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L.U.S.T.LINE

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

The Man Behind the Cartoons: Meet Hank Aho, L.U.S.T.Line's Cartoonist Extraordinaire

By Cheyenne Ellis

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Figure 1. Hank Aho posing with his license plate at his home in Maine.

For more than 30 years, LUSTLine has been dotted with cartoons poking fun at the complexities and intricacies of the world of underground storage tanks. From artistic renderings of tank workers grappling with on-the-job struggles to personifications of tanks reacting to the changing industry, LUSTLine cartoonist Hank Aho's work has brought a recognizable and humorous flair to an otherwise dense and technical publication.

"Hank has an uncanny ability to personify the most unperson-like things using nothing more than pen, ink, and paper," said Marcel Moreau, a petroleum storage specialist who has known Aho and his work for decades.

For Aho, drawing has always been second nature. "If I look back at any of my old school papers, they are all embellished with a variety of doodles," he said.

By the time he enrolled at the University of Maine at Orono, Aho had decided to major in biology but made a point of supplementing his scientific studies with a number of art classes. After graduating, he embarked on a 37-year career with the Maine Department of Environmental Protection (DEP), where he held a variety of roles focused on remediating hazardous waste.

A Career in Hazardous Waste Mitigation

Figure 2. A tanks worker scratches his head in a room full of hazardous materials (featured in Issue #21).

Aho got his start in 1974 as a member of Maine's Oil Spill Response Team out of the Portland field office.

The team was made up entirely of workers like himself who were new to the field. In this role, Aho monitored tankers that were moored in Casco Bay, while aboard a modified Webber's Cove lobster boat. The state assembled a group of responders to locate and clean up oil spills along the state's navigable surface waters.

"At the time, Maine felt that one of the biggest threats to the environment was surface oil spilled from tankers," said Aho.

L.U.S.T.Line

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NEIWPCC is a regional commission that helps the states of the Northeast preserve and advance water quality. We engage and convene water quality professionals and other interested parties from New England and New York to collaborate on water, wastewater, and environmental science challenges across shared regions, ecosystems, and areas of expertise.

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Figure 3. An abandoned gas station tank, which is covered in duct tape bandages, sheds tears (featured in Issue #87).

In addition, Aho and his team inspected tankers and oil-separators for compliance and manned the state's oil spill response phone line, which required one of the six staff members to be on call 24/7.

One of Aho's first marine surface water spills occurred late at night along Little Diamond Island in the bay. He responded to a call about a strong petroleum-like odor and immediately set off to investigate.

Armed only with flashlights, coveralls, and boots, Aho and another officer navigated their boat to the island and carefully scrambled over the rocks, barnacles, and seaweed piled along the shore. They immediately detected an odor and, upon surveying the water, spotted oil floating on top of the surface.

Though they could not see the full extent of the spill in the darkness, Aho and his colleague were concerned enough to request the activation of the oil response contractor, a costly procedure which involved the deployment of specialized tools and personnel. This proved to be the correct decision as the daylight soon revealed the significance of the spill.

But Aho soon found that not all cleanup efforts would be as straightforward. "One thing I learned in this field is that the cure is sometimes just as bad as the disease," he said.

He witnessed this firsthand when he was called out to Little John Island in the bay to examine a slick of heavy black oil that had gotten stranded on the island's seaward side. The scene was messy, with oil coating the nearby rocks, seaweed, and tidal pools. Soon after, a contractor arrived and surrounded the spill with a floating boom to help contain and slow the spread of oil. But this alone was not enough. The contractor also recommended stripping the affected area of all vegetation and power-washing the island's rocks.

"What was left of the island's impacted area afterwards was pretty much just bare rock, devoid of any vegetation," he said.

Aho also witnessed firsthand the impacts of leaking underground storage tanks when he investigated a site in Readfield, which had reported a strong gasoline odor. He evaluated the water supply at a convenience store and examined a surface water well located in the basement. Under the lid, he discovered a layer of gasoline floating on top of the water. He then entered a nearby building's fieldstone cellar to assess the magnitude of the leak and discovered gasoline coating the entire floor.

"I quickly notified the people in the building and asked them to turn off the furnace and power, before calling the fire department," said Aho. "I was quite concerned that this could become a dangerous situation before it could be stabilized." The source of the leak turned out to be a small crack in the 3,000-gallon UST, which had to be pumped and removed.

In 1979, Aho transferred to DEP's Augusta office, where he was in charge of the DEP's Oil Spill Research Program. One of his projects was to create a map of

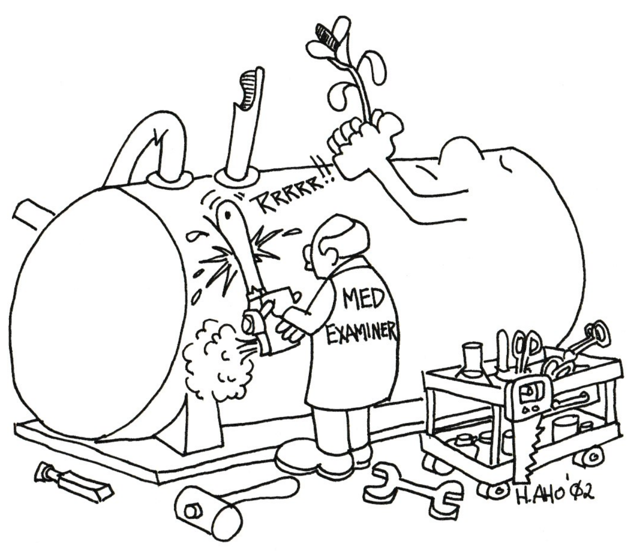

Figure 4. A tank lies on an autopsy table holding a flower, while a medical examiner cuts into it with a saw (featured in Issue #41).

Figure 5. Two tanks workers stand outside of a hazardous area site looking at a map (featured in Issue #93).

Casco Bay that identified vulnerable areas, such as clam flats, that could be at risk from oil spills. Other projects included the disposal of oil-soaked debris and researched the effects of dispersants used in clean-up efforts on marine intertidal zones.

Following the passage of the Comprehensive Environmental Response, Compensation, and Liability Act (commonly known as the Superfund Act, or CERCLA) in 1980, Aho managed and organized Maine's new Uncontrolled Hazardous Substances Sites Program, which addressed threats to human health and the environment posed by abandoned hazardous substance contaminated sites. His responsibilities included overseeing a team of project managers and hiring contractors to remediate contaminated sites.

One of the sites he worked on was the Eastern Surplus Superfund on the banks of Meddybemps, which consisted of more than three acres of land near Meddybemps Lake and the Dennys River. The land was originally operated by the Eastern Surplus Company, who sold army surplus and salvage items. When it closed in the early 1980s, many artifacts were left behind, along with large amounts of contaminated soil and groundwater.

"The site was like a potpourri of hazardous waste," said Aho. "The path we walked along during our initial inspection wound around drums of chemicals, small tanks, transformers, containers of calcium carbide, an old torpedo, and 5-gallon buckets of paints and other solvents."

The EPA began the process of removing above-ground objects, excavating and disposing of contaminated soil and sediment, and remediating groundwater supplies. Though much progress has been made, these efforts are still continuing today.

Before his retirement in 2009, Aho found a way to integrate his passion for art into his career. Throughout his time with DEP, Aho doodled constantly in the margins of his notes and submitted an occasional cartoon to the department's newsletter. When his long-time colleague David McCaskill heard from Moreau that LUSTLine was looking for an illustrator, he immediately thought of Aho.

"I brought this challenge up to Hank, and he agreed to take it on," said McCaskill, who worked as a senior environmental engineer before retiring after 38 years with DEP. "What he did not know was how often I was going to walk up to his floor and pester him about the illustrations for my LUSTLine articles over the years."

Joining Team LUSTLINE

Figure 6. A cartoon of former editor Ellen Frye honoring her accomplishments in LUSTLine's 30-year anniversary special (Issue #79).

