NEIWPCC
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Lowell, MA 01854

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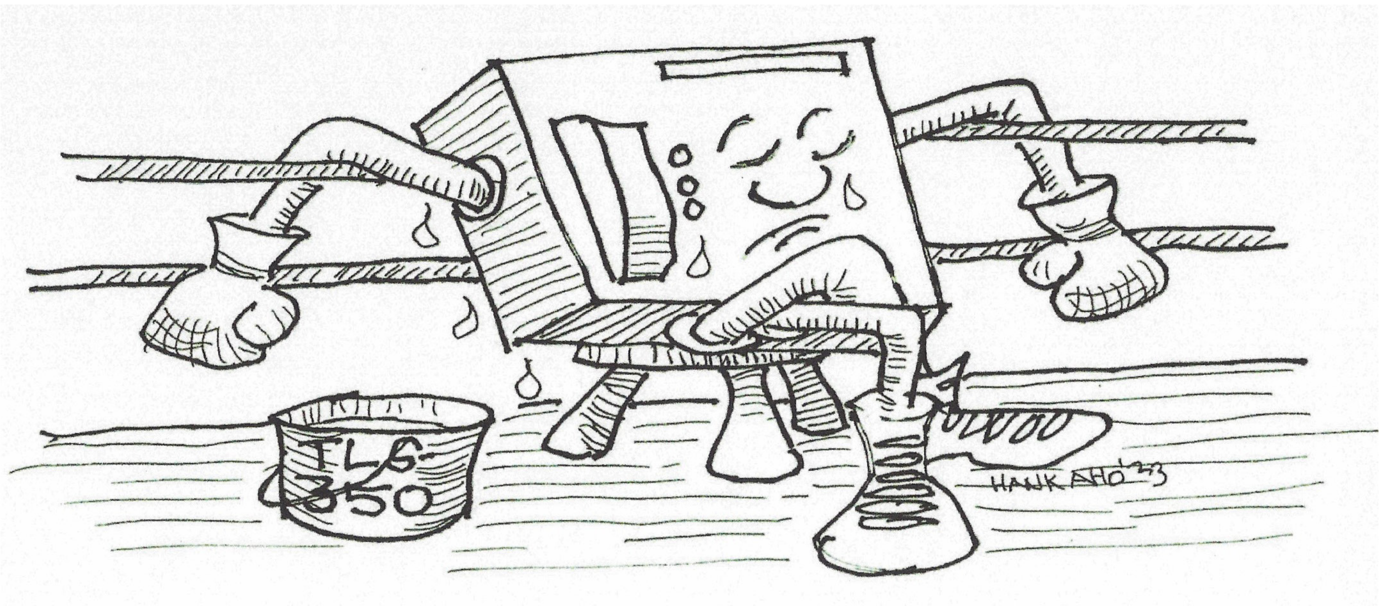
# L.U.S.T.LINE

**A Report on Federal & State Programs to Control Leaking Underground Storage Tanks**

## Requiem for a Heavyweight[1]

By Marcel Moreau




Over a quarter century ago, I wrote an article for LUSTLine entitled "The ABCs of ATGs." (Issue #24, July 1996.) In the article, I told the sad tale of a tank owner who kept running out of super unleaded gasoline prematurely but refused to believe that he had a massive leak in his tank. His automatic tank gauge (ATG) had twice determined that the tank was leaking, but an unhelpful tank technician had solved the problem by removing the offending probe from the tank. Operating on the theory that the fuel was being stolen, the tank owner spent several nights in his closed gas station waiting to catch the thief. He finally locked up the tank and the dispenser and monitored the fuel level with a gauge stick to determine that he was losing fuel. At this point, he had lost 10,000 gallons of fuel from a tank a half mile from the town's water supply.

I expect such scenarios are a good deal less common these days as tank technicians and tank owners have a better understanding and greater confidence in their ATGs. Back then, ATGs were just coming into their own, evolving from being viewed

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as overly expensive gauge sticks to helpful tools in managing a storage system. In this article, I want to recognize the role that ATGs, especially the Veeder Root TLS 350, have played in bringing about the UST world we have today.

## The Way We Were

The last 40 years have seen remarkable changes in fuel marketing[2]. The number of tanks has declined dramatically from upwards of 2 million down to half a million, while annual gasoline consumption has increased from 1.2 billion gallons in 1983 to 1.6 billion gallons in 2022. Obviously, this means that the volume of fuel sold from a typical fuel tank has increased substantially, from an average of 600,000 gallons per year per tank to 3.2 million gallons per year per tank.

As the petroleum marketing industry has evolved, tank gauges have evolved with it. Tank gauges started out nearly 50 years ago as a more convenient way to measure the fuel in an underground tank than a wooden stick. But in that era, accurate inventory recordkeeping was most often deemed too much of a bother and 'taking inventory' most often meant sticking a tank to see whether it might be time to order another load of fuel. It is easy to see why the market for a tank gauge that was hundreds of times more expensive than a wooden stick was a hard sell in those days.

**L.U.S.T.Line**

Lillian Zemba, NEIWPCC Environmental Analyst
Cheyenne Ellis, NEIWPCC Information Officer
Susan Sullivan, NEIWPCC Executive Director
Erin Knighton, U.S. EPA Project Officer

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NEIWPCC
650 Suffolk Street, Suite 410
Lowell, MA 01854
Telephone: (978) 323-7929
lustline@neiwpcc.org
www.neiwpcc.org

## Enter RCRA Subtitle I

The advent of Subtitle I of the Resource Conservation and Recovery Act (RCRA) in 1984 established a national regulatory program for USTs. The rules that followed in 1988 included requirements to reliably detect reasonably small leaks in tanks. This created a new possibility for ATGs: What if tank gauges could also be used for leak detection?

At the time, this was a fairly radical idea because the most common method for detecting small leaks was volumetric tank testing that required special equipment and trained technicians. Most tank tightness tests also required that the storage system be overfilled so that all components of the system (e.g., vent pipes, tank top fittings, and bungs) could be tested. Fire codes also set a standard of being able to detect a leak of 0.05 gallons per hour (gph). For in-tank measurement devices such as a tank gauge, overfilling was not possible and finding leaks of 0.05 gph was a daunting standard to meet.

But the authors of the federal rule saw value in leak detection methods that, although not up to the standards of a tightness test, could be applied routinely by the station operator with little interference with station operations. Plus, there would be no additional cost after the original expense of purchasing the equipment. In 1988, the federal regulations blessed the concept of only testing those portions of the storage system that routinely contained product. The rules also loosened the standard for leak detection to 0.2 gph in exchange for increased frequency of testing.

After the federal rules were published, tank gauge salespeople had another angle besides inventory to promote their product: ATGs that could meet the leak detection standard of the regulations could be sold as a regulatory compliance tool. ATGs provided the only method of leak detection described in the regulations that offered the business benefit of improving the ease and accuracy of inventory management, as well as providing regulatory compliance.

## The TLS-250

At the time of rule publication, the state-of-the-art in ATGs was the Veeder Root Tank Level Sensing (TLS) 250. It could provide inventory information, print reports to document fuel deliveries, and had a 0.2 gph tank test function — but it could not do much else. The probe technology was based on electrical capacitance, which was reasonably good because it had no moving parts, but barely adequate for finding 0.2 gph leaks.

In 1990, another problem appeared for the TLS-250. The Clean Air Act that year mandated the large-scale use of oxygenated fuel (remember MtBE?)[3] in areas of the country with air pollution issues. Oxygenated fuel was initially required for wintertime use in 1992, and then year-round in 1995.

The capacitance probe used by the TLS-250 would not work well in oxygenated fuel.

## Enter the TLS-350

Around 1993, Veeder Root introduced the successor to the TLS-250, the TLS-350. The TLS 350 was designed to work with magnetostrictive probe technology[4], a much more accurate and reliable method of measuring the liquid level than capacitance probes. Additionally, magnetostrictive probes worked equally well in all motor fuels, oxygenated or not.

ATG features soon began to multiply. With the addition of a pressure sensor in the piping, the TLS-350 could perform piping leak detection, in addition to tank leak detection. Now, a single device could automatically meet all of a storage system's monthly leak-detection requirements. The TLS-350 console also had the ability to monitor many types of leak detection sensors that could be located in double wall tanks, piping sumps, under dispenser containment, observation wells, or any other location that needed monitoring. In addition, the TLS-350 had remote communication capabilities. Initially, this was primarily via phone lines, but soon the TLS-350 could be connected to the internet.

For astute businesspeople, the benefits of the TLS-350 became very compelling:

- Leak detection for both tanks and piping could be done automatically and almost painlessly after the initial capital investment.
- Inventory accuracy could be dramatically improved.
- Fuel delivery logistics could be greatly facilitated because a fuel dispatcher could see from her desk exactly how much fuel was in a tank and schedule a delivery accordingly.

After December 23, 1993, the five-year phase-in schedule for leak detection that had been a key part of the 1988 federal regulations was complete. All active storage systems now required leak detection. While there were cheaper options for leak detection compliance, none offered the additional business benefits of an ATG.

The capabilities of the TLS-350 soon expanded to include continuous tank testing, so that a facility did not have to interrupt fuel pumping operations to conduct a tank leak test. The introduction of continuous leak detection meant that scheduling tank tests that might interfere with 24-hour fueling operations was no longer necessary.

ATG capabilities continued to expand. As remote communications became more sophisticated, remote alarm monitoring made it possible to outsource alarm response and associated service calls. Remote communications also made it possible to have recordkeeping services where compliance paperwork for all of a tank owner's facilities could be easily stored in dedicated offsite databases. The store owner's focus could be selling fuel and merchandise, while fuel alarms and regulatory compliance were automatically taken care of.

By the turn of the millennium, the TLS-350 had become the workhorse of the industry and the dominant brand of ATG in the U.S. But the Veeder Root engineers were still not done with the TLS-350.

> With the addition of a pressure sensor in the piping, the TLS-350 could perform piping leak detection, in addition to tank leak detection. Now, a single device could automatically meet all of a storage system's monthly leak-detection requirements.

## Blending Dispensers

As the volume of fuel sold per facility increased, retailers looked for ways to increase storage capacity that did not involve the expense and disruption of installing additional tanks. The sale of three grades of gasoline had been a longstanding tradition since the elimination of leaded gasoline in the 1980s.

Even though sales volume of regular gasoline was many times the volume of middle and premium grades, most facilities had three tanks that were all the same size. This meant that for the mid- and premium-grades the available storage capacity was greatly underutilized. But the thought of selling only two grades by converting a mid- or premium-grade tank to regular-grade fuel was not attractive.

The answer came with the advent of accurate blending dispensers that made it possible to store only regular and premium gasoline, with the mid-grade product blended on demand in the dispenser. The elimination of the mid-grade tank oftentimes allowed a doubling of the storage capacity for regular fuel.

