCs

Hester Groenevelt, Todd McAlary, Robert Ettinger, Tadeusz Górecki, Marios Ionnadis,
and Faten Salim

Passive sampling for monitoring volatile organic compounds (VOCs) in soil vapor has been used for about three decades. However, the ability to calculate concentrations from the mass adsorbed on geometrically fixed passive samplers has only recently been demonstrated to be reliable via mathematical modeling, laboratory testing, and field testing that illustrate the basic principles controlling the radial diffusion of vapors through soil to a borehole containing a passive sampler, the uptake rate of the sampler needed to minimize the starvation effect, and practical alternatives for field sampling methods for deep, shallow, and sub-slab samples (ESTCP Project ER2008-30). With proper design of the uptake rate, sorbent, and deployment time, passive samplers can be used to measure concentrations with similar precision and accuracy to conventional active soil vapor samples. Furthermore, the sampling protocols are faster and simpler, so there is less inter-operator error and there is no pressure gradient, so there is no potential bias associated with leaks (which is a common challenge for active soil vapor samples, especially for shallow samples or low permeability soils). Passive sampling also has a lower cost because complex procedures for leak prevention and tracer testing are not necessary and passive samplers cost much less to ship than Summa canisters. This presentation will outline recent developments in quantitative passive soil gas sampling, including consideration of wet soils and of the effect of analyte transport within the sampler's sorbent bed. Both mathematical modelling and field data will be presented to illustrate how these two considerations can be addressed by designing a passive sampler with a very low uptake rate and deploying the sampler for a duration long enough to achieve a detectable mass of the target analytes. For the Waterloo Membrane Sampler, a lower uptake rate can be achieved simply by using a thicker membrane, which has now been calibrated for the most VOCs of concern.

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Resolving Vapor Intrusion Challenges via Automated Continuous Real-Time Monitoring and Response

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Vapor intrusion characterization efforts can be challenging due to complexities associated with background indoor air constituents, preferential subsurface migration pathways, concentration dynamics, and representativeness limitations associated with traditional passive sampling methods. For sites experiencing trichloroethylene (TCE) vapor intrusion, the potential for acute risks poses additional challenges, as there is a critical need for rapid response to exposure exceedances in order to minimize health risks and liabilities. To address these challenges, continuous monitoring and response platforms have been deployed to monitor indoor and subsurface concentrations of key volatile constituents, atmospheric pressure, and pressure differential conditions that can result in upward toxic vapor transport and entry into overlying buildings. Response components, including automated alerting and engagement of ventilation controls, have been integrated to ensure that risk exposures do not exceed acute durations of concern. This presentation will describe how vapor intrusion risks can be successfully managed through automated continuous monitoring and response to dynamic conditions. Multiple field examples will be presented to illustrate how continuous analytical monitoring has been employed to develop temporal correlations between indoor TCE concentrations and pressure trends, to rapidly identify vapor entry points, to distinguish between indoor sources and vapor intrusion, to optimize remediation efforts through an adaptive strategy, and to automatically reduce liabilities by engaging controllers when conditions exceed risk levels.

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Vapor Intrusion II

Protecting Human Health and the Environment – A Vapor Intrusion Case Study from a Regulator's Perspective

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Summary of State-of-the-Science for Indicators, Tracers, and Surrogates of Chlorinated Vapor Intrusion

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Investigation and Mitigation of the Sewer Gas to Indoor Air Vapor Intrusion Pathway

Andrew Wallace and Aaron Friedrich, ERM, Indianapolis, IN

Application of Multiple Lines of Evidence to Develop a Rigorous Vapor Intrusion Site Conceptual Model

Steve Luis, Ramboll Environ, Irvine, CA; Blayne Hartman, Hartman Environmental Geoscience, Solana Beach, CA

In Flux – A Case Study of a Vapor Intrusion Site Transitioning from Active to Passive Sub-Slab Depressurization Systems (SSDS)

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Protecting Human Health and the Environment – A Vapor Intrusion Case Study from a Regulator's Perspective

Abigail Hendershott

A Michigan Department of Environmental Quality (MDEQ) investigation of an orphan dry cleaning facility led to Michigan's first emergency vapor intrusion evacuation driven by elevated concentrations of dry cleaning solvents found in the indoor air of nearby buildings. A property that had been historically used for a dry-cleaning business was redeveloped in 2013, at which point the MDEQ received information that elevated levels of tetrachloroethylene (PCE) were present in the soil and groundwater at the property. The MDEQ requested funds to evaluate the extent of the contamination at the facility and surrounding urban area.

In 2016, six structures including residential homes and commercial buildings were evaluated for vapor intrusion. Results were above MDEQ screening levels and as an interim measure, the MDEQ placed carbon filters inside the at-risk buildings while further evaluation was conducted. After a second round of vapor sampling, the MDEQ consulted with the Michigan Department of Health and Human Services (MDHHS) and the local health department to make them aware of the situation. After consultation, the decision was made to immediately evacuate buildings that had indoor air values exceeding The Agency of Toxic Substances and Disease Registry's Minimum Risk Level (MRL) for PCE. In addition, all of the people who worked or lived in those buildings were requested to have their blood tested for PCE within 24 hours of the evacuation. MDHHS contacted the Environmental Protection Agency (EPA), Emergency Response Section to implement emergency measures to address the vapor intrusion occurring in the buildings. It was two months before the buildings were deemed safe to reoccupy.

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Summary of State-of-the-Science for Indicators, Tracers, and Surrogates of Chlorinated Vapor Intrusion

Henry Schuver, Chase Holton, Christopher Lutes, Jeff Kurtz, and Robert Truesdale

Chlorinated vapor intrusion (CVI) is complex, involving multiple factors and interactions. Indoor air chemical samples represent all the factors influencing CVI exposures, but indoor air chemical concentrations are highly variable between buildings and over time, and can be subject to “background” influences. Many indoor samples may be needed to document reasonable maximum exposures (RME). However, because chemical indoor air samples are expensive, difficult to collect, subject to interference, and disruptive to occupants, few samples are typically collected. Fortunately, there are numerous opportunities for related, practical, and inexpensive supplemental measurements that can represent significant portions of the VI pathway and can help 1) verify the overall conceptual site model for CVI and 2) identify the most representative/meaningful buildings and times for chemical sampling to minimize the number of samples needed to defensibly document RME. Example supplemental measurements include temperatures, air exchange rates, pressures, and radon levels. This presentation will show a compilation of the existing high-quality evidence and analyses of the statistical associations between various supplemental measurements and indoor CVI concentrations across both time and buildings. It will focus on explaining which portions of the CVI pathway these measurements best represent, along with cost considerations related to the number and types of samples. Steps in the CVI pathway where these supplemental measurements can provide information include: source(s) of the chlorinated chemicals, shallow advective migration, preferential/pipe pathway (direct entry and with soil gas), mixing/dilution in indoor air, advective driving forces (temperature and pressure differentials, wind, HVAC operation), and exposure point concentrations. Recommendations for further analysis of existing and newly collected data sets will be made, including future research involving more building types in a variety of hydrogeologic and climatic settings and release scenarios, as well as designs for testing the real-world “in-field” practicality of these approaches.

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Investigation and Mitigation of the Sewer Gas to Indoor Air Vapor Intrusion Pathway

Aaron Friedrich and Andrew Wallace

The evaluation of atypical preferential pathways, such as subsurface sewers, presents a significant challenge when developing the vapor intrusion (VI) conceptual site model (CSM). While most preferential pathway assessments include an evaluation of vapor or groundwater migrating preferentially in higher permeability strata around the outside of a sewer, there is very limited understanding on the methods necessary to evaluate potential exposure risks resulting from volatile organic compounds (VOCs) migrating inside a sewer. Preferential pathways, including the sewer gas to indoor air pathway presented here, are an emerging pathway of concern for VI. At sites where VOC contamination is intersecting or near subsurface sewers, there is an increased attention on completing an adequate pathway assessment for potential contaminant migration.

As such, the objective of this presentation is to i) present a generalized sampling approach for the sewer gas to indoor air pathway using site-specific data and ii) present the screening data and criteria at known sites where VOC-impacted groundwater is infiltrating a sewer. The CSM development tools and investigation approaches will be presented on how we determined that the source of VI in off-site structures was vapors migrating within subsurface sewers and entering the structures. Attendees will learn about i) the mechanisms that influence VOC migration within sewers, ii) the sampling approaches used to evaluate the pathway, and iii) a decision making framework leading to remediation. To support this presentation, a case study demonstrating these aspects as well as a presentation of the final remedy, a sewer abandonment and rerouting effort, will be presented. Post-abandonment sewer gas, sewer water, sub-slab, and indoor air data will also be presented to summarize remedy effectiveness.

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Application of Multiple Lines of Evidence to Develop a Rigorous Vapor Intrusion Site Conceptual Model

Steve Luis and Blayne Hartman

California and federal vapor intrusion guidance emphasizes the collection and evaluation of multiple lines of evidence to determine whether or not subsurface vapor sources pose or have the potential to pose a vapor intrusion condition of regulatory concern (DTSC, 2011; US EPA, 2015). One such line of evidence is indoor air quality sampling results. Typical indoor air quality sampling approaches emphasize 8-hour and 24-hour time-averaged sampling using Summa canisters or comparable methods. Although time-averaged sampling is suitable for evaluating potential human health risks, it may lack the spatial and temporal resolution necessary to develop a rigorous conceptual site model. In such cases, real-time adaptive discrete sampling and continuous monitoring can be of significant benefit.

This case study focuses on a vapor intrusion investigation for a property transaction in Southern California. As part of due diligence, the buyer's consultants conducted a Phase II investigation and identified significant TCE and PCE soil vapor impacts directly beneath one of the buildings on the property. The buyer's consultants proposed indoor air sampling to evaluate potential human health risks. The seller opted to retain its own consultants and conduct its own indoor air investigation in an effort to expedite the investigation process and ensure timely closure of the deal.

This presentation describes the investigation of the property in question conducted in the spring and summer of 2017. Initial time-averaged sampling proved inadequate to develop an adequate site conceptual model for this complex site. It was therefore necessary to also apply discrete sampling and continuous monitoring methods. Over the course of six rounds of sampling, a rigorous conceptual site model was developed and confirmed, with the result that the deal was closed and the seller realized millions of dollars of savings.

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In Flux – A Case Study of a Vapor Intrusion Site Transitioning from Active to Passive Sub-Slab Depressurization Systems (SSDS)

Lisa Campe, Lisa McIntosh, and Nicholas Kutil

Achieving site closure is always challenging, though some sites pose greater obstacles than others. At one site in Massachusetts, a creative approach to vapor intrusion issues and risk communication led to a less expensive and greener remediation that still can achieve permanent closure. This former manufacturing facility was redeveloped into residential condominiums. Legacy contamination resulted in a complete vapor intrusion pathway for chlorinated volatile organic compounds (VOCs), particularly trichloroethene (TCE), within residences. Tight deadlines driven by regulatory and homeowner concerns led to an investigation and mitigation of vapor intrusion conditions and targeted (source area) groundwater remediation, better positioning the Site for permanent closure. Using soil, groundwater, and air data, we refined the conceptual site model, finding that VOCs in soil (present in vapor phase) were the likely source of VOCs, rather than the typically suspected shallow aquifer.

