IEc

High Resolution Site Characterization at Petroleum Underground Storage Tank Release Sites – Applicability, Benefits, and Costs

Final Report | April 13, 2023

Prepared for:

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Office of Land and Emergency Management

Office of Communications, Partnerships and Analysis and Office of Underground Storage Tanks

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EXECUTIVE SUMMARY

BACKGROUND

The US Environmental Protection Agency Office of Underground Storage Tanks and Office of Communications, Partnerships and Analysis sponsored a study on High Resolution Site Characterization at Leaking Underground Storage Tank sites.[1] EPA contracted with Industrial Economics, Inc. to support this effort. This study is a follow-up to the LUST cleanup cost study conducted by EPA and IEc, which used data provided by multiple states to attempt to characterize typical per-site cleanup costs.[2]

The primary goals of this study were: 1) to quantify the costs and benefits of HRSC investigations and their impacts on overall project costs and time at petroleum UST release sites that have been identified by the "implementing agency" as requiring further investigation to assess risk and the need for further cleanup[3], and 2) to identify situations where HRSC is likely to provide a benefit in site characterization compared to the use of only traditional (i.e., non-HRSC) methods at petroleum UST release sites. The results of this study may help to inform site owners and other stakeholders on the best use cases for HRSC in site cleanups, including where it is most cost effective, and/or where it may inform selection of effective remediation techniques.

Summary of Key Findings

In comparison to traditional boring and monitoring well investigations at petroleum UST release sites, HRSC could:

- Provide a more complete understanding of the release site geology and contaminants.
- Increase confidence in corrective action decisions.
- Help achieve No Further Action sooner.
- Result in lower project costs by reducing monitoring costs and better targeting the remedial activities.

For three common types of petroleum UST release scenarios the expert panel concluded HRSC could save on average:

- 9% to 19% in project costs.
- 3 to 8 years in project time.

Unsuitable geology and a lack of available expertise were cited by many respondents as barriers to the use of HRSC

APPROACH

This study was divided into two phases, which are summarized below. We also conducted an additional round of data collection to compile

[1] In this report, "HRSC" refers to direct sensing tools used on direct push tools, such as Laser Induced Fluorescence, Optical Image Profiling, Membrane Interface Probe, Hydraulic Profiling Tool, and Electric Conductivity. Respondents recognized that HRSC with these tools is limited to geologically suitable conditions.

[2] US EPA and Industrial Economics. 2022. Leaking Underground Storage Tank Cleanup Cost Study. Mar. 29.

[3] Sites where enough information is available to make corrective action decisions (for example, sites where data collected during UST closure sampling or from prior "traditional" monitoring well investigations) were not the focus of this study or the questions asked of the study participants. The evaluations of the scenarios in this study assumed an unresolved data gap related to the nature and extent of the petroleum release that could either be assessed using traditional techniques or by using HRSC. In addition, respondents recognized the technical limitations of HRSC – it cannot detect low level concentrations, cannot practicably penetrate certain geologies, and cannot reach great depths. HRSC Investigations are typically limited to the top 30 to 60 ft.

additional cost estimates for HRSC investigations at a typical gas station LUST site. **Figure 1** summarizes the approach taken in each phase.

- **Phase one:** In the first phase of this study, we set out to collect information on the cost and usefulness of HRSC at petroleum UST release sites from different perspectives to then share with three expert panelists in phase two. We held discussions with 20 contacts, including state and federal regulators (12), HRSC technology providers and consultants (5), and EPA representatives (3), all of whom had been involved in investigations that used HRSC at petroleum UST release sites. Respondents discussed their experiences using HRSC tools in site characterization, including investigation costs, barriers to HRSC, and time and cost differences between HRSC and traditional investigation techniques in various scenarios. We also asked respondents to rate the usefulness, cost, and time saving potential of HRSC use under 15 hypothetical cleanup use cases using a scale of 1 (least useful) to 5 (most useful).[4] The barriers and use cases were developed by EPA OUST staff.
- **Phase two:** In the second phase, we conducted a Delphi Panel approach with three industry experts to try and gain consensus on the best use cases and cost impacts of HRSC at petroleum UST release sites.[5] This structured elicitation process included three experts and two rounds of interviews. The experts first provided their reactions to information collected in phase one, along with their own ratings for the 15 use cases. We then asked experts to estimate HRSC costs, and overall project costs/durations with and without an HRSC investigation at three hypothetical sites. The assumptions for each site (a "typical" release site, a catastrophic release site, and a site where remediation has stalled) were developed by EPA OUST staff. The experts formed their opinions independently of each other and their identities were not shared with one another. We synthesized expert responses from round one of the interviews and shared the anonymized version with each expert. We gave each expert an opportunity to revisit their estimates and assumptions in round two of the interviews, which resulted in greater convergence.
- **Phase three:** We conducted an additional cost exercise where we gathered additional cost estimates for conducting an HRSC investigation at a typical gas station UST site. Ten respondents provided this information, including one EPA respondent, six technology providers and consultants, and three state regulators.[6]

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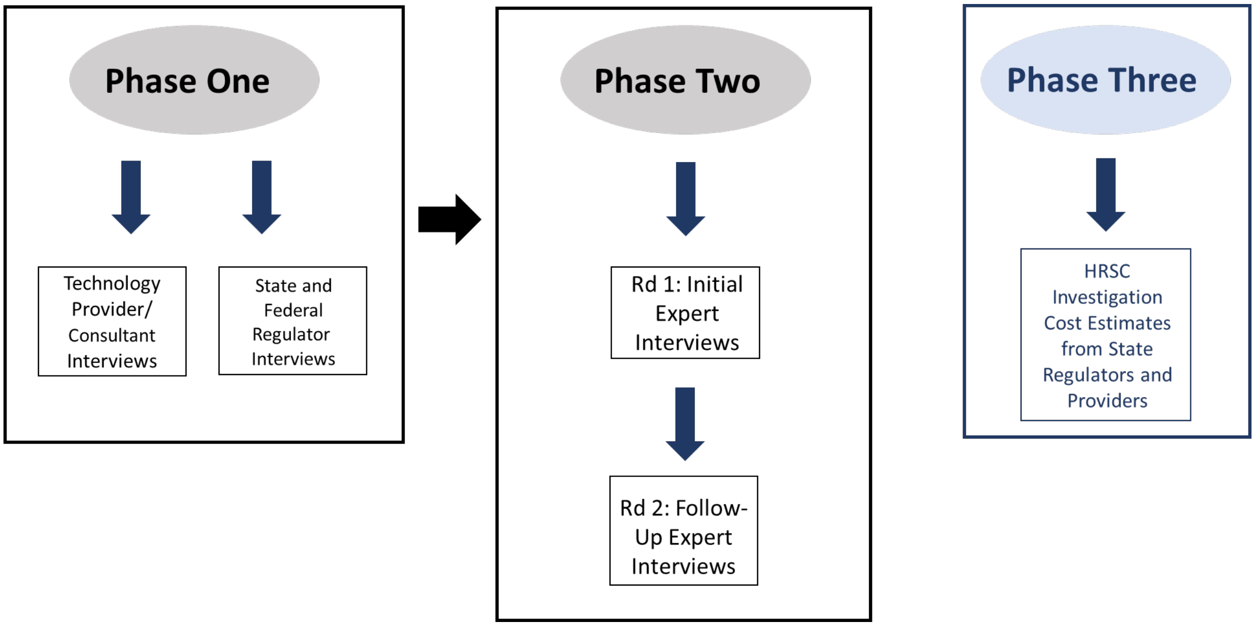
[4] Due to time constraints, we asked state respondents to fill out a survey with "yes"/"no"/"maybe" responses to indicate whether HRSC would be useful under each scenario. In order to show responses side by side, we convert these responses to the 1-5 scale by multiplying the percentage of "yes" responses by 5 and "maybe" responses by 3, throughout this report.

[5] A Delphi Panel is a structured process that attempts to gain consensus across a panel of experts, often used to solve a problem where real-world data are not immediately available.

[6] Seven of the 10 respondents also participated in the first phase of the study.

FIGURE 1. HRSC COST STUDY PHASES



RESULTS: USE CASES FOR HRSC [STATES, TECHNOLOGY PROVIDERS, EXPERTS]

To determine the best use cases for HRSC, we asked interviewees to examine 15 use cases developed with EPA OUST to rank the usefulness of HRSC for a given situation using a 1 through 5 scale.[7] While usefulness ratings were high across all 15 use cases, and every use case had at least one interviewee rate HRSC as useful, there were eight scenarios where all three groups (round two experts, and round one state representatives and technology providers/consultants) agreed that HRSC would be particularly beneficial. **Figure 2** shows these scenarios, along with the average ratings from each group. In addition to highlighting the benefits in these scenarios, the interviews provided the following key findings:

- **Experts agreed that HRSC will always provide more detailed information about a site relative to traditional investigation techniques[8], which allows for more efficiency and certainty in site characterization and remediation, compared to non-HRSC methods.** Interviewees across phase one and two stated that using HRSC to develop a conceptual site model leads to more efficient and informed decision making when selecting a remediation technique. The richer data set leads to increased confidence in the CSM and greater certainty in remedial decisions.
- **There was consensus among the experts that HRSC can provide time and cost savings because accurate site characterization will result in a more efficient site remediation strategy.** State representatives and technology providers also indicated that HRSC can reduce long-term project costs, provide useful insights into how to adequately address a release, and expedite sites

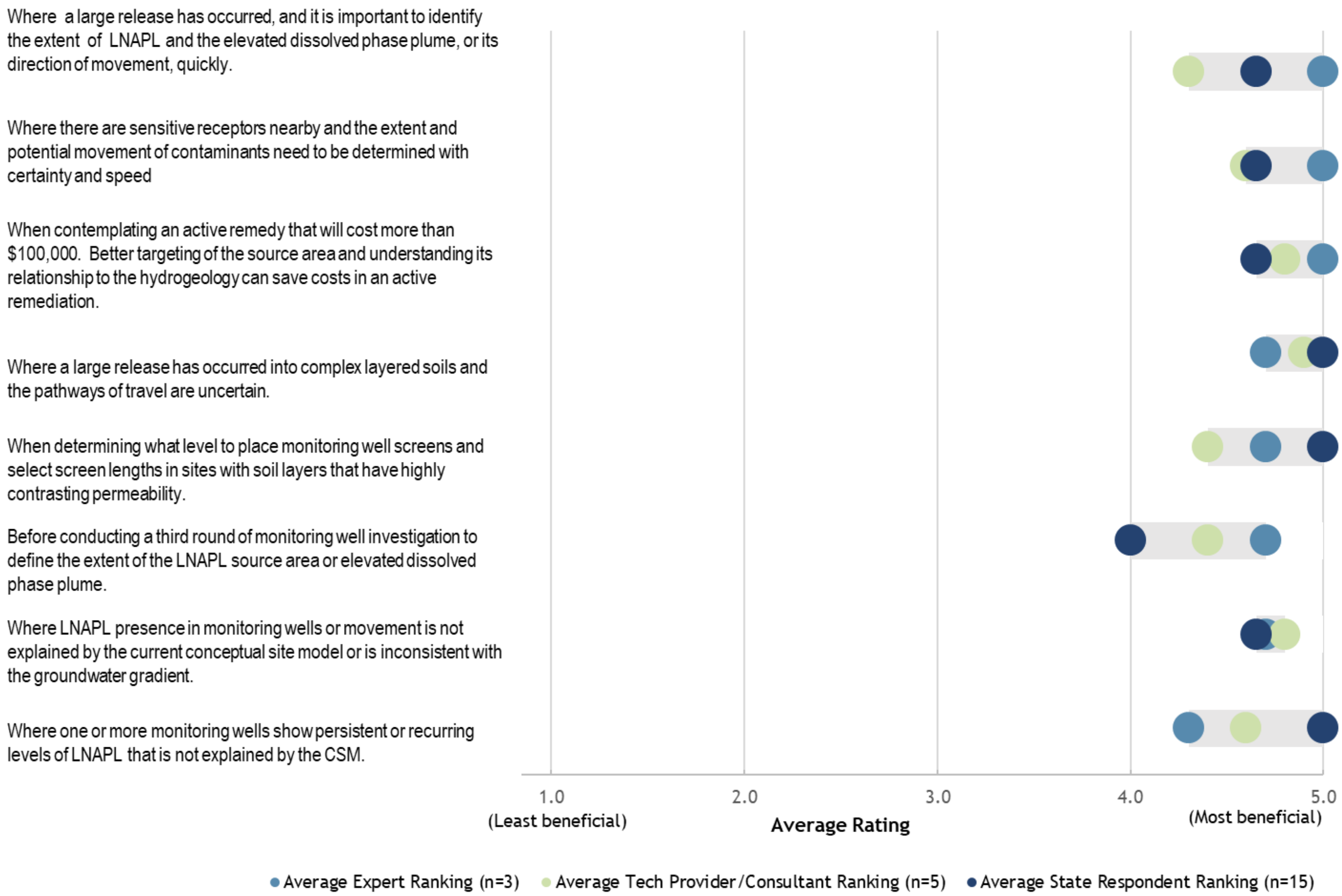
[7] We also asked participants to indicate whether HRSC would or would not save time or money for the 15 scenarios. We report those results in the main body of the report.

[8] Respondents noted that direct sensing HRSC is not effective at low concentrations and would not be useful in identifying the leading edge of a plume to drinking water standard concentrations.

reaching closure or No Further Action status due to better targeting of the source area and a more granular understanding of the soil characteristics.

- **States and technology providers/consultants converged in their ratings for the usefulness of HRSC compared to traditional techniques in many use cases.** States and technology providers/consultants agreed that HRSC would be highly beneficial in most of the 15 use cases provided (**Figure 2**). While individual responses varied to some extent, some of the most highly rated use cases were: where there are sensitive receptors nearby and the movement of contaminants needs to be determined quickly; when determining what level to place monitoring well screens and select screen lengths in sites with soil layers that have highly contrasting permeability; where one or more monitoring wells show persistent or recurring levels of LNAPL that is not explained by the CSM; and where a large release has occurred into complex layered soils and the pathways of travel are uncertain. Both groups of interviewees showed the least support for HRSC's usefulness when there is a need to differential between an old and new release. Another scenario where both states and technology providers/consultants showed less support for the usefulness of HRSC was when active remediation has been conducted for over 10 years. Respondents also acknowledged that HRSC is less useful when geologic conditions prevent it from being used, and it cannot provide the lab test information needed to fulfill regulatory requirements.
- **While states and technology providers/consultants largely converged on their opinions about the usefulness of HRSC, there were some cases where their responses differed.** States and technology providers/consultants had less agreement on several HRSC use cases (**Figures 7** and **10**). In some cases, state representatives valued HRSC differently than technology providers. For example, when asked if HRSC would be useful "when chemicals, absorbents, or nutrients will be injected into the ground", 60% of state interviewees responded yes, while technology providers/consultants considered this to be one of the most beneficial applications for HRSC, likely reflecting different experiences with HRSC between the two groups.
- **Respondents reported that HRSC use has increased over time, but the adoption of HRSC technologies is still not widespread due to many barriers.** There was no consensus among interviewees about which barriers were the greatest. The given reasons why HRSC is not widely used varied by state and each person's perspective. For example, technology providers cited state fund reimbursement restrictions as a barrier, but that was the barrier with the lowest average rating from state respondents. The technology providers explained that the structure of state reimbursement programs limits the ability of site owners and consultants to conduct HRSC investigations if they are not included in the rate schedule, or it is otherwise unclear what the funding mechanism for HRSC is.

FIGURE 2. AVERAGE RATINGS FOR USE CASES WHERE EXPERTS, TECHNOLOGY PROVIDERS/CONSULTANTS, AND STATE RESPONDENTS AGREED HRSC PROVIDED THE MOST BENEFIT COMPARED TO TRADITIONAL SITE CHARACTERIZATION OF PETROLEUM UST RELEASES



RESULTS: TIME AND COST SAVINGS [EXPERTS]

We asked the three expert panelists to provide project cost and duration (i.e., time from discovery to closure) estimates for three hypothetical sites. These sites included a "typical" release, catastrophic release, and a site where remediation is stalled.[9] Through our Delphi Panel approach, we attempted to reach a consensus to find the impacts of conducting an HRSC investigation at each type of site. Two out of three experts interpreted the scenarios as occurring at complex LUST sites, while one expert responded thinking of a "typical gas station" LUST site. While this meant that the absolute values of the costs and cost savings differed based on the different assumptions about the magnitude of the corrective actions made by each expert, percentage changes in cost and duration when applying HRSC

[9] Appendix B provides the specific wording for each scenario.

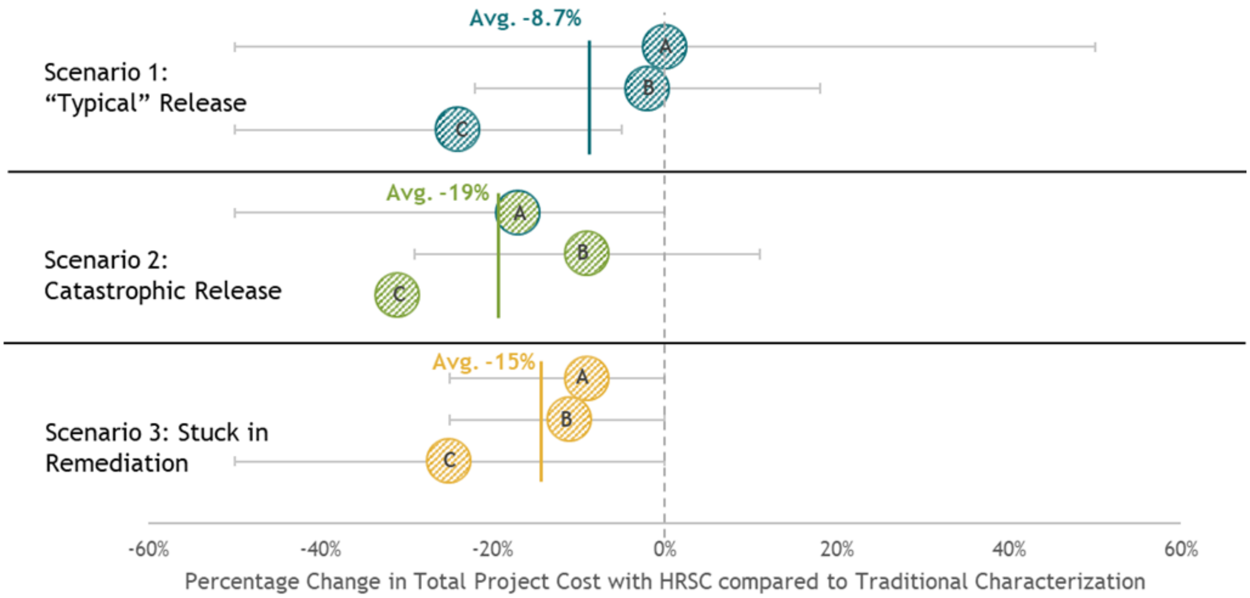
were similar across each respondent. To address this disparity and get more HRSC cost information for the typical gas station assessment, we conducted an additional cost exercise described in the next section. Expert opinions from the Delphi panel converged around the following key findings:

- **Experts agreed that including HRSC in an investigation at a catastrophic petroleum UST release site, or at a site where remediation is stalled, was very likely to reduce overall project costs, in large part by reducing project durations and the need for long term monitoring.** While experts acknowledged that there could be substantial variation across individual sites due to specific characteristics, all three experts estimated that using an HRSC investigation at these types of projects would typically reduce overall project costs. Experts reiterated that the data that comes from an HRSC investigation makes it worth doing regardless of whether HRSC lowers costs or has no impact on them. Experts predicted average cost savings of 19 percent at catastrophic release sites and 15 percent at sites where remediation is stalled, compared to total costs if HRSC was not used in the initial investigation/characterization (**Figure 3**).

- **Experts reported that HRSC use would likely be cost neutral or yield minor savings at a typical petroleum UST release site, while providing important information to inform the remediation.** Two experts believed that total project costs would be roughly identical when using HRSC versus traditional techniques at a typical release site (estimating 0 percent and 2 percent cost reductions, respectively). The third expert believed that HRSC would lead to substantial cost savings (24 percent) over a typical release site using only traditional techniques. All three experts agreed that the added information provided by an HRSC investigation would make this type of investigation worthwhile (**Figure 3**). The value of the added data means that HRSC is worth doing even if the overall project cost impacts are neutral. The added information can help uncover site complexity at the start and prevent unexpected roadblocks later, which could prevent some sites from becoming stalled in corrective action, or the need to later reopen sites that were closed without being properly characterized.

- **Experts believed that HRSC would reduce project durations across all three petroleum UST release scenarios, with the greatest reductions occurring at sites where remediation is stalled.** Expert responses about project durations with and without HRSC tended to be similar and moved closer together through the Delphi Panel process. Experts reported that HRSC could save an average of 3 to 8 years compared to a site using only traditional investigation techniques across sites where remediation is stalled, catastrophic release sites, and typical release sites (**Figure 4**).

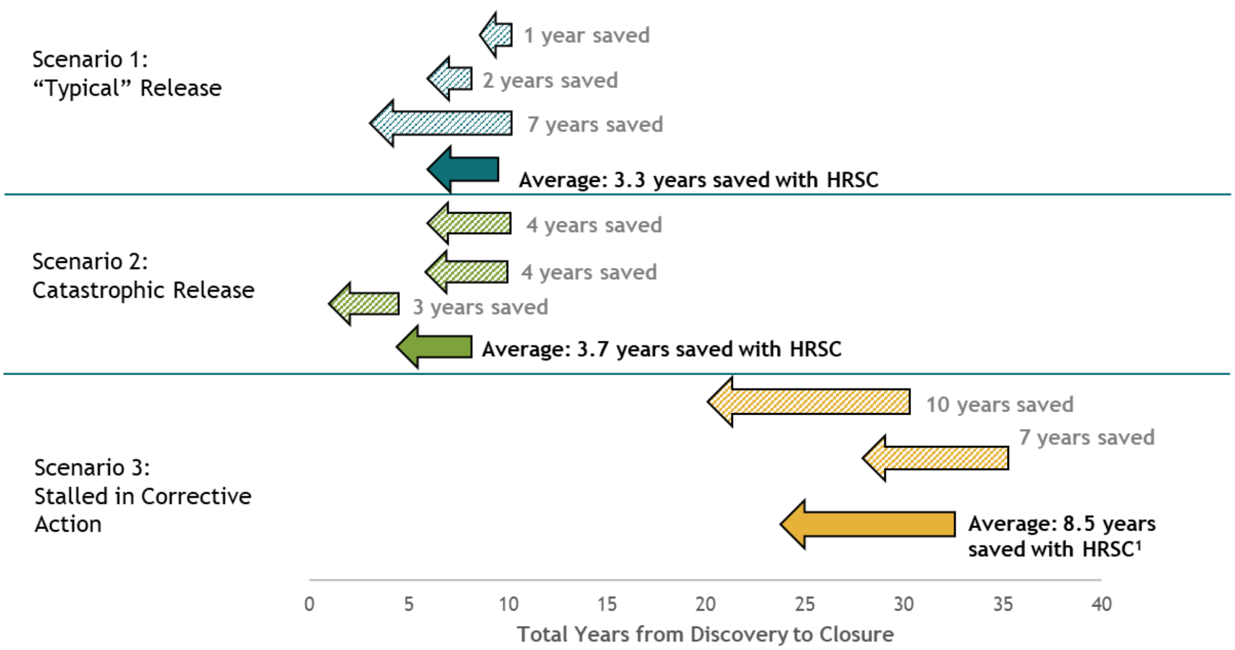
FIGURE 3. EXPERT INDIVIDUAL AND AVERAGE COST IMPACTS WHEN USING HRSC INVESTIGATION COMPARED TO TRADITIONAL TECHNIQUES ALONE ACROSS THREE PETROLEUM UST RELEASE SCENARIOS



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.

FIGURE 4. EXPERT INDIVIDUAL AND AVERAGE ESTIMATES OF CHANGES TO PROJECT DURATIONS WHEN USING HRSC INVESTIGATION COMPARED TO TRADITIONAL TECHNIQUES ALONE ACROSS THREE PETROLEUM UST RELEASE SCENARIOS



Notes:

1. Expert C did not provide a duration estimate for the Stalled in Corrective Action scenario due to the complexity of the scenario. The average reflects the responses provided by experts A and B.
2. Right end of arrows represent expert's estimates of total project duration using traditional characterization techniques while left end represents duration when using HRSC (e.g., Expert A estimated a 30-year duration with traditional characterization and 20-years with HRSC in Scenario 3).

RESULTS: ADDITIONAL COST EXERCISE [STATES AND TECHNOLOGY PROVIDERS]

We conducted an additional cost exercise to obtain cost ranges for 3- and 5-day HRSC investigations at a "typical" gas station release scenario. To do this, we sent phase one contacts a specific scenario and asked them to provide cost assessments.[10] This exercise resulted in the cost estimates shown in **Figure 5**, along with the following key findings:

- **Responses yielded an average cost of $36,679 for 3-day investigations and $49,550 for 5-day investigations.** The respondents pointed out that site investigation costs vary significantly based on provider, project location, and specific circumstances of the site. As such, each respondent

[10] Appendix B provides the worksheet we sent respondents, which includes a description of the scenario (developed by EPA OUST).

had to make additional assumptions about the scenario that likely relied on their own experiences and therefore differed amongst respondents. Despite this, when asked to provide a cost estimate range, most respondents predicted ranges that centered around the averages in **Figure 5**.

- **State respondents and technology providers/consultants tended to be in close agreement on these cost estimates.** The estimates provided by both groups were similar, indicating that the perception of actual HRSC costs from the state and federal regulator perspective is reasonable.

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.

I. METHODOLOGY

METHODOLOGY OVERVIEW

During the initial LUST cleanup cost study conducted by EPA and IEc, we attempted to quantify the impacts of a number of potential cost drivers on final cleanup costs and durations.[11] One of the cost drivers that we had hoped to study was the impact of using HRSC techniques for site characterization. Due to limitations in the project data that states provided, along with the lack of a counterfactual (i.e., it is impossible to determine what the final cost would be at a site when using HRSC if it was not actually selected, or vice versa), we were unable to answer this question. Still, the data suggested that higher investments in site characterization efforts might reduce cleanup and total project costs. As a result, we conducted this follow-up study to try to determine the cost and project duration impacts, along with the best use cases, when using HRSC. Because of the lack of project data, we relied primarily on in-depth interviews with industry experts and an expert elicitation process.

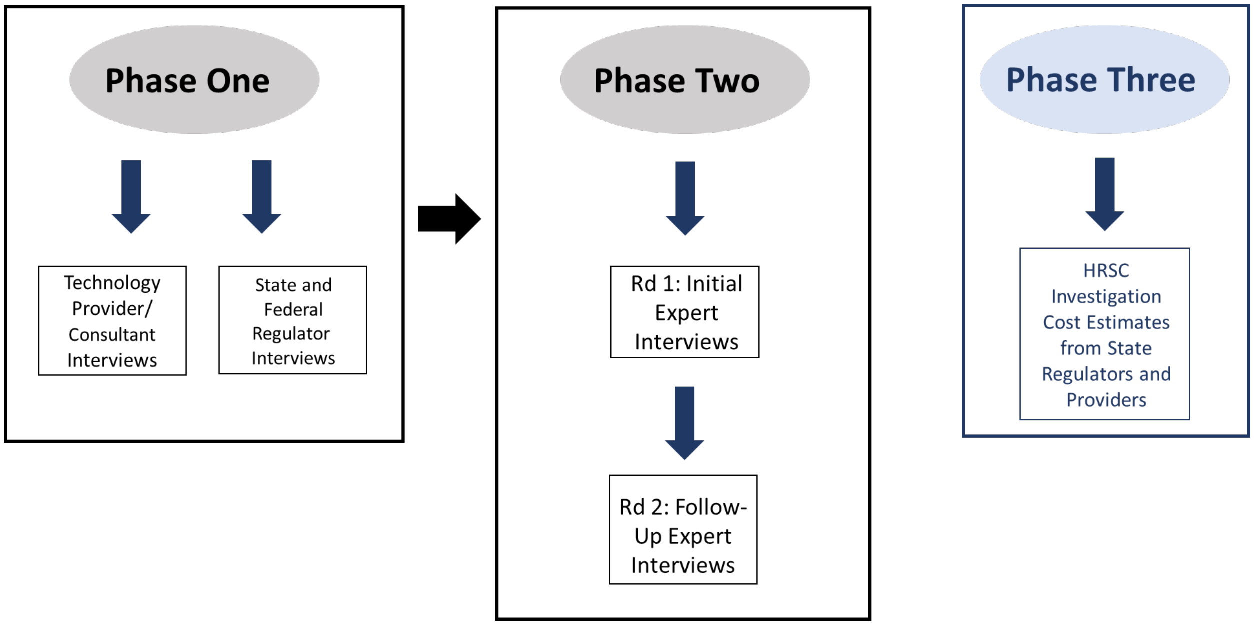
Specifically, we conducted our study in three phases, depicted in **Figure 6** below:

- **Phase one** consisted of interviews with technology providers and state and federal regulators.
- **Phase two** consisted of two rounds of interviews with three experts using an expert elicitation/Delphi Panel approach that aims to reach consensus.[12]
- **Phase three** was an additional cost exercise that consisted of asking state fund managers, technical LUST managers, and HRSC providers for cost ranges for 3- and 5-day investigations at a pre-defined "typical" LUST site scenario.

[11] US EPA and Industrial Economics. 2022. Leaking Underground Storage Tank Cleanup Cost Study. Mar. 29.

[12] A Delphi Panel is an expert elicitation technique used in cases where data is not widely available to answer a specific question. This approach involves soliciting information on a topic from a group of experts, compiling the estimates of all experts involved, presenting the anonymized estimates to the other experts, and allowing them to change their estimates based on the responses from the rest of the group, with the goal of finding consensus amongst experts. In this case, we were looking for expert consensus on the potential cost and time savings of using HRSC techniques in site characterization at three LUST site scenarios we described.

FIGURE 6. HRSC COST STUDY INTERVIEW PHASES



We describe each phase in more detail below. Additional documentation including interview guides can be found in **Appendix B.**[13]

PHASE ONE

TECHNOLOGY PROVIDER INTERVIEWS

EPA OUST compiled a list of five HRSC technology providers and consultants (hereafter referred to as "technology providers" or "tech providers") as potential interview targets. We conducted 90-minute interviews with each of these industry experts. During the interviews, we asked about their experience using HRSC tools, the impact of HRSC on overall project costs, the use cases where HRSC would be most or least beneficial, and the barriers to widespread HRSC adoption[14].

[13] While we include most materials as they were provided to the experts, we do not include the full phase one synthesis documents that we provided to them, as the key information in the synthesis documents is incorporated in the report findings.

[14] We described 15 potential use cases developed by EPA OUST where HRSC could be used in UST cleanups and asked interviewees to rate the potential usefulness and cost and time saving potential of HRSC compared to traditional techniques for each one. We describe this process further in the Use Cases section below. The use cases were implicitly for sites where existing information was not sufficient to resolve important data gaps and where additional information needed to be gathered and either traditional or HRSC investigation techniques could be used to resolve those data gaps. Many petroleum release cases may not require significant additional data gathering to allow case decisions to be made. Those cases were not the focus of this study.

STATE REPRESENTATIVES INTERVIEWS

EPA OUST compiled a list of 16 state representatives involved in LUST site management. We conducted 60- or 90-minute discussions with these contacts across four separate group calls, ranging from two to seven participants in each group. We spoke to a total of 13 state representatives from nine states (Alabama, California, Colorado, Indiana, Kentucky, Louisiana, Minnesota, South Carolina and Tennessee), and three EPA representatives (two from Region 8 and one from Region 5) during this process. These interviews were nearly identical in structure to the technology provider interviews, again focusing on each respondent's experience using HRSC tools, the impact of HRSC on overall project costs, the use cases where HRSC would be most or least beneficial, and barriers to more widespread adoption of HRSC.

PHASE TWO

EXPERT SELECTION PROCESS

During the phase one interviews, we asked all participants to provide us with the names of any independent experts who could speak in-depth about HRSC to participate in phase two. We worked with EPA OUST to refine the list of contacts, ultimately deciding to reach out to seven contacts to participate in the Delphi Panel. From this effort, we conducted screening calls with four potential panelists to explain the structure of the Delphi Panel and the time commitment needed to participate. We gave the experts an opportunity to ask questions about the process and confirmed that each expert panelist did not have a conflict of interest that would prevent them from being objective participants.[15] After the initial screening calls, we finalized a list of three independent experts who did not have any conflicts of interest and who felt comfortable in their expertise to participate.[16] The goal of the Delphi Panel was to get closer to expert consensus.

Prior to beginning the phase two interviews, we used the information collected from phase one to create two synthesis documents which we shared with the experts. We also shared additional background reading, including articles about HRSC, and our initial report on the cost of LUST cleanups.[17] Additionally, we sent an expert questionnaire which we asked the experts to fill out in advance of the first meeting.

INITIAL EXPERT INTERVIEWS

During the initial expert interviews, experts provided feedback on the key takeaways from the round one interviews and provided their own feedback to the expert elicitation questions and the use case questions from phase one. We then provided experts with an exercise involving three hypothetical cleanup scenarios that we developed with EPA OUST – a "typical" release, catastrophic release, and site

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[15] One expert did invent a multilevel sensor technology from which he receives minimal royalties, however this technology differed from those we were focused on during this study.

[16] Experts were provided with an honorarium for their participation in the Delphi Panel.

[17] Dyment S., and Kady, T. 2018. Part 1: To HRSC or Not? What a Great Question! L.U.S.T.LINE. Aug. LUSTLine_84.pdf (neiwpcc.org) ; Dyment S., and Kady, T. 2019. Part 2: To HRSC or Not? Cost vs. Benefits. L.U.S.T.LINE. Mar. LUSTLine-85.pdf (neiwpcc.org) IEc Leaking Underground Storage Tank Cleanup Cost Study

stalled in corrective action – and asked the experts to estimate project costs and durations with and without HRSC for each scenario.

FOLLOW-UP EXPERT INTERVIEWS

We synthesized all three expert responses and shared a summary of anonymous responses with the experts. On a second call with each, we asked for feedback on the responses from other experts, and asked each expert to consider whether those answers made them rethink their own assumptions and responses. We took note of their thoughts and any adjustments they wanted to make after seeing the results.

PHASE THREE

EPA OUST created a worksheet that we shared with 10 respondents, including seven respondents who participated in phase one and three who did not. We selected the 10 respondents based on their backgrounds and the extent to which they worked with cost data. The worksheet described a typical gas station LUST site and asked respondents to fill in low- and high-cost range estimates for a 3- and 5-day HRSC investigation. **Appendix B** shows the full worksheet that we sent participants.

II. USE CASES AND BARRIERS

SUMMARY OF KEY FINDINGS

The phase one and two interviews produced the following key findings pertaining to use cases for HRSC:

- Respondents across all interview phases agreed that HRSC is beneficial in nearly all use cases. This was reflected in an exercise where we provided respondents with 15 use cases and asked the state and federal regulators, technology providers, and independent experts to rate the time and cost saving potential, and benefits of HRSC compared to traditional techniques. All 15 use cases received the highest possible rating from at least one respondent; and the majority of use cases received high rankings from most to all respondents.
- Respondents agreed that using HRSC to develop a conceptual site model leads to more informed decision making when selecting a remediation technique.
- Expert panelists, state and federal regulators, and technology providers indicated that HRSC can reduce long-term project costs, provide useful insights into adequately addressing a release, and help sites reach closure or No Further Action status more quickly.
- HRSC was described as having the greatest potential cost and duration benefit at catastrophic release sites and sites that are stalled in corrective action, although “typical” release sites can also benefit from the additional information available through HRSC.
- If access to HRSC was limited, all respondents noted they would prioritize use of HRSC at the sites with the highest risk to human health and the environment.

Each group noted major benefits of using HRSC tools, but also noted that HRSC is still not used at most LUST sites. This can be explained in part by the many barriers to widespread HRSC adoption that each group raised. Key barriers raised by each group are listed below:

- **State representatives:** Site geology and lack of available expertise.
- **Technology providers/consultants:** Lack of incentive for an owner to incur higher upfront cost and inertia (i.e., more support for traditional approach and/or lack of traction for HRSC approach). Technology providers also noted that a lack of clear reimbursement guidelines for HRSC in state funds is a barrier for widespread HRSC adoption because site owners risk not being reimbursed for the activity.
- **Experts:** Inertia (i.e., more support for traditional approach and/or lack of traction for HRSC approach) and lack of guidance regarding these tools for states and providers.

A detailed description of the takeaways from each group of interviews can be found below.

STATE AND FEDERAL REGULATOR INTERVIEW FINDINGS

All state and federal respondents had experience working on cleanups at LUST sites, but each state regulator had varied levels of experience employing HRSC techniques. The responses from state and federal regulators reflect their experiences.

TYPICAL CASES WHERE HRSC IS USED

Respondents agreed that HRSC is a powerful tool for increasing the amount of information available from nearly any site beyond the capabilities of traditional monitoring wells. It can be useful at any contaminated UST site to better characterize the extent of the pollution and the geologic structures in the area. One interviewee noted that the value created by the additional HRSC investigation data allows them to say “we know” instead of “we think” when it comes to risk-based site closure. Another interviewee echoed this sentiment, saying HRSC allows site managers to have more confidence in their understanding of site geology. State respondents converged on many key situations where HRSC would be most beneficial. These included:

- Sites where an investigation has stalled and/or remedial action has been unsuccessful so far due to limited or incorrect information.
- Sites with sensitive receptors in the vicinity of the release.
- Sites with a release that is complex and not easy to characterize.

HRSC USE OVER TIME

State LUST programs had different levels of experience in implementing HRSC. Some states, such as Alabama and California, have used HRSC in their investigations for years, while others, such as Indiana and South Carolina, were new to HRSC investigations and had only used it for a small number of sites.

State respondents reported that HRSC is not used at a large percentage of cleanups today, even in states that are very familiar with HRSC. Overall, respondents reported that HRSC use has increased over time, due to improved access to the technologies and awareness of the benefits, but the adoption of HRSC technologies is still not widespread. This is due in part to state fund reimbursement restrictions. We explain the additional reasons that HRSC adoption has been slow in further detail in the **Barriers** section below.

HRSC USE AND EXPERIENCE

State and federal regulators highlighted the benefits of the in-depth information that HRSC provides in in reducing the time and number of iterations required to characterize a site. State representatives explained that efficiency in characterization leads to the development of targeted remedial decisions that can result in faster site closure than traditional site characterization methods. While the specific HRSC technologies used vary somewhat by state and site, the following were mentioned multiple times: direct push, MIP, OIP, LIF, HPT and EC. In some cases, project managers mentioned other technologies such as multilevel groundwater sampling, high density soil sampling, passive soil gas sampling, and geophysical techniques. HRSC technologies can also be used to visualize a 3D rendering of the subsurface release, soil layering, quantify the volume of the release, and determine the type of contaminants, among other uses.

The timing of when HRSC is used in an investigation also varies across states. Some states use it as a first step of the investigation, while others use it as part of a traditional monitoring well investigation. States conducting an HRSC investigation after the first round of monitoring wells are installed do so to optimize the placement of subsequent monitoring wells and reduce the number of monitoring wells needed.

Other states use HRSC primarily long after the normal site assessment phase when they feel that a flawed conceptual site model has led to an ineffective remedy. States that had more experience with HRSC were more comfortable using it in the initial investigation phases.

CASES WHERE HRSC IS NOT BENEFICIAL

State and federal regulators indicated that the information collected from an HRSC investigation would always be beneficial, but there are some cases where an HRSC investigation may not be worth the cost. Respondents reported that HRSC would not be necessary if the geology was simple, the release did not threaten any sensitive receptors, or if the remedial action plan in place was progressing as expected. HRSC may not be beneficial if geologic barriers such as bedrock or underground utilities prevent the use of direct push techniques as that could cause the process to be more complex and more expensive.[18]

INVESTIGATION COSTS

When asked about the costs to complete an HRSC investigation, state and federal representatives provided different descriptions of overall costs using different units (e.g., per day, per foot, per project). This makes it difficult to compare the cost estimates across respondents. **Table 1** on the following page summarizes the cost estimates provided by state and federal regulators.

COST SAVINGS

Participants agreed that HRSC is likely to save money over the course of the corrective action project compared to using traditional characterization methods alone, due to time and resources saved by efficiently and accurately characterizing a site from the beginning. Seven participants believed that HRSC had higher upfront costs than traditional methods but noted that “you get what you pay for” in terms of the value added through information gained using HRSC. When asked to compare costs of HRSC investigations to projects using just traditional methods, one participant noted that HRSC had saved them over $100,000 in investigation costs in one instance.[19] Other interviewees agreed with this sentiment but did not have enough data to make the comparison using actual numbers. One interviewee suggested that the more complex a site, the more money HRSC will save states over the course of the project. Another said that although they did not have exact data yet, they predicted that HRSC would save money in the long term by better defining cleanup goals and targeting contaminant masses better with corrective action.

State and federal regulators tended to view the cost question in the short term and focused their responses more on the comparison between upfront costs of HRSC and those of traditional methods during the initial investigation phase. This differed from the technology providers, who tended to view the cost question in the long run and emphasized the potential cost savings throughout the duration of projects.

[18] Technology providers we spoke with indicated that many of the challenges due to geology could be addressed by tailoring an HRSC and drilling procedure to get past areas of refusal. Some states had done this in the past, but that did not appear to be a common course of action from the state and federal regulator perspective.

[19] Investigation costs at a site that used traditional methods were $188,000 but investigating a site with HRSC cost $78,000.

Cost estimates varied by state because costs are dependent on geology, size of release, type of release, complexity of release, distance traveled by HRSC contractor, etc. Cost savings in the long run come from the reduction in time spent characterizing the site and the ability to specifically tailor the remediation strategy to the details of the release.

TABLE 1. COST ESTIMATES FROM STATE AND EPA INTERVIEWEES

Technology	Respondent Region	Number of HRSC Sites[1]	Notes	Cost		
				Per Day	Per Foot	Per Project
LIF/OIP, MIP, HPT	South	40	Respondent noted an issue with per-day costs because equipment breakage can mean that little to no progress is made in a day of drilling, so they created per-foot rates. Mobilization costs were $1,360 per project and HRSC 3D models were $4,040	-	$27, $29, $33.50	-
LIF, MIP	Midwest	Several hundred	Respondent typically uses LIF at the beginning of an investigation to determine with the extent of LNAPL instead of using HRSC technologies later in the assessment process to create a conceptual site model	$12,000	-	$20,500 to $25,000
UVOST/LIF, MIP	South	68	Respondent said that complex sites could cost as much as $100,000 and that the investigation typically lasts four days but could take 2 weeks.	-	-	$50,000
MIP	West	-	Respondent indicated that three days of MIP are typically included in their investigations	$3,000 to $3,500	-	$10,000
MIP	Midwest	3	Respondent said that previous work was closer to $3,500 per day in some cases, but that including mobilization brings the per day cost closer to $5,000	$4,100	-	-
Not specified	South	16	Roughly 40% of costs would get added on for time and mobilization	$6,000 to $7,000	-	-
Not specified	West	Over 100	Respondent noted that a report with 3D modeling would be an additional $1,200	$6,000	-	-

Technology	Respondent Region	Number of HRSC Sites[1]	Notes	Cost Per Day	Cost Per Foot	Cost Per Project
Not specified	West	20	Respondent noted that the cost per day depended on the tool used but that the costs typically fall in that range	$4,000 to $4,500	-	-
Not specified	West	Over 100	Respondent noted that $1,500 would get added to the cost if traffic control was needed and $1,000 would get added if you had to core	-	-	$17,500
Not specified	South	140	Respondent noted that mobilization would add $4,000 to $6,000 to the total project costs, and that the project costs given would be for a four-to-five-day investigation	-	-	$36,000
Not specified	West	25	Respondent indicated that the number of days the investigation would last depends on how many borings and confirmation samples are needed but said the average is four to five days	-	-	$60,000 to $80,000
Not specified	Midwest	3	Respondent said that total project costs have varied widely across the handful of sites HRSC has been used at so far but that this was a good estimate	-	-	$75,000 to $78,000

1: Estimated number of HRSC sites that each state has completed according to the interviewee from that state.

2. "Not specified" includes one or more of LIF, OIP, MIP, EC, HPT.

DURATIONS

Some state representatives did not have enough HRSC experience to say with certainty that HRSC shortened project durations. Those who did have enough experience reported seeing reductions in time spent on site characterization, deciding on a remedial action, and overall time to site closure when using HRSC. At a specific site, one respondent reported that they had characterized the site one and a half years faster than it typically takes them using traditional methods. Another interviewee said that they reached NFA at a site within nine months of the HRSC investigation being conducted. One respondent also noted that HRSC can help kickstart interest in stalled sites and help them to move faster through the decision-making process. Other participants echoed this sentiment.

USE CASES

We provided state and federal interviewees with a list of different cleanup use cases developed with EPA OUST. For each use case, we asked respondents whether HRSC would be useful, would save money, and would save time, compared to a site using traditional characterization methods ("Yes", "No", or "Maybe" responses were allowed for each). **Figures 7**, **8**, and **9** show the results of that exercise. In each scenario, the majority of respondents said "Yes" or "Maybe" when asked if HRSC would be useful, would save money, and would save time. This indicates that respondents view HRSC as a useful technology that can generally save both time and money over the lifespan of a cleanup compared to traditional techniques. The use cases listed below were highly rated in each of those categories:

One hundred percent of interviewees responded "Yes" when asked if HRSC would be useful in the following use cases:

- When determining what level to place monitoring well screens and select screen lengths in sites with soil layers that have highly contrasting permeability.
- Where one or more monitoring wells show persistent or recurring levels of LNAPL that is not explained by the CSM.
- Where a large release has occurred into complex layered soils and the pathways of travel are uncertain.

One hundred percent of interviewees responded "Yes" or "Maybe" when asked if HRSC would save money in the following use cases:

- When contemplating an active remedy that will cost more than $100,000.
- When chemicals, absorbents, or nutrients will be injected into the ground.
- Where there are sensitive receptors nearby and the extent and potential movement of contaminants need to be determined with certainty and speed.

One hundred percent of interviewees responded "Yes" or "Maybe" when asked if HRSC would save time in the following use cases:

- When determining what level to place monitoring well screens and select screen lengths in sites with soil layers that have highly contrasting permeability.
- Where one or more monitoring wells show persistent or recurring levels of LNAPL that is not explained by the CSM.
- Where LNAPL presence in monitoring wells or movement is not explained by the current conceptual site model or is inconsistent with the groundwater gradient.

FIGURE 7. USEFULNESS OF HRSC IN SPECIFIC USE CASES (STATE AND FEDERAL REGULATORS)

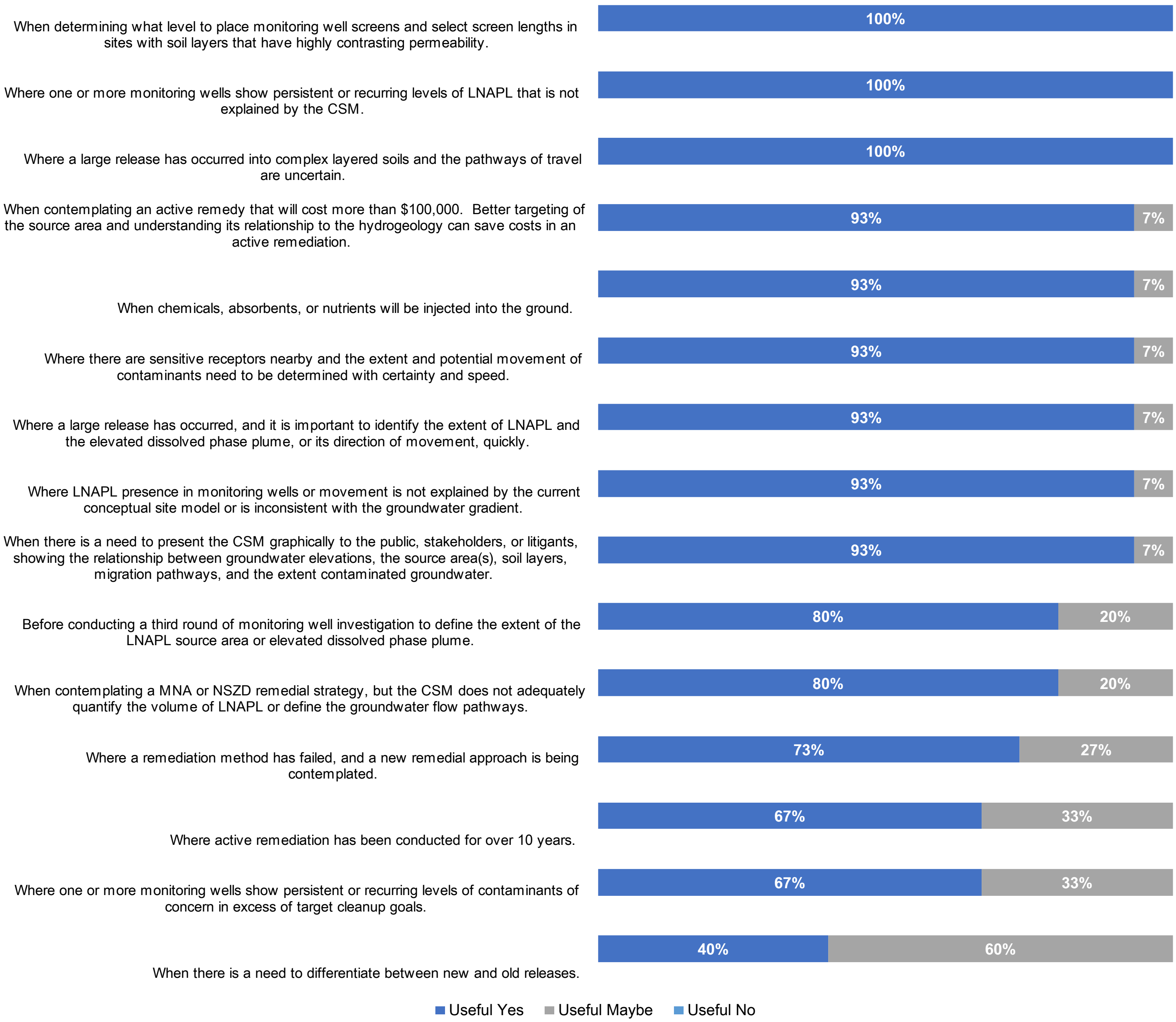


FIGURE 8. COST SAVING POTENTIAL OF HRSC IN SPECIFIC USE CASES (STATE AND FEDERAL REGULATORS)

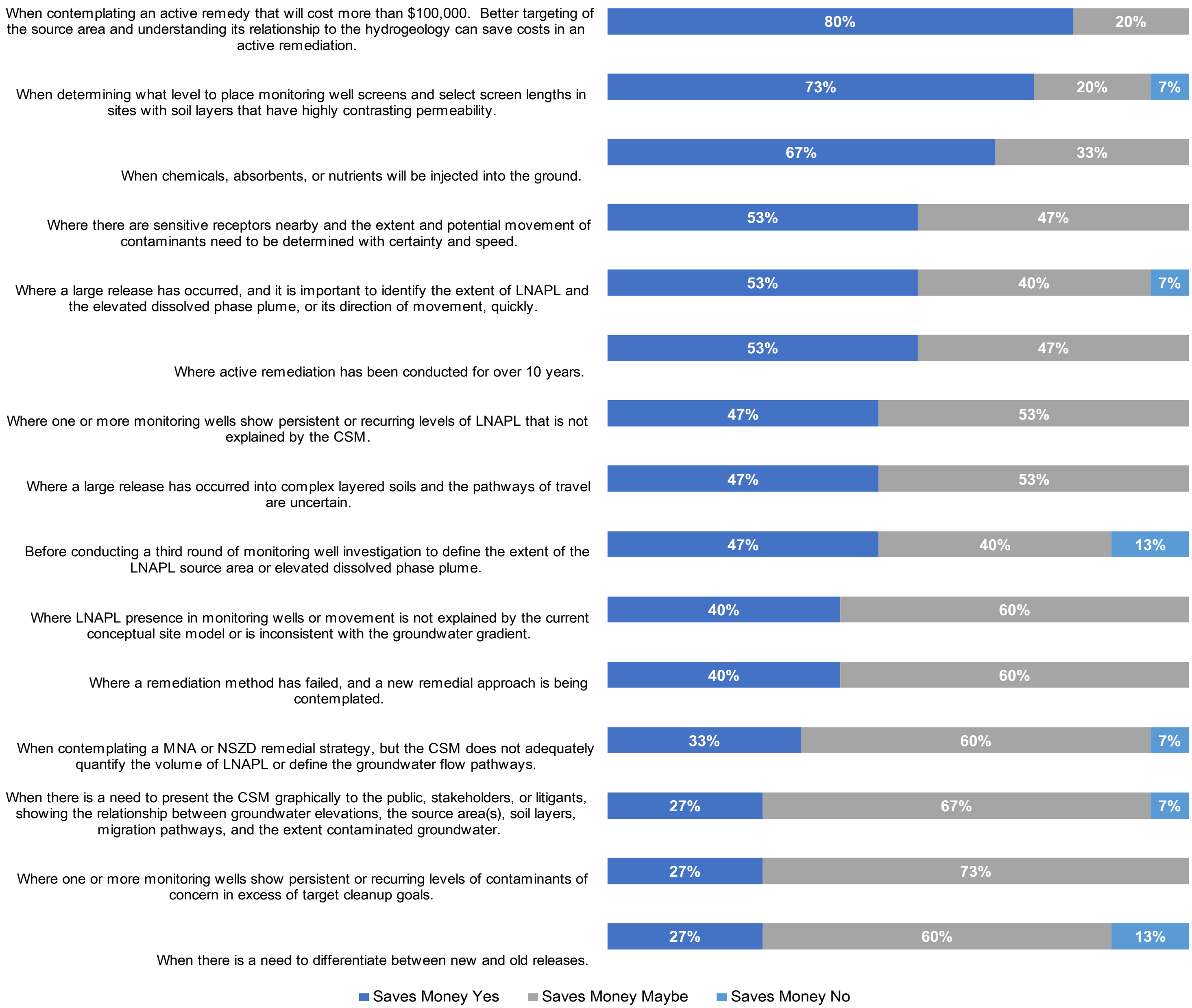
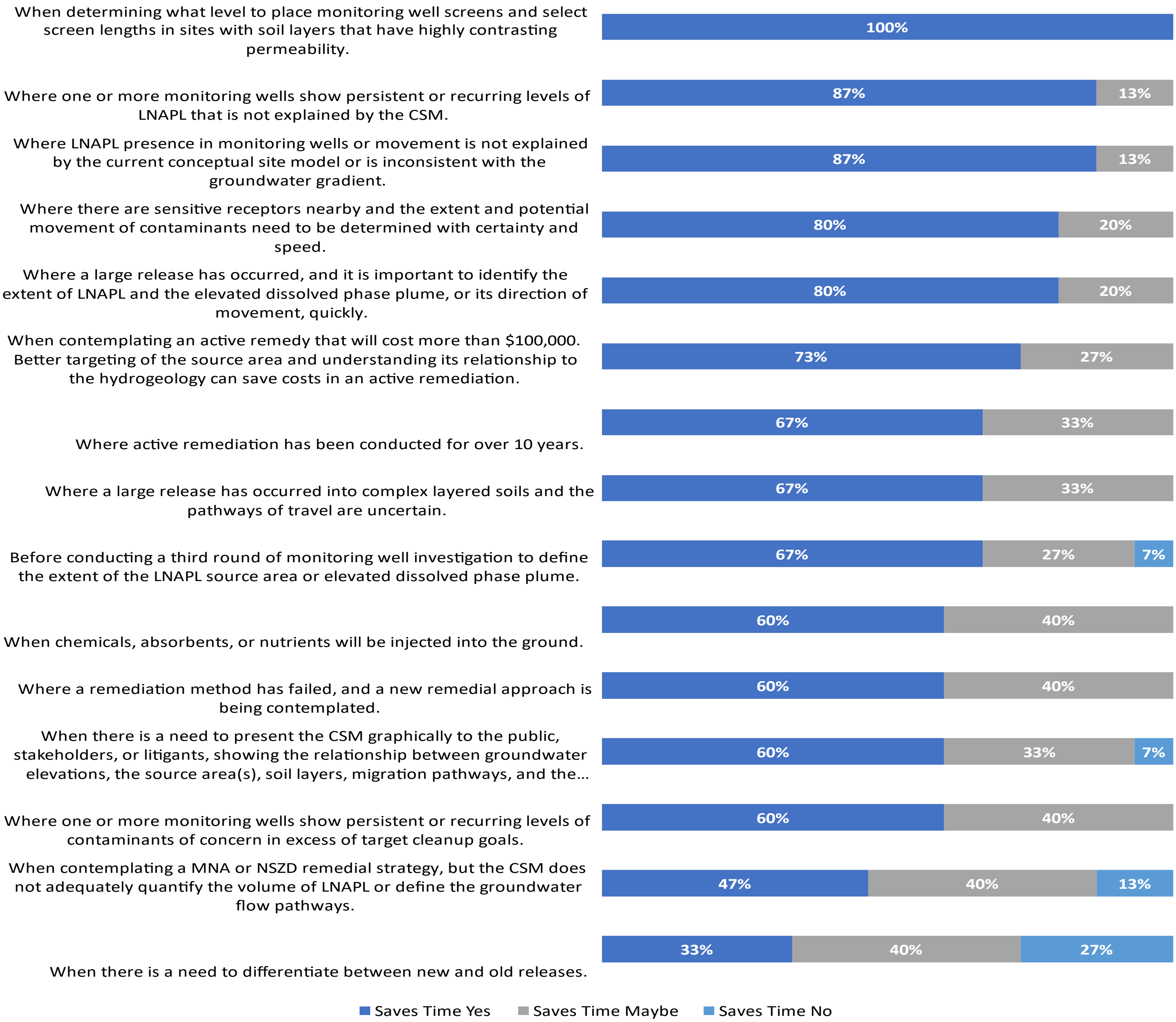


FIGURE 9. TIME SAVING POTENTIAL OF HRSC IN SPECIFIC USE CASES (STATE AND FEDERAL REGULATORS)



BARRIERS

We asked respondents to rate a list of potential barriers to increased HRSC use on a scale from 1 to 10 (with 10 representing the greatest barrier to more widespread HRSC adoption). **Table 2** shows the list of barriers, along with the maximum, minimum, and average rating given to each. The ratings varied widely across participants, indicating that the barriers to HRSC differ across states and specific projects. Unlike the HRSC use cases where interviewees consistently agreed, there was no clear consensus on ratings for barriers to HRSC adoption. For example, across all barriers there was at least one ranking as low as 2 and at least one greater than 7. This was due in part to the varied experiences that each state has with HRSC at LUST cleanup sites. The following takeaways are also worth noting:

- "Site geology" (depth of release, hardness, thickness of rock, etc.) was most frequently rated as a 10 (33 percent of respondents) and had the highest average rating (7.2). The next highest average rating was for "Owners or their consultants do not propose HRSC," at 6.7.
- Cost was not rated as a 10 on its own, but "Lack of information on cost savings that result from HRSC investigations" had the sixth highest average rating at 5.9, suggesting a potential gap in awareness about the potential long-term financial benefits of HRSC.
- State and federal representatives commonly referenced "Inertia" as a barrier to HRSC – the idea that HRSC technologies must overcome the status quo (traditional methods) to be more commonly used.
- The barriers with the third, fourth, and fifth highest average ratings were "Resistance from site consultants," "Inability to interpret results," and "Lack of available expertise," respectively. These results may emphasize a gap in knowledge between technology providers and state and federal regulators. Some state representatives also mentioned the difficulty of using HRSC due to the limited availability of skilled HRSC contractors, which is reflected in this result.

TABLE 2. BARRIERS TO HRSC ADOPTION (STATE AND FEDERAL REGULATORS)

Barrier	Average Rating	Max Rating	Min Rating
Site geology/other underground factors (e.g., utilities) that prevent the use of HRSC	7.2	10	1
Owners or their consultants do not propose HRSC	6.7	10	3
Inability to interpret results	6.6	10	1
Lack of available expertise	6.4	10	3
Resistance from site consultants	6.2	10	2
Lack of information on cost savings that result from HRSC investigations (when can HRSC be beneficial)	5.9	10	1
Inertia (e.g., more support for traditional approach and/or lack of traction for HRSC support)	5.7	10	2
Lack of incentive for the owner to incur a higher upfront cost	4.9	10	1
Cost	4.8	9	1
Lack of guidance that identifies situations where HRSC is appropriate	4.8	10	1
"Psychology" dealing with unexpected results from HRSC	4.1	8	1
Lack of correlation to monitoring well investigations	4.1	8	1
Not incorporated into the actual decision-making process or regulatory standards	4.1	10	1
Owners do not want detailed information on, and explicit graphics of the contamination	3.5	10	1
Not covered under allowable costs under fund guidelines	2.6	10	1

TECHNOLOGY PROVIDER AND CONSULTANT INTERVIEW FINDINGS

We spoke to five technology providers/consultants who all had at least 25 years of experience in the industry. Based on their experiences, these interviewees shared the following information:

TYPICAL CASES WHERE HRSC IS USED

Technology providers agreed that HRSC is an important component in providing additional information and contributing to the full picture when characterizing a site. It can be useful at any contaminated site and is beneficial for characterizing site geology, evaluating conceptual site models, and to understand the spread of contaminants in NAPL form or the dissolved phase. HRSC direct push techniques can be used at nearly any site where there are no geological or other physical restrictions. Some geologic limitations can be overcome by case specific modifications of the technology or how the technology is applied.

When asked about specific cases where HRSC would be beneficial, one respondent specified that any site with at least 500 gallons of release would be a place to use HRSC. However, this respondent also mentioned HRSC is beneficial at any “non-trivial” site including those with smaller releases but a highly transmissive geology or with substantial concerns about water. Other respondents agreed that HRSC would be beneficial at nearly any site where a non-trivial cleanup is required.

When asked how to prioritize which sites to conduct HRSC from a pool of sites with limited resources, two respondents mentioned risk as their first criteria, while two indicated that they would rely on site complexity/where the conceptual model or remedy has failed in the past. The remaining respondent said they would prioritize conditions where they knew the plume had not yet traveled far.

HRSC USE OVER TIME

Respondents reported that HRSC use represents a small number of LUST sites that they have been involved with in their careers (one respondent estimated its use at just two percent of the LUST cleanups with which they have been involved). There was some consensus that HRSC is being used more frequently now than in the past due in large part improved and expanded technology options and greater understanding of these technologies, although many decisionmakers are still slow to adopt the technologies.

HRSC USE AND EXPERIENCE

Respondents agreed that HRSC has been highly beneficial in helping to characterize sites and in providing expanded information. The additional data provided by HRSC investigations was cited by all respondents as its greatest benefit, allowing the sites to be characterized correctly and ultimately leading to quicker and more effective cleanups. Respondents reported using several HRSC technologies, including direct push technologies, MIP, LIF and UVOST. These technologies were used to quantify the mass and type of contaminants in releases, find high resolution lithology, create 3D profiles, conduct additional hydraulic profiling and more.

Similar to state and federal respondents, technology providers were split on the timing of when to use HRSC. All had used the technique in cases where traditional methods had failed, but some respondents advocated for using HRSC in concurrence with installing monitoring wells at new sites, while others suggested using HRSC only after some initial investigation (e.g., installing boreholes).

CASES WHERE HRSC IS NOT BENEFICIAL

Most respondents agreed that HRSC would be beneficial in almost all cases, provided there are no geological or infrastructure concerns physically preventing HRSC from being used.

Two respondents mentioned that if a release was small with no concerns about migrating plumes, receptors, and/or if decisionmakers felt that they could fully characterize the release with a few boreholes then HRSC may not be needed. However, both specified that these cases are rare. Respondents reiterated the importance of the additional data provided by HRSC and one stated that although they had done HRSC at some sites where it did not explicitly add information to the results of the traditional characterization, it was still beneficial in giving them confidence that the data were correct.

INVESTIGATION COSTS

Four respondents provided cost estimates for conducting HRSC investigations. We show the range of these costs in **Table 3**.

TABLE 3. COST ESTIMATES FROM TECHNOLOGY PROVIDER/CONSULTANT INTERVIEWEES

Technology	Notes	Cost		
		Per Day	Per Foot	Per Project
OIP/MIP/HPT	$7,500 was the estimate excluding mobilization. With mobilization he said costs would increase but should stay below $10,000.	$7,500-$10,000	-	-
Direct Sensing	Estimated costs of ~$10,000 per day for direct sensing and direct push. Respondent said roughly $20,000 in total for a full direct sensing investigation. Estimates were based on costs from about ten years ago.	$10,000	-	$20,000
Hydraulic profiling, UVOST, membrane interface probe, and electrical resistivity	Respondent did not specify that these costs were specific to the listed technologies but told us separately these were the technologies with which he had worked the most.	$3,500-$4,000	-	-
Not Specified	Respondent did not provide specific technologies but had worked with many in the past.	-	-	$30,000-$40,000

Respondents typically estimated per-day HRSC costs to be similar to the costs of installing a monitor well. They estimated total HRSC costs to be similar or slightly less than typical total costs of traditional assessment/characterization techniques.

COST SAVINGS

According to respondents, HRSC reduces total project costs by helping to 1) characterize the release, 2) select the correct remedial action and 3) conduct the remediation in a faster manner. Above all, cost savings are mainly driven by reaching closure faster, especially by reducing the time (years) spent doing monitoring, sampling, and investigation, and by increasing certainty in both selecting a remediation strategy and recognizing when a site can be closed. HRSC can also inform the correct place to do injections to ensure that this expensive approach is not being wasted. Respondents agreed that cost savings varied substantially based on the site but the larger, more complex, the site, the greater the benefit of doing HRSC.

Three respondents talked specifically about the financial benefits of conducting HRSC early at a site to be sure the site is characterized correctly and to save costs in the long run by ensuring that cleanup money is not wasted on a site that was not correctly characterized.

Three respondents provided estimates on cost savings. These were:

- Roughly $10,000-$30,000 per year in reduced costs to do sampling and write reports at sites that remain open. This respondent estimated that based on these costs, HRSC would save money over the project's life cycle if 2-3 years could be reduced (which they felt would almost always be the case).
- Up to $1.5 million at larger/high risk sites (from $50k of HRSC costs upfront).
- Roughly $100,000 per site as an average across a portfolio of sites.

Respondents gave examples of small LUST sites where the releases were easy to characterize as places where HRSC might be less likely to save money. However, most respondents reported HRSC would still be beneficial to use in these cases if there was any uncertainty regarding the characteristics of the releases. Site complexity, region, geology, and technology were all cited as reasons why costs may vary across sites.

DURATIONS

Respondents agreed that HRSC reduces cleanup durations at sites and allows decisions to be made about a remedial approach more quickly than at non-HRSC sites. They also agreed that HRSC enables closure to be achieved sooner.

Three respondents provided direct estimates of how much time HRSC could reduce at a site. These responses were:

- HRSC could "easily [shave] off a couple of years" by reducing time to wait for lab results, 2nd and 3rd mobilizations and becoming sure of the characterization.
- "There isn't a UST site that can't be closed in about three years [by relying on HRSC], if you can find the mass or masses and get the remedy in place."
- "[At some sites] you can eliminate decades by refining your understanding of the contaminant and where it is."

USE CASES

We asked respondents to use a 1 to 5 ranking to rate the usefulness of HRSC in the same 15 use cases provided to state and federal respondents (where 5 means most useful). **Figure 10** shows the results of this exercise. Respondents gave high ratings to the usefulness of HRSC in all use cases that we described.

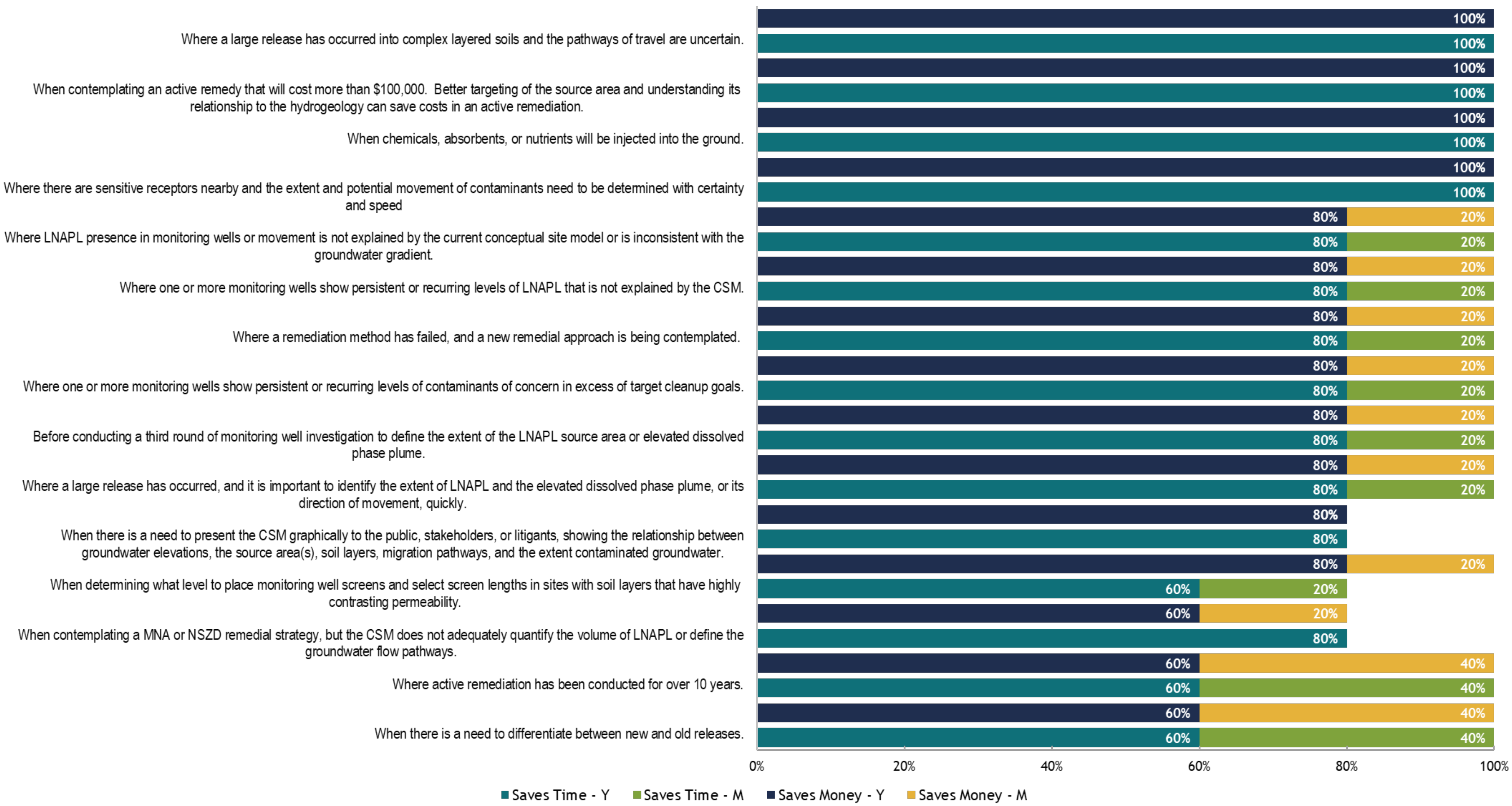
Cases where a “large release has occurred into complex layered soils and the pathways of travel are uncertain” received the highest rating (4.9 average). Situations where “chemicals, absorbents or nutrients will be injected into the ground”, “contemplating an active remedy that will cost more than $100,000”, and cases where “LNAPL presence in monitoring wells or movement is not explained by the current conceptual site model or is inconsistent with the groundwater gradient” received the next highest scores (4.8 average each). Only two scenarios received average ratings below 4. Each of these cases (“When there is a need to differentiate between new and old releases” and “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”) had an average rating of 3.8, suggesting that HRSC is still somewhat beneficial in those situations.

For each case, we also asked respondents to indicate if HRSC would save time and/or money compared to traditional approaches. Over half of the respondents indicated that HRSC would save time and/or money in every scenario. There were four cases where all experts agreed that HRSC would save time and money (**Figure 11**):

- Where a large release has occurred into complex layered soils and the pathways of travel are uncertain.
- Where chemicals, absorbents or nutrients will be injected into the ground.
- When contemplating an active remedy that will cost more than $100,000.
- Where there are sensitive receptors nearby and the extent and potential movement of contaminants need to be determined with certainty and speed.

FIGURE 10. USEFULNESS OF HRSC (TECHNOLOGY PROVIDERS/CONSULTANTS)

FIGURE 11. TIME AND COST SAVINGS OF HRSC (TECHNOLOGY PROVIDERS/CONSULTANTS)

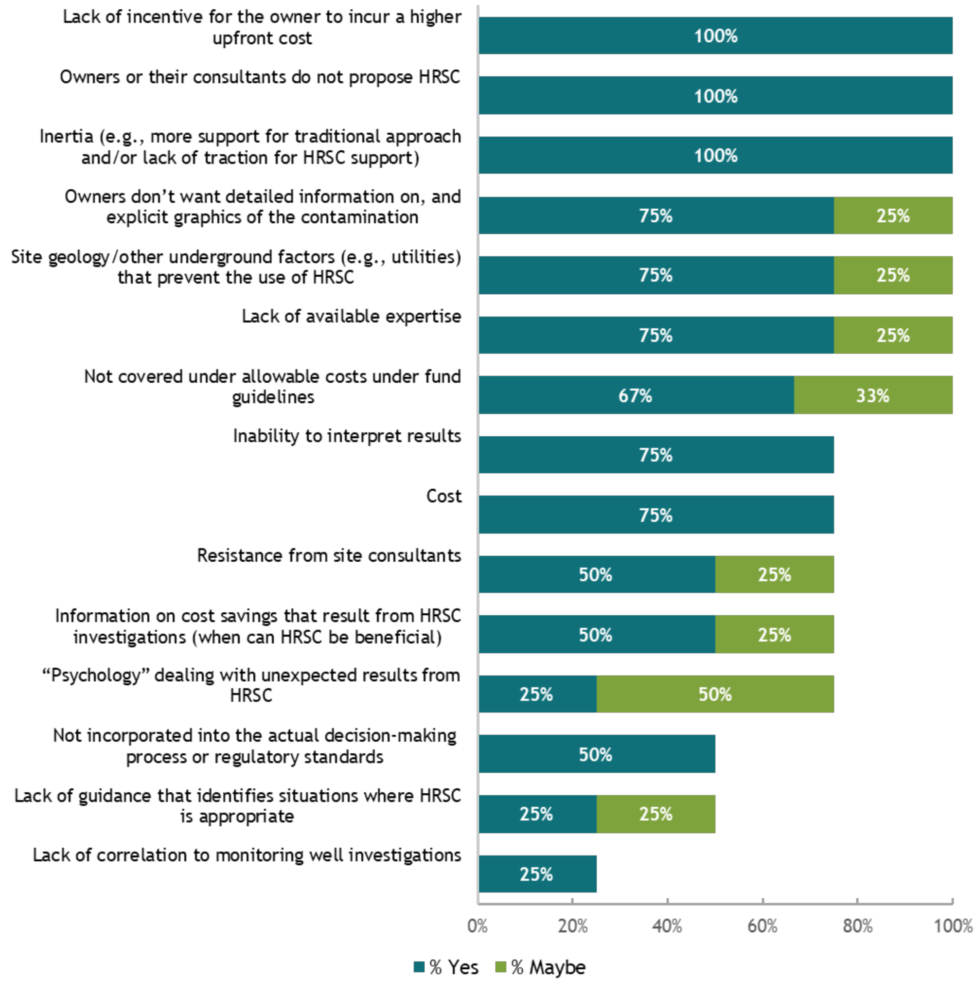


BARRIERS

We gave respondents a list of potential barriers that may prevent HRSC adoption and asked if they considered each to be a reason HRSC is not more widely utilized. **Figure 12** shows these responses. All respondents agreed that a lack of incentive for the owner to incur higher upfront costs, owners or consultants not proposing HRSC, and inertia are barriers to HRSC adoption. Owners not wanting detailed information, site geology, and lack of expertise were also cited as barriers or potential barriers by all respondents (three indicated yes and one indicated maybe for each of these scenarios. One participant did not provide responses). Only one respondent cited a lack of correlation to monitoring well investigations as a barrier, the least commonly cited of any category. However, another did mention that they thought this lack of correlation occurs frequently but is a greater indication that there is a problem with the monitoring well results than with the HRSC investigation.

When asked about the one or two greatest barriers to adopting HRSC, three respondents mentioned psychology/inertia. One described this succinctly saying many site owners view HRSC as something "extra" that they do not understand the value of adding when it is not required. Site geology and upfront costs were also mentioned twice when asked about the greatest barrier(s), while contractor attitudes towards HRSC and interpreting the data were each cited once.

FIGURE 12. BARRIERS TO WIDESPREAD HRSC ADOPTION (TECHNOLOGY PROVIDERS/CONSULTANTS)



*N=4. One respondent did not provide responses to this set of questions. One respondent did not provide a response on the state guidelines question due to lack of expertise.

EXPERT INTERVIEW FINDINGS

In this section we summarize the information from first and second rounds of the expert interviews that aligned with the questions asked in the first phase of interviews. As listed above, our phase two panel consisted of three accomplished industry experts each with decades of experience in site characterization. We provide additional details on each expert's background in **Appendix A**. In the **Cost Impacts** section below we summarize the second part of the phase two interviews, which involved collecting the expert's responses to an exercise where we asked each expert to provide estimates for investigation, remediation, and total project costs, along with total project durations, for three hypothetical sites (a "typical" release, catastrophic release, and site stalled in corrective action).

After the first round of interviews with the experts, we provided an anonymous summary of responses from the other two experts to see if this influenced any experts to change their responses. We note places where experts made changes following the first round below. The Delphi Panel approach resulted in more convergence after the second round of interviews when the experts had a chance to see each other's responses, but the experts were already generally in agreement prior to that step. This is a testament to the expert consensus on the utility and time/cost saving potential of HRSC. The responses below are condensed summaries from sections of the first and second round of interviews.[20]

ROUND ONE

TYPICAL CASES WHERE HRSC IS USED

The three experts agreed that HRSC is used to delineate LNAPL plumes and understand where the material is, both horizontally and vertically. It is also used for the process of matrix diffusion and for mass flux calculations. HRSC is used widely for chlorinated solvent release sites in unconsolidated geologies for groundwater investigations where contamination persists at depths down to about 150 feet and depth to groundwater above 50 feet, and HRSC can help more accurately define the depth of the plume. One expert noted that HRSC is also becoming more widely applied at groundwater sites with persistent contaminant levels above targets to modify CSMs. Another expert mentioned that HRSC methods, in particular sampling tools advanced with direct push rigs, are the most used site characterization technology today. However, they also noted that HRSC is not performed at every site where a direct push rig has been used. Their usage is appropriate to generate detailed understanding of the subsurface geology and contaminant distribution.

HRSC USE OVER TIME

All three experts agreed that HRSC use has increased over the past decade or two, particularly at chlorinated solvent sites, but also for LNAPL to a lesser extent.

[20] Although we attempted to standardize all assumptions given to each expert, opinions were influenced by personal experience and assumptions about how various actors would behave, which led to some differences amongst the experts' responses. Despite this, experts were in firm agreement that HRSC is an extremely useful tool in adequately characterizing a site under nearly any circumstances, saving time and money over cleanups using only traditional techniques, and contributing a high level of value through the additional information that the investigation provides.

BENEFICIAL ELEMENTS OF HRSC INVESTIGATIONS

Experts highlighted the beneficial elements of HRSC investigations at hydrocarbon sites in LNAPL detection and high-resolution vertical distribution of LNAPL. For chlorinated/PFAS sites, experts mentioned benefits as a combination of hydraulic profiling and groundwater sampling to estimate mass discharge. A key insight across each interview was that HRSC is the best way to collect high-quality and necessary data about a site. Transects using HRSC are highly beneficial for target or "precision remediation" and should always be part of a second round of investigations once the direction of groundwater flow is determined. Experts indicated that HRSC methods should be included in the full sequence of CSM development, starting with defining the subsurface geology and groundwater flow system, followed by delineating the nature and extent of solid phase (soil), residual NAPL, dissolved phase, and vapor phase contaminants.

CASES WHERE HRSC IS NOT BENEFICIAL (RELATIVE TO TRADITIONAL METHODS)

In general, experts agreed that there are very few cases where HRSC would not be beneficial relative to traditional methods due to the quality of the data collected. However, experts said that HRSC may not be necessary at what one expert described as "old, exhausted sites," meaning sites that may not be closed but have low concentration, stable plumes that are not spreading. When there is limited risk to receptors at a site with modest petroleum release and human health impacts are unlikely, HRSC may not be needed. One expert added that traditional monitoring well approaches capture an important element of a CSM that is typically lacking in one-time assessments using traditional HRSC methods, which is the temporal changes in the plume and mass loading rates.

USE CASES

We asked all experts to review the rankings provided by state and federal regulators and technology providers in the phase one interviews, before providing their own rankings for the usefulness of HRSC compared to traditional technologies using a 1 (least beneficial) to 5 (most beneficial) scale. **Table 4** shows the individual and average expert rankings. The experts gave consistently high rankings across all 15 use cases, but the following three use cases were given a five by all three experts:

- 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
- Where there are sensitive receptors nearby and the extent and potential movement of contaminants need to be determined with certainty and speed
- When contemplating an active remedy that will cost more than $100,000

The following use case had the lowest ratings:

- Where active remediation has been conducted for over 10 years

After speaking with interviewees, we determined that this scenario had lower ratings because people felt that a long remediation does not necessarily indicate an ineffective remediation because it could be going exactly as planned but taking longer than 10 years. This interpretation resulted in low ratings for this scenario across all three expert panelists.

TABLE 4. USEFULNESS OF HRSC (EXPERTS)

Scenario	Expert A	Expert B	Expert C	Average Expert Ranking (n=3)
Site Characterization				
1. 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.	5	5	5	5
2. When there is a need to differentiate between new and old releases.	4	3	5	4
3. Where a large release has occurred into complex layered soils and the pathways of travel are uncertain.	4	5	5	4.7
4. When determining what level to place monitoring well screens and select screen lengths in sites with soil layers that have highly contrasting permeability.	4	5	5	4.7
5. Before conducting a third round of monitoring well investigation to define the extent of the LNAPL source area or elevated dissolved phase plume.	4	5	5	4.7
6. Where LNAPL presence in monitoring wells or movement is not explained by the current conceptual site model or is inconsistent with the groundwater gradient.	4	5	5	4.7
7. Where there are sensitive receptors nearby and the extent and potential movement of contaminants need to be determined with certainty and speed	5	5	5	5
Stakeholder Communication				
8. 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 extent contaminated groundwater.	3	3	5	3.7
Remediation Design				
9. When chemicals, absorbents, or nutrients will be injected into the ground.	2	5	5	4
10. 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.	5	5	5	5

Scenario	Expert A	Expert B	Expert C	Average Expert Ranking (n=3)
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.	1	4	5	3.3
Stalled Corrective Actions				
12. Where one or more monitoring wells show persistent or recurring levels of LNAPL that is not explained by the CSM.	3	5	5	4.3
13. Where one or more monitoring wells show persistent or recurring levels of contaminants of concern in excess of target cleanup goals.	2	5	5	4
14. Where active remediation has been conducted for over 10 years.[1]	2	1	NA	1.5
15. Where a remediation method has failed, and a new remedial approach is being contemplated.	3	5	4	4

1. The usefulness ratings for scenario 14 were consistently lower than other scenarios. After speaking with interviewees, we determined that this scenario had lower ratings because people felt that a long remediation is not necessarily a negative thing, because it could be going exactly as planned which may take longer than 10 years.

BARRIERS

Experts agreed that the barriers to HRSC adoption are varied, but the main themes that came out of the interviews was a lack of thorough education on its benefits (both in data quality and cost/duration) of HRSC, and a focus by some regulators on restoration to pre-release conditions rather than risk-based closure. Regulations require a lab-based concentration to make decisions, so the regulator does not have the flexibility to use the bigger picture provided by HRSC. Therefore, the regulator will have to do the traditional investigation anyway which contributes to the perception that an HRSC investigation is superfluous. HRSC is not effective at low concentrations and when you need to delineate the leading edge of a plume or investigate movement to a drinking water supply, low level concentrations need to be known. The costs of HRSC were noted as a barrier because of the lack of education about the long-term cost benefits of the technologies. Additionally, the structure of state reimbursement programs limits the ability of site owners and consultants to conduct HRSC investigations if they are not included in the rate documents, or it is otherwise unclear what the funding mechanism for HRSC is. Lastly, “inertia” was a key theme that came up related to barriers to HRSC adoption. This is essentially the idea that people do not want to change their ways. In all industries, change is slow and difficult to incentivize. However, the experts feel it is time for an industry-wide shift in favor of HRSC now that the evidence in favor of it has mounted and their personal experience shows them the potential of cost and duration benefits relative to traditional techniques.

ROUND TWO

The Delphi Panel process includes synthesizing round one interview responses and sharing them with each expert, to see if the answers given by their fellow panelists make them reconsider their own responses. During round two, the experts were given the opportunity to refine their answers based on that new information. Between round one and round two, expert responses did not change substantially, which is a testament to the consensus already reached even prior to seeing each other's responses. Experts changed some ratings for the usefulness of HRSC in different use cases after more context was provided for the different assumptions made, and some small changes were made to the cost estimates as well which are covered in the **Cost Impacts** section below.

HRSC CONSIDERATIONS AND KEY INSIGHTS FROM THE EXPERTS

The experts converged on major themes throughout the Delphi Panel. The primary theme was the benefit of the added data provided by HRSC technologies. There was no scenario where the experts felt that HRSC would not be beneficial, and they only came up with cases where it would not be necessary when asked specifically. From the perspective of three experts who have decades of experience with site characterization, the increased information about the site and increased confidence in the conceptual site model that HRSC provides is well worth any added up-front investment relative to traditional technologies and is even likely to save money relative to traditional technologies over the lifetime of the whole cleanup project. The case for HRSC is clear from the findings regarding lower costs and durations, but the experts helped to underscore the idea that HRSC would be worth doing even if those other benefits were not present.

Additionally, experts agreed that there is a gap between theoretical understanding of these benefits and practical application that can be bridged by more national guidance and education. One expert struggled to see why anyone would choose not to characterize a site using HRSC, and even felt that one-time deployment of HRSC tools was not enough to adequately understand the movement of contaminants over time. This represents a substantial difference in perspective on best practices in site characterization between experts and the technology providers/consultants and state regulators from phase one interviews, who currently employ HRSC at a small percentage of their sites despite agreeing that the tools are very useful.

Experts indicated that there is a lack of knowledge on the benefits of HRSC and the value it adds regardless of the cost and duration implications, which contributes to the minimal use of HRSC at LUST sites despite the general understanding that it is useful. The interviews from phase one revealed a common misconception that HRSC increases overall project costs, which is the opposite of what we found in the cost component of the Delphi Panel, described in the section below.

III. COST IMPACTS

This section summarizes the findings from the cost exercise that experts completed during the phase two expert elicitation/Delphi Panel process. During this exercise, we asked experts to provide us with the following information across three hypothetical scenarios:

- Total costs of traditional (i.e., non-HRSC) site characterization with and without HRSC
- Total costs of HRSC investigation
- Total costs of corrective action over entire lifecycle of site with and without HRSC
- Time to closure with and without HRSC

The scenarios were defined as follows:

1) **"Typical release":** Investigation and scenario begin shortly after release discovery. The release was discovered during tank removal and the source and date of release is unknown. It has been an operating gas station for over 40 years. Some contaminated soil was removed at the time of tank removal. Some residual soil contamination was documented to remain in place. Two investigation monitoring wells were placed and confirmed groundwater exceeded state standards for benzene, BTEX, and MTBE.

2) **Catastrophic release:** Investigation and scenario begin shortly after release discovery. The release was approximately 5,000 gallons of gasoline and occurred over a weekend and was discovered Monday morning when they ran out of fuel. It has been an operating gas station for over 40 years. The fire department is checking basements and utilities for liquid petroleum and petroleum vapors. The implementing agency is planning a public meeting in the next week to explain the release and measures to protect the public.

3) **Stalled in corrective action:** Investigation and scenario began shortly after release discovery. The release was discovered during tank removal in 2000 and the source and date of release was unknown. It had been an operating gas station for over 40 years and was closed at the time of tank removal. Some contaminated soil was removed at the time of tank removal. Some residual soil contamination was documented to remain in place. LNAPL was removed by a series of short-term dual phase extraction events over a period of 3 years. Air sparging with soil vapor extraction was then conducted for five years at 10 feet below the water table. There are twenty-four monitoring wells, screened across the water table. Several show measurable free product, occasionally. Groundwater continues to exceed state standards for benzene, BTEX, and MTBE concentrations both on and off site. From 2008 to 2013 the site was monitored and elevated BTEX levels persisted. From 2013 to 2016 ISCO injections were made in the areas where free product continued to be detected. Three rounds of ISCO were conducted, but elevated BTEX levels eventually returned in several of the originally contaminated monitoring wells. In 2020 the consultant proposed to close the remediation based on technical infeasibility. The state has not agreed and is instead requiring continued quarterly monitoring of all 24 monitoring wells.

We provide additional assumptions given to the experts in **Appendix B**. The remainder of this section presents results from the exercise.

SUMMARY OF KEY FINDINGS

This exercise generated the following key findings:

- **While total cost estimates varied across participants, estimates of the percent cost savings and project duration reductions as a result of HRSC being conducted were similar across experts.** One expert's cost estimates were substantially lower than the other experts, especially in the catastrophic release scenario where this expert described a roughly $500,000 project compared to a $2-$3 million project envisioned by the other experts. All three experts agreed that this was because the first expert was envisioning a "corner gas station" while the others were basing their assumptions on a "truck stop" being remediated. Despite these differences in magnitude, the first expert's estimates for percentage in cost reduction and duration impacts when using HRSC typically fell in between the other experts' estimates, or within a few percentage points, indicating that the impacts of HRSC likely scale with the project size.
- **Experts agreed that including HRSC in an investigation at a catastrophic release site, or a site where remediation is stalled, was very likely to reduce overall project costs.** While experts acknowledged that there could be substantial variation across individual sites due to specific characteristics, all three experts estimated that using an HRSC investigation at these types of sites would typically reduce overall project costs. Experts predicted average savings of 19 percent at catastrophic release sites and 15 percent at sites where remediation is stalled, compared to total costs if HRSC was not used in the initial investigation/characterization.
- **Experts reported that HRSC use would likely be cost neutral or yield some savings at a "typical" release site, while providing important information to inform the remediation.** Two experts believed that total project costs would be roughly identical when using HRSC versus traditional techniques at a typical release site (estimating 0 percent and 2 percent cost reductions, respectively). The third expert believed that HRSC would lead to substantial cost savings (24 percent) over a typical release site corrective action using only traditional techniques. All three experts agreed that the added information provided by an HRSC investigation would make this type of investigation worthwhile. The value of the added data mean that HRSC is worth doing even if the there are no project cost savings. The added information can help uncover site complexity at the start and prevent unexpected roadblocks later, which could prevent some sites from becoming stalled in corrective action or being closed without fully understanding the significance of contamination at a site, potentially leading to the need for cases being reopened.

TOTAL COST ESTIMATES

Table 5 shows each expert's estimated costs and durations for each scenario without the use of HRSC. Experts total project cost estimates for scenarios 1, 2, and 3, ranged from $150,000-$250,000, $440,000-$750,000, and $475,000-$3 million, respectively. Experts estimated that scenarios 1 and 2, the typical and catastrophic release cases, would reach closure in under 10 years, while they estimated scenario 3 (site stalled in corrective action) would take at least 35 years to close without HRSC.

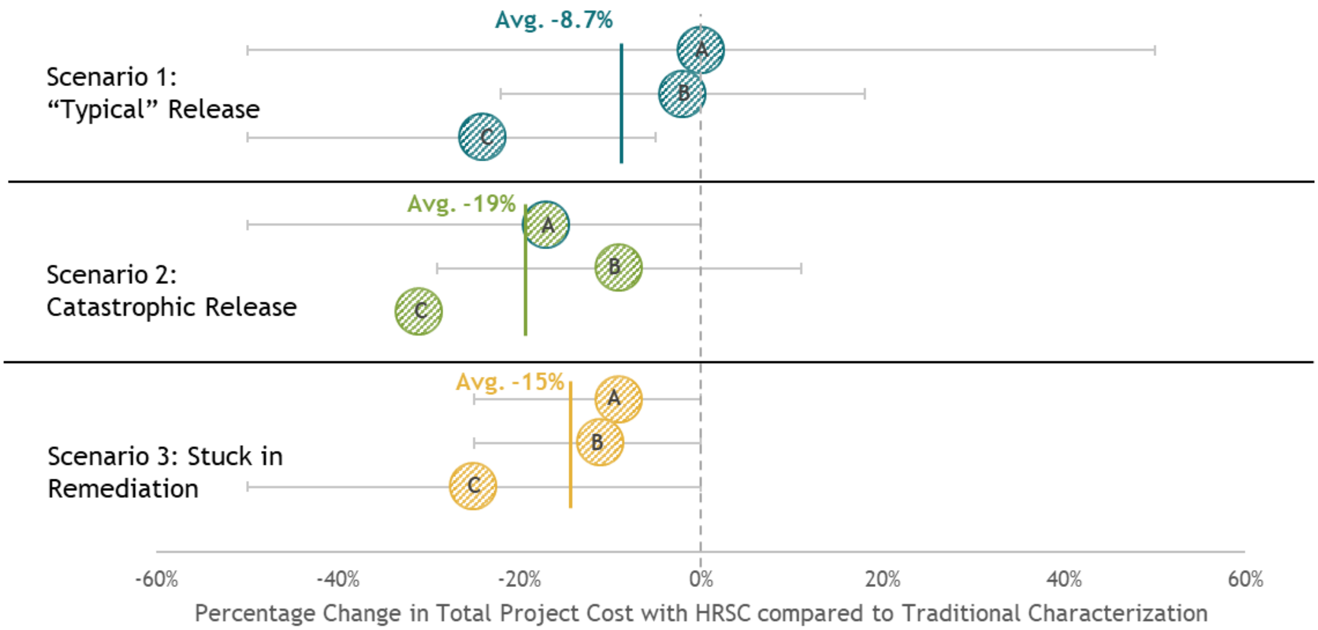
TABLE 5. EXPERT COST SCENARIO ESTIMATES WITHOUT HRSC

Scenario #	Expert #	Without HRSC		
		a) Total Costs of Traditional (i.e., non-HRSC) Site Characterization	b) Total Costs of Corrective Action over entire lifecycle of Site	c) Time to Closure
1 (Typical Release)	A	$50k	($100k Additional)=$150k total	10 Years
	B	$75k	$225k	5 years
	C	$50K, including groundwater monitoring & reporting	$200K, not including characterization and monitoring. $250K if characterization costs included.	10 years
2 ("Catastrophic" Release)	A	$150K	($300k Additional)=$450k total	10 Years
	B	$150k	$750k	10 years
	C	$40K per scenario described. Assuming investigation performed with backhoe, soil borings and installation of 3 monitoring wells & monitoring for 4 years	$400K, assuming emergency response that was primarily excavation and disposal of impacted soil. Total costs with characterization & monitoring: $440K	4 years
3 (Stalled in Corrective Action)	A	$100K	($475k Additional)=$575k total	30 Years
	B	$500k	$3,000k	35 years
	C	$700K+	$1.5M+. Spending will continue because site not effectively remediated, and many data gaps still exist	Not known. Results of monitoring are ambiguous, and extent of plume is unknown.

COST IMPACTS

Experts predicted average total project cost savings of 8.7 percent, 19 percent, and 15 percent when using HRSC compared to traditional methods across scenarios 1, 2, and 3, respectively (**Figure 13**). One expert reported that in the typical release scenario the added costs of HRSC would nearly exactly offset the cost savings in remediation resulting in net-neutral cost impacts. The remaining two experts predicted small to moderate-cost savings in this scenario, while all three experts reported substantial anticipated cost savings across each of the other three scenarios. These cost savings were reported as the most-likely scenario for a given site, or the savings that could be anticipated across a portfolio of sites. When asked to envision all potential cost outcomes at a single site, experts reported a range of expected cost outcomes that could result in some cost increases in scenarios 1 and 2 based on site-conditions, when using HRSC (grey error bars in **Figure 13**). However, experts also reported that savings could be far greater than anticipated within this range.

FIGURE 13. EXPERT INDIVIDUAL AND AVERAGE COST IMPACTS WHEN USING HRSC INVESTIGATION COMPARED TO TRADITIONAL TECHNIQUES ALONE ACROSS THREE PETROLEUM UST RELEASE SCENARIOS



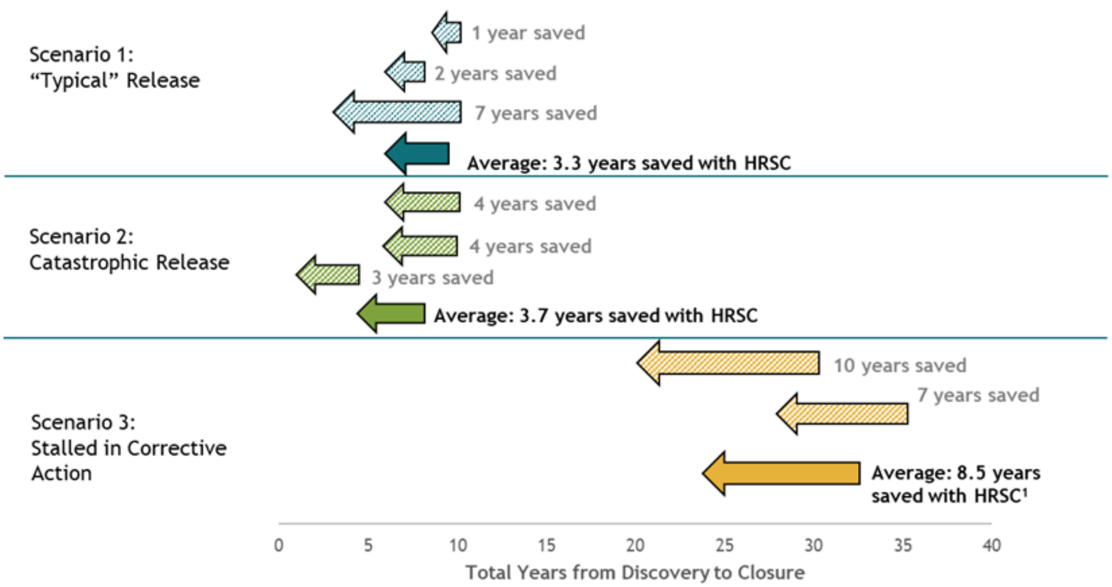
Notes:

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.

DURATION IMPACTS

All three experts reported anticipated reductions in overall project duration (i.e., time from discovery to closure) for each of the three scenarios. Experts predicted an average reduction in project duration of 3.3 years under the typical release scenario, 3.7 years under the catastrophic release, and 8.5 years for a site stalled in corrective action (**Figure 14**). One expert did not provide an estimate for the site stalled in corrective action but explained that the reduction in project duration could mean quickly closing a site that would otherwise be stalled in corrective action indefinitely, after conducting an HRSC investigation. Since project duration and failure to close sites is a major driver of costs, the reduction in time to closure when using HRSC is a potential major driver in reducing costs at a site.

FIGURE 14. EXPERT INDIVIDUAL AND AVERAGE ESTIMATES OF CHANGES TO PROJECT DURATIONS WHEN USING HRSC INVESTIGATION COMPARED TO TRADITIONAL TECHNIQUES ACROSS THREE UST RELEASE SCENARIOS



Notes:

1. Expert C did not provide a duration estimate for the Stalled in Corrective Action scenario due to the complexity of the scenario. The average reflects the responses provided by experts A and B.
2. Right end of arrows represent expert's estimates of total project duration using traditional characterization techniques while left end represents duration when using HRSC (e.g., Expert A estimated a 30-year duration with traditional characterization and 20-years with HRSC in Scenario 3).

IV. ADDITIONAL COST EXERCISE