Traditionally, this change to fuel blending would have involved the installation of siphon piping connecting the two regular tanks to equalize the fuel level in each tank. This would have meant breaking concrete and excavating to the tank tops, with significant cost and disturbance.

Then, engineers realized that the tank gauge already could control the submersible pumps as part of the piping leak detection function, and the tank gauge knew the level of fuel in the tanks. With some software changes, it would be possible to have the ATG turn on the pump in the tank with the higher level of regular gas whenever a customer called for fuel. This would keep the tank levels in the two regular tanks more or less equal without the need for a physical piping connection between the tanks. All that would be needed was minimal modification to the piping at the base of the dispenser without the need to break concrete or have any excavation. The creation of this virtual siphon by the tank gauge greatly simplified the conversion of facilities to blending dispensers to maximize the use of existing storage capacity. Today, blending dispensers and virtual siphons are very common features at busy gas stations.

## To Everything There is a Season

In an era where electronic devices are outdated after a few years, the TLS-350 has performed and continues to perform admirably after decades, but there are limits.

### Connectivity

Today, connectivity is a key element of our society and businesses. We want the ability to access and control nearly everything from anywhere. Connectivity allows remote troubleshooting of equipment, remote updating of software, remote management of fuel delivery, remote compliance and recordkeeping, and management of many other aspects of a fuel facility.

But connectivity comes with security concerns. How do we keep prying eyes out of our data? How do we keep bad actors from holding us hostage? While there are techniques we can use today to secure information and devices, these issues hardly even existed when the TLS-350 was created. The TLS-350 has fundamental security vulnerabilities that cannot be addressed within the existing hardware.

### Data Storage

Today's data storage technologies are vastly superior to what was available when the TLS-350 was born. Back then, a megabyte of storage was a huge amount, while today we talk of storage in terms of a terabytes—equal to a million megabytes. While the TLS-350 can hold no more than the last 50 alarms in its history, today's tank gauges can record thousands of alarms in memory, as well as multitudes of fuel deliveries and other events.

### User Interface

The TLS-350 is outdated in other ways as well. A two-row, monochromatic, alphanumeric, 24-character display seems out of the Stone Age when compared to today's colorful touch-screen graphical user interfaces.

## Rest in Peace

So, as of December 31, 2021, the TLS-350 has come to the end of the production line. But with the sheer number of units out there, and the longevity they have displayed over the decades, it will likely be a while before the last operating TLS-350 is laid to rest.

The TLS-350 has played a central role in improving the management of UST systems. While regulatory requirements helped ATGs blossom, ATGs helped tank owners achieve the leak detection and tank management goals of the regulations. It has been a long and mutually beneficial relationship which shows every sign of continuing into the future.

## A Salute

To the engineers who designed and refined the TLS-350, the technicians who installed and serviced them, the salespeople who promoted them, and the tank owners who invested in them: Thanks for a job well done!

## Postscript

I know there are other ATG manufacturers with fine products. I do not mean to slight what other ATG brands have contributed to the evolution of fuel system management, only to honor the passing what we all must acknowledge is a heavyweight in the field.

## Disclaimer

This article is meant to highlight the role that the Veeder Root TLS-350 has played in fuel management and underground storage system regulation over the last several decades. Explicit mention of the Veeder Root TLS-250 and TLS-350 in this article does NOT constitute endorsement of these devices (or any other tank gauge) by the author, NEIWPCC, or the U.S. EPA.

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Marcel Moreau is a nationally recognized petroleum storage specialist and is a regular contributer to LUSTLine. Contact Moreau with ideas or suggestions for future articles at marcel.moreau@juno.com.

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### Endnotes

1 Apologies to Rod Serling.

2 For an overview of these changes, see, "When Winkle Woke Up," LUSTLine #71, September 2012.

3 See "MBTE — If Ye Seek It, Ye May Well Find It...And Then What?" in LUSTLine Bulletin #24, July 1996 for an overview of MBTE issues.

4 See the "ABCs of ATGs" article in LUSTLine Bulletin #26, July 1996, for a description of how this technology works.

# A Message From Mark Barolo

**Acting Director, U.S. EPA's Office of Underground Storage Tanks**

## High Resolution Site Characterization — Coming to a LUST Site Near You?

ITRC's guides for LNAPL (LNAPL-3), petroleum vapor intrusion, advanced site characterization, and fractured bedrock describe high-resolution technologies and sampling approaches in detail.

The LUST community has made tremendous strides in cleaning up releases from UST systems, with more than 500,000 cleanups completed and thousands more completed each year. Due to advances in science and cleanup technologies, we have increased our understanding and our ability to clean up LUST releases. However, we still have nearly 60,000 confirmed releases to address, and more than 4,000 new releases are reported each year. We regularly hear about innovative approaches and emerging technologies to address this backlog of LUST sites. With than in mind, I want to share some recent work EPA completed regarding high-resolution site characterization (HRSC).

There are many types of HRSC for use in a wide variety of contaminants and geologic settings. EPA describes HRSC as strategies and techniques that use scale-appropriate measurements and sample density to define contaminant distributions, and the physical context in which they reside, with greater certainty, supporting faster and more effective site cleanup. In other words, more data is better. We decided to study the applicability of HRSC to LUST sites, focusing on driven probe, direct sensing investigations, which have been the most widely used HRSC techniques used with UST releases.

EPA has been encouraging the use of HRSC at large, complex RCRA and Superfund sites to help focus site investigations and improve cleanups. HRSC techniques identify the contaminant mass in soil and groundwater, including Light Non-Aqueous Phase Liquid (LNAPL). HRSC provides a detailed geologic profile of soil zones that are storing and transmitting contaminants. In contrast, HRSC use at LUST sites has not been widespread. A few states are using HRSC at some of their UST release investigations, but most petroleum UST release sites continue to be assessed using traditional monitoring well investigation techniques. Our study examined the potential utility, benefits, and cost impacts of using HRSC at various types of LUST sites.

### EPA Study of HRSC at LUST Sites

In 2022, EPA worked with its economics consultant, Industrial Economics, Inc., on a study called High Resolution Site Characterization (HRSC) at Petroleum Underground Storage Tank Release Sites – Applicability, Benefits, and Costs. The study goals were to:

- Quantify the costs and benefits of HRSC investigations and their impacts on overall project costs and time at petroleum UST release sites.

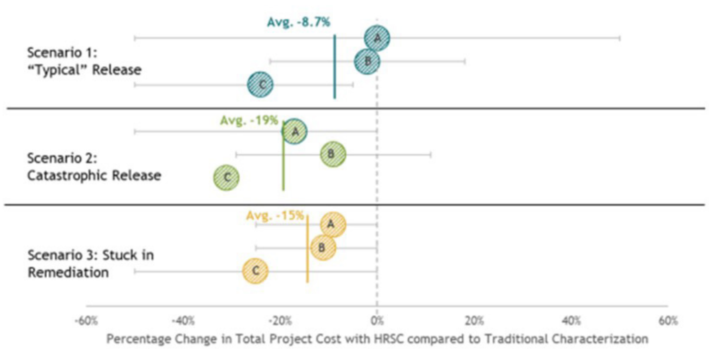
# A Message From Mark Barolo... continued

FIGURE 5. HRSC INVESTIGATION COST ESTIMATES FOR A 3- AND 5-DAY INVESTIGATION (STATE REPRESENTATIVES AND TECH PROVIDERS/CONSULTANTS)


Notes:

1. One respondent did not provide cost estimates for the 3-day investigation. The average reflects the responses provided by the remaining 9 respondents.
2. Responses reflect individual responses. The highest-cost responses for 3- and 5-day investigation were provided by the same respondent.

FIGURE 3. EXPERT INDIVIDUAL AND AVERAGE COST IMPACTS WHEN USING HRSC INVESTIGATION COMPARED TO TRADITIONAL TECHNIQUES ALONE ACROSS THREE PETROLEUM UST RELEASE SCENARIOS




Notes:

1. Stripe-filled markers represent individual expert responses.
2. Brackets represent range of cost impacts that experts believed would encompass nearly all possible project outcomes (e.g., expert A believed costs at a single site when using HRSC could range from +/- 50 percent in total project costs when compared to use of traditional characterization methods). While experts believed site to site costs may vary, they expected the midpoints (i.e., dots) to represent the most frequent outcome and the likely overall cost impact across a portfolio of projects.

- Identify situations where HRSC is likely to provide a benefit in site characterization compared to the use of only traditional, non-HRSC methods at petroleum UST release sites.
- Identify barriers to more widespread use of HRSC.

The study results indicate that in comparison to traditional boring and monitoring well investigations at petroleum UST release sites, HRSC provides the following benefits:

- Provides a more complete understanding of the release site geology and contaminants.
- Increases confidence in corrective action decisions.
- Helps achieve No Further Action sooner.
- Often results in lower project costs by better targeting remedial activities.

### HRSC Can Lower Overall LUST Site Cleanup Costs

Experts interviewed as part of the EPA 2022 study concluded that average costs of HRSC investigations at typical petroleum UST release sites are $36,679 for a 3-day investigation, and $49,550 for a 5-day investigation.

For three common petroleum UST release scenarios, the expert panel concluded HRSC could save on average 9% to 19% in project costs — HRSC would sometimes add 20% to overall project costs on the typical UST release, and on other sites save 40%. On average HRSC would save 9% on overall project costs at typical UST releases. The experts concluded that HRSC would always save costs when investigating catastrophic releases and stalled remediation projects.

### HRSC Can Reduce Cleanup Time at LUST Sites

The experts in the study agreed that HRSC also saves time in the remedial process. Three experts analyzed three UST release scenarios, with and without HRSC and concluded that HRSC can save 3.3 years of a typical 10-year remediation project, 3.7 years off catastrophic release cleanups, which typically take 9 years to complete, and 8.5 years off 33-year timeframe for sites that are not progressing to their cleanup goals.

### HRSC has Widespread Applicability at LUST Sites

States, consultants, and practitioners identified many situations where HRSC was useful in developing the conceptual site model when collecting additional information was necessary. The study participants evaluated 15 different LUST site scenarios. All scenarios had at least one person support HRSC use and there was near unanimous support for using HRSC in eight of the 15 scenarios.

## Barriers to HRSC Use at LUST Sites

Despite potential benefits, barriers to HRSC use at LUST sites remain. In the study, experts identified a couple of technical barriers.

