Per- and Polyfluoroalkyl Substances at Remediated Petroleum Sites

Innovative Remediation Project in Delaware

In-Situ Removal of PFAS

Firefighting Training Creates Soil Contamination

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KOMAN Government Solutions, LLC (KGS), on behalf of the U.S. Army Corps of Engineers (USACE) New England District, has begun a per- and polyfluoroalkyl Substances (PFAS) Remedial Investigation (RI) at the former Fort Devens Army Installation (Devens) located in Devens, Massachusetts. Two sites investigated during the PFAS RI are former gas stations and vehicle maintenance areas that were previously remediated for petroleum impacts to soil and groundwater. Neither of these sites have any documented history of use, storage, or disposal of aqueous film-forming foam (AFFF); often considered to be a primary source of PFAS in the environment. This paper summarizes the results of the PFAS investigations at these two sites, including an evaluation of potential sources other than AFFF.

Camp Devens was established in 1917. Pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Fort Devens was placed on the National Priorities List on November 21, 1989, due to environmental contamination at several sites. Under CERCLA, 325 environmental investigations have been conducted at Devens, including the former petroleum sites that are the subject of this article, designated as Area of Concern (AOC) 43G and AOC 57. Devens is in a glacial environment with a wide range of types and thicknesses of glacial deposits overlying crystalline bedrock.

Investigations related to PFAS at Devens began in 2016 with a Preliminary Assessment (PA). The PA was focused on sites at which AFFF, potentially containing PFOS and PFOA, may have been used, stored, or disposed of. Eight sites were selected to be included in the Site Inspection. Five additional sites were added to the Site Inspection; the current Devens Fire Station and sampling of groundwater at existing CERCLA long-term monitoring (LTM) sites (where AFFF was not known to have been used, stored, or disposed). Based on results of the Site Inspection and detections of PFAS at two water supply well sites, the RI began with 15 sites. During the course of the RI, three more sites were added to the investigation.

There is a large range of types of PFAS sites included in the RI, including a number of different sites were AFFF was used, stored, or disposed. PFAS was also detected at sites where there was no known AFFF usage, storage, or disposal. Specifically, a general disposal area, in a commingled tetrachloroethene (PCE) groundwater plume associated with parachute cleaning at the airfield, and at a number of sites that had previously been addressed under CERCLA due to petroleum contamination but did not have a known history of AFFF storage, use, or disposal. These sites consisted of gas stations, vehicle maintenance and storage areas, overfilled underground storage tanks (UST), petroleum disposal areas, and a petroleum, oil, and lubricants storage area.

Field sampling for the RI included collection of:

- 391 groundwater samples from existing and new monitoring wells in overburden and shallow bedrock
- 1,620 groundwater samples from vertical profiles via direct push technology (DPT) and rotosonic drilling. Samples were collected every 10 feet from the water table to refusal.
- 411 surface and subsurface soil samples using DPT
- 74 surface water and sediment samples
- 11 synoptic groundwater and surface water monitoring events to allow for hydraulic assessment.
Samples were analyzed for PFAS using a LC/MS/MS liquid chromatography-mass spectrometry-mass spectrometry isotope dilution method. The 16 analyte list included:

- Perfluoroundecanoic acid (PFUnA), Perfluorobutanesulfonic acid (PFBS), Perfluorodecanoic acid (PFDA), Perfluorododecanoic acid (PFDoA), Perfluoroheptanoic acid (PFHpA), Perfluorohexanesulfonic acid (PFHxS), Perfluorohexanoic acid (PFHxA), Perfluorononanoic acid (PFNA), Perfluoroctanesulfonic acid (PFOS), Perfluorooctanoic acid (PFOA), Perfluorotridecanoic Acid (PFTriA), Perfluorotetradecanoic acid (PFTeA), and the precursors N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA), N-methylperfluorooctane sulfonamidoacetic acid (NMeFOSAA), 1H, 1H, 2H, 2H-perfluorooctane sulfonate (6:2 FTS), and 1H, 1H, 2H, 2H-perfluorooctane sulfonate (8:2 FTS).

This traditional PFAS analysis targets a small number of key PFAS analytes while the bulk of PFAS chemical exist in more complex molecules. Total oxidizable precursor (TOP) assay was completed on a subset of the samples to indirectly quantify unknown PFAS that are precursors to the commonly measured PFAS. The TOP assay process breaks down the complex PFAS molecules to the more recalcitrant perfluorinated forms such as PFOA and/or PFOS and other PFAS listed in the analyte list above (excluding the precursors). The results of the TOP assay allow for a greater understanding of the potential extent of PFAS in the environment through a rough assessment of select PFAS compounds. The results of the TOP assay may also be useful in determining the PFAS source. AFFF impacted samples analyzed by the TOP assay have been shown to reveal an additional mass of PFAS.

Figure 1
compounds that can comprise of up to 70% of the fluorinated organics in the sample.

Select samples were also reviewed for the presence of PFAS branched isomers in order to potentially gain information on how the detected PFAS was manufactured and thus potentially providing information on the source of the PFAS. The presence of branched isomers within a sample suggests that the PFAS present was created using the older electrochemical formulation (ECF) process (ITRC, 2020). The lack of branched isomers suggests the PFAS was created using the newer fluorotelomerization process, which results in primarily linear isomers (ITRC, 2020).

AOC 43G
The first site presented is AOC 43G, which consisted of Historical Gas Station G with a motor pool, and the former Army Air Force Exchange Service gas station, which included a pump station, service station, waste oil UST and above ground storage tank, gasoline USTs, and sand and gas traps (Figure 1). There is also a car wash adjacent to the site. The site was remediated for petroleum contamination via removal of the USTs, AST, and sand and gas trap removal and associated soils removals. There were no records of, and site personnel interviews did not indicate, that AFFF was ever stored, used, or disposed of at the site.

The analytical results for the highest concentrations and most prevalent PFAS concentrations are presented with gradationally sized pie charts (Figure 2). The PFAS results in groundwater indicated PFAS contamination was greatest downslope and downhill of the area where former gasoline USTs and the pump station were located (Figure 2). The groundwater flows to the east from the source area. Across the site, the PFAS concentrations are dominated by PFOS and PFHxS concentrations with lesser concentrations of PFOA, PHFpA, and PFHxA. Precursors were not detected in groundwater at the site.

The highest PFAS results in soil were collocated with the highest PFAS concentrations in groundwater, suggesting that the source was close to where former gasoline USTs and the pump station were located. The PFAS concentrations were dominated by PFOS and PFHxS. Precursors were not detected in soil at the site.

The dominance of PFOS and PFHxS, and the lack of 6:2 FTS and 8:2 FTS precursors, suggest that the PFAS impacts are caused by an AFFF that might have been an older formulation that was manufactured with the ECF process and released to the environment in the vicinity of the former gasoline USTs and the pump station.
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AOC 57

The second site presented is AOC 57, which consists of three areas (Figure 3). Area 1 is an outlet of a storm drain that received flow from a No. 4 fuel oil spill that occurred at former Building 3713. Area 2 is an eroded drainage ditch adjacent to former vehicle maintenance motor pools where polychlorinated biphenyls (PCB) (soil and groundwater), and lead (soil), arsenic (soil and groundwater), chromium (soil), extractable petroleum hydrocarbons (EPH) (soil and groundwater), and PCE (groundwater) were identified as the contaminants of concern (COC).

Area 3 is a former area of stained soil adjacent to the former vehicle maintenance motor pools where arsenic (groundwater), chromium (groundwater), 1,4-dichlorobenzene (groundwater), cadmium (groundwater), EPH (soil), and PCE (groundwater) were identified as COCs. All three areas were remediated for petroleum contamination via soil removal. The groundwater flow direction for all three sites is to the southeast towards a brook.

Low PFAS concentrations, below the US Environmental Protection Agency (EPA) Lifetime Health Advisory (LHA), were detected in Area 1 during the RI, indicating minimal PFAS impact in that area (Figure 4). Greater PFAS impacts to groundwater were detected in Area 2 and Area 3.

Most of the groundwater sampled in Area 2 was dominated by PFHpA and PFHxA, but three locations immediately upgradient and crossgradient to the south of the previous soil removal area had higher concentrations of PFOA, PFHxS, and PFOS (DPT-B, DPT-C, and DPT-D). As the investigation progressed, additional upgradient DPT vertical profiles were conducted. One of the upgradient DPT locations (DPT-E) was dominated by PFOS and PFHxS. Three other upgradient DPT locations, were dominated by PFHpA and PFHxA (DPT-F, DPT-G, and DPT-H). These three additional upgradient locations were also within the footprint and downgradient of former Building 3713, which was a former vehicle maintenance building where drywells were present.

Area 3 groundwater samples were dominated by PFOA, PFHxA, and PFHpA. The highest concentrations were detected close to the former soil removal area.

In Areas 2 and 3, one groundwater sample from each area was evaluated for branched and linear isomers (DPT-D and DPT-A). In Area 2 at DPT-D, branched PFOA isomers were detected, branched isomers for PFOS and PFHxS were tentatively identified, and no branched isomers were detected for PFHpA and PFHxA. The data suggest the PFAS was manufactured using the ECF process. In Area 3 at DPT-A, no branched isomers were detected, suggesting the PFAS was not manufactured using the ECF process.

A total of three groundwater samples from Area 2 (DPT-D and DPT-E) and Area 3 (DPT-A) were analyzed via TOP Assay. There was a 16 percent increase in PFAS concentrations in one sample from Area 2 (DPT-D), due to increases in PFHxS and PFBA. A 47 percent increase in PFAS concentration was observed in the one sample collected upgradient of Area 2 (DPT-E), due to increases in PFHxA, perfluoropentanoic acid (PFPeA), and PFHpA. The results indicate the presence of more complex PFAS molecules than are measured using...
the standard PFAS analysis. The significant increase in PFAS concentrations at DPT-E also suggest that AFFF might be the source of PFAS at this location. There was no increase in PFAS concentrations in the sample from Area 3 suggesting there are no complex PFAS molecules present that would break down to the PFAS in the specified analyte list.

There were only a few detections of precursors across AOC 57. Of the 282 groundwater samples collected in AOC 57, there were eight detections of 6:2 FTS. One of the detections was in Area 3 and the remaining detections were in Area 2. There was only one detection of 8:2 FTS in AOC 57, specifically at DPT-E. The data suggest that in Area 3, either PFAS manufactured using the fluorotelomerization process was not a significant contributor to the PFAS detected or that precursors that may have been present have since degraded.

At Area 2, the greater number of detections of 6:2 FTS and 8:2 FTS suggest the presence of PFAS manufactured using the fluorotelomerization process are present and that precursors are present that may eventually degrade to perfluorinated forms of PFAS such as PFOA and/or PFOS and other PFAS listed in the analyte list above. Neither NEtFOSAA nor NMeFOSAA were detected in any of the groundwater samples.

Overall there is a large area of groundwater impacted by PFAS at AOC 57 that may or may not have been associated with AFFF.

Historical records and site personnel interviews did not indicate that AFFF was ever used, stored, or disposed of at any of the three AOC 57 areas or upgradient of these areas. The results suggest that chemicals with PFAS other than, or in addition to AFFF, were disposed of in the areas where petroleum impacted soil was removed. PFAS are part of many chemicals associated with vehicles and vehicle maintenance, including car wash products, automobile waxes, cleaners, paints, anti-fogging products, and hydraulic oils. PFAS chemicals are also used in the manufacture of components of vehicles such as metal plating, plastics, textiles, and electronics (EPA, 2020).

The variation in PFAS concentrations, isomer analysis results, and the TOP Assay results in Area 2 and Area 3 suggest a variation in the PFAS source(s) across the area. The areas immediately upgradient and cross-gradient (to the south) of the Area 2 soil removal area had higher concentrations of PFOA, PFHxS, and PFOS than the PFAS detected close to the soil removal area. These results suggest a different source of PFAS resulting in a different PFAS signature in this area.
Farther upgradient of Area 2, the higher concentrations of PFOS and PFHxS, the detection of 8:2 FTS, and the significant increase of PFAS concentrations in the TOP assay at DPT-E suggest there may be a source of AFFF in that area. The other three upgradient DPT locations (DPT-F, -G, -H) were dominated by PFHpA, PFHxA, and PFOA. The presence of these PFAS constituents and the lack of precursors suggest that activities at former Building 3713, a vehicle maintenance building, resulted in discharge of PFAS not associated with AFFF to the groundwater via dry wells. In Area 3, the lack of branched isomers, the scarcity of precursors, and the dominance of PFOA, PFHpA, and PFHxA do not suggest that AFFF is the source of PFAS in this area.

SUMMARY

In summary, two sites impacted by PFAS were identified where there were no historical records or interview results that indicated potential use, storage, or disposal of AFFF. These sites also were not commonly associated with PFAS impacts such as waste-water treatment plants or landfills. At AOC 43G (historic gas and service station), the data suggest the PFAS impacts may be attributed to an undocumented use of an older formulation of AFFF. At AOC 57 (fuel spill, historic disposal site associated with vehicle maintenance and storage), the data suggest a wider range of potential PFAS sources.

Two historic disposal sites (Area 2 and Area 3) have similar chemical signatures with slight variations, suggesting only minor differences of the PFAS source chemicals. Chemical results from an upgradient location (DPT-E) suggest the PFAS impact in that area may be related to a newer formulation of AFFF. Upgradient of the historic disposal sites, PFAS impacts to groundwater were identified at and downgradient of a former vehicle maintenance building. Dry wells at this location may have been the conduit for discharge of chemicals containing PFAS to the groundwater.

Katherine Thomas, PMP, KOMAN Government Solutions, LLC, Penelope Reddy, USACE, Robert Simeone, U.S. Army, Base Realignment and Closure

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Innovative Remediation Project Provides Long-Term Sustainability, Natural Resource Management Benefits for All Living Creatures in Delaware

By Tommy A. Jordan, P.G., Christina Wooldridge, MBA, CP APMP, and Gia Huynh-ba, P.E., PMP

In the northwestern corner of Delaware lies the scenic Yorklyn Valley. The remnants of the National Vulcanized Fiber (NVF) plant are a reminder of a once thriving industrial center; but after years of neglect, the site now seeks new life as a clean, vibrant centerpiece for this small community.

For nearly a century, the NVF plant used zinc and other toxic materials in its paper manufacturing process, poisoning the soil and groundwater. Although the plant shut down years ago, the zinc had contaminated the groundwater.

The State of Delaware’s Department of Natural Resources and Environmental Control (DNREC) Site Investigation and Restoration Section (SIRS) contracted with Black & Veatch to help remediate the site by removing the zinc and making the site amenable for redevelopment. At the time, NVF’s consultant had overseen the installation of a pump and treat system that was removing about 8,500 pounds of zinc a year; however, at that rate, it would take an estimated 40 years and cost the state about $14 million to solve the problem.

Black & Veatch partnered with DNREC to go beyond their initial remedial design assignment by developing a solution that would provide the added benefit of long-term sustainability and improvements to natural resources for all living creatures in the Yorklyn Valley region.

MAYBE A BETTER WAY

“Maybe there was a better way,” thought Michael Naughter, Project Manager with Black & Veatch’s federal business. Black & Veatch worked with DNREC to oversee environmental investigation, design and remedial action at multiple sites in Delaware. Recognizing that the state was interested in incorporating...
park features at cleanup sites, Black & Veatch project manager Michael Naughter and the NVF team devised a solution that would accomplish much more than just removing zinc contamination in soil, sediment and groundwater.

The contaminated soil was along Red Clay Creek, an area prone to flooding. To address this, the NVF team suggested excavating the contaminated soil and then turning the resulting pit into a landscaped wetlands area that would help mitigate flooding and provide a nature sanctuary with publicly available trails. The team designed a landscaping plan with water-tolerant trees, shrubs and grasses, and a network of multi-use trails. The plan satisfied SIRS and DNREC’s Division of Parks & Recreation.

Within one year, crews removed 340,000 lbs of contaminated zinc soil for approximately $2.5 million. DNREC has since installed plantings, replaced an asphalt road with porous pavers, and seeded areas.

The wetlands also help contain flooding that often plagues the area. A brand-new porous paver road allows rainwater to pass through, naturally cleaning pollutants and allowing residents to come and go during times of heavy rain.

“There was a pump and treat system that was out here handling the contaminated ground water on this site when NVF was still in production,” Naughter said. “This wetlands project took care of the groundwater contamination in one year and we also saved in the $10 million range what it was going to cost to operate that pump and treat system for the next 40 years.”

THE RETURN OF WILDLIFE

Of the 20 bird species now in residence, the most impressive inhabitant is the Spotted Sandpiper, notorious for its spotted breeding plumage and distinctive, teetering gate. According to DNREC’s Wildlife Action Plan for 2015 to 2025, these sandpipers are classified as a Tier 2 species, which means that they have “rare to uncommon” breeding populations in the state, i.e., Delaware reports less than five sightings of this elusive bird each year.

The nearby Delaware Nature Center (DNC) reported a testament to the Yorklyn project’s success after a DNC employee reported that within a 23-minute visit to the NVF site, he had spotted 20 different species of birds, including three Spotted Sandpipers – two fledglings and an adult. Having three of them at a Black & Veatch project is worth some warbling.

“Although this began as remediation, our work turned it into a birds, bugs and bunnies restoration,” Naughter said. The DNREC was recognized by the U.S. Environmental Protection Agency (EPA) Office of Wastewater Management for the NVF Yorklyn Site Wetland Project in Yorklyn, Delaware. The project was one of only five projects in the nation to be recognized by the Environmental Protection Agency Office of Wastewater Management in the “Exceptional” cat-

The industrial complex converted to wetland and flood storage area.
egory for demonstrating excellence and innovation within the Performance and Innovation in the State Revolving Fund Creating Environmental Success (PISCES) program. Black & Veatch has been providing environmental consulting, remedial investigation, remedial design and project management services for DNREC on the project since 2015.

**BROWNFIELDS TO WETFIELDS**

The first of its kind in Delaware, this brownfield-to-wetlands conversion project uses natural systems to remediate an area of a site that was impaired by decades of industrial activity.

NVF and other companies produced paper at the site for nearly 100 years, relying on minerals such as zinc, which is harmful to aquatic life and the health of the adjacent Red Clay Creek. Remaining historic portions of the factory are being repurposed as part of the redevelopment.

Some key outcomes of the environmental remediation project included:

Black & Veatch provided engineering support to the State of Delaware for the Remedial Design (RD), flood mitigation, stormwater management, land development plans, and Remedial Action (RA) for the contaminated site.

The project involved coordination with numerous State agencies to successfully integrate all aspects of the project and obtain necessary state and federal permits. Remediation of the Site addresses heavy metal and polycyclic aromatic hydrocarbons (PAH) contamination found in soil and groundwater through the use of a capping system and removal of source material.

Land development plans for the site include relocation of public roads out of flood prone areas. The public roads were constructed with porous materials to help mitigate flooding in the area.

Black & Veatch’s remedial design addresses both contaminated soil and groundwater on the site. The new wetland was purposely placed in the most contaminated area of the site. Over-excavated zinc-containing soil was sent for offsite disposal, followed by capping with clean fill and topsoil. The remaining depression was converted to a functional wetland that helped remove the remaining zinc from the impacted groundwater. The existing pump-and-treat system completed treatment of the groundwater and has since been decommissioned.

The new wetland feature was incorporated into planned park improvements and has helped mitigate persistent flooding problems in the Red Clay Creek valley. Existing Gun Club Road, which was long prone to flooding, has been replaced with a new road designed by Black & Veatch, using pervious pavers that offer additional flood mitigation benefits to the site and surrounding area.

“For decades the Delaware Clean Water State Revolving Fund (CWSRF) has supported critical water infrastructure projects that help grow the Amer-
ican economy and support our way of life,” said Mike Shapiro, Acting Assistant Administrator for EPA’s Office of Water. “These projects are a testament to the power of the Clean Water State Revolving Fund in leveraging investment to meet the country’s diverse clean water needs.”

The CWSRF provided $3.3 million in low-interest financing to excavate and dispose of contaminated soils and create two acres of wetlands. These wetlands, along with other site enhancements, improves water quality and stormwater storage to mitigate flooding, and helps support the economic redevelopment of the Fiber Mills District in Yorklyn. An additional $1 million CWSRF loan helped fund the creation of a series of additional wetlands around the project site to provide additional protection to residents and new buildings from flooding and runoff.

Each phase of the remedial action was its own unique project. These phases included:

- Phase 1 – Identify and remove hazardous waste from the buildings.
- Phase 2 – Demolish a portion of the buildings so that Gun Club Road could be relocated, and final sampling could take place in the main source area.
  - Added two more extraction wells to pump additional groundwater in before excavation could occur.
  - Realigned the onsite tributary beneath the new road and installed new culverts.
  - Designed in such a way to allow the preservation of some buildings.
- Phase 3 – With the new Gun Club Road open, demolish the remaining buildings and remove the remaining concrete foundations.
- Phase 4 – Excavate and create the wetland area, addressing additional hazardous waste found onsite and installing utilities (e.g., water, sewer, electric) on-site.
- Phase 5 – Shut down the existing groundwater treatment system after six months of creek surface water sampling. Zinc TMDLs below the 24 lbs/day (EPA standard). This saved DNREC 40 years on pumping and $14 million.
- Phase 6 – The redevelopment process.

A COMPREHENSIVE REMEDIATION EFFORT

The Black & Veatch team helped transform an eyesore into an eye-catching environment that is attracting pipers as well as people. Black & Veatch truly put innovation to the test to go beyond the initial assignment and devise a winning solution that is not only been good for the birds and birders, but for all living creatures in the Yorklyn Valley region. With its, clean natural beauty, Yorklyn celebrates a rich history, and looks forward to a vibrant future. ■

In-Situ Removal of PFAS with Catalyzed Ultrafine Bubble Ozone and Recirculating Wells

By William B. Kerfoot, Brian Baumgaertel and George Heufelder

The need to remove perfluoroalkyl compounds from contaminated soil and groundwater from residual fire-fighting foam for health reasons has recently been raised (EPA, 2016). The compounds contain major perfluoroalkyl derivatives and are very resistant to bacterial breakdown (Suthersan, 2016; Schultz, et al., 2006). The decomposition of PFAS to mineralization requires cleaving of the carbon-fluoride bond. This is difficult since the bond strength is one of the strongest of organic compounds.

Additional modification of perozone, however, appears to boost the cleavage capacity of ozone. This employs nanobubble gaseous ozone with peroxide coating in an emulsion, referred to as Perozone®-3.0 (Kerfoot and Strajin, 2014). Microbubble gaseous ozone injected into groundwater and saturated soils has demonstrated a half-life of 23 hours compared to 20 minutes using dissolved molecular ozone common to drinking water treatment. With alkaline pH adjustment, perozone attacks and decomposes PFOS and PFOA (Lin et al., 2016).
al., 2012), and the reaction is rapid.

This article reports on pilot testing for removal of PFAS found in saturated soils containing fire foam residuals. The testing was conducted at the Massachusetts Alternative Septic System Test Center (MASSTC) at Joint Base Cape Cod (JBCC) (Fig. 1).

TESTING AND SAMPLING PROCEDURES
The sandy loam soils from a nearby fire training area were excavated and placed in containment in high density polyethylene (HDPE) 55-gallon drums. The contained soils were injected with peroxide-coated nanobubble ozone produced in two manners: 1) Case A - formed in a generator above ground and injected through three slotted points placed in the soil, and 2) Case B - formed below ground in a nanoporous stainless-steel laminar Spargepoint placed in saturated groundwater. In the latter case, ozone and peroxide were produced separately above ground and then combined within the below ground point to yield peroxide-coated nanobubble ozone.

A single 10-slot PVC monitoring well was installed in the center of the container for groundwater sampling. Three soil samples were obtained with a stainless-steel sampler with stainless-steel insert tubing. The samples were placed in a 250 ml sample container supplied by Maxxam Analytics and mixed with a stainless-steel spatula before overnight shipment in ice to the laboratory.

Groundwater and soil sampling procedures followed best current procedures. Monitoring well water samples were removed with glass syringe and silicon tubing and placed in polyethylene containers provided by the analytical laboratories. Detailed procedures are discussed in Obal, et al., 2014. Soil samples were taken vertically by use of a stainless-steel, hand-driven sampler containing a tubing insert. The core was pushed out with a glass rod to obtain the sample volume which was dropped into the glass jar. The weight was recorded to assure at least 40 gms.

NANOBUBBLE SOLUTION GENERATORS
The above-ground generator was similar to that described in Kerfoot and Strajin (2014). A pressur-
ized glass cylindrical reactor cell (17-20 psi) held a laminar stainless-steel Spargepoint with an outer .20 micron porous surface and an interior fine glass bead cylinder.

The below-ground injector system consisted of components similar to micro to nanoporous Perozone® systems – a compressor, an ozone generator, and a liquid peroxide delivery system. The major differences involve a stainless-steel laminar point with a nanobubble screen, ozone injection at 2,400 ppmV, and pH-adjusted peroxide injection.

The point was installed at a depth of one meter below grade in the soil. Two tube lines fed ozone gas and liquid peroxide separately. Peroxide-coated bubbles were formed as the gas passes through fine beads containing peroxide. The suspension was then injected into the soil. Water table height was controlled.

**SOIL PREPARATION**

The soil first tested was obtained from the center of an adjacent historic fire training area. The soil was unadulterated sandy loam from the center of the fire training site, removed to a one-meter depth. The soil type had been previously characterized as fine-to-medium sandy loam from the Mashpee glacial outwash plains extending about one meter deep. The surface consisted of decaying organic matter mixed in with fine sandy loam, often referred to as Enfield sandy loam (USDA, 1969).

Initial analysis of the soil revealed a moisture content of 2.0% to 23% (after rain). PFAS values were: fluorotelomer sulfonate <1.0, PFOS 46, PFOA 1.1, PFHxS 7.3, and perfluorooctane sulfonamide (PFOSA) 2.7 µg/kg. This soil was excavated, mixed, and placed in containment for treatment with three stainless-steel slotted points. A small diameter PVC monitoring well was installed to one meter’s depth in the soil.

In Series A, three stainless-steel slotted points were placed within the container to inject the emulsion

---

**TABLE 1.**

Groundwater removal pilot test – A Series (µg/L concentration)

(2-column fitting for table 1)

<table>
<thead>
<tr>
<th>Liquids – Groundwater</th>
<th>Start</th>
<th>24 Hr.</th>
<th>48 Hr.</th>
<th>60 Hr.</th>
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<td>A3</td>
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<tr>
<td>PFHxA</td>
<td>7.7</td>
<td>.28</td>
<td>.31</td>
<td>.36</td>
</tr>
<tr>
<td>PFOA</td>
<td>6.8</td>
<td>&lt;.053</td>
<td>&lt;.053</td>
<td>&lt;.053</td>
</tr>
<tr>
<td>PFHpS</td>
<td>3.5</td>
<td>&lt;.036</td>
<td>&lt;.036</td>
<td>.060</td>
</tr>
</tbody>
</table>

| 6:2 Fluorotelomer Sulfonate | 5.0  | <.065 | <.065 | <.065 | >98.7 |
| 8:2 Fluorotelomer Sulfonate | 3.0  | <.055 | <.055 | <.055 | >98.2 |

Fig. 3. Drop in PFAS in groundwater with time-of-treatment (2-column fitting)
sequentially at equal intervals. During the test, over 74 volatile organics by GCMS were analyzed by EPA Method 8260 for four separate periods: Start (0 HR), 12 HR, 36 HR, and 48 HR. All registered nondetect. Common benzene, toluene, ethylbenzene, xylenes registered aqueous reporting limits of 0.5, 0.75, 0.5, and 1.0 µg/L, respectively.

The second soil volume (B Series) was removed from a more southern location on the historic fire training area where scrub pitch pine was scarce. Initial analysis of this soil revealed a moisture content of 18%, fluorotelomer sulfonate <0.25, PFOA 0.52, PFHxS 2.4, and PFOSA <0.17. This soil was excavated and then mixed with 1% (1 to 100) silty fine soil originating from a fire training area in Hamilton, Ontario, Canada to raise the mean concentrations of PFAS. Sampling of the soil after mixing showed a moisture content of 19%, and compound concentrations of 6:2, fluorotelomer sulfonate 4.7, 8:2 fluorotelomer sulfonate 19, PFOS 160-270, PFOA 1.6, PFHxS 3.7, and PFOSA 4.8 µg/kg.

**TABLE 2.**

Soil removal pilot test – B Series (µg/kg concentration) (2-column fitting for table 2)

<table>
<thead>
<tr>
<th>Time (hr)</th>
<th>0</th>
<th>12</th>
<th>36</th>
<th>48</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PFOS</strong></td>
<td>270</td>
<td>150</td>
<td>130</td>
<td>100</td>
<td>43</td>
</tr>
<tr>
<td><strong>6:2 Fluorotelomer Sulfonate</strong></td>
<td>18</td>
<td>18</td>
<td>13</td>
<td>12</td>
<td>6.2</td>
</tr>
<tr>
<td><strong>8:2 Fluorotelomer Sulfonate</strong></td>
<td>30</td>
<td>9.9</td>
<td>13</td>
<td>8.2</td>
<td>9.4</td>
</tr>
<tr>
<td><strong>PFHxS</strong></td>
<td>3.7</td>
<td>5.0</td>
<td>3.8</td>
<td>2.3</td>
<td>2.3-2.6</td>
</tr>
<tr>
<td><strong>PFHxA</strong></td>
<td>1.0</td>
<td>2.6</td>
<td>3.3</td>
<td>4.3</td>
<td>4.3-3.1</td>
</tr>
<tr>
<td><strong>PFOA</strong></td>
<td>1.6</td>
<td>1.9</td>
<td>2.5</td>
<td>2.8</td>
<td>2.6-3.5</td>
</tr>
<tr>
<td><strong>PFHxS</strong></td>
<td>&lt;0.3</td>
<td>0.4</td>
<td>&lt;0.3</td>
<td>0.3</td>
<td>0.35-0.5</td>
</tr>
</tbody>
</table>

*Mean values*

**PILOT TEST RESULTS**

**A Series**

For the A Series, ozone was delivered with an ozone generator at 4 gm/minute. For over 60 hours of total treatment, 240 gms O3 were delivered through three points into the soil, placed .9 meter below the surface.

Field measurements of temperature, oxidation-reduction potential (ORP), oxygen, and pH were made with an Oakton pH 700/mV/°C/°F meter and a Sensitron Associates Model DO-1 Oxygen Analyzer. Samples were taken for laboratory analysis of PFAS, sulfate, fluoride, and volatile organic compounds (VOCs). Ozone concentration/flow and peroxide concentration/flow were measured. A Vacuettes® Kit K-5510C was used to verify peroxide concentration. Ozone con-

![Fig. 4. Rise in fluoride concentration with decomposition of PFOS (2-column fitting)](image-url)
centration at start was 3,500 ppmV and increased stepwise to 14,000 ppmV after 48 hours. Peroxide was diluted to 8.75% and measured at pH 5.5. Soil temperature increased from 57°F (13.9°C) to 62°F (16.7°C) after six hours of operation. Emulsion flow was 13.5 cc/minute during the day sequentially to each of three points for 60 minutes each. After 24 hours, the soil temperature was 73°F (22.7°C). The ORP was increased from 317 to 394 mV, and pH had dropped from 7.2 to 1.6.

Groundwater samples were removed at the Start, 24 Hr., 48 Hr. and 60 Hr. of treatment and forwarded to Maxxam Analytics for analysis of PFAS. The results of testing is presented in Table 1 for the primary perfluorocompounds PFOS, PFHxS, perfluorohexanoic acid (PFHxA), PFOA, and perfluorohexanesulfonate (PFHpS), along with the two fluorotelomer sulfonates (6:2 and 8:2) and graphed in Fig. 2 for PFOS, PFHxS, and 6:2 and 8:2 fluorotelomers. The % removal was calculated by subtracting the 60-hr. value from the Start value, dividing by the Start value and multiplying by 100.

The Perozone-3.0 suspension was not introduced continuously, but by 30-minute sequences of 23 hours a day for sampling, then begun a second time of eight hours from 48 hours from Start to 56 hours. Sampling of groundwater was performed at 24, 48, and 60 hrs.

With A Series, a large decrease in the aqueous concentration is observed after the initial sampling event. Soil samples taken during A Series testing showed a pattern with all VOCs at nondetect. The normal BTEX analyses revealed benzene, toluene, ethylbenzene, total xylenes at nondetect with reporting limits at 65, 98, 65, and 140 µg/kg.

The lack of VOCs was uncharacteristic with previously-tested, untreated fire training soils (Kerfoot and Strajin, 2014). Historically, the upper portion of the soil on the adjacent old fire training area had undergone thermal desorption treatment in 1995 to reduce organic residues. A fire in the treatment facility was treated with foam to extinguish the blaze. An explanation of thermal desorption can be found in CLU-IN (EPA 542-12-OID). The thermal evaporation changes VOCs into vapors (gases) and separates them from the solid material. Normally volatile organics or VOCs and some semi-volatile organic compounds of SVOCs are removed.

**B Series**

With the B Series, the higher concentration of PFAS on soils should allow a closer look at the rate of removal on the soil fraction. Here, the injected nanobubble emulsion is formed below ground in a special stainless-steel laminar Spargepoint receiving ozone gas through a tube and peroxide with a second tube. Peroxide flow was 10 cc/min or 14 liters per day. To correct the acidification, the peroxide was adjusted to above pH 8.0 (alkaline condition). The temperature at Start was 61-62°F (16.7°C), pH was 6.85 and ORP 264mV. Online test of ozone indicated 2,000 ppmV. With 36 hrs. running, the pH had risen further to 7.15, and ORP was 299 mV. Samples of groundwater were taken at 12, 36, 48, 60, and 72 hours for analysis of fluoride and forwarded to Alpha Analytical for analysis.

Three soil samples were collected at midway depth (at least 40 gm) each time period, mixed with a stainless-steel spatula, placed in containers provided by the laboratory, placed in ice, and shipped overnight. Groundwater samples were taken from a one-inch diameter PVC monitoring well (10-slot screen) placed slightly off the center opposite the injection laminar Spargepoint placed on the bottom. They were placed in amber glass 250 cc containers with HDPE lids provided by Alpha Analytical. Sample bottles were placed in plastic foam, joined zip-lock bags containing ice, and shipped overnight to the laboratory for testing. The analytical procedure for fluoride was EPA Standard Method 121, 4500 F-BC. Samples were prefiltered and shipped in polyethylene 250 cc bottles, cooled to below 40°F (3.5°C) for shipping.

Replicates were run at 60 hr. The mean values and range are included in Table 2.

The major PFAS in the soil was PFOS. Table 2 presents the B Series results showing reduction of PFOS in the soils with time (Fig. 4). When PFOS concentration is plotted versus fluoride concentration, a direct correlation is apparent. Fluoride increases as PFOS decreases. This would be expected if the C-F bond were broken during decomposition, releasing fluoride into solution.
NEW PRODUCT ANNOUNCEMENT

OCCAM RAZOR FOR DEGRADING PFAS COMPOUNDS

Kerfoot Technologies, Inc. (KTI) has isolated a mineral which catalyzes the breakdown of the perfluoroalkyl molecule into basic inorganic components in the presence of ozone gas nanobubbles. OCCAM refers to: “Ozone Catalyst Combined Adsorption Mineralization.” KTI has isolated an iron-based silicate catalyst which adsorbs PFOS in aqueous solution (groundwater), and when exposed to nanobubble ozone, decomposes the perfluoro compound into its mineral components of sulfate, carbon dioxide, fluoride, and oxygen.

The “Razor” refers to the efficiency of detaching the basic C-F bonds in a quick, zipper-like manner. The adsorption catalyst can be combined in cannisters containing activated carbon to effectively remove PFOS without high temperature incineration of the activated carbon. A canister comprised of the catalytic adsorber is set above activated carbon. Groundwater containing PFOS is pumped through the interior compartment where the PFOS adsorbs to the catalyst and sorbent. The interior compartment then receives gaseous ozone which is transformed into micro to nanobubbles which percolate through the fine particles of the catalyst, decomposing the perfluoroalkyl compounds by the unzipping process, regardless of the end group (sulfonic or carboxylic).

In operation, the aqueous solution being treated has PFOS adsorbed by the mineral catalyst in the catalytic adsorption compartment, which is then exposed to the micro to nanobubble ozone, which decomposes the perfluoro compound into its mineral components. The off-gas ozone untransformed to oxygen is sent through a second catalyst to transform all gaseous ozone to oxygen for release to the atmosphere. The treated liquid flows through specialized sieves to the activated carbon.

The catalytic canister can be attached to a double- or triple-screened well to promote recirculation of water through a surrounding ground/aquifer region. The treated groundwater meeting drinking water standards can be recharged to the periphery of the radius of influence of the recirculation system.

Applications
➢ Recirculation wells – vertical or horizontal
➢ Treatment trains – low-level contamination
➢ Pump-and-Treat – low volume, low concentration

Advantages
➢ Low capital equipment/operating costs
➢ Minimal installation site disturbance
➢ In-situ rapid destruction of PFAS
➢ Clean reaction – no hazardous byproducts
➢ No vapor control necessary

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Phone: 508-539-3002 · Fax: 508-539-3566
www.kerfoottech.com
A linear regression analysis was performed on the decay of PFOS, rise of fluoride, and correlation between PFOS and fluoride. These demonstrate a correlation coefficient of better than 0.94 and confidence coefficients of 0.95 with significant levels of 0.05. A standard linear regression analysis was run on 1) PFOS content of soil with time, 2) fluoride concentration with time, and 3) PFOS concentration versus fluoride concentration. The correlation coefficient of PFOS drop versus time was -0.92. The correlation coefficient of fluoride versus time was +0.94. The correlation of PFOS with fluoride was -0.94. The confidence coefficient of both was 0.95 at a significance level of 0.05.

One can clearly statistically say that as the PFOS dropped, the fluoride content increased linearly.

Ozone injection was computed as 4 gms/hr during injection at a rate of .5 CFM (liters per hour). The volume of soil contacted was 241 kg, which contained 65,313 µg of PFOS, an estimated 32% of the total petroleum hydrocarbon content. Over the test period of injection of 72 hours, over 80% of the PFOS appeared removed. The fluoride content was 64.6% by weight of the PFOS molecule. If the groundwater content of the saturated soil is 25% volume, 45.6 liters of groundwater would receive the fluoride, resulting in an expected concentration of .84 mg/L fluoride. The observed concentration was .75 mg/L, about 89% of that expected (.84 mg/L). Fluoride is not a perfect tracer (as compared to chloride) since it decays with time in the saturated soil, so the slightly lower value is consistent with expectations.

**BREAKDOWN OF PFOS TO FREE FLUORIDE IN SERIES A AND B**

The decomposition of PFOS by peroxide and ozone yields carbon dioxide, water, sulfuric acid, hydrofluoric acid and oxygen when completely mineralized.

PFOS → Hydrogen Peroxide → Ozone → Carbon Dioxide → Water → Sulfuric Acid → Hydrofluoric Acid → Oxygen
C8F17SO3H + 15H2O2 + 5O3 = 8CO2 + 6H2O + H2SO4 + 17HF + 11O2

With a soil solution (saturated conditions), the amount of fluoride can be computed by multiplying the fraction of molecular weight of fluoride in PFOS by the weight of PFOS:

\[
\left( \frac{\sum MW F}{MW PFOS} \right) \left( \frac{V \text{ solid}}{V \text{ liquid}} \right) \left( \frac{W \text{ sal}}{W H_2O} \right) = \text{Fluoride content in groundwater}
\]

The ratio of F/PFOS is equal to 323/500, or .646 by weight. To find the concentration of fluoride in groundwater solution, we multiply the fraction ratio time 3.0 (solid 75% divided by pore liquid volume 25%), times 1.6 (weight of solids over weight of water). This would give the concentration of fluoride in groundwater solution of .84 mg/L, if fluoride acted as a conservative tracer. The observed concentration was .75 mg/L, about 89% of that expected (.84 mg/L).

**RECIRCULATION WELL TREATMENT**

Combining slotted screen injection with laminar point injection can be done with a recirculation well system as shown in Figure 5. Coated micro to nanobubble injection occurs below the double-screened well and is pulled into the upper screened section. The rising pulsed microbubbles create eddies which draw water towards the recirculating well. A certain fraction (i.e., 25%) of the recirculation drawn into the upper portion of the well is sent to a canister containing catalyzed adsorber and activated carbon which distributes the clean water back to the edges of the recirculation.