NEIWPCC began publishing LUSTLine in 1985 to communicate with state regulatory agencies across the country. Editor Ellen Frye, who worked on the publication until her retirement in 2020, found illustrations and humor to be unexpectedly helpful tools in conveying complex topics to the audience.

"It was truly a miracle to meet up with a cartoonist who actually understands the quirky world of regulators and petroleum storage systems," wrote Frye in Issue #50 of LUSTLine. "There is nothing like a Hank cartoon to get us in the right frame of mind to crank out a new issue."

For Aho, working on LUSTLine has been the perfect way for him to combine both his technical and artistic skills. He has now worked on more than 75 issues and has created hundreds of cartoons to accompany submitted articles.

"My objective is to provide drawings that support the article, add a little humor, and perhaps, act as a hook to get the reader interested in the piece," said Aho.

Throughout his time illustrating for LUSTLine, he has frequently created humanized underground storage tanks. From abandoned USTs shedding tears (Figure 3) to an angry tank ripping apart oil pipelines (Figure 7), Aho finds unique ways to bring the inanimate storage containers to life.

Moreau wrote a piece in Issue #41 that described the process of looking for answers as to why USTs ended up leaking. In return, Aho created a cartoon of a tank undergoing an autopsy (Figure 4).

In Issue #94, Aho created a cartoon based on the past, present, and future of the tanks program (Figure 8). "He illustrated the history of the tanks program from birth to maturity," said Moreau. "Who else could have pulled this off so charmingly?"

While Aho excels in bringing to life unexpected components of the UST world, he is also successful at capturing the personalities of tanks workers and adding humor tailored to those who work in the field. In Issue #84, he created a cartoon of a frustrated tanks worker who has become fed up with the number of alarm messages produced by an automatic tank gauge (Figure 10).

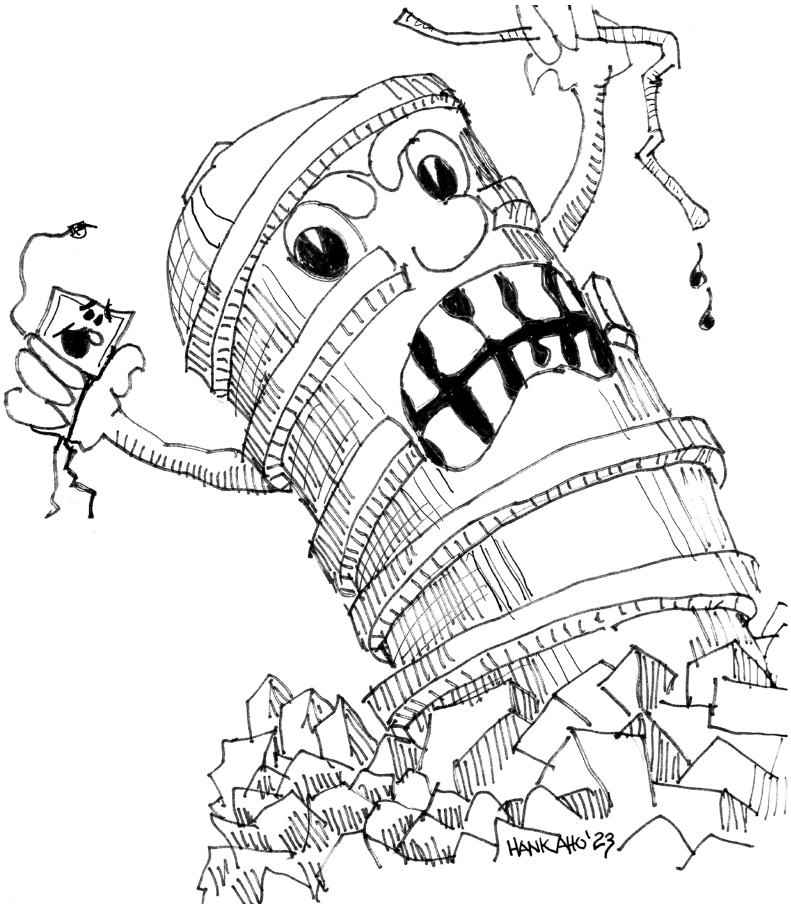

Figure 7. An angry-looking tank ripping apart an oil pipeline (featured in Issue #92).

"My characters are like my family," said Aho. "I recognize them as my own unique style."

One of Aho's favorite pieces is from the second issue that he worked on. In it, he created a cartoon reenacting a well-known episode of "I Love Lucy" where Lucy and Ethel take on a new job at a sweets factory (Figure 9). As the confections begin coming down the conveyer belt at an increasing speed, the quality of Lucy's work decreases until she can no longer keep up. The article's author uses this scene — and Hank's recreation of it — to explain how tanks workers can feel when the number of leaking underground storage tanks in their area pile up.

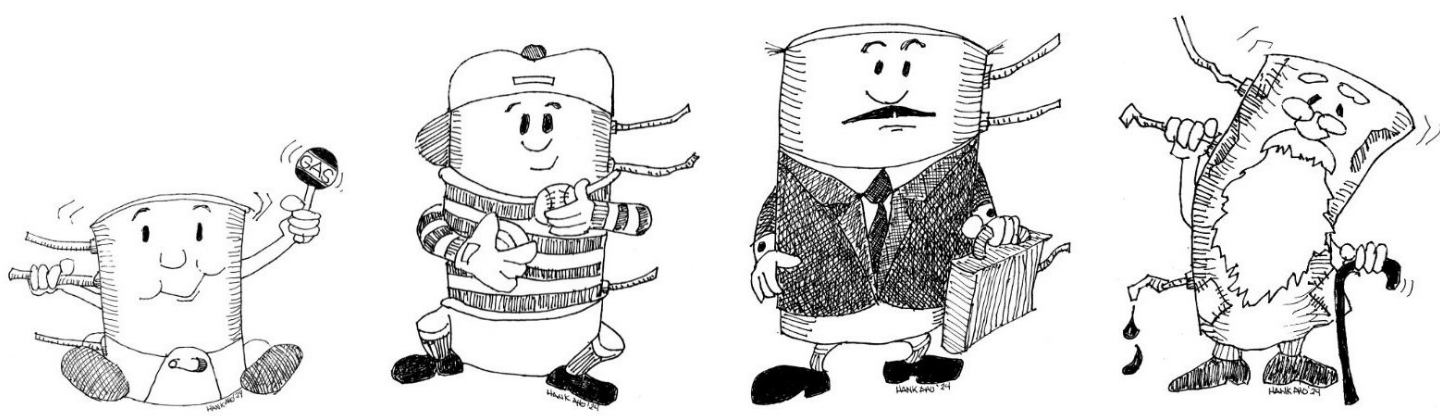

Figure 8. A collage of aging tanks, beginning with a baby tank waving a rattle labelled "gas," to an elderly tank using a cane (featured in Issue #94).