## A Message From Mark Barolo... continued

### HRSC Use Case Scenarios in EPA Study

1. When determining what level to place monitoring well screens and select screen lengths in sites with soil layers that have highly contrasting permeability.*
2. Where a large release has occurred into complex layered soils and the pathways of travel are uncertain.*
3. When contemplating an active remedy that will cost more than $100,000. Better targeting of the source area and understanding its relationship to the hydrogeology can save costs in an active remediation.*
4. Where there are sensitive receptors nearby and the extent and potential movement of contaminants need to be determined with certainty and speed.*
5. Where a large release has occurred, and it is important to identify the extent of LNAPL and the elevated dissolved phase plume, or its direction of movement, quickly.*
6. Where LNAPL presence in monitoring wells or movement is not explained by the current CSM or is inconsistent with the groundwater gradient.*
7. Before conducting a third round of monitoring well investigation to define the extent of the LNAPL source area of elevated dissolved phase plume.*
8. Where one or more monitoring wells show persistent or recurring levels of contaminants of concern in excess of target cleanup goals.*
9. When there is a need to differentiate between new and old releases.
10. Where one or more monitoring wells show persistent or recurring levels of LNAPL that is not explained by the Conceptual Site Model (CSM).
11. When contemplating a MNA or NSZD remedial strategy, but the CSM does not adequately quantify the volume of LNAPL or define the groundwater flow pathways.
12. Where a remediation method has failed, and a new remedial approach is being contemplated.
13. Where active remediation has been conducted for over 10 years.
14. When chemicals, absorbents, or nutrients will be injected into the ground.
15. When there is a need to present the CSM graphically to the public, stakeholders, or litigants, showing the relationship between groundwater elevations, the source area(s), soil layers, migration pathways, and the extant contaminated groundwater.

** Scenarios with near unanimous support for using HRSC.*

There was widespread recognition that HRSC would not be used at sites where there were no significant data gaps – such as a "straightforward" UST closure where only limited contamination was identified and cleaned up during the excavation work. Also, uncooperative consolidated geology is a fundamental barrier to the use of direct sensing HRSC tools.

Beyond those two technical barriers, administrative and economic barriers remain that prevent wider HRSC use and application. LUST site practitioners and experts identified a number of barriers to wider use of HRSC to investigate UST releases, but there was little agreement on which barriers were most important. HRSC practitioners rated the lack of state fund reimbursement schedules for HRSC as a reason for not using HRSC, while state regulators pointed to the providers not proposing HRSC investigations as a significant barrier. Other barriers included the lack of guidance on when to use HRSC on petroleum UST release sites and on how to incorporate HRSC data into corrective action decisions. Some barriers seem to be "chicken or egg" situations. Overcoming these barriers to reap the many benefits of HRSC at LUST sites will require creativity and collective effort.

### Conclusion

The results of our HRSC study can help inform site owners and other stakeholders on the best use cases for HRSC in site cleanups, including where

> Data generated by the HRSC approach is often more detailed and comprehensive than traditional monitoring well investigations can yield, which allows for the creation of more complete conceptual site models (CSM), clearer communication with the stakeholders, more informed remediation decisions, quicker site closures, lower overall remediation costs, and ultimately, better protection of human health and the environment.

## A Message From Mark Barolo... continued

it is most cost effective, and where it may inform selection of effective remediation techniques. This study points to an opportunity to improve environmental protection and to save time and money by expanding HRSC use at petroleum UST release sites. We are going to work with our partners to spread the word about the benefits of HRSC at LUST sites. In addition, we plan to develop guidance for use of HRSC at federal-lead LUST cleanups in Indian Country.

Below you will find an article from our state partners in Michigan regarding use of HRSC at a LUST cleanup site. Have you also used HRSC in your state or at your LUST site? If so, I ask you to share your experiences with others. In particular, you may wish to contact EPA staff in your region, or Alex Wardle or Tom Schruben at our headquarters office.

# Case Study From Michigan

On January 7, 2016, a contractor identified red sulfur diesel beneath the sump of a dispenser. It was estimated that 5,000 gallons of red sulfur diesel was released as the result of a leak in the primary fuel line that then filled the secondary lines which then leaked at multiple locations from the tank dispensers. While conducting emergency response activities a second release was discovered on January 19, 2016.

Because of the volume of product released and a concern with potential for Non-Aqueous Phase Liquids (NAPL) to migrate beneath the building or off-site, excavation activities were conducted from January 7-27, 2016. Soil was removed from around the dispensers and the canopy, creating a sump which allowed recovery of liquids through the use of vac trucks. In total, 40 temporary monitoring wells were installed to delineate mobile NAPL and to guide excavation activities, 2,386 tons of soil were excavated, and 42,504 gallons of liquids were removed.

A Laser Induced Fluorescence (LIF) investigation was conducted March 28-30, 2016. Stock Drilling provided geoprobe services and the Ultra-Violet Optical Screening Tool (UVOST). The objective of the investigation was to collect information on depth, thickness, product type, and location of NAPL. Thirty-eight LIF borings were advanced with log standards supporting that the product released was diesel and that NAPL was generally located between 4.0′ and 6.0′ below ground surface (bgs).

Through the investigation, a previously unknown location of NAPL was identified and discovered to have migrated to the property boundary. Following delineation activities, additional material was excavated from the area and liquids were recovered by vac truck.

Use of LIF at an approximate cost of $10,570 led to:

- Identification of a previously unknown impact.
- Successful mitigation of off-site migration.
- Acquisition of information that assisted in the design and implementation of a remediation system.

Following the removal of source material and the mapping of the NAPL body, an air sparge/soil vapor (AS/SVE) extraction system was designed and mobilized to the site to reach cleanup objectives. The system was installed between March and June 2016. Utilizing information from the March LIF event, 41 sparge points were completed to a depth of 17.5′ to 18.5′ bgs and two SVE lines were installed. Equipment operated 12 hours per day, seven days a week from June 6, 2016, through March 3, 2017.

A closure report was received by the Michigan Department of Environment, Great Lakes and Energy on February 26, 2019, and closure was granted on March 21, 2019. In total $590,384 in reimbursement was requested from the Michigan Underground Storage Tank Authority (MUSTA); after the $10,000 deductible, $580,384 in reimbursement was provided.

In Michigan we currently do not have any guidance or standard operating procedures for when high resolution site characterization (HRSC) should be performed. With it being recognized as a potentially valuable technology, the State Fund (MUSTA) provides reimbursement for this activity as long as it is considered a reasonable and necessary corrective action to secure restricted closure of the covered release and as long as our bidding requirements are followed. The Alpena EZ Mart Project is a good example of how HRSC used with existing practices can help direct cleanup activities, manage cleanup costs, and expedite the closure timeline.

Alpena EZ Mart
2222 US Highway 23, Alpena, MI 49707
Facility #: 00018989
Confirmed Releases: REL-0004-16, REL-0006-16

# Implementing High-Resolution Site Characterization in South Carolina's UST Management Program

By Matt Wykel

## The Foundation


The UST Division of the South Carolina Department of Health and Environmental Control (SCDHEC) was first introduced to high-resolution site characterization (HRSC) through suggestions made by South Carolina certified UST contractors. This technology was seen as a potential tool to aid in the delineation of UST releases. Additionally, HRSC reports were reviewed by SCDHEC's non-permitted petroleum section, highlighting the benefits of HRSC in accurately identifying and delineating petroleum contamination in the subsurface. Recognizing the potential value of HRSC in improving site assessments, the UST Division embarked on pilot studies for HRSC in 2018. These studies aimed to explore the technology and compare it to traditional assessment methods, test the limitations of HRSC, and ultimately develop reimbursable rates for HRSC work within the UST program. Throughout the three case studies, the UST Division collaborated with two state certified contractors and three HRSC firms, providing an opportunity to observe the variations in HRSC capabilities at petroleum releases across the state. Figure 1 outlines the structure of the three case studies:

| | Contract #1 | Contract #2 | Contract #3 |
|---|---|---|---|
| SC Certified Contractor | Contractor A | Contractor B | Contractor B |
| HRSC Sub-Contractor | HRSC Contractor 1 | HRSC Contractor 1 & 2 | HRSC Contractor 3 |
| Technologies Utilized | MiHpt, LIF, OIP | MiHpt, LIF | MIP, OIP |
| Number of Sites | 13 | 13 | 9 |

*Figure 1.*

## Pilot Study 1 – A Brief Case Study

The primary objective of the first pilot study was to compare HRSC to traditional investigative methods. One notable facility from this study is UST Permit #19190, situated in the Piedmont region of South Carolina. In 2012, a single release was reported at this facility, however information regarding the status and total number of USTs remained unknown.

A Sanborn map revealed the presence of a dry-cleaning facility adjacent to permit #19190. Laser induced fluorescence (LIF) and a membrane interface probe (MIP) were the primary HRSC tools used at this site. The LIF and MIP points were compared to diesel range organics (DRO) and gasoline range organics (GRO) soil borings. Figure 2 shows one of the potential benefits of using HRSC.

Figure 2 represents LIF, MIP, DRO and GRO, and groundwater samples overlayed together. The DRO and GRO soil samples were often collected near, but not right at the highest concentration interval of the borings. MIP and LIF can be used to determine the exact depths and locations of the highest concentration areas more accurately.

Before HRSC was employed at the facility, assessment reports indicated that LNAPL extended north of the site and across the street on an adjacent property. LIF was implemented to assess the LNAPL plume and find the migration pathways that the product could be traveling through. Figure 2 shows the three-dimensional LIF model developed by the HRSC firm. The resulting data shows that the product observed to the north and across the street from the facility could potentially be attributed to a nearby historical dry-cleaning release. This was determined because LIF has the capability to distinguish between different types of products based off the wavelength the product fluoresces. The wavelengths on the offsite property were comparable to Stoddard solvent The blue represents the boundaries of the gasoline free-

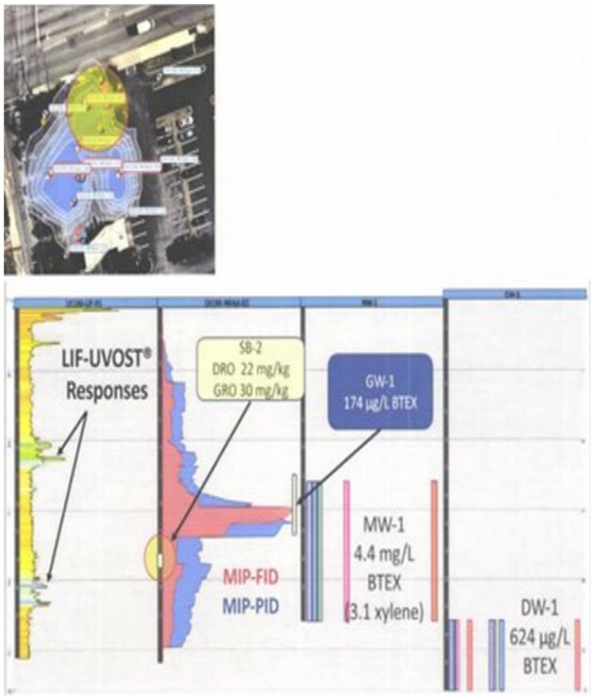



Figure 2a.