**CONCLUSIONS**

Several conclusions were apparent from the pilot test:

1. PFAS removal in soils and groundwater appears feasible with injection of peroxide-coated micro to nanobubble ozone.
2. Injection through slotted screens successfully reduced aqueous PFAS concentrations of PFOS and PFOA by 98.5% and 92.3%, respectively, including precursors over 98% with 48-hour treatment.
3. Injection through a nanoporous laminar point clearly reduced PFOS concentration on the soil fraction, slightly over 80% removal within 72 hours.
4. The proportional release of fluoride closely followed the reduction of PFOS. A linear regression analysis confirmed the coincidence.
5. Alkaline adjustment of peroxide eliminated acidic conditions and enhanced PFOS removal on the soils.
6. A double-screen recirculation well with a lower laminar Spargepoint offers a convenient arrangement to treat soil and groundwater.

William B. Kerfoot, Kerfoot Technologies, Inc. Brian Baumgaertel and George Heufelder, Massachusetts Alternative Septic System Test Center (MASSTC)
Firefighting Training Creates Soil Contamination

After years of ongoing use of aqueous film-forming foam (AFFF), a fire training center located in the United Kingdom showed high levels of PFAS (Per- and Polyfluoroalkyl Substances) contamination. Faced with a potentially expensive cleanup, the remediation team devised a treatment strategy to immobilize the harmful chemicals through in-situ stabilization and solidification using CETCO FLUORO-SORB® 100 adsorbent.

PFAS CHEMICALS AND THEIR IMPACT
In recent years, PFAS substances (man-made chemicals that includes PFOA, PFOS, PFBS, GenX, and many other derivations) have become recognized as Contaminants of Emerging Concern. Attention to this issue has grown enough that in the United States, the EPA has begun the regulatory development process for listing these chemicals as a hazardous substance.

For over six decades, PFAS have been key components in common products used worldwide such as non-stick cookware, waterproof fabrics and clothing, stain-resistant carpeting, food wrappers, make-up, paints, firefighting foams, and numerous products designed to resist grease, water, and oil. Over time, these commonplace chemicals have been found to have seeped into the food chain and water supply—a significant concern, as scientific study has determined PFAS exposure can lead to negative health impacts on both animal and human populations.

In addition to their health risks, the strong carbon-fluorine chemical bonds of PFAS, which is what provides their useful properties, make them highly environmentally stable. As a result, PFAS remain intact in the environment—they do not readily break down over time—lending them the nickname “forever chemicals.” This persistence can lead to accumulation, increasing contamination levels while posing remediation challenges for contaminated groundwater, surface water, and wastewater—and in particular, contaminated soil and sediment, which are frequently the source of water contamination.

A CONTAMINATED SITE
The UK-based fire training center is a prime example of a PFAS contamination problem and the challenges its remediation presents. Years of firefighting training at the site had left it substantially contaminated—PFAS chemicals are key ingredients in the aqueous film forming foam (AFFF) firefighters use to extinguish fires involving flammable and combustible liquids. Because of PFAS’s stability to the point of near indestructibility, when applied, these chemicals form a thermal and evaporation barrier that extinguishes combustion, making them highly effective in dousing flames under conditions where water is ineffective. Facilities all over the world provide AFFF training instruction to firefighters to help them develop proficiency in the use and application of these firefighting foams. This typically includes hands-on exercises, and the repeated use of AFFF in regular training results in a build-up of PFAS contamination at training sites.

This center was no different, and as part of the firefighting training conducted regularly at the facility, these PFAS-laden foams had been used consistently for years.

As a result, groundwater and near-surface soils at the site had PFAS contamination levels of long-chain compounds, PFOS and PFOA exceeding 100 ppb (parts per billion—research suggests PFAS concentrations above 1.4 ppb may cause groundwater contamination). Also, because the fire training facility had been used for practice with gasoline and diesel fires, the PFAS contamination was compounded with a co-contamination of significant TPH (total petroleum hydrocarbons).

Further, because the site was situated near a tidal marine estuary, additional concerns included poor geotechnical ground conditions due to marine silts and groundwater tidal influences, as well as the presence of high sulfates.

THE CHALLENGES FOR REMEDIATION
This contamination profile created a set of challenges for PFAS remediation. The presence of gasoline/diesel...
contaminants can affect the efficiency of certain remediation products, with the presence of seawater complicating circumstances further, as saltwater can adversely affect the removal efficiency of ionic exchange resins (IER) that might otherwise be employed to remediate PFAS contamination.

**A SOLUTION FOR PFAS CONTAMINATION**

The remediation team’s plan for the training facility was to devise a remediation strategy that maximized reduction of the PFAS contaminants and was also cost conscious—the public sector training facility had a very limited budget for a contamination solution.

Beginning with solidification/stabilization treatability trials, the team tested various approaches using separate 64-day leach tank tests based on EA NEN7375:2004/US EPA 1315. Once the results were analyzed, the team was able to confirm that the levels of PFAS and TPH in the soil would prevent the use of granular activated carbon (GAC)—adsorption by GAC would be fouled by the co-contaminants found in the samples.

CETCO and ATG Group commissioned a laboratory study of PFAS contaminated soil treated with FLUORO-SORB® 100 adsorbent media and cement. Samples of an untreated soil, TTP1, were obtained. The soil was a brown loam with clay and gravel. TTP1 was tested for total petroleum hydrocarbons (TPH) and two PFAS compounds, PFOA and PFOS.

Test results for untreated TTP1 were:
- Aliphatic TPH = 1100 mg/kg
- Aromatic TPH = 610 mg/kg
- PFOS = 1.5 mg/kg
- PFOA < 0.1 mg/kg

Because the PFOS concentration was lower than expected, the TTP1 sample was spiked with 100 mg/kg of PFOS (heretofore referred to as TTP1-S). Thus, the total PFOS concentration in the spiked soil sample, TTP1-S, was 101.5 mg/kg. Spiked soil specimens were then treated with 2% by weight cement and 0.5-4% by weight FLUORO-SORB™ 100. Six 500g monoliths were formed and separate 64-day tank tests conducted on each per EA NEN 7375:2004/US EPA 1315. In the US EPA 1315 tank test, each treated soil monolith was placed in a water bath and then removed after periods of 6-hr, 24-hr, 2.25 days, 4 days, 9 days, 16 days, 36 days and 64 days. The water bath was then analyzed for contaminants that have leached out of the treated soil monolith and into the water. The water bath was replaced to start the next time period and the process was repeated.

Test results of leach water of TTP1-S treated with 2% cement and 0.5% FLURO-SORB® 100 adsorbent after 6-hr, 24-hr and 2.25 days were all:
- Aliphatic TPH < 1.0 ug/l (below detection limit)
- Aromatic TPH < 1.0 ug/l (below detection limit)
- PFOA < 50 ppt (below detection limit)
- PFOS < 50 ppt (below detection limit)

Tank tests for the higher adsorbent media loadings, up to 4% FLURO-SORB® 100 adsorbent, were also below detection limits; therefore, FLURO-SORB® 100 adsorbent did not show any signs that overdosing was detrimental.

In summary, the test results showed that FLURO-SORB® 100 adsorbent is an effective additive for in-situ solidification stabilization of PFAS con-
taminated soil, even when the soil has TPH co-contaminants. Granular activated carbon (GAC) can be fouled by TPH and reduce its PFAS adsorption effectiveness. Thus, there may be an advantage to using FLUORO-SORB® 100 adsorbent instead of GAC as an additive in PFAS in-situ solidification stabilization applications.

With IER and GAC determined to be less effective due to the known co-contaminants, the team selected CETCO FLUORO-SORB® adsorbent as the most effective sorbent additive to use in their remediation plan. An NSF-certified treatment media, FLUORO-SORB® adsorbent handles PFAS effectively and economically, specifically targeting and adsorbing PFAS in groundwater and soil. It was found to be particularly appropriate for use at the fire training site, as it treats the full spectrum of PFAS without being affected by co-contaminants such as diesel, BTEX, TCE, hydrocarbons, 1.4 dioxane, natural organic matter, diesel, and saltwater.

REMOVAL AND REMEDIATION PLAN
PFAS remediation using CETCO FLUORO-SORB® adsorbent, can take any of several forms:

- As a flow-through filtration media for drinking and groundwater
- As a component in sediment capping within a CETCO REACTIVE CORE MAT® composite geotextile mat
- As part of an In Situ Stabilization and Solidification (ISS) solution to immobilize the PFAS at the contamination site
- As a Permeable Reactive Barrier between contaminated area and downstream water sources to filter water of contaminants as they move though the permeable barrier

With their findings and understanding of the specific circumstances of the fire training site, including the soil type and level of contamination (which determines the size of sorbent particles required) and the type of groundwater present (which indicates both how much the contamination may be carried by groundwater movement), the team selected a solution that included excavating and disposing impacted soil and treating near-surface soil through ISS, utilizing cementitious binders and FLUORO-SORB® 100 adsorbent.

Methods for ISS include permeation grouting, soil mixing, and jet grouting, each with its own particular advantages and applicability, depending again on the specifics of the site.

- Permeation grouting is the least destructive method, involving the drilling of small holes and injecting a slurry mixture (typically FLUORO-SORB® and concrete) to permeate the ground at targeted depths. This method is effective for mass treatment and containment, and is safe to use in proximity to buildings and other structures.
- Soil mixing involves mechanical rotary mixing of the contaminated soil, either dry or wet. Because of the sizable machinery required, this method cannot be used in proximity to structures and requires substantial overhead space.
- Jet grouting requires highly specialized equipment to inject the slurry mixture at high pressure and mix it with the soil at targeted depths. Also good near structures, jet grouting equipment requires minimal headroom and can be used even in the basement of a building. This method is good for mass treatment with minimal disruption to the soil.

PFAS REMEDIATION SUCCESS TO SAFEGUARD THE COMMUNITY
As a result of the remediation team’s research and careful evaluation, a plan has been presented to address the PFAS contamination taking into consideration the unique circumstances of the fire training center. FLUORO-SORB® and REACTIVE CORE MAT® are registered trademarks of Minerals Technologies Inc. or its subsidiaries.
Proven PFAS Removal from Soil, Groundwater, and Drinking Water

FLUORO-SORB® Adsorbent

- NSF-Certified
- More Adsorptive than GAC
- Proven to Treat All PFAS
- Resists Competitive Adsorption
- Versatile Deployment Strategies

Easily incorporate into your existing remediation strategy:
- In-Situ Stabilization and Solidification
- Permeable Reactive Barrier
- Sediment Capping
- Pump & Treat

To obtain a free sample for your laboratory treatability study, contact cetco@mineralstech.com or visit pfas.cetco.com

THE EXPERTS IN REMEDIATION TECHNOLOGIES
The convergence of climate change and global conflict has created conditions throughout the world that threaten water security, and as a result, human security on a scale never before seen in recorded history. In every corner of the world, access to water has been impaired, affecting human health and even survival. Access to safe drinking water and sanitation are essential for human habitation, and without these resources human security becomes compromised.

WATER SECURITY
According to the United Nations (UN), water security is defined as “the capacity of a population to safeguard sustainable livelihoods, human well-being, and socio-economic development for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.” (Salik, 2015). Even though it was implicit in previous covenants and declarations of human rights, the July 2010 UN Resolution 64/292 was the first time that human right to water and sanitation was explicitly acknowledged (United Nations, 2010). Despite this progress, water is less secure now than it was a mere generation ago.
As the global population increases, resulting in 50% increase in water withdrawals by 2030, the 780 million people currently without access to improved drinking water and 2.5 billion without access to improved sanitation will increase as well. Three quarters of the global population is served by 260 major rivers, shared by two or more states, many of which are experiencing reduced flow rates (Wouters, 2010). It is not surprising, therefore, that organizations ranging from the Global Water Partnership, UNESCO’s Institute for Water Education, the World Economic Forum, the North Atlantic Treaty Organization (NATO), and others

### TABLE 1: SUMMARY OF CASE STUDIES

<table>
<thead>
<tr>
<th>CASE STUDY</th>
<th>LOCATION</th>
<th>WATER CHALLENGES</th>
<th>ENVIRONMENTAL CHALLENGES</th>
<th>POLITICAL CULTURE</th>
<th>CASE STUDY</th>
</tr>
</thead>
</table>
| Arab Spring                 | Middle East North Africa | • Drought  
• Water rationing  
• Lack of access to water | • Extreme weather more common  
• Desertification | • Mismanagement of resources  
• Manipulation of water access | • Over 50% of food imported  
• Lack of work in generational farming and cities  
• Climate migration |
| Syrian civil war            | Middle East            | • Experienced one of the worst droughts in history (2006-2011)                    | • Prone to drought  
• Water scarcity | • Corruption and mismanagement of resources  
• Manipulation of public access to water | • Tens of thousands of climate migrants  
• Crop yields drastically dropping |
| Libyan civil war            | North Africa           | • Intrusion of seawater due to over extraction  
• 93% of water used for agriculture | • Depleting coastal freshwater aquifers | • Power Struggle over control of water  
• Political factionalization due to water access | • Growing agricultural industry  
• Oil conflicts |
| ISIS Caliphate, Iraq, and Syria | Middle East | • 2nd highest rate of groundwater loss in Tigris-Euphrates Basin between 2003-2009 | • Drought  
• Shrinking aquifers | • Turkish and Iranian control of Tigris headwaters.  
• Regional political destabilization | • ISIS attempting to control dams to provide water and electricity to their new subjects |
| Yemeni civil war            | Middle East            | • One of the most water scarce countries  
• Water has been shut off to most Yemeni homes | • Prone to drought  
• High vulnerability to climate change | • Failed state: completely lawless  
• Compounded by a regional proxy war | • Humanitarian aid relied on for water & food  
• 19.3 million without access to clean water and sanitation |
| Ethiopia’s Grand Renaissance Dam | North Africa | • Conflict over allocation of water from the Nile River  
• Water shortages | • Land degradation  
• Water scarcity | • War threatened by Egypt if GERD put in service  
• Regional political destabilization | • Threat to Egypt’s primarily agricultural economy |
| Sri Lanka                   | South Asia             | • Dependence on water for irrigation  
• Irrigation centrally controlled | • Deforestation  
• Water pollution  
• Coastal erosion | • Ongoing civil war vulnerable to environmental terrorism | • Large share of population lives slightly above poverty line |
including the U.S. Environmental Protection Agency and National Intelligence Council have prioritized research in water security (Cook & Bakker, 2012), (Bakker, 2012).

Consequently, research and publications in the area of water security have steadily grown over the past decade. These discussions have included multiple sectors, scales, external drivers and key responses to contextualize the challenges of water insecurity and offered solutions ranking from managing risks, to considering rights, and promoting sustainability and adaptation (Jepson et al., 2017). Various frameworks have also been recommended to advance our understanding of water security. For example, Larson argues that a water security paradigm may provide a better argument, where the climate change construct fails to progress toward the common goals of addressing food, energy, and water insecurities (Larson, 2017). Others have been extensively covered by (Cook & Bakker, 2012), (Jepson et al., 2017) and others.

**CASE STUDY APPROACH**

In this article, we use a case study approach to underscore the relationship between water degradation and security. In some cases, water insecurity causes unrest. In other cases, a lack of human security, caused by social unrest, political ideologies, violence, and terrorism have adversely impacted a region’s water resources.

The first case study covers global food prices, drought, and the Arab spring. The Middle East and North Africa are one of the top food importers, with more than 50% of food imported (PBS, 2011). As climate change drives extreme weather in countries exporting food, this causes an increase in food prices for importing countries. This is one of the many pressures this region is facing, as well as food scarcity, water rationing, crop failure, migration, and urbanization. Mismanagement and resource scarcity have played a central role in the citizens’ frustrations against their central governments. Water plays a large role in these frustrations as the lack of access to water continues to be manipulated by major players in conflicts; worsening the humanitarian crises that are already present.

In Tunisia, North Africa, uprisings started in a rural area where many small farmers live and were simply trying to support their families. The uprising in Tunisia was begun by a young man setting himself on fire to protest corruption (PBS, 2011). Many see this as the beginning of the Arab Spring.

In Egypt, approximately 32% of the population works in agriculture, many as small farmers wanting to pass down their land to the next generation (PBS, 2011). However, with growing issues from climate change and resource scarcity, the land cannot support second or third generation farmers and they are forced to move to the cities. These climate migrants are further frustrated when they also cannot find work in the...
cities and will then demonstrate against the government. This pattern has repeated itself throughout the Middle East-North Africa (MENA) region, including in Syria.

The Syrian uprising started in Daraa, in the center of the Horan plains, which is one of the centers of wheat and wheat farming in that region of the world (PBS, 2011). For five years leading up to the civil war, Syria experienced one of the worst droughts on record. In eastern Syria, the water shortages killed upwards of 85% of the livestock, the average crop yields by 23% in irrigated areas and 79% in rain-fed areas (Northrup, 2017). This destroyed the livelihoods of 800,000 Syrians and created tens of thousands to climate migrants (Northrup, 2017). The impacts the Syrian people felt by this drought were exacerbated by corruption and mismanagement of resources.

Several times in the ensuing years in Syria, water has been used as a weapon during the civil war. In late 2011, the Islamic State, rebel factions, and the Syrian regime all used water access as a military weapon. In early 2012, rebel forces took control of the Ain al-Fijeh natural spring, which supplied many loyalist neighborhoods in Damascus (Northrup, 2017). This allowed rebels to deter regime advances by threatening to cut water off to the capital. Finally, in July 2015, the rebel Wadi Barada Shura Council stopped all water-services to Damascus in retaliation for the regime’s attacks on Zabadani (Northrup, 2017). These examples directly show how water can and will be used as a weapon, especially in resource scarce areas.

The Libyan civil war showcases another case of the weaponization of water in a struggling region. Extraction of freshwater has caused the intrusion of seawater into the freshwater aquifers since the 1930’s, with estimates showing 60% of the freshwater wells have been compromised (Alexander, 2020). Furthermore, a growing agricultural industry is fueling the freshwater shortage, with approximately 93% of the country’s water used for agricultural purposes (Alexander, 2020). Water availability has also been impacted as a result of oil conflict. Gunmen forcing water-workers to turn off supplies in Tripoli for two days added to the violence, along with the country’s power grid and water control systems suffering damage from the violence (Alexander, 2020).

Iraq, Syria, and the ISIS Caliphate all have links to weaponizing water. Most notably, in August 2014, ISIS took control of the Mosul Dam in Iraq. This could have impacted up to 500,000 people (Wilson Center, 2019). ISIS’ stated goal was the end of the Iraqi state, and to replace it with a new Islamic Caliphate. ISIS set out to deliberately control the nation’s dams as a tool of terrorism. Capturing the country’s dams would allow ISIS to deprive Baghdad and the Shi’ite farmlands south of the capital of much needed water for drinking and irrigation, and thus give ISIS the ability to provide water and electricity produced by facilities to their new subjects (Collard, 2014). Fortunately, Kurdish peshmerga fighters led the ground offensive to retake the Mosul Dam. ISIS has also used control of the Fallujah Dam to flood adjacent lands and cut water to south and central Iraq (Collard, 2014).

Prior to its ongoing civil war, Yemen was already classified as one of the world’s most water-scarce countries. Five factors play a pivotal role in Yemen’s water crisis: high population growth, short sighted agricultural development and policies, the use of water to grow non-essential crops, (like qat, its cultivation
requires 40% of the country’s water supply), a lack of water use regulation, and a high vulnerability to climate change (Alimehri, 2016). Most of the population relies solely on humanitarian aid to receive water, which was become increasingly scarce due to difficulties in delivery as violence escalates. There have been reports of the Houthi and Saudi forces blocking deliveries of humanitarian aid, containing both food and water. In February 2016, Saudi planes bombed and destroyed a reservoir containing about 5,000 cubic meters of water, which supplied 30,000 people with drinking water (Douglas, 2016). Reports have also stated guards at Houthi-controlled checkpoints around the city of Taiz have been confiscating water from civilians (Douglas, 2016).

The Grand Ethiopian Renaissance Dam (GERD) on the Nile River in Ethiopia is another example of the weaponization of water. Tensions among Egypt, Sudan, and Ethiopia have escalated after Ethiopia announced the beginning stages of filling the dam’s reservoir. This action goes against Egypt’s protestation that the dam not be filled without a legally binding agreement over the equitable allocation of the Nile’s water (Mbaku, 2020). Tensions have continually escalated since Ethiopia began construction of the GERD in 2011, while Egypt has threatened war if the dam is put into service. Ethiopia’s highlands supply more than 85% of the water that flows in the Nile River, and has long argued its right to the water (Mbaku, 2020). Ethiopia has argued the GERD will not significantly affect the flow of water into the Nile, but Egypt still sees the dam as a major threat to their water security, as the Nile is the main source of Egypt’s commercial and household water uses (Mbaku, 2020).

The last example highlights the weaponization of water during the Sri Lankan civil war. During the civil war, the farmers of Mavil Aru had to fight the militant organization known as the Tamil Tigers for their water resources. In July 2006, the Tamil Tigers closed the sluice gates of the region’s eastern reservoir, which cut off water to more than 60,000 people (Williams & Weaver, 2009). This prompted the government to launch its first major offensive on Tamil Tiger territory since the 2002 ceasefire (Williams & Weaver, 2009). The attack on Tamil Tigers that followed by the Sri Lankan army is seen as a turning point in the civil war (Liyanaarchchi, 2016).

WATER SECURITY

Definitions of water security have evolved over time and across disciplines, with improvements that acknowledge the role of the human or social components in addition to the hydrological, economic, and political factors that have been increasingly become integrated, necessitating researchers from multiple fields to engage in addressing the challenges (Bakker, 2012). Even as a resource that transcends geographical boundaries, and with guidelines from a global body such as the United Nations on its management to ensure equitable availability and access, water security remains a national security issue. Development of tools such as Water Security Index after often limited by availability of data, as acknowledged by Capelli, who examined geographic water insecurity in clusters, where countries were divided into five groups ranging from very high levels of water security to very low levels of water security (Capelli, 2017).

For the United States, the Department of Defense has clearly stated that water security is a national security issue, recognizing the economic downturn linked to future reductions in water supplies and consequently in global food security efforts. Cousin used this to recommend that the US focus on collaborative efforts in the food-water nexus including supporting private-sector investments in these areas (Cousin et al., 2019). They also recommend ways to leverage US leadership in the area to reform governance and improve sustainability and strengthen research in these interconnected areas.

The case studies underscore the multidimensional challenges targeting water security. A comprehensive development focused approach that factors in collaboration across the technological, social, political, and economic landscapes will be critical to make work toward becoming water secure. It is in the national security interest of the United States, as well as the rest of the world, to focus on improving water security, and as a result, human security, to mitigate and prevent conflicts worldwide.

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Hormesis & Probabilistic Risk Assessment: Important Considerations

By Christopher M. Teaf, Douglas J. Covert and Michele M. Garber

The science and practice of risk assessment have progressed in some areas dramatically since the groundbreaking theoretical and applied approaches in the 1970s and early-1980s (Hoel, 2018; NRC, 1983; Teaf et al., 1995). This article treats important aspects of two areas which have received extensive historical and recent attention, and which have important implications: "probabilistic risk assessment" and "hormesis".

PROBABILISTIC RISK ASSESSMENT (PRA)
The standard "point estimate" or deterministic risk assessment approach avoids consideration of the fact that individuals within a given population exhibit a range of levels of exposure to environmental contaminants. The point estimate approach intentionally and sequentially applies conservative bounds to exposure assumptions, yielding a result that is much more restrictive than it otherwise would be, due to the compounding of multiple individually upper range assumptions.

The historical literature is large, demonstrating that the probabilistic approach recognizes inherent uncertainty and variability within specific aspects of the receptor population and allows for a reasonable and coordinated calculation of protective exposure or cleanup levels including susceptible subpopulations (Thompson and Graham, 1996; Bowers, 1999). In many instances, the incidental soil ingestion pathway is a dominant component of the risk estimates, including for dioxins.

In a site-specific Florida case study (Simpson et al., 2016), the exposure variables that define the soil ingestion pathway were treated statistically through PRA using a repetitive (Monte Carlo) sampling and simulation approach for the chlorinated dioxin compounds. The result of this approach is a population of simulated receptors, each with a single set of exposure parameter values and an associated Lifetime Incremental Cancer Risk (LICR) result. The risk values assigned to each receptor can then be summarized statistically and used to demonstrate that even the most exposed element of the population is protected.

HORMESIS
The term hormesis is well-established in the scientific literature, initially described in the early-1940s (Southam and Ehrlich, 1943), though many reports primarily were descriptive (Calabrese and Baldwin, 1998; Calabrese, 2004). Many historical studies addressed radiological effects, though many physiological, chemical and radiological examples in the US and abroad have expanded understanding and application of the phenomenon (Mattson and Calabrese, 2010; Calabrese, 2013; Calabrese and Mattson, 2017; Berry and Lopez-Martinez, 2020; Agathokleous et al., 2020; Jargin, 2020; Kabilan et al., 2020).
The term “hormesis” covers a wide range of phenomena representing one or more processes, including cellular repair, adaptation (cellular or biochemical), and biochemical stimulation processes such as sequestration, immunity, and metabolic degradation.

Hormesis holds that the fundamental shape of the dose-response curve is neither linear nor threshold, but rather U-shaped. The breadth and diversity of agents for which effects have been reported, and the variable degrees of response, support that different mechanisms are at work. For entire classes of chemicals in the medical arena, comparison of beneficial effects (therapeutic) against adverse effects (toxic) is a standard process which addresses mechanisms (Schulz et al., 2020).

The dilemma posed by accounts of hormesis, or at least reports of “paradoxical” responses over a range of doses for some agents, is that existence of the phenomenon is acknowledged, but there are difficulties in practical applicability. This especially is true in a regulatory context, where the paradigm of increasing response with increasing dose underlies virtually all state and federal risk-based programs regarding site remediation.

One tangible example is the federal Guidelines for Carcinogen Risk Assessment (USEPA, 2005) vs. practical realities as illustrated by discussions of application of the guidelines to the recommended Maximum Contaminant Level (MCL) for chloroform, a common byproduct of essential public water chlorination processes. The Guidelines discuss reasons for, importance of, and methods to address incorporation of information about toxicological mechanisms of action into carcinogen risk assessment, as an adjunct to or a replacement for the common linear modeling approaches.

A huge volume of relevant information is available on the toxicology, chemical behavior, and environmental occurrence of chloroform, yet there remains significant controversy regarding the concentration that is set as acceptable by the federal disinfection byproduct rules (0.070 milligrams per liter or 70 micrograms per liter, equivalent to parts per billion or ppb) based on noncancer endpoints. This is quite different from highly restrictive, often sub-ppb, targets established by some state agencies based on a presumed linear, no threshold, carcinogenic mechanism of action.

Many scientists view chloroform as an excellent example of just the situation envisioned by the USEPA Guidelines, particularly for putative nongenotoxic carcinogens. Reliance on default benchmark values creates interesting inconsistencies or potential conflicts with the conclusions of other entities, such as the U.S. Food & Drug Administration (USFDA), which makes recommendations for dietary intake of certain essential nutrients.

Selenium, for example, which is an essential antioxidant and enzyme component, has an oral Reference Dose (RfD), a lifetime protective noncancer value, of 5 ug/kg•day, while the upper end of the FDA dietary recommended range is 600 to 800x less restrictive (3 mg/kg•day for adult males, 4 mg/kg•day for adult females; 200 mg/day recommended intake and body weights of 70 and 50 kg). A similar oddity relates to fluoride, where thousands of U.S. municipalities intentionally fluoridate water supplies as a protective measure for teeth, yet cleanup requirements may be set for groundwater which contains less fluoride than present in municipal water.

At present USFDA can consider beneficial as well as adverse effects (Maynard, 2011; Gaylor et al., 1998). Similarly, USEPA has no formal policy regarding beneficial effects of low level exposures, but has the capability to take such information into account, given adequate detail (USEPA, 2005; Davis and Farland, 1998). A parallel approach is taken by the U.S. Consumer Product Safety Commission (CPSC), which has a mechanism in place to address specific cases (Babich, 1998), but such instances are rare in practice. The Agency for Toxic Substances and Disease Registry (ATSDR) acknowledges the value of such information, and has taken it into consideration in its decisions concerning agents such as essential nutrients chromium, manganese and zinc (De Rosa et al., 1998). Personal experience, and review of selected state environmental regulatory agency guidelines (Jones, 2010; Rodricks, 2003), suggests that mechanisms of action often receive limited treatment in standard or guideline setting.

**NUTS AND BOLTS**

When considering how regulatory agencies should or could address concepts of adaptation and beneficial low dose effects, one is inevitably faced with examples such as arsenic. This metal, in organic and inorganic forms, has been extensively studied. Yet the complexity of the “bad vs good” issue has been elevated for arsenic.

Acknowledging the historical crisis in Bangladesh, where millions were affected by high levels of arsenic in drinking water (Lepkowski, 1998), we also see reports
of arsenic trioxide causing remission of one form of leukemia in patients receiving 0.15 mg/kg•day (Soignet et al., 1998). In addition, arsenic is one of the substances with the Gordian Knot-like situation of regulation as a Known Human Carcinogen by a variety of agencies, while also being regularly present in the diet and even exhibiting plausible evidence of essentiality (Hughes et al., 2011; Snow et al., 2005; ATSDR, 2007; ATSDR, 2016; USEPA, 1988; NAS, 1977).

Given these characteristics, coupled with its dominant role influencing cleanups at many sites, arsenic may represent a useful case for documentation of important distinctions between low dose and high dose effects. Arsenic also has been the subject of PRA evaluations of interest (Boyce et al, 2008).

Another area of important research and practical application is that of the quantitative modeling that is used to develop Cancer Slope Factors (CSFs), and to a lesser degree RfDs. The overwhelming majority of CSFs have been developed on the linear or linearized no-threshold model format for toxicological actions at very low doses. Therefore, it would be useful to address agents such as arsenic, with large underlying exposure databases, in order to reconcile dilemmas described earlier in this section.

Revisiting the foundation by which most arsenic environmental decisions are made (e.g., as a carcinogen using a very restrictive CSF) may assist in addressing criteria such as those in U.S. EPA Region IV, Region VI, Region IX and many individual states where default recommended residential soil cleanup criteria in the range of 0.4 to 0.8 mg/kg are associated with arsenic intakes (<0.1 mg/day) that are several orders of magnitude less than common arsenic dietary intake (10 to 50 mg/day), and perhaps below potentially beneficial effects as well (Boyce et al., 2008).

**SUMMARY AND CONCLUSIONS**

Many, notably Aldous Huxley, have observed that “facts do not cease to exist because they are ignored.” This applies both to hormesis, where the standard risk assessment paradigm of “higher dose - higher risk” proves not to be true, and to PRA where it is no longer essential to assume a series of individually conservation exposure assumptions layered upon one another, rather than applying what we know about statistical ranges of human exposure-related behavior. The issue concerning hormesis is not so much whether information regarding the phenomenon, mechanistic data, and demonstration of beneficial effects of low dose exposures should be taken into consideration, but rather how to accomplish that in the context of extant regulatory frameworks and practices, or how to develop new paradigms.

In principle, regulatory agencies have noted that incorporation of such information is plausible under existing procedures at environmental agencies, by invoking the “case-by-case” provisions for risk assessment that are present in many state and federal rules. However, it is necessary to acknowledge the difficulty inherent in practical implementation of that suggestion, and to provide adequate detail and reproducibility in the data to persuade regulators that such decisions will not put the public at risk.

Beyond historical searches of the technical literature that seek to identify inverse dose/response curves, apparently paradoxical results, and other evidence of hormetic effects, the most constructive approaches are likely to include technically solid, quantifiable demonstrations of these phenomena, presented as practical precedents that an agency or multiple agencies can implement in existing programs. Such examples have been successful in application of PRA, and they can be for hormesis as well. There should be no doubt regarding the existence of beneficial effects of chemicals at low doses. Successful individual instances of persuasive evidence should receive continuing attention, as described previously herein.

In the case of PRA, the goal remains the incorporation of what we know to be true of statistics regarding human exposure variability into our considerations of what constitutes a “safe” or “acceptable” set of circumstances. All risk-based decisions carry with them both health-based considerations, and economic considerations. If it is possible to demonstrate an equivalent level of protection at a less restrictive environmental remediation target, then the cost is virtually certain to be lower. Evidence is mounting that information and techniques are available to accomplish that goal, and that it often is not necessary to push cleanup criteria ever numerically lower.

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Update on Reducing Vapor Intrusion Uncertainties by More Frequent Simple Measurements and Community Involvement

All conventional methods for assessing and managing vapor intrusion (VI) rely on assumptions about temporal and spatial variability. Building-specific measurements such as temperatures, pressures, and indoor radon levels, when properly implemented, can be relatively-easily and cost-effectively applied to better understand these uncertainties, improving both initial and long-term VI assessments and management, and enabling more reliable, quantifiably confident, defensible, and protective VI decisions.

This session will expand the critical evaluation of existing data-rich studies of indicators, tracers, and surrogates (ITS), including temperatures, pressures and radon, as an alternative technology to improve current VI sampling practice. Previous workshops, and papers have defined ITS concepts and described our current understanding of on how VI ‘drivers’ such as temperatures and pressures affect chlorinated volatile organic compound (C VOC) VI and its assessment. In this session, the emphasis shifts to indoor radon levels and how they can relate to indoor CVOC concentrations from VI. To do so we investigated how both CVOCs and radon are affected by temperature differentials, pressure differentials, and changes in barometric pressure, and how indoor (and differential) radon levels can help us estimate CVOC concentrations in indoor air from VI.

This review has shown that the relationships between these variables and CVOC VI are building specific, generally nonlinear, and sometimes monotonic. Summary presentations will include false-negative and false-positive rates for conventional ‘random’, as well as seasonal, sampling events versus ITS-guided sampling results. This session will also discuss how ‘at risk’ communities could voluntarily apply these simple ITS measurements (for example, through citizen science programs) to help ensure that Environmental Justice and other community concerns are being adequately addressed. The session will also provide updates on EPA-ORD research including soil vapor extraction (SVE) to control VI exposures, VI in large buildings, and potential VI for some PFAS (per- and polyfluoroalkyl substances).

Integrated Large-Scale Green/Sustainable Remediation of Chlorinated Volatile Organic Compounds and Perchlorate in Soil Bermite Facility, Santa Clarita, California

The former Bermite facility (the Site) comprises 996 acres and historically was used for manufacturing of flares, fireworks, munitions, and rocket motors beginning in 1934 and continuing until operations ceased in 1987. Soil and groundwater at various operations areas at the Site were impacted by volatile organic compounds (VOCs), perchlorate, and to a far lesser degree, metals. VOC con-
centrations in soil in 20 areas warranted remedial measures based on exceedances of risk-based threshold concentrations (RBTCs) established for the Site. Many of these areas were also impacted with perchlorate in excess of RBTC and/or soil screening level (SSL). Based on pilot studies, soil vapor extraction was determined to be the most effective and efficient technique for VOCs remediation of the impacted soils.

Several technologies were considered and evaluated in laboratory and in field pilot studies for remediation of perchlorate-impacted soils. Due to the large-scale nature of soil impact areas, attention was given to understanding potential negative effects of the remedial activities on the surrounding communities and environment (i.e., air, surface water, and groundwater). Compared to the alternative of large-scale transport and off-site disposal of perchlorate-impacted soils, or large-scale soil washing or amendment flushing, the on-site treatment and destruction of perchlorate by enhanced biological treatment has been highly efficient, with substantially lower negative impact on the environment and surrounding community.

SVE units were successfully operated in areas of VOC impact to reduce concentrations appropriate for perchlorate excavations and ex-situ bioremediation. Perchlorate-impacted soils were excavated and transported to treatment pad areas (TPs) where stockpiled soils were screened and conveyed to one of two pug mills operating in parallel where an amendment solution consisting of water, glycerin (electron donor), and di-ammonium phosphate (DAP) (nutrient) were added and thoroughly mixed with the soil. The amended soils were conveyed from the pug mills into the treatment cells on TPs, covered with tarps, and secured to minimize contact with air. More than five million tons of soil with perchlorate concentrations exceeding the RBTC and/or SSL needed to be excavated and treated. The depths of excavations for ex-situ perchlorate treatment range from approximately 5 to 45 feet.

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Sustainable Groundwater Remediation at Coal Ash Pond Sites
Due to the growing concerns with global climate change, exploding population, and rapid urbanization, incorporation of the principles of sustainability and sustainable development has become indispensable in engineering projects/products/solutions. The large amounts of resources and energy used in infrastructure and environmental projects provides major avenues for inclusion of sustainable practices in engineering designs and substantially contribute towards global sustainable development. In order to achieve this, it is essential to quantitate the sustainability of the design alternatives and identify the most sustainable design to implement in a project. Realizing this need, several qualitative and quantitative tools have been developed over the years to evaluate the design alternatives for their environmental sustainability but with no or less regard to economic and social aspects of sustainability. However, for sustainable development it is crucial to consider all of the broader environmental, economic and social impacts of the design alternatives and a life cycle approach for a holistic assessment of sustainability.

This study presents a new framework for quantitative assessment of life-cycle sustainability (QUALICS) for sustainability assessment of alternative options or designs in engineering projects. The framework integrates two multi-criteria decision analysis methods, namely the Integrated Value Model for Sustainable Assessment (MIVES) and Analytic Hierarchy Process (AHP), to support decision making on the potential design alternatives. A brief overview of the framework is presented, and the applicability of the framework to evaluate sustainability of groundwater remediation options at coal ash pond sites is explored with an example case study. Finally, the implications of sustainability assessment on the remedial decisions are highlighted.

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Transitioning from Active to Passive Remediation by Refining the CSM Using Existing Data
This case study examines how existing data were applied in order to transition a combined petroleum site from active remediation to MNA. Multiple remediation tech-
ologies have been implemented at the site, including excavation, LNAPL recovery, AS, SVE, DPE, and oxygen injection (OI). In 2015, four remedial systems (two DPE and two OI) were operating near source areas and downgradient portions of the groundwater plume. LNAPL monitoring and recovery were conducted on a monthly basis. The monitoring program consisted of approximately 90 monitoring wells sampled at various frequencies from quarterly to annually.

As part of a sustainability effort to optimize remediation systems, the effectiveness of each system was evaluated using various assessment tools. Prior to initiating activities, routine meetings were conducted with the regulatory agency to establish a communicative and transparent relationship. Existing data were used to evaluate mass discharge rates over time at multiple transects to determine ongoing benefit of remediation systems that mainly relied on mass transport through treatment areas. A limited soil vapor risk assessment was performed, and results indicated that remaining soil and groundwater impacts did not pose a VI risk for current and future land use scenarios. Studies suggested that natural attenuation rates in groundwater exceeded mass discharge and were sufficient to achieve remedial objectives. Remaining contaminant mass is predominantly stored in fine-grained lithology with low risk of transport to nearby sensitive receptors.

Through evaluation of existing data, rebound testing of pilot shutdowns, and transparency with the regulatory agency, each system was approved for shutdown by the end of 2018 and LNAPL recovery was suspended in 2020. Recently, a plume stability analysis was performed to optimize the monitoring well network. The regulatory agency approved an approximately 40 percent reduction in the well network and a decrease in monitoring frequency to annual sampling.

Scott Stromberg, P.G., is a Senior Project Geologist with Orion Environmental Inc. in the Bay Area.

This presentation will examine the evolution of corporate sustainability and ESG in the context of growing environmental and social awareness. We will look at opportunities and actions corporations can take to improve their sustainability footprint and ESG ratings, and avoid being the target of environmental and social activism.

Roy Thun is professional geologist, certified sustainability professional, and accomplished environmental portfolio manager.

The Changing Landscape of Environmental, Social, and Governance (ESG) Expectations

Corporate sustainability statements and Environmental, Social and Governance (ESG) ratings have rapidly become the key measures of corporate positions on climate change and sustainability. While the consumption of resources is part of society, the growing awareness of climate change and our impact on the planet has increased environmental and social activism. As a result, there is expanding interest by consumers, shareholders, financial institutions, and others to see companies meet, if not exceed, sustainability commitments, often as expressed in ESG ratings.