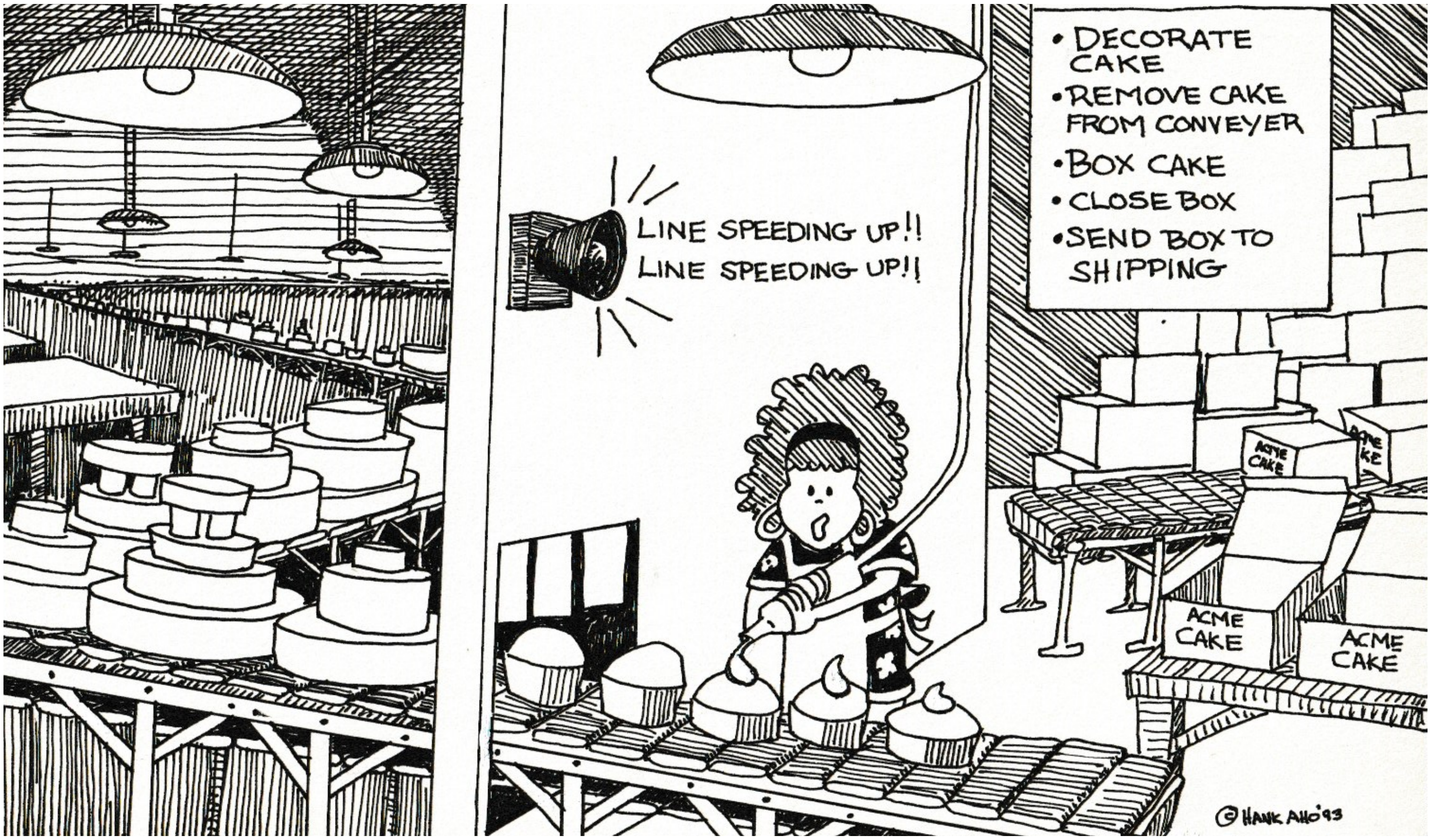

Figure 9. A cartoon inspired by an episode of "I Love Lucy" where Lucy struggles to keep up with a factory conveyor belt as it speeds up (featured in Issue #19).

Reflecting on how the industry has changed throughout his career, Aho noted that there is now much more awareness about tanks and the dangers that they pose. "It is important to keep stressing how beneficial tanks work has been, and how much still needs to be done," he said.

Throughout his time with LUSTLine, Aho's cartoons have certainly garnered a fan base among members of the tanks community, like Moreau, who look forward to seeing his witty interpretations of the articles when each new issue is published.

Figure 10. A frustrated tanks worker receives nonstop alarm messages from an automatic tank gauge (featured in Issue #84).

"Hank has added immeasurably to the content, readability, and enjoyability of LUSTLine for decades," said Moreau. "His images stay with the reader long after the words themselves have faded from memory."

Cheyenne Ellis is an information officer at NEIWPCC and the editor for LUSTLine. Cheyenne can be reached at cellis@neiwpcc.org.

View more of Hank's work by visiting the online version of this article or browsing through old editions in the LUSTLine archive.

A Message From Mark Barolo

Director, U.S. EPA's Office of Underground Storage Tanks (OUST)

What is in Store for State Underground Storage Tank Programs?

The Future of State Tanks Programs in a Changing Landscape

What does the future hold? While no one can be certain, it is important to prepare for the possibilities. States are doing just that, and for various reasons, states are growing increasingly concerned about the future viability of their tanks programs. In recent years, state tanks programs have experienced declining revenues and staffing shortages and are feeling the crunch of having to do more with less. In addition, current and possible future changes in the petroleum storage industry, in the transportation sector, and in U.S. consumer habits feels like a journey into uncharted territory.

To express their concerns about the future, the states, through the Association of State and Territorial Solid Waste Management Officials (ASTSWMO), issued a position paper on the long term sustainability of state UST and LUST programs. In the paper, ASTSWMO outlined the complex mixture of issues and trends affecting the future of tanks programs. States called upon EPA to conduct a more detailed analysis of the concerning trends.

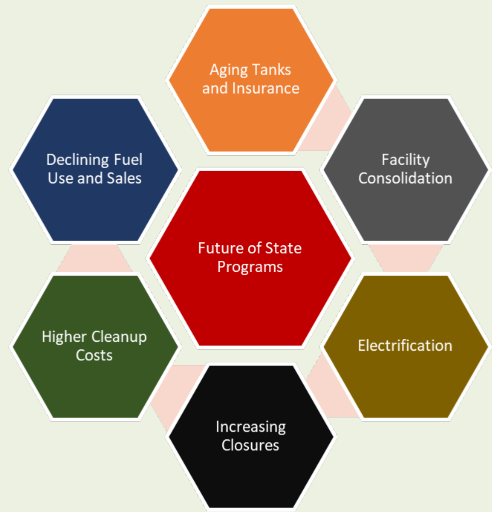

Figure 1. Many factors influence the future of the state tanks programs.

EPA's Report and Forecasting Tool

In December 2024, the EPA's OUST published "UST and LUST Program Challenges in a Changing Transportation Sector." In the report, we describe the issues that state programs face in keeping their UST and LUST programs afloat for the long term. We also include a discussion of topics and alternatives that states should keep in mind as they engage in long term planning. The various issues currently affecting or likely to affect state programs in the future are many and complex. The issues intersect and interact with each other and may occur at different times and at varying intensities from state to state. They include:

- Aging tank infrastructure. Older tanks may be replaced at a higher rate and may lead to closure of facilities and consolidation of fuel storage infrastructure. A reduction in the number of operating UST systems will impact UST and LUST programs that receive funding from per tank fees.
- Owners of older tanks may have fewer options for insurance and may have to close or abandon tanks if they are unable to obtain insurance to demonstrate financial responsibility. This could mean more cleanups, and possibly more abandoned tanks, for state programs to handle.
- Older USTs may mean increased releases from tanks. States may experience higher expenditures for cleanup activities.
- Internal-combustion engines entering the market today use significantly less fuel than those in older vehicles aging out of use. Increasing fuel efficiency will have a significant impact on fuel demand.
- Alternative vehicle technologies require even less liquid fuel than the newest internal-combustion engine vehicles. Declining fuel sales will impact UST and LUST programs that receive funding through taxes or fees from fuel sales. These trends could lead to a decrease in revenues for state programs.

A Message From Mark Barolo... continued

Each state faces a unique situation in terms of their UST infrastructure, existing and future transportation sector program budgets and priorities, and regulatory and legislative frameworks. The timing and magnitude of issues will vary from state to state. Environmental agencies need to plan ahead so that financial constraints do not curtail their ability to support UST release prevention and cleanup activities.

As states grapple with an uncertain future for their programs, there are many different factors they need to consider. Our report provides a menu of both general and specific ideas that states might consider using as they begin to plan and develop solutions. A few of the considerations that states should keep in mind are listed below.