A risk-based approach identified individual units requiring mitigation using active sub-slab depressurization systems (SSDS). After system monitoring and indoor air data analysis demonstrated the systems were effective, and had operated for approximately 1.5 years, periodic pilot tests were performed to assess indoor air quality with the systems in passive mode. As of this date, up to four separate rounds of passive mode pilot tests ranging from one to three weeks have been performed in each of the affected units. Comparison of data from pre- to post-SSDS installation indicates that the SSDS in all affected units have reduced sub-slab soil vapor concentrations and effectively mitigated exposures to TCE. Furthermore, comparison of active vs. passive mode SSDS indicates that the passive systems are effective at maintaining levels of chemicals of concern in indoor air that are consistent with background and/or pose no significant risk to health. These data show that the more sustainable, economical passive SSDS supports a protective closure strategy for the Site.

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Water Quality and Management

Redeveloping a Waterfront Shipping Terminal with Stormwater in Mind

Ross Dunning, Kennedy/Jenks Consultants, Federal Way, WA; Weston Ellis, Kennedy/Jenks Consultants, Long Beach, CA

Chrysotile Asbestos in Reservoir Water: Is It an H&S Impact?

Bradley Erskine, Kleinfelder, Benicia, CA; Mark Bailey, Asbestos TEM Laboratories, Berkeley, CA

Challenges, Successes and Lessons Learned – California's Industrial General Permit for Storm Water

Jodie Crandell, KERAMIDA Environmental, Inc., Sacramento, CA

Horizontal Well Used for Coal Ash Basin Dewatering

David Bardsley, Directed Technologies Drilling, Bellefonte, PA; Michael Lubrecht, Directed Technologies Drilling, Bremerton, WA

Citizen Lawsuits – Do They Build Bridges to Better Water Quality?

Ed Othmer, Stantec, San Diego, CA

Redeveloping a Waterfront Shipping Terminal with Stormwater in Mind

Weston Ellis and Ross Dunning

Kennedy/Jenks Consultants is currently assisting the Port of Bellingham with planning and site design for redevelopment of the Bellingham Shipping Terminal (BST). The Port purchased the BST from Georgia Pacific Corporation and is redeveloping the property to suit tenants with varying operations. Site soil and groundwater are contaminated from previous industrial operations and the adjacent Bellingham Bay is defined by the Washington State Department of Ecology (Ecology) as a Puget Sound Sediment Cleanup Site that will be cleaned up or capped in the coming years. The Port received an Ecology grant to improve stormwater runoff quality from the BST helping to protect the Bay.

Kennedy/Jenks is working with the Port to evaluate potential commodities and site uses, identify permitting influences for facility improvements, manage subcontractors, design of site resurfacing, and incorporation of a stormwater collection and treatment system to address potential pollutants while considering large areas of the site impacted by previous industrial uses limiting traditional approaches. The facility design includes site grading promoting sheet flow towards linear media biofiltration trenches providing enhanced stormwater runoff treatment protecting the Bellingham Bay and allowing maintenance outside of critical operating areas. The stormwater drainage, collection, and treatment approach was adapted from the Washington State Department of Transportation Media Filter Drain and the installation at the BST is the first known application at an industrial facility. In addition, the middle wharf of the BST will be fitted with an innovative gutter-type media filter that will collect and treat stormwater runoff from the main commodity transfer area at the site.

Engineers, consultants, regulatory agencies, and other environmental professionals will benefit from a comprehensive description of the design details, biofiltration media content and benefits, and lessons learned from this non-traditional approach to site redevelopment that has numerous potential applications in the commercial, industrial, and residential fields.

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Chrysotile Asbestos in Reservoir Water: Is It an H&S Impact?

Bradley Erskine and Mark Bailey

Many reservoirs in northern California contain asbestos in apparently large concentrations, and this is likely the case nationally in reservoirs whose watersheds are located in metamorphic rock belts, particularly serpentinite and other ultramafic rocks. The Calaveras Reservoir is typical for northern California, containing an average chrysotile concentration of 484 million fibers per liter (MFL). The Calaveras Dam Replacement Project (CDRP) has displaced more than six million cubic yards of rocks containing naturally occurring asbestos (NOA), and has used large volumes of water for dust control. At this point in the project (six years into a seven-year schedule), approximately 2×10^{14} chrysotile fibers have been added to the asbestos fiber inventory. Several questions emerge: Is chrysotile released directly into the air by evaporation of fine water droplets or possibly re-entrained after soil dries out? If so, does this quantity carry a significant additional risk to workers and offsite residents? Are contractors running counter to the intent of dust suppression by using this water? What about using this water for personal decontamination? With these questions as a backdrop, potential H&S impacts at the Calaveras site were investigated using fiber dimensional analysis of chrysotile from more than 32,000 perimeter air samples; 4,200 personal exposure samples; and 350 rock, soil, and water samples collected over the last six years. The analysis began by establishing a dimensional fingerprint of chrysotile in source-rock serpentinite and chrysotile that was transported through normal geological processes to the reservoir. This data was compared to data collected from construction area samples, perimeter station samples, and offsite ambient station samples. The investigation found no evidence for a significant contribution of airborne chrysotile asbestos from the use of reservoir water as a dust suppressant. Chrysotile concentrations measured at the site following the early excavation of serpentinite appear to be related to offsite sources.

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Challenges, Successes and Lessons Learned – California's Industrial General Permit for Storm Water

Jodie Crandell

Metals industries (fabrication shops, machine shops, fence manufacturers, metal casting industries, scrap metal recyclers, and others) have unique and challenging issues in regard to managing storm water discharges to meet California's 2014 Industrial General Permit for Storm Water Discharges. What seem to be the most obvious and straight forward solutions do not reduce the sites' industrial impact to discharged storm water, and in many cases make the impact from the industrial storm water discharges worse. Several case studies profiling a fence manufacturer, a fabrication shop, a metal casting foundry, and a die casting operation will be presented. The case studies will document the past, current, and future activities that these facilities are engaging in to find a sustainable and long-term solution to ensure that storm water discharges from the selected sites meet the established Numeric Action Levels. The case studies will provide: 1) information regarding facility status when our firm was brought on board and started working with the site; 2) collaborative actions between the facility staff, consulting staff, regulatory agencies and other actors as changes are made to the site and storm water sampling results are reviewed; and 3) summaries of activities and changes at the sites that show significant improvement, some promise, failed to provide any improvement or are unworkable, or made the results much worse than before the activity or change was implemented. Final remarks will provide the opportunity for questions and answers and also provide information regarding current status of the facilities.

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Horizontal Well Used for Coal Ash Basin Dewatering

David Bardsley and Michael Lubrecht

Coal combustion residuals (CCRs), or coal ash, are a byproduct of burning coal. The ash has a variety of constituents including silicon, iron, and aluminum oxides, along with trace amounts of heavy metals such as arsenic, selenium, mercury, boron, and chromium. Power plants are the main generators of CCRs and normally the ash is beneficially used or stored onsite in landfills or impoundments.

According to the Environmental Protection Agency (EPA), there are over 1,000 active coal ash sites in the United States. In 2015, in response to several ash basin failures, the EPA published rules regulating the management and disposal of coal ash as a non-hazardous waste; under these regulations, CCR impoundments are required to have groundwater monitoring programs while active and for 30 years after closure. Many coal ash basins will require dewatering before remediation and/or closure activities can occur. This presentation details the design, construction, and results of a 650-foot long dewatering well installed in a 9-acre closed ash basin using horizontal directional drilling methods. The CCR materials at the site were characterized as fly ash (10-100 μm) and bottom ash (5-38 mm). Design challenges included well screen and casing selection and drilling/installation methodology. Well installation challenges included geometry of the landfill and unexpected site conditions encountered during well completion.

Once installed, the horizontal well performed better than anticipated; the level of water in the basin was drawn down by ~18 feet in less than four months and CCR-related constituents in the surrounding groundwater declined considerably.

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Citizen Lawsuits – Do They Build Bridges to Better Water Quality?

Ed Othmer

Citizen lawsuits are the new norm in California and are being used to fill the gap when there is no enforcement by the regulatory agency. These are real life consequences, which are based on alleged non-compliance with the Clean Water Act (CWA). Companies finding themselves in this situation are discovering that efforts to comply with the Industrial General Permit are far less expensive and burdensome than settling with citizen groups. Decide for yourself if this is the most effective approach to achieving CASQA's vision – managing stormwater as a vital component of California's water resources, to support human and ecological needs, to protect water quality, and to restore our waterways.

This presentation is based on the experiences of a number of recent settlement agreements, conversations with non-government organizations, and strategies employed by technical experts and attorneys. This presentation will: (1) provide an overview of the authority empowered to citizen groups; (2) review the recent history of citizen suits – where are they taking place, who is being targeted and by whom; (3) prerequisites and pitfalls citizen groups consider before taking action; (4) identify sources of information and the approaches being used by citizen groups to support their cases; (5) how citizens collaborate with attorneys to support their cause; (6) discuss common allegations; (7) discuss when citizen groups push litigation over settlement; (8) summarize typical settlement demands; (9) provide strategies for responding to a 60-day Notice of Intent to File Suit; (10) inform what to expect when settling the case; and (11) discuss the expenses that will be incurred.

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POSTER PRESENTATIONS

**(in alphabetical order by
presenting author)**

Environmental Occurrences of Herbicide Safeners Benoxacor and Furilazole

Saraswati Acharya and Jennifer Weidhaas

Approximately 1.1 billion pounds of pesticides are applied in the U.S. annually. Herbicides are a major class of pesticides, accounting for nearly 57% of pesticide usage in 2012. While herbicides prevent growth of weeds, they can damage crops, often called “herbicide injury.” To reduce herbicide injury of plants, “herbicide safeners” are added to formulations to increase the herbicidal tolerance of crops. Herbicidal safeners are labeled as “inert ingredients” in the herbicide formulations. More than 50 % of the formulations contain inert ingredients for which minimal fate and transport information is available. An adequate understanding of fate and transport properties of these safeners is important to estimate their actions and interactions in the environment. For this study, two safeners were studied, benoxacor and furilazole, both dichloroacetamides which represent the class of most commonly used safeners in the U.S., with about 3.8 million pounds annually. We developed a method to analyze safeners through HPLC with Luna Omega C18 Polar column and using acetonitrile and water in mobile phase. Archived river water samples from USGS containing active ingredients (metalochlor and acetochlor) were found to contain safeners with concentrations ranging from 3.6 to 68 µg/L in benoxacor and 43 µg/L in furilazole. The aqueous solubility of benoxacor and furilazole was determined to be 154.36 mg/L and 231.69 mg/L, respectively, while the estimated values through EPI SUITE were 102.7 mg/L and 255 mg/L, respectively. Analyses of safener sorption on GAC were done by varying mass of GAC (5-100 mg) in three different concentrations of safeners (10, 25, and 50 ppm) until the solution reached equilibrium. The results indicated that freundlich isotherm is a good fit for the solid-liquid partitioning of the compound. The freundlich parameters, $\log K_f$, and n for benoxacor were found to be 1.77 L/g and 1.01 and for furilazole were 1.48 L/g and 1.008.