These groups expect improvements in corporate and industry behavior with respect to stewardship of natural resources, societal impacts, and Board of Directors accountability. When improvements are lacking campaigns for change have occurred through proxy votes, legal challenges, ballot measures and social media platforms.

Application of Lean Tools and Management Practic-es to Reduce Site Cleanup Costs: Case Study of a Large EPA Superfund Site Under the New EPA Accelerated Closure Directives

Many sites impacted with calcitrant chemicals have completed assessment and feasibility studies and implemented groundwater remedies over the past 30-plus years under the jurisdiction of Federal State and local regulatory agencies. The basis for deeming remedy completion on these sites is achieving published regulatory cleanup values such as Maximum Contaminant Levels (MCLS). While many small sites often meet these remedial objectives cost-effectively, large-scale groundwater plumes (greater than half a kilometer in length) pose a significant challenge for remedial technology selection, and as a result, typically default to implementing a pump and treat approach for plume containment. A review of large-scale Environmental Protection Agency (EPA) superfund site cases indicates that after 20+ years of treatment, over 95% have not achieved
MCLs, continue to have large diffuse plumes, and pose little or no human health or ecological risk. Further, these sites are not likely to achieve MCLs after an additional 25 years of treatment and hundreds of millions of dollars in cost. The lengthy and costly cleanup of these sites also results in lost redevelopment opportunities due to slow regulatory decision-making.

In an effort to streamline the regulatory compliance and decision-making process associated with these complex cleanup activities, Lean principals and tools commonly used to improve efficiency and value in the manufacturing and management consulting industries were used. Value Assessment, Value Stream Mapping, Gemba, Force Field, 5-Whys, Affinity Grouping, Impact-Difficulty, RACI, and A3 Improvement/SDS were used to deeply understand what the project stakeholders valued and quickly identify where “waste” elements existed and could be addressed. The process included all three primary project stakeholders: The Responsible Party implementing the cleanup, the lead regulatory agency, and the contractors implementing the work. Through a number of focused workshops and continuous improvement, significant opportunities for improvement were identified and progressively implemented. The initial application of Lean resulted in an improvement in schedule-items by up to 40 percent and cost savings of up to 30 percent. The continuous application of Lean thinking by the entire project team, combined with the plan-do-check-adjust cycle continues to find schedule and cost improvements each subsequent year.

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Update on California Water Board’s Per- and Polyfluoroalkyl Substances (PFAS) Actions
California State Water Resources Control Board is performing a state-wide investigation of per- and polyfluoroalkyl substances (PFAS) in public drinking water supply and in the subsurface. These are data gathering investigations at municipal solid waste landfills, airports, industrial facilities, and wastewater treatment plants. Investigations are also occurring around these sites involving the sampling of nearby public water supply wells. The State Water Board will provide an update on the status of these investigations and a summary of the data coming in along with some analysis.

Wendy Linck is a Senior Engineering Geologist at the State Water Resources Control Board (State Water Board).

Proactive Characterization of PFAS Impacts to Groundwater at Former Marine Corps Air Stations Tustin and El Toro, California
In 2016, the Navy identified multiple sites at Former Marine Corps Air Stations Tustin and El Toro that may have served as sources of per- and polyfluoroalkyl substances (PFAS) to groundwater as a result of the historical use of aqueous film-forming foam (AFFF) for firefighting operations and training. The top priority was to determine if Principal Aquifer (PA) groundwater extracted for potable use in areas cross/downgradient of El Toro was impacted. Subsequent priorities have included characterizing plumes in both the PA and overlying Shallow Groundwater Unit (SGU) and identifying potential source areas. The Navy and local water districts have collected and analyzed more than 170 SGU and PA groundwater samples for PFAS since 2016.

This has included groundwater extraction wells (both remedial and potable supply), influent and effluent of existing pump-and-treat systems that address volatile organic compound (VOC) impacts, and regional monitoring wells screened at depths ranging from approximately 20 to 1,100 feet below ground surface. Perfluorooctanoic acid (PFOA)/perfluorooctane sulfonate (PFOS) plumes were discovered in both the SGU and PA at El Toro at maximum combined concentrations of 5,310 and 700 nanograms per liter (ng/L), respectively, but drinking water remains unimpacted. PFOA+PFOS plumes were discovered in several locations at Tustin at concentrations up to 1,051,900 ng/L. Sources appear to be fire stations and crash crew training areas where AFFF may have been directly discharged to the ground surface or water-filled unlined pits. At El Toro, the SGU PFOA+PFOS plume has migrated laterally approximately 2 miles downgradient in a pattern similar to the existing VOC plume and has reached the deeper PA as a result of discontinuities in the aquitard separating the two aquifers.

Groundwater is much shallower...
at Tustin and PFOA+PFOS concentrations attenuate by several orders of magnitude with depth. The PFOA+PFOS plumes at both El Toro and Tustin are mingled with VOC plumes that pump-and-treat systems have been addressing for more than a decade. At Tustin, existing liquid-phase granular activated carbon systems are effectively treating PFOA+PFOS impacts, but at El Toro, existing air stripping systems are (not surprisingly) ineffective. The Navy is actively working with the local water districts to ensure that PA groundwater extracted for potable purposes remains unimpacted, but the current lack of enforceable standards has created legal and financial challenges.

Guy Chammas is a Lead Remedial Project Manager in the U.S. Department of the Navy Base Realignment and Closure Program Management Office in San Diego, California.

PFAS Food: How “Forever Chemicals” Impact the Food System
PFAS has taken the spotlight in emerging contaminant concerns. These long-enduring residuals pose health risks to humans, affecting development, the immune system, thyroid, kidney, and liver, and potentially increase the likelihood of cancer. Recent reports of PFAS contamination in the dairy industry have ramped up public concern and triggered regulatory action. The FDA has performed sampling and analysis for PFAS in a variety of foods as well as dairy products and found impact ranging from non-detect to levels many times higher than water standards or advisories. Recent data collected from Maine sheds further light on the potential for PFAS transference from soil/amendments to feed and cows/dairy.

This presentation will offer a brief overview of PFAS and explain how PFAS may enter the food system. Attendees will learn about common exposure routes as well as scenarios that make PFAS contamination a more likely concern. While some instances of PFAS discovery in agricultural products are tied to use of biosolids, the levels in biosolids as well as their potential for uptake into plants are up for debate; studies are underway. We’ll discuss root sources and how they enter the equation.

Examples will be provided with data and tables evaluating health risk as well as taking a deeper dive into some of the recently collected data and proposed or implemented action levels. The presentation will also outline a high-profile news story involving PFAS contamination on a dairy farm in Maine. In addition, we’ll address the difficulty of identifying a single source of PFAS.

The discovery of PFAS contamination poses significant outreach and communication challenges. The presentation will offer lessons learned in hazard evaluation and risk communication. Attendees will leave with an understanding of the necessary steps to follow discovery of PFAS, as well as tools for navigating testing, standard-setting, and risk communication.

Lisa Campe has over 25 years of extensive experience managing a variety of risk assessment and corrective action projects for clients in the public and private sectors.

PFAS – Basis, Application and Management Implications of California’s New Human Health and Ecological Screening Levels (ESLs)
In the absence of comprehensive federal guidance, numerous state agencies in the US are developing their own screening levels for the protection of human health and ecological receptors for individual PFAS compounds. California has developed both cancer and non-cancer toxicity values for PFOS and PFOA that lead to extremely low cancer-based screening levels. In May 2020, the San Francisco Region of the Water Board published Environmental Screening Levels (ESLs) for soil, groundwater and surface water that are protective of human health and terrestrial and aquatic biota. These ESLs are significantly more stringent than USEPA’s Regional Screening Levels (RSLs) and may also exceed reported levels of PFAS in the ambient environment.

This presentation highlights the technical basis of the proposed ESLs, and the practical implications and site management decisions that would arise from applying these ESLs at sites with PFAS investigations. The ESLs are compared to currently-available ambient PFAS data for environmental media in California based on Vedagiri et al (2018) and other subsequent data sources, as well as current analytical limits of detection, and screening levels from other sources.

Suggestions will be provided for how the values may be used and interpreted by presenting actual site data in comparison to these values and the role of analytical limits and
Post-Remediation High-Resolution Site Characterization

High-resolution site characterization is becoming more widely accepted as a preferred approach to site assessment in the environmental consulting and regulatory communities. For cases involving volatile organic compounds (VOCs) in groundwater, if remedial efforts do not completely remove or remediate the source of the VOCs, post-remediation monitoring may indicate persistent or increasing VOC concentrations in groundwater. In such cases, additional site assessment is typically required by regulatory agencies. The use of advance site characterization tools, such as the membrane interface probe (MIP) and hydraulic profiling tool (HPT), can be instrumental in helping to locate remaining source areas that were not discovered using traditional site assessment methods.

This presentation will provide a case study of high-resolution site characterization for a release of VOCs at a former circuit board manufacturing facility in Orange County, California. The source area was remediated by excavation and the case was closed in 2006, but the case was reopened in 2017 when a downgradient groundwater monitoring well indicated increasing concentrations of trichloroethene in groundwater. A high-resolution site characterization using MIP and HPT technologies combined with conventional soil and groundwater sampling was performed during 2017 and 2018. The investigation resulted in the discovery of a remaining source area that had not been detected during previous investigations or remedial excavation activities. The results of the investigation will be used to determine appropriate interim and final remedies for soil and groundwater.

Comparison of X-Ray Fluorescence Spectrometer (XRF) and Sanitary Epidemiological Station (SES) Laboratory Results for Environmental Assessment at Mercury Site in Kyrgyzstan

Doctors without Borders (MSF), the Ministry of Health of Kyrgyzstan (MOH), and TerraGraphics International Foundation (TIFO) have partnered to investigate environmental contamination at one of the world’s largest and last primary mercury production facilities in Batken Province, Kyrgyzstan. A key goal for project partners is to support the MOH’s local Sanitary Epidemiological Station (SES) Environmental Laboratory in their efforts to monitor environmental contamination in the region. In 2019, MSF, MOH, and TIFO partnered to conduct a human health risk assessment and collected over 600 soil, water, air, dust, and food samples.

During this sampling effort, a field-portable x-ray fluorescence spectrometer (XRF) was used as an in situ (undisturbed soil) screening tool at sampling sites. Ex situ-bulk (extracted homogenized soil) samples were collected at locations exceeding in situ screening criteria and analyzed again before laboratory analyses.

Once soil samples were sieved (Ex situ-sieved) and returned from the laboratory analysis, the samples were measured by the XRF a third time. In order for in situ XRF screening data to be useful for SES, a site-specific XRF conversion factor between the XRF and laboratory results was established. Using R statistical software, linear regressions were used to compare three different XRF measurements (in situ, ex situ-bulk, and ex situ-sieved) to the laboratory results for mercury in soil.

The results showed that XRF measurements that were either ex situ-bulk or ex situ-sieved and less than 60 mg/kg had the best correlation to lab results. The conversion factors between XRF results and laboratory results were established to be 1.90 (P-value= 2.874E-62, R2=0.85) for ex situ-bulk and 1.81 (P-value=6.649E-67, R2=0.90) for ex situ-sieved for the Batken Province. This information will enable SES to deploy the XRF as a low-cost and rapid screening tool to identify areas in the local communities.

Sandra Spearman is a graduate student in Environmental Science at the University of Idaho.
Managing Complex Sites with High Resolution Site Characterization and Focused Remediation

Background/Objectives: Recent groundwater characterization and instrumentation approaches have proven helpful in providing a sound and defensible Conceptual Site Model (CSM) to help design a range of different remedies to reach the overall goal at a complex site.

High Resolution Site Characterization: An integrated approach has been developed to use ultra-high resolution scanning technology and three-dimensional (3-D) data integration and visualization, to more effectively characterize baseline groundwater hydrogeology and contaminant distribution, and to identify microbially active subsurface zones as confirmed by Next Generation Sequencing. A former dry-cleaning site with dense nonaqueous-phase liquid (DNAPL) impacts (i.e., trichloroethene [TCE] and tetrachloroethene [PCE]) was remediated via excavation and injection. To evaluate remediation effectiveness, the site was further characterized using a proprietary electrical resistivity imaging (i.e., Aestus GeoTrax Survey™), and targeted confirmation soil borings.

The high-resolution data indicated that the injection program was partially successful in accelerating degradation of PCE and TCE at the site, particularly in the vadose zone. However, the ERI detected residual PCE and TCE at DNAPL saturation levels below the vadose zone and lateral to the injection plane. The consultants were provided with the means to reach the site clean-up objectives via a more focused remediation plan that showed precise location of DNAPL related hot spots that required additional remediation.

At another site, the U.S. Army Corps of Engineers’ consultant conducted a groundwater investigation and remediation design at Fort Ord, a former army base near Monterey Bay, in central California. Carbon tetrachloride had migrated from a shallow aquifer to two underlying aquifers. Historical flow directions in the deepest aquifer have varied significantly because of the effects of municipal and agricultural pumping, which have also resulted in regional seawater intrusion.

Even after dozens of standard monitoring wells had been installed, there were significant gaps in the data available. Multilevel wells were installed and gave a detailed interpretation of the contaminant distribution. This allowed the consultant to carry out agreed remediation. The availability of multilevel data also provided new insight into seawater intrusion in the area. Continued monitoring will indicate whether intrusion is continuing to migrate inland or if the county’s efforts to mitigate intrusion are effective.

John Sankey, P.Eng., is an engineer for True Blue Technologies.

The Background on Soil Background: Regulatory Frameworks and Guidance Documents Across the States

Site management decisions at chemically impacted properties are usually based on human and/or ecological risks. However, sometimes risk-based, protective concentrations for some chemicals in soil can be lower than concentrations present in the environment from natural sources or anthropogenic ambient background. In these cases, some regulatory agencies typically would not require responsible parties to clean up soils to risk-based levels but rather to background concentrations. Thus, evaluating soil background levels at a site and its implications for risk assessment can make a significant difference in overall clean-up time and costs.

A limitation in realizing adequate soil background chemical evaluations, especially as they apply to risk assessments, is that approaches vary widely across states. Some states have no guidance, others provide limited information, and many that do have guidance do not incorporate advanced statistical, geochemical or forensic methods that could richly inform the background evaluation. For this reason, the Interstate Technology and Regulatory Council (ITRC), a state-led-coalition of regulators, private sector, academia, public and tribal stakeholders, launched a new team in 2020 to develop guidance on conducting soil background studies for risk assessment.

Development of the ITRC guidance document included surveying state agencies and researching existing state guidance and policies on soil background evaluations and their use in risk assessment. In this presentation, we will summarize the current regulatory and guidance frameworks at the State level.

Kanan Patel-Coleman, Burns and McDonnell, Los Angeles, Calif., Joann
The Use of Adaptive Management and High Resolution Site Characterization to Advance Closure at a Superfund Site

Adaptive Management principles can leverage outputs from recently developed High Resolution Site Characterization (HRSC) technologies. This presentation will discuss how adaptive management principles were used with HRSC technologies to advance site closure at the Commerce Street Plume Superfund Site in Williston, VT. This site is contaminated with TCE and its reductive daughter products beneath a mixed-use area, with a multi-component remedy selected by the ROD.

The remedy for this site features ISCO for TCE concentrations greater than 50,000 ug/L, ISB where TCE is greater than 500 ug/L but less than 50,000 ug/L, and MNA where TCE is less than 500 ug/L. A comprehensive pre-design characterization program was implemented using the latest in HRSC technologies [specifically the membrane interface probe/hydraulic profiling tool (MiHPT) and Waterloo Advanced Profiling System (APS)], vertically discrete soil/groundwater sampling, and onsite laboratory analysis. This intensive characterization program was coupled with 3-D visualization to update the CSM in real time in order to guide subsequent portions of the investigation. In addition, a field pilot program was conducted to evaluate the best amendment injection strategy for the site and to assess overall ISB performance under field conditions.

The characterization and subsequent 3-D visualization of the site lithologies revealed that lower permeability silts are directly impacting contaminant transport in some areas of the site. In areas of the site where high concentrations remained, the profiling revealed the presence of previously unidentified silt layers interbedded within the sand unit. Importantly, the characterization program showed that the 50,000 ug/L hotspot is no longer present. This implies that the entire ISCO remedy component is no longer needed, and that the entire site can be treated with ISB and MNA, which represents a savings of up to $3 million.

In addition, results from the pilot study revealed extremely slow amendment transport and variable groundwater flow directions in some areas of the site. The implication was that the previously designed biobarriers would be troublesome to maintain and would require many re-injection events. To account for this, in the downgradient portion of the site, the remedy was adapted to feature permeable reactive barriers installed using one-pass trenching and filled with a carbon-zero valent iron mixture, rather than using standard injection wells to introduce an EVO.

Ryan Wymore is an associate with CDM Smith in Denver, CO, where he serves as the West region manager for the firm’s Environment and Technology Group.

A Digitized Heat-Pulse Flowmeter for Detailed Complex In-situ Flow

Reworked urban sites often contain complex groundwater flow through buried rubble piles, old utility pathways, decayed foundations, and abandoned roadways. The Model 40-D GeoFlo heat-pulse groundwater flowmeter provides immediate, on-site, determination of direction and groundwater flow rate. Flow is plotted in vector arrays and can be cross-correlated with waterheads for hydraulic conductivity variability. The direct velocity measurements, combined with concurrent water elevation measurements can identify local recharge conditions caused by water mains, septic systems, or storm drains.

Field measurements take only 15 minutes. Usually four, 10-foot screened wells can be profiled (three vertical locations each) during an eight-hour day. Recordings are automatically recorded on a memory chip. The memory chip can use a special program for analysis and plotting data across a site map. Mean vector sums for direction and depth can be depicted. Cross-checks can be performed on borehole logs for adequate formation hydraulic conductivity. Heat dispersal characteristics can be tested to determine closeness of fit to a cosine relationship. Time recordings can be done for flow near ocean shorelines or isolated pumping events. Examples of site characterization are shown

William B. Kerfoot is president of Kerfoot Technologies, Inc. located in Mashpee, Massachusetts.
Supplemental Guidance: Four Steps to Protect People Faster

In February 2020, the Department of Toxic Substances Control and the California Water Boards released “Supplemental Guidance: Screening and Evaluating Vapor Intrusion” as a draft document for public review. This presentation will summarize the content of the supplemental guidance, the main comments received, the changes in the works to address the comments, and the anticipated timeline to finalize and roll out the supplemental guidance.

The supplemental guidance was developed by a joint agency workgroup to promote a consistent approach to evaluating vapor intrusion (VI) throughout the State of California. The guidance presents a four-step process designed to evaluate vapor intrusion early in the investigation of a release site and protect people faster: first, prioritize buildings and select the sampling approach; second, evaluate vapor intrusion risk using soil gas data; third, evaluate VI using concurrent indoor air, subslab, and outdoor air data; and fourth, assess the risk to current and future occupants and make management decisions.

During the public comment period, which ran through June 1, 2020, the team received over 500 comments on the document. The comments represented a range of perspectives, from asking for more flexibility to wanting more specificity. The presentation will discuss the top themes of comments, anticipated changes, states, and schedule.

Cheryl Prowell is a Unit Chief at the Department of Toxic Substances Control in Berkeley, Calif.

GeoTracker VI Database: Building a Database Through Implementation of the Supplemental Guidance

A component of the CalEPA’s Supplemental Guidance: Screening and Evaluating Vapor Intrusion is compiling data into a statewide database to better understand how human-caused and natural factors influence vapor intrusion. To facilitate constructing the database, the California Water Boards’ GeoTracker data management system has been updated to further differentiate vapor sample types and capture important building-specific information. Once GeoTracker has sufficient statewide vapor intrusion data, the State Water Board will evaluate the database to determine if California-specific attenuation factors are justified.

In this presentation, we will provide a brief history of vapor intrusion in GeoTracker, demonstrate how to correctly use the new features and capabilities in GeoTracker, and provide insight on the database going forward.

Tina Ures received her B.S. in geology from California State University, Sacramento.

A Community Perspective on the CalEPA Supplemental VI Guidance

Many community members find themselves in neighborhoods threatened by vapor intrusion. They are faced with a confusing tangle of information, including lofty goals written in guidance documents and other regulatory writings that do not seem to comport with the way their cleanup projects are actually carried out. As a consequence, many laypeople do not have faith that the state can protect them from exposure to toxic chemicals.

They see large corporations securing approval for soil vapor cleanup standards far above the screening levels specified in the Draft VI Guidance. They hear from regulatory staff that soil vapor concentrations above screening levels are “not that bad,” leading them to question why the state bothers to issue screening levels if they are not taken seriously. This is first a problem of consistency (i.e., vapor intrusion cases are handled very differently in different parts of the state) and second, a problem of communication and transparency. Launching the Statewide VI Guidance will help resolve the first problem, but to address the second problem more attention needs to be paid to communication and transparency in decision-making and the regulatory process.

Jim Wells is Principal Geologist and COO at L. Everett & Associates, and is a Professional Geologist licensed in the State of California.

Environmental Sampling to Evaluate Cleaning and Disinfecting Program Effectiveness

In the era of the COVID-19 pandemic, the “new normal” includes employee and customer expectations for physical distancing coupled with enhanced cleaning, sanitizing, and disinfection. Physical distancing compliance is obvious.
But how will we know if the cleaning, sanitizing, and disinfecting are effective?

The United States Centers for Disease Control and Prevention (CDC) has outlined cleaning and disinfecting procedures for several types of facilities, defining the terms as follows:

- **Cleaning** refers to the removal of dirt and impurities, including germs, from surfaces. Cleaning alone does not kill germs. But by removing the germs, it decreases their number and therefore the risk of spreading infection.

- **Disinfecting** works by using chemicals to kill germs on surfaces. This process does not necessarily clean dirty surfaces or remove germs. But killing germs remaining on a surface after cleaning further reduces the risk of spreading infection.

Cleaning and disinfecting (C&D) are separate, distinct and important steps. Cleaning removes dirt, grime, and surface contaminants that can otherwise render disinfectants ineffective against target infectious agents. Disinfectants require contact time to work. It is therefore important for the disinfectant to be applied to and remain on the surface in accordance with manufacturer’s label instructions. Thus, effective cleaning and disinfecting requires defined protocols that are understood and followed by cleaning crews if their work is to be effective.

With the increased attention to C&D, building owners and occupants are trying to understand if the C&D effort has been effective. Accordingly, a variety of methods have been developed to evaluate C&D effectiveness, including real-time analysis for biological residuals and specific methods for the detection of SARS-CoV-2, the virus that causes COVID-19.

This presentation will review C&D procedures and various methods to evaluate biological and viral residuals on surfaces, in the air, and in wastewater.

David Elam is a technically grounded environmental consulting professional who delivers business results.

### Implementation of Large Scale In-Situ Remediation Programs During the COVID-19 Pandemic

The implementation of site remediation programs requires extensive time and planning in order to have a successful and safe outcome. A successful project must effectively remove and/or destroy site contaminants; provide for an optimized reduction of the exposure of field personnel to hazardous contaminants, unsafe working conditions, and physical and biological hazards; comply with the relevant regulatory framework; and while fulfilling the expectations and demands of the different stakeholders.

All parties involved must recognize the different obstacles to implementing field remediation and to work together to find solutions that are in the best interest of all parties. With the onset of the COVID-19 pandemic, caused by a novel coronavirus (SARS-CoV-2), for which understanding of the methods of transmission have been evolving, entirely new and previously unknown obstacles have created additional and extensive procedures to ensure the safe work activities including, and not limited to mobilizing to the project site, daily field activities, overnight accommodations, and social distancing.

The presentation will include processes and approaches taken in planning and implementing remediation in March and April 2020, at the beginning of the declared pandemic, and will also include modifications made since. The presentation will detail field procedures specific to COVID-19 such as modes of travel, modified PPE, health monitoring programs, overnight accommodations, and the creation of additional sections within the existing HASP(s) and JSAs. Social distancing, and later the use of masks, were key factors in each of the updated procedures.

For many field remediation activities improved safety with lower potential for incident occurs when performed by more than one site worker. Therefore, procedures needed to be modified to allow social distancing and/or minimize potential for virus transmission when adequate interpersonal distancing needed to be less than 6 feet. Additionally, ISOTEC personnel deployed during the COVID-19 emergency response had site-specific details regarding their essential work assignment as a remediation worker and were required to have all documentation available upon request by Local, State or Federal personnel.

Tim Elber is based in Denver, Colorado and serves as Director of Western Operations and Project Manager with ISOTEC.

### Benefits of SARS-CoV-2 Virus Analyses of Wastewater and Pooled Saliva Samples
The global COVID-19 pandemic has affected all aspects of our communities, businesses, and the economy. Using existing technology, scientists can support efforts to combat this viral outbreak while a vaccine is being developed and deployed. SARS-CoV-2 (aka novel coronavirus) is the virus that causes the COVID-19 disease. Genetics laboratories have been using Reverse Transcriptase-quantitative Polymerase Chain Reaction (RT-qPCR) to analyze DNA and RNA for decades. Within the last year, this method has been modified to specifically analyze for the RNA of the novel coronavirus not only for clinical purposes but also for environmental samples.

Infected humans, whether symptomatic or asymptomatic, shed the novel coronavirus in their feces. Studies have shown that the novel coronavirus can remain detectable in wastewater for at least 48 hours. Recent efforts in Europe and the US have been able to successfully detect the novel coronavirus in wastewater using RT-qPCR and use these data to track viral baselines in a community. When infection rates go up, the viral loads go up. Analysis of saliva also has been used successfully for surveillance purposes. Saliva from up to 100 individuals can be combined into one “pooled sample” and analyzed for the coronavirus. By this method, many people can be screened with a single test. If the virus is not detected, the entire pool of individuals is considered to be free of the virus. If the virus is detected, then all individuals within that pool are individually tested using clinical RT-qPCR analyses to identify those infected with the virus.

Most interesting is that increases in viral loads can be observed in saliva and wastewater up to two weeks before infections are being reported in the community – because of asymptomatic and pre-symptomatic infected carriers who shed viruses prior to displaying clinical symptoms. Communities can use these data to issue stay at home orders, social distancing guidelines, business operating practices, mask usage directives, gathering restrictions, and other actions that are intended to stem the transmission of the virus. The effect of these measures can be monitored by the virus concentration in wastewater and saliva as well as epidemiological and clinical data.

Sam Williams is a senior principal hydrogeologist for Geosyntec Consultants with over 30 years of professional experience. Duane Graves, a senior principal scientist based in Knoxville, Tennessee, has over 30 years of experience in environmental chemistry, microbiology, and biotechnology.


Reducing the risk of exposure to SARS-CoV-2 relies on effective cleaning and disinfection, along with continued social distancing practices. EPA researchers are evaluating innovative ways to inactivate aerosolized virus and reduce airborne transmission of COVID-19 in large spaces, such as office environments and mass transit settings, that are intended for use in occupied spaces. Different devices and product technologies, including UV-C, chemical-based, and physical removal, will be assessed for their ability to reduce airborne virus concentrations in indoor environments. Researchers are also studying indoor air pathways to determine whether exhaled aerosols spread over distance in an office environment.

This work focuses on an “open office” or cubicle work environment where there is concern about the potential for direct movement of aerosols from an infected or asymptomatic individual to others. Researchers will test the impact of practical office modifications that could potentially reduce viral exposure. This information will provide stakeholders with data on the effectiveness of available products in reducing aerosolized SARS-CoV-2. Researchers are building on a foundation of research of SARS-CoV-2 surface disinfection in mass transit settings, working collaboratively with New York City Metropolitan Transportation Authority and the Los Angeles Metropolitan Transportation Authority to test real-world applications.

Dr. Katherine Ratliff is a Research Physical Scientist in ORD’s Center for Environmental Solutions and Emergency Response.


Granular Activated Carbon (GAC) treatment has been established as a reliable and effective solution to PFAS of current focus from water sources. As predictive modeling capabilities for PFAS adsorption is lacking in the industry, it is often recommended to test each source
water directly to gain an understanding of removal efficiencies and GAC usage rates. Often to capitalize on time and cost efficiencies, Rapid Small Scale Column Tests (RSSCTs) are utilized to assess treatment capabilities. As a relative comparison of PFAS adsorption between carbon types, the actual RSSCT column design parameters are less relevant if each column utilizes consistent parameters (column size, carbon size, assumed diffusivity, and flowrate). Thus, RSSCTs are effective and useful in this scenario.

The results herein show the performance of multiple GAC types for removing both “long-“ and short-chain PFAS. Beyond those results, also included is the performance of GAC for the removal of a suite of several of the most commonly reported PFAS precursor compounds, as well as PFOA and PFOS from ground water. Pertinent characteristics of these GACs, such as activity level and pore volume distribution, were measured and then compared statistically to their performance in the RSSCTs. For utilities and industries facing the need to treat for PFAS precursor compounds, knowledge of the relative importance of these GAC characteristics can be used to guide GAC selection and maximize treatment performance.

Though RSSCTs are widely used to predict large-scale operation for PFAS removal there is a limited understanding of their accuracy and shortcomings in this application. To this end, this work presents a comparison of RSSCT column operations under various operating conditions (mainly carbon particle size and resulting diffusivity assumption) to large scale columns operating with the same influent water. Moreover, the data set includes several different types of carbons, including bituminous coal and modified coconut shell. The results are a novel evaluation of RSSCT operations to validate the predictability of large-scale operations.

Adam Redding completed his Ph.D. in environmental engineering at Penn State University in 2008.

**In Situ PFAS Sequestration – Plume Management Strategies Using Colloidal Activated Carbon**

Colloidal activated carbon is emerging as a low cost in situ method to manage the risk associated with PFAS compounds in groundwater. By coating flux zones of an aquifer with colloidal activated carbon, a permeable sorption barrier is created in situ, and PFAS constituents from up-gradient source zones are rapidly sorbed. In this manner, colloidal activated carbon is able to increase the retardation factors of the migrating PFAS species by orders of magnitude and provide a strategy to passively manage PFAS plumes.

Data are presented from three field case sites where a single application of colloidal activated carbon resulted in orders of magnitude reduction in PFAS groundwater concentrations to below USEPA health advisory levels. Design considerations for plume management are discussed, including the potential for competitive sorption/elusion and applications such as amending existing pump & treat systems to reduce project cost and to eliminate down-gradient risk to public health. Plume modeling is presented indicating longevity of in situ colloidal carbon treatment for PFAS to be on the order of multiple decades before reapplication is required.

Kristen Thoreson leads the chemical research and product development program at REGENESIS.

**Thermal Remediation of PFAS Contamination**

The majority of PFAS (Per- and polyfluoroalkyl substances) contamination is the result of surface applications of aqueous film forming foams (AFFF) used for firefighting in addition to industrial manufacturing processes, spills, and releases of PFAS. This has created a fate and transport problem like the chlorinated solvent problems (PCE, TCE, etc.) with source zone areas and downgradient groundwater plumes. In addition, the majority of PFAS subsurface contaminate mass resides in the vadose zone.

PFAS resist most in situ treatment processes. Recent laboratory thermal remediation testing that heated PFAS contaminated soils to 440 C demonstrated nearly complete removal of the PFAS from the soil matrix through vaporization and capture. Two ESTCP (Environmental Security Technology Certification Program) projects that will demonstrate ex situ and in situ thermal treatment of PFAS contaminated soils for the US Air Force and Navy have been approved for field implementation. This presentation will provide a summary of the laboratory testing, plans for the ESTCP demonstration projects and a road
map to commercialization of the treatment technology.

Gorm Heron holds a Ph.D. in Environmental Science and Engineering from Technical University of Denmark.

Sustainable PFAS Resin Technology Applied at Multiple Locations for Military Base Aquifer Remediation

Emerging Compounds Treatment Technologies (ECT2) was engaged to supply, install, and operate PFAS removal systems at three locations at the Royal Australian Air Force (RAAF) Base Williamtown, located in Australia. A stormwater treatment system was installed at Moors Drain, and two groundwater pump and treat systems were installed; one at the former Fire Training Area (FTA) and one on the PFAS plume identified in the Southern Area. Regenerable ion exchange (IX) resin treatment systems were selected as the best solution for this application. Through the installation and use of a central regeneration system to service all three treatment systems on the site, minimal waste is generated, primarily because the spent resin is regenerated onsite.

Additionally, the programmable logic control systems installed on these treatments systems allow for seamless transition between extraction wells and treated water discharge methods, ensuring maximum reduction in groundwater contamination while operating 24/7. Multiple treatment systems were installed to ensure the primary issue in each of the areas could be managed without impacting overall operations on the property.

Installing multiple IX water treatment systems, along with a central regeneration facility, has proven to be an effective, efficient, sustainable approach to removing PFAS and achieving consistent compliance with Australia’s HBGVs and other project objectives. The combination of treatment systems is already having a measurable impact on source area PFAS concentrations. Regenerating the resin on site, rather than disposing of spent resin, has resulted in minimal PFAS waste generation.

The considerable reduction in waste generation, storage and thermal destruction has had a positive impact on the environment. The lessons learned to date have been largely around optimization of the pretreatment processes and resin regeneration system.

Steve Woodard is the President and co-founder of ECT2 (Emerging Compounds Treatment Technologies).

Methods Used to Reduce Exposure from Cannabis Odors

Exposure to the scent of Cannabis may result in dry cough, congestion, itchy, red and watery eyes, nausea, sneezing, and sore or itchy throat. More severe physical reactions, including anaphylaxis, have been reported from direct exposure to the plant (smoking, handling, ingestion). This presentation focuses on the involuntary second-hand exposure from cultivation operations and best practices to mitigate malodorous concerns.

Cannabis cultivation results in generation of a variety of terpenes, which are odorous organic compounds produced by a variety of plants, including cannabis and conifers. Exposure to terpenes emitted during the cannabis cultivation process are commonly referred to in health codes as public nuisance. During siting approval for cultivation sites, state, county, and local regulations and ordinances have been enacted to mitigate odorous terpenes to a level below their respective odor threshold at or beyond fence-line locations where sensitive receptors may be present. Both passive and active forms of mitigation are now being implemented through on-site controls during the growing cycles, trimming, and packaging process.

This presentation provides an account of these control measures, methods for implementation, and their effectiveness from point-of-origin to perceived individual. Technical supporting documentation and empirical data demonstrations are also discussed in this presentation, along with interviews with those in the know.

GES’ subject-matter expert in Air Quality and Odors has prepared many odor-control plans that have been reviewed by many agencies and have been implemented in the field.

Douglas Wolf is a Director of Air Quality Services at Groundwater & Environmental Services, Inc. with over 35 years of multidisciplinary environmental permitting, compliance, and management consulting experience.

EPA’s Pesticide Program Activities

The US Environmental Protection Agency (EPA) is a critical partner in agricultural policy and implementation of the enacted 2018 Farm Bill. By evaluating and regulating pesticides manufactured, used, and imported into the United
States, EPA ensures that growers have tools to support production while protecting human health and the environment. Acting Deputy Director of the Office of Pesticide Programs Michael Goodis will provide an update on EPA’s Pesticide Program activities and the evolving conversation around hemp.

Michael Goodis is the Director of the Registration Division of the Office of Pesticide Programs (OPP) at the U.S. Environmental Protection Agency (EPA), and is responsible for managing the registration program for all conventional pesticides to be used in the U.S. to ensure their compliance safety regulations.

### Case of Legally Defensible Cannabis Data with Known and Documented Quality

Since any scientific data may potentially be used in civil or criminal litigation, it should be judged as acceptable for use as admissible evidence. All potentially relevant data need to originate and remain secured under a litigation hold, in order to protect that data and all its content and associated files, from inadvertent deletion or alteration. In order for data to be defensible and of known and documented quality, all sampling, custody, and analysis activities must be performed according to technical standards and operating procedure. All processes must be clearly outlined and fully documented. As indicated in the adage: “say what you do and do what you say,” a break in the trust would result in a crack in data defensibility.

Additionally, detailed and pristine record keeping must be stressed throughout all sampling, custody, and analysis activities; failure to keep proper records is a common allegation in enforcement actions and a cause for lack of data defensibility. In this presentation we are going to review the life of a sample from sampling the cannabis plant, to custody, transfer to the laboratory, log in, preparation, and final analysis. As a final point, the QA/QC procedure and reporting the data process will be addressed. We will also exam and review the verification process for cannabis legally defensible data.

Harry Behzadi is President, CEO of AccuScience Laboratories

### Vapor Intrusion Risk Evaluation Using Automated Continuous Chemical and Physical Parameter Monitoring

Vapor intrusion risk characterization efforts are challenging due to complexities associated with background indoor air constituents, preferential subsurface migration pathways, and representativeness limitations associated with traditional randomly timed time-integrated sampling methods that do not sufficiently account for factors controlling concentration dynamics.

The U.S. Environmental Protection Agency recommends basing risk related decisions on the reasonable maximum exposure (RME). However, with very few exceptions, practitioners have not been applying this criterion. The RME will most likely occur during upward advective flux conditions. As such, for RME determinations, it is important to sample when upward advective flux conditions are occurring. The most common vapor intrusion assessment efforts include randomly timed sample collection events, and therefore do not accurately yield RME estimates.

More specifically, researchers have demonstrated that randomly timed sampling schemes can result in false negative determinations of potential risk corresponding to RMEs. 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 to minimize health risks and liabilities. To address these challenges, continuous monitoring platforms have been deployed to monitor indoor concentrations of key volatile constituents, atmospheric pressure, and pressure differential conditions that can result in upward toxic vapor transport and entry into overlying buildings.

These platforms enable determination of vapor intrusion risks via simultaneous monitoring of concentration and parameters indicating upward advective chemical flux. Time series analyses from multiple selected 8 and 24hr time increments during upward advective TCE flux conditions were performed to simulate results expected from the most commonly employed sampling methods.

These analyses indicate that, although most of the selected time increments overlap within the same 24hr window, results and conclusions vary based on the selected sampling increment start and end times. As such, these findings demonstrate that continuous monitoring of concentration and physical parameters and determination of a time-weighted concentration average over a selected duration.
Fast Forward Redevelopment Using a Barrier System Background/Objectives: Brownfield development is widely occurring on sites where volatile organic compound (VOC) soil vapor concentrations exceed the accepted USEPA Regional Screening Levels (RSLs) for unmitigated construction. Developers want and need agency review and approval of this work, because future stakeholders (owners, occupants, lenders, etc.) have greater trust in the mitigation process when there is governmental approval. The overarching goal of the session will be presenting and discussing the proposed performance standards for building barriers systems for regulatory consideration.

Approach/Activities: This session will focus on aspects of mitigation system (vent, barrier, and monitoring) design, specification, construction, testing, performance, contingency plans, and oversight. Additionally, critical elements of regulatory review, approval, and performance standards will be presented. Laboratory and site-specific performance data for various membranes and systems will be discussed as well as the successes and pitfalls of construction.

Results/Lessons Learned: Soil vapor intrusion mitigation systems (VIMS) must be designed to accommodate contingencies. Systems are normally provided with special (deputy type) inspection and certified by an environmental professional. Nevertheless, there may be unknown flaws in barrier and venting elements due to initial construction or later site activities. Thoughtful monitoring programs, and the ability to "upgrade" the system with additional items such as whirly birds, fans, and/or HVAC controls, is important in VIMS planning.

Mark Kram is the Founder and CTO for Groundswell Technologies, Inc., a group specializing in automated Cloud based monitoring and modeling of environmental sensor and analytical instrumentation networks.

Using Radon and Thoron in Vapor Intrusion Assessments The migration of vapors into buildings is increasingly becoming a focal point in the investigation and remediation of sites impacted by volatile organic compounds (VOCs). Assessments of the vapor intrusion (VI) pathway often require the collection of numerous sub-slab and indoor air samples to determine if VOCs are migrating into a building and, if so, to what extent. Because it has many of the same physical properties and moves by advection and diffusion, radon is increasingly being used as a surrogate for VOCs in VI assessments to identify entry points and reduce sampling costs.

As part of a VI assessment at a large food-processing facility, Gannett Fleming used passive radon detectors at 13 locations to identify areas where there may be openings in the foundation allowing sub-slab vapors into the building. The vertical distribution of radon within the building was also measured by placing paired radon detectors at the floor level and in the breathing zone to document air mixing within the building. An electronic radon detector was then used to measure thoron and radon to further pinpoint openings in the building’s foundation.