- What is your state's transportation environment and how might it impact your regulated community and UST and LUST programs?
- What incentives or requirements could you provide for upgrades or removals of aging UST systems?
- What funding mechanisms do you have available to address cleanups at abandoned sites?

State tanks program staff may have to describe and defend their budget and related concerns to stakeholders outside their immediate program. We hope our report helps state staff to articulate both their concerns and proposed solutions.

Accompanying our report is the "UST Futures Forecasting Tool" and "Users' Guide." The primary goal of the forecasting tool is to help states identify potential mismatches between state UST cleanup fund revenues and corrective action costs under a range of future energy use scenarios. We hope that the UST Futures Forecast Tool will help states anticipate challenges and test potential solutions by helping them estimate UST corrective action fund revenues and costs under a variety of declining fuel-use scenarios.

States can populate the tool with data to examine the effects of various declining fuel use scenarios on facility closures, cleanups, and state fund solvency. States can model various future scenarios in order to estimate:

- The number of new release discoveries.
- State fund and program funding.
- The potential number of abandoned sites needing fuel cleanups.

The tool allows states to project the impact of different combinations of potential solutions. Where firm values are not available, the tool can be run under a range of assumptions to examine the range of likely outcomes. It is difficult to predict the pace of changes and the impact such changes will have on specific state UST and LUST programs. States should plan to reevaluate their situation and forecasts on a regular basis as the transportation and energy sectors continue to evolve.

The tanks program has made great strides at the national level over the past few decades. In order to continue our collective success, we must have healthy and sustainable tanks programs at the state level. As trends change and other issues emerge, EPA will continue to communicate and to work with states, industry, and other partners on solutions. I encourage you to read the report and to try out the forecasting tool. OUST's technical team is available to discuss the document and the tool. Please reach out to Ryan Haerer (Haerer.ryan@epa.gov) and Tom Schruben (Schruben.thomas@epa.gov) if you have any feedback or questions.

Become a L.U.S.T.Line Author

LUSTLine is a national bulletin that promotes the exchange of information among UST and LUST stakeholders.

NEIWPCC has published LUSTLine since 1985, and it has become the publication of record for UST matters nationwide.

Do you have an idea for an article? NEIWPCC is currently seeking authors to provide content on a variety of pertinent topics related to release prevention, corrective action, and financial responsibility.

To learn how to become a contributer, please contact James Plummer (jplummer@neiwpcc.org).

Leveraging Brownfields Funding to Remove Out-of-Compliance Underground Storage Tanks in South Carolina

By Corie White

Figure 1. An aerial shot overlooking an UST removal for site 19247 in Eastover.

Project Beginnings

It is often said that you should not reinvent the wheel, meaning that someone else has likely already perfected the task. This was the case for the South Carolina Department of Environmental Services (SCDES) when it came to utilizing Brownfields grant funding to remove USTs and assess site conditions. During an EPA Region 4 meeting and again at the ASTSWMO Tanks Workshop in 2023, both the state of Mississippi and EPA Region 6 gave presentations detailing their success stories when teaming up with their Brownfields Programs. While these presentations planted a seed, an opportunity arose for the UST Division to collaborate with the Brownfields Program when SCDES was awarded a $2 million 104(k) Assessment and Redevelopment Grant through the Infrastructure Investment and Jobs Act in 2023.

This grant allowed for inventory, characterization, assessment, and clean-up plan development for brownfield sites. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) defines a brownfield as: "...real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant." Sites contaminated by petroleum or petroleum product are also eligible if they meet the following criteria: no viable responsible party, site not assessed/investigated/cleaned up by a liable party, and site not subject to a corrective action order under the Resource Conservation and Recovery Act (RCRA). Using the CERCLA definition and criteria outlined above, the SCDES UST Division and Brownfields Program set out on a collaborative effort to remove out of compliance USTs in pursuit of site assessment.

Site Selection

The SCDES UST Division keeps a list of out of compliance underground storage tanks that do not have a viable owner, were not upgraded to 1998 standards, and through extensive enforcement and legal proceedings have accrued fees and property liens. Internally, this list is referred to as the "Dead List." It was the intention of the Division to start with these sites. Based on the requirements for petroleum sites to meet the criteria mentioned above, 29 sites were

Figure 2. Click the image to view a drone video showing the process of a tank removal in Woodruff.

selected to evaluate further.

Initial steps involved contacting property owners through mail and by phone to gain access to the sites themselves. While many property owners were not willing to grant access, permission was acquired for seven sites. UST staff conducted site visits to verify the tank information stored in the database, gauge tank levels if accessible, observe site conditions, and meet with property owners. Once this was complete, the UST Division and Brownfields Program met to discuss bid specifications and devise a detailed work plan. Each site was discussed with the Brownfields Program to ensure that nothing was overlooked during the initial steps and that all sites met the criteria required for funding.

Contract Development

The general framework for the bid solicitation was modeled after a previous UST Division tank removal project. Alterations were made to add assessment language and meet the requirements of the 104(k) Assessment and Redevelopment Grant. The contract was divided into two parts, with the work completed on each of the seven sites including tank removal (emptying, removing, and disposing) and a modified Tier I site assessment plan (eight grab samples analyzed for BTEX, polycyclic aromatic hydrocarbons, oxygenates, ethylene dibromide, and metals; three permanent monitoring wells; and lithologic description). Estimates were provided based on database records and field observations for the

Facility ID (County)	Tank Info	Compliance	Ownership	Release	Enforcement/Legal	Costs	Total
02472 (Colleton)	(2)-2K Emptied 2008	Last operated 1995. Not upgraded	Purchased in Tax Sale. Not Tank Operator.	1-NFA	Enforcement Action-new owner	$15.3K $15K	$30,368
04878 (Jasper)	(1)-6K, (1)-8K, (1)-10K Measurable Amount	Last operated 1998. Not upgraded	Not Tank Operator.	1-Active	Enforcement Action/Civil Penalty-new owner	$40K $15K	$55,000
04887 (Jasper)	(2)-3K, (1)-2K Emptied 2002	Last operated 1996. Not upgraded	Not Tank Operator.	1-Active	None	$28.1K $15K	$43,144
05289 (Jasper)	(1)-3K, (2)-4K, (1)-4K Measurable Amount	Last operated Unknown Date. Out of Compliance	Not Tank Operator.	1-Active	None	$36.5K $15K	$51,500
08299 (Spartanburg)	(2)-2K, (1)-3K, (1)-4K Not Accessible	Last operated 1979. Not upgraded	Purchased in Tax Sale. Not Tank Operator.	N/A	None	$32.8K $15K	$47,828
09573 (Darlington)	(1)-550 gal No Records	Last operated 1994. Not upgraded	Not Tank Operator.	N/A	None	$7.3K $15K	$22,270
11160 (Jasper)	(3)-10K. Measurable Amount	Last operated 2006. Out of Compliance	Purchased from Forfeiture. Not Tank Operator.	1-NFA	Property Lien-2023	$48.5K $15K	$63,488
7 Sites	**20 Tanks**						**$313,598**

Table 1. An overview of each site and the associated tanks, as well as the cost.

Facility ID (County)	Tank Info	Tank Status	Release	Costs	Total
15228 (Saluda)	1 confirmed tank; 7 in database	Pre-74	None	$18.8K $11.9K	$30,754
16073 (Bamberg)	3 confirmed tanks; 5 in database	Pre-74	1-NFA	$37.4K $11.9K	$49,300
19247 (Richland)	3 confirmed; same in database	Rendered Non-Useable (RNU)	None	$19.4K $11.9K	$31,350
19268 (Orangeburg)	5 confirmed tanks, 9 in database	Pre-74	1-CNFA	$35.5K $11.9K	$47,450
09344 (York)	4 confirmed tanks, same in database	8 Abandoned, 4 Permanently Out of Service (POS)	1-CNFA	$41.9K $11.7K	$53,579
00332 (Allendale)	9 confirmed tanks, same in database	Rendered Non-Useable (RNU)	1-Active	$76.1K $11.9	$88,000
20265 (Marion)	2 confirmed tanks, same in database	Pre-74	None	$13.1K $16.8K	$29,900
7 Sites	**27 Confirmed Tanks**				**$330,333**

Table 2. An overview of each site and the associated tanks, as well as the cost.

total number and contents of the tanks, as well as quantity of the contents. Twenty tanks were registered in total across the seven sites. The first contract ran from March 13, 2024 through May 24, 2024 and was awarded for $313,598. An extension to July 31, 2024 was granted. Table 1 shows an overview of each site and the associated tanks, as well as the total cost (the costs column breaks out the tank removal costs and assessment costs respectively in Table 1).