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Distribution and Relationship Between Antibiotic Resistance Genes and Heavy Metals in Surface Sediments of Taihu Lake, China

Felix Gyawu Addo and Kwaku Anim-Larbi

The use of antibiotics hastens the development of antibiotic resistance genes (ARGs) and bacteria, which poses health risks to both humans and animals. Research has proven that increasing antibiotic resistance (AR) results from overuse of antibiotics in medicine, therapeutic applications, and nontherapeutic applications in agriculture. Heavy metals, pharmaceuticals, and other wastes released into the environment can significantly influence environmental AR. Over the years, Taihu Lake, located in the Yangtze Delta, has become one useful site as it receives discharge from various sources, mainly industrial pollution and aquaculture; antibiotics are used sparingly in medicine and agriculture. This research quantified 22 ARGs, physicochemical characteristics, and 10 heavy metals at 7 sites. Our aim was mainly to determine the distribution and relationship of ARGs and heavy metals in surface sediments along Taihu Lake, owing to the rapid development of industry, agriculture, and fishery production. The results showed significant correlations between psulfonamides (e.g., tet(A), tet(D), tet(E), tet(O), sul I, sul II, int-1) and specific heavy metals (Fe, Mn, Cr, Cu, Zn, among others) in the lake. In the surface sediments, heavy metals had a close relation with the resistance genes, but their interaction was abated with an increase in depth. For most of the heavy metals, the concentration of elements in the top sediments was higher than that in other depths. All ARGs tested were detected in the collected samples except tetJ, tetK, tetL, tetQ, tetS, tetX and tetY. They had a trend which inferred a statistically significant increase and then decreases in the relative abundance of these ARGs (normalised to 16SrRNA genes) with increasing depth. This study revealed that tetA, tetO, TEM, OXY, int-1, sul I, and sul III were widespread in surface sediments with high abundance, indicating that these genes deserve more attention in future work.

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Sustainable Energy Generation Through Wastewater: A Situation in the Urban City of Lagos, Nigeria

Timothy Ajayi

As Nigeria's economic capital and commercial nerve centre, the city of Lagos is undergoing speedy urbanization. With an estimated population of over seventeen million people, Lagos is one of the world's fastest growing cities. One of the prominent natural endowments that has borne the brunt of this rapid expansion is the Lagos Lagoon, a water body that has been used for sewage disposal for more than half a century. The large volume of sewage deposited in the lagoon on a daily basis has escalated due to the rapid growth in the city's population. The thrust of this presentation is to explicate the repercussions of wanton sewage disposal into the Lagos Lagoon and to highlight the potential which Lagos has to generate massive energy from sewage waste in order to meet its energy challenges. This paper strongly recommends the dynamic use of faecal sludge to save the Lagos Lagoon from sewage pollution and upscale energy supply in Lagos.

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Accumulation of Heavy Metals in *Miscanthus* (*Miscanthus* × *giganteus*)

Violina Angelova

Comparative research has been conducted to allow us to determine the accumulation of heavy metals (Pb, Zn, and Cd) in the vegetative organs of *Miscanthus*, and to identify the possibility of its growth on soils contaminated by heavy metals and efficacy for phytoremediation. The experiment was performed on an agricultural field contaminated by the Non-Ferrous-Metal Works (MFMW) near Plovdiv, Bulgaria. The experimental plots were situated at different distances (0.5, 3.5, and 15 km) from the source of pollution. The contents of heavy metals in plant materials (roots, stems, and leaves) were determined. The quantitative measurements were carried out with inductively-coupled plasma (ICP). *Miscanthus* is a plant that is tolerant to heavy metals and can be successfully used in the phytoremediation of heavy metal contaminated soils. The possibility of further industrial processing will make *Miscanthus* an economically interesting crop for farmers of phytoremediation technology.

Acknowledgements: The authors gratefully acknowledge the financial support by the Bulgarian National Science Fund (Project DFNI H04/9).

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Soil Sampling Utilizing Horizontal/Directional Drilling Methods

David Bardsley

Horizontal/directional drilling (HDD) methods have been utilized in the environmental drilling industry for the installation of monitor and remediation systems. New refinements in drilling equipment, steering/locating technology, and sampling tooling have given consultants, site owners, and drillers the ability to use the technology to obtain soil samples using HDD technology.

The specific tooling technology includes a variety of soil samplers for use in multiple types of geologic conditions. The equipment is designed for use with small (less than 25,000 lb capacity) drilling rigs which require a small surface operating footprint. Benefits of the method include: (1) accessing areas under obstructions limiting the use of vertical drilling equipment; (2) steerable drilling assembly allows for multiple samples from one borehole or rig up location; (3) bore entry point can be located in areas where overlying formations are not contaminated, eliminating the potential for cross contaminating vertical formations; and (4) reduced crew risk by moving the drilling equipment from hazardous locations, busy roadways, ponds, and manufacturing-operating units.

Several recent projects detailing the effectiveness of horizontal/directional soil sampling operations will be examined.

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Sewer Preferential Pathway Vapor Intrusion: Fake News or the New Normal?

Lila Beckley and Thomas McHugh

There is a growing recognition that preferential pathways can play an important role at sites affected by vapor intrusion. Although this pathway is often mentioned in regulatory guidance documents, there is little information concerning the prevalence of this pathway and limited guidance on identifying sites with preferential pathways. As a result, preferential pathways are not currently being investigated in a consistent manner.

Through a research project funded by the Department of Defense ESTCP program, we have conducted a systematic testing program in order to better define the prevalence of VOCs in sewer lines. For this purpose, we measured VOC concentrations in sewer lines at more than 30 sites with known chlorinated VOC plumes in groundwater, with multiple rounds of sampling at a subset of these sites. At most of these sites, there was no prior sewer testing and no prior evidence of a sewer pathway.

Chlorinated VOCs were detected in over 90% of sewer manholes located in close proximity to known groundwater plumes and at a lower frequency at background locations. Approximately 50% of samples contained VOCs at concentrations more than 10 times indoor air screening levels. Maximum concentrations were as much as 1000 times indoor air screening levels. For manholes tested multiple times, VOC concentrations commonly varied by up to 100x between sample events. Tracer testing was also conducted as part of our research program. This testing showed that measurable gas exchange commonly occurs between sewer lines and connected buildings. As a result, when VOCs are present at elevated concentrations within sewer lines, there may be some risk to connected buildings.

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Advances in Oil Spill Forensics Using Biomarkers and Isotope Ratio Technique

Harry Behzadi

Determination of parties liable or guilty in order to recover costs of cleanup and remediation has grown dramatically in last decade, and environmental forensics has emerged as a discipline directed toward this goal. Traditionally, these studies have been addressed through utilization of techniques such as gas chromatography (GC) and gas chromatography/mass spectrometry (GC/MS). Biological markers, or biomarkers, play a very important role in characterization and source identification in environmental forensics investigations of oil spills. Biomarkers are one of the most important hydrocarbon groups in petroleum for chemical fingerprinting. Relative to other hydrocarbon groups in oil such as alkanes and most aromatic compounds, biomarkers are more degradation-resistant in the environment. Also, biomarkers formed under different geological conditions and ages may exhibit different biomarker fingerprints. Biomarkers can be detected in low quantities in the presence of a wide variety of other types of petroleum hydrocarbons by the use of GC/MS. Chemical analysis of environmental samples for biomarkers generates great information to environmental forensics investigations in terms of determining the source of spilled oil. This is achieved by differentiating and correlating oils and monitoring the degradation process and weathering state of oils under a wide variety of conditions.

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Environmental Risk Assessment of Rural Industrial Suspended Particulate Matter: A Review

Craig Bowe

Environmental hazards and pollutants play a major role in the development of health effects in rural population, particularly when the pollutants are airborne and exposure is prolonged. Airborne suspended particulate matter is a very important indicator of air quality. Particulate matter is categorized to include elemental particulates and compounds of organic and inorganic composition. In regions of heavy material production and movement, these particulates include inorganic matter, several heavy metals, radionuclides, nitrogenous compounds, sulphur compounds, and classes of organic matter including poly aromatic hydrocarbons (PAHs) and other xenobiotic substances introduced into the atmosphere by human activity. The health risks associated with these substances have been extensively reviewed globally in areas with similar demographics. There is a particular need for a comprehensive investigation of the environmental health effects of exposure to particulates in a rural industrial environment. We are reviewing the literature on these substances in conjunction with particular emphasis on this underrepresented socio-geographic area from a regional and global perspective.

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Applying the Oral Bioaccessibility Testing to Refine the Human Health Risk Assessment of Contaminated Land in Urban Area of Belfast

Tatiana Cocerva, Siobhan Cox, Rory Doherty, and Ulrich Offerdinger

Urban environments have been changed significantly, especially during the industrial revolution due to the release of many Potentially Toxic Elements (PTEs) and their accumulation in topsoil. Belfast, the largest city in Northern Ireland, faced an intensive process of industrialisation, being historically recognised for linen production and shipbuilding.

Previous studies that used Tellus geochemical data demonstrated a relationship between historical development zones and the presence of PTEs, that suggests the origin of PTEs in Belfast are both geogenic and anthropogenic. In some areas of the city, concentrations of PTEs (including As, Cd, Cr, Ni, Pb, V, and Zn) exceed the current soil Generic Assessment Criteria (GAC) for the protection of human health. However, not all these contaminants in soil are bioavailable to humans; therefore, oral bioaccessibility testing is used to refine the risks posed to human health by measuring the contaminant fraction that is released in the digestive tract.

In this investigation, a subset of 103 samples from across the metropolitan area of Belfast was selected from the Tellus archive held by Geological Survey of Northern Ireland (GSNI). This subset was chosen to be spatially representative of the city while covering different development zones, land uses, bedrock geology, and soil type. The Unified BARGE Method (UBM), an *in-vitro* method which simulates the human gastro-intestinal tract and is validated against *in-vivo* studies for As, Cd, Pb, and Sb, was used to undertake bioaccessibility testing on selected samples. The bioaccessibility results were investigated and compared to identify the controlling factors over the PTEs bioaccessibility in different soil parent materials and development zones. The outcomes of this research have potential applications for policy makers, urban developers, and risk assessors of contaminated land.