Those results, combined with total VOC concentrations measured in sub-slab vapors with a photo-ionization detector (PID), were used to choose indoor air sample locations. Paired indoor air and sub-slab vapor samples were then collected for radon and VOC analyses from areas where the highest radon and PID concentrations were measured. The paired radon and VOC indoor air and sub-slab vapor sample results were then used to calculate the attenuation factor of the building’s foundation.

The results of the VI assessment including the distribution of thoron, radon, and VOC concentrations in the sub-surface vapors and indoor air will be presented.

John Sepich is president of Brownfield Subslab, with offices in Texas and California, providing design and consultation related to soil vapor mitigation on projects across the U.S.

Anthony Miller is a senior environmental scientist with Gannett Fleming’s Madison, Wisconsin, office and has been conducting hydrogeological investigations and vapor intrusion assessments for 30 years.

More Data from Large Industrial Buildings – VI Attenuation Factors and Seasonal Variability Two questions of frequent interest for vapor intrusion (VI) studies are 1) what attenuation factor is reasonable to assume for large industrial buildings, and 2) how many rounds of testing are needed to adequately characterize sub-slab soil gas. An on-going investigation...
Factors Development and Evaluation

CalEPA is developing new guidance for evaluating the vapor intrusion pathway in California. As part of this new guidance, CalEPA has recommended the use of generic empirical attenuation factors (AFs) developed by USEPA (2012) for the purpose of evaluating the potential for vapor intrusion. However, as has been pointed out in the literature, vapor intrusion is influenced by a variety of site characteristics that can make the development of empirical AFs challenging, including building construction, climate conditions, and the nature and distribution of subsurface impacts. Although USEPA’s AF database discusses selection of the data pairs and some aspects of data pairing (most notably screening of data pairs exhibiting potential influence of indoor or ambient sources), USEPA does not consistently provide rationales and clear criteria to ensure the reliability of data pairs.

This presentation will discuss challenges of developing site-specific empirical AFs, present a general framework for developing site-specific empirical AFs, and present an illustrative case study based on a site located in Southern California. The approach to develop empirical AFs is generally consistent with and more systematic than the approach employed by the USEPA (2012). As part of the evaluation, the authors will also discuss some of the challenges encountered when developing representative empirical AFs, including shortcomings of USEPA’s AF study.

The case study focuses on a residential neighborhood located in Southern California where VOCs in groundwater have migrated from a former manufacturing facility to the neighborhood. The former manufacturing facility and residential neighborhood have been well characterized and a robust conceptual site model has been developed. Soil vapor data and indoor air data for 34 residences spanning a 12-year period are considered. In addition to presenting the approach and empirical AFs for the residential neighborhood, spatial and temporal variability of empirical AFs will also be discussed.

Yuan Zhuang has eight years’ working experience in chemical fate and transport, environmental engineering, and human health risk assessment.

Sewer Design, Construction, and Operation and Relation to Vapor Intrusion

CalEPA is developing new guidance for evaluating the vapor intrusion pathway in California. As part of this new guidance, CalEPA has emphasized sewers as potential preferential pathways for transport of vapor-forming compounds (VFCs) “beneath or directly into buildings.” CalEPA is motivated by the desire to protect building occupants. However, CalEPA’s conceptualization of sewer systems appears to be incomplete and does not take into consideration modern design features mandated for sewer systems in California.

In addition to sewage, sewers convey air in the headspace above the liquid flow. The air commonly referred to as “sewer gas,” is undesirable and includes methane and hydrogen sulfide. These gases are natural byproducts of sewage and are recognized as odorous and a

Bart Eklund is a Vice-President at AECOM, a $20 billion/year engineering & environmental firm.
had identified a comingled plume extending a distance of four miles. 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. The objective soon became source area identification and dissection of the commingled plume to assign ownership.

Following plume delineation, the sources of CVOCs were addressed through a variety of source area remedial actions (some of which are still proceeding). A GAC Treatment system was added to the public water system and affected domestic well owners were provided permanent connections to public water. The current objective is to monitor the return of groundwater quality to drinking water standards throughout the length of the plume.

Working in cooperation, the consultants shared regional-scale analytical results from hundreds of monitor wells, domestic wells, production wells, temporary wells, and surface water samples to form a groundwater and surface water quality database. Based on GIS analysis of contaminant ratios 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 their particular goals, including: 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.

To date, four sources have been remediated and groundwater quality has improved dramatically. The use of GIS to present contaminant ratios proved to be a very powerful tool in assessing the very large and diverse dataset. The presence of cis-1,2-dichloroethene was key to locating source areas where anerobic conditions existed locally. Due to the very high hydraulic conductivity and associated groundwater flow velocities, in-plume groundwater treatment options including permeable reactive barriers, containment (pump and treat), recirculating wells, and the like proved infeasible.

Craig Cox currently serves as President and Principal Scientist for Cox-Colvin & Associates, Inc, and is responsible for providing managerial and technical oversight on major environmental projects conducted by the firm under RCRA, CERCLA, and Brownfield programs.

A Case Study of Low-Intensity Electrochemical Reduction of Tetrachloroethene (PCE) at a Brownfields Site

The patented E-Redox® technology establishes low-intensity electric fields within the contaminated environmental matrix (e.g., groundwater and sediments), manipulating redox conditions to promote contaminant destruction and transformation. In practice, the application of the E-Redox® system induces reductive reactions that are dominated by abiotic dechlorination of chlorinated solvents, and desorption of chlorinated compounds from solid into aqueous phase. The abiotic dechlorination process, also known as beta elimination reactions, produces no dichloroethenes and vinyl chloride.

A full-scale implementation of
the technology was conducted at an undisclosed brownfields site (a former dry cleaner site) in Colorado, where tetrachloroethene (PCE) was the main constituent of concern in the groundwater. The subsurface formation is clayey with highly limited permeability. Five E-Redox® systems were installed and powered by a municipal power source. In the primary monitoring well, approximately 62% of the PCE was degraded without any rebound, while the whole site PCE concentration has been substantially reduced during five months of operation, without any rebound.

The PCE degradation rate is 31 mg/L/day (maximum 50 mg/L/ day). Increases of ethane level, the final product of complete PCE reduction, coincide with the PCE degradation. Stoichiometrically, ethane production actually exceeds the groundwater PCE degradation, indicating that undissolved PCE and PCE adsorbed to the matrix were being reduced within the radius of influence of the E-Redox® system.

The site is currently in post-remediation evaluation phase, and no further action/closure is expected. E-Redox® system will be disassembled, adjusted, and used for other sites.

Paul Fallgren is a Vice President at Advanced Environmental Technologies, LLC, where he leads the development and implementation of innovative and effective technologies and solutions for environmental remediation, wastewater treatment, energy, and agriculture.

Reducation
A decades-old groundwater tetrachloroethene (PCE) plume extends 1,200 feet from a back-diffusion fed fractured bedrock zone to an off-facility intermittent creek within unconsolidated sediments. The geology and hydrology are complex. Pre-remediation PCE concentrations ranged from approximately 100 ug/L at the source to 10 ug/L at the creek intercept. The plume was attenuating but not necessarily shrinking. The bedrock exhibits high magnetic susceptibility from magnetite and other ferrimagnetic minerals yet contribution to plume attenuation by naturally occurring mineral-based abiotic pathways is not apparent. A detailed investigation identified the causative factor to be clay coatings serving to restrict PCE contact with crystalline reactive surfaces. Concentration attenuation towards the toe of the plume, in unconsolidated sediments, is driven by surface water – groundwater interaction. Remediation is underway to achieve the USEPA MCL of 5 ug/L.

Various in-situ groundwater treatment technologies were evaluated at bench-scale and a micro-scale zero-valent iron (ZVI) pilot test program was completed. Ultimately, Biogeochemical Reductive Dechlorination (BiRD) was selected and documented in the Record of Decision. Design-basis characterization, including intensive biogeochemical characterization of core, and permeable reactive zone (PRZ) installation were completed in 2017. The PRZ in the plume source area was created by advancing four borings to 50 feet below grade, followed by straddle-packer positioning and pressurized direct injection of aqueous solution containing fast and slow release carbon-based electron donor, sulfate, iron, and a pH buffer.

Performance monitoring demonstrated physical disruption of previously undetected PCE mass in the source area resulting in increased dissolved-phase PCE concentrations up gradient of the PRZ. Iron monosulfides generated through the BiRD process led to near complete elimination of PCE from the groundwater over a plume distance of at least 350 feet, with minimal vinyl chloride production. The highly notable performance over such a distance, as documented after 2.5 years, is plausible against the backdrop of the subsurface hydraulics and biogeochemistry. Performance monitoring continues.

Jim Studer is an engineer, scientist, and business leader based in Albuquerque, New Mexico.

Enhanced Reductive Degradation Using Mg-based Bimetal: Transformation and Fate of 2,4-dinitroanisole (DNAN) and Nitroguanidine (NQ)

The production of energetic materials produces wastewater-containing residual levels of insensitive munition (IM) formulation constituents such as nitroguanidine (NQ) and 2,4-dinitroanisole (DNAN). Treatment of IMs using zero-valent metal or bimetal technology is well-studied, particularly iron-based treatment such as the use of zero-valent iron (ZVI). However, ZVI is usually effective only under acidic conditions. Mg-based reagents, on the other hand, remain
effective without acidic conditions and offer greater reduction potential. In this work, the reductive degradation of pure NQ and DNAN in water by Mg/Cu bimetal was studied.

Treatment of NQ produced two parallel reactions: nitroreduction led to aminoguanidine formation, or reduction of the encompassing nitramine group resulted in N-N bond cleavage forming guanidine. Additional byproducts identified were urea, cyanamide, formamide, and dicyandiamide. Experimental evidence on the degradation of NQ byproducts elucidated a complete reaction pathway, along with complete carbon closure from NQ byproducts. Results on conditions controlling reaction selectivity will be discussed. Conversely, treatment of DNAN in a solvent matrix resulted in subsequent nitroreduction: one nitro group was reduced (ortho or para) to form 2-amino-4-nitroanisole or 4-amino-2-nitroanisole (2-ANAN or 4-ANAN), and subsequent reduction of the other nitro group formed 2,4-diaminoanisole (DAAN). However, in an aqueous matrix, adsorption to the bimetal was significant. A fraction of DNAN partially reduced to 2-ANAN and adsorbed to the bimetal. Concurrently, DAAN formed in the liquid phase, but in insufficient amounts, i.e. resulting in an open mass balance in the liquid phase. Adsorption to the bimetal increased with oxygenation. Subsequent experiments indicated DAAN was not necessarily the final product from Mg/Cu treatment. In oxygenated systems, DAAN degraded and led to adsorption of DAAN or DAAN transformation products to the bimetal. Complete mass balance and transformation products from DNAN and DAAN degradation will be discussed.


Electrical Resistance Heating and Passive Vapor Barrier Pilot Tests to Evaluate Remedial Design
This presentation provides a case study using pilot studies to refine the final approach for an electrical resistance heating (ERH) remedy. Historical investigations at a confidential superfund site in California (Site) observed both mobile and immobile dense non-aqueous phase liquid (DNAPL) consisting of dichloro-diphenyl-trichloroethane (DDT) and monochlorobenzene (MCB). The remedial objectives include “reduce mobile DNAPL mass to the extent practicable” and the selected remedies include Electrical resistance heating (ERH) in the saturated zone and soil vapor extraction (SVE) in the vadose zone. In 2019, an ERH pilot test was conducted with over 20,000 lbs of mass removed and demonstrated effective removal of MCB in the saturated zone to meet site cleanup objectives. A repeatable method using MCB concentrations to evaluate NAPL mobility in multiple soil types also was determined.

An additional SVE vapor barrier pilot test (VBPT) was performed in 2020 demonstrated the effective use of a passive barrier wall to prevent mobilization of off-property contaminants onto the Site. During the 38 weeks of VBPT system operation, an estimated 85,011 pounds of volatile organic compounds (VOCs) were removed from the Focused Treatment Area (FTA). Mass recovery rates achieved during the SVE were evaluated to develop the final ERH and SVE conceptual model, which includes a two-phased heating approach with a single steam regenerated granular activated carbon (SRGAC) for ERH, while maintaining continuous SVE operations in the unsaturated zone with a second SRGAC. Field data collection conducted during the VBPT also determined that vapor screening with a flame ionization detector (FID) and Dräger™ tubes is more reliable than a photoionization detector (PID) to identify polish VGAC breakthrough during SVE and ERH operations in the FTA.

This presentation will present results of both pilot tests, Mass recovery rates and SRGAC operational data for both tests, and lessons learned to develop the final remedial approach for combined SVE and ERH in the focused treatment area.


Biogeochemically Enhanced
Reductive Dechlorination of Chlorinated Organics

For over two decades, biotic (enhanced reductive dechlorination; ERD) and abiotic (in situ chemical reduction; ISCR) processes have been applied to degrade chlorinated volatile organic compounds (CVOCs) in situ. Recently, biogeochemical reduction (BGCR), a process which combines biological and chemical processes, has been combined with ERD and ISCR to provide an additional mechanism to more aggressively degrade CVOCs.

During ERD and ISCR, highly reducing conditions are generated which are favorable to the reduction of ferric iron (Fe3+) to ferrous (Fe2+) and sulfate (SO4) to sulfide (S-). If present, the ferrous and sulfide rapidly combine to produce iron-sulfide minerals such as mackinawite (FeS), and pyrite (FeS2). These biologically generated minerals have been demonstrated to abiotically degrade CVOCs on contact by the α elimination pathway. This pathway minimizes the generation of toxic degradation products thereby substantially reducing the clean-up time. In addition to forming reactive minerals, the sulfide will precipitate on zero valent iron (ZVI) if present. This sulfidation of ZVI has been demonstrated to substantially enhance ZVI reactivity.

ERM conducted laboratory and field studies to evaluate the effectiveness two BGCR enhancing reagents (GeoformTM Extended Release and GeoformTM Soluble) for treatment of CVOCs at two confidential sites in the San Francisco Bay area. Hydrogeologic and geochemical conditions were similar at both sites, however, soil and groundwater at Site 1 had been affected by high concentrations of chlorinated ethenes (CEs), whereas high concentrations of CEs, chloroethanes (CAs), and chloromethanes (CMs) were present at Site 2.

The bench tests demonstrated that BGCR enhancement significantly increased the reactivity of the ISCR reagent. The field tests demonstrated that the biological establishment of highly reducing conditions resulted in the reduction of the supplied sulfate to sulfide. The sulfide combined with the supplied ferrous resulting in the rapid generation of reactive iron sulfide minerals and sulfidation of ZVI. The BGCR enhancement increased the PRB downgradient reactive zone at Site 1. The combination of ERD and ISCR with BGCR at Site 2 resulted in the rapid treatment of the mixed CVOCs to the remedial goals. Following 15 months of monitoring at Site 2, ERM received a determination of no further action; 30 months rom the start of treatment. Both sites are currently under redevelopment.

Dan Leigh is the Technology Applications Manager for Peroxychem.

Full-Scale Implementation of Propane Biosparge System for In-Situ Remediation of 1,4-Dioxane in Multiple Treatment Zones

1,4-Dioxane is a common co-contaminant with chlorinated solvents but is not readily remediated via similar treatment approaches (e.g., sorption, reductive dechlorination). However, 1,4-dioxane can be co-metabolically biodegraded in the presence of alkane gases and oxygen. At Vandenberg Air Force Base in California, USA, historical use of chlorinated solvents resulted in 1,4-dioxane in groundwater across three groundwater zones.

Between April 2013 and December 2016, laboratory testing and various field demonstrations were conducted, both by us and others. The results from these tests showed in-situ propane biosparging as a promising technology for reduction of both chlorinated solvent and 1,4-dioxane concentrations, with up to 99 percent reduction in groundwater concentrations. Stable isotope probing (SIP) was also used in 2015 to verify that biodegradation was a (destructive) mechanism occurring in the subsurface. The success of the propane biosparge demonstrations, and confirmation of the biodegradation mechanism via SIP, has led to the full-scale implementation of a propane biosparge treatment system at Vandenberg Air Force Base.

The treatment area is a relatively small footprint (e.g., less than 200 feet long), with 83 new wells installed simultaneously across the three groundwater zones. Ultimately 98 wells were connected to an above-ground treatment system which includes an air compressor, a propane tank, controls to ensure safe operating conditions, and nutrient amendment elements. After system start-up activities were performed, the full-scale treatment system was brought online in December 2019. Ten monitoring wells are currently used to monitor system performance across the three groundwater zones. After three months of operation, baseline concentrations decreased from a maximum concentration of 870 μg/L to 180 μg/L, with overall
reductions across the three zones between 33 and 99 percent. This full-scale system is currently known to be among the first of its kind.

Kelli Parsons has been a geologist at Arcadis over 5 years and has been involved in a variety of large-scale remedial well installations.

1,4-Dioxane Treatment in Groundwater to Achieve Drinking Water Goals Using a Synthetic Sorbent Media
Previous solvent spills and leaks at Site 1 in Yuma, Arizona resulted in chlorinated contaminants present in groundwater at approximately 80 feet below ground surface. The selected remedy in the ROD to treat the site chemicals of concern (TCE and 1,1-DCE) was groundwater recirculation. This system uses GAC to prevent further migration of these compounds at concentration greater than the drinking MCLs. Sampling of 1,4-dioxane, a contaminant not previously assessed at this site, was initiated by the Navy in 2012 at the request of the regulatory agency. A maximum concentration of 180 mg/L was reported prior to initiation of the pilot study, greater than the U.S. EPA RSL for drinking water (0.46 mg/L).

A pilot study to treat 1,4-dioxane to below 0.46 mg/L, TCE to 5 mg/L, and 1,1-DCE to 6 mg/L and was conducted using the existing 100-gpm groundwater recirculation system retrofitted with a synthetic media mobile unit. The pilot system diverted untreated groundwater directly from extraction wells, processed it through the synthetic media vessels, and then directed the treated groundwater through the existing GAC vessels to ensure compliance with the ROD. Unlike GAC, the synthetic media was regenerated onsite using superheated steam to restore its sorbent capacity. Groundwater samples were collected from influent and effluent sampling ports of the treatment vessels to evaluate the effectiveness.

During the 11 contaminant loading and regeneration cycles over a period of approximately 4 months, a total of more than 3 million gallons of extracted groundwater was processed through both the synthetic media and the groundwater recirculation system. The study consistently demonstrated the ability to reduce 1,4-dioxane, TCE, and 1,1-DCE concentrations in groundwater. Pre-treatment influent 1,4-dioxane concentrations ranging from 1.5 to 2.1 mg/L were consistently treated to less than the laboratory detection limit of 0.084 μg/L. All treated effluent concentrations for TCE and 1,1-DCE were below their respective laboratory reporting limits of 0.4 μg/L throughout the entire treatment duration. Each steam regeneration cycle was effective in restoring the sorptive capacity of the synthetic media. 1,4-dioxane generated from the onsite steam regeneration cycles was captured, cooled, and condensed during the pilot study. The steam was vented to the atmosphere during regeneration in compliance with the Arizona air discharge requirements.

Lansana Coulibaly is a licensed Professional Engineer in California, and current serves as a Principal Engineer in the San Diego office of Wood.

Treating 1,4-Dioxane with a New Approach Using Activated Potassium Persulfate
1,4-Dioxane has emerged as a contaminant of concern for numerous sites. It is most commonly found at sites co-mingled with the chlorinated solvents it was used to stabilize and their daughter products. The co-mingling of 1,4-dioxane with chlorinated solvents can make treatment of the entire contaminated suite more complex as 1,4-dioxane is typically treated using an oxidative radical pathway and several of the chlorinated solvents are best treated with a reductive pathway. In several instances this has led to sites where the chlorinated solvents were treated only to expose the untreated 1,4-dioxane.

Approach: Alkaline activated potassium persulfate was evaluated at two separate sites contaminated with a mixture of 1,4-dioxane, chlorinated ethenes, and chlorinated ethanes. The sites were first evaluated in a series of column reactors where site groundwater was then run through the columns until the potassium persulfate had been consumed. One of the sites subsequently had a successful field pilot test with alkaline activated potassium persulfate applied with a full-scale application in 2018.

Results: This presentation will provide the results from each site and highlight key conclusions in terms of the effectiveness of the oxidative and reductive pathways and comparative benefits of two activation schemes for potassium persulfate. The data indicate hydrated lime induced alkaline-activated potassium persulfate reduced 1,4-dioxane, chlorinated ethenes, and the chlorinated ethanes concentrations to below the detection
limit. ZVI-activated persulfate resulted in treatment to non-detect of 1,4-dioxane and chlorinated ethenes while reducing chlorinated ethanes by 20 to 60 percent.

Field data not only evaluated treatment effectiveness but also the persistence of potassium persulfate compared to the site’s groundwater velocity. Field data indicates the potassium persulfate was persisting as expected based on the observed groundwater velocities and that 1,4-dioxane was treated to below the detection limit at the PRB and significant reduced down gradient.

Stacey Telesz, PeroxyChem, has 16 years of experience in the environmental remediation industry.

Absolute Radical Kinetics and Reaction Mechanism for Antidiabetic and Related Compounds in Water
The development of pharmaceutical therapies for the treatment of human diseases and agricultural management has resulted in enormous health benefits for our planet. However, this increased use of pharmaceuticals has concomitantly increased the contamination of a variety of environmental matrices. One approach for selecting targets of potential concern is to examine world-wide pharmaceutical consumption patterns. For example, a 2014 study showed that 411 million people had type two diabetes. Metformin, a common treatment for this form of diabetes, accounts for 20% of pharmaceutical consumption globally.

Therefore, a logical extension of this knowledge would suggest that metformin could potentially become an emerging contaminant of concern, especially since the active pharmaceutical ingredient is mostly excreted unchanged from humans. As such, active removal of this pharmaceutical from contaminated waters may become necessary. Considerable work has demonstrated that radical-based advanced oxidation processes are a viable cost-effective option for such treatments.

However, the use of these processes is strongly dependent upon a complete understanding of the radical kinetics and reaction mechanisms. In this study, we report on our determination of the absolute second-order rate constants for metformin and metabolite/model compounds guanidine and “impurity A” with a suite of oxidizing and reducing radicals. For comparative purposes we also report the synthesis and absolute second-order rate constant for imeglimin a second generation biguanide antidiabetic compound.

Stephen Mezyk is a Professor of Physical Chemistry at California State University, Long Beach, California.

State of the Science: PFAS Sampling Guidelines and Frequency of Cross-Contamination
What makes a PFAS investigation different is the potential for sample contamination from commonly used consumer products and sampling materials. Per- and Polyfluoroalkyl substances (PFAS) are a large group of manufactured compounds used in a variety of industries. With their widespread distribution and target detection limits in parts per trillion (ppt) there is heightened concern regarding the potential for cross contamination.

A complicating factor is the lack of published EPA methods or guidance for addressing PFAS in various media. The Agency is working to develop validated analytical methods but these are not expected to provide the level of detailed sampling guidance the industry is looking for. Over the past several years various State, Federal, and private agencies have developed their own protocols and recommendations specific to the collection of samples for PFAS analysis.

This presentation will review what is available and being utilized today from published guidance on PFAS sampling protocols. This review includes several State, Federal and trade association documents. We will take a look at the available checklists containing acceptable and prohibited items, and, more importantly, what data there are to substantiate these lists or that conflicts with certain claims. Lastly, we will present data from tens of thousands of samples from around the country to see what frequency of detections there are in field quality control samples and what these data might tell us about our current approach.

Taryn McKnight, PFAS Practice Leader for Eurofins Environment Testing America based in Sacramento, California, has nearly 20 years of experience in the environmental testing industry.

A Mass Balance Framework for Assessing PFAS Concentrations in California Municipal Wastewater due to Residential Sources
PFAS are generally acknowledged to be ubiquitous in the environ-
ment due to various points of origin such as manufacturing, firefighting, and consumer products. Although PFAS are not produced in California, they are used by manufacturers and consumers, have been detected in California drinking water, and are receiving increased regulatory scrutiny. To date, the State Water Resources Control Board (SWRCB) has implemented Phase I and II investigations that have focused on sources of PFAS and impacts to drinking water. Phase III, which will be implemented beginning in the second half of 2020, extends the investigation to include municipal wastewater treatment facilities (WWTFs).

WWTFs neither produce nor use PFAS and are generally regarded as passive recipients of PFAS. To the extent PFAS are present in municipal wastewater, they originate in the same three sources from which municipal wastewater typically is derived: industrial/commercial, residential, and storm water inputs. Industrial/commercial and storm water discharges are regulated under USEPA’s National Pollutant Discharge Elimination System (NPDES) program. In contrast, residential discharges typically are not regulated. Moreover, residential sources contribute the overwhelming majority of biosolids to municipal wastewater. Given the ubiquitous nature of PFAS in consumer products, it is likely that PFAS are present in wastewater due to residential/consumer sources. However, the ability to characterize residential inputs to wastewater is constrained by analytical challenges as well as the dispersed nature of residential inputs.

These challenges notwithstanding, assessment of PFAS in municipal wastewater should account for this PFAS background due to dispersed consumer inputs.

The objective of this study is to develop a framework to assess the presence of PFAS in municipal wastewater due to residential sources. To accomplish this objective, the authors propose a mass balance-based framework that relies on readily available information and data, including the professional literature and the results of the SWRCB’s Phase I, II, and III investigations. The framework takes into consideration the various household activities that generate wastewater (e.g., bathing), residential per-capita water use and wastewater generation, published literature on the use, cleaning, and disposal of PFAS-containing consumer products (e.g., personal care products and clothing), and analysis of PFAS in behavior in the wastewater environment (e.g., partitioning between aqueous and solid matrices such as biosolids).

Steve Luís has more than 20 years of experience in environmental consulting, focusing on site investigation and remediation, human health risk assessments, chemical fate and transport analyses, and independent third-party review and oversight.

### Aviation Contamination – Looking Upstream to Prevent PFAS from Contaminating Municipal Wastewater

PFAS in municipal wastewater has become a concern for many municipalities in the US. As local residents naturally contribute PFAS to the system, focus should be placed on removing the higher PFAS concentration industrial sources from entering the waste stream. This can be accomplished by treatment on site, prior to discharging to the sanitary sewer.

After a hangar release increased the focus on PFAS management at an airport in the Northeast US, the airport looked to install a PFAS treatment system that could handle the challenging deicing fluid and remove PFAS prior to discharging to the sanitary sewer. The deicing fluid is collected in underground storage tanks and surface lagoons prior to discharge. Deicing fluid is difficult to process as the high glycol and biological activity can easily foul conventional systems.

A 20-gpm containerized system was provided to meet the primary project objective of producing treated water with combined PFOS+PFOA concentrations below the 70 ng/l Health Advisory Level (HAL). The compressed schedule resulted in a rapid deployment of the system which started treating water only 4 weeks after receipt of the purchase order. The SORBIX M6 system includes back-washable GAC pretreatment to remove incoming particulates, a cartridge filter, and ECT2’s SORBIX PT1 resin for pretreatment and conditioning. The PFAS removal is accomplished by ECT2’s SORBIX LC4 Ion Exchange (IX) resin in a lead-lag vessel orientation. The entire system sits inside of a 40’ container and can be easily relocated as warranted.

The PFAS remediation system has treated more than 400,000 gallons of deicing fluid having a total influent (24 compounds) PFAS concentration of between 20-250 ng/l. The effluent quality from the SORBIX M6 system has been con-
sistently non-detect for the 6 monitored PFAS compounds, including the short-chain species, readily achieving compliance with the 70 ng/l HAL target.

After graduating from the University of Maine with a degree in Civil and Environmental Engineering, Mr. McKeown, ECT, spent 4 years in the environmental engineering field, focusing on wastewater and stormwater design.

Air Sparging Directly In Aquifers to Concentrate and Remove PFAS From Groundwater

Current remediation strategies for PFAS contaminated groundwater are effectively limited to pump and treat technologies with no reliable, cost effective in-situ treatment options. Air sparging is considered to be ineffective for PFAS because it relies on biodegradation of aero- bically biodegradable contaminants and/or volatilization of volatile contaminants while PFAS have low volatility and are not completely biodegradable. An emerging technology, downhole foam fractionation, relies on sparging within a well and recirculating groundwater, but does not consider sparging the aquifer itself.

However, the surfactant characteristics of PFAS suggest that conventional air sparging directly in aquifers can be effective for concentrating PFAS in dilute PFAS groundwater plumes in the upper portion of the aquifer. Due to the hydrophobic and lipophilic properties of PFAS, PFAS molecules preferentially partition to the surface of the sparged air channels/bubbles, which then will carry the PFAS to the top of the saturated zone. As such, when a sparged gas is intro-

duced directly in a groundwater treatment zone, PFAS will collect at the air/groundwater interfaces and be drawn upwards by the buoyancy of the sparged gas. The sparging results in reduced concentrations in the deeper sparged zone, reme-
iating this portion of the aquifer. The sparging will also create higher PFAS concentrations in groundwater and PFAS foam near the top of the aquifer.

The key benefit of this concent-
ration near the top of the water bearing unit is that the removal of the concentrated PFAS-contain-
ting groundwater and foam will be much more efficient than the removal of large volumes of low concentration groundwater, thereby substantially reducing costs. An even more cost-effective strategy is to use sparging to reduce the PFAS mass flux in the aquifer, and then rely on the air/water partitioning mechanism to sequester the PFAS near the top of the water table for long time periods. Overall sparging for sequestration will significantly reduce the mass flux of the former PFAS plume without the need for expensive removal and treatment of the PFAS at the surface.

The process, now patent pend-
ing, has been tested in simple laboratory tests and is now ready for demonstration in the field.

Charles Newell is a Vice President of GSI Environmental Inc.

Treatment Train for Com-
plete Destruction of PFAS in Contaminated Water

Per- and polyfluoroalkyl substances (PFAS) are widespread in the envi-
ronment due to their extensive use in thousands of product formulations. Their unique strength and stability make them one of the most difficult classes of chemicals to remediate. This presentation will highlight advances in a pilot-scale treatment train consisting of 1) foam fractionation (SAFF™) to concentrate PFAS from dilute water streams to reduce the volume of contaminated water, 2) electrochemical oxidation (ECO) to destroy PFAS in these concentrates, and 3) biological polish of the byproduct perchlorate for a complete destructive treatment of PFAS.

ECO using boron-doped diamond electrodes has been demonstrated at the bench-scale to degrade PFAS to innocuous end products using a reactive anode and cathode electrodes via 1) direct electron transfer (particularly important for PFAA) and 2) hydroxyl radical oxidation (which is important for PFAS precursors in AFFF mixture). A pilot system was constructed focused on developing a closed loop treatment system coupling SAFF™/ECO and biological treatment to remove perchlorate.

Overall, the SAFF™ technology concentrates PFAS and reduces treatment volume by up to 500,000x to 1,800,000x. Pilot testing of the SAFF/ECO pilot system achieved removal rates from PFAS-contaminated AACO groundwater of >85% sum of PFAS including >99% priority compounds, generating a tertiary foamate with concentrations of total detectable PFAS (4118 mg/l), including PFOS (2080 mg/l), PFOA (380 mg/l) and PFHxS (1200 mg/l). The SAFF concentrate was subsequently treated in
Management and Treatment of Per- and Polyfluoroalkyl Substances (PFAS) in Wastewater Associated with Aqueous Film Forming Foam (AFFF)

PFAS have emerged globally as high-priority and high-profile contaminants. Several countries and local regulatory authorities have expanded their guidelines and promulgated rules around PFAS contaminated media and respective exposure pathways. Regulations will continue to evolve as research into the potential health impacts of this chemical class develops. Therefore, it is expected that further scrutiny will be placed on management and disposal of waste associated with AFFF which is a source for PFAS contamination.

In an effort to develop a more robust, cost-effective and efficient method to manage PFAS impacted water, Wood is demonstrating a mobile system to treat a mixed wastewater with high concentrations of PFAS compounds to below published U.S. Environmental Protection Agency (EPA) health advisory levels. The wastewater is from underground storage tanks (USTs) associated with AFFF systems at an active U.S. Military Installation. The treatment system used a sorbent media train to effectively reduce PFAS and other contaminants in the wastewater in accordance with local sewer discharge requirements.

Tamzen Macbeth is Senior Vice President and Remediation Practice Leader at CDM Smith.

Remediation of Hexavalent Chromium Contamination Using In-Situ Redox Manipulation

At a plating shop in San Bernardino County, CA, a soil sampling investigation discovered elevated levels of hexavalent chromium at a depth of 5 feet to 12 feet beneath large portions of the interior of the building and extended to the exterior walls. A slot excavation approach was implemented by digging 4-foot wide trenches in an alternating fashion perpendicular to the building wall. Unfortunately, confirmation sampling performed during the excavation determined that the hexavalent chromium extended laterally under the footing of the building which could not be safely excavated.

To keep the project moving forward, an in-situ treatment plan was designed to reduce the toxicity of the hexavalent chromium in the subsurface soils beneath the Site. The treatment plan involved the use of chemical reducing agents to promote conversion of the highly toxic hexavalent chromium to the less toxic trivalent chromium using a process known as In-Situ Redox Manipulation (ISRM). A treatability bench scale test was performed to evaluate the treatment effectiveness of two remediation agents (ferrous sulfate and ferrous sulfide based reagents).

A treatment reagent named Metal Treatment Solution (MTS) was selected as the best performing reagent, showing a removal of 97% of the hexavalent chromium using a MTS dose of 7% (weight to weight). Based on these results, an in-situ treatment plan was developed to reduce the hexavalent chromium levels (as high as 1,200 mg/kg) to below the regulatory cleanup level of 12.5 mg/kg and form an insoluble non-leachable precipitate.

Using a powdered form of the MTS product, allowed for mixing with the soil using the backhoe bucket.

Soil mixing was initially performed on small areas at the bottom of the excavation, then increasing to larger areas once the testing confirmed the treatment effectiveness. As a means of treating the undisturbed side walls of the excavation, the MTS was mixed into a water solution and injected into lateral injection wells penetrating the side walls.

The soil remediation project was completed in 20 days. The work was completed under the regulatory authority of the US EPA (Emergency Response Unit) who provided approval of the remediation design and granted final closure of the site.

Gary Cronk is the President of JAG Consulting Group, Inc., a consulting and remediation firm based in...
Planning and Implementing Proactive Combined Technology Remediation

Combined remedy treatment programs are being applied at many contaminated sites where more than one remediation technology is implemented to treat and/or remove contamination in efforts to achieve site-specific objectives. More often multiple technologies are performed reactively where additional technologies are used when one remediation technology was no longer effective or was not adequate to achieve site criteria, and then another remediation process is proposed. In contrast, a proactive combined remedy approach incorporates multiple treatment processes/technologies into the remedial design. Proactively utilizing a combined technology remediation approach can improve treatment performance, increase efficiency, and reduce clean-up time and cost.

A proactive combined remedy plan will harness the advantages of each individual technology, determine the most optimal remediation schedule, and better predict overall cost and cash flow requirements. Such proactive remediation planning is especially appropriate for redevelopment projects with aggressive timelines.

This presentation will detail projects where combined remediation approaches were proactively planned to identify synergies in treatment and limit inhibitory effects. Example combinations that were designed proactively and implemented will be detailed for planning, and lessons learned will include in-situ chemical oxidation (ISCO) with bioremediation via enhanced reductive dechlorination (ERD), ISCO applying two different oxidants, surfactants with ISCO, injectable activated carbon with ERD, and thermal remediation with bioremediation.

Consideration will be presented on reaction byproducts, contaminant mobilization, and spatial and sequential combined remediation application. In addition, the presentation will discuss combined remedy remediation projects where additional technologies were applied reactively. This presentation will help in identifying indicator parameters to support making the decision to change treatment technology or to continue with another application of the previously selected technology.

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Paul Dombrowski, Senior Remediation Engineer at ISOTEC Remediation Technologies, Inc. has over 16 years in the environmental industry with experience in hazardous waste site investigation and remediation, with a focus in designing and implementing in-situ remediation technologies.

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Column Testing the Impact of In Situ Amendments on Aquifer Permeability

The treatment of contaminated aquifers with in-situ amendments is widely practiced and offers remediation practitioners a versatile toolbox to effectively address a range of contaminants. Creating permeable treatment zones with these amendments in the form of barriers is often a cost-effective and flexible remediation strategy for petroleum hydrocarbons, chlorinated solvents, and other emerging contaminants.

While such in situ methods can be highly effective for remediation, care must be taken to ensure minimal effects on aquifer permeability and thus groundwater flow within a treatment zone. In this study, changes in the permeability of water-saturated, fine, and medium grain silica sand columns were tracked following the addition of colloidal activated carbon (CAC), colloidal zero-valent iron (c-ZVI) and other common remediation injectates. The effects of several parameters, including substrate injection concentration, ionic strength, and pH were accessed. Permeability changes were determined primarily by pressure measurements at the column inlet and, in some cases, also by changes in falling head measurements.

By monitoring pressure as a function of flux at a constant flow rate, colloid deposition rates can also be estimated. Long-term changes in permeability were also determined as colloidal amendment-treated columns developed biofilms over the course of several months. Permeability changes correlated well with the estimated amount of solid material deposited within the pore space. The results of this study help demonstrate that the emplacement of relatively small mass percentages of activated carbon or zero-valent iron into aquifer pore volumes does not negatively impact permeability or alter groundwater flow within a treatment area.

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Paul Erickson is the Technology Development Manager with REGENESIS and currently specializes in research and development of new environmental solutions to address complex remediation challenges.

Brea, CA that specializes in providing services for the design and implementation of in-situ chemical oxidation, enhanced bioremediation, chemical reduction, and other in-situ technologies.
Using Electrical Wells to Monitor Groundwater
Advancements in instrumentation and techniques have allowed temporal electrical resistivity imaging to be applied to monitoring groundwater sites. By reducing the noise in temporal datasets, a set of electrodes can be installed at the surface and changes in the subsurface can be monitored on timescales ranging from observing an injection program to monitoring seasonal aquifer changes. Protocols for effective electrical monitoring of aquifers are discussed and case studies of electrical well datasets are illustrated to provide understanding of their long-term application.

Todd Halihan is a Professor and the Sun Company Clyde Wheeler Chair in Hydrogeology at Oklahoma State University, and Chief Technical Officer for Aestus, LLC.

Colloidal Activated Carbon Distribution at Petroleum Hydrocarbon Sites
Colloidal activated carbon (CAC) has emerged in recent years as an effective sorption technology allowing for low-pressure injection methods, due to its small particle size (1-2 um) and the addition of a biodegradable stabilizer that prevents particle agglomeration. This technology can be highly effective in the sorption and degradation of petroleum hydrocarbons when combined with electron acceptors such as nitrate and sulfate. The synergistic effect of combining CAC with electron acceptors promotes rapid sorption of dissolved phase contaminant mass and subsequent degradation by anaerobic hydrocarbon degrader population.

Reagent distribution is an often-overlooked component of in-situ injection applications. This is in stark contrast to the level of time and money spent on reagent selection and budgets. As with any in-situ technology requiring direct contact between the reagent and the contaminant, it is critical that reagent distribution be monitored during the field application. Further, the injection design should be modified to improve distribution within the Target Treatment Zone (TTZ) where needed.

To meet this goal, remediation practitioners need a distribution confirmation test that is rapid and does not add substantial time or money to the application budget. CAC has unique features that allow the remediation practitioner to quickly document its distribution in the subsurface. CAC has an ink-like appearance that allows for visual confirmation of reagent distribution with the collection of post-injection soil cores or by groundwater color changes in monitoring wells. The concentration of CAC in groundwater samples can be observed using a commercially produced field kit. These methods can be used to modify the injection design in the field by modifying injection volumes or injection point spacing to ensure the CAC is properly distributed.

This presentation will focus on the field aspects associated with documentation of CAC distribution within the target treatment zones at three sites.

Craig Sandefur is the Vice President of Remedial Applications Development at REGENESIS and a recognized expert in the areas of in situ remedial design and applications.

Limiting Vapor Intrusion Liability Through Standardized Practices
It has been 35 years since the federal Environmental Protection Agency’s (EPA) first Vapor Intrusion (VI) Site in Bowling Green, Kentucky. Since then, many Radon and Vapor Intrusion Guidance documents have emerged. Generally, the VI documents are termed as Guidance documents and are highly descriptive in areas of sampling and site characterization procedures. They typically have only a few pages on mitigation and even less on Extended Stewardship and structuring and effective Operation Maintenance & Monitoring (OM&M) plans. The federal EPA, American National Standards Institute (ANSI), the Association of Radon Scientists and Technologists (AARST), and several states have developed standards that are highly prescriptive for both radon measurement and mitigation. ANSI AARST has nationally taken the lead in proscribing standards for mitigation systems and OM&M programs.