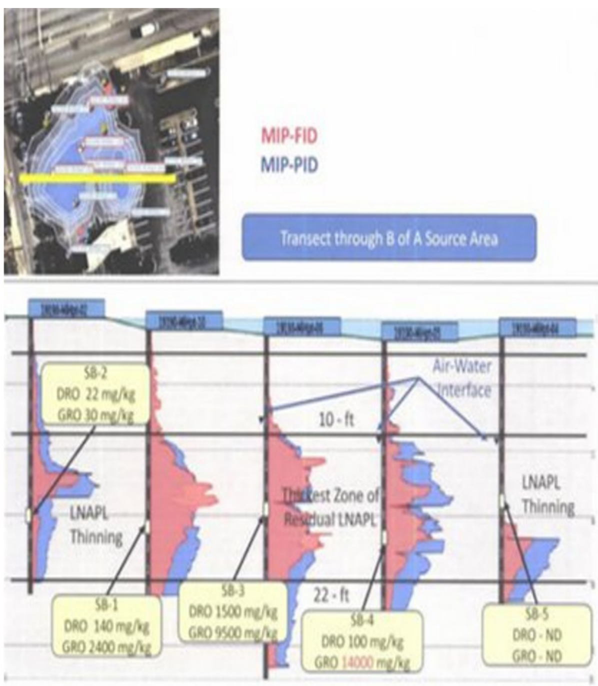



Figure 2b.

constituents while the onsite wavelengths were comparable to gasoline and motor oil range constituents.

The limitations of HRSC on this facility were access issues, utilities, shallow boring refusal, and downtime the contractors had due to equipment troubleshooting. The lessons learned include that LIF is able to distinguish between solvent and gasoline products, and that HRSC could fill in data gaps that traditional soil borings might miss. In identifying the solvent product, the UST Division was able to eliminate the use of state funds in cleaning up that specific release and apply focus to the gasoline release only.

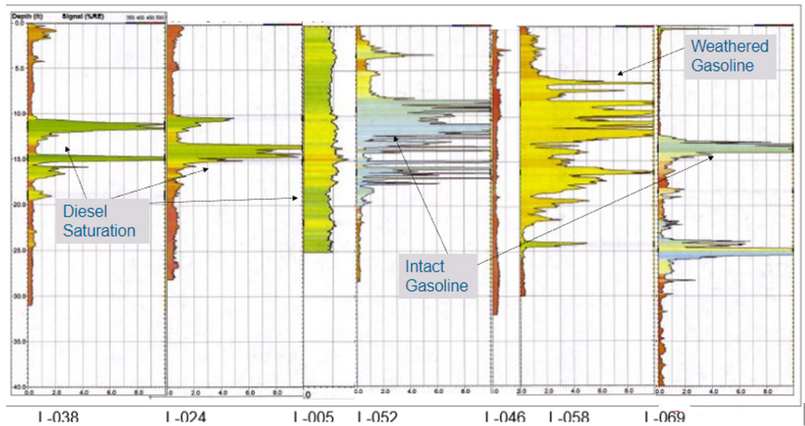



Figure 3a.

## Pilot Study 2 - A Brief Case Study

One notable facility from pilot study two was UST Permit #02698. This facility had two reported releases, a gasoline release reported in 1989 and a diesel release reported in 2001. The site had 13′ of LNAPL spanning across 10 monitoring wells on site. The releases had already been through an unsuccessful cleanup attempt. Use of HRSC on this site was seen as a great and necessary opportunity to fully define the LNAPL plume so that a future cleanup project will be more successful. LIF was the primary tool used to fully define the LNAPL plume (see figures 3A and 3B).

Figure 3a illustrates the capabilities of LIF to distinguish between different types and ages of petroleum products. The HRSC contractor was able to characterize the type of product found in each of the borings and the condition that the product was in (weathered or not weathered). Figure 3b shows a map of the product boundaries as depicted by LIF.

Figure 3b.

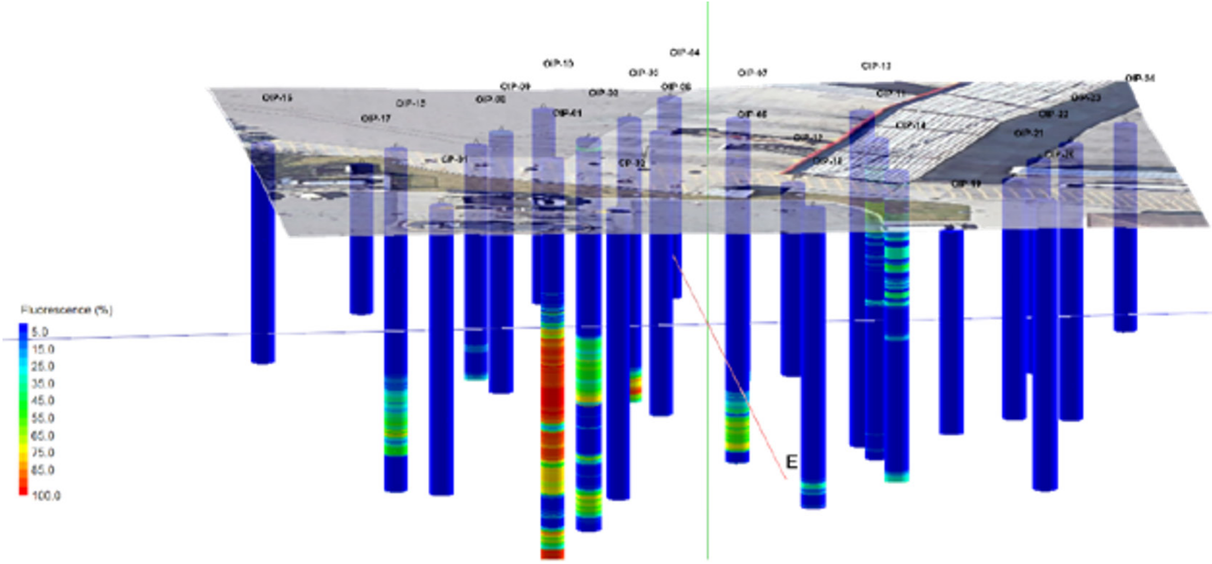



*Figure 4.*

The blue represents the boundaries of the gasoline free-phase plume and the green represents the diesel free-phase plume. HRSC at this site provided a better three-dimensional stratigraphic and LNPAL distribution maps. This new data will allow for a more successful and targeted corrective action that may use different technologies depending on the diesel and gasoline plumes.

The limitations of HRSC at this site were the following: uneven terrain that made it difficult to move the equipment, refusal encountered in some of the boreholes, time-consuming malfunctions of the equipment, and an inability to recover electrical conductivity (EC) data.

## Pilot Study 3 – A Brief Case Study

Pilot study three was implemented to delineate additional releases and to establish fair and reasonable state reimbursable rates for HRSC work. This contract used a combination of MIP and an optical image profiler (OIP). A notable site for pilot study three was UST permit #14688. This facility had one confirmed release reported in 2009. LNAPL was found in 12 wells that spanned about a 3,600 square foot area. Figure 4 shows the three-dimensional figure generated for the facility at the end of the HRSC. The OIP at this facility was able to delineate the FPP plume well.

This facility had numerous issues and limitations. Due to probe refusal, OIP points had to be pre-drilled to 5 feet and the deep MIP points proposed were deemed impractical because the subsurface conditions made it difficult to use direct push drilling technology. Due to equipment malfunctions, the hydraulic profiling tool (HPT) was only successful on four boring locations and the EC data was unable to be recovered. At the time of this study, OIP technology was not able to distinguish between different types of products and only showed percent fluorescence.

## Conclusion

The first and second pilot studies were paid based on a flat daily rate. The contractors initially estimated they would be able to drill about 250 feet per day, however the data collected at the end of the first two contracts revealed an average of about 150 feet drilled per day. Because of this, the third pilot contract was based on a unit rate structure where contractors were paid by foot and deliverables. This ensures that the UST Division is compensating its contractors for work completed. The UST Division's rate schedule can be found at https://scdhec/gov/environment/land-management/underground-storage-tanks-release-assessment-clean-superb-funding-1.

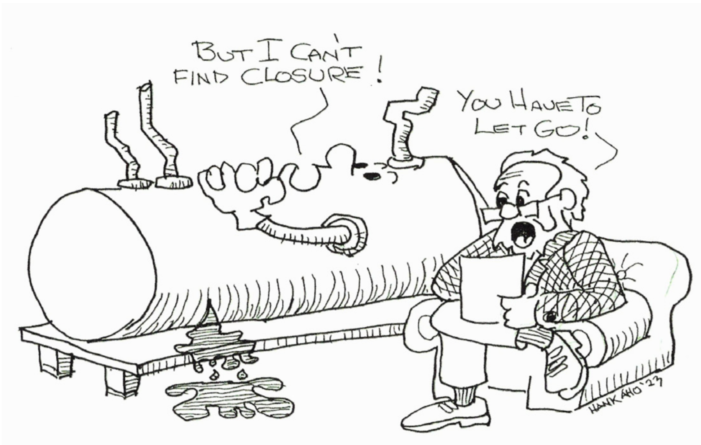
HRSC tooling is often combined with HPT. This is a wonderful resource for determining estimated hydraulic conductivities and for identifying preferential flow pathways. This becomes important for the assessment of a site and to know where remedial designs need to target. EC is another tool that is often used and can be very helpful in determining differing lithology in the surface such as clay lenses and sand stringers, which can affect a plume's migration.

Overall, HRSC has proved to be an invaluable resource for delineating appropriate sites for the UST Division, especially regarding source area delineation.

Matt Wykel is a hydrogeologist III with the South Carolina Department of Health and Environmental Control. He can be reached at wykeljm@sdhec.gov.

# Into the MStC — Developing a New Standard for Moving Petroleum Release Sites to Closure

By Tom Schruben




UST cleanup programs have made remarkable progress over the last 34 years and our mission is as crucial now as it was in 1989. We have completed more than 512,000 UST cleanups and have learned a lot in the process. Keeping our drinking water safe is a primary concern. About half of our active UST facilities and ongoing cleanups are in source water protection areas. Further, an estimated 400,000 private water wells are located within 1,500 feet of an UST release. An additional concern is preventing petroleum vapors from entering confined spaces and indoor air.