With the success of the first contract, a second evaluation was completed to identify any additional sites from the original list where property owners may now grant access. The same process was used to narrow down the sites as well as a similar bid structure. Again, seven sites were identified totaling 39 potential tanks and 27 confirmed. Unlike the first set of sites, some of the sites in the second set only had tank estimates due to incomplete records. The contract period was from February 1, 2025, to May 31, 2025 and was awarded for $330,333. Table 2 shows an overview of each site and the associated tanks as well as total cost.

Results

At the conclusion of the first contract, all seven sites were assessed and a total of twenty tanks were removed. Based on an UST Division Regulatory review of the results collected during the tank closures and groundwater sample collection, three sites were recommended for continued remediation (active releases already existed at these sites), one was issued a No Further Action (results below Risk Based Screening Levels), and three were referred to the UST Division Assessment Section. This included two re-opened releases. The Assessment Section reviewed the data and calculated Site-Specific Target Levels (SSTLs). The results from the initial sampling were below these levels for all three sites. Therefore, they were each issued a Conditional No Further Action (results below SSTLs).

The second contract is still ongoing at the time of this writing. Six removals have been completed, and assessment is scheduled to be completed by the contract deadline of May 31, 2025. So far, 24 tanks have been removed, which is one more than anticipated.

Figure 3. Tanks that have been removed from a site in Woodruff.

Figure 4. Click the image to view a drone video showing a tank being removed in Colombia, South Carolina.

The collaborative efforts outlined in this article between the SCDES UST Division and Brownfields Program exemplifies the importance of interdepartmental communication and ingenuity. Upon the completion of the second contract this year, 14 total sites will have been assessed with more than 45 out of compliance tanks removed. Sites that have been issued a NFA (No Further Action) or CNFA (Conditional NFA) can be returned to their owners and community for redevelopment. Sites that have a new release declared may be able to apply the grant funding to their overall deductible. A total of $643,931 from the $2 million dollar award will be utilized.

Throughout the process, SCDES learned many lessons that may benefit other states looking to replicate this work. It is important to maintain good communication with the property owner, as this can allow you to gain initial site access. Consistent communication will also help the property owner understand the ins and outs of the project, stay up-to-date and build trust. Other tips include:

- Having contingency plans to handle different outcomes. States should consider using ground-penetrating radar and using all available data (imagery, records, talking to the public, Sanborn Maps, etc.) to document as much information ahead of time as possible.
- Ensuring contractors are able to complete the work and keep you updated on their schedules and any problems that arise.
- Conversing with your Brownfields Program and developing a plan so everyone has a clear picture and understanding of the project.

Going forward, the state plans to target orphaned releases that need initial assessment work. The partnership between the two program areas as well as between SCDES and the people of South Carolina will last a lifetime and hopefully allow for many more successful projects.

Conclusion

Aside from gaining property access, which was the most difficult hurdle of this project, other challenges did present themselves. The lack of historic records in the database due mainly to pre-1974 tanks made the construction of the bids less accurate. Due to the location of a few of the sites in the low country of South Carolina, compaction was hindered by increased water levels causing the contractor to expend unforeseen costs. However, the response from the property owners that participated was overwhelmingly positive.

Responses from Property Owners

"Thank you so much, this has been such a financial relief. Not having the money to remove the tanks has been a set-back. Now we can start having community events. Thank you for recommending this program to us and following through. We truly appreciate it."

"It is a beautiful thing. We could not have removed the tanks without these funds. We are planning redevelopment when we can afford it."

"I am so anxious to get started with this project. I have been so worried about the situation prior to you calling me. Now I feel like I am going to be able to breathe."

Corie White is currently a senior consultant at the South Carolina Department of Environmental Services. She can be reached at corie.white@des.sc.gov.

Resetting Expectations for the Rates of Natural Source Zone Depletion

By Julio Zimbron, Ph.D.

Figure 1. Picture of a soil core taken from a petroleum contaminated site, showing microbially-driven geochemical changes, including precipitation of black metal sulfides and biogas formation (CO^2 and methane bubbles). These biodegradation processes, collectively known as natural source zone depletion, are common at most petroleum contaminated sites. Quantifying the rate of these processes is key to the LNAPL conceptual site model. Measured NSZD rates can vary by as much as 10x, depending on the methodology used.

Natural Source Zone Depletion (NSZD) is a term used for the mass loss of LNAPL contaminants in the subsurface due to a combination of processes. NSZD has become a buzzword associated with petroleum releases and is increasingly proposed as a final remedy for contaminated sites. Additionally, measured NSZD rates are used to shut down treatment systems that perform poorly. However, readers must be cautioned. The magnitude of the measured NSZD rates can change depending on critical method implementation details. Hence, the accuracy of the results can vary.

This article describes the evolution of the measurement of NSZD rates by surficial CO^2 flux using passive traps. This evolution has led to NSZD rates that are more accurate and significantly lower than earlier estimates. The ranges of reported NSZD rates from different sources vary considerably because of the technique evolution. Based on early reports, an industry wide value of 1,000 gallons annually per acre of LNAPL losses was thought to be common. Practices developed over the last decade to control measurement error result in median measured values of 200 gallons/acre/year - while measured rate values of 1,000 gallons/acre/year are still occasionally obtained with the more recent practices, they are relatively uncommon. A "one size fits all" range should not be expected before performing the measurements.

Introduction: NSZD and Methods to Measure NSZD Rates

A fundamental concept of NSZD is that degradation of petroleum contaminants (mostly due to microbial activity) results in the production of biogas, a mixture of carbon dioxide (CO^2) and methane (see Figure 1). These gases are more easily monitored in the unsaturated zone than in groundwater. While CO^2 is stable, methane is not — it is readily transformed by aerobic microbes into CO^2 once it migrates to shallow depths and encounters ambient O^2.

Measured NSZD rates obtained using the multiple methods available have been compiled (Garg et al., 2017; Kulkarni et al., 2022). These compilations show median ranges around 1,000 to 2,000 gallons/acre/year. Based on these compilations, a "common knowledge" average of 1,000 gallons/acre/year has become an unwritten rule for NSZD. Because the magnitude of the measured ranges can have a strong impact on the LNAPL conceptual site model (e.g., see DiMarzio and Zimbron, 2019), these published ranges have generated an industry-wide expectation.

The goal of this article is to alert the reader that the common knowledge ranges are based on early NSZD rate measurement work using the first version of the passive CO^2 flux traps. This technique has been improved over the years. The latest improvements show that the median value is in the order of 200 gallons/acre/year, much lower than the 1,000-2,000 gallons/acre/year or higher measured using the first version. In the next section, the method changes associated with each version and their impact on the measured values will be discussed.

Conceptually, a direct NSZD rate measurement would require two independent measurements of the contaminant mass at different times: the difference between both mass measurements, divided by the elapsed time would result in mass losses. This conceptually simple approach is impractical because: a) the methods to measure source mass are expensive; b) these methods have uncertainty (it is easy to miss part of the contamination); and c) a time required for significant contaminant mass losses might be impractically long (i.e., decades).