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Successful Closure of a DNAPL Site – Lessons Learned

Craig Cox

In 1985, a catastrophic release of 500 gallons of TCE occurred inside an industrial site in Ohio. Initial remedial efforts reduced a small portion of the contaminant mass located in the immediate vicinity of the building. However, it was suspected that the majority of the mass remained trapped beneath the building slab and foundation. The site was assessed and a long-term groundwater monitoring program ensued under a consent order. A proposed remedy for the site would have required demolition of the facility, which was unacceptable to the site owner. The site owner's objective was to successfully obtain RCRA close without the need to demolish the site and abandon its operations. The released TCE presented itself as a dense non-aqueous phase liquid (DNAPL) beneath the building and in perched water bodies within a glacial till setting. After completing the final two years of groundwater monitoring required by the consent order, a cooperative approach to site remediation was negotiated with Ohio EPA to complete the final investigation and remediation phase on a voluntary basis.

Membrane interface probe (MIP) and high-resolution soil sampling techniques were used to refine the understanding of the DNAPL configuration. Remediation consisted of a combination of high vacuum dual phase extraction (HVDPE) followed by potassium permanganate flooding. Mass reduction was assessed using continuously monitored vapor stream concentrations, recovered fluid concentrations, and the results of phased three-dimensional soil sampling efforts. By 2007, the site was closed under RCRA and has completed the Post-Closure Care and Monitoring period. Multiple lines of evidence estimates of the mass removal ranged from 89% to 96%. Pre- and post-injection MIP evaluations demonstrated that the DNAPL was forced into new areas ahead of the injectate. Reducing DNAPL through the use of dual-phase SVE, followed by potassium permanganate flooding, proved to be effective.

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Evaluation and Remediation of a Large, Commingled, Dilute VOC Plume in Western Ohio

Craig Cox

In 1998, the detection of chlorinated volatile organic compounds (CVOCs) in a public well field led Ohio EPA to begin a search for potential sources. By 2002, as many as four different consultants representing local industries had identified a four-mile-long commingled plume. By chance, most of the industries lay along a common groundwater flow path and had tended to use similar CVOCs. This situation complicated the issue of source identification and potential responsibility. Following plume delineation, the sources of CVOCs were addressed through a variety of source area remedial actions. The current objective is to monitor the return of groundwater quality to drinking water standards throughout the length of the plume.

Regional-scale analytical results from hundreds of monitor wells, domestic wells, production wells, temporary wells, and surface water samples were used to establish a groundwater and surface water quality database. Based on GIS analysis of contaminant ratios of tetrachloroethene, trichloroethene, cis-1,2-dichloroethene, and 1,1,1-trichloroethane coupled with groundwater flow data, the commingled plume was found to be sourced from at least six separate areas. Each responsible party chose remedial options based on its particular goals. The options included excavation, in-situ chemox injection, in-situ emulsified zero-valent iron injections, in-situ thermal desorption, and air sparge/soil vapor extraction. The treatment option for the public well field was granular activated carbon. Monitoring of the plumes, which have responded positively to the source removal, continues.

To date, four sources have been remediated and groundwater quality has improved dramatically. Periodic regional plume updates are performed to monitor progress. The use of contaminant ratios proved to be a very powerful tool in plume delineation. The presence of cis-1,2-dichloroethene was key to locating source areas where anaerobic conditions existed locally.

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Soil from a Source of Raw Materials Back to Agricultural Production

Jean-Francois David

Quarries for aggregates and sand extractions are ruled and run under 1) public regulations which include land remediation provision since the 1980s and 2) private contracts (royalties/fee contracts) with private landowners. Those provisions are customarily enforced under public supervision so far as public interest – fauna, flora, groundwater and water tables – are at stake; methods have been developed to insure biodiversity, for example. But when such an interest as agriculture is at stake, the matter is more privately tackled, and less commonly described in an end to end scope and approach.

Former agricultural soils remediation is deemed to provide a soil apt to bear new agricultural crops, according to quality and economy standards, on a long-term basis, erasing all consequences of quarry extraction and allowing a natural subsoil water table flows. The main model is 1) replacing sand and aggregate by waste from demolition sites, 2) checking quality insurance and tracking for those materials, and 3) adding arable layer as surface layer which is previously put aside before aggregate excavation is run. Agricultural remediation is not so precisely driven by regulations as biodiversity reclamation, so an example of agro remediation is to be developed beyond other types of environmental remediation schemes already in process.

This presentation will describe the context and organisation, methods and channel, and quality assurance process unfurled at the field level. It will also build a picture of the tripodal success factors which insure a sustainable remediation: reliability of process, accuracy of data, and employment of agricultural expertise. The conclusion will give an outlook of management of environmental diseconomy applied to sustainable agricultural remediation, how to win the challenge of a return to a sustainable agricultural land after aggregates extraction through 1) a designed process aimed to agricultural and hydraulic efficiency, 2) regulatory compliance, and 3) transparency between quarry operator and landowner.

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Maximizing Performance and Minimizing Cost of EVO Injections

Brad Elkins and Robert Borden

Emulsified vegetable oil (EVO) has been injected at many sites to serve as a long-term electron donor source for treating chlorinated solvents, chromium, nitrate, explosives, and other contaminants by enhanced biological reductive processes. This remedial method can result in very effective site cleanup of contaminated groundwater. However, there are significant costs associated with installation and periodic rejuvenation if the EVO formulation does not match a site's hydrogeology.

The primary factors controlling treatment efficiency are (a) effective distribution of EVO across the targeted zone and (b) sufficient contact time for contaminant biodegradation. When EVO is injected, the oil droplets are transported away from the injection well by dilution and chase water. As they migrate through the aquifer pores, they will collide with sediment surfaces and adsorb. In the subsurface, the oil droplets gradually hydrolyze releasing glycerol and long-chain fatty acids (LCFAs). Acetate and molecular hydrogen (H_2) are released from LCFAs during fermentation. H_2 reacts very rapidly and remains in close proximity to LCFAs. Since H_2 is required for complete dechlorination, the contaminant must come into close contact with residual LCFAs. If EVO is not effectively distributed away from the injection wells, there will be gaps leaving significant volumes of groundwater untreated.

The principal cost drivers for EVO systems are well installation, substrate purchase, labor for injection, and reinjection frequency. The amount of EVO required is controlled by (a) oil retention capacity of the aquifer sediments and (b) amount of electron donor required to reduce the target contaminant and background electron acceptors. Our methodology for maximizing performance and minimizing cost considers the following factors in identifying the most cost-effect design: (a) site hydrogeology and groundwater velocity; (b) concentration of target contaminants and background electron acceptors; (c) aquifer mineralogy, particle size distribution, and surface charge; and (d) oil droplet size distribution and surface charge.

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Solar Installations on Landfills: Development Success Involves the Combined Skills of Environmental & Electrical Engineering

Robert Fritz, Ian Webster, and Mary Esper

The global call for renewable energy is being met on many fronts aided by the commercial evolution of innovative technologies, within an arena of changing public perspectives and policies. The relatively new world of smaller-scale, often privately owned, geographically distributed, utility-scale solar power projects often has significant challenges. Economic margins, being the driving force of any industry, are typically low. Strategically, the mainstream solar power developers have chosen to build larger plants in remote areas where the land is inexpensive, but the power from such projects often must be transmitted hundreds of miles to the urban load and end-user. Another strategy is to develop utility-scale projects on otherwise unusable land in urban areas, such as closed landfills.

The United States has more than 10,000 landfills, the majority of which are not suitable for standard commercial development. Thus, there are many thousands of acres of land, typically adjacent to urban cores that are largely useless. Experience has shown that self-ballasted, photovoltaic (PV) solar projects offer a compatible land use on closed landfill. Given the proximity to users, a landfill solar project can feasibly deliver power either directly to off-takers or to the utility grid. A PV installation can be built on a closed landfill's cap, cause no interference with landfill operations (i.e., gas and surface water management and groundwater monitoring), and will not damage the landfill's engineered cover. Such technologies as "self-ballasted" racking, above-grade foundations, and sun resistant electrical conduits and cables are design elements that are compatible with above grade installations that do not penetrate the engineered landfill cover.

This presentation includes discussion of the "unusual business space" that addresses key development criteria including permitting, environmental engineering, solar power expertise, and economic forecasting.

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Practitioner's Overview of Methane Sources to Soil Vapor, Subsurface Methane Intrusion, and Regulatory Responses

Karen Gruebel, Earl James, Antone Jain, Michael Moes, and Kel Mitchel

Methane in the shallow subsurface at residential, commercial, and industrial sites may potentially create hazardous conditions to which response actions are required (ASTM, 2016). If methane is encountered, is a regulatory agency responsible for determining whether the methane should be mitigated? This presentation provides an overview of different methane sources using example sites in California and describes regulatory responses at the example sites.

Methane in the subsurface is typically categorized as thermogenic methane or microbial (also called biogenic) methane. Thermogenic methane is associated with geologic occurrences of coal, oil, and gas. Thermogenic methane is often regulated and codified for certain areas such as in Los Angeles. Microbial methane occurs at shallow depths and is created from accumulations of naturally occurring organic matter in environments including mudflats and wetlands where organic deposition rates are high relative to rates of contact with available oxidants. Microbial methane is also created from anthropogenic accumulations of organics such as municipal solid waste (MSW) landfills, areas with historical dairy operations, construction-related fill, and accidental releases of biofuels into soils. In addition, a relatively recent anthropogenic source of methane is injection of organic electron donors, such as vegetable oils, to the subsurface to accelerate anaerobic degradation of chlorinated organic compounds.

Methane created at MSW landfills is regulated under the Resource Conservation and Recovery Act (RCRA). However, it is less clear which agencies are responsible for regulating methane emissions created by other sources. In California, agencies have stepped up to or declined the responsibility. Sites described in this presentation will include: (1) a US EPA Superfund site in Mountain View where electron donor was injected, (2) a CalEPA site in Oakland where organic-rich San Francisco Bay mud is present in the subsurface, and (3) an example of a small site in southern California thermogenic methane that has been mitigated.

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Alginite – A Nature-Based Solution for Emerging-Contaminant-Polluted Water

Andrea Guhl and Ramona Troebs

While wastewater treatment has been recognized and put into action during the half-century around 1900, it was the discovery of activated sludge in 1912 that led to modern wastewater treatment systems. A breakthrough finding at the time, the techniques largely in use today fail to address the increasing contamination with organic pollutants. One class of contaminants gathering increasing concern is endocrine-disrupting chemicals (EDCs). This pollution stems from one of three sources: agriculture (pesticides), industry (plasticizers, etc.), and pharmaceutical products. With the multitude of chemical additives, nature-based solutions are in particular demand.

The rock Alginite, mined in Hungary, Europe, has been studied regarding its potential for EDC remediation in polluted water. Alginite is an immature oil shale, consisting of clay minerals, feldspars, quartz, accessories, and an organic component. This organic component, mainly derived from ancient algae and pollen, has been diagenetically modified and is now harmless, rendering Alginite a safe material for treating water. Although the material is already approved and in use for soil amelioration, technologies for water treatment are still missing.