Approximately 58,000 known cleanups remain in our program backlog. New, and newly discovered releases will eventually be found at some of the 192,000 operating UST facilities, particularly as these facilities close or replace their USTs. While most newly discovered UST releases are addressed and resolved promptly, a percentage are likely to pose technical and administrative challenges. It is going to take our best collective efforts for the cleanup programs to keep up with the workload.

## Early Days

When considering a change, I like to look back at where we have been and what we have learned. I first got into petroleum UST cleanups in the 1980's.

> The question before us today is — Can we make changes in the cleanup process to improve protection of human health and the environment and at the same time provide a clear and consistent pathway to get cleanups completed and closed?

Back then, the prevailing conceptual model of contaminant spread assumed that:

- Contaminants are released and spread underground following the groundwater and will eventually reach drinking water wells and surface water bodies.
- As contaminants move with the groundwater they spread out through dispersion and dilution.

In the early days of the UST program, some regulators tried to apply a single standard for what concentration of petroleum in the ground posed a threat, but we quickly realized that every release site is different. A small release in some settings could cause a lot of problems while large releases at other sites would not harm human health and the environment. It became apparent that we needed cleanup goals that were tailored to the specific circumstances of each site.

Starting in the 1990s, the program employed simple conceptual models that considered the relationships between sources, pathways, and receptors. We developed back calculation models to determine how much source had to be removed to keep exposures to an acceptable level at the receptor well or body of water assuming dispersion and dilution of the petroleum. This approach was called risk-based corrective action (RBCA) or risk-based decision making.

Some states adopted this approach for setting target cleanup goals, and it has proved very successful over the years. However, we knew that the risk-based approach was conservative because it did not consider biodegradation. In practice, at most sites we found that instead of dilute concentrations reaching exposure points once the risk-based cleanup targets were met, no measurable petroleum concentrations reached the exposure points.

## Technical Leaps Forward — LNPAL and the Conceptual Model

Over the years, with lots of experience cleaning up petroleum UST releases and in-depth studies of large petroleum releases, we developed a much more sophisticated understanding of how petroleum releases behave underground. Several years ago, leading experts in petroleum contamination convened and updated a guide under the Interstate Technology & Regulatory Council called "Light Non Aqueous Phase Liquid (LNAPL) Site Management: LCSM Evolution, Decision Process and Remedial Technologies, LNAPL 3" or the LNAPL Update,

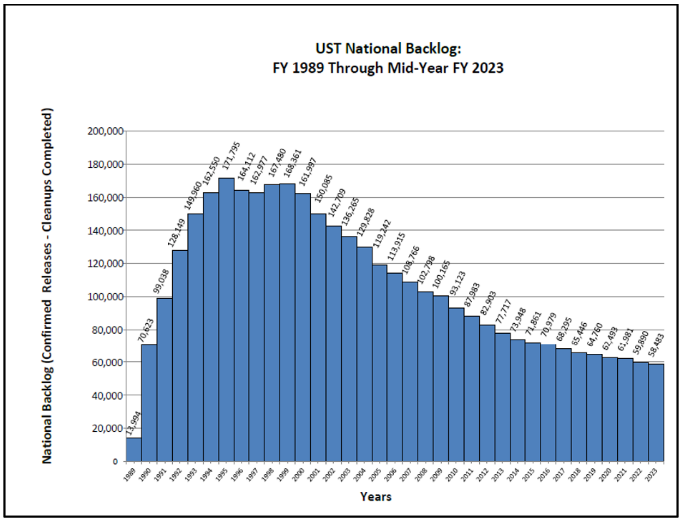



*Figure 1. National UST Corrective Action Backlog.*

available at https://lnapl-3.itrcweb.org/. This is an excellent guide on how petroleum behaves underground and provides new ways to approach releases.

Building on the source-pathway-receptor framework from the 1990s, as shown in Figure 2, we have learned that biodegradation occurs throughout the LNAPL, soil, and dissolved plume and begins soon after the petroleum is released into the ground. While the interior of the plume is generally starved of oxygen (anaerobic), petroleum is still degrading. The evolution of the contamination can be divided into three stages:

**Stage 1.** When the release first occurs, the LNAPL moves through the ground and the plume expands. It reaches a limit of horizontal movement relatively quickly. The rising and falling groundwater may spread it vertically over the first few seasons, but the footprint is set relatively quickly.

**Stage 2.** The dissolved plume also becomes stable, and the plume will reach its maximum length, and spread no further (Connor, et. al.[1] found that the benzene extended less than 425 feet in 90% of gasoline plumes). This is very different than we often see with chlorinated solvents where the plume can extend over much longer distances.

**Stage 3.** Over time, the contaminants will degrade, reducing the amount of petroleum in the ground and shrinking the footprint of the plume. This phenomenon is often referred to as natural attenuation or natural source-zone depletion.

We have also learned that over time, the remaining LNAPL will get trapped in the soil, becoming residual, and at many sites with measurable amounts of petroleum in monitoring wells, hydraulic recovery methods have limited effectiveness in removing the LNAPL.

The ITRC LNAPL-3 conceptual site model demonstrates that we can include the concept of LNAPL and plume stability when making decisions to resolve and close sites. LNAPL can be migrating (spreading laterally), mobile (able to spread up and down and accumulate in monitotring wells), or residual (trapped in the soil matrix). The key focus of assessment and corrective actions should be to understand whether LNAPL is migrating; decide whether utilized groundwater is affected by a release; and verify that no petroleum vapor intrusion is occurring or probable.

It takes specific data for each site to develop a conceptual model and to determine what needs to be done. The threat posed by a release at a particular site depends on the circumstances of the release, receptors, ground structure, and groundwater movement. If the release poses a threat, or if we cannot be certain that there is no threat, implementing agencies typically require corrective action to remove the source, break the pathway, or eliminate the exposure point.

## Moving into the MStC

The LUST program (federal, state, tribal, and local) has come a long way, but we've got a lot of work ahead of us to turn our improved understanding of LUST sites into an actionable strategy for moving sites to closure (MStC). A task group of 73 members from all petroleum cleanup sectors is working to reimagine the corrective action process to safely move remediation projects to closure. We are developing MStC as a standard guide under the American Society for Testing and Materials (ASTM)

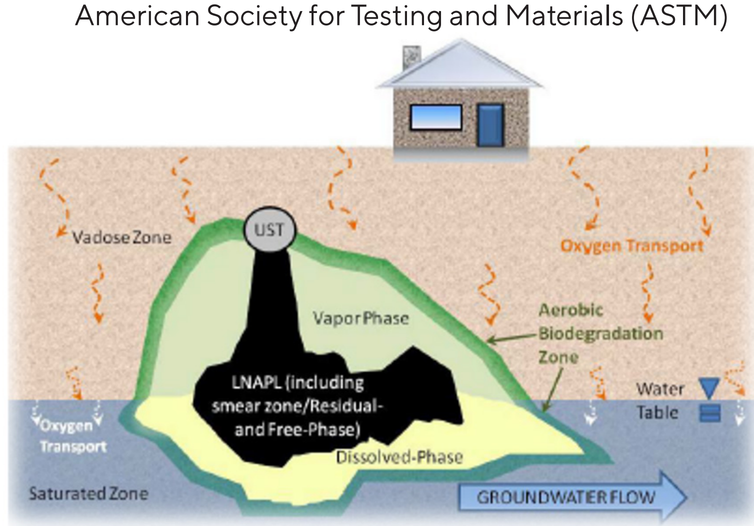



*Figure 2. From: "Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites" EPA 510-R-15-001 (2015).*

1 "Review of Quantitative Surveys of the Length and Stability of MTBE, TBA, and Benzene Plumes in Groundwater at UST Sites", Connor, et. al, Vol. 53, No. 2– Groundwater–March-April 2015.

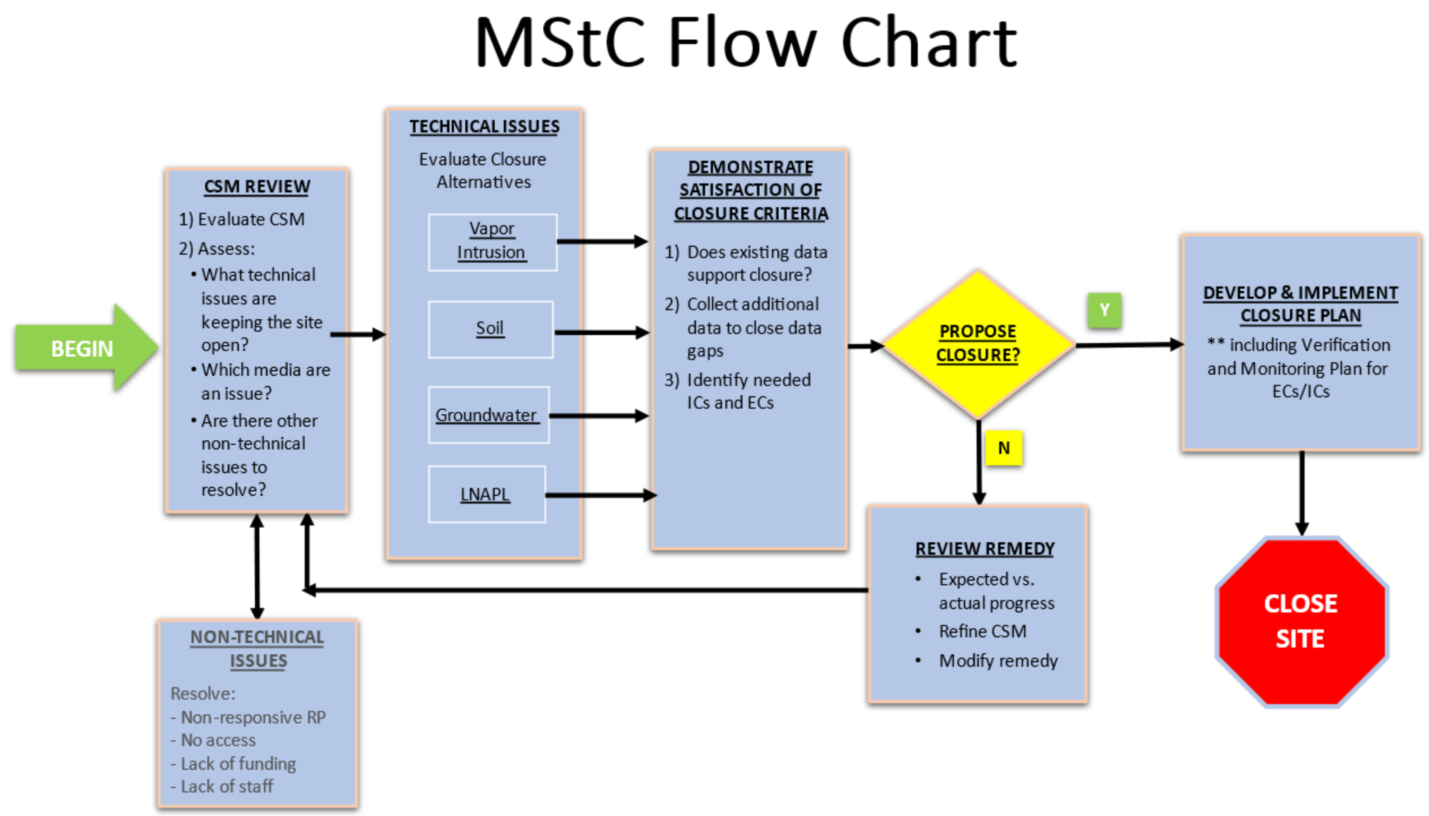



*Figure 3. Draft MStC process.*

process because it encourages consensus and full consideration of dissenting comments. ASTM hosted the development of the RBCA standard 30 years ago; however, this standard is different from RBCA in that we are developing alternative strategies for moving cleanups to closure as opposed to developing initial target cleanup goals. In addition, this standard does not presume the initial cleanup goals were developed using RBCA. We have been meeting for a year and have made significant progress toward a complete draft standard that can be balloted. Our plan is for the MStC guide to provide a decision framework for closing petroleum UST remediation projects based on the latest science and our decades of program experience.