Fortunately, short term expressions of contaminant mass losses can be measured, and they constitute the base of indirect NSZD rate measurements. These methods assume a reaction and rely on measuring the production rate of the reaction products (for example, CO^2 or heat, measured using a mass or a heat balance, respectively), which is then converted to contaminant losses on a per footprint area and time basis (for example, gallons of contaminant per acre per year).

The compositional method is one additional method based on changes in composition of the remaining LNAPL, which provides relative mass losses for individual compounds with respect to others (Hostettler et al., 2013). These methods are included in multiple guidance documents (API, 2017; ITRC, 2018; CRCCare, 2018; ASTM, 2022, among others). These documents typically describe the rationale of the methods, case studies, example calculations, and results from different methods.

All the byproducts used in the methods are naturally produced by soils, so it is essential to distinguish between a source not related to contamination ("natural") and a source from petroleum contaminants. In other words, it is critical to separate the signal from NSZD and the noise (from sources not related to NSZD). For example, CO^2 is produced by non-contaminated soils through the natural carbon cycle. Processes not associated with contamination are known as background processes. Some techniques rely on measuring the signal used to calculate NSZD rates (i.e., CO^2 production rate) at one or more non-contaminated (background) locations. A background location correction means that the measured rate at one or more background locations is subtracted from measurements at contaminated locations.

Some methods do not require this background location correction. For example, a radiocarbon correction can be applied to surface CO^2 flux-based methods. The radiocarbon (14C) composition of ancient carbon (including petroleum) is vastly different from ambient carbon (modern carbon). Modern sources are radiocarbon rich (with similar 14C levels to atmospheric values, where it is produced due to the action of cosmic rays). Because 14C is unstable (its self-decay half-life is ~ 6,000 years), samples older than ~ 60,000 years (i.e., petroleum) are completely depleted of 14C. The 14C correction is location specific, while the background correction assumes a constant site-wide value.

The Evolution of the Passive CO^2 Trap Method

Colorado State University developed and validated the passive CO^2 trap method using column soil experiments starting in 2009. A prototype was then tested at multiple sites (McCoy, 2012). The method was licensed to E-Flux in 2012. The hardware

Figure 2. From left to right, first, second and third generation CO^2 trap and rain cover designs. Small deviations from the stated dimensions may have occurred in a few cases, as changes from first generation to second were iterative.

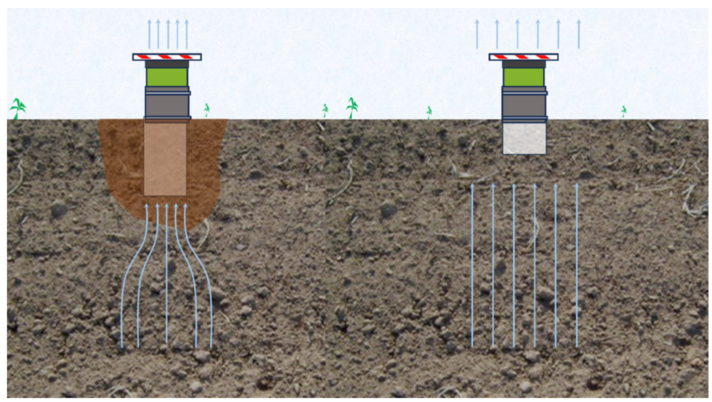

Figure 3. Schematic diagram illustrating preferential flow effects caused by installation of a deep receiver on a pre-dug hole (the dig-and-refill installation) compared to those of the shallow receiver pushed directly into the ground (direct push installation). A third-generation trap is shown for both installations, although the "direct push" was nearly exclusively used with the third generation (while earlier generations used the dig and refill more often).

design, the installation method, and the correction applied to differentiate between CO^2 from NSZD and naturally produced CO^2 in soils evolved as follows:

1. First-generation CO^2 traps (used from 2009 to approximately 2011). This first prototype provided proof of concept data (McCoy, 2012). The trap was approximately 20 inches tall, with a 6-inch tubular rain cover. NSZD rates were calculated using the background correction technique (instead of the 14C-correction). Figure 2 shows this design in comparison with the ones that followed. Most first-generation installations were done with the dig-and-refill method, in which the soil receiver was installed in a pre-dug hole, with the excavated soil used to refill the void, and then compacted back to the original soil conditions (see Figure

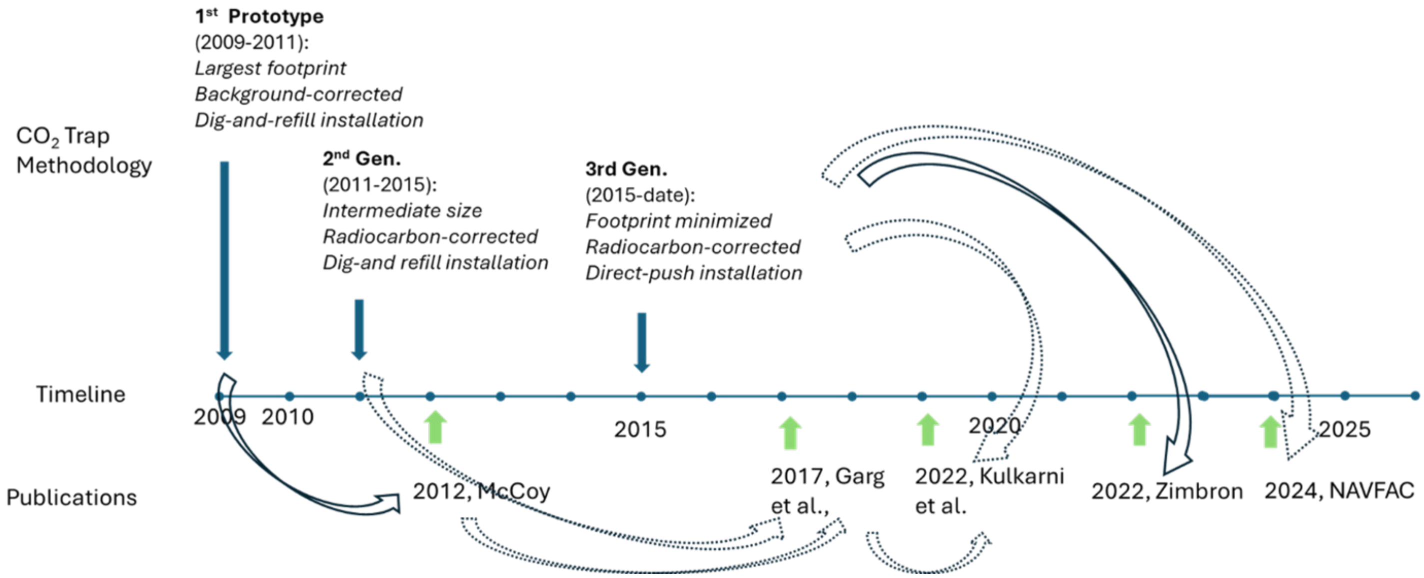

Figure 4. Timeline of changes in the CO^2 trap design. Curved arrows illustrate how data with different features fed into different data sources. Solid line curved arrows indicate data was from CO^2 traps only, while dotted line curved arrows included data from multiple methods. Data included in this report is exclusively from CO^2 traps.

3). Note this last practice was part of the original protocols included in the API guidance document (API, 2017).

2. Second-generation CO^2 traps (used from 2011-2015). The height was ~ 12 inches, with a 6-inch OD tube rain cover. Some projects that used this design continued to use the 20-inch tall rain cover from the previous design. Additionally, some of these projects might have used the dig-and-refill receiver installation, but that practice was discouraged after 2011 as there was evidence that this caused a high bias (Goodwin and Palaia, 2011). Instead, the standard recommendation was to push the receiver directly into the soil to a depth of about 1 inch. Figure 3 illustrates the relative preferential flow effects caused by the soil disturbance of the dig-and-refill method.
3. Third-generation CO^2 traps (used since 05/2015 to date). This version was designed to minimize high bias due to high wind smokestack (Venturi) effects (Tracy, 2013; E-Flux, 2015). The height was 7 inches, with a flat rain cover (rather than a tube) to minimize the lateral profile. All values using this last generation design were 14C-corrected. A reinstallation at a field site replacing the first-generation design (installed with dig-and-refill method) with the direct-push installation of the third-generation design resulted in a reduction of 90% in the 14C-corrected measured values (one order of magnitude) (CDPHE, 2015).