Findings show the extensive capability of Alginite to immobilise EDCs, such as 17 β -estradiol, diclofenac, and others. Adsorption isotherms have been determined for a multitude of compounds (by the co-author); the general capability of Alginite to remedy endocrine-disrupting contamination has thus been shown. However, the actual mechanism of EDC removal by Alginite remains elusive. Acknowledging the heterogeneous nature of this material, a fractionation of the material into clay-rich and organic-rich parts aims at understanding the individual component's action towards particular contaminants. Interestingly, ethinylestradiol- and carbamazepine-polluted waters react differently to Alginite components. However, it has already been published that organo-clay materials are suitable for treating diclofenac-polluted waters (diclofenac adsorbs poorly onto untreated clay). Are the action mechanisms of the natural material Alginite and man-made organo-clays related?

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A Plain Language Guide to Isotope Dilution – Eliminating Measurement Uncertainty in PFAS Analyses

Paul Henige

A key challenge associated with accurate analyses for poly- and perfluoroalkyl substances (PFAS) in different sample matrices is overcoming the chemical and physical behaviours of these compounds. The surfactant-like behavior of PFAS, which makes them valuable as chemical additives, is also what makes them challenging from an analytical standpoint.

Isotope dilution is used in analytical mass spectrometry to provide sample-specific recoveries of the analytes of interest. Isotope dilution mass spectrometry (IDMS) provides greater data accuracy and reliability than other calibration methods because it compensates for any matrix effects that may suppress recovery of the parameters being measured. This is particularly important in PFAS analyses because of the propensity for these compounds to adsorb to solid surfaces to different degrees and at different rates.

This presentation will provide a plain language guide to isotope dilution techniques, highlighting 1) factors influencing measurement uncertainty and 2) principles of isotope dilution, and 3) advantages and limitations of IDMS in the determination of PFAS.

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Assessment of Potential Hazard from Subsurface Methane Intrusion

Antone Jain, Karen Gruebel, Logan Hansen, Michael Moes, and Earl James

Recent methane hazard assessment guidance documents from ASTM (Standard Guide for Evaluating Potential Hazard as a Result of Methane in the Vadose Zone, 2016) and DTSC (Evaluation of Biogenic Methane, 2012) provide information and analysis to support a conclusion that methane concentration alone is not a sufficient criterion to determine whether a site poses an explosive risk from methane in soil gas; there must also be sufficient gas pressure to drive methane flux through the ground and into buildings at a level that will result in concentrations that exceed the lower explosive limit (LEL) in indoor air.

At a brownfields remediation and redevelopment site at the edge of San Francisco Bay, methane has been observed in the subsurface at concentrations well above the LEL. As will be described in this poster, field investigations, laboratory experiments, and isotope analyses were conducted that demonstrated the methane was a result of biologic activity in naturally occurring organic-rich Young Bay Muds.

As part of the development of plans for a multiunit, mixed-use residential building on the site, the need for methane mitigation was evaluated. After completion of excavations to remove petroleum and chlorinated organic impacted soils in 2016, the site was re-assessed for potential hazard due to methane intrusion, using the principles outlined in the ASTM (2016) and DTSC (2012) documents. Site-specific worst case assumptions for methane intrusion into a proposed mixed commercial and residential building were modeled based on pressure-driven flow through soil with a) the DTSC (2012) flux model for methane intrusion into buildings and b) a modified, more conservative version of the model. The results demonstrated that the methane does not pose a risk of intrusion to the proposed building at a level of concern, and so installation of a methane mitigation system was not necessary.

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Field Implementation of a Bioelectrochemical Technology to Enhance Back Diffusion and Degradation of Chlorinated Contaminants

Song Jin, Paul Fallgren, and John Eisenbeis

One major factor that delays the closure of contaminated sites using contemporary technologies is the slow rate of back diffusion of contaminants from lower permeability soils into groundwater. As a result, the operational times of many existing remedial systems to achieve site closure have been estimated to be several decades. Bioelectrochemical treatment (E-Redox-I™) is a low cost, sustainable, and *in situ* technology that applies a low voltage gradient electric field to the subsurface via electrodes inserted into existing or new wells. Field data have indicated that this technology significantly enhances the rate of contaminant (e.g., trichloroethene and other chlorinated VOCs) back diffusion. In addition, laboratory and field data have shown that this technology also sustains both biological and abiotic degradation of many contaminants, such as beta elimination pathway for rapid destruction of chlorinated VOCs.

This presentation summarizes the key findings from field applications of the E-Redox-I™ technology and describes how this technology can be used in conjunction with other technologies to reduce site cleanup times: (1) E-Redox-I™ is based on a low voltage gradient electrical field, which is not limited by matrix permeability. Matrix such as clay is favorable thanks to its higher conductivity. (2) At the chlorinated solvent sites, the end product ethene concentrations significantly increased, indicating that E-Redox-I™ had enhanced the reductive dechlorination. (3) At the chlorinated solvent sites, acetylene was detected, indicating that the abiotic degradation (beta-elimination of chlorinated VOCs) had been initiated by E-Redox-I™. (4) At two of the chlorinated solvent sites, multi-phase extraction (MPE) was used to further enhance the contaminant back diffusion rates and achieve mass removal. One of these sites has an existing MPE system and at the second site a vacuum truck was used as a low-cost approach to quickly performing MPE on existing wells within the treatment zone of the E-Redox-I™ system.

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Durability and Sustainability of Laterite-Cement Admixture Bricks in a Chloride Environment

Edwin Eyram Klu, Samuel Kwasi-Baah Owusu-Ansah, and Elizabeth Gyamfa
Akuamoah

Fishing is a lucrative venture in Africa and other parts of the world. Fishmongers, however, have a major problem in storing freshly caught fish from the sea since their storage houses by the sea shores made from metals (mostly aluminum) corrode at an alarming rate due to the highly corrosive chloride environment by the seashore, rendering the fish unwholesome. Storage houses made from concrete also suffer deterioration from this harsh environment. This study, therefore, looks at determining the durability of laterite cement admixture bricks in a chloride environment. Investigation of the durability of laterite cement bricks was conducted. The laterite was soaked, dried, and sieved into particle sizes of 250 μ m and 1mm. Cement was added to the laterite in proportions of 5% and 30%. The moulded bricks were dried and immersed in a 3.5% sodium chloride solution, depicting a coastal environment for a period of 30 days. The bricks were removed at intervals of 3 days for testing until the 30th day. Porosity, water absorption and compressive strength tests were measured in order to assess the durability of the various brick formulations. The parameters were observed to be interrelated. The formulations with 30% cement content were observed to have lower water absorption due to lower porosity values. The compressive strength of these bricks increased with increasing subjection to the chloride environment. On the other hand, the compressive strength of bricks decreased with increasing subjection to the chloride environment for formulations with 5% cement content. Bricks with smaller laterite particle size of 250 μ m were observed to deteriorate faster than those with laterite particle size of 1mm for formulations with the same cement content when compared to each other. The investigation assessed that bricks with higher cement content and a larger particle size comparatively can withstand harsh sodium chloride environments.

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Remediation of Oil-Contaminated Soil by Newly Developed Microwave Thermal Desorption Technology

Taehoon Koh, Donggeun Lee, and Hanjoo Yoo

In this presentation, the feasibility of microwave thermal desorption technology is investigated to treat the polluted lubricating oil-contaminated soil. Microwave thermal desorption technology has been recently developed in Korea as a technically-effective as well as cost-effective technology for the remediation of lubricating oil-polluted soil. This technology uses microwave and microwave absorber as an energy source to enhance the energy efficiency for the thermal treatment of the lubricating oil-contaminated soil. Based on a series of field test results from this study, it is found that microwave thermal desorption technology can substantially reduce the remediation cost of oil-contaminated soil with low electric power consumption and contribute to low CO₂ emissions.

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Vapor Intrusion Investigation in 23-Acre Department of Defense Building: Navy's Challenges to Maintaining Mission-Critical Operations

Karen Campbell, Todd Creamer, Donna Caldwell, and Jeff Kurtz

The Navy conducted a vapor intrusion (VI) investigation in Building 8, Corpus Christi Army Depot (CCAD), Corpus Christi Naval Air Station, a large, active military manufacturing building. The investigation required speed, transparency, and responsiveness despite significant access limitations and limited existing data to form the basis for investigation. Potentially complicating the investigation was the use of trichloroethylene (TCE)-containing products indoors. The speaker will describe the Navy's approach to fingerprinting consumer products and thereby ruling out contributions of TCE to indoor air, allowing the subsurface investigation to proceed with confidence. Whether or not consumer sources of TCE are present, relying on comparison of indoor air analytical results to regulatory screening levels to determine VI pathway completeness can be fraught with uncertainty, and on active military installations, the base's lead Industrial Hygienist has responsibility for worker health and safety regardless of a chemical's source. The speaker will describe the Navy's pathway completeness evaluation independent of screening levels, and the collaboration between Navy Environmental and Army Occupational Health to choose appropriate and protective next steps.

The speaker will also discuss how the VI conceptual site model (CSM) was used to address the applicability of existing data and to communicate a clear plan to regulators and to the Army before, during, and after the investigation. Successful rapid response is a series of progressive steps demonstrating site knowledge, transparency to stakeholders, a timeline of responsiveness, and knowledge of available tools. The Navy used a variety of tools during the rapid response investigation including a targeted approach based on the VI-CSM, forensic background source evaluation, deploying carbon filters, sealing foundation cracks, and HVAC modifications. The results included ruling out the VI pathway across most of the investigation area with high confidence, no disruption of the Navy's tenant (CCAD) operations, and low cost.

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Technical Approaches to Reduce Remediation Costs at Former Refinery – A Success Story

Kevin Lienau

A former refinery property exhibited widespread elevated concentrations of lead in surface soil resulting from historic refining processes. The site was entered into the Texas Commission on Environmental Quality (TCEQ) Texas Risk Reduction Program (TRRP) to prepare it for beneficial reuse. The potential presence of the Texas horned lizard, a threatened species, risked a significant escalation of remediation costs.

Strategy: Data was accumulated into an Affected Property Assessment Report (APAR) for regulatory review. Supplemental investigations were completed, where necessary, to complete the site characterization for the target contaminants. Using X-ray fluorescence field screening methods to create a robust data set for delineation of lead and geostatistical methods to demonstrate impact delineation, Tier 2 protective concentration levels (PCLs) were developed for the industrial/commercial human ingestion/exposure criteria that were protective of human health. A site-specific ecological risk assessment (ERA) included assessment of lead uptake into the food source of the horned lizard, statistical evaluation, and hot-spot analysis. The site was rigorously surveyed for the presences of the threatened horned lizard species. Regulatory approval was granted for a risk recommendation that demonstrated that cleanup to human health PCLs would also be protective for ecological receptors. A remedial alternatives analysis of methods to reduce the soil lead concentrations within a subset of the subject site as determined by geostatistical methods and risk was prepared. As part of the process, a treatability test was performed to evaluate lead-fixation technologies as a means to treat lead soils to avoid a potentially hazardous waste determination.