As a result of this metamorphosis, the vapor intrusion industry is lagging behind and using a patchwork of unharmonized regulatory documents, radon standards and site specific agreements. California alone has several different guidance documents. The disparity between states, and a complete absence of standards in other states, has created significant undefined long-term liability for building owners, responsible parties, and insurance carriers who are seeking to define those liabilities.

In an attempt to explain the root of the disparities, this paper
will examine the evolution of the standards process as well as explore solutions toward harmonizing best practices. We will discuss the best technical merits of state guidance documents as well as integrating standardized practices such as check lists and guidelines similar to those that will be provided in the Quarter 3 2020 Draft ITRC Vapor Intrusion Design and OM&M check lists. The conclusion will discuss how adopting a framework of Best Design, Mitigation and OM&M practices could promote transparency in performance, documentation, energy efficiency, limit health and long-term liability risks.

Thomas Hatton has thirty-three years of experience in design and installation management of Vapor Intrusion and Radon mitigation systems totaling approximately 11,000 combined commercial and residential properties.

**AFFFT Forensics – Identification of Sources to Surface Water and Groundwater & Remedial Option Selection and Implementation**

Evaluation of the relative assemblage and concentrations of individual PFAS compounds in surface water and groundwater samples provides the basis for effectively discriminating the source or sources of PFAS in these media. The discrimination of potential sources is facilitated by the increasing list of PFAS compounds that laboratories can detect and quantify in response to demands by regulatory agencies to expand the list of analytes. As a result, the assemblage of compounds quantified in laboratory analytical results are used to “fingerprint” compound assemblages in environmental samples. Comparison of chemical fingerprints in samples collected from surface water bodies and groundwater located downstream and downgradient of AFFF impacted sites can be utilized to identify and/or distinguish the major source(s) contributing to the water media.

TRC has effectively distinguished the major AFFF source to surface water and groundwater for sites containing multiple AFFF releases. Identification of the correct AFFF source is critical to the identification of responsible parties and the first step to evaluate and implement effective source remediation strategies. This presentation will include a discussion of basic AFFF forensics as illustrated by two cases studies where AFFF forensics were utilized to identify and differentiate AFFF sources. The presentation will also discuss the selection of the appropriate remedial strategy based on the source characterization, including the successful implementation of a surface water remedial strategy.

Mr. Hovey is an engineer at TRC with five years of experience in environmental remediation with a focus on contaminated groundwater projects.

**Fate & Transport of Modern C6 AFFF Release, Including TOP Assay of Surface Water, Soils, and Sediment**

Although all AFFF foam formulations contain concentrations of PFAS, we have identified three general types of foam based upon ranges of PFAS concentrations as the primary chemical components. Legacy AFFF contains the persistent, C8-chain perfluorooctane sulfonate (PFOS) and was mainly produced in the US from 1960s to 2002 by 3M. Second generation legacy fluorotelomer AFFF predominantly contains C8 and C6 fluorotelomer sulfonates (FTS) that eventually transform to Perfluorooctanoic acid (PFOA) and other Perfluorocarboxylic acids (PFCAs) in the environment. The modern fluorotelomer foams, almost exclusively contain short-chain (C6) PFAS that do not transform into PFOA or PFOA.

The transition to shorter-chain PFAS in modern AFFF formulations is mainly driven by indications in the scientific literature that toxicity and bioaccumulation generally increase with carbon-chain length. Since ensuring that the same level of performance and effectiveness as legacy AFFF is essential in modern AFFF because the formulation is relied upon to saves lives. The short chain fluorotelomer, 6:2 FTS, is currently the leading alternative product to traditional C8 AFFF as it is expected to result in decreased human health and environmental impacts. Additionally, 6:2 FTS degradation appears to produce shorter chain, C2 to C7 PFCAs intermediates, and does not produce PFOA or PFOS.

We present a case study in which F&T of PFAS compounds associated with a modern C6 AFFF release were monitored until PFAS sampling results approached background concentrations in surface water and sediments of the receiving stream. PFAS sampling, including TOP assay result for surface water and sediment were monitored at 12 locations from source zone through a five-mile length of receiving stream. Emergency response actions undertaken to address the source were evalu-
ated via collection and analysis of surface water samples. Sampling results indicate that the PFAS associated with the modern C6 AFFF were depleted in surface water within two months of the AFFF release.

In addition, PFAS associated with the C6 foam did not accumulate in sediment. Pre- and post-TOP assay results converged as the major component of the AFFF release attenuated from the stream system. Based on the results of our study, PFAS associated with C6 based AFFF do not appear to accumulate the environment following a release.

Lee Hovey is an engineer at TRC with five years of experience in environmental remediation with a focus on contaminated groundwater projects.

A Novel Bioelectrochemical Barrier for Treating a BTEX Plume

Bioelectrochemical technologies have been field implemented to enhance microbial degradation of contaminants such as petroleum hydrocarbons, without zero energy input and minimal material consumption. E-Redox® is a patented in situ bioelectrochemical remediation technology that has been applied in a dozen field sites to treat petroleum contaminants in groundwater and saturated soils. Although E-Redox® technology has been mostly used to treat source areas and locations with high levels of contaminants of concern, the field proven radius of influence of an E-Redox® unit is 10 – 16 ft, and the feature of ZERO energy operation makes a row of E-Redox® units a cost-effective and sustainable in situ treatment barrier.

A groundwater contaminant plume containing benzene and other petroleum compounds was determined to be migrating and expanding downhill from the source area, where a remediation system was operating (primarily oxygen diffusion). To mitigate and prevent the spread of the contaminant plume further downhill, an in situ barrier consisting of a row of E-Redox® units was installed. Results indicate that biodegradation of contaminant was effective at the E-Redox® barrier and no benzene was detected downhill from the barrier. Overall, the results demonstrated that the E-Redox® technology can serve as a sustainable and cost-effective in situ barrier technology with no consumable material or energy requirements.

Song Jin is the Founder and CTO of Advanced Environmental Technologies.

Real-time In Situ Monitoring of Biodegradation by a Novel Bioelectrochemical Tool

Biodegradation of organic contaminants involves the release of electrons to be transferred to an electron acceptor. The number of electrons released is proportional to the amount of biodegradation activity within a matrix, which can be measured via a bioelectrochemical system. The BioRemeterTM is a portable type of bioelectrochemical system that is designed to directly measure levels of in situ microbial activities.

This tool can “capture and transfer” electrons released from the biodegradation of organic compounds, including contaminants of concern, resulting in an electrical potential (voltage) within the device. Differences in the voltage readings from the tool are translated to levels of microbial activities.

In one case study, a microbial enhancement treatment was implemented at a fuel station with benzene-contaminated groundwater. BioRemeterTM surveys of the site were conducted before the treatment implementation and 60 days after the treatment implementation. The survey indicated that microbial activities increased in wells within the treatment area, but little change in microbial activity was observed outside the treatment area.

In another case study, an in situ bioremediation system was actively operating to treat benzene-contaminated groundwater, where a BioRemeterTM survey was conducted in wells two weeks after shutting down the system, and then the system was reactivated at one well. After one week, biodegradative activities of wells surrounding the treatment well were measured by the BioRemeterTM. Results indicated that the voltage measurements decreased linearly with distance from the treatment well. From the data, a linear correlation estimated that the radius of influence would dissipate at distances >13.6 ft from the location where the treatment system was installed.

Song Jin is the Founder and CTO of Advanced Environmental Technologies.

Comparing ISCO Effec-
tiveness with and without Pneumatic Enhancement at a UST Site

ISCO was selected to treat groundwater impacted by fuel oxygenates, including MTBE and TBA at concentrations over 100,000 µg/l, at a former gasoline station site in San Diego County, California. Lithology at the site is heterogeneous and generally consists of semi-consolidated, partially-cemented silts, silty sands, and clayey sands, with discontinuous clay lenses.

An ISCO pilot test was performed in the vicinity of former source areas to evaluate the effectiveness of the technology. Borings were advanced using a direct-push drill rig and high pH-activated sodium persulfate was injected at each location. Reductions in MTBE and TBA concentrations indicated that ISCO was effective at treating dissolved-phase oxygenates. However, chemical application challenges were encountered, including nonuniform ROI, high injection pressures, and low flow rates. Lithology was shown to be more complex than initially assumed and necessitated a modified injection approach.

Full-scale ISCO was conducted utilizing pneumatic enhancement (PE) to address issues related to complex lithology. Borings were advanced using a sonic drill rig with nitrogen gas injected into discrete intervals sealed off using packers prior to chemical injection. High pH-activated sodium persulfate was again injected at each location in approximately similar dosages and quantities as during pilot test injections. Field water quality and post-ISCO groundwater monitoring indicated that PE improved lateral extent and uniformity of the injection ROI, increased injection flow rates, and decreased injection pressures.

A final injection event with PE to treat a remaining hot spot was completed 1 year later. Improvements in chemical application with PE resulted in greater reductions in contaminant concentrations and overall ISCO effectiveness. Oxygenate concentrations decreased by an average of 94 percent at source area monitoring wells with the modified approach using PE. MTBE and TBA concentrations decreased below cleanup objectives throughout the plume and the regulatory agency approved case closure.

Adair Johnson, brings her experience in research and field programs to site assessments, water quality monitoring, and implementation of environmental remedial programs.

Combating Climate-Exacerbated Harmful Algal Blooms (HABs) Using Artificial, In-Lake Hydraulics

Harmful algal blooms are not only crippling threats to aquatic ecosystems, but also to public and economic health. Cultural eutrophication, the introduction of excess nutrients to an aquatic ecosystem from anthropogenic forcing, disturbs the balance of production, consumption, and decomposition of organic matter and can increase algae growth. Concurrently, climatic eutrophication, eutrophication due to climate forcing, presents new challenges. Changing precipitation patterns, severe storms, and extreme temperatures can all impact nutrient loading and hydrodynamics. HABs are emerging contaminants that pose serious public, environmental, and economic health risks. The objective of this research is to investigate options for scalable and economical engineering controls for sites where source controls have failed.

Current initiatives to control nutrient loading do not adequately address climatic eutrophication and there is little policy aimed at controlling nutrient runoff under extreme and changing weather patterns. Yet, climate projections indicate that without successful remedial solutions, we will likely see more severe eutrophication in the coming decades. In the absence of effective source controls, engineering controls will be needed to oppose the coupling effects of cultural and climatic eutrophication. This research will focus on amassing and analyzing a variety of case studies that use artificial, in-lake hydraulics as corrective and preventive solutions to address recurring or potential HABs in water bodies.

In-lake hydraulics can be defined as the movement of water that is influenced by wind mixing, internal currents, inflows, or stratified water layers that affect turbulent mixing. Hydraulic management strategies that simulate this movement have been effective in small, eutrophic lake/reservoirs, as well as in some larger reservoirs, provided sufficient flows are available and the hydraulics are conducive. Hydraulic management strategies may include flushing, drawdown, hypolimnetic oxygenation or aeration systems, and mechanical circulation, also called destratification.

These strategies are primarily aimed at maintaining or redistributing oxygen levels throughout the...
Amelia Jones received a Master of Science in Civil and Environmental Engineering from the University of California, Davis, where she researched the impact of hydrology, meteorology, and land use changes on water quality at Lake Tahoe, CA/NV.

The Next Generation of Gas Sampling Capabilities: Review of Key Factors Driving Adoption of Long-Duration Air and Soil Gas Sampling Methods

Vapor intrusion sampling often requires sub-slab soil gas sampling in addition to indoor and ambient air to determine risks to building occupants. New regulatory guidance in California prescribes the use of similar sampling devices and testing methods when collecting air or gas data across different media and during the same sampling periods for correlation. However, this is not possible with active soil gas due to potential for cross-contamination from sub-slab to indoor air. Moreover, temporal variability is significantly contributing to the decision basis regarding the sampling methods to manage factors of timing, duration, locations, and external influences.

Research completed by Dr. Paul Johnson and others have determined that the temporal variability of indoor air contaminant concentrations from vapor intrusion can vary by orders of magnitude over time and that short duration samples collected over 24 hours are likely to produce results that are not truly representative of long-term health risks. Sub-slab and soil gas VOC concentrations have also been demonstrated to vary irregularly in similar fashion as does indoor air concentrations. Sub-slab and uncovered soil gas VOC concentration variability has been demonstrated to range from 3 to more than 30 times (EPA, 2010) and over 100 times in other DoD studies (McHugh, et al., 2007, and ESTCP, 2008).

Key performance data will be presented to demonstrate that quantitative adsorbent type samplers can passively sample gas for a brief period of time (e.g., hours) to provide short-duration average concentrations or extended periods of time (e.g., 7 to 30+ days) to provide long-duration average concentrations in ug/m3 with low reporting limits in the sub-ppbv range in accordance with US EPA Method TO-17. The time-weighted average concentrations provide data that reduce the risk of underestimating true concentration resulting from unpredictable temporal variability and episodic occurrences of vapor intrusion.

Lowell Kessel, MSc, P.G. is a registered professional geologist (PG) in California and has managed environmental projects and designed remediation solutions for over 20 years on five continents.

Why Bedrock is the Same and Different for LNAPL Transmissivity Testing

Background/Objectives. This will provide a discussion of the recent publication unifying NAPL drawdown theory for NAPL under various conditions focused towards bedrock. LNAPL Transmissivity was initially applied to LNAPL in unconsolidated formations and through wider application is now being employed in bedrock formations. It is appropriate to review the assumptions of LNAPL drawdown testing and evaluate whether they are met and what if any additional considerations are needed for bedrock application of LNAPL transmissivity testing methods.

Approach/Activities. The primary assumption in drawdown testing is the relationship between discharge and drawdown. The Bower-Rice and many field test results indicate this relationship to be linear in many instances. The calculation of discharge is straightforward as it is directly related to area of the well being recharged and rate of change in gauged LNAPL thickness over change in time. Drawdown has been shown to be reliant on the LNAPL distribution of LNAPL in the soil profile relative to the water-table elevation. Different solutions exist for calculating LNAPL drawdown for confined, perched and unconfined conditions. A brief discussion of theory and modeling results will provide an understanding of expected behavior. Through understanding how drawdown varies as the gauged LNAPL thickness changes improved understanding of how discharge and drawdown vary as a well screen over multiple
bedrock fractures recharges with NAPL.

**Results/Lessons Learned.** The resulting behavior model will provide the basis for identifying best field testing and analysis practices will be provided with reference to the recent publication by Kirkman and Koons, Unifying NAPL Drawdown and Transmissivity Testing in Unconfined, Confined, Perched, and Fractured Settings Using the Z-Factor and MH Principles.

Andrew Kirkman is a hydrocarbon and hydrogeology subject matter expert for BP.

**Installation, Startup, and Operation of World’s First Regenerable Resin System for PFAS Removal**

The United States Air Force Civil Engineering Center (AFCEC) is conducting on-going response activities to remove and remediate groundwater impacted by poly- and perfluoroalkyl substances (PFAS) at the former Pease Air Force Base in New Hampshire.

AFCEC responded by contracting with Wood Group PLC to conduct a side-by-side pilot test in 2016, comparing the performance of Emerging Compound Treatment Technology’s (ECT2) regenerable ion exchange (IX) resin and bituminous granular activated carbon (GAC). The regenerable resin system was selected for full-scale application, based on system performance and a lower overall lifecycle cost than GAC.

A 200-gpm system was provided to meet the primary project objective of producing treated water with combined PFOS plus PFOA concentrations below the 70 ng/l Health Advisory Level (HAL). The full-scale IX resin system was installed from fall 2017 through spring 2018.

The PFAS remediation system has treated more than 31 million gallons of groundwater having a total average influent PFAS concentration of 55 µg/l. The effluent quality from the IX resin system has been consistently non-detect for PFOS and PFOA, readily achieving compliance with the 70 ng/l HAL target.

Five successful resin regenerations have been performed to date. Operational modifications have been made to address and correct minor challenges with the distillation system, and regenerant recovery and super-loading processes have proven successful. The original superloading media is still operational, having removed and concentrated greater than 99.99 percent of the recovered PFAS mass, and therefore no PFAS waste has needed to be hauled off site to date.

Mrs. White is an Environmental Engineer with ECT2 (Emerging Compounds Treatment Technologies), an equipment company focused on developing and commercializing treatment technologies for emerging, difficult-to-treat compounds including PFAS.

**New Perspectives on Horizontal Wells for Assessment and Remediation**

Remediation technologies can sometimes be established, but are not prevalent, for a variety of reasons; however, creative economics and process improvements can drive new applications and levels of acceptance. We submit that this is what is happening with the deployment of nested, segmented horizontal wells for site assessment and remediation, where each segment is plumbed to the surface. In essence, decreasing costs and “greater systems flexibility,” are two factors that have brought about a resurgence of new designs in horizontal well systems as described. These evolutionary features specifically migrate the industry away from monolithic single well systems, which present certain complications for sampling and treatment.

The two central applications of the new designs are in discrete site assessment and subsequent treatment, as objectives warrant. In assessment, gas and water can be extracted providing additional accuracy to site conceptual models (CSMs). This is especially important for sites challenged by access issues (e.g., the built environment, natural obstacles, secure locations, property interferences). Further, the same operations have a remediation application as well, if contaminant gases or liquids are actively extracted, but as required, the well systems are also an important tool for the surgical deployment of treatment reagents.

In essence, the surgical precision of these systems can significantly enhance conceptual site models with a new strategic approach that can be called high-resolution contaminant distribution (HRCD), in the horizontal plane, that marries well with high resolution site characterization (HRSC) that addresses its domain. For site treatment, the “discretized management” of extraction and injection operations, and the economic advantages therein, is self-evident- noting it is
the individual communication of well segments to the surface that makes this possible.

Several case studies will be presented that illuminate the advantages of a next generation horizontal well system. In the site assessment arena, two cases will be presented that quickly illuminate how access under the built environment can be achieved and radically alter the CSM. In terms of site remediation, another two cases will illustrate treatment management advantages. One example involves the discrete application of a chemical oxidant in a series of “as needed” injections, thus saving time and cost to site closure. In a second application, a large site with extensive dissolved phase contamination was effectively addressed with a combination of air sparging (AS) and soil vapor extraction (SVE) operations mediated by the well systems as described.

The presentation will also introduce design software that can help remediation professionals consider the operational and economic advantages of horizontal well systems over vertical well systems in these cases. In general terms, one horizontal well unit system can substitute for up to a dozen vertical wells, depending on variable site conditions, and those principles and benefits will be featured by example.

Stephen Koenigsberg, Ph.D., Lance Robinson, Wes Wiley, EN Rx, Inc.

A Decision Tool to Determine if Horizontal Well Systems Can Replace Vertical Well Systems

Directional, or horizontal drilling has been used for a variety of purposes, including utilities, dewatering, and remedial activities. Using this method for site cleanup versus traditional vertical extraction wells needs to be considered based upon today’s remedial challenges. An approach to evaluate the cost-benefit of one system over another is to base it on the number of vertical wells per a given length of a directional well and to evaluate it more on the zone of influence of both designs through a mathematical and hydrogeological approach. This can be done by comparing flow to an HDD well (using flow to a line trench as a proxy) and that of flow to a single well.

The solution approximates the ratio of horizontal to vertical extraction wells and provides information to allow for a cost comparison to be performed. Additionally, using the known hydraulic conductivity, depth to groundwater, and the desired depth of drawdown with adjustable pumping rates can maximize the desired outcome for remedial designs. The solution explained above approximates the ratio of horizontal to vertical extraction wells and provides information to allow for a cost comparison to be performed. Utilizing actual site data in the approach allows for the ability to make better decisions without the expense of conducting a full-scale groundwater flow model.

W. Richard Laton is an expert in the field of hydrogeology. He is currently an Associate Professor of Hydrogeology in the Department of Geological Sciences, California State University, Fullerton, and the prestigious 2014 Ross Oliver Award winner.

3D Imaging of Injectate Distribution in Varying Horizontal Well Configurations

Horizontal wells are well suited to remediation of environmental sites by providing significant injectate distribution in a horizon of interest. These wells can be installed beneath areas where vertical wells cannot be placed due to logistical or other constraints. Significant issues of concern for horizontal well configurations are the quality control of grout and effective distribution of injectate into the formation through screened intervals.

Electrical imaging methods have been used pre- and post-injection to provide temporal monitoring of injected treatments into impacted horizons. Imaging was performed for horizontal well systems using both a singular screened interval and multiple segmented well screens. The results indicate injectate migrates vertically in both configurations and screened intervals provide preferential flow into the domains that they treat. These temporal imaging data also illustrate that the injections can be modified by nearby pumping wells used to control and enhance lateral and vertical distribution. These 3D imaging case studies will be reviewed, and lessons learned for horizontal well configurations will be shared.

Todd Halihan is a Professor and the Sun Company Clyde Wheeler Chair in Hydrogeology at Oklahoma State University, and Chief Technical Officer for Aestus, LLC.

Air Sparging Curtain Wall with Vertical and Horizontal Air Supply

Background/Objectives: After
years of vigorous remediation efforts, low concentrations of dissolved chlorinated volatile organic compounds (CVOCs) remained in groundwater at an industrial railroad locomotive shop facility. In order to mitigate potential migration of VOCs across the facility, the company agreed to test the effectiveness of implementing an air sparge/soil vapor extraction (AS/SVE). The purpose of this ongoing pilot test is to evaluate AS/SVE technology for its ability to remove CVOCs from the alluvial aquifer at the Facility and decrease dissolved CVOC concentrations and mass discharge downgradient of the AS/SVE curtain. The specific objectives were to:

1. Conduct baseline and pilot testing to establish design parameters including air flow rates, sparging and SVE zones of influence
2. Conduct long-term system performance monitoring to evaluate the expanded system’s effectiveness at

**Approaches/Activities:** The target barrier wall installation area has a complex hydrogeology that is characterized by annual fluctuation in groundwater depth, extreme permeability, and correspondingly large superficial groundwater flow velocities. The target aquifer consists of sands and gravels atop a bedrock varying in depth from 25 to 32 feet. Groundwater depth varies seasonally in the installation area between 2 and 12 feet in depth.

The AS/SVE curtain installation has been performed in several stages:

- 2015/16: System A installed consisting of 15 vertical air sparge and 3 vapor extraction wells
- 2017: Overall curtain wall length expanded with System B installation consisting of 12 vertical air sparge wells and 2 SVE wells
- 2018/19: Installation of seven, 20-foot horizontal air sparge screens utilizing the En-Rx VertebracTM

The performance of the curtain wall has been monitored extensively.

**Results/Lessons Learned:** The performance of the curtain wall will be discussed as changed by the sequential upgrades to the system. The economics and performance of horizontal versus vertical sparging wells will be discussed.

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**Advances in EVO Deployment Using In Situ Alcoholyis**

Emulsified vegetable oil (EVO) slowly ferments and can act in the subsurface as an organic carbon and hydrogen source that stimulates organohalide-respiring bacteria that in turn mineralize chlorinated solvents. Indigenous microorganisms first consume and ferment EVO to generate hydrogen, fatty acids, and other important nutrients and cofactors. The prevailing anaerobic conditions are ideal to reduce chlorinated solvents like PCE and TCE through dechlorination processes such as dehaloelimination. Then specialized bacteria such as Dehalococcoides mccartii, Dehalobacter or Dehalogenomonas use subsurface-generated hydrogen when transforming reduced solvent compounds like 1,2-DCA, 1,1,2-TCA, cis and trans-DCE to Vinyl Chloride and innocuous Ethene.

Although emulsifying vegetable oil allowed for the overcoming of limitations of pure vegetable oil injection and minimized field interventions by using a long-lasting electron donor. Hundreds of EVO injection events over the past years has demonstrated that EVO effects are limited to the area in the immediate vicinity of the injection point. This is evident through low TOC values measured even tens of meters downgradient to injection points where only acetic acid predominates. A favorable fatty acid diversity seems to be limited to the injection points immediate vicinity (< 5 meters). Another inconvenience that becomes more evident when using permanent, screened wells is biofouling. This phenomenon is typically attributed to biomass developing in the aerobic vicinity of injection wells due to hydrophobic oils creating a film (residual electron donor) that stimulates biomass growth. In many cases, biofouling or permeability losses could very well be attributed to geochemical incompatibilities between EVO and cations in the subsurface, or EVO’s intrinsically high retention to soils.

To overcome two of the main challenges associated with EVO injection: poor fatty acid subsurface distribution and biofouling, this presentation will discuss deploying electron donors via in situ alcoholyis. The reaction is accomplished in situ with a homogenized alkaline catalyst, heat, or biocatalyst to form fatty acid alkyl esters, carboxylic acids salts and glycerol.
The products formed in situ travel far easier than EVO, add a pH buffer to the system and leave the system less susceptible to clogging and biofouling.

Gary Birk is a founder and Managing Partner of Tersus Environmental.

Improving Phytoremediation Success for Mixed Contaminant Plumes in Cold Regions Using Endophytes

Bioremediation projects in cold regions will often encounter significant challenges including infrastructure damage from soil frost heaving, increased cost and schedule associated with logistics, and slow microbial kinetics. Phytoremediation has the potential to overcome many of these challenges, but maintaining healthy plant populations in such settings will require significant attention. This presentation describes a successful implementation of a phytotechnology system designed to remediate petroleum hydrocarbons and ethylene dichloride at a former fuel terminal in Fairbanks, Alaska. Phytoremediation has not been widely used in Alaska, especially in the northern regions, with the majority of projects using grasses and willows. At this site, the longer-lived Balsam Poplar was selected because of its deep root system and being native to the area. The trees were inoculated with two different bacterial endophytes to improve growth, health, and enhance remediation effectiveness for the site contaminants.

The phytoremediation design included two different plots focusing on an approximate 0.5 acre area of impacts. Over 600 trees were planted immediately after ground thaw in spring 2018, with the inclusion of nutrients and mycorrhizae in backfilled boreholes. Irrigation was conducted with buried drip heads to address winter frost conditions. Following one year of monitoring, more than 90% of planted trees demonstrated healthy growth. A combination of factors was identified as relevant for those trees exhibiting stressed conditions, including excessive summer heat, deep groundwater due to unseasonably low precipitation, and hot spots of high contaminant concentrations.

The majority of the treatment area demonstrated relatively high plant productivity and resilience, so the newly established trees were used as stock for replants in 2019 with modified planting protocols. The presentation will emphasize the importance of early plant care for tree growth, practices that are especially relevant for sites with extreme cold winters, summer temperature spikes, and unreliable precipitation.

Chris Schultz is a licensed engineer in the state of Alaska that focuses on project management of contaminated fuel terminal sites, site reporting, subcontractor oversite, regulatory compliance, and site investigations of industrial and military facilities.

Post ERD Injection Site Dynamics: Long-term Trends at a VOC Contaminated Site in Monterey, CA

In-situ remediation of VOCs continues to evolve. As more sites move beyond an initial field application event, valuable information emerges from ongoing performance monitoring. Data gathered following a 2016 enhanced reductive dechlorination (ERD) injection event in Monterey, CA continues to inform the conceptual site model and illustrate the importance of reagent selection, field verification during injection and performance monitoring. This project demonstrated the applicability of ERD treatment of high strength concentrations (likely indicative of DNAPL/DAPL) in a conductive, sand aquifer with a nearly flat potentiometric surface that presented unique benefits and challenges.

Post-injection monitoring results offer insights into single injection reagent performance over four years as well as information useful in evaluating future remedial steps, including completion of a second more limited injection in the fall of 2019. The talk will also touch on the proper use of performance monitoring data to guide decision-making on additional injections, the importance of selecting an appropriate reagent, and the benefit of close coordination between design and implementation stages of remedial activities to remediate a challenging site.

Andrew Halmstad is an engineer with 8 years of consulting experience focusing on environmental remediation and cost allocation of contaminated sediments, groundwater, and soils.

Bioremediation Options for 1,4-Dioxane

1,4-dioxane (1,4-D) is a probable carcinogen commonly detected in groundwater due to its use as a solvent stabilizer. The high solubility of 1,4-D often leads to large dilute plumes with associated remediation...
tion challenges. Fortunately, available options for implementing bioremediation in 1,4-D contaminated groundwater are increasing. Aerobic cometabolic bioventing utilizes the addition of oxygen and alkane gases to groundwater and has been tested in the lab and successfully implemented in the field.

For example, at a DoD site in Arizona, sequential methane and oxygen gas infusion was used to enhance cometabolic 1,4-D degradation. Delivery of sufficient oxygen was identified as a major challenge for in situ bioremediation of 1,4-D and in some cases may favors ex situ approaches, such as bioreactors.

Bioremediation of 1,4-D by aerobic energy yielding pathways has growing promise. A major milestone was the discovery of Pseudonocardia dioxanivorans CB11902, a microorganism that uses 1,4-D as an energy source. Other metabolic cultures, which can be used for bioaugmentation, have been developed from ex situ bioreactors. In laboratory microcosms for a confidential site, both cometabolic and bioaugmentation treatments using a metabolic 1,4-D culture, achieved complete removal of 1,4-D within 100 days. Given, the technical complexity of applying a cometabolic remedy in the field (adding both an alkane gas and oxygen), bioaugmentation with the metabolic culture was selected as the remedy for a field pilot-test, currently in planning. Available field results from this pilot test will be discussed.

Phytoremediation has also been deployed successfully at 1,4-D sites in North America and in Europe. Phytoremediation is an application of bioremediation that can provide hydraulic control, remove 1,4-D from groundwater and deliver of oxygen to groundwater, encouraging microbial biodegradation of 1,4-D in the rhizosphere. Interest in phytoremediation paired with bioaugmentation is growing and the potential for this combined approach for treatment of 1,4-D plumes and to address co-contaminant phytotoxicity will be discussed.

Sandra Dworatzek is an environmental microbiologist with advanced technical experience in laboratory treatability studies.

**Accounting for Polar Degradation Metabolite Risk at Petroleum Sites with a Previous Ecological Risk Assessment**

In early 2019, The San Francisco Bay RWQCB established saltwater ecological receptor screening levels for petroleum degradation metabolites or “polar compounds”. Although not specifically accounting for polar compounds, the use of prior Ecological Risk Assessments (ERAs) could provide benefits in evaluating impacts from site-specific polar compound mixtures. The applicability would be dependent on testing being performed on sediment from proper groundwater discharge zone locations, and the testing being performed using acceptable methodology.

To be comprehensive, ecological risk assessments for aquatic habitats typically evaluate both aquatic (water column) and benthic (sediment-associated) biota. A previous ERA was evaluated as a case study for this assessment. The ERA included acute and chronic toxicity testing using near-shore, intertidal bulk sediment and to the sediment-water interface (SWI) in to mimic exposure to porewater. Toxicity was not observed for amphipod, crustacean, and larval fish species. In the re-assessment of the ERA for the case study, ecotoxicity was observed only in the most sensitive test species (mysid shrimp) when similar species were exposed to serially diluted and adjusted groundwater. Regulatory concerns focused on (1) the fact that porewater in the hyporheic zone (groundwater-surface water mixing zone) was not tested in the previous ERA for polar compounds, and (2) confirmation that the off-shore test locations represented groundwater discharge locations.

Results from the previous ERA were applicable to polar compounds based on the empirical testing methods. With respect to the porewater issue, this assessment established that the previous ERA test methodology and results were appropriate because (1) the biota of the hyporheic zone exposed to porewater and the biota of shallower sediments are similar, and (2) SWI tests using mysid shrimp have been the preferred tests in San Francisco Bay due to sensitivity and reliability. With respect to the SWI test, it can be a key indicator of polar compound ecotoxicity based on capturing degradation metabolites from any residual petroleum hydrocarbon in the sediment, as well as polar compounds captured in sediment porewater from groundwater discharge and upwelling. Care needs to be taken to identify the proper groundwater discharge locations by establishing a robust site conceptual model as
well as sediment collection methods (e.g., Trident Probe, UltraSeep Meter) to collect intact sediment samples that can support a risk-based approach at estuarine sites.

Arnab Chakrabarti is a professional engineer at Terraphase Engineering with over 19 years of experience in environmental site characterization, remediation, and project management.

NAPL Mobility in Sediments: Categorizing NAPL Migration Potential Using a Multiple Lines of Evidence Approach

Quantifying NAPL mobility in sediments is critical when evaluating remedial alternatives and remediation engineering design. NAPL mobility in sediments cannot readily be evaluated using methods that are typically effective at upland sites. Little standardized guidance exists to evaluate NAPL mobility in sediment (currently in development with ASTM) and so programs must be developed on a site-specific basis and negotiated with regulatory agencies. The objective of this presentation is to introduce a sustainable and risk-based approach to categorize NAPL as immobile, mobile (present, but lacking sufficient saturation or site conditions for lateral or vertical migration), or potentially migrating (present at saturations high enough that may result in lateral or vertical migration).

If NAPL is determined to be mobile or migrating, then additional remedial actions may be necessary to eliminate the potential for NAPL to migrate beyond its existing extent. Multiple lines of evidence may include collection of sediment cores for laboratory analysis of physical properties and NAPL mobility potential, as well as analysis of hydrogeologic conditions and driving forces from the individual core scale up to the site-wide scale. Incorporating these lines of evidence into the CSM allows remediation to be targeted to only where there are risk drivers. The overall environmental footprint of remediation is therefore reduced and more efficient than the presumptive remedy of complete removal via dredging.

A case study example of implementing the multiple lines of evidence approach on a major US river will be presented. The approach was designed in a step-wise fashion with “off ramps” after each step if the NAPL mobility is defined at that point. Thus, it is not necessary to complete the entire process, but only to conduct sufficient analysis to define the NAPL mobility potential. The case study resulted in a regulatory-approved path to characterize NAPL mobility as part of development of site-specific remedial endpoints, remedial design alternatives, and a potentially expedited path to remedial implementation and site closure.

Camille Carter is a Senior Geologist with GEI Consultants in Denver, Colorado.

Fate of Polycyclic Aromatic Hydrocarbons in Urban Runoff and their Effects on Receiving Sediment

Urban stormwater runoff is known to be a major source of particle-associated polycyclic aromatic hydrocarbons (PAHs) that contaminate receiving sediments. Historically, stormwater assessment has been centered on loads rather than impacts and that can lead to misevaluating the risk associated with runoff discharges. In this study, we examined PAHs in storm runoff solids from a mixed-use urban watershed to determine the physical, chemical, and biological effects they incur on receiving sediment.

The study was conducted in Paleta creek at Naval Base San Diego (NBSD) in 2015-2017 and involved a variety of sampling approaches such as intensive sampling of individual storms with size-fractionation of solids, water and sediment collection before and after the 2015-2016 winter storm season, and sediment traps throughout the same storm season. Porewater sampling and both in-situ and ex-situ bioassays with bent-nose clams (Macoma Nasuta) were employed to determine the effects or runoff on the receiving benthos.

Our analysis showed that PAHs in stormwater were surprisingly associated with coarser, rather than finer, organic-carbon rich particles that settle close to the creek discharge point. Parent and alkylated PAH ratios allowed us to distinguish watershed runoff solids from sediments transported from other parts of the Bay and confirmed that the physicochemical effects of runoff are localized in the near-field. The bioaccumulation studies indicated that solids-associated PAHs in stormwater runoff have limited bioavailability that is significantly lower than what sediment PAH concentrations would predict. However, bioaccumulation was better predicted by porewater
Successful Large-Scale Vapor Intrusion Investigation – A Regulatory Perspective

A former aeronautics and electronics research, development, and production facility operated on 98 acres in Orange County from 1957 until 1993. The former facility was demolished and remediated in the 1990s and rezoned for residential use after receiving a soil closure from Orange County Healthcare Agency. The surrounding area is primarily residential with some commercial use. The environmental case was referred to Santa Ana Regional Board for off-site groundwater assessment and remediation. In 2017, an updated conceptual site model was prepared in which the historical site data were evaluated and compared with the newer screening levels and standards. As a result of this evaluation significant data gaps in soil vapor were identified, requiring further evaluation for potential vapor intrusion.

The primary contaminant of concern for the site is trichloroethylene (TCE). Since TCE has the potential for short-term health risks, a decision flow chart was created as part of the initial work plan to outline a path forward based on actual analytical data so the assessment could be streamlined. Therefore, the investigation has been conducted in phases and has included indoor air assessments to occur concurrently with assessment and delineation of the soil gas plume.

Two TCE soil gas plumes have been identified that require the need for indoor air evaluation. The larger of the two TCE soil gas plumes is over 1.5 miles in length and over 0.5 miles wide. To date, over 540 homes and 3 commercial businesses have been identified to have their indoor air evaluated for potential vapor intrusion. This presentation will elaborate on the key components for the efficient and successful vapor intrusion assessment. These components were proven effective in facilitating the modification of field activities to incorporate principles of the new Cal/EPA Draft Supplemental Vapor Intrusion Guidance as well as navigating the COVID-19 pandemic repercussions.

Jessica Law has a bachelor’s degree in Geology from California State University San Bernardino and is a registered professional geologist with the State of California.

Rapid Closure of 98 Petroleum Vapor Intrusion Sites

Petroleum underground storage tank (UST) sites are typically managed under State programs which allow closure even if residual petroleum is present in soil and/ or groundwater and has not been remediated to unrestricted site use standards. A desktop petroleum VI (PVI) evaluation was conducted at a facility where 98 UST sites had previously been granted No Further Action (NFA) status with land use restrictions (LURs) by the State regulatory agency. The evaluation was conducted using the 2015 United States Environmental Protection Agency (USEPA) and the 2014 Interstate Technology and Regulatory Council (ITRC) PVI Guidance, which recommend determining the clean soil vertical separation distance of the buildings within the site’s lateral PVI inclusion zone.

This desktop evaluation gathered all historical data available for sites and integrated those data into a screening database and then into a Graphical Information System format to evaluate the data geospatially. The desktop evaluation resulted in 27 buildings being retained at 20 sites for further PVI investigation under a Phase 1 Field Investigation. Groundwater grab and subsurface soil samples were collected from the historical tank basins to characterize current source strength. Exterior soil gas and subslab soil gas samples were collected at each of the 27 buildings as recommended in the desktop evaluation. Only 8 of the 27 buildings at 7 of the 20 UST NFA-LUR sites evaluated during Phase 1 were retained for further investigation during Phase 2 in order to evaluate temporal variability. During Phase 2, 19 subslab soil gas samples were collected from 8 buildings at 7 UST NFA-LUR sites. Subslab soil gas concentrations during Phase 2 were consistent with concentrations during Phase 1 and significantly below the vapor intrusion.
Therefore, NFA for VI was also recommended at these 8 Phase 2 buildings. Application of the PVI guidance to UST sites to account bioattenuation allowed the project team to effectively assess PVI using state-of-the-science methods and focused the VI investigation on the buildings with the highest VI potential, saving both time and money. Use of the PVI criteria significantly reduced the number of buildings selected for sampling compared to what would be expected using the traditional VI evaluation process and allowed closure of the VI pathway after only 2 phases of focused investigations.

Keri Hallberg is a Senior Vapor Intrusion Technologist and a registered Professional Engineer with over 19 years of experience providing in Environmental Site Assessment; developing strategy for Remedial Investigations and assessing Remedial Investigation data, development and implementation of Corrective Action Plans and Feasibility Studies including pilot testing, design, and construction oversight.

Inter-comparison of Multiple Subslab Sampling Strategies - Defining Temporal and Spatial Variability for Vapor Intrusion

Although subslab sampling is viewed as an important line of evidence in vapor intrusion studies, there is a lack of consensus regarding methodologies. Some guidance documents recommend installing subslab probes that barely penetrate the slab, while others define subslab probes to include implants constructed substantially below grade. Sampling durations of less than 15 minutes to one day are commonly performed. Passive samplers, capillary flow controllers and continuously operated field GCs are utilized to extend sampling periods thereby incorporating temporal variability. High volume sampling methods can be used to address spatial variability.