The Sources of Reported NSZD Ranges

The reported ranges of field-measured NSZD rates from multiple sources are summarized in Figure 4. These sources include:

1. McCoy, 2012. This work laid the initial development of the passive CO^2 traps, including laboratory validation and data from five sites using a first-generation design. The NSZD values were background-corrected, not radiocarbon (14C) corrected. Locations with total CO^2 fluxes equal or smaller than a clean background location (if available) were not reported.
2. Garg et al., 2017. This overview included a description of the mechanisms related to NSZD, a summary of reported rates using multiple methods at a total of 25 NAPL sites, as well as potential factors controlling the mechanisms. The sites included those reported in the McCoy, 2012 and Piontek, et al., 2015 references.
3. Kulkarni et al., 2022. This study collected NSZD rates using multiple methods from 40 LNAPL sites, and looked at correlations between fuel type, methods used, and seasonal and multi-year trends for sites with available data.
4. Zimbron, 2022. This work compared two different corrections for the total CO^2 flux raw using the CO^2 traps, one using radiocarbon (14C) analysis, and a second using the background location correction for total CO^2 flux. All these values were obtained using the third- and current generation of the CO^2 traps, used since 2015 to minimize concerns about wind effects caused by the large size and footprint of previous versions (E-Flux, 2015).
5. NAVFAC, 2024. The Naval Facilities Engineering Systems Command (NAVFAC) recently conducted NSZD measurements at five sites, all with the third generation CO^2 trap, reporting average site-wide values, rather than

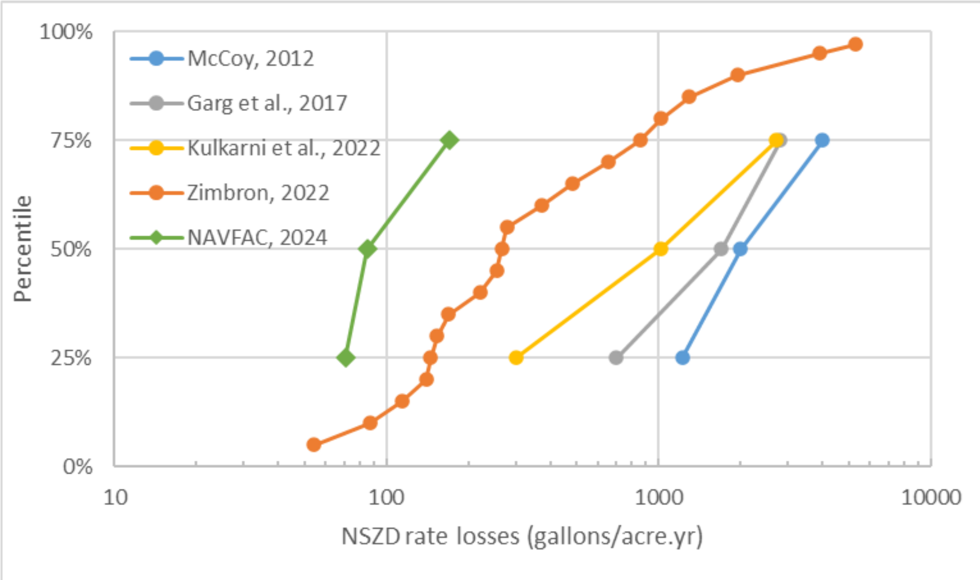

Figure 5. Probability distributions for measured NSZD rate values from different literature sources (percentile of the population as a function of measured mass loss rate values).

individual measurements. This report included measurements using other techniques.

Figure 5 helps visualize how the data set for each of the literature sources compares to the other. This might be better illustrated by assuming how a hypothetical site falls in these ranges. For example, a site with a measured NSZD rate of 265 gallons/acre/year would exceed about 50% of the measured values in the Zimbron, 2022 data set, but would only exceed about 25% of the values in the Kulkarni et al. (2022) data set. A site with a measured NSZD rate of 1,000 gallons/acre/year would be in the middle (the median) of the Kulkarni et al. (2022) dataset, but would exceed 80% of the values in the Zimbron (2022) dataset.

Why Are Different Sources of NSZD Rates Inconsistent With Each Other?

The different NSZD rate measurement methods were based on first principles (i.e., laws of nature), using seemingly reasonable assumptions (e.g., one-dimensional gas flow). Some methods were further validated in laboratory studies (e.g., the CO^2 trap-measured fluxes were compared against actual fluxes on a large soil column, see McCoy, 2012). Field applications were expected to include site variability (either between locations, or temporary soil conditions) – as a result, field measurements were expected to be an "order of magnitude estimate" (API, 2017). When trying to compare different methods in the field, or while repeating measurements on the same site using the same method, large differences (100%, equivalent to 2x, or higher) were expected.

The Kulkarni et al. (2022) and the Garg et al. (2017) compilations mentioned above provided similar ranges between the 25 and 75 percentile values, with the Kulkarni et al. (2022) report showing values two times smaller than those of Garg et al. (2017), at the lower range (and very similar values at the upper range, i.e., the 75 percentile). However, the data set from Zimbron (2022) shows a range approximately one order of magnitude smaller (the values are ~10x smaller) than the two above-mentioned compilations, whereas the data set from McCoy (2012) shows a range with larger values than the two compilations mentioned.

The McCoy (2012) and the Zimbron (2022) data sets were obtained with a similar instrument (passive CO^2 traps) – however, the differences in the trap design, the installation, and the 14C correction resulted in much lower values associated with the last CO^2 trap version. The original sources for CO^2 trap data used in the Garg et al. (2017) and Kulkarni et al. (2022) compilations included data from either background-corrected first-generation CO^2 traps (McCoy, 2012) and/or 14C-corrected values obtained with second-generation traps (e.g., Goodwin and Palaia, 2014). The reported values of the five sites included in the NAVFAC Fact Sheet (2024) (obtained with the last generation CO^2 trap design and its updated recommended practices) are even lower than those of the Zimbron (2022) data set.

The Zimbron (2022) data set included only five sites, whereas the Garg et al. (2017) and Kulkarni, et al. (2022) reports included larger data sets (25 and 40 sites, respectively). The Zimbron (2022) data set was used because these data sets were publicly available (non-confidential), and the measurements included total CO^2 fluxes in addition to the radiocarbon corrected (or fossil fuel) CO^2 fluxes used to calculate NSZD rates. The two values (total CO^2 and 14C-corrected CO^2) allowed a comparison of both corrections (14C and background location). The E-Flux historical database comprising hundreds of sites measured since 2015 (not shown in Figure 4 to preserve the confidentiality of the data), includes values of the 14C-corrected NSZD rates even smaller than those in the Zimbron (2022) report.

Background corrected values had relatively poor correlations against the more rigorous 14C-corrected values (Zimbron, 2022). The two corrections agreed with each other in only one of the five sites included. Although other sites showed correlations between the results of both corrections, these vary among the different sites. More importantly, these correlations often resulted in higher average values for the background corrected NSZD rates than the 14C-corrected NSZD rates. The current standard approach for the passive CO^2 traps is to apply the

14C-correction to multi-day deployment time integrated CO^2 fluxes - error propagation techniques suggest that a typical detection limit equivalent to ~30 gallons/acre per year (the detection limit for each batch of samples is calculated based on the variability of the total and 14C analyses conducted).