Outcome: GES gained site closure via technically sound least-cost measures that were protective of human health and the environment. Cost savings in excess of \$1 million were achieved by the acceptance of the industrial/commercial human ingestion/exposure criteria as the critical PCLs. Lead-fixation technology of potentially hazardous soils reduced disposal costs by approximately \$3 million.

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Degradation of Energetic Material DNAN Using Mg-Based Bimetals

Andrew Mai

The manufacturing of insensitive munition DNAN generates effluents that require further treatment. Bimetals, a group of emerging chemical reagents, have been shown to treat various organic and inorganic contaminants, including DNAN that was treated by Fe-based bimetal. This work reports results on the degradation of DNAN by three Mg-based bimetal: Mg/Cu, Mg/Ni, and Mg/Zn. Advantages of Mg-based bimetal over Fe-based bimetal include potential higher reactivity and relative insensitivity to pH conditions. Kinetic data obtained using benchtop-scale batch reactors modelled with a pseudo-first-order expression allowed the determination of kinetic constants. Parametric studies were conducted to assess the effect of type of bimetal pair, bimetal dose (solids-to-liquid ratio (%S/L)), and initial pH on DNAN degradation. Pseudo-first-order kinetic constants were 0.11, 0.020, and 0.022 min⁻¹ for Mg/Cu, Mg/Zn, and Mg/Ni, respectively; under unadjusted neutral initial pH. treatment with Mg/Cu was the most effective with >95% removal within 30 minutes without the need to lower the pH. Increasing the bimetal dose resulted in faster removal kinetics in each bimetal configuration. Lowering the initial pH to 3-4 significantly enhanced reagent performance and >90% DNAN removal was achieved within 6 minutes regardless of catalytic metal; kinetic constants were increased by a factor of 4, 50 and 20 in treatment with Mg/Cu, Mg/Zn and Mg/Ni, respectively. Furthermore, investigation of reaction byproducts supported a partial degradation pathway involving sequential reduction of nitro groups to amines. The reduction of one nitro group (ortho or para) formed 2-ANAN or 4-ANAN, and subsequent reduction of the other nitro group formed DAAN. However, these byproducts were only detected in small quantities. Further investigation is underway to close the open mass balance, which includes analyses of gaseous and adsorbed (i.e., to the reagent surface) phases. Results of these experiments will also be presented.

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The Use of Biochar to Remove Organic Nutrients and Heavy Metals in Wastewater

Frank Addo Mante and Felix Gyawu Addo

Wetland technology is inexpensive, efficient, and easy to operate and maintain compared to the traditional methods of wastewater treatment. Constructed wetlands since its application have been modified to improve the quality of point and non-point sources of water pollution, including stormwater runoff, domestic wastewater, agricultural wastewater, and coal mine drainage.

Biochar is an organic material produced by means of pyrolysis which offers simple and low-cost techniques to treat water and reduce carbon footprint. It has a highly porous structure, containing various functional groups, and is effective in the adsorption of heavy metals, particularly in aquatic systems. The complex and heterogeneous chemical and physical composition of biochar gives it its adsorptive property. Also, more hydrogen and oxygen remain in its structure along with the ash originating from the biomass and can absorb hydrocarbons, organics, and some inorganic metal ions. Biochar can be loaded with nutrients for subsequent use as a soil amendment, providing long-term sorption capacity and a fertilizer. Combining both technologies can greatly augment the effectiveness of the constructed wetland system in wastewater treatment.

The objectives of this work were to evaluate the efficiency of constructed wetlands by using biochar as a substrate; create a surface for the growth of beneficial bacteria; and study the bacteria community, enzymes, and activities during the whole process where the substrate is mixed with the soil. The biochar for this study was prepared from the reed plant. Three horizontal wetland beds with dimensions 1m × 0.5m × 0.5m will be prepared using gravels and biochar as substrates and cultivated with the *Canna* species. Synthetic wastewater was passed through these beds with an average flow rate of $1.3 \times 10^{-7} \text{ m}^3/\text{sec}$, achieving a retention time of three days. Pollutant removal performance was compared to the controlled and experimental wetland beds.

Keywords: biochar, constructed wetlands, adsorption, sedimentation, wastewater treatment

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ITRC's TPH Risk Evaluation at Petroleum Contaminated Sites Guidance Update

Roy Thun, Thomas Booze, Mike Kwiecinski, and Diana Marquez

Total petroleum hydrocarbon (TPH) is made up of thousands of chemical compounds, most of which are not well understood from a human or ecological risk perspective. Many states' guidance utilize the more volatile BTEX (benzene, toluene, ethylbenzene, and xylene) aromatic fraction of TPH as a means to derive cleanup standards. There is evidence to suggest that risk evaluations based solely on BTEX may not accurately identify the total risk associated with TPH. In addition, the existence of TPH metabolites may lead to unquantified risk. In 2016 an Interstate Technology & Regulatory Council (ITRC) project team began its work of compiling and reviewing information for developing new internet-based TPH risk guidance to help inform practitioners of the current state of knowledge, methods, and procedures for evaluating TPH risk at petroleum contaminated sites. This new guidance document will highlight both human and ecological risk. Other sections planned include: regulatory framework, physical and chemical properties, TPH conceptual site model, investigative strategies, special considerations, risk calculators, and stakeholders' perspectives.

This presentation will: 1) give an update on the ITRC team's work, 2) provide a "sneak peek" of the guidance, 3) indicate timing for publication, and 4) solicit audience input.

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Regional Assessment of Climate Change Hazards in Southern Nigeria with GIS

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In sub-Saharan Africa, storm surge zones are concentrated in four nations, including Nigeria where half of the region's surge zones resulting from sea level rise and violent storms originate. This comes in an era in which Africa's coastline population risks severe sea level rise and coastal flooding over the coming decades. Much of Nigeria's urban population and economic activity are located along the low-lying coastline, including the Niger Delta and Lagos. Exposure will increase as the population of these areas grows. Considering that significant levels of CO₂ and CH₄ emissions come from the region, the projected effects of rising sea levels from warming temperatures will submerge southern states such as Lagos and others. Given the economic potentials of the coast, highlighting inclement weather patterns in the zone spatially offers opportunity for mitigation. While very little has been done to capture these concerns, the threats from sea level rise in the region have been exacerbated by different elements like human activities, greenhouse gas emission, and natural forces. Seeing the connections between sea level rise threats and many factors, there is a need for mixed-scale analysis. Accordingly, this project focuses on regional assessment of climate change hazards in Southern Nigeria with emphasis on the issues, trends, factors, impacts, and efforts. Using the mixed-scale method of descriptive statistics and secondary data connected to GIS, preliminary results show that the region remains vulnerable to climate change. This is evident with changes in climatic parameters like land use, precipitation, coastal agriculture, and others due to socioeconomic and physical factors. GIS mapping of the trends points to gradual dispersal of several climatic predictors in the study area. To remedy the situation, the presentation proffers suggestions ranging from effective policy to the continual use of GIS and the design of a regional climate information system.

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LNAPL Management: Strategy Development Through Investigation, LCSM and NSZD

Christopher Mulry

Background/Objectives: Operation of a fuel storage and distribution terminal in South Carolina from the 1940s through the late 1980s resulted in a LNAPL plume, consisting primarily of kerosene/jet fuel, approximately 30 to 40 feet below ground surface. Investigation and remediation efforts have been ongoing since the late 1980s, resulting in the recovery of over 163,000 gallons of fuel. Recovery rates demonstrate a clear decline over time and the LNAPL plume has correspondingly reduced in extent, yet conditions still do not meet state standards for cessation of remediation.

Recent efforts to evaluate risk scenarios, clarify regulatory drivers, and evaluate site strategy have led to a revised LNAPL Conceptual Site Model (LCSM) which incorporates quantitative metrics unknown earlier in the project lifecycle. Reappraisal of the LNAPL plume behavior and practical means to effect and demonstrate LNAPL removal have been undertaken with the hope of establishing consensus with regulators on a practical management approach.

Approach/Activities: Discussion of investigative techniques to evaluate LNAPL plume behavior will address review of historical recovery data, well-specific yield testing, laser-induced fluorescence (LIF) analysis, core collection and lab analysis, baildown testing at select locations, and completion of Natural Source Zone Depletion study.

Results/Lesson Learned: An evaluation of project datasets will be provided to include changes in LNAPL plume footprint and recovered fuel volumes, LIF response, baildown test results, and lab results. Trends and correlations among these datasets will be discussed in the context of development of a practical site management strategy and development of technically defensible remedial endpoints.

Findings from this body of work mirror key lessons identified from recent advances in LNAPL science; namely, in-well LNAPL thickness is a poor indicator of mobility or recoverability, oil transmissivity proved to be a meaningful basis for gauging relative LNAPL recoverability, and natural destruction mechanisms appear to outpace mechanical extraction techniques in LNAPL removal.

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Current Status for the Analysis of Polyfluoroalkyl Substances (PFAS) in Environmental Samples

Charles Neslund

The group of compounds referred to as PFAS are considered emerging contaminants. Even though PFAS compounds have been in use for many years, the label of "emerging" indicates that regulations, analytical methodologies, reporting limits, and treatment technologies are still evolving. The rapidness with which compound lists, methods, matrices, and limits are changing is a challenge for all of us in the environmental community. We will evaluate the current state of methodologies used for the analysis of PFAS compounds and what may lie ahead for this analysis venue.

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A Field Analysis Technique for the Determination of PFAS Compounds

Charles Neslund

The analysis and evaluation of the extent of groundwater contamination of PFAS compounds can be costly. The time and cost of transporting samples to a fixed lab and the time it takes for sample analysis and evaluation can add substantially to field investigation costs. Those costs may actually seem small, in a relative sense, when you consider the cost of personnel and equipment in the field waiting on sample analysis results. An analytical technique has been developed that will allow for mobilization of the analytical instrumentation to the site and the generation of near real-time data. This presentation will cover the development and validation of the method as well as the logistics of the field deployment.

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ASTM and California Standards for Assessing Methane for Environmental Due Diligence

James Nguyen

Methane gas in the subsurface presents many challenges for assessment, determination of action levels, and remediation in connection with property transactions. In addition to ASTM standards for environmental site assessments, various regulations, standards, advisories, guidance documents, and local ordinances also come into play. ASTM International standards that apply to subsurface methane include E2993-16 (Standard Guide for Evaluating Potential Hazard as a Result of Methane in the Vadose Zone). Guidelines and advisories issued by the California DTSC for assessing biogenic methane, conducting soil gas investigations, and evaluating vapor intrusion add further complexity to methane assessments. Due diligence evaluations for subsurface methane need to consider the universe of applicable ASTM standards and DTSC guidelines and advisories.