As currently drafted, the MStC process, shown in Figure 3, begins with an evaluation of the conceptual site model and an assessment of what is keeping the corrective action from closing — whether it is a technical issue (e.g., high concentrations of contaminants in a monitoring well), or a nontechnical issue (e.g., getting site access for sampling).

The standard then divides the technical closure issues into four categories: LNAPL, groundwater, soil, and vapor. For each of these categories, the standard describes alternative criteria that could be used to demonstrate that the site is no longer a threat. The standard provides several alternative closure criteria so that the user has flexibility to choose one that best fits their site and available data. For each alternative closure criteria, the standard describes the data needed to demonstrate the criteria and the remaining uncertainties.

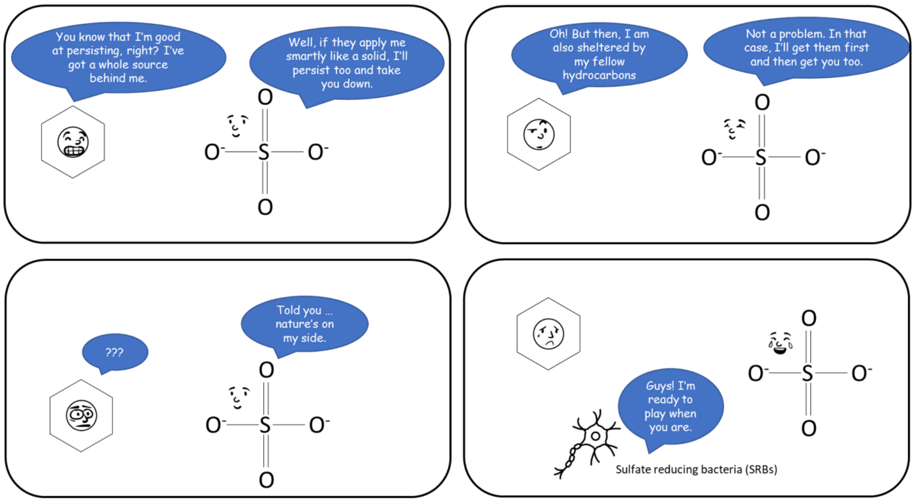
If the user decides to propose closure, the standard describes how to present the proposal and the closure plan. If the user decides not to propose closure, the standard describes how to review remedial progress, refine the conceptual site model, and modify the remedy or the remedial goals to get on a pathway to closure.

We plan to include examples in the appendices of the standard that provide examples of how the standard could be applied to various petroleum UST release scenarios. The appendices will also include background on the science that supports the various closure criteria included in the standard. The task group has made considerable progress, but we still have a lot of writing ahead of us and getting a complete standard through ASTM's ballot process will take significant effort. If you are interested in participating in the task group, send me an email at Schruben.Thomas@epa.gov.

Tom Schruben has been invovled with underground storage tanks for most of his career and helped write the original Federal UST regulations in the late 1980s. He initiated the ASTM Risk Based Corrective Action Task Group in the early 1990s and returned to the US EPA Office of Underground Storage Tanks (OUST) as a physical scientist in 2021.

# Sulfate Delivery Methods to Accelerate BTEX Biodegradation and Expedite Site Closure

By Kammy Sra, Ravi Kolhatkar, Daniel Segal (Chevron Technical Center), and John Wilson (Scissortail Environmental)




*A cartoon illustrating benzene's "sizing up" of sulfate. Sulfate highlights the nature-based process of sulfate reduction, longer persistence when applied as a solid salt, and ability to overcome limitations of typical conditions encountered in petroleum hydrocarbon biodegradation to enhance biodegradation of target contaminants such as benzene.*

## Why Add Sulfate to Impacted Subsurface?

Natural biodegradation of petroleum hydrocarbons is a useful mechanism to reduce concentration and destroy mass of petroleum hydrocarbons in the subsurface. Natural biodegradation begins through metabolism of petroleum hydrocarbons using electron acceptors that are naturally occurring such as oxygen, nitrate, iron III, or sulfate. When these electron acceptors are depleted, petroleum hydrocarbon biodegradation continues to proceed through fermentation reactions that ultimately produce methane. These reactions can be very slow, particularly for benzene biodegradation. Depletion of electron acceptors is common at UST sites, and the slower rates of biodegradation result in persistent high concentrations of benzene, toluene, ethylbenzene, and xylenes (BTEX) in groundwater and persistent source zones of NAPL hydrocarbons in the subsurface. Under these conditions, it is beneficial to overcome these limitations by providing a desirable electron acceptor using an appropriate subsurface delivery method. Of all the naturally occurring electron acceptors, sulfate stands out as the most desirable. It can be applied in large quantities as a solid salt like gypsum, providing a source of sulfate in solution in groundwater that is persistent over time. It can be applied to reach higher target concentrations, which can treat higher concentrations of contaminants in the impacted groundwater.

Sulfate does not adversely affect the flow paths needed to deliver the electron acceptor to the contaminated portions of the aquifer. It does not promote biofouling and the reaction products have a small volume. Sulfate-reducing conditions are ubiquitous in the presence of petroleum hydrocarbons, and sulfate is often a depleted electron acceptor, which underlines its active participation in petroleum hydrocarbons biodegradation processes. A comparative summary of natural electron acceptors is provided in Table 1.

Addition of sulfate to groundwater has been shown to increase the rate of biodegradation of hydrocarbons, including BTEX, enabling cost-effective site clean-up and helping to expedite site closure (Kolhatkar and Schnobrich, 2017; Wei et al., 2018; Buscheck et al. 2019; Sra et al., 2022a).

| Reaction | Electron Acceptor (Reactant) | Maximum Concentration in Water (mg/L) | Benzene Consumed (mg/L) | Notes / Likely Issues |
|---|---|---|---|---|
| Aerobic oxidation | $O_2$ | 9 | 3.0 | • Limited solubility.<br>• Numerous other oxygen sinks.<br>• Potential aquifer clogging.<br>• Biofouling near injection point. |
| Nitrate reduction | $NO_3^-$ | 45 | 9.5 | • Drinking water concern.<br>• Primary MCL 10 mg/L $NO_3^-$-N (45 mg/L $NO_3^-$).<br>• Expensive. |
| Sulfate reduction | $SO_4^{2-}$ | 250 | 55 | • Hydrogen sulfide is the product, but rarely an issue due to precipitation with iron in soil or sediment.<br>• Secondary MCL for sulfate – 250 mg/L.<br>• Much cheaper than nitrate. |

*Table 1: Summary of Soluble Electron Acceptor Advantages and Concerns (adapted from Cunningham et al., 2001; Sra et al. 2022b).*

### When is Sulfate Addition Most Suitable?

- Sustained concentrations of petroleum hydrocarbons in groundwater that prevent achieving groundwater cleanup objectives and/or site closure and depleted sulfate concentration in plume / source zone compared to background.
- Absence of measurable LNAPL in the monitoring well(s) within the target area for sulfate addition at a site. Target areas at a site with residual LNAPL (i.e., without measurable LNAPL in a monitoring well) can be considered for sulfate addition.

### Key Benefits of Appropriate Site Application

Addition of sulfate in petroleum hydrocarbon-impacted subsurface where sulfate is depleted in groundwater:

- Provides a cost-effective and sustainable alternative to mechanical remediation, oxygen release-based biodegradation (e.g., use of oxygen release compounds, ORC) and in-situ chemical oxidation (ISCO). Sulfate addition enhances biodegradation of petroleum hydrocarbons and can address the more depleted portions of the source area (fringes of the source), thereby reducing the area/volume requiring active remedial alternatives such as excavation (Kolhatkar and Schnobrich, 2017
- Can reduce time to closure (and enable cost savings in reduced long-term groundwater monitoring costs). At sites with high benzene concentrations (e.g., >1,000 µg/L) considered indicative of residual LNAPL source, a decrease in benzene concentration will likely be observed after concentrations of other hydrocarbons have decreased following sulfate application.

### Chevron Experience With Sulfate to Promote Enhanced Biological Degradation

As of 2023, Chevron has performed sulfate delivery at nine sites including one former terminal site, four former retail sites, one former chemical storage facility, two former refinery sites, and one operating refinery. Evaluation and/or remedial action is underway at four more sites (two oil field sites and two refinery sites).

For wells at these sites, long term monitoring data were analyzed to calculate attenuation rate constants for benzene before sulfate addition (kMNA for conditions of "monitored natural attenuation" or MNA) and after sulfate addition (kSEA for conditions of "sulfate-enhanced attenuation" or SEA). The rate constants were estimated as the slopes of a linear regression of the natural logarithm of benzene concentration on the date of sampling. Example data from two wells are presented in Figure 1.