In this study multiple subslab sampling methods are being inter-compared in a month-long intensive study within a small area of a large commercial building, including comparisons of:

- Duplicate samplers for each of three types of subslab ports; conventional, vapor pin and implant. These locations are being sampled daily for one month using an on-site GC to assess temporal variability.
- Triplicate samples with passive samplers, including tube type and Waterloo Membrane samplers.
- Tube type samplers operated over varying durations and in varying boring diameters.
- Passive samplers and an innovative capillary controller for Summa canisters over a two-week sampling duration.

All of the passive and relatively low volume sampling methods are being compared to a high-volume sampling method, which will be applied after completion of the low volume testing. Meteorology, radon and differential pressure data sets are also being acquired during the field testing.

Temporal variability of subslab concentrations in the same building has been observed in another project over a full year using near-continuous VOC sampling. Extensive high time resolution indoor air data have been collected over a full year and continue to be obtained throughout the duration of this project. Thus, the project team intends to evaluate the information content provided by these various subslab methods for understanding the overall vapor intrusion behavior of the building.

Chris Lutes of Jacobs is a nationally recognized expert in vapor intrusion.

Continuous Monitoring of Indoor Air Helps to Evaluate Risk from PCE and TCE Exposure in a Residential Complex in Brazil

A complex of 4 residential high-rise buildings was built in Campinas, SP Brazil in the early 2000’s on a lot that had been previously used as a solvent recycling facility. Soil and groundwater were impacted by PCE and TCE. The real estate transaction took place before state legislation required site assessment prior to a change of use from industrial to residential. The seller neglected to inform the developer/buyer about the soil contamination. The first 12-story building was finished and released to residents in 2001, while buildings two and three were in the final stages of construction. All buildings have residential units on the ground level. During the foundation work for building 4, a worker passed out from exposure to soil vapors.

The contamination of the foundation area was then noted by an engineer on site and reported to the State of Sao Paulo EPA. Occupation of buildings 2 and 3 was then prohibited by the Sao Paulo EPA and construction of building 4 was stopped. The developer of the complex vanished after construction was halted and the contaminated site was left unfinished. A judge
ruled that the City of Campinas would take responsibility for the management of the contaminated site in 2002. An emergency SVE system was installed under building 1 where the residents refused to move. Over the next 17 years, there was a great deal of uncertainty about the exposure of the residents of building 1 to vapors while occupancy of buildings 2 and 3 was prohibited.

Sampling of ambient air was only done several times using Summa canisters and TO-15 analysis. The sampling was done at a limited number of locations due to financial limitations, still leaving great uncertainty about the real risk to the residents. In August of 2019, a 2-week continuous monitoring campaign was conducted in 16 locations of the complex under the supervision of the State of Sao Paulo EPA and the DEQ of the City of Campinas. The TCE and PCE concentrations in air generated during the two-week sampling event documented that ambient air in the residential units on the ground level was below acceptable risk levels. The Sao Paulo EPA and the DEQ of the City of Campinas are now considering a release so that occupation is prohibited.

With TCE soil gas concentrations greater than 100 times state screening criteria. It is known that the large building, covering more than 250,000 square feet, was constructed at or above grade over multiple decades with subsequent additions and structural footings; however, building design drawings were not available. Historical areas of operation within the building changed with time and locations of manufacturing and subgrade utilities were unknown. In 2016 and 2017, the state regulatory agency updated their guidance to include pathway evaluations, additional screening criteria for indoor air samples and emissions, and mitigation requirements. This presentation summarizes the vapor intrusion pathway evaluation and the subsequent mitigation that resulted from the updated guidance.

**Approach/Activities:** A vapor intrusion pathway evaluation was conducted within five building areas and included an interior building survey, paired sub-slab soil gas sampling, and indoor air monitoring for radon and site-specific chemicals of concern (COCs). Long-term differential pressure and temperature was monitored at several sample locations. Short-term radon testing in sub-slab soil gas and indoor air was conducted with paired COC sampling activities in four building areas. Sample results indicated a potential vapor intrusion risk, such that interim mitigation was necessary prior to designing a full-scale mitigation system. Interim mitigation measures included sealing cracks/holes/penetrations, air treatment, and modifying building ventilation with confirmation sampling to evaluate combined effectiveness. Pneumatic testing and building material testing were also conducted along with other building data collection to support the full-scale mitigation design. Three-dimensional scanning of the building’s interior and exterior were used to create a model of building layout, design piping runs, and identify potential vapor pathways.

**Results/Lessons Learned:** Radon and COC sample data and differential pressure monitoring results support the presence of an indoor source of COCs in one building area. Strategic, pragmatic, and iterative interim mitigation efforts successfully reduced indoor air concentrations of COCs to below the applicable criteria allowing for time to develop a full-scale design. Pneumatic testing and building survey results show that sub-slab depressurization is a viable approach for vapor intrusion mitigation. Building material testing shows contributions to indoor air. However, sub-slab depressurization alone has reduced indoor air TCE concentrations below regulatory criteria.

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Paulo Negrao is the CEO of Clean Environment Brasil and has a Ph.D. in Geosciences from State University of Campinas.

**Large Building Vapor Intrusion Pathway Evaluation and Mitigation**

Background/Objectives: Sub-slab soil gas investigations identified areas beneath the slab of a former manufacturing facility building with TCE soil gas concentrations greater than 100 times state screening criteria. It is known that the large building, covering more than 250,000 square feet, was constructed at or above grade over multiple decades with subsequent additions and structural footings; however, building design drawings were not available. Historical areas of operation within the building changed with time and locations of manufacturing and subgrade utilities were unknown. In 2016 and 2017, the state regulatory agency updated their guidance to include pathway evaluations, additional screening criteria for indoor air samples and emissions, and mitigation requirements. This presentation summarizes the vapor intrusion pathway evaluation and the subsequent mitigation that resulted from the updated guidance.

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Prediction of Volatile Organic Compound (VOC) Indoor Air Concentration Temporal Variability Using a Newly Developed Modeling Approach Indoor air VOC exposures, as a result of Vapor intrusion (VI), can be difficult to characterize because of temporal and spatial variability. Adding to this challenge is the lack of VI models that reliably account...
for weather conditions and building characteristics, especially at sites where active preferential pathways, such as sewer connections and other alternative pathways, are present. In this presentation, building science modeling tools are incorporated to predict indoor air contaminant concentration variability in a residential house overlying a groundwater plume impacted by trichloroethene (TCE).

The new modeling approach accounts for local weather conditions and building characteristics and is the first VI model to account for these processes. To account for high uncertainty in model input parameters that influence indoor air concentration variability, this study incorporated Monte Carlo simulations and compared model results to field data to verify the modeling approach. The Monte Carlo simulation results indicate that the model results and field data followed the same trend of seasonal variability for indoor air concentrations.

The greatest TCE concentration was predicted for winter, then shoulder seasons, with the lowest TCE concentrations occurring in the summer. Comparison between model results and field data demonstrate how the presence of an alternative or preferential VI pathway, can cause considerable temporal variability in mass entry rates and indoor air concentrations. The modeling approach used in this study will allow practitioners to cost-effectively evaluate variability in exposure risks (e.g. indoor air concentrations) based on weather conditions and building characteristics.

**In-Situ Bio-Air Sparge (ISBAS), San Francisco Bay Area Site**

An industrial Site in the San Francisco Bay Area was found to have a hydrocarbon-impacted soil and groundwater plume in an area measuring 350 x 150 feet, located adjacent to a tidally-influenced creek which drains to the San Francisco Bay. An In-Situ Bio-Air Sparge (ISBAS) Pilot Study was conducted in the area from 2015 to 2018 to evaluate whether addition of electron acceptors in the form of oxygen and sulfate would enhance biodegradation of the petroleum hydrocarbons. Pilot Study injection wells were installed in four study areas. Each Pilot Study Area contained three monitoring wells placed around each injection point to monitor progress of biodegradation. During the study, bacterial samples were collected and used in bench-scale testing. Based on the results of the microbial bench-tests, interim ISBAS injection of a dilute mixture of ammonium polyphosphate and ammonium sulfate was proposed to enhance biodegradation.

The ISBAS Pilot Study included continuous air injection into the four injection wells, dye injection, pump testing, and injection of nutrients and bacteria on a quarterly basis through December 2018. Following successful Pilot Study results, a full-scale ISBAS system was designed and constructed, and currently injects air and approximately 10,000 gallons of dilute nutrient solution on a quarterly basis into forty-four (44) injection wells, placed in two intersects upgradient of the tidally-influenced creek. Twelve additional monitoring wells were placed throughout and downgradient of the injection area and are monitored quarterly prior to injection for geochemical conditions, hydrocarbons, nutrient, and bacteria.

The results are used to modify nutrient additions. The full-scale system began operation in February 2019 and preliminary results indicate 51-95% declines in hydrocarbon concentrations, including gasoline, diesel, motor oil and their metabolites in groundwater.

**Performance of a Micron-Scale Carbon Remedial Fluid With Soluble Electron Acceptors for Remediating Petroleum Plumes**

Many in situ remedial technologies for petroleum hydrocarbon sites fail to perform due to short product lifespans that fail to fully treat contaminants, inability to fully distribute in the contaminated aquifer, or both. Products offering longevity and easy distribution provide an advantage.

Here we present a self-applied, micron-sized activated carbon remedial fluid with nitrate and sulfate salts serving as electron acceptors. This remedial fluid is...
non-hazardous and provides remediation practitioners with a technology that indeed has a multi-year lifespan and easily distributes using common multi-port pull-back or top-down injection tooling. Once in place, the high surface area of the carbon combined with the enhanced biostimulation of anaerobic biodegradation provides multiple-orders-of magnitude in reductions and multi-year treatment longevity.

The physical properties, optimal application scenarios, and general injection practices of this micronscale carbon remedial fluid will be discussed. Additionally, recent data from treated petroleum contaminated sites will be presented. Examples will include a former fueling station, where starting BTEX of 1,131 µg/L and TPH-GRO of 3,100 µg/L achieved non-detect in less than 2 months and remained at non-detect for 14 months after which full-scale injections commenced. Also, results will be shown from a high concentration, full-scale, retail petroleum site with TPH-G concentrations as high as 44 mg/L before treatment that were reduced by 97.6% and resulted in the site receiving an NFA status within 12 months.

Todd Herrington provides remediation technology selection expertise, engineering design and oversight services to REGENESIS clients in the Western U.S. and Canada.

Low-Temperature Thermal Remediation and Use
Low-temperature thermal applications involve the transfer of thermal energy (heat) to the subsurface to increase the treatment area above ambient temperatures but generally below 70 degrees Celsius (°C). Studies have shown degradation of organic contaminants occurring three times faster by increasing the temperature from 10°C to 20°C. Temperature improved abiotic hydrolysis and dehydrohalogenation reactions along with increased biodegradation and volatilization rates can enhance natural attenuation processes or aid in physical removal efforts via extraction applications. Low-temperature thermal does not require extraction or delivery of remediation reagents that can be limited or unachievable in low-permeability or heterogeneous settings. The propagation of heat is reliant on the thermal properties of the soil and heat losses associated with the groundwater flux which is generally favorable in low-permeability zones. This distinction allows low-temperature thermal to target high mass reduction where permeability-dependent technologies cannot easily access.

Low-temperature thermal can reduce degradation timeframes using significantly less energy input than high-temperature alternatives. The reduced energy requirements allow for a broader range of heating methods including in-line/instantaneous water heaters or utilization of waste heat from nearby industrial processes. Another sustainable method involves the direct use of solar energy for subsurface heating. This system transfers solar radiation to the subsurface by means of solar collectors, a closed loop heat transfer fluid system, and borehole heat exchangers to facilitate the conductive transfer of heat to the subsurface.

Case studies will include a system operating since 2015 at a site in the state of New York which has successfully reduced 17 milligrams per liter benzene by 99.9%. Another case study involves enhancement of electron-reductive dichlorination (ERD) in Denver, Colorado where a favorable groundwater temperature increase has been observed in comparison to measured seasonal groundwater temperatures prior to system installation. Post heating data has shown measured changes in vinyl chloride production from a well within the treatment zone. This is an early indication that biologically-mediated reductive dichlorination is being enhanced with a modest increase in subsurface temperature.

Jonah Munholland is an engineer at Arcadis’s San Diego office where he has designed and implemented various remediation systems throughout California.

A Clay-Friendly Bioelectrochemical Technology for Degradation Petroleum Hydrocarbons
Bioelectrochemical (BEC) technologies can substantially enhance microbial degradation of a variety of contaminants, such as petroleum hydrocarbons. BEC technology is built on the pathways of electron transfer and therefore not restricted by permeability of the matrix, including clay. It operates with ZERO energy input and minimal material input. E-Redox® is a patented in situ bioelectrochemical remediation technology that has been through field pilot test and full-scale application at a former fuel station in the Denver metropolitan area, where the contaminant plume consists of persistent
benzene and methyl tert-butylether (MTBE). Due to the low-permeable clay formation that is typical of groundwater aquifers in the area, conventional remedial efforts had limited performance in removing the contaminants.

The E-Redox® technology, which relies on electron transfer, is not limited by matrix permeability but favored by the higher electrical conductivity of clay. Its application at the site substantially enhanced microbial activities, as indicated by sound electrical current production within the E-Redox® devices and the corresponding destruction of contaminants of concern. Overall trends indicated decreasing benzene concentrations (up to a 97% decrease within 6 months).

The MTBE concentrations at the site decreased by 51-88% during a 24-month operation the E-Redox® technology. Overall, the field data have demonstrated that E-Redox® technology is cost-effective in achieving in situ degradation of benzene and MTBE within a clay-dominant, low-permeable subsurface matrix.

Song Jin is the Founder and CTO of Advanced Environmental Technologies.

Natural Attenuation of a Deep Aquifer System Impacted by LNAPL

At a site impacted by significant LNAPL volume to over 100 feet depth, geochemical parameters collected from monitoring wells were used to evaluate the biodegradation of petroleum hydrocarbons. Hydrocarbons can influence the geochemistry of a groundwater system, and similarly, the geochemical composition can affect the behavior of hydrocarbons in the aquifer system. Geochemical parameters are also a tool for evaluating biodegradation processes that affect the fate and transport of hydrocarbons in hydrologic systems. The types and concentrations of dissolved geochemical constituents indicate whether the aquifer condition is aerobic or anaerobic. Changes in the concentrations of certain constituents, whether because of natural or anthropogenic causes, may affect ongoing attenuation processes.

Samples were analyzed for various general and wet-chemistry parameters. Field parameters (temperature, pH, EC, DO, ferrous iron, sulfide, and ORP) were also included in the groundwater geochemical assessment. The shallow zone at the site is a discontinuous perched aquifer that has progressively been going dry since commencement of monitoring, so the bulk of available data and the focus of remedial actions are in the deep zone. LNAPL in the deep zone is detected at various (but inconsistent) locations and depths over an approximately 35-acre area, comprising gasoline-like product that may be 50+ years old.

There are strong indications of natural attenuation processes (biodegradation) active in both shallow and deep groundwater zones. The dominant terminal electron-accepting process is methanogenesis, confirmed by significant (i.e., 10,000s of pounds) methane extracted by vertical and horizontal soil-vapor extraction systems. Outside the area of LNAPL impacts, conditions evolve rapidly to sulfate-reducing and then oxidizing conditions (including at background locations). The remedial action plan for this site comprises monitored natural attenuation (MNA), which results in orders-of-magnitude decrease in dissolved-phase petroleum hydrocarbon concentrations, and secondary actions in the deep zone including LNAPL removal and groundwater bio-sparging.

Jim Finegan is a Senior Principal Hydrogeologist with Kleinfelder, Inc., in Riverside, Calif.

Challenges of Managing Complex Sites and People – A Regulatory Perspective

Being a regulator for environmental cleanup projects is more complicated than one would imagine. Quite often, regulators are required to wear many different hats. One day you may have to be a detective and need to be equipped with the knowledge to unravel complexities in geology, hydrogeology, contaminant characteristics, contamination depth, contamination magnitude, and comingling of contamination. The next day you may have to be a psychologist and need to figure out the best way to convince the responsible party to cooperate. Another day you may have to be a policeman and issue enforcement actions. Sometimes you even have to be the environmental consultant.

These challenges are both technical and non-technical. While technical challenges appear to be more complex, in some instances non-technical challenges including social, economic, and political factors can be even more difficult to overcome. Both technical and non-technical challenges are impediments to cleanup progress. It is the regulator’s responsibility to
navigate and steer the project in the optimal direction. Easier said than done. In this discussion, I will discuss the various types of challenges and experiences I have encountered as a State regulator on site cleanup cases. Furthermore, I will discuss these challenges in the context of a constantly evolving industry and changing cleanup targets.

Alan Kuoch is an Engineering Geologist with the Santa Ana Regional Water Quality Control Board.

Status of Environmental Investigations and Remediation at an Impacted Industrial Site – A Regulatory Perspective

Historical operations at an industrial facility in Huntington Beach, California (Site) resulted in significant release of chemicals of concerns (COCs) including volatile organic compounds (VOCs) and 1,4-dioxane to soil at concentrations reaching several hundred million micrograms per kilogram and to groundwater at concentrations up to millions of micrograms per liter. The Site is an operating facility servicing and rebuilding pumps used in the petroleum and water production industry. The main source of impact has been attributed to two former clarifiers at about 70 feet depth, approximately 30 feet below the historical LDA depth of excavation – an evidence that a substantial mass of COCs has remained beyond the excavation and mass removal depths. This presentation outlines a regulatory view and key perspectives of the requirements for environmental investigations at a highly impacted industrial site.

Mehrnoosh Behrooz is a California licensed civil and environmental engineer and a member of the Site Cleanup team in the Santa Ana Regional Water Quality Control Board (RWQCB).

Cleanup Challenges of a Small Site located within a Large Regional Plume – A Regulatory Perspective

From a regulatory perspective, we will discuss the challenges experienced with the site in determining additional liabilities due to off-site migration of contaminant plume, and the importance of conducting good site characterization practices within an area with a known regional plume.

Kayla Kawamura currently works as a Water Resource Control Engineer in the Site Cleanup Program for the Santa Ana Regional Water Quality Control Board.

Integrating RCRA Corrective Action with Facility Demolition: How Flexibility and Cooperation Achieve Rapid Results

The former Agrium Advanced

In Orange County from 1991 to 2014. Preliminary environmental assessments revealed staining on the concrete floors and found containers of petroleum-based solvents, lubricant oils, and alcohol-based solvents within the warehouse.

This small site is located in an area within a regional plume with known VOC impacts. The primary contaminants of concern at the site are Tetrachloroethylene (PCE) and Trichloroethylene (TCE). Multiple groundwater, soil, soil vapor, and indoor air investigations have been conducted to distinguish the impacts resulting from previous site operations. Additional complicating factors include the following:

- The liability for contamination at the site was transferred to the property owner.
- The same party operated at the property immediately downgradient of the site and little information on the nature of discharge from that operation is available.

As a State regulator, I have encountered such challenges in the past and I will discuss the challenges experienced with the site in determining additional liabilities due to off-site migration of contaminant plume, and the importance of conducting good site characterization practices within an area with a known regional plume.

Kayla Kawamura currently works as a Water Resource Control Engineer in the Site Cleanup Program for the Santa Ana Regional Water Quality Control Board.

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Kayla Kawamura currently works as a Water Resource Control Engineer in the Site Cleanup Program for the Santa Ana Regional Water Quality Control Board.
Technologies Facility in Fairbury, Nebraska produced dry micronutrient fertilizer products until production was ceased in 2014 when current owner Loveland Products/Nutrien Ag Solutions (Nutrien) acquired the property. The Facility has been under regulatory oversight since the 1980s due to metals contamination. SWMUs outside of buildings were remediated in the 1990s but progress stalled as SWMUs within buildings were investigated or remediated. In spring of 2016, Nutrien’s goals for the site became: redevelopment of the property; minimization of risk; reduction of regulatory oversight; and minimization of long-term environmental management needs. An adaptive risk management approach was developed to integrate soil remediation under the RCA process simultaneous with facility demolition with a proposed timeline for completing all demolition and remediation activities of the end of 2016.

Obtaining early regulatory buy-in to an adaptive process was crucial to project success. Tools for success included: a Work Plan with decision trees and detailed directions on potential field iterations; pre-characterization of the materials and soil present at the site to allow for effective planning of excavation, handling, and disposal; and a Waste Management Plan, including a pilot study for treatment of the waste, which was developed and approved by the regulatory agencies during demolition but prior to the start of remediation.

Open communication was promoted between team members and the regulators, which allowed the project team to address concerns as they arose. A construction manager with remediation expertise was on site throughout the project. Approximately 9000 tons of soil were excavated, treated, and disposed of off-site as nonhazardous waste. Pre-characterization of the concrete allowed reuse of the concrete as fill with no additional import of soil needed for backfilling excavations.

The Facility was successfully decommissioned, and soil was remediated to established cleanup levels on schedule and within budget.

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Diana Marquez is an Associate Toxicologist and Project Manager with Burns & McDonnell and leads the company’s Risk Assessment and Vapor Intrusion Services.

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A Method for the Determination of Total Organic Fluorine and Its Correlation with PFAS Analysis

Estimates place the total possible number of per- and polyfluoroalkyl substances (PFAS) higher than 4500 compounds. Considering that current targeted compound analyses offered by commercial labs may report as many as 40 or 50 specific compounds, it becomes apparent that we are only seeing a sliver of the possible total impact. Add to that the fact that most of the current analytical techniques only address the anionic forms of PFAS, ignoring cationic, zwitterionic and neutral forms, it seems that our total assessment of impact is significantly biased. Use of the Total Oxidizable Precursor (TOP) assay, potentially gives us a better handle on the unknown mass remaining from targeted compound analysis, but still does not address everything.

One of the analytical approaches that have been used extensively by our colleagues in Australia is the determination of Total Organic Fluorine (TOF). The application for determining TOF combines a total organohalogen analysis with ion chromatography and is therefore referred to as combustion ion chromatography. PFAS impacted samples are combusted and mineralized in a furnace at near 1100°C and the gaseous effluent is collected, and then chromatographed for fluoride ion by ion chromatography. An evaluation of the technique, advantages as well as pitfalls will be described, through comparison to the other analytical techniques described previously (targeted compound analysis and TOP assay) as well as qTOF analysis.

The presentation will describe the set-up and validation of the CIC analysis towards the determination of TOF. Results from spiked PFAS samples will be compared to the targeted compound results as part of the validation. PFAS impacted samples will be compared to the TOF results as well as TOP assay results from those same PFAS impacted samples. Lastly, some correlation regarding the presence of polymeric PFAS, in the midst of the non-polymeric forms typically analyzed for, will be made.

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Charles Neslund is the Scientific Officer for Eurofins Lancaster Laboratories Environmental, LLC. and PFAS Practice Leader for Eurofins Environmental Testing, US.

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Effect of Analytical Approaches on Reported PFAS Source Concentrations in Complex Matrices
This study compares PFAS concentrations analyzed using isotope dilution, TOP assay, total fluoride, and total fluorine analyses in complex matrices. Three sources were used, including a first-generation AFFF source (C8-based), a second-generation AFFF source (telomer-based), and a mixed organic sludge waste from a paper mill. Samples of the two AFFF sources are from a northeast airport; the soil matrix is similar for both sources, and the time of release is known for both areas.

The first generation AFFF site was associated with a mid-1990s emergency response and the second generation AFFF site was associated with a nozzle test area that was utilized in the mid-2000s. Three samples are evaluated from each AFFF site, including dry vadose zone soils, shallow smear zone soils, and puddled surface water. Paper mill samples are from a PFAS-impacted sewer line and include sediment/sludge, grab turbid water samples, and filtered/settled clear water samples.

Due to the increasing complexity in manufactured AFFF formulations with time, the increasing opportunity for PFAS transformations in the environment with time, and anticipated complexity in the mixed-source paper mill samples, the first generation AFFF samples are expected to show the strongest correlation among all analyses, followed by the second generation AFFF samples, and lastly the paper mill samples. The presentation will look at the data from many angles, including the differences in total and speciated PFAS concentrations among the analyses, the effectiveness of the TOP assay oxidation to quantify nonspeciated PFAS, and the effect of the PFAS analyte list on sample characterization. Lessons learned from this study have broad implications for source identification and PFAS forensic analyses.

**Analytical Issues Concerning Quantitation and Identification of PFAS Compounds**

Analysis for perfluoroalkyl and polyfluoroalkyl substances (PFAS) in environmental samples has risen in importance over the last several years. There are several published analytical methods for the determination of PFAS in samples. In addition, commercial laboratories have modified the published methods in attempts to address the needs of their clients. However, these methods and modifications are highly variable in quantitation techniques and do not address interferences very well. Because of these differences, one of the issues facing the environmental community is the lack of data comparability.

Several quantitation techniques, including external standard, internal standard, and isotope dilution are being utilized to determine PFAS concentrations.

In addition, the internal standard and isotope dilution techniques have an added variable, that being which labeled compounds are being utilized for quantitation. As the published methods that include the use of internal standards do not specify which label compounds are associated with which native PFAS. Isotope dilution is not specifically identified in the analytical methods, but is utilized by the Department of Defense, however, laboratories are selecting their own labeled compounds to be used.

With regard to PFAS identification, some of the published methods indicated that branched and linear PFAS standards must be used to establish retention times for the target analytes. For laboratories that have modified an analytical method, they can choose to analyze this type of standard or not. In addition, the published methods do not include any chromatographic separation criteria to ensure branched linear separation. The separation becomes significant when experiencing chromatographic interferences from unknown PFAS or potential branched PFAS.

This presentation will include several examples of issues with PFAS data and the variability in sample quantitation. Data comparability is an issue that needs to be addressed to ensure that the data being utilized for decision making.

**Can PFAS be Transferred from Common Products Used During Sampling?**

There is the potential for PFAS to be present in many products that are routinely used in the environmental field. Although sampling for PFAS is performed using conventional techniques, current guidelines contain stringent provisions for products and materials to avoid when sampling for PFAS to reduce the potential cross-contamination of samples. The potential

**Mr. Zeiner has 28 years of analytical and quality assurance experience.**

**Amy Wilson is a civil engineer and hydrogeologist with 24 years of experience in research and environmental consulting.**

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presence of PFAS in equipment typically used to collect environmental samples, coupled with the need for very low reporting limits heightens this concern.

This presentation will show the results of a study recently performed investigating the potential for cross-contamination from several commonly used products. Polytetrafluoroethylene (PTFE), low density polyethylene (LDPE), and high-density polyethylene (HDPE) tubing, pump bladders, and other materials were evaluated along with associated products such as aluminum foil and plastic storage bags.

A series of experiments were performed utilizing a leaching procedure to evaluate the relative concentrations of PFAS in the leachates of each of the tested sampling materials and the types of PFAS that can be potentially transferred from the tested materials during the sampling process. Knowing the types of PFAS that may leach off from a particular sampling material may also be helpful in the forensic evaluation of sample data. Analytical results will be presented along with experimental observations and recommendations.

Liz Denly is a Director in the Technical Development Unit and is the Chemistry/Quality Assurance Director in the Environmental Sector at TRC.

PFAS Data Validation: A Technical Perspective
Over the past 30 years, the Environmental Protection Agency (EPA) and the Department of Defense (DoD) with on-going research and investigations have identified a variety of emerging contaminants; each presenting a unique set of challenges and impacts. A current significant group of contaminants that have been identified are Per- and Polyfluoroalkyl Substances (PFASs). As testing for these contaminants expands using EPA Methods 537 and 533, as well as modifications of these and other methods, e.g. SW 8327, laboratories have been confronted with developing applicable analytical procedures to produce high quality data. Data validation has become a critical component of the EPA and DoD data quality process to assure the quality of the PFAS results.

In the evolution of data validation, several validation documents have been produced, including the EPA National Functional Guidelines (NFGs) developed for the EPA Contract Laboratory Program (CLP) and the DoD PFAS Data Validation Guidelines. This presentation will highlight the most current status and process for data validation of PFAS methods and results relative to these guidelines.

Additionally, it will provide a perspective on the path moving forward in PFAS data validation and how it relates to the DoD/DOE QSM 5.3 and the DoD PFAS Data Validation Guidelines. We will walk through critical elements in the DoD/DOE QSM 5.3 document and how DoD data validation guidance specific to PFAS analyses will foster consistency in validation and reporting of PFAS data for DoD projects.

Linda Ta is a Project Manager/Chemist at Laboratory Data Consultants, Inc.

Benefits of Automated, High-Resolution Fluid Interface Data Collection for LNAPL Sites

Background/Objectives. Air/LNAPL and LNAPL/groundwater interface elevations are often measured in monitoring wells at sites affected by LNAPL and used to calculate in-well LNAPL thickness and potentiometric surface elevation. Additionally, calculation of LNAPL transmissivity (which has become a desired component of LNAPL conceptual site models) requires intensive fluid elevation data collection over a short period of time.

The industry standard practice of manually measuring fluid elevations using an interface probe has inherent challenges related to health and safety, well accessibility, labor and equipment costs, potential for human error, and data quality. Manual fluid elevation measurement for LNAPL transmissivity tests in areas with limited access or sites with fixed working hours undermines high-quality, accurate data interpretation. These challenges can be readily overcome through automated fluid elevation data collection.

Beyond the benefits for LNAPL transmissivity testing, the ability to automate collection of high-frequency fluid elevation data over the course of weeks and months provides an enhanced understanding of LNAPL behavior in the subsurface, including quickly identifying hydrogeologic conditions, clearly defining the mobile NAPL interval, understanding LNAPL thickness fluctuations in tidal settings, and long-term monitoring and optimization of active LNAPL recovery systems.

Approach/Activities. A unique
system was developed and deployed at LNAPL-affected sites to automatically collect high-resolution LNAPL and groundwater elevation data in monitoring wells. This system is different than other automated data collection solutions because it can readily accommodate large LNAPL thicknesses and potentiometric surface fluctuations without manual adjustment.

**Results/Lessons Learned.**

LNAPL transmissivity tests, tidal studies, and routine fluid-level elevation monitoring are more technically sound, less expensive, and safer with automated fluid elevation data collection. This presentation will include case studies of transient conditions identified through automated data collection that would have been missed using manual methods. Automated data collection resulted in improved LNAPL CSMs at sites where the system was deployed.

Daniel Buckley is a project manager with AECOM in Long Beach, California.

**Challenges and Considerations for Conducting Remedial Investigations for Per- and Polyfluoroalkyl Substances (PFAS) and Understanding of Fate and Transport**

Perfluoroalkyl substances (PFAS) are very stable, manmade chemicals that have properties that allow them to repel both water and oil. The different PFAS have different lengths and/or differ in their properties at one end, which can change the toxicity of the chemicals. The most commonly found and best studied PFAS are perfluorooctanoic acid (PFOA) and perfluorooctane-sulfonic acid (PFOS). PFAS do not readily breakdown in the environment and are water soluble. As a result, there are very low levels of PFAS in many areas of the environment. These properties were first used commercially in the 1950s, and they are used in a wide variety of consumer products, including carpets, clothing, non-stick pans, paints, polishes, waxes, cleaning products, and food packaging. Due to a history of firefighting exercises and the military use of them in fire-suppressing foam, PFAS remedial investigations are being undertaken at several military facilities throughout the United States.

Conducting a remedial investigation for PFAS involves careful consideration of several aspects of the investigation, such as sampling techniques and minimizing the potential for cross-contamination, and the use of common field sampling equipment. Multiple source areas throughout a facility may have historical use or storage of PFAS-contamination substances and there is a consideration of the potential for offsite sources; agreement on the governing regulatory agency requirements and screening criteria for use in the investigation, and, because of the limited toxicological information available on these chemicals and their complexities in fate and transport, evaluating the risk for PFAS exposure for both human and ecological receptors is challenging and requires early scoping and planning with the Project Team throughout the remedial investigation.

This poster presentation summarizes the current understanding of PFAS with regard to specific aspects of conducting a remedial investigation including: (1) the current standard practices used in planning and executing a successful PFAS sampling program for a remedial investigation at a PFAS-contaminated facility; (2) the known chemical/physical characteristics and unique properties of the compounds which govern the fate and transport mechanisms of various PFAS compounds in groundwater, air, sediment, and surface water used in developing the conceptual site model; and (3) the current limitations in using the available risk-based screening criteria in risk assessments and risk evaluations at sites contaminated PFAS.

Gina Calderone, CPG, PG, Senior Hydrogeologist, Tetra Tech, King of Prussia, Penn., Katherine Super, DABT, Senior Toxicologist/Department Manager, Tetra Tech, Pittsburgh, Penn., Catherine Kohler, Vice President, Deputy Program Manager, Tetra Tech, Norfolk, Va.

**Driving Forces and Indicators of Vapor Intrusion Temporal Variability in an Industrial Building**

Information is lacking on the degree and causes of temporal variability of indoor air concentrations in industrial buildings. An extensive data set was analyzed using six hour time resolution for six continuous months including TCE, radon, differential pressure, barometric pressure, differential temperature, wind speed and precipitation. The data were collected under natural conditions in an occupied space as part of a yearlong monitoring program. The samples were collected in a sampling zone or compartment within a large industrial building. The objectives for this work included: 1) assessing VOC...
temporal variability in an industrial building; 2) evaluating whether the use of vapor intrusion (VI) indicators/tracers, which are less costly and time intensive to measure, may be able to predict VOC concentrations; and 3) evaluating whether indicators/tracers can be used to minimize the number of VOC sampling events by predicting the best sampling periods.

In addition to traditional statistical approaches (e.g., exploratory data analysis and time series analysis), the analyses conducted for this task also employed techniques of machine learning. The most significant terms (p<.001) in the time series analysis were for current radon concentration, radon 6 hours before the higher VOC event, current barometric pressure, and a term that describes the regularly recurring behavior over diurnal cycles. Several regression and machine learning methods were applied to the same data set and showed that radon was the best predictive variable for the sampling zone in this dataset, with barometric pressure second. Radon observations predicted approximately 63-percent of the variance in the TCE indoor air concentrations. Outdoor wind speeds between approximately 5 to 20 mph correlated with higher indoor air TCE concentrations.

The results of this intensive statistical analysis will also be compared in this presentation to results from other sampling zones in the building where radon was not as effective a tracer, along with results of time series analyses previously published of VOC concentrations in a residence.

Chris Lutes of Jacobs is a nationally recognized expert in vapor intrusion.

High Resolution Screening Level Assessment for Off-Site HVOC Release from Sanitary Sewer Sag in California
The results of a high-resolution site characterization investigation of a dry cleaner (Site) are used to evaluate if historical sanitary sewer discharges may have been released from a 30-foot long sagging section of the sewer main beneath a State highway. A 30-foot long sag in the sanitary sewer main east of the Site was identified by the City in the late 1990s and to date has not been repaired. As early as 1992, sags in sanitary sewer lines were identified as sources of tetrachloroethylene (PCE) releases to the environment (Izzo, 1992. Central Valley RWQCB).

The high-resolution investigation at the Site employed the use of high-density quantitative passive soil gas (PSG) sampling to achieve rapid screening-level assessment over a large area. PSG samplers were placed in areas of suspected contamination in a grid-like pattern that extended off-site in the downgradient direction of groundwater flow to identify preferential pathways, and unknown possible sources. The samples were analyzed by thermal desorption gas chromatography / mass spectrometry by EPA Method 8260c with results provided in ug/m3.

The high-resolution quantitative PSG site investigation confirmed two HVOC soil vapor plumes; one in the area of the original dry cleaner and the other emanating from the sag in the sanitary sewer line that extends from beneath a State highway to residential and commercial areas to the east. Elevated concentrations of PCE and degradation daughter products from beneath the sewer line sag suggest long term accumulation in this portion of the sewer main for several years with sufficient time for reductive dechlorination to have occurred. Quantitative PSG data exceeding SFBRWQCB soil vapor ESLs indicates there is a potential for PCE and/or TCE vapor intrusion to indoor air at selected commercial and residential properties located above the HVOC soil vapor plume emanating from the sanitary sewer sag.

Dana Katofsky McCarthy has over 20 years of experience in environmental consulting, having worked on several soil, soil vapor, and groundwater assessment and remediation projects.

Extinguishing a Significant Source of PFAS Water Quality Contamination: Fluorine-Free Foams and Implications for Utilities
PFAS are present in some firefighting foams used to extinguish Class B fires and have been used since the mid-1960s in fire suppressant applications and during fire training events. AFFF, and other film forming fluoroprotein foams, are known to have historically contained high concentrations of long chain PFAS (i.e., parts per thousand) and are a significant contributing source of PFAS released to the environment in some locations. PFAS persist indefinitely in the environment and are highly mobile in natural waters.

Thus, they have been discovered in global drinking water supplies.
Regulatory agencies are developing restrictive criteria for numerous PFAS (i.e., parts per trillion). Water utilities may be tasked with managing high capacity drinking water supplies to remove PFAS to extremely low concentrations with limited practical options. While some relevant water treatment options exist, their inefficiencies necessitate enacting measures to prevent or limit future PFAS discharges to the environment. The evolving understanding of PFAS toxicity has already prompted industrial and commercial manufacturers/users to procure and use new formulations of fluorinated foams (i.e., short chain PFAS) and/or fluorine-free foams (F3). Although short chain PFAS are less bioaccumulative in humans, they are more mobile in natural waters, are suspected of potential human health risks, and may represent a future threat to drinking water.

Transitioning to F3 for fire suppression has promise but requires planning to ensure decontamination (e.g., system flushing/rinsing), reliable disposal/destruction of historical long chain fluorinated foams, proper equipment and infrastructure updates/replacement, and robust training to properly extinguish fires with the new foams. This presentation will discuss the benefits of the industry transition to F3 for water utilities and highlight the need for utilities to be engaged stakeholders in this transition at both the local and national level.

Jeffrey McDonough, M.S., P.E., Arcadis, is a Technical Expert and Associate Vice President specializing in the remediation of impacted matrices for a wide variety of compounds over a global footprint.

Assessing Hydraulic Fracking Issues In The US South East and Western Region
In the last several years, the choice of hydrological fracking as an alternative method of nonrenewable energy production in the US oil and gas sector has continued to gain currency, in a country where fracking is no longer deemed as an exercise on the fringe amidst unprecedented boom and ecological liabilities. The use of fracking techniques in shale fields remains so widespread across different states from California to Mississippi, that it now exceeds half of the nation’s output. This occurred in the face of favorable regulatory environments that catapulted the US to the top of global ranking of producers.

While this led to ample generation of oil and gas revenues in the respective states, communities in those places have endured grim impacts on their ecosystems in the form of pollution, degradation, hydrological stress, induced seismicity, land disturbance and greenhouse gas emissions. Aside from efforts towards a common ground on the issues, the mounting ecological liabilities have on many occasions exacerbated tensions between affected communities and the oil sector. Yet very few studies exist on the vulnerability of the study area to the impacts of hydraulic fracking using mix scale approach of GIS (Geographic Information Systems) and energy statistics. Accordingly, this enquiry will fill that void in research. Emphases are on the issues, trends, factors, impacts, and efforts using GIS and descriptive statistics.

Just as results revealed a surge in production and revenues, the impacts consist of overuse of water and chemicals together with pollution, disturbance of fragile landscapes and the ecosystem. Additionally, GIS mappings pinpointed a gradual spread of production and concentration of risks across states in the zone due to several socio-economic and physical elements located within the larger energy mix. To remedy the situation, the paper proffered solutions ranging from ecological monitoring to the design of regional energy information system.

Edmund Merem graduated with a Ph.D. from Jackson State University, Miss.

Case Studies: Data Visualization for Enhanced Communication and Decision Making
This presentation will use case studies from California Superfund sites (which utilize treatment systems such as pump and treat and/or soil vapor extraction) to demonstrate how data were used to communicate with clients and stakeholders more effectively, to facilitate project success and to confirm project compliance. For these projects, communication and strategy centered around data visualization which is more powerful than conveying the information through a laboratory data report or a spreadsheet of data alone.

Historically (prior to the data visualization techniques presented in this presentation), site derived data were forced into spreadsheets, potentially left unchecked and uncontrolled and not readily available to all members of the project team. Using this method, analytical insights were gained at a snail's pace.
pace; and the sharing of information was confusing, encumbered, and prone to human error. Utilizing up to date robust data analysis and technological innovations in data visualization allows for data to be transformed into actionable information.