The importance of the range of NSZD rate measurement values might be put in perspective by comparing NSZD data with other systems associated with gas phase biodegradation products. For example, Garg et al. (2017) referenced degradation rates in similar units (gallons/acre/year) for methane digesters, wetlands, landfills, and LNAPL NSZD sites (among others). LNAPL contaminated sites studied for vapor intrusion (VI) offer the same problem analyzed with similar tools from a different point of view. Lahvis et al. (1999) analyzed a gasoline spill in Beaufort, South Carolina. The reported biodegradation rates for individual gasoline components based on gas transport-based rates were equivalent to 180-830 gallons/acre/year. A similar analysis at the Bemidji, Minnesota site resulted in a range of rates between 18-540 gallons/acre/year in 1985 and 120-570 gallons per acre per year in 1997 (Chaplin et al., 2002). Note that these VI-derived values are more consistent with the more recent lower ranges for NSZD values shown in Figure 1 than with those of the earlier NSZD rate compilations.

Using Measured MSZD Values: Should Size Matter?

NSZD rates are rarely used in isolation. They are often used as an estimate of mass losses of the total contaminant mass at a site in a certain amount of time or to provide a comparative level for active remedies.

The NSZD rate is a measure of contaminant mass loss - the contaminant mass existing at a site might be as important as the NSZD rate. A comparison of both metrics can be used as an indicator of site longevity (ASTM, 2022): for example, a site with an existing mass of 32,000 gallons per acre, experiencing an NSZD rate of 700 gallons/acre/year, would yield a mass loss per year of 2.2%. Sustained NSZD rates for approximately 30 years would lead to nearly complete LNAPL source depletion (ASTM, 2022). This analysis provides a lower boundary estimate, because the NSZD rates might drop as the LNAPL becomes weathered, extending the LNAPL depletion period. If the mass loss rates are off by a large factor (for example a factor of five, or 400%), a longevity estimate will be off by the same factor. A combination of an underestimate of the contaminant mass and an overestimate of the mass loss (the NSZD rate measurement) could grossly result in a site longevity estimate of multiple hundreds of years (instead of 30 years in the example given). Similarly, an overestimate of the mass combined with an underestimate the NSZD rate measurement could grossly overestimate the site longevity. This illustrates the importance of considering the uncertainties for both the NSZD rate and the mass associated with the spill, based on a site-specific risk tolerance.

In addition to estimating site longevity, mass loss rates associated with NSZD are often used as an argument to transition from a poorly performing active remedy to NSZD as a final remedy. For this, the difference between both remedies considered (NSZD and the active remedy) is relevant (rather than their absolute values). If this difference is small, deciding which of the two is larger could be a toss-up, given the uncertainties (errors) of each individual estimate (i.e., the rate of NSZD, the mass removal rate, or that of the active remedy). A large difference (20x or more) might enable a higher tolerance in the uncertainties of both estimates. NSZD rate values obtained with a less rigorous technique (prone to a high bias) might lead to an incorrect decision (i.e., shutting down a remedy by comparing it to an apparently high site-wide NSZD rate).

Summary and Recommendations

NSZD has been shown to occur at most petroleum-contaminated sites. In fact, LNAPL sites where NSZD does not occur might be rare exceptions. Furthermore, using multiple techniques, these processes have proven to be measurable. The first guidance document compiling all available methods at the time indicated that these rates would be an order of magnitude estimate (API, 2017). This report shows variability larger than one order of magnitude, depending on the data source. While NSZD is likely to continue to be a key part of understanding LNAPL contaminated sites, the rates should be expected to be closer to hundreds of gallons/acre/year than thousands. Values in the thousands of gallons/acre/year may occur, but they need to be demonstrated by site specific measurements using techniques that address measurement uncertainty appropriately.

The values reported using the 14C corrected CO^2 trap technique show a median value of 200 gallons per acre per year, with only about 20% of the observations exceeding 1,000 gallons per acre per year. Only about 10% of the observations exceed a value of 2,000 gallons per acre per year. This suggests that correcting for interferences (e.g., the 14C-correction to eliminate the interference due to modern carbon soil CO^2 flux) can impact the calculated NSZD rate (Zimbron, 2022). Other, apparently subtle, details in method implementation, such as the receiver installation method, contribute to large differences in the results. As the knowledge base has developed over more than a decade, measurement bias has been reduced and so have the measured values.

NSZD rates are often compared to either the performance of an active remedy, or the total contaminant mass. The comparison with the total contaminant mass relates to the time to reach a significant mass depletion of the LNAPL source. These long-term changes might occur over decades, rather than years. NSZD rate measurement methods have been available for about one and a half decades - the ultimate test of the accuracy of these NSZD estimates will be the actual multi-decade mass depleted at sites (a comparison of the indirect measurements now available with a more direct estimate). Until then, measurements of NSZD rates should be conservative, built on an adequate conceptual site model, and carefully validated. A follow-up paper will discuss potential sources of error for commonly used NSZD rate measurement methods and best practices of method implementation. After more than 10 years of NSZD, a large need exists to reconcile different measurements and discuss the sources of errors that affect each one.

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News and Resources

A Message From NEIWPCC's UST/LUST Program Coordinator: James Plummer

In May, tanks staff from states in Region 1 came together in our office for our triannual workgroup meeting. Mike Hollis from the New Jersey Department of Environmental Protection joined us to talk about tank tightness testing and the National Work Group of Leak Detection Evaluations. Mike and I met up for dinner the night before and talked a lot about music. I am going to ramble for a bit, but stay with me...

Recently, I watched "A Complete Unknown" about Bob Dylan's rise to stardom and his infamous performance at the Newport Folk Festival. He was booed offstage by audience members for using an electric guitar at a traditional folk festival. At the time, I am sure the folk purists thought him to be outside the well-defined boundaries of folk music. Today, in a musical landscape shaped largely by Spotify listens and Ticketmaster fees, the lines between genres are blurring. It feels like we are moving into a post-genre era characterized by a population with unmatched access to sound.

In some ways, new tanks staff today have unmatched access to training resources. Despite that, you still need to dig and ask around to find the right tool or compendium, and in-person networking opportunities are not necessarily affordable for the masses. We unfortunately do not have Spotify for training materials... I will work on it, patent the algorithm, and keep you posted.

It seems today that professionals in the tanks community are still mostly grounded in their "genre" (e.g., site cleanup, facility compliance, financial responsibility). We have come a tremendous way from the early days of USTs, and a lot of the folks who got their start back then have retired and are no longer "touring." It is more important than ever to talk with folks who have bounced between genres inside and outside the realm of USTs and hazardous waste so you can learn from both generalists and specialists. Similarly, we try to infuse varied perspectives into LUSTLine.

Like musicians today who blur the lines between jazz, funk, rap, folk, electronic, and soul to create something wholly original, we need the same kind of creative fusion in our field. At the very least, it is helpful to have varied perspectives on the work that you are doing to help create a more holistic sound.

Organizations like NEIWPCC and the Association of State and Territorial Solid Waste Management Officials (ASTSWMO) sort of act as producers – bringing voices together, setting the stage for collaboration, and making space for harmonies we did not know we needed. These conveners play a powerful role in building community across regulatory, technical, and

News and Resources

Message From James Plummer (continued)

institutional lines. We are only able to succeed because of the contributions of so many people in this community who consistently bring their enthusiasm and insight.

Participation is not just for program managers or seasoned professionals, but for newer folks as well. Entry-level staff and early career professionals can and should add their voice to the chorus. All it takes is asking to join a virtual roundtable, telling your supervisor you want to connect with peers in other roles, or stepping out of your comfort zone to understand how your work fits into the larger performance. Cross-genre collaboration does not just sound better – it is smarter, more resilient, and just generally more enjoyable.

There is no better time than the 28th National Tanks Conference and Exposition from September 22–25, 2025, in Spokane, Washington. This event brings together hundreds of tanks professionals from across the country to share insights, build relationships, and explore the future of our field. You can learn more and register through NEIWPCC's National Tanks Conference webpage. We will see what "music" we make together at the conference!

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Click to register for the 28th National Tanks Conference