In the well depicted in Panel A of Figure 1, the addition of gypsum increased the attenuation rate constant for benzene from 0.55 per year to 1.6 per year. Starting at 10,000 µg/L benzene in 2006, it took 4.2 years to get to 1,000 µg/L and would take

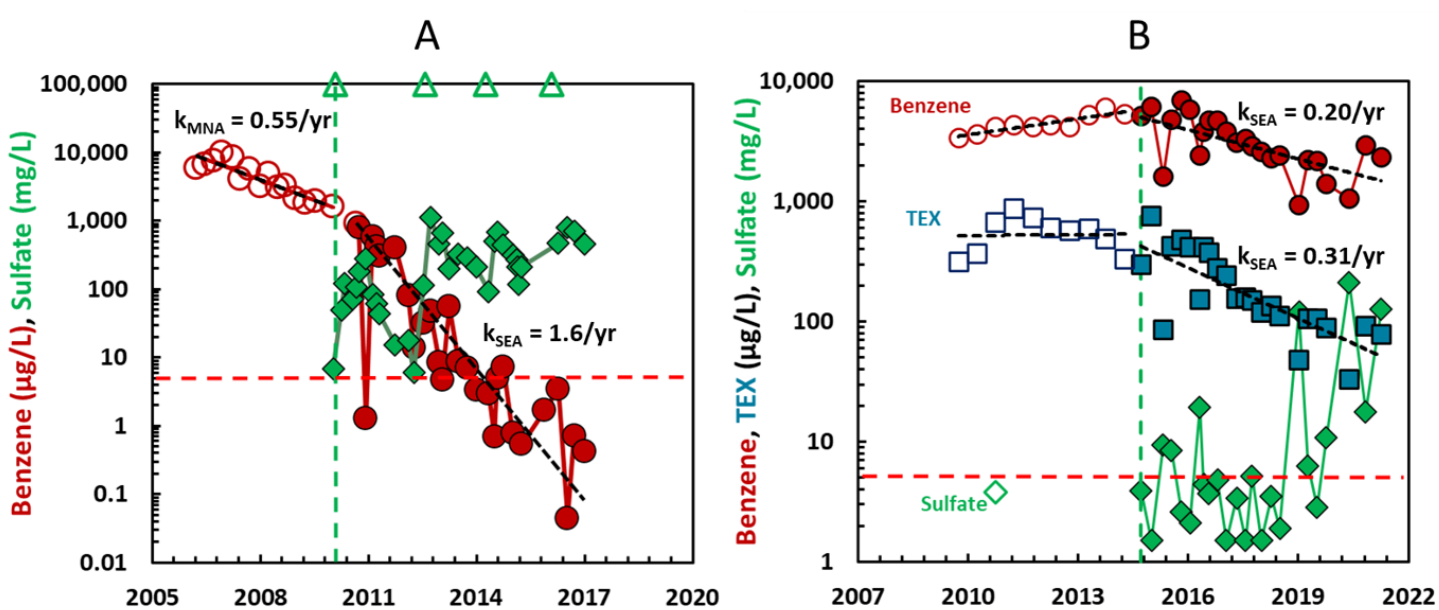



*Figure 1. Example data from wells at two sites that were amended with sulfate. The open green triangles in Panel A identify dates for the four separate applications of gypsum. The filled green diamonds are concentrations of sulfate. The open red circles are concentrations of benzene before significant concentrations of sulfate accumulated in the groundwater. The filled red circles are data after appreciable sulfate accumulated in the groundwater. The dotted black lines are fitted regression lines. The horizontal dotted red line is the MCL for benzene of 5 µg/L. The vertical dashed green line is the time of the first addition of sulfate.*

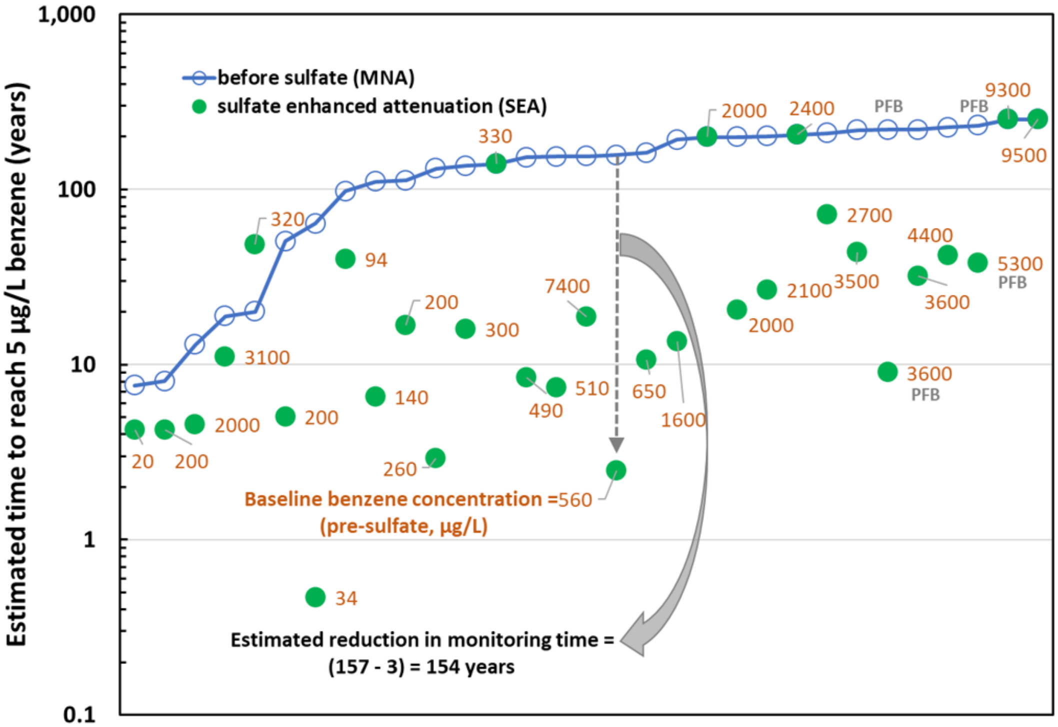



*Figure 2. Comparison of estimated time for benzene to reach assumed regulatory threshold of 5 µg/L based on concentration vs. time trends for MNA (before sulfate addition; open blue circles) and sulfate-enhanced attenuation (after sulfate addition; solid green circles). The values in orange next to the solid green circles are the baseline benzene concentrations (prior to sulfate addition). The two wells treated by permeable filled borings are identified as PFB.*

another 10 years to reach the MCL of 5 µg/L under conditions of MNA, attaining the goal by 2020. Starting at 1,000 µg/L in 2011, it took 3.3 years to the MCL under conditions of sulfate-enhanced attenuation, attaining the goal by 2015.

In the wells depicted in Panel B of Figure 1, the initial concentration of benzene was very high (5,500 µg/L). Prior to the addition of sulfate, there was no evidence for attenuation of benzene or the TEX compounds (toluene, ethylbenzene, and xylenes). Even though the concentration of benzene was high, the addition of sulfate resulted in a substantial rate constant for attenuation of benzene and an even more substantial rate constant for the attenuation of the TEX compounds.

Figure 2 summarizes data from 31 wells at the nine sites subjected to sulfate addition using gypsum land application (29 wells) and permeable filled borings (two wells). In many of the wells prior to sulfate addition and for a few of the wells after the addition of sulfate, there was an increasing trend in benzene concentrations, or the attenuation rate constant was essentially the same as zero. In these cases, we arbitrarily assigned a low, non-zero value to kMNA or kSEA (0.03 per year), to allow us to estimate a lower boundary on the time required to reach the MCL for benzene. Many of the wells in Figure 2 with > 100 years of cleanup time fall in this category. The pre-sulfate benzene concentrations range from 20 to 9,500 µg/L with 16 wells having pre-sulfate benzene concentrations > 1,000 µg/L considered indicative of residual LNAPL conditions.

The gray dashed arrow and solid gray arrow in Figure 2 illustrate the significant decrease in the timeframe to reach the MCL for one particular well. The timeframe decreased from an estimated 157 years to three years marking a change of 154 years. Overall, sulfate addition at sites depleted with sulfate significantly improved timeframe to cleanup from a median of 150 years (for MNA) to 15 years (for sulfate-enhanced attenuation through sulfate addition).

At these monitoring wells the gypsum land application and permeable-filled borings resulted in sustained sulfate breakthrough, induced sulfate-reducing conditions, and enhanced degradation of BTEX. Petroleum hydrocarbon degradation through sulfate reduction was also monitored through CSIA of 13C and 2H in benzene, 34S in SO42- and 13C in DIC in groundwater which had been depleted in sulfate prior to sulfate addition.

Based on the experience and results from these sites, sulfate addition to impacted subsurface with depleted sulfate has significantly enhanced the rate of BTEX biodegradation and improved site outcomes (e.g., optimize excavation footprint, expedite site closure).

## What Sulfate Delivery Method is Suitable for My Site?

Table 2 presents a summary of different sulfate delivery strategies that are recommended, with the corresponding preferred site conditions. Recommended strategies include land application, permeable filled borings, permeable trench, and excavation backfill.

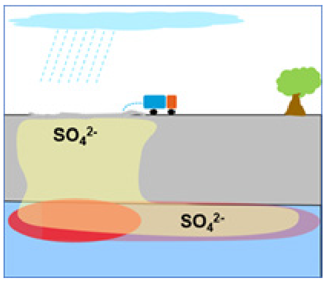
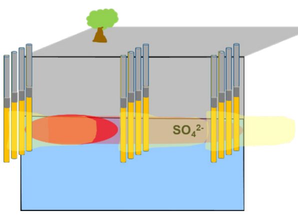
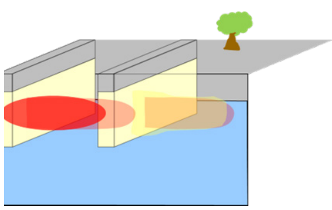
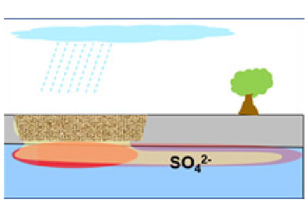
Note that injection or placement of sulfate slurry (or solution) into wells has been shown to be ineffective and is not recommended. This recommendation is based on lower mass loading for liquid injections compared to solid application, limited radius of influence, lower persistence and possible density-driven effects.