Environmental data are typically collected at many stages of a remediation project through a variety of methods. For efficiency, it is necessary to align your data collection and management plans with the questions you need answered and the issues you need resolved. Incorporating data management and visualization into your initial project planning is crucial for enabling your ability to use data to support and communicate decisions. Data can be synthesized to objectively confirm an assumption (for example: does the pump and treat system effluent meet the injection standards into the aquifer?). Data can almost instantly be evaluated using automated approaches (for example: does the indoor air sample contain levels of contaminants of concern above Regional Screening Levels, requiring immediate action?). Data can be presented to validate an assertion (confirming that all elements of a treatment system are operating as intended). Data can be explored to learn something new about the site (data is instantly available to all stakeholders for review and decision making).

The case studies presented will highlight how, through innovative handling of data, project communication was improved, costs were controlled, and regulatory requirements were quickly assessed. This presentation will show how effective visualization of up to the minute data provided for insightful decisions and ultimately resulted in greater control of how the site was run.

Laura Millan is a Project Manager/Business Analyst with de maximis Data Management Solutions, Inc.

### Use of Mass Flux to Guide Decision Making in Plume Management

A former bulk fuel storage facility located in the Appalachian Piedmont Province of North Carolina had undergone extensive in-situ thermal remediation. The site was impacted with petroleum hydrocarbons including a large LNAPL plume from historic operations and spills. A thermal remediation project was completed in stages between 2005 and 2013, recovering more than 800,000 lbs of petroleum contaminant mass. However, a large dissolved phase plume remains with VOC concentrations in excess of applicable regulatory standards. A transect-based mass flux strategy was adopted to more accurately characterize the distribution of dissolved contaminants in the subsurface, conceptualize contaminant behavior, evaluate the magnitude of COC flux and attenuation from the secondary/residual source area, and determine if discharge to identified receptors was occurring.

Fifty-seven new wells were installed via sonic drilling techniques to characterize four hydrogeologic zones: water table, intermediate saprolite, deep saprolite, and bedrock. Thirty-nine of these wells, plus 25 existing wells, were incorporated into four ground-water flux transects comprised of four vertical transects each and aligned perpendicular to groundwater flow. The mass flux network was thus comprised of 64 discrete cells. A series of 48 slug tests were performed to determine representative hydraulic conductivities of the cells, and each was sampled. Head evaluations were also performed to determine vertical groundwater gradients and understand net groundwater transport.

Contaminant distribution varies by compound and is greatest beneath an off-site property downgradient of historical petroleum storage and subsequent remediation areas. Quantitation of compound movement across the site and recognition of discrete contaminant migration pathways were elucidated to a degree not previously understood and point to a well-defined and finite area for TBA flux. The analysis also indicated that MNA activity may prevent migration of contaminants to potential receptors. This mass flux data management framework provides a more complete understanding of the site, forms the basis for the current conceptual site model, will allow for improved risk-based decision-making and has also met with approval from the responsible regulatory authority.

Christopher Mulry, PG is a Senior Vice President based out of GES’ Maryland office.

### Development of a Forensics Based Approach to Evaluating Impacts of PFAS Contamination in the Environment

Per- and polyfluoroalkyl substances...
(PFAS) are considered persistent organic pollutants (POPs). As such our expectation is that they remain in the environment for years and in many cases are not biodegradable. As the analysis and investigation of sites contaminated with PFAS continue to mature, there is a growing interest in determining the contributions of different sources, to the overall contamination. Treatment technologies are also maturing in application and complexity of remedy options. The complexity and magnitude of the treatment can significantly impact costs for said treatment.

Therefore, the development of analytical methodologies that can at least, start to delineate sources/contributions and assign responsibility can be a useful tool in environmental investigations.

There are several tools already available in the analytical chemist’s toolbox, from the recognition of the presence of branched chain isomers and relative ratios, to the unique targeted compound profile presented by certain PFAS contamination sources.

Add to that the judicious use of results from the Total Oxidizable Precursor (TOP) Assay, and a reasonably good foundation has been established upon which to build a forensics discipline. If we now add the results of accurate mass qTOF, applied to targets, known/unknowns and unknown/unknowns, we are progressing towards a robust forensic profiling application. In addition to the limited libraries that have been obtained, we will show how we have assembled libraries from known sources (AFFF and other products) that can be used like a fingerprint, to borrow terminology from our petroleum hydrocarbon colleagues.

The presentation will describe the process that we went through in deriving a forensics-based approach to identifying PFAS source/contributions. We will demonstrate how the various techniques complement each other towards source identification and how the use of relatively standard statistical programs improve the strength of the analytical results and solidify the conclusions drawn from the data.

**Waves of Problems to Solve: A Long-Term Perspective of the Remediation Field**

The remediation field has evolved considerably since it began about 40 years ago, with paradigm shifts sparked by scientific breakthroughs and hard-fought experience superimposed over the emergence of new contaminants every few years. The result has yielded new conceptual site models, waves of innovation, stronger remediation technologies, and more credible management strategies. This talk will attempt to take the key lessons learned in the remediation field since the first pump and treat sites in the 1980s and apply them to our field’s newest, most difficult challenge: management of PFAS in the subsurface.

**Bench-Scale Demonstration of Short and Long Chain**

**PFAS Retardation Using Colloidal Activated Carbon**

In recent years, colloidal activated carbon (CAC) has emerged as a low cost, in situ method to retard and contain PFAS plumes for many years with a single application. As no viable destructive methods are currently available, the approach with CAC relies solely on adsorption. This paper will review laboratory column studies that were conducted to demonstrate the efficacy and quantify the longevity of a CAC treatment to retard the transport of four PFAS compounds: PFOS, PFOA, PFHpA, and PFBA. The study was performed in 20” x 1” fine sand columns that were pre-saturated to minimize hydrodynamic variability within the column.

Colloidal activated carbon (1-2 microns) was pumped onto the column and subsequently flushed with water, resulting in a colloidal activated carbon dose of approximately 700 mg/kg of sand. The PFAS influent concentration was held constant at 100 ug/L for each compound with a combined concentration of 400 ug/L. The columns were run at a flow rate of approximately one pore volume (PV) per week. An additional column was also set up with powdered activated carbon (PAC, <50 microns) mixed into the sand at an equivalent dose for comparison to CAC. Control and blank columns were run alongside the treated columns.

Data from this on-going study has shown CAC to be an effective strategy for retarding a PFAS plume. Until now, only PFBA has broken through the CAC treated columns, while PFBA, PFHpA,
and PFOA have all broken through in the PAC column. This is well explained by the difference in particle size of the activated carbon particles and is on par with existing literature that has examined the effect of particle size on sorption of PFAS compounds. These results follow with data from existing sites where CAC has already been implemented for PFAS remediation.

Sophia Nguyen is a Senior Research Associate/Analytical Chemist with REGENESIS where she plays a key role in the development and testing of new REGENESIS technologies.

Case Study of Bioremediation and ISCR at a Chlorinated Solvents Site in Southern California

Chlorinated solvents originating from clothing and textile dry cleaning operations can quickly degrade an aquifer. The introduction of low-cost electron donor substrates and a microbial consortium into the heterogeneous aquifer has accelerated anaerobic biodegradation in the aquifer impacted with chlorinated solvents to less toxic forms. PCE and TCE have been reduced to non-detect in most of the wells, 90 days after injection. The key to success is managing the site geochemistry and hydrogeology before, during and after bio-stimulation and bioaugmentation injections.

The edible oil substrate was supplied as oil concentrate (EDS-ER), a microbial consortium, cheese whey, and buffer supplied as a solution, mixed in the field, and pumped into the aquifer, making contact with greater areas of concern beneath the site. Data have confirmed the establishment of anaerobic conditions within 90 days after application. Field results have shown the ability to successfully distribute cheese whey and EDS® into contaminated aquifers up to 25 feet from the injection point, depending on site-specific hydrogeological conditions.

Managing the microbial environment by characterizing the soil buffering capacity, adding the appropriate amount of buffer, monitoring the pH, ORP, TOC other geochemical parameters, and microbial (DHC) population counts for months after the injection is key to the success of the remediation. The second phase involved adding more EVO and microbes downgradient. The third phase was to target the remaining contaminated zones with ZVI in a suspension (mZVI).

Lessons learned from where the low-cost electron donor substrates, a microbial consortium, and ZVI in a suspension were injected will be presented. This presentation will show how the technology is implemented, share project data, and illustrate the advantages of managing the site geochemistry and hydrogeology.

John Sankey, P.Eng., is an engineer for True Blue Technologies.

Enhanced Anaerobic Attenuation of Subsurface Contamination Source Zones using Direct Hydrogen Delivery

Use of a Hydrogen-based treatment (H2T) technology is evaluated where anoxic environment is needed to enhance biodegradation of contaminants of concern (CoCs), and where implementation of traditional soil treatment technologies such as soil vapor extraction (SVE) or excavation is not feasible, and monitored natural attenuation may not be sufficient to control the groundwater plume that is sourced by the residual con-
taminants in the unsaturated zone. Many organohalogen compounds such as chlorinated solvents and perfluorinated surfactants as well as other types of reducible contaminants such as perchlorate and explosives can be treated using hydrogen injection.

Hydrogen injection may present a cheap polishing step to replace expensive SVE systems that are no longer removing large amounts of contaminant mass, and potentially as a method to eliminate migration of solvent vapors to indoor air. Existing SVE system hardware (injection points, manifolds, monitoring points) can be easily retrofitted to accommodate H2 injection. With such a technology, the cost for remediating the vadose zone sources may be reduced, and a much more sustainable remedy can be implemented.

The H2T technology may be used either as the initial remediation technology applied at a site or as a polishing technology that will allow site managers to shut down expensive, low-performance SVE systems that are no longer cost effective. This technology is an anaerobic variation of bioventing that involves injecting electron donor gases (hydrogen in this case) into the unsaturated or saturated zones to stimulate biodegradation. H2T is implemented by injecting a nonexplosive mixture of nitrogen (N2), hydrogen (H2), methane (C3H8), and carbon dioxide (CO2) through a series of widely spaced injection points.

When compared to SVE system, the H2T system does not require costly surface treatment equipment such as thermal oxidizers or activated carbon; it has a lower carbon footprint as no thermal oxidization or carbon regeneration are needed; and it is easier to permit in areas with stringent air discharge regulations. When compared to liquid-based injection technologies, an H2T system will likely have a larger radius of influence, thereby reducing the number of injection wells that are needed. An H2T system also enhances treatment of lower-permeability units due to the high diffusion coefficient of the hydrogen gas.

Mir SeyedAbbasi, PhD PE is a Senior Project Manager – Environmental Services with Jacob & Hefner Associates Inc.

**Influence of Matrix Diffusion from Low-Permeability Lenses within Source Zones on Contaminated Aquifers Cleanup Time**

A key site metric for most site stakeholders is to understand how long non-aqueous phase liquid (NAPL) sources in the saturated zone will continue to contribute to the long-term dissolved phase concentrations. Low permeability compartments within source areas, and in plumes downgradient of sources, can store significant amounts of dissolved contaminant mass and therefore hinder the site cleanup efforts even with complete NAPL depletion. This “secondary aqueous phase source” can be the dominant factor governing the source longevity and downgradient groundwater quality after complete NAPL depletion.

Recently there has been an increased appreciation of the effects of matrix diffusion on source zones and secondary aqueous phase sources where extensive numerical modeling efforts were performed to evaluate the relative importance of each contributing component (Chapman et al., 2012; Seyedabbasi et al., 2012; Farhat et al., 2020). Matrix diffusion has been shown to greatly increase the remediation timeframe for plumes downgradient of isolated source zones. In this study, NAPL and secondary aqueous phase sources surrounding low-permeability (low k) aquitards are numerically modeled to study the relative contribution of NAPL versus matrix diffusion to source longevity.

The results of this vertically high-resolution modeling exercise show the matrix diffusion can be a critical component of source zone longevity, and may contribute more to source longevity than NAPL dissolution alone at many sites. Multiple single-component NAPLs with various degrees of aqueous-phase solubility are examined. For example, one simulation with a single-component 650 kg TCE DNAPL source indicated that dissolution of DNAPL would take approximately 50 years, while the back diffusion from low-permeability zones could maintain the source above a 5 ug/L groundwater standard for an additional 200+ years.

A high-solubility contaminant (1,2-DCA) showed a much more dramatic contribution to the matrix diffusion source compared to DNAPL dissolution (99% of longevity due to matrix diffusion), while a low-solubility contaminant (PCE) showed a more equal contribution from DNAPL dissolution vs. matrix diffusion sources. The assumptions and limitations of this simulation approach will be

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Influence of Porous Media Heterogeneity on NAPL Dissolution Fingering and Upscaled Mass Transfer

Laboratory and numerical studies were conducted to evaluate the influence of a very important factor on NAPL dissolution fingering: heterogeneity in the initial NAPL saturations before dissolution begins, which is controlled by the NAPL spill conditions and porous media heterogeneity. During a spill event heterogeneous porous media favor the formation of nonuniform residual NAPL saturation fields that may later affect the fingering mechanism. A light transmission technique was used to measure the NAPL saturation fields at a 0.05 cm resolution that resulted from such spills in heterogeneous media packed in laboratory cells.

Different packings were created, with the correlation scale of the heterogeneities similar to or greater than the scale of the dissolution fingers. NAPL dissolution fingering occurred in all media, but fingering patterns and growth were influenced by the heterogeneous permeability patterns. Experimental and numerical results will be presented illustrating the role of porous media heterogeneity on dissolution fingering.

Four different methods developed for upsampling mass transfer rate coefficient [Imhoff et al., 2003], Saenton [Saenton and Illangasekare, 2007], Christ [Christ et al., 2006] and Basu [Basu et al., 2008] models will be compared here using the data gained in this study. These models are all developed to account for the influence of dissolution fingering and/or NAPL architecture on the long-term flux of contaminants from NAPL source zones at the field scale, where upscaled models are needed. Two different heterogeneous packings were tested with large correlation scale (e.g., less heterogeneous) and small correlation scale (e.g., more heterogeneous) of heterogeneities.

In the packing where the correlation scale of the heterogeneities was greater than the scale of the dissolution fingers, all upscaling approaches predicted the effluent concentrations reasonably well. In the packing where the correlation scale of the heterogeneities was similar to the scale of the dissolution fingers, the capability of different models in predicting the tailing in the effluent concentrations when the source zone is dominated by discrete NAPL pools will be tested.

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Horizontal Biosparging for Expedited Remediation of Jet Fuel at DOD Sites

Horizontal air sparging remains a proven remedial technique to cover large areas and to access areas beneath multiple types of surface infrastructure. This presentation will provide a brief overview of horizontal remediation well design and installation processes. Two case studies will be presented for sites where horizontal air sparge wells were installed and operated to remediate jet fuel plumes at two Department of Defense installations.

Site 1: Air Force Base in New York State: Soil and groundwater was impacted from at least two documented jet fuel releases and other site activities. The site is underlain by a complex geological formation providing a porous media for migration of petroleum LNAPL and dissolved constituents in groundwater. To maximize oxygen distribution without impacting site redevelopment, horizontal biosparge wells were selected as the preferred remedial technique. Within three years of operation of the horizontal biosparging system, groundwater sampling results indicated no volatile organic compound (VOC) concentrations above the regulatory groundwater standards.

Site 2: Joint Air Force Base and International Airport in the Southeast: Based on the successful remediation of the DOD site in New York State, the DOD approved horizontal biosparging at a second facility in the Southeast. Unlike the site in New York State, this site was underlain by estuarine deposits with a shallow groundwater table. One main target area for remediation was located beneath an active tarmac and taxiway used by military and commercial aircraft. A total of 10 horizontal biosparge wells were installed with directional drilling to access these areas for remediation without impeding aircraft traffic and operation schedules.

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Mir SeyedAbbasi, PhD PE is a Senior Project Manager – Environmental Services with Jacob & Hefner Associates Inc.

Tomas Will is an environmental professional helping consultants and regulators find solutions to their most pressing remediation challenges.
**Drones/UAV: Providing Rapid Innovative Leaps in Environmental Remediation Strategies**

Drones, or Unmanned Aerial Vehicles (UAV), are being utilized across many industries as a safer and more efficient data-collection platform. GES will present information on how the use of UAV can enhance site functions such as asset management, equipment inspection, environmental management, and process engineering in the oil and gas sector. By combining UAV-mounted sensor types such as visual light, thermal, LiDAR, laser gas detection, and magnetometers, improved levels of project insight can be achieved, allowing for faster communication and doubtless decision-making. GES will present use-cases demonstrating benefits gained by incorporating drone-derived data into traditional practices.

For example, thermal imaging can be used to measure the fill level of many aboveground storage tanks more rapidly and safely than conducting it on foot. Incorporating UAV services into your workflows enables you to keep pace with innovation. GES will provide details on the evolving regulatory environment surrounding UAV, including the current state of UAV detection and countermeasure technology. GES will present topics for discussion on the macro-trend of innovative technology adoption and the greatly improved perspectives that are gained from using this solution-oriented tool.

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**Hydrocarbon Treatability Study of Antarctica Soil with**

**Fenton’s Reagent**

Accidental spills and leaking fuel have resulted in hydrocarbon contamination of surface soils at McMurdo Station, Antarctica. During a recent excavation, distinct and strong off-gassing of hydrocarbon odors were emanating from soil at depths up to 10 ft below ground surface. Melting snow and glacier ice contacting the hydrocarbon contaminated soils have resulted in elevated hydrocarbon levels in surface water runoff. Common in-situ remedial technologies for hydrocarbon treatment such as bioremediation are ineffective under the sub-freezing conditions of the Antarctic.

The remediation of hydrocarbon contaminated soil with hydrogen peroxide and Fenton’s Reagent has been proven in temperate climates but its effectiveness under persistent cold weather conditions and frozen soil is unknown. A treatability study was conducted with frozen contaminated soil shipped from Antarctica. The presentation will discuss the effectiveness of in-situ treatment of McMurdo Station hydrocarbon contaminated soils with hydrogen peroxide and Fenton’s Reagent under near freezing to subfreezing temperatures.

Jay Clausen is a Physical Research Scientist with the US Army Corps of Engineers, Engineering Research and Development Center, Cold Regions Research and Engineering Laboratory located in Hanover, New Hampshire.

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**Full Scale Remediation of TCE in a Low Permeability Aquifer Using Sulfidated Colloidal ZVI**

Sulfidated zero valent iron (SZVI) is an emerging remediation amend-

ment that accomplishes the rapid and complete abiotic reduction of chlorinated hydrocarbons and other toxic groundwater contaminants. We describe the largest full-scale application of SZVI to date that occurred in 2018 in Southern California. The aquifer at this location is about 50 to 80 feet below ground surface in a low to medium permeability soil; the fine to medium grain lithology required the use of a small particle size SZVI product to accomplish product distribution without channeling or fracking.

A uniform product distribution was accomplished using top down DPT and a maximum injection pressure of 50 psi. Injection rates in the low permeability aquifer were relatively slow at 1 to 5 gpm per injection point but using a colloidal product allowed for injection into up to ten point simultaneously with a total of 52,000 pounds of colloidal ZVI applied into 35 points. Remediation progress was evaluated at monitoring wells in the treatment area with ORP dropping immediately from a baseline of about 0 mV to -200 mV or lower. A greater than two order magnitude decrease in TCE concentrations was achieved in all monitoring wells without producing any chlorinated daughter products.

John Freim has a B.S. in Chemical Engineering from the University of Illinois and a Doctorate in Materials Science from the University of California at San Diego.

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**Pneumatic Fracturing to Enhance Soil Vapor Extraction**

Trichloroethylene (TCE) in sediment at an industrial site served as
a contributing source of groundwater contamination and presented a potential indoor air hazard to occupants of a planned future building. The site conceptual model cited a 500-gallon aboveground TCE degreasing unit, paint spray booth and steam cleaner within a warehouse that were occasionally cleaned and drained, as sources of TCE contamination to the vadose zone and groundwater. The potential threat to groundwater quality and potential for vapor intrusion to occupants of future structures served as the basis for a remedial response action.

The remedy included pneumatic fracturing enhanced soil vapor extraction (SVE) to target TCE in low-permeable vadose zone sediments (silt and clay). Seventeen 3-3/4-inch diameter boreholes on 25-foot centers were advanced to within several feet of the groundwater interface. Within each of these boreholes, directional fractures were induced every 2-feet using an injection nozzle to direct inert gas through the subsurface to initiate fractures in low-permeability sediments thereby enhancing the SVE remedy. After fracturing, 9 vapor extraction wells and 12-multi-depth vapor monitoring probes were installed. The soil vapor was treated by granular activated carbon before discharge to the atmosphere. It was estimated that only one pound of TCE was present in the vadose zone. In two years of operation, the SVE system removed 2.5 pounds of TCE and a cumulative mass of 3.8 pounds of VOCs. The SVE system operated for two years as planned, and groundwater extraction ceased after the first year of SVE operations. Soil gas and groundwater analytical results during rebound monitoring confirmed remedy completion.

The use of pneumatic fracturing, SVE, and an innovative revision of the site conceptual model negated alternatives that included a significantly more expensive groundwater pump and treat remedy. After completion of SVE and rebound monitoring, the USEPA granted No Further Action status for both groundwater and vadose zone remediation with Land Use Controls for continued vapor intrusion protectiveness.

Charlie O’Neill is a senior project manager at HDR with over 30 years of experience conducting subsurface investigations and managing projects pertaining to the remediation of contaminated soil and groundwater.

State-of-the Art Consensus on How to Evaluate Soil Background to Inform Risk Assessment: Guidance from ITRC

The Interstate Technology and Regulatory Council’s (ITRC) Soil Background and Risk (SBR) team is creating a guidance document and training on natural and anthropogenic ambient soil background values instead of a risk-based value. Regulators use concentrations of contaminants in soil to evaluate the potential risks to people or the environment and develop risk-based concentrations to inform cleanup decisions. The derivation of risk-based values takes into account toxicity criteria, as well as exposure and chemical-specific parameters. For some chemicals, the risk-based values may be lower than some of the concentrations in soil from natural or anthropogenic background. In those cases, regulators often allow the use of soil background instead of a risk-based value.

Because of the inherent complexities, there is not a “one-size-fits-all” approach for establishing soil background values and using them in risk assessment. The upcoming guidance document and training from ITRC will provide state and federal regulatory agencies, private sector, academia, and tribal and public stakeholders with appropriate and reasonable options for making informed decisions that take into account soil background and its implications for risk assessment.

Claudio Sorrentino is the Senior Toxicologist and Chief of the Northern
Dry Cleaner Releases and Forensic Considerations

Dry cleaner cleanups continue to be a significant source of environmental liability resulting from decades of operations. Given the number of historical dry-cleaning operations throughout the United States that have not yet been investigated, it is reasonable to expect environmental cleanups to continue and to be required for a long time into the future.

While assessing the extent and magnitude of solvent contamination is a normal part of any remedial investigation, there are other forensic information and data collection considerations for ensuring the cleanup liability is equitably divided. While each site is different and requires site-specific evaluation, consideration of the information needed to support an overall framework for forensic evaluations during the site investigation phase may be advantageous, as some possible forensic efforts are above what a typical remedial investigation would include.

Bjorn Wespestad, P.E. is a Senior Engineer at Roux Associates’ Oakland, California office with over 12 years of experience in the environmental field.

Groundwater Plume Analytics® Tools for Environmental Forensics Evaluations

Converting numerical groundwater environmental data into unique, but easy to understand, visual graphics using statistics and mathematics is what is termed “Groundwater Plume Analytics®”. Groundwater Plume Analytics® is an innovative evaluation technique to reliably and effectively communicate meaningful patterns in groundwater data, and it relies primarily on graphical displays to communicate valuable insight into groundwater plume behavior which leads to better site management decisions, from both a technical and financial perspective.

The Ricker Method® is an example of a unique Plume Analytics® method of evaluating plume stability that overcomes limitations posed by conventional well-by-well analysis techniques. Outputs from the Ricker Method® can be used as a basis for primary analysis and other plume diagnostic tools that allow the user to further evaluate and communicate groundwater plume dynamics. These tools are especially useful in environmental forensics settings.

This presentation highlights the use of molar-based concentration, especially in the case of parent-daughter degradation sequences commonly observed at contaminated sites. Multiple examples of the benefits of using molar-based concentration data in environmental forensics studies will be presented.

Joe Ricker is a licensed Professional Engineer in 27 states.

1,4-Dioxane – An Environmental Forensic Perspective

1,4-Dioxane is a challenging emerging contaminant worldwide. Its high environmental mobility and persistence, along with its many recorded uses and presence as byproduct create the potential for widespread occurrence in water supplies. Over one-fifth of tested U.S. public drinking water supplies had detectable levels of 1,4-dioxane. While 1,4-dioxane’s historical use as a stabilizer of chlorinated solvents is well-publicized, many other sources exist, related to its uses by research facilities and many industries, as well as its formation as byproduct of ethoxylated surfactants, including in a large variety of consumer products.

Therefore, 1,4-dioxane from groundwater plumes in urban locations and contaminated supply wells may be a result of multiple sources and release mechanisms and not solely attributable to chlorinated solvent uses. In this context, environmental forensics becomes an essential component of 1,4-dioxane investigations to discern between sources and evaluate contributions for remedial cost-recovery. However, published cases focused on the use of 1,4-dioxane to help with forensic investigations of chlorinated solvent plumes, rather than distinguishing between 1,4-dioxane sources and contributions within those plumes.

This presentation will provide an overview of key aspects related to 1,4-dioxane uses, fate & transport and recorded environmental occurrences relevant to the selection of adequate environmental forensic tools. Subsequently, the forensic techniques applicable to 1,4-dioxane will be reviewed, focusing on two fingerprinting techniques with high potential for discerning between sources and contributions. These techniques are chemical fingerprinting via signature chemicals and isotopic fingerprinting via...
compound specific isotope analysis (CSIA).

1,4-dioxane multiple uses and the composition of different commercial formulations provide many potential signature chemicals (e.g., impurities, additives, co-contaminants) for source identification and allocation on a case-specific basis. The data from chemical analyses may be evaluated using various graphical, statistical or geospatial techniques. The available stable isotopic data on both C-13 and H-2 isotopes of 1,4-dioxane denote that the potential exists to distinguish between chlorinated solvents versus other sources of 1,4-dioxane, as well as to better evaluate fate & transport processes, which may be used to adjust environmental models, building additional lines of evidence. Hints for data interpretation will also be provided along with representative examples.

Ioana G. Petrisor is a biochemist with over 25 years of experience specializing in environmental forensics/litigation support.

**Leaky Dump or Leaky Pump: Using Soil Gas Isotopes to Identify Source(s) of Elevated Methane**

Different sources of contamination have the potential to yield similar analytical results; common sources of methane in soil gas include naturally buried organic soil matter, sewer gas, leaky natural gas pipelines, petroleum-related releases, and landfills. Therefore, complex redevelopment sites with co-mingled soil gas contaminants may benefit from a more in-depth approach to differentiating contamination sources.

This presentation will highlight a case study that incorporated a geochemical testing program into the environmental site investigation as a way to discern contaminant sources. The site consists of an over 100-acre mixed commercial-residential redevelopment area with a closed dump capped in-place. Elevated methane was detected in soil gas beyond the dump footprint and, initially, was suggestive of an ineffective landfill cap and passive venting system. If proved ineffective, an expensive, active venting system was the potential next step to manage methane migration.

Since the redevelopment area was host to multiple historical industrial and commercial uses, there were other potential sources of methane to consider before investing in an active landfill venting system. Therefore, it was proposed to conduct a geochemical analysis of the soil gas to determine potential source(s) of elevated methane in conjunction with an environmental site investigation. The soil gas geochemical testing program included analyzing for volatile organic compounds, sulfur compounds (including Mercaptan, the odorant used to detect natural gas leaks), and the composition and isotope ratios for carbon and hydrogen. The composition and isotope analyses provided information to distinguish potential methane (biogenic, thermogenic, or petroleum) sources.

Results of the geochemical testing program determined that the source of elevated methane detected at the site included the biodegradation of petroleum-related constituents comingled with natural buried organic soil matter and, therefore, the approach to manage and remediate methane impacts changed drastically as a result of incorporating geochemical analyses into the site investigation.

**Building Capacity in Environmental Security to Address the Complex Impacts of Climate-Related Conflict**

Climate change has become a threat multiplier in every corner of the globe. The effects of climate change have had substantial impacts on human security, especially in societies with economic and socio-political instability. Drought and desertification result in climate migration to urban centers, overwhelming governments’ abilities to provide adequate housing, food, and water/sanitation. Conditions are exacerbated by flood and sea level rise in the littoral environments that host many of the world’s emerging megacities. When these conditions manifest, civil order breaks down, human security becomes compromised, and regional and national security interests come to center stage. The environmental conditions that result in this cycle of conflict and human insecurity will become more critical as climate change accelerates and strains international military and humanitarian response capacity.

This interaction between conflict and climate change impacts nearly every aspect of society, including sustainable development, gender vulnerabilities, education, economic stability, agriculture, public health crises, and extraction of renewable and nonrenewable...
The interrelated nature of conflict, climate change, and resource extraction, for example, highlights the complex relationships that must be tackled by future leaders. This nexus and other climate-related human security challenges require new approaches to address environmental security systematically and holistically.

The cross-disciplinary education of future military and civilian leaders in environmental security is critical to meet the challenges of climate change in the near and mid-term. This session will explore these issues and present recommendations to achieve these critical first steps in our attempt to advance a more resilient and sustainable future.

Balancing Ecosystem and Security Goals in Coastal Systems: Planning for Resilience in an Uncertain World

Sustainable development goals (SDGs) are increasingly informing environmental policy and legislation; this may reduce ecosystem degradation and enhance human well-being, but requires substantial understanding of ecological and social systems; particularly along already extensively altered and exploited coasts and estuaries, adapting to natural variability and stress, and to increasing global, regional and local-scale anthropogenic stresses and changes, including climate change, sea level rise, ocean acidification, eutrophication, pollution, invasive species and habitat loss. “Environmental security” and resilience planning acts on two scales: in the short-to mid-term, the consequences of extreme natural or anthropogenic events such as storms, floods, wars, pandemics and terrorism, and in the longer term, consequences of gradual events such as global warming, sea level rise, ecosystem degradation, and the consequent losses of ecosystem services, equity, and thus socioeconomic and political stability.

Ensuring environmental security, sustainable development and healthy ecosystems involves the prognostic and retrospective identification, ranking, and management of various types of risks, hazards, and vulnerabilities, via the consideration and balancing of scientific, societal, sociological, economic, and political issues: planning for resilience. Vulnerabilities must be identified and ranked; decisions must be developed based upon a number of issues including scenario probability, preventability, causality (human-caused or natural), timescale (gradual or sudden), and potential costs and risks. Different prevention strategies and response strategies (whether a scenario is unpreventable or if prevention fails) must be developed for different types of risks.

This paper will describe progress in the development of tools to link the complex science that should underlie the ecosystem management process to clear, and usable communication and decision tools for the public and policy makers in a way that is compelling and understandable to both groups. Examples linking coastal research to management frameworks, and frameworks for classifying risks and tools needed to manage them equitably will be discussed.

Sabine E. Apitz, Ph.D., is the Director at SEA Environmental Decisions, Ltd., a UK-based consultancy providing advice on how one uses cross-disciplinary science to support stakeholder-engaged environmental policy, management and decision making.

National Security and the Arctic: The Next “Gray Zone” Conflict?

This paper provides an overview of American foreign policy in the Arctic, and calls attention to the geopolitical, economic and environmental implications of the effects of global warming in the region. As the race starts to heat up for its oil and resource-rich waters and shipping lanes, and in the absence of international legal frameworks administering the region, the growing national security and economic interests of the more aggressive regional stakeholders - Russia in particular - are seeking to alter the geopolitical landscape for decades to come. Despite Russia’s mass military build-up and contempt for international law, the United States’ efforts in response has been inadequate at best over the past two decades.

This paper argues that if left unchecked, the Arctic could evolve into a “gray zone” conflict that will threaten the security of the United States and its allies. To address this, the paper recommends developing a comprehensive strategy that will strengthen our defense, promote sustainable economic development and foster international cooperation and respect for international norms.

Lana Obradovic is an Associate Professor of Political Science and the Director of the Intelligence Community Center of Academic Excellence at University of Nebraska at Omaha.
Respect for Human Rights and Increase of Human Security: Practical Applications

This presentation will focus on how a norms-based approach, which is a conscious and systematic integration of international norms and rights principles into all aspects of activities and policies, can offer a robust basis for creating human security and durable sustainability. This presentation will consider how activities and policies influence the enjoyment of rights of the societies in which one operates. It will describe the underlying principles such as participation, accountability, and non-discrimination.

This presentation will provide tools to implement standards that are binding first and foremost for states, but a rights-based approach can and should be applied to all actors. Having such an approach makes it easier to foresee what mandatory regulations will come out of e.g. the EU as well as the UN Principles for Responsible Investors. Furthermore, this approach allows for much more pragmatism regarding what sustainable development and progress look like in areas of the world which are less developed where a number of investors and firms are based, as well as what steps can and should be taken in complex sectors and geographical areas and still be able to show sustainable progress.

The presentation will focus on how to integrate this into sustainability strategies, how to base indicators and report on said standards and importantly how to use the approach in a real effective multi-stakeholder engagement. Without respect for rights there is no human security, and without human security there is no broader societal security. This presentation will also touch upon the links to environmental sustainability efforts and the effects on lack of respect for rights in environmentally induced migration movements.

Kristina Touzenis is a lawyer and recognized leader in the business of international human rights standards and principles, particularly in complicated and volatile regions worldwide.

Multiple Oxidant Soil Mixing/Injection to Position Site Closure

This presentation describes the full-scale implementation and results for soil mixing and injection of oxidants into a source area/distal plume at a former manufacturing facility in western Arizona. The site has a 30 year open Underground Storage Tank (UST) case where gasoline and Bunker C fuel oil were released. Free product skimming, dual phase extraction, excavation, and soil vapor extraction were used to reduce contaminant mass. In spring 2017, a property transaction was underway. The Arizona Department of Environmental Quality (ADEQ) indicated it would consider closure if soil total petroleum hydrocarbons (TPH ->10,000 mg/kg) and groundwater concentrations of benzene, toluene, ethylbenzene, and xylene (BTEX ->5 mg/L) were reduced by an order of magnitude.

Using conventional sampling and the Membrane Interface Probe (MIP) to refine treatment areas, electrical resistance heating (ERH) and a combination of soil mixing/injection of oxidants were candidates to drive site closure. A soil oxidant demand test was completed to aid in decision making. The soil mixing/injection remedy was selected based on cost and expected duration. Sodium percarbonate, hydrogen peroxide, sodium persulfate, and slow release calcium hydroxide were the chosen oxidants.

Soil mixing began in October 2017 taking one week to mix 30 varying sized cells across an 11,000 square feet area through a 12 to 22 ft. vertical interval. Three rounds of injection occurred in the distal plume over a 90-day period, 50 points included in each injection event across a five-foot interval (16 to 21 ft. bgs). As of Spring 2020, >90% reduction in concentration in the soil mixing area plus reductions in injection area wells has put the site on a trajectory to closure. Final groundwater sampling and Mann Kendall statistical analysis are being completed. In addition to the results, site logistical challenges, oxidant quantities and the mixing process will also be discussed.

Jack Sheldon is a Senior Remediation Specialist with Antea Group located in West Des Moines, Iowa.

In-Situ Chemical Immobilization of Arsenic in Groundwater Using Hydrogen Peroxide and Chelated Iron

Industrial use of arsenical compounds at a site resulted in elevated concentrations of arsenic in soil and groundwater. Supplemental site investigations completed after the removal of impacted soils delineated a shallow groundwater plume originating from the soil excavation areas and extending approximately 850 feet downgradient. A feasibility study concluded
that in-situ chemical immobilization of arsenic, in addition to land-use controls and long-term monitoring, would be the most cost-effective long-term remedy for groundwater at the site. Injection of chelated iron and hydrogen peroxide was the technology selected to establish the geochemical environment necessary for arsenic immobilization within the impacted groundwater zone.

The primary objective of the remediation program was to reduce arsenic concentrations in groundwater to 10 µg/L. Arsenic concentrations exceeding 10 µg/L were observed at nine treatment area wells prior to the start of the remediation program and ranged from 12 to 100 µg/L. Laboratory and field pilot test studies were performed to determine optimal injection design parameters. Multiple injection events targeting an approximately 124,000 square feet groundwater plume area were implemented over a period of several years.

Each injection event consisted of the sequential delivery of chelated iron and low concentration (1.5% to 9%) hydrogen peroxide into the impacted groundwater zone through temporary injection points installed at regular intervals across the groundwater plume area. The injection process was designed to uniformly distribute chelated iron throughout the impacted groundwater zone while simultaneously creating oxidizing conditions that promoted the formation of ferric iron [Fe(III)] and arsenate [As(V)]. As ferric iron and arsenate combined with dissolved oxygen generated from hydrogen peroxide decomposition, arsenic was immobilized via co-precipitation/adsorption with iron-arsenic compounds and iron oxides.

Two plume-wide injection events were conducted in 2013 and 2014 followed by two “hotspot” injection events in 2016 and 2017. Overall concentrations were reduced 70% and arsenic concentrations were below the project goal of 10 µg/L at five of the nine problematic wells following the injection events. Post-injection concentrations at all nine problematic wells ranged 1.3 to 26 µg/L.

Paul Dombrowski, Senior Remediation Engineer at ISOTEC Remediation Technologies, Inc. has over 16 years in the environmental industry with experience in hazardous waste site investigation and remediation, with a focus in designing and implementing in-situ remediation technologies.

Carbohydrate Activation of Sodium Persulfate: Observations and Lessons Learned from Laboratory and Field Application

Based on recent research evaluating the use of food grade carbohydrates for activation of sodium persulfate, field application of this innovative activation method was performed at multiple sites. Laboratory data has indicated that food grade carbohydrate activation method has been successful both as sole activation and in the presence of alkalinity to effectively oxidize many organic contaminants of concern (COCs). In the presence of base/alkalinity, carbohydrate activation of persulfate has been advantageously used to accelerate persulfate decomposition in the absence of base/alkalinity is one of the challenges. However, introduction of base/alkalinity in the presence of carbohydrates can trigger an exothermic reaction and persulfate decomposition in the mixing tank. Therefore, the mixing ratios need to be carefully selected to minimize temperature increase or persulfate loss.

Prasad Kakarla, Technical Director at In-Situ Oxidative Technologies, Inc. has over 25 years of experience and is responsible for overall project design, bench-scale/laboratory studies, field implementation, project manage-
Detection of Elevated Gamma Radiation Attributed to Radon Accumulation in Vapor Phase Granular Activated Carbon

Background: Application of soil vapor extraction (SVE) to remediate impacted soils often uses vapor phase granular activated carbon (V-GAC) for vapor treatment. A load of spent V-GAC from a site at Vandenberg Air Force Base (VAFB) was trucked for disposal at a permitted facility. Upon arrival, the V-GAC triggered the facility portal gamma radiation monitors, with measurements ranging from background (15 microRoentgen per hour (µR/hr)) to 30-45 µR/hr. The initially suspected source of the gamma emissions was radon and its decay products. Uranium-bearing marine shales are known to be present beneath VAFB; radon is a decay product of uranium, and it is known to have a short half-life (3.8-days).

Approach: The initial conceptual model proposed that through application of SVE, the radon present at low relative concentration in the subsurface is concentrated within the V-GAC resulting in technologically enhanced naturally occurring radioactive materials (TENORM). Radiation surveys were then performed on other VAFB SVE and groundwater treatment system sites. Monitoring data demonstrated elevated gamma emissions, as high as 65 times background immediately adjacent to the V-GAC vessels at operating sites. Liquid phase GAC also exhibited gamma readings, but at 2-3 times background. Idled systems exhibited V-GAC readings near background. Radon daughter-specific instrumentation was used to confirm that the gamma emissions were attributed to radon-222 decay.

Results: A number of best practices were developed to ensure the potential occupational doses associated with TENORM generated during the operation of V-GAC systems are kept as low as reasonably achievable. This presentation intends to increase and heighten awareness of this phenomenon, and ultimately enable personnel to take appropriate measures to protect workers, the general public, and those handling and transporting potentially radon-impaired spent GAC. The survey program from VAFB, as well as work conducted elsewhere in the Department of Defense will be discussed along with best practices developed from the experience.