The interplay between ASTM standards and California requirements will be illustrated via a case study for a site in the Los Angeles area. Methane was not identified as an issue during site investigations conducted in 1990, 2007, and 2014. Methane was discovered during a site investigation in 2017 at concentrations as high as 88%. Once methane was discovered, the next step was to determine how best to manage it. Depending on site circumstances and regulatory requirements, remediation may not be needed for the source of the methane. ASTM acknowledges that “remediation, or source removal, is seldom done for methane in soil gas.” On the other hand, DTSC advisory calls for excavation, monitoring, and methane collection. Regulatory methane requirements are not clear cut. This presentation will closely outline how to assess methane, which action level is applicable for your site, and appropriate actions to manage it.

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Impacts of Flooding and Elevated CO₂ Level on Live Oak (*Quercus virginiana*) Saplings

Zhu Ning, ChongFeng Gong, Deric Chambers, Delarian Dyson, and Kamran Abdollahi

Trees in urban environments face stress conditions induced by global climate change, including flooding and elevated CO₂ levels. Using the flooding simulation tanks and a LI-6400 Portable Photosynthesis System, this study assessed the physiological responses of five-year-old Live oak (*Quercus virginiana*) saplings to flooding with the change of in-chamber CO₂ concentrations by examining photosynthetic rate, stomatal conductance to H₂O, and transpiration rate. Three hypotheses were tested on whether there was: 1) any significant difference on physiological characteristics between the saplings under control and under flooding treatment; 2) any significant difference among the saplings under flooding treatment with the change of in-chamber CO₂ concentrations; and/or 3) any interaction between the effects of flooding treatment and the variations of in-chamber CO₂ concentrations. This study confirmed the effects of flooding and elevated CO₂ level on Live oak saplings. However, these effects varied with the seasons, CO₂ concentrations, and physiological parameters.

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VOC Removal and DO Changes During Vacuum Driven In-Well Air Stripping and Recirculation Pilot Tests

Mehmet Pehlivan

This presentation shows comparative results of two pilot tests performed using VacCirc in-well stripping and recirculation method. Tests were performed in two different settings and geographic locations. The first test was performed in New York using two separate wells, one for injection and one for extraction. The second test was performed in California using one well with dual screen and packer circulating water from saturated zone to vadose zone, allowing water to percolated to saturated zone. Additionally, the duration of the first test was only two days and the duration of the second test was four weeks. The results of both tests were also somewhat different in terms of DO changes, temperature changes, and VOC removal. The conceptual model of in-well stripping and recirculation method, setting, and monitoring of two different tests; comparative evaluation of two tests; lessons learned; further improvement potential; and full-scale implementation potential will be discussed. A comparative analysis of VOC stripping, DO changes, and water chemistry (Fe(ii), BOD, COD) will be also discussed.

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New Photocatalytic Nanocomposites in Water Purification

Igor Peternel, Zvonimir Katančić, Vanja Gilja, and Zlata Hrnjak Murgic

Water resources globally are facing tremendous pressures due to increased consumption and pollution caused by growing population and industrialization. Thus, the development of novel advanced treatment technologies is highly required. Technologies using nanomaterials are one of the fast-growing fields creating a variety of new commercial nanoparticles. One of the innovative applications of nanomaterials with great potential involves their usage as water/wastewater treatment tools.

Titanium dioxide is one of the most important photocatalysts, which is widely used due to its chemical stability and high photocatalytic activity. However, a relatively high recombination rate of electron-hole pair in excited TiO₂ restricts its photocatalytic activity, thus hindering its practical application in the water treatment processes.

Conducting polymers as poly(3,4-ethylenedioxythiophene) (PEDOT) with extended π -conjugated electron system and satisfactory environmental stability can act as a stable photosensitizer to sensitize TiO under solar light irradiation. The objective was to synthesize PEDOT-TiO₂ based photocatalysts and to investigate photocatalytic activities under UV/Visible and solar light irradiation using simulated wastewater containing organic azo dye C.I. Reactive Red 45 (RR45) as a water pollutant to determine the degradation efficiency in terms of decolorization, total organic carbon (TOC) removal, and toxicity tests. Photocatalysts were synthesized by oxidative chemical polymerization with two different oxidants, FeCl₃ and (NH₄)₂S₂O₈, at different polymerization conditions (time and temperature) and characterized by SEM, FTIR, and TGA analyses.

Keywords: azo dye, AOPS, fly ash, photocatalysis, titanium dioxide

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VARs: Exploring a New Method for Climatological Metadata Formation, Focusing on North American Landfalling Atmospheric Rivers

Cody Poulsen, Scott Sellars, Maryam A. Lamjiri, Brian Kawzenuk, Rachel Weihs, and F. Martin Ralph

With a changing global climate, it is increasingly more important to understand extreme and impactful synoptic weather events, such as elongated narrow plumes of mid-latitude water vapor transport named Atmospheric Rivers (ARs) that produce intense rainfall and winds speeds over land. In California, studies have shown that climate change is catalyzing the increase in yearly precipitation extremes due to an elevated variance in the density and intensity of landfalling AR events. Accurate forecasting of ARs would provide California water managers with information supporting implementation of proper flood/drought protection techniques. This study focuses on a non-automated method for the generation of analytical metadata to catalog prediction models, algorithms, and dynamical traits of ARs. The Video and Annotation Reference System (VARs), created by the Monterey Bay Aquarium Research Institute (MBARI), was used to produce an analytical metadata set. VARs was applied to a case study using Water Years (WYs) 2001 and 2011 to compare the results of the anomalously high frequency of landfalling AR events over California/Oregon to a secondary computational approach by Guan et al. (2013). The latter showed that in 2010/2011, the increase in snowpack in the California Sierra Nevada was due to a yearly increase in landfalling AR events, and for 2010 an irregularly high number in December. The advantage of this method is the systematic cataloging structure of expert-generated knowledge when analyzing atmospheric data, especially in subjective conditions with variables which computer algorithms cannot accurately interpret. The dynamic and unpredictable nature of the planet's hydrological system can cause algorithms and mathematical models to produce inaccurate values, rendering incomplete assumptions and falsifiable data. Implementing a synthesis of computational and human methods as a novel form of analysis will be an effective tool to study the changes in Earth's complex climatological system exacerbated by climate perturbations.

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Minimizing Environmental Exposure by Incorporating Redevelopment Design in Remediation of Former Wood Treatment Facility

Nicky Robinson and Derrick Willis

Northgate managed the remediation of a 12-acre site located north of Channel Two at the Port of Long Beach that historically served as a wood treatment facility and an oilfield for 70 years. The site was impacted with pentachlorephenol, metals, VOCs, dioxins/furans, and methane. Northgate was brought on to the project in 2012 when site features included remnants of former tank farms, wood treatment operations, two RCRA-permitted concrete drip pads used in the wood treatment process, several previously abandoned oil wells, an operating oilfield water injection well, and an abandoned-in-place subsurface pipeline corridor. Northgate remediated and mitigated contaminated soil, soil vapor, and groundwater to allow the safe development of a 250,000 square foot cold-storage facility.

Remediation/mitigation consisted of monitored natural attenuation for groundwater and a multi-component RCRA-equivalent cap for soil, which incorporated a passive methane/vapor mitigation system (VMS) beneath the proposed structure to address VOCs and methane. The multi-component cap was unique in that it allowed former RCRA-permitted features to remain and be closed in-place and allowed the new cold-storage facility to serve as part of the cap so long as the VMS was incorporated (which was already required for the refrigerated building construction). Areas of the site not improved with the building were capped with a low-permeability, high-durability asphalt/concrete pavement that was required due to heavy truck traffic anticipated during facility operation.

The project's environmental exposure was minimized during remediation by integrating the decontamination/closure-in-place of RCRA-permitted drip-pads with vapor intrusion mitigation that incorporated the building's foundation design into the VMS. The project reduced the amount of soil hauled to a landfill by reusing and capping site soils and reduced overall costs. A qualitative analysis determined this to be the most efficient and cost effective mitigation with a reduced environmental exposure compared to other remedial options, including dig-and-haul.

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Enhanced In Situ Chemical Oxidation Using Surfactants and Shear Thinning Fluids

Sina Sadeghi and Scott Hauswirth

In situ chemical oxidation (ISCO) is a remediation technique whereby target compounds are degraded in place to less harmful compounds. Field applications of ISCO have been plagued by “rebound” of contaminant concentrations after treatment. The cause of rebound is typically associated with back-diffusion from finer grained, low permeability units or the presence of non-aqueous phase liquids (NAPLs). Modifications to traditional ISCO methods have been proposed to overcome these challenges, including the use of shear thinning polymers to improve delivery of oxidants to low permeability units and the addition of surfactants to improve dissolution of contaminants from NAPLs. We investigate the application of these approaches to the oxidation of NAPLs composed of polycyclic aromatic hydrocarbons (PAHs). We conducted experiments to test the compatibility of various surfactant-polymer-oxidant combinations to determine the impact of each component on the remediation of recalcitrant compounds. Experiments were designed to: determine the effectiveness of contaminant-oxidant reactions, screen several surfactants in terms of their ability to increase PAH solubility and their compatibility with oxidant systems, measure the impact of oxidants and surfactants on the rheology of several polymer additives, and assess the effect of surfactants and polymers on the consumption of oxidants/activators. The results provide insight into the chemical and physical mechanisms associated with enhanced ISCO approaches and an improved basis with which to model and design ISCO applications.

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Full-Scale Treatment of Pesticide-Impacted Soil in Brazil, Canada, China, Colombia, and the USA Using In Situ Chemical Reduction

Alan Seech, Stacey Telesz, and Todd Slater

As urban centers grow, agricultural land is converted to residential use. An issue often encountered in such land-use changes is the presence of chlorinated pesticides and herbicides at unacceptable levels. Over the past 20 years, soil at many pesticide/herbicide-impacted sites has been successfully remediated using an *in situ* chemical reduction (ISCR) treatment based on zero valent iron combined with organic carbon, using a cycled, anaerobic/aerobic approach. This ISCR treatment has enabled attainment of residential remediation standards and has served as an environmentally sustainable, greener alternative to excavation and off-site disposal. As a result, ISCR technology is now viewed as a proven alternative to traditional excavation and off-site disposal. Large-scale ISCR treatment is usually conducted only after completion of bench-scale testing on representative soil to determine if adequate pesticide removal efficiency can be attained, and estimate the required soil amendment dosage and treatment time. In some cases, bench results indicate that remedial objectives cannot be attained. After successful bench-scale testing, a pilot-scale demonstration may be warranted to ensure successful scale-up under field conditions. Subject to site conditions, treatment may be conducted *in situ* or on excavated soil using a variety of soil mixing equipment to incorporate the soil amendments. In most cases, irrigation is also required to achieve a soil water content conducive to the reductive dehalogenation process. A variety of soils containing chlorinated herbicides and pesticides, including 2,4-D, 2,4,5-T, Metolachlor, Chlordane, DDT, Dieldrin, Aldrin, Lindane, and Toxaphene, have been treated to residential and industrial land-use criteria. In some cases, treatment has been completed rapidly, without difficulty, within the predicted time, and on budget. In others, soil characteristics, weather, and unexpected site conditions have rendered treatment slower or ineffective often due to the need for numerous treatment cycles. A particularly interesting treatment scenario is application of different technologies in series, such as conducting chemical oxidation for mass removal followed by ISCR to attain the remedial standard. Several full-scale case studies, both successful and unsuccessful, will be presented. Reasons for observed performance will be proposed and discussed.

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The Case for Alternate Methods in Lab Extraction

Susan Sylvester

Problem: The Environmental Protection Agency (EPA) Region 1 requires that Soxhlet extraction (EPA Method 3540C) be performed for polychlorinated biphenyl (PCB) analysis, as per the Toxic Substances Control Act (TSCA). However, most people involved in the cleanup and disposal of PCBs do not realize that published, approved, less expensive, and “greener” methods are available. Anyone who deals with PCBs should be aware that the Soxhlet method for extraction is not the only method, and certainly not the best method for PCB extraction.

Solution: Although not specifically mentioned in the TSCA regulations, the EPA has approved other methods that are more efficient in terms of time, labor, materials, energy, and waste. The problem is that in order to get EPA approval to use an alternate method for extraction, an extensive study is required to be initiated on a project-specific basis. Due to the process required to get an alternative study approved, tight deadlines, and fear of the unknown, contractors generally just ask the laboratory to perform the (expensive, cumbersome, and less “green”) Soxhlet extraction. Absolute Resource Associates (ARA), an environmental firm in Portsmouth, New Hampshire, has found that performing Subpart Q studies for clients has been well worth the time and effort. ARA has reported reduced waste, reduced energy, reduced turnaround time (TAT), reduced mobilization on site, and millions of dollars in savings for clients by utilizing alternative methods.

Benefits for one alternative method, microwave extraction, include: (1) reducing extraction time (hours versus minutes), (2) reducing project completion time, (3) saving customer money on field related expenses, (4) reducing energy usage by over 99%, (5) reducing chemical usage by over 80%, and (6) increasing capacity to extract more samples.

Some regulations are outdated, energy inefficient, and waste generating. ARA hopes the EPA will provide more support to environmental laboratories and the folks who are making real efforts to reduce energy and waste costs.

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Heavy Metals Distribution in Street Dust

Li-Chu Tsai, Kuang-Chung Yu, and Jun-Hao You

The concentrations of heavy metals – zinc (Zn), lead (Pb), copper (Cu), chromium (Cr), and nickel (Ni) – in street dust samples were collected from 18 sites located in urban areas at Kaohsiung City, Taiwan. They were sampled during four seasons and were determined by flame atomic absorption spectrometry (FAAS). Street dust was separated into four groups with diameters of <0.074, 0.074-0.297, 0.297-0.5, and 0.5-2.0 mm, collected using a three-stage vibration shaker. With modified sequential extraction procedure, heavy metals in street dust were also fractionated into exchangeable, bound to carbonates, bound to Mn-oxides, bound to Fe-oxides, and bound to organic matters fractions.

The results of the analyses were used to predict major sources and magnitude of heavy metal pollution. The highest concentration levels of Zn, Pb, Cu, Cr, and Ni were found to be 1052, 732, 301, 50, and 23 mg/kg-1, respectively. Higher concentrations of heavy metals were detected in south urban areas and close proximity to emission sources such as industrial and shipbuilding areas, etc. The highest concentrations of heavy metals were found in the finest fraction of street dust particle (< 0.074mm), and decreased with increase in particle sizes. Over 90% of Cu bound to organic matters. Pb existed in five fractions with mean percentage. Zn primarily bound to carbonate fraction. About 65% of Cr primarily bound to Fe-oxides fraction. Ni primarily bound to Fe-oxides, and next bound to organic matters fraction. Enrichment factors (EFs), as the criteria for examining the impact of the anthropogenic emission sources of heavy metals, were calculated with background levels. The highest EFs of heavy metals were 55, 10, and 8 for Cu, Pb, and Zn, respectively in the street dust samples. EFs revealed that the sampling area was mainly influenced from four pollution sources, namely Dafa, Kaohsiung Linhai and Ren Da Industrial Parks, as well as shipbuilding areas.

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Phosphorus Fractionations in River Sediments

Li-Chu Tsai, Kuang-Chung Yu, and Jun-Hao You

The assessment of total phosphorus (TP) and orthophosphate (PO₄³⁻) concentration is usually used to judge the eutrophic tendency of lakes, reservoirs, streams, and coastal areas. The phosphorus (P) speciation in river sediment particles was predicted to release TP and PO₄³⁻ into aqueous solution affecting by environmental parameters. The concerned parameters included sampling depth, particle size distribution, and geochemical components of river sediment, i.e., carbonate, iron oxides, manganese oxides, and organic matter. The P fractionations in river sediments were separated with chemical sequential extraction scheme (SEDEX) into exchangeable or loosely-bound P (Ex-P), iron-bound P (Fe-P), authigenic apatite plus CaCO₃-bound P plus biogenic apatite (Authi-P), detrital apatite plus other inorganic P (Det-P), and organic P (Org-P). The percentages of Authi-P in Ell-ren, Yan-shuei, and San Yen-korn River sediments were higher than the other P fractions, and were 76%, 61%, and 40%, respectively. The percentages of Fe-P were lowest among three river sediments with 1.7 to 3.0%. The concentrations of Authi-P in Ell-ren, Yan-shuei, and San Yen-korn River sediments had positive correlation with depth of river sediment samples. The sum of P speciation varied with particle size of Ell-ren River sediment, and the Pearson correlation coefficient analysis was used to assess the correlation coefficient among environmental factors which affected the release of P speciation from river sediment into water phase. P existed in Authi-P and Org-P fractions and had positive correlations with carbonate and organic matter contents in sediment matrix of Ell-ren, Yan-shuei, and San Yen-korn Rivers; the correlation coefficients r^2 were above 0.56. The factor analysis with principal components methods was also applied to reduce the environmental parameters into two major factors, which could be used to explain the migration of P speciation between sediment and surface water in 65%, 57%, and 67%, respectively, among Ell-ren, Yan-shuei, San Yen-korn Rivers.

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Use of Activated Carbon in a Remedial Excavation: A Case Study

Trent Weise, Veronica Statham, and Jonathan Sanders

AEI is currently evaluating the effectiveness of granular activated carbon placed within the backfill of a remedial excavation to control the potential rebound of PCE concentrations in soil vapor. From the 1990s to approximately 2015, dry cleaning operations at a Site located in San Jose, California utilized tetrachloroethene (PCE). Several subsurface investigations performed at the property identified the presence of PCE in Site media (soil, soil vapor, and indoor air), presumably as a result of the dry cleaning operations. PCE was detected in soil vapor at concentrations suggesting a potential human health risk from vapor intrusion of PCE into indoor air at the dry cleaner and adjacent tenant spaces. As such, remedial activities commenced at the Site. The remediation consisted of excavating accessible areas within the dry cleaner space to a depth of approximately eight feet below ground surface (bgs) for removal of PCE-impacted soils. Due to access limitations, low levels of residual PCE in soil remained as documented in excavation side-wall samples that may continue to source PCE into soil vapor at the Site. Following completion of the excavation, the area was backfilled with virgin quarry materials as well as approximately 1,500 pounds of granular activated carbon, which should be capable of adsorbing up to 150 pounds of PCE to control the rebound of PCE in soil vapor beneath the Site. Post-remediation vapor sampling and modeling is underway to document the effectiveness of GAC in the control of PCE in soil vapor beneath the Site.

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Development of a Hybrid Molecular Catalyst-Semiconductor Structure for Hydrogen Evolution

Nicholas Williams and Jing Gu

With the depletion of fossil fuels and an increasing rate of worldwide energy consumption, a cleaner source of renewable energy is essential to meet energy security requirements as well as rescue many fragile ecosystems on Earth. Hydrogenase analogues, by mimicking the biological active centers that produce hydrogen gas as a fuel, pose potential to solve this issue. In our novel strategy, $\text{Fe}_2(\text{CO})_6(\text{SC}_6\text{H}_4\text{OH})_2$, a hydrogenase photo catalyst, is chemically grafted to a p-type Si (100) surface. The modified surface contains a monolayer of catalyst, thus forming a catalyst-semiconductor hybrid structure. The attachment of the catalysts has been confirmed via contact angle measurements, ATR-IR, linear sweep voltammetry (LSV), and X-ray photoelectron spectroscopy (XPS). The modified wafers were fashioned into electrodes and the catalytic abilities were tested using LSV and were found to be significantly more catalytically active relative to an unmodified surface. The stability of the hybrid interface was tested using i-t amperometry. In the future, the efficiency of this hybrid system will be measured using gas chromatography (GC) to determine the rate of hydrogen production.

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Cr(VI) Removal by Membrane-Based Zero-Valent Metallic Nanoparticles in Aqueous Solution

Kuang-Chung Yu and Li-Chu Tsai

The nanoscale zero-valent metal (nZVM) containing properties of quick reaction and high reduction ability could efficiently remove the contaminations in the water environment, which is widely used in current wastewater treatment processes. However, the metal size at nanoscale easily forms a cluster effect that decreases its removal efficiency in water. Therefore, the purpose of this study is to dispersedly coat the nanoscale metal onto the supporting layer to prevent its cluster effect, and finally enhance the treatment efficiency.

This study combined the advantages of MF and nZVM. The membrane-based nZVM was synthesized by using polyvinylidene (PVDF) as the supporting layer to crosslink with the metallic nanoparticles (NPs) by polyacrylic acid (PAA). The bench-scale experiments for Cr(VI) removal by two different metallic NPs membranes were conducted under different conditions of various pH values (4.0 and 7.0) and pore sizes (0.10 μm , 0.22 μm , 0.45 μm , and 0.65 μm). The metallic NPs membrane that illustrated the best performance was carefully examined and confirmed. The differences of Cr(VI) removal by bimetallic Fe⁰/Ni⁰ NPs membrane, MF membrane, and nZVM were executed and compared.

The Cr(VI) removal using bimetallic NPs membrane was achieved at the highest efficiency under acidic conditions. The best result was confirmed by using Fe/Ni NPs membrane under pore size at 0.65 μm . The effect of Fe/Ni NPs membrane was higher than that of nZVM and PVDF MF membrane. Under a different process in making Fe/Ni bimetallic NPs membrane, the efficiency of Cr(VI) removal was improved by extending heating time and lowering the Ni/Fe ratio and soaking time. The Cr(VI) removal mechanism for Fe⁰ NPs membrane at pore sizes equal to 0.22 μm , 0.45 μm , and 0.65 μm was confirmed as adsorption reaction, where the mechanism for Fe⁰/Ni⁰ NPs membrane at the pore sizes equal to 0.10 μm , 0.45 μm , and 0.65 μm was confirmed as reduction reaction.

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