*Table 2. Site Conditions to Choose an Appropriate Sulfate Delivery Method*

| Sulfate Delivery Method | Preferable Site Conditions | Advantages | Limitations |
|---|---|---|---|
| Land application | • Open, unpaved land surface free of obstruction.<br>• Permeable geological materials .<br>• Shallow depth to groundwater (up to 15 ft. bgs).<br>• Significant natural precipitation (or easy access to source of irrigation water). | • Potential benefit to entire plume footprint and vadose zone impacts.[1]<br>• Simplicity of application and reapplication (surface broadcasting, no drilling required).<br>• Groundwater fluctuations do not impact delivery method. | • Uncertainty about sulfate breakthrough to groundwater.<br>• Possibility of sulfate consumption or retention in vadose zone.<br>• Additional irrigation required if natural precipitation is insufficient. |
| Permeable filled borings (PFB) (gypsum and gravel) | • Primarily saturated zone hydrocarbon impacts.<br>• Surface access for drilling.<br>• Well-defined groundwater flow velocity and direction. | • Effective sulfate delivery to groundwater.<br>• Provides sustained source of sulfate (longevity >5 years).<br>• Can respond to fluctuating groundwater table.<br>• Can treat deeper impacts and beneath confining layers. | • Requires multiple soil borings for PFB due to limited radius of influence.<br>• Reapplication at same PFB location not feasible. |
| Permeable trench (gypsum and gravel) | • Permeable geological materials.<br>• Land free of obstruction.<br>• Shallow depth to groundwater (up to 15 ft. bgs). | • Effective sulfate delivery to groundwater.<br>• High longevity (> 5 years).<br>• Can respond to fluctuating groundwater table.<br>• Continuous sulfate curtain upgradient and/or within source and plume area. | • Trenching required.<br>• Reapplication within the same trench not feasible.<br>• Limited to shallower groundwater-related impacts. |
| Excavation backfill | • Excavated sites where residual impacts around and beneath the excavation still remain.<br>• Intersecting groundwater, significant natural precipitation or easy access to source of irrigation water. | • Provides sustained source of sulfate (longevity > 5 years).<br>• Easy to apply during excavation activities.<br>• Potential benefit to groundwater plume and possibly to vadose zone impacts that may remain below the excavation. | • Feasible only at sites undergoing some degree of excavation.<br>• Application limited to the practical depth of excavation.<br>• Emplaced sulfate may not intersect groundwater, depending upon depth of excavation and groundwater depth. |

1 Land application delivery method can address PHC impacts related to shallow unsaturated soils (Sra et al., 2022a).

*Table 3. Summary Guidance on Implementation of Sulfate Delivery Methods*

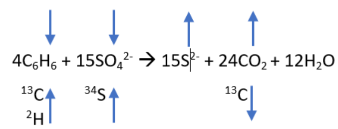
| Sulfate Delivery Method | Key Considerations |
|---|---|
| Land Application<br>(granular agricultural gypsum)<br> | 1. Select the land application footprint around the appropriate monitoring wells.<br>2. Broadcast agricultural gypsum3 on the land surface at the rate between 0.6 to 1.2 lb./ft2 (track mounted spreader or fertilizer broadcaster).<br>3. Till the top 4 to 6 inches of soil to mix in gypsum.<br>4. Create a 4 to 6 inches high berm with soil or haybales (to minimize surface run-off to areas outside the target area).<br>5. If possible, time the land application when ground is already wet (during snow melt) to enable gypsum to dissolve naturally (without artificial irrigation). If artificial irrigation is needed, estimate irrigation volume based on monthly maximum precipitation intensity. |
| Permeable Filled Borings<br>(granular agricultural gypsum-gravel)<br> | 1. Can be placed upgradient of source, as well as to intersect the dissolved plume.<br>2. Drill borings at the closest spacing and the largest diameter feasible.<br>3. Pour 1:1 mix ratio of granular agricultural gypsum and gravel (proppant) into the soil borings. (Note: Consider using a proppant with a similar density/particle size as gypsum, such as rhyolite or pea gravel, that can help prevent material segregation in borehole).<br>4. Cap with two feet of bentonite and cement to ground surface. |
| Permeable Trench<br>(granular agricultural gypsum-gravel)<br> | 1. Can be placed upgradient of source, and/or to intersect the dissolved plume.<br>2. Advance a trench up to the depth of groundwater impacts. The length of the trench will be determined by width of the source area or plume and other site constraints.<br>3. Place 1:1 mix ratio of granular agricultural gypsum and gravel (proppant). Mixture would be placed up to the depth of shallowest groundwater depth to account for water table fluctuations. (Note: Using a proppant with a similar density as gypsum, such as rhyolite, can help prevent material segregation).<br>4. Cap with approximately two feet of bentonite and cement to ground surface. |
| Excavation Backfill<br>(granular ag gypsum)<br> | 1. Add agricultural gypsum (one percent w/w of the excavation backfill). This quantity could be uniformly mixed with the backfill or placed as a layer at the bottom of the excavation.<br>2. Dissolution and transport of sulfate could be achieved by infiltration, intersecting groundwater, or through artificial irrigation. |

## Implementation of Sulfate Delivery Methods

While overlaps exist in the possible site settings and benefits of the sulfate delivery methods, each method also has some unique features that need to be considered during the design, implementation, and monitoring phases. Table 3 presents guidance on implementation for these methods.

## Monitoring and Analytical Plan

Monitoring is an important element prior to designing the remedy and for assessing performance over time. It should be conducted considering the expected changes that will likely occur in the target analyte(s) (e.g., benzene, sulfate) in accordance with the redox stoichiometric equation. The arrows indicate the direction of change for concentrations and isotopic shifts.




For concentration shifts, a down arrow means concentration of the identified constituent is expected to decrease and an up arrow means concentration is expected to increase as reaction proceeds. For isotopic shift, a down arrow means the constituent is expected to be depleted in the heavier isotope and an up arrow means it is expected to be enriched in the heavier isotope as reaction proceeds.

Table 4 provides example analytical data that can be used for pre-baseline monitoring (to determine if sulfate addition is suitable), baseline monitoring before applying sulfate, and post-delivery performance monitoring. Bromide salt (e.g., CaBr2) is sometimes added along with gypsum to use bromide as a conservative tracer to track infiltration and delivery of applied salts. In addition, it is recommended to collect 34S in SO42- data for the gypsum used as a source of sulfate. This can be done by adding a small quantity of gypsum salt into a sample jar filled with distilled water and submitting the resulting water sample for 34S in SO42- analysis.

The primary line of evidence would be a (log-linear) concentration-time series plot such as Figure 1. Compare the trends before and after sulfate addition.

*Table 4. Sample Analytical Plan*

| Analytes | Example Method | Preliminary Assessment | Baseline | Performance Monitoring | Expectations |
|---|---|---|---|---|---|
| Bromide, Nitrate, Sulfate | EPA 300.0/ 9056A | X | X | X | Sulfate concentration is depleted at baseline and increases upon sulfate addition. Bromide used for breakthrough assessment. Nitrate for general geochemistry. |
| Iron | SW-846 6010B/ 6020 | X | X | | Iron II concentration may decrease after sulfate addition as precipitation with sulfide occurs. |
| Dissolved Inorganic Carbon (DIC) | 5310C | X | X | X | DIC may increase upon sulfate addition but is generally expected to be buffered. |
| Methane | RSK-175 | X | X | X | Helps assess methanogenesis at baseline and change in methane concentration following sulfate addition. |
| Sulfide | EPA 9034 | | X | X | Sulfide is stoichiometrically expected to increase after sulfate addition but is precipitated out with iron. Therefore, it is expected to be low or non-detect. |
| $^{34}S$ in $SO_4^{2-}$ | Specialty Isotope Lab | | X | X | Signature is enriched after sulfate addition compared to source sulfate signature. |

| Analytes | Example Method | Preliminary Assessment | Baseline | Performance Monitoring | Expectations |
|---|---|---|---|---|---|
| $^{13}C$ in DIC | Specialty Isotope Lab | | X | X | Signature is depleted compared to baseline condition as mineralization of petroleum hydrocarbons occurs. |
| BTEX/TPH | EPA 8260/8015 | X | X | X | Petroleum hydrocarbon concentrations are expected to trend downwards after sulfate addition. |
| $^{2}H$ in Benzene and/or $^{13}C$ in Benzene | Specialty Isotope Lab | | X | X | Signature is expected to be enriched following sulfate addition compared to baseline or control. 2H-benzene is usually more responsive than 13C-benzene. |

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# Get to Know ASTSWMO: An Interview With Gina Miranda

By Evan Bartow and Daphne Short

Gina Miranda (she/they) is an emerging young professional in the world of underground storage tanks (UST). Having graduated in 2020 with a degree in public health from the University of Rhode Island, they are now the project manager on the tanks subcommittee with the Association of State and Territorial Solid Waste Management Officials (ASTSWMO).

Founded in 1974, ASTSWMO focuses on enhancing and promoting effective State and Territorial programs to affect relevant national policies for waste and materials management, environmentally sustainable practices, and environmental restoration. Through technical assistance, workgroups, trainings, and forums, ASTSWMO fosters information exchange through all 50 States, 5 Territories, and the District of Columbia.

**Q:** Could you tell us about yourself, your background, and the work you do?

**A:** I'm from Rhode Island and come from a Cape Verdean family, which are islands off the west coast of Africa. I'm also a first-generation American. I studied public health at the University of Rhode Island and had an internship with the University of Michigan focusing on environmental public health, which sparked my interest in the field.

After graduating in May 2020, I took a job at my university and later moved to D.C. to explore environmental public health opportunities. There, I found my current role as the Program Manager for the tanks subcommittee within a ASTSWMO. I manage communications, projects, information sharing, and act as a point of contact for members, the board of directors, and the EPA Office of Underground Storage Tanks. I enjoy the people and culture of the organization, as well as being a problem solver and applying my public health knowledge to the tanks world. The challenges and importance of the work keep me motivated as an environmental public health advocate.

**Q:** Can you provide more details about your role and what you enjoy the most?

**A:** As the Program Manager for the tanks subcommittee, I oversee four task forces with a total of 42 volunteer members, one from each EPA region. I manage communications, ongoing and new projects, information sharing, and coordinate with the board of directors, members, and the EPA Office of Underground Storage Tanks. I enjoy the people I work with and the dedication and passion they bring to their work. The culture and environment are inspiring. I also enjoy being a problem solver and finding ways to apply my public health knowledge to the tanks world. The challenges that arise in this role make it fulfilling, and the overall importance of the work we do as environmental public health advocates keeps me motivated.

**Q:** If you could sum up your work experience so far, how would you describe it?

**A:** It's complex issues and multifaceted solutions. I love being a problem solver, so it's right up my alley.

NEIWPCC
650 Suffolk Street, Suite
410 Lowell, MA 01854

## Interview With Gina Miranda (continued)

**Q:** What advice would you give to someone interested in joining the industry or learning more about it?

**A:** Ask every single question you have and be proactive in seeking information. Watch videos, read articles, and take advantage of training opportunities. If possible, go on site visits to gain a deeper understanding. Dive into the industry because it's always changing, and the more you immerse yourself, the more you'll learn.

**Q:** What would you like to see as a future focus for the tank subcommittees?

**A:** I believe it would be beneficial to focus on engaging and encouraging the younger workforce to get involved in environmental public health, specifically within tanks. As the industry faces potential labor and workforce challenges with retiring professionals, it's important to attract and retain younger generations to keep the industry thriving. Promoting the industry through platforms like LinkedIn and exploring innovative approaches can help attract and involve younger professionals in the tanks world.

More information about ASTSWMO can be found on their website https://astswmo.org/.

*Daphne Short and Evan Bartow served as Youth in the Environment program coordinators in summer 2023.*

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To learn how to become a contributer, please contact Lillian Zemba (lzemba@neiwpcc.org).