Richard Murphy, PhD, has over 40 years of experience in radionuclide, metal and organic compound analytical chemistry, environmental science and engineering, geochemistry, and forensic science.

The Value of 3-Dimensional Implicit Modeling to Support In Situ Remediation Design at a PCE-Contaminated Site

Chlorinated solvents, including tetrachloroethylene (PCE), were detected in groundwater beneath a former dry cleaner site in the San Francisco Bay area. An efficient remediation design and implementation schedule was desired for this project to identify and target subsurface contaminants and apply in situ remediation techniques prior to redevelopment. The major objectives were to 1) delineate the PCE plume emanating from beneath the site and identify areas of elevated concentrations, 2) identify potential preferential flow paths, 3) target optimal locations for in situ remediation, and 4) perform these tasks quickly and cost-effectively.

Using 3-dimensional implicit modeling in the site characterization phase of the project (with Seequent’s Leapfrog software), we were able to interpret the plume size and location based on available data and quickly develop additional sampling and monitoring locations and depths. Existing groundwater chemistry data were compiled and used to identify the plume location, and soil lithology data were used to map zones of high, medium, and low hydraulic conductivity and likely transport pathways. As data were collected, locations, lithology, and contaminant concentrations were added to the model, updating the plume interpretation and refining the conceptual site model in near real time.

We used the refined model to design injection points and target injection volumes to support design of an in situ enhanced reductive dechlorination remedial program. The model was used to visualize proposed injection points, identify the likely soil lithology-type at each injection interval, and support the overall remedial design. The model results greatly improved our understanding of the site and therefore our ability to design an effective remedial plan.

Three-dimensional implicit modeling is an effective tool to rap-
Steady-State Collection of Soil Vapor Samples May Provide a Better Approximation to the Average Concentration in Soil Vapor than Vacuum Extracted Soil Vapor Samples

This paper presents an evaluation of theoretical models for indoor air (Fick’s Law) and soil gas sampling applications (Millington-quirk and Dusty Gas Model) to highlight the difference between steady-state and transient sampling methods. During active soil gas sampling, non-isobaric transient conditions prevail as active soil gas samples are collected under a vacuum of approximately 100 inches of water. The concern is that relatively small gradients in total pressure results in advective gas fluxes that are much larger than diffusive gas fluxes in silty and clayey soils (Massmann and Farrier, 1992, and others), biasing concentrations towards high Henry’s constant and octanol-water partition coefficient (Kow) compounds.

Indoor air sampling theory is fundamentally based on Fick’s First Law, which relates the diffusive flux of gases in the air to the concentration under the assumption of steady-state conditions. In porous soil media, a combination of air permeability and diffusion with high moisture conditions prevail. Accordingly, McAlary, et al. (2014) correctly employed the Millington-Quirk model to incorporate the effects of tortuosity and moisture in evaluating steady-state passive soil gas sampling. In the case of active soil gas sampling, the Dusty Gas Model is adopted as the most appropriate transient model (Scanlon, et al., 2001) and provides the means for comparative evaluation of sampling methodologies.

The authors contend that steady-state quantitative passive soil gas sampling analyzed in accordance with US EPA Method 8260c or TO-17, provides a better approximation to steady-state soil vapor conditions for VOCs and SVOCs compared to active soil gas (instant) sampling. The steady-state soil gas sampling model resolves data quality concerns related to soil gas sampling and vapor intrusion risk assessments: longer sampling time (i.e. days to weeks) mitigates temporal variability, zero-vacuum sampling eliminates selective desorption and advection of COCs, and reduced variability in sampling implementation reduces operator errors.

Lowell Kessel, MSc, P.G. is a registered professional geologist (PG) in California, and has managed environmental projects and designing remediation solutions for over 20 years on five continents.

Comparison of Real-Time TCE Measurement Methods for VI Studies

In vapor intrusion (VI) studies, trichloroethylene (TCE) often gets special attention because of its toxicity and concerns about relatively short-term exposure. Some States require evacuation of buildings if certain concentrations are exceeded. There is interest in being able to find and address preferential pathways and indoor sources of TCE as quickly as possible.

A field trial was performed to compare the performance of a field GC, a HAPSITE GC/MS, and a FROG portable GC for making real-time TCE measurements to address VI. The field GC configuration and operating conditions were developed by AECOM air measurement staff. The instrument uses a dry electrolytic conductivity detector (DELCD) and has a detection limit of approximately 0.25 µg/m3. The HAPSITE and FROG instruments were standard, commercially-available units. In addition, a photoionization detector (PID) was used in the studies. Data are presented and discussed related to the analytical sensitivity of the various analyzers, the correlations found during side-by-side measurements, measurement frequency and turnaround time, and ease of use.

Real-time TCE measurements were made at multiple buildings at a major industrial facility in the Midwestern US and at an active Air Force Base. General findings are presented and discussed regarding the performance and usefulness of the real-time TCE measurements to evaluate lateral and vertical concentration gradients; emissions from drains, slab cracks, and other openings; distribution of vapors via HVAC systems; and distinguish between VI and indoor sources during building pressure manipulation.

Bart Eklund, Marty Hale, Lisa DeGrazia, and Michael Wolfskill AECOM, Austin, Texas
Assessment of the USEPA Attenuation Factor for Vapor Intrusion Screening

Many regulatory agencies calculate risk-based subslab or soil-gas screening levels (SSSLs) for chemicals that pose potential vapor intrusion (VI) risks based on the US Environmental Protection Agency’s (USEPA’s) recommended attenuation factor of 0.03. The representativeness of this AF has recently been questioned with respect to its application at VI sites with differing climatic conditions and building types than those on which the AF was based. Understanding the limitations and other potential biases in the USEPA study is critically important in establishing technically defensible SSSLs that effectively screen out low-risk sites.

A VI database containing 8,432 paired subslab/soil vapor and indoor air samples collected at 34 sites (including 4 from the USEPA database) across California was compiled and used to derive an empirical AF. The database contained information on building and foundation types and other variables not critically evaluated by USEPA. An empirical AF was derived based primarily on its reliability to identify instances where indoor air chemical concentrations exceed indoor air screening levels attributable to VI.

An empirical AF = 0.002 was calculated from the reliability analysis conducted on filtered trichloroethylene (TCE) data. This AF is roughly an order-of-magnitude less than the USEPA value, yet essentially equivalent to the AF representing 95% of AFs calculated from an analysis of filtered TCE vapor data (AF = 0.003). The attenuation factor. H&P’s Radon Attenuation dataset includes samples that have been collected over the past 11 years by certified soil gas sampling contractors from more than 100 commercial structures nationwide (with a large focus in California).

The results from this compilation will be presented and compared to default attenuation factors currently being used by regulatory agencies around the country. The results should engage consultants and oversight agencies to consider more realistic attenuation factors when evaluating the potential vapor intrusion risk from subslab soil gas data in commercial settings.

Matthew Lahvis received a B.S. in Geology from Bucknell University and M.S. and PhD degrees in Engineering from Drexel University.

Radon Attenuation Factors in Commercial Settings – A Review of Subslab to Indoor Concentrations

In the wake of recent screening-level and attenuation factor updates, there continues to be much discussion in the regulatory and consulting community regarding appropriate screening levels for subsurface vapor investigations. The EPA and many States are moving toward a default attenuation factor of 0.03 for residential and commercial structures alike, despite the 0.03 value being derived from a primarily residential database. This is resulting in what some see as overly conservative screening levels for commercial vapor investigations.

In the absence of a robust commercial dataset, H&P has compiled radon data from subslab soil gas and concurrent indoor air to determine the resulting cross-slab

Suzie Nawikas is the Operations Manager for H&P, Inc., a nationwide leader in the environmental industry for high quality soil vapor sampling and analytical services.

Overcoming Shortcomings of Traditional Vapor Intrusion Sampling Approaches via Continuous Monitoring

Indoor air sampling for volatile organic compounds (VOCs) is generally performed with passivated canisters or passive sorbent samplers. Typically, only a few contaminant concentration measurements are made in a structure, and the results represent an assumed average concentration over the sampling duration. In recognition of the potential for concentration dynamics, regulators require multiple sampling rounds typically six months apart. This paucity of data does not allow for recognition of contaminant concentration temporal variations at resolutions appropriate for developing cause-and-effect correlations. More specifically,
short-term (e.g., hourly) temporal concentration patterns must be understood in order to recognize impacts due to common natural and anthropogenic controlling factors. As such, it is common for critical cause-and-effect relationships to remain elusive when employing conventional vapor samplers.

Automated continuous concentration monitoring provides a large amount of data over time (e.g., approximately 150 analyses per day). The detailed data patterns generated exhibit concentration dynamics over time and space. Using this approach, we have documented concentration temporal variations in every structure sampled, with changes occurring over periods as short as one hour. Simultaneous monitoring of controlling factors such as wind speed, barometric pressure, ventilation operations, drain covers, and differential pressure enables practitioners to rapidly determine the cause of the concentration pattern and the vapor entry point in a single deployment. Once the cause is determined, remedies can be implemented and impacts on the concentration pattern can be evaluated to determine and optimize mitigation effectiveness. Data from the system is uploaded in real-time to a Cloud dashboard, which allows practitioners to view the data within minutes of analysis from anywhere with an Internet connection. Alerts and automated responses can also be engaged.

Data from selected sites will be presented to demonstrate situations where traditional sampling methods were unsuccessful at determining cause-and-effect relationships. For each of these “mystery” sites, continuous monitoring was employed, and key correlations developed to allow practitioners to resolve the vapor intrusion challenge and proceed to the next step in the risk management process.

Blayne Hartman is an internationally recognized expert on soil vapor sampling, soil vapor analysis, and vapor intrusion.

Analysis of Four Decades of Crude Oil Weathering and its Effects on Fluid Properties and LNAPL Mobility at the 1979 Pipeline Release Site Near Bemidji, MN

Light non-aqueous phase liquids (LNALPs) that reach the water table will spread downgradient along the water table until mass losses due to weathering balance with declining rates of spreading. Weathering changes the initial chemical composition by removing lighter, more soluble, and degradable compounds leaving a blend that becomes more dense and viscous, with altered interfacial tensions between contacting fluids. These changes reduce LNAPL mobility and spreading rates. Here we share results of analyzing 4 decades of weathering on the composition and physical properties of a light crude oil spilled in 1979 and contacting ground water in glacial sediments in northern MN, a research site managed by the U.S. Geological Survey (USGS).

We analyzed an archived sample of the pipeline oil and many USGS samples collected prior to 2010. We supplemented those with samples from the same, plus additional wells during 2010-2012, and resampled 14 wells again in 2019. Compositions were determined by Gas Chromatography and physical properties followed API and ASTM methods. Assuming Pristane was a conservative species increasing in all samples as other compounds were removed, we calculated a fraction of mass lost and mass remaining for 40 oil samples.

We found a linear zero-order trend for the first 3 decades, which became first-order during the 4th decade. With assistance from USGS colleagues, we found the best-fit trend for all 4 decades agrees with a Monod kinetics function. Weathering was spatially heterogeneous, consistent with heterogeneous glacial sediments near the water table. The most altered fluid property that reduces mobility is viscosity, which changed from 13 centipoises in the reference oil to 98 centipoises in the most weathered oil collected near the downgradient leading edge of the oil body in 2019.

Don Lundy is a Principal Hydrogeologist with Groundwater & Environmental Services, Inc., in Tucson, Ariz.

Simple NAPL Depletion Estimates from Changes in Chemical Composition

Spills and releases of petroleum can result in zones of non-aqueous phase liquids (NAPL) in soils and groundwater. The chemical constituents in the NAPL will deplete at different rates due to dissolution, volatilization, and degradation, and the NAPL composition will vary over time. Here we present some relatively simple methods for estimating bulk NAPL depletion based on limited NAPL compositional analyses at multiple points in time. Methods for selecting the most
conserved markers in the NAPL mixture, estimating depletion based on those markers, and confidence in the depletion are shown. Several examples are included.

George DeVaull is a Principal Engineer at Shell Global Solutions US Inc. in Houston, Texas and a member of the American Petroleum Institute [API] Groundwater Task Force.

Cumulative Effect of NSZD Through Compositional Analysis

Background/Objectives. Natural Source Zone Depletion represents the natural attenuation capacity of the subsurface to reduce LNAPL sources over time. Multiple methods have been developed to calculate the instantaneous rate of biodegradation but few have been able to directly identify the cumulative effect NSZD has induced.

Approach/Activities. Hydrocarbons released to the subsurface whether a crude oil or a refined gasoline are comprised of hundreds of compounds. Each of these compounds exhibits different partitioning behavior as well as substrate preference by microbes. This results in NSZD changing the composition of the LNAPL over time where it is possible to estimate the fraction lost as a function of a single compound as documented by CRC Care guidance. This discussion will provide the results of two dozens samples collected over 17 years at a crude oil release. The results will be related to the weathering behavior currently documented in literature as well as other NSZD related publications indicating NSZD as a plume stability mechanism.

Results/Lessons Learned. The resulting behavior model can be used to directly identify the cumulative compositional effect NSZD has achieved at various locations within the plume. A discussion of alternative methods to help quantify the confidence of these estimates will be provided. The intent is to provide improved guidance on analysis methods and consideration when applying the compositional NSZD based methodology in addition to highlighting the cumulative losses of LNAPL.

Andrew Kirkman is a hydrocarbon and hydrogeology subject matter expert for BP.

Natural Source Zone Depletion Estimation with Multiple Permeable Zones and Confined LNAPL

Natural Source Zone Depletion (NSZD) is an important process in the remediation of LNAPL. NSZD describes the reduction of LNAPL mass by naturally occurring processes that degrade hydrocarbon constituents. Guidance documents from API and ITRC summarize systematic processes to qualitatively assess and quantitatively measure NSZD through various evaluation processes. NSZD rates have been reported in the range of 300 to 7,700 gallons/acre/year. However, these rates are reported from sites with unconfined LNAPL where there are no barriers to vertical transport of gases produced by biodegradation processes. Saturated soils above the biodegradation zone may interfere with the vertical transport of gases and require modifications to the standard methods.

NSZD was measured at a site with LNAPL in multiple permeable zones and in an aquifer that can be confined or unconfined depending on the elevation of the water table. Three methodologies (surface carbon traps, biogenic heat, and degassing) were implemented to evaluate the applicable methodologies under varying conditions. The results were compared for areas of the site with and without a shallow saturated zone as well as in the same location with LNAPL under confined and unconfined conditions. The test results were evaluated to assess the conditions where each method was applicable, determine if other methods were required to characterize NSZD at the site, and assess the seasonal variation of the estimated rates. The evaluation indicated that no single measurement approach was applicable to monitor NSZD for all site conditions, but a combination of the methodologies could be used to estimate NSZD rates site-wide.

Lisa is a Senior Engineer, with GEI Consultants, specializing in non-aqueous phase liquid (NAPL) multiphase characterization and risk-based remediation.

Field Based Approach to Evaluating Natural Source Zone Depletion at LNAPL Sites

Remediation of LNAPL sites is one of the largest challenges faced by both responsible parties and the regulatory community. About a decade ago, initial attempts were made to evaluate the importance of source zone natural attenuation (SZNA) at a large LNAPL plume in an oil field. Since then, there have been numerous studies building upon this initial work which is now characterized as natural source
zone depletion (NSZD). However, the trend of long and costly cleanups has continued as NSZD has not become a widespread and acceptable approach as these newer investigations have been costly and take considerable time and effort to complete.

Building on investigations made at a number of LNAPL sites throughout the U.S. and one in Australia, a rapid field-based approach to evaluate a site conceptual model (SCM) for NSZD has been developed. The approach relies on easily obtainable field measurements to supplement existing site data and integrates both groundwater and vadose zone data. Currently, most NSZD guidelines follow a generic SCM that invokes aerobic oxidation of methane in the vadose zone resulting in production of CO2 as a soil gas. Although this type of conceptual model is appropriate for some LNAPL sites, this model is not consistent with many of the sites we have evaluated.

Determination of the rate of methane transport to the vadose zone can be determined from measurements taken at the base of the vadose zone using existing monitoring wells screened across this interval and from the upper portion (upper two feet) of groundwater using dissolved gas analysis. Though NSZD is a measure of aerobic biodegradation, the absence of a methane plume in the vadose zone would nullify the default assumption that NSZD is a result of methane oxidation in the vadose zone and indicate that NSZD is a result of direct biodegradation of LNAPL.

**Vapor Mitigation Telemetry – Adding Short and Long-Term Performance Certainty**

Vapor Intrusion continues to evolve in the environmental industry, with increasing burdens on investigation, mitigation, site closure, and long-term stewardship. Active soil depressurization (ASD) continues to be the primary mitigation solution, for which national consensus standards have been collaboratively developed through the American National Standards Institute by the American Association of Radon Scientists and Technicians to refine and standardize ASD implementation. Traditional ASD operation, maintenance, and monitoring (OM&M) typically consists of regular on-site visits (e.g. monthly, quarterly, annually) to assess operating conditions and ensure the protectiveness of occupants. However, periods between visits represent potential undetected failure and exposure for building occupants. Traditional OM&M is often encumbered by the successful coordination of site access, which has been further challenged by COVID-19 social distancing precautions.

Telemetry solutions for monitoring ASDs eliminate common roadblocks to providing short and long-term assurances that the ASDs properly operate to protect occupants while monitoring continuously for potential undetected system failure. The Massachusetts Department of Environmental Quality recognizes these protective benefits and requires the inclusion of telemetry in ASDs. As additional state regulatory programs update guidance, the benefits telemetry affords, such as reduced oversight costs from potentially reduced or eliminated long-term sampling obligations, are being recognized.

Deployments of the patented Vapor Sentinel™ remote monitoring system at several vapor intrusion sites provide valuable case study examples for examining continuous mitigation system performance. Examples to be presented include a multi-unit condominium site in the Milwaukee area for which telemetry was a key component to the successful demonstration of a long-term vapor mitigation solution, and an industrial site with offsite residential VI impacts in the Atlanta area. These case studies provide a comparison of continuous telemetry data that illustrates seasonal, diurnal, and weather-related impacts on vapor mitigation system performance in different regions.

Dr. Bonniwell is the Director of Products for Protect Environmental, a nationally recognized provider of radon and chemical vapor intrusion mitigation solutions.

**In Situ Thermal Treatment Case Study: From Kickoff to Completion in Less than 12 Month**

Background/Objectives: Excavation was selected to rapidly remove subsurface soils impacted by chlorinated ethenes and ethanes. Specific site characteristics included high concentrations of chlorinated volatile organic compounds (CVOCs) in vadose soils with low porosity.
and highly variable bedrock at a Site that hosted more than a century of manufacturing activities. Numerous on-site utilities and subsurface features within the treatment area posed challenges to planning and implementation. As the proposed excavation was being planned, it became clear that transportation and soil disposal costs would be three times the original budget, due to soil concentrations of chlorinated VOCs exceeding 20,000 mg/kg. The project team pivoted to implement In Situ Thermal Treatment (ISTT) for onsite soil treatment within an accelerated timeframe. The state regulatory agency agreed to the use of ISTT and set a remedial goal of 75 percent mean reduction in Tetrachloroethene (PCE) and Trichloroethene (TCE) soil concentrations with predetermined institutional controls.

Approach/Activities: The 5,000 square foot treatment area consisted of heterogeneous soils with maximum PCE concentrations up to 20,000 mg/kg and TCE concentrations up to 1,000 mg/kg. ISTT was selected utilizing thermal conductive heating (TCH) due to its rather uniform heat transfer throughout heterogenous subsurface lithologies. Due to the absence of existing onsite power and the expense required to bring electricity or natural gas to the treatment area, propane was selected as the energy source for TCH. Utilizing the remedial design investigation data, three soil vapor extraction (SVE) well designs [dual-nested, horizontal and shallow] were installed throughout distinct areas of the treatment area. This network of SVE wells captured contaminant vapors and prevented off-site migration. The vapor stream was treated by a C3 system which cools, compresses and condenses extracted CVOCs resulting in non-aqueous phase liquid (NAPL) for offsite disposal.

Results/Lessons Learned: The project was completed in 9 months (construction, operations, demobilization) to support the site redevelopment schedule. Following 104 days of subsurface heating, confirmation soil samples were collected that demonstrated a 98.7% mean reduction of PCE and TCE throughout the target treatment zone. A total of approximately 3,200 pounds of contaminants were physically removed from the subsurface. A combination of daily photoionization detector CVOC measurement, analytical laboratory data of the extracted vapor stream was used to track system progress and update state regulators. Soil confirmation samples

Mr. Grant Geckeler is the Director of Remediation Services at ISOTEC.

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**Synthetic Media as a Sustainable Treatment Solution for PFAS**

Per- and polyfluorinated alkyl substances (PFAS) have emerged as high-priority contaminants for management around the world that require innovation to successfully and sustainably treat. Granular Activated Carbon (GAC) can effectively adsorb PFAS from water, but frequent carbon change-outs limit the sustainability of this technology. In addition, GAC is not as effective at removing the shorter-chain and branched PFAS which are attracting increasing focus from researchers and regulators. Synthetic media (resin) technology shows significant advancement in treating total PFAS while generating considerably less waste. When combined with on-site regeneration of the resin, this technology is sustainable and cost-effective.

A comparative trial using groundwater was performed using GAC and resin as the two treatment media. Both GAC and resin trains used vessels in series: four GAC vessels with 5-minute empty bed contact time (EBCT) per vessel, for a total system EBCT of 20 minutes, and three resin vessels with 2.5-minute EBCT per vessel, for a total EBCT of 7.5 minutes. Bed volumes (BVs) were equal for each vessel; flows were adjusted to achieve the desired EBCTs. Routine samples from both trains were analyzed for PFOS, PFOA, and 21 other PFAS compounds. Both the GAC and resin processes operated for an initial loading cycle to evaluate PFAS breakthrough.

The resin system demonstrated faster removal and higher treatment capacity than GAC. Compared at 5 minutes EBCT, the resin treated over eight times as many BVs as GAC before PFOS breakthrough and five times as many BVs before PFOA breakthrough. Similarly, resin demonstrated higher treatment capacity for all other PFAS compounds in the groundwater matrix.

Successful in-vessel regeneration of the resin was demonstrated to near-virgin conditions during the pilot. The residual still bottoms, containing concentrated PFAS in a brine solution, were then super-concentrated onto a very small volume of Sorbix resin for thermal destruction.
ECT2’s patented regeneration process which removes PFAS from the IX resin using a solvent-brine blend. Following media regeneration, the regenerant is recovered and the PFAS is superloaded into a highly concentrated solid waste.

Over 18 months and 815 million liters of PFAS-contaminated water treated, there have been no detections of PFOS, PFOA, or PFHxS in exceedance of the Health Based Guidance Values in the water discharged from either of the treatment systems. A stringent controls and remote monitoring scheme allows the plants to operate 24/7 with a combined uptime of 99.4%. Owing to the innovative process design and regenerable IX resin technology, waste generation has been limited to approximately 1 liter per 10,000,000 liters of PFAS-contaminated water treated.

Sarah Shipley is a chemical engineer with ECT2 (Emerging Compounds Treatment Technologies), an equipment company focused on developing and commercializing treatment technologies for emerging, difficult-to-treat compounds including PFAS.

Novel Approach to In-Situ Remediation of Trichloroethylene (TCE)

GHD was asked to re-evaluate the groundwater remedial strategy at an auto repair facility impacted with trichloroethylene (TCE) and associated daughter products. Working through an abbreviated multi-criteria analysis approach, GHD selected remedial injection as the optimal means to accelerate remediation of groundwater concentrations.

The small size of the project site limited area to stage and store equipment and material. To address this, GHD utilized small footprint mobile injection equipment (direct-push rig and mixing rig) and injection materials were stored offsite. Hydrogeologically the site soils in the water-bearing zone are predominately fine-grained, making the injection of coarser and more viscous remedial products problematic. After considering the remedial drivers, site-specific characteristics, and several different products, GHD designed an in-situ remedial injection utilizing Tersus Environmental’s EDS-ERtm and micro zero-valent iron (mZVI). The combination of these two products allowed for: easy mixing with water; no requirement for an additional suspending agent such as guar; and the mixture’s relatively low viscosity allowed for a low injection pressure.

GHD’s remedial design was successful at delivering the mixture of EDS-ERtm and mZVI across the targeted treatment zone. Evidence of success are the rapid and continued reduction of historically elevated TCE concentrations in source area monitoring wells during the past three quarterly post-remediation groundwater monitoring and sampling events. Current concentrations are one (1) to three (3) orders of magnitude lower than pre-remedial groundwater concentrations. If concentrations remain at or near the current concentrations, the site should be receiving case closure following the fourth post-remedial groundwater monitoring and sampling event.
From MGP to Rail – A Brownfields Story
An investigation was initiated as a result of a pending property transaction associated with the expansion of one of LA Metro's maintenance divisions. Since 1894, the Site was developed for industrial purposes, and includes various historical facilities of concern, including those associated with the former Southern California Gas Company (SCG) Aliso Street Manufactured Gas Plant (MGP), as well as former cold storage, warehousing, and food-processing facilities. MGP operations were performed between 1874 and 1927, and butadiene production was performed between 1942 and the early 1950s. Three interconnected vacant buildings remained on Site and were the focus of the assessment.

Initial results from this ultra-fast-track assessment had to be received and evaluated in less than a month as part of the due diligence process, and final reports submitted within a two month period. Since California DTSC had regulatory oversight of the former MGP facility, Metro sought DTSC oversight through the California Land Reuse and Revitalization Act (CLRRA) process. A total of 30 total bores were drilled, and 47 soil vapor probes installed, including two single probes, 18 dual-nested probed, and three triple-nested probes. In addition to the soil and soil vapor sampling, groundwater was evaluated (as it was recognized that groundwater had been impacted by MGP operations), and water from two remaining subsurface clarifiers was sampled.

Detected contaminants include chlorinated hydrocarbons (including dicyclopentadiene), metals, PAHs, SVOCs, and hydrocarbons. The expedited deadline was met for results of the site characterizations for property purchase. Additionally, a soil/groundwater management plan was prepared to keep LA Metro in compliance with soil disposal during construction activities and groundwater for potential dewatering activities. This allowed LA Metro to move forward with their expedited demolition and construction schedule. Up-front planning allowed for continued forward momentum when construction brought its share of surprises.

Liz Simmons is a Senior Principal Geologist and Senior Fellow for Kleinfield with over 37 years of experience, specializing in Environmental Site Characterization.

Ion Exchange Groundwater Treatment System Addresses PFAS Contamination at an Australian Air Base
Historical use of aqueous film-forming foam at Royal Australian Air Force (RAAF) Base Williamtown in Australia has resulted in PFAS contamination of groundwater and stormwater, both of which migrate off-base. Defence asked Emerging Compounds Treatment Technologies (ECT2) to provide a system to treat a groundwater source beneath the former Fire Training Area at the base. The aquifer was historically used for drinking water, and residents continue to use the aquifer for non-drinking domestic purposes.

The treatment system operates at or near its design capacity of 12.5 L/sec. The various components are installed inside three international shipping containers. The process flow includes sand filtration for iron and solids removal, two stages of pretreatment resin to remove TOC and colloidal iron, lead and lag regenerable resin vessels for PFAS removal, and polish resin to enhance the removal of short-chain PFAS compounds. The regeneration system facilitates the delivery and recovery of ECT2's proprietary regeneration solution, which maximizes reuse of the regenerant solution and minimizes waste generation. The treated water is dispersed via an extensive sprinkler array, which is monitored to ensure surface pooling does not occur, particularly during times of high rainfall.

The groundwater treatment system has been operational since commissioning in July 2018 and has treated more than 584 million liters of water to below the Australian Health Based Guidance Values 0.07 µg/l for PFOS+PFHxS and 0.56 µg/l for PFOA. The high rainfall in the region and resulting increases in the groundwater table can impact upon the capacity to disperse the treated water without impacting the operational capability of the base. Close collaboration with the environmental consultant and Defence has allowed ongoing operations with limited downtime. The utility of the SCADA system, combined with the regenerable resin technology, results in consistent attainment of sustainable remediation objectives and minimizes waste generation.

Ms. Sinnett is the Director of Design and Product Engineering at ECT2 (Emerging Compounds Treatment Technologies), an equipment com-
Considerations and the Essential Aspect for Sustainable Energy Recovery from Rice Husks

Biomass is a source of sustainable energy and a promised resource for Japan because there is almost no fossil fuel reservation in the country. Since 66% of Japan’s entire area is covered by forest, timber may be considered a suitable form of renewable energy. However, in reality timber cannot be a good renewable energy source because the tree life span is too long. Unlike timber, rice plants grow in only a few months and are cultivated every year because rice is the main diet for Japanese. Consumption of rice results in the generation of rice husks. Rice husks are burnable and have 12 MJ/kg of heating value, which makes for an excellent energy source. We produce rice every year, eat rice, and recover energy from rice husks, which seems an ideal loop in terms of utilizing a biomass resource.

The things do not work out, however, quite as well as we hoped. There are several drawbacks on utilizing rice husks. Rice husks contain 20% of silica by weight and silica will be crystallized under high burning temperature. Crystalline silica is classified into the carcinogenic substances according to World Health Organization. We have been researching rice husk recycling for nearly ten years. In this paper, some considerations and the essential aspects are discussed for pursuing sustainable energy recovery from rice husks. The discussion presented here is also applicable for the countries that have environmental problems on rice husk treatment.

Masafumi Tateda is an associate professor in the Department of Environmental Engineering at Toyama Prefectural University, Japan.

Multiple Applications Using Novel Technology for Extended Release of Low Solubility Potassium Persulfate: Field Case Studies

In situ chemical oxidation (ISCO) using activated Klozur Persulfate has been applied at thousands of sites to treat a wide assortment of environmental contaminants of concern. Activated Klozur® persulfate is based upon a highly soluble environmental grade sodium persulfate. This high solubility has enabled the injection of a significant amount of oxidant in reasonable injection volumes allowing Klozur persulfate to treat highly contaminated soils and groundwater.

Potassium persulfate is another commercially available persulfate that, once activated, releases the same remediation potential as sodium persulfate but has several different key characteristics. Two of these critical characteristics are a theoretical solubility that is over an order of magnitude lower than sodium persulfate and the use of the potassium salt which would be beneficial at a limited number of sites that have regulatory guidance on sodium (Na) concentrations in groundwater.

Since being introduced, activated potassium persulfate has been applied at several sites thought to benefit from the slow extended release mechanism. These applications have tended to fall into three categories: permeable reactive barriers, fractured into low permeable soil to treat entrapped contamination, and for soil mixing applications. Case studies for each of these three types of applications will be presented. Key elements will be presented and used to illustrate the benefit of the extended release mechanism of potassium persulfate and how it was used to achieve remedial goals at each site. This will include up to 3 order of magnitude reduction in contaminated groundwater flowing through a potassium persulfate permeable reactive barrier, low permeable soil being treated to below detection limits, and extended release persulfate achieving remedial goals in a soil mixing application.

Stacey Telesz has 16 years of experience in the environmental remediation industry.

Latest Developments in TCE Short-Term Indoor Air Standards

Description: Given the uncertainty around trichloroethylene’s (TCE’s) inhalation reference concentration (RfC), how do we evaluate and manage potential risk from inhalation exposure? Many states and several USEPA Regions have published their health-protective air standards; however, there is significant variability across these air standards. Therefore, how do we know which standards are health protective for our sites? This presentation will walk through the equations used to calculate health-protective air standards for TCE and explain the variability across different envi...
environmental regulatory agencies.

Learning Objectives: To provide a review of various short-term TCE action levels for indoor air, until such time that US Environmental Protection Agency (EPA) finalizes their assessment on this topic. Confusion and misinterpretation are the state of the 2019 regulatory environment as it pertains to short-term TCE action levels for indoor air. Despite the controversy surrounding the Johnson et al. 2003 study, it is apparent that the study is used as the ultimate goal (in the case of the two 2013 ATSDR studies) basis of the inhalation reference concentration (RfC) of 2 µg/m3.

Different Regions of EPA have developed short-term action levels, which have been adopted by several states, including California, Colorado, Michigan, New Hampshire, New Jersey, New York, and Ohio. Other states have established their own TCE indoor air action levels, such as Massachusetts, Minnesota, Connecticut, and Indiana. A comparison of the Federal and State values will be presented and discussed.

Meanwhile, in 2014, ATSDR identified 2 µg/m3 as an intermediate (52-week) and chronic minimal risk level (MRL). ATSDR has not developed an acute MRL, which would be protective of an exposure lasting from 1 – 14 days. The presentation will conclude with EPA TSCA reform developments, including EPA’s February 2020 Draft TCE Risk Evaluation.

Target Audience: Based on the information provided in this presentation, the targeted audience (consultants, regulators, industry) will better understand how the variability in input assumptions results in a wide range of health-protective air standards for TCE and how to identify the appropriate TCE air standard for their sites.

Laura Trozzolo is a Senior Human Health Risk Assessor with TRC, where she provides data management and regulatory oversight for human health risk assessment and risk management services for military sites, former Manufactured Gas Plant sites, active and former refineries, as well as railroad derailments and operational sites.

The Estimation of the Octane Rating of Fresh and Evaporated Gasoline with the Use of Detailed Hydrocarbon Analysis

Gasoline is the most consumed petroleum product in Taiwan. Leakage of gasoline from underground tanks and pipelines has caused severe environmental problems. Besides, gasoline is susceptible to weathering and biomarker compounds are undetectable in light fuels. Therefore, discrimination of gasoline grades and manufacturers is more difficult compared to middle distillates and heavy fuel oils.

The objective of this study is to develop an environmental forensics technique to differentiate the grades of gasoline to enable the source tracing of the spilled gasoline. A total of 90 gasoline samples, covering three different octane ratings (92, 95 and 98), were randomly collected from 30 gas stations in Taiwan over a one-year period. The individual components in gasoline were characterized with detailed hydrocarbon analysis (DHA).

We successfully set up a numerical index referred to as the octane rating by selecting specific compounds. Then, the evaporation studies of three grades of gasoline were carried out to examine the stability of the index value. With the aid of this environmental forensics tool, it can enhance the possibility to find out the likely source of free-phase gasoline releasing to the subsurface.

Chiwei Wang is an environmental engineer working for exploration and development institute of CPC corporation, Taiwan.

In Situ Reductive Dechlorination and Biogeochemical Transformation of Chlorinated Ethenes, Alameda, California

The former maintenance site, located in Alameda, CA, is approximately 5.6 acres in size and relatively flat, covered by buildings and asphalt, concrete, roads, and parking lots. Previous investigations identified groundwater COCs PCE, TCE, cis-1,2-DCE, and VC. COCs are confined by a continuous bay mud unit to the first water bearing zone from approximately 4.5 feet to 10 feet bgs. The record of decision (ROD)-selected remedy was a sequence of ISCO, ISB, if necessary, and MNA with ICs. ISCO was implemented in 2011 but did not meet cleanup goals, i.e., federal or state MCLs. ISB treatment was conducted from July through August 2014 and again in November 2015.

The first round of ISB treatment recirculated groundwater to distribute a biostimulant (EHC-L) and bioaugmentation (Dehalococcioides [DHC] culture). The treatment approach utilized abiotic, in situ biogeochemical transformation, taking advantage of elevated sulfate from both the naturally brackish bay water and the pre-
previous ISCO treatment with activated persulfate. This sulfate, along with added iron, formed reactive iron-sulfide minerals to break down the COCs via elimination processes. Post-treatment performance monitoring demonstrated that the EHC-L provided sustained and favorable biochemical conditions for reductive dechlorination of COCs as well. A second round of ISB injection was performed using sodium lactate in selected areas not demonstrating significant dechlorination.

The effective pore volume within the treatment area was replaced with amended groundwater via 66 injection and 10 extraction wells in the first round of ISB treatment and 39 injection and 10 extraction wells during the second round of ISB treatment. Substrate distribution was confirmed through field monitoring of iron and carbon at the 10 extraction wells and 11 monitoring wells within the treatment area.

Results from 10 rounds of ISB post-treatment performance monitoring concluded that all parent COCs were reduced to concentrations below their RGs or to below detection levels with an overall reduction in plume area of approximately 53%. Despite the challenges in overcoming geochemical conditions within the optimal range for ISB in the shallow, unconfined, and tidally-influenced aquifer, the selected ISB remedies were successful at the site through a combination of impervious asphalt cover, manual control of extraction and injection processes, and the combined use of a fast-fermenting, mobile lactate and the sustained electron donor EHC-L.

Shuangshuang Xie, Senior Environmental Engineer, Lansana Coulibaly, Principal Engineer, Kathryn Robinson, Wood. PLC, San Diego, Calif.

Semi-quantification of Chrysotile using Indicator Metals analyzed by X-ray Fluorescence (XRF):
As a Naturally Occurring Asbestos (NOA) mineral, Chrysotile is often a problematic component of Pentinite, a common rock type in California. Standard procedures for quantification involve using somewhat complex and labor intensive techniques that generally include Polarized Light Microscopy (PLM) and/or Transmission Electron Microscopy (TEM). The objective of this study was to evaluate if Chrysotile could be semi-quantified using the concentrations of Chromium (Cr) and Nickel (Ni) as indicators of its presence.

More than 50 samples of Pentinite and derived alluvium were collected from a site located in central California. The samples were pulverized per California Air Resources Board (CARB) Method 435 and analyzed for asbestos using PLM and/or TEM, and for Cr and Ni using a NITON Model XLT 792 X-ray Fluorescence Spectrum Analyzer (XRF).

The results are promising showing moderately strong correlations ($r > 0.65$) between Chrysotile and both Cr and Ni in source rocks with a similar but weaker relationship that varied with the distance of the alluvium from the source rock. Based on the limited results, it appears that Chromium and Nickel may be useful indicators of the presence of Chrysotile and that XRF analytical techniques may be capable of providing reliable screening level data useful for the semi quantification of Chrysotile in both the laboratory and the field.

Thomas Zdeb is a California Professional Geologist (PG) and a Certified Industrial Hygienist (CIH).

The Fate and Transport of Produced Water Released into Vadose Zone
Groundwater is a major source of drinking water. It is also used for agriculture, industry, and mining. It is crucial to protect groundwater from accidental release of potentially harmful produced water. Produced water is a complex mixture of dissolved and particulate organic and inorganic chemicals in the water that ranges from essentially freshwater to concentrated saline brine.

The zone between surf ace and groundwater table, the vadose zone, contains solid soil particles, air, and water. To model groundwater flow and solute transport in the unsaturated zone, it requires to make some simplifications and assumptions due to the heterogeneous and complex nature of soil in the vadose zone. Water movement to and from aquifers and the ground surface is controlled by processes in the unsaturated zone. Understanding these processes are crucial to simulate water flow and solute transport in the unsaturated zone.

The objective of the study was to evaluate the potential impact of produced water release to current or proposed land use within the study area. A numerical simulation was used to assess the
potential impact of produced water-release that contain elevated total dissolved solids (TDS) to the groundwater table. For this purpose, the one-dimensional HYDRUS numerical model was used to simulate the fate and transport of the produced water. HYDRUS is a computer code that used to simulate water, heat, and solute transport in one, two, and three dimensional variably saturated porous media based on finite elements.

Biniam Zerai is a California Certified Hydrogeologist with over 13 years of experience in geologic and hydrogeologic investigations.

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**Catalytic Hydrothermal Liquefaction of Water Hyacinth for the Generation of Biofuels Production**

Biofuels can be an alternative to fossil fuels and their economic production can meet the current energy demands. Hydrothermal liquefaction is one of the effective thermochemical processes for converting biomass into liquid fuel. Water hyacinth is a harmful and unwanted aquatic biomass, as it has a negative footprint on aquatic life which depletes the nutrients and oxygen in the water bodies and affects aquatic life.

This lignocellulosic material can be converted to high-value biofuel by hydrothermal liquefaction. In this research, the potential feasibility of water hyacinth for its conversion to biofuel production was investigated. Hydrothermal liquefaction of iron impregnated water hyacinth was conducted and the maximum total biofuel obtained was 34.86% with the conversion of 81.3%. GC-MS and 13C-NMR spectroscopy show the presence of value-added chemicals such as alcohols, esters, ketones, and phenols in bio-oils. XPS, TEM, and FESEM-EDX of water hyacinth and residues samples confirmed the presence of Fe nanoparticles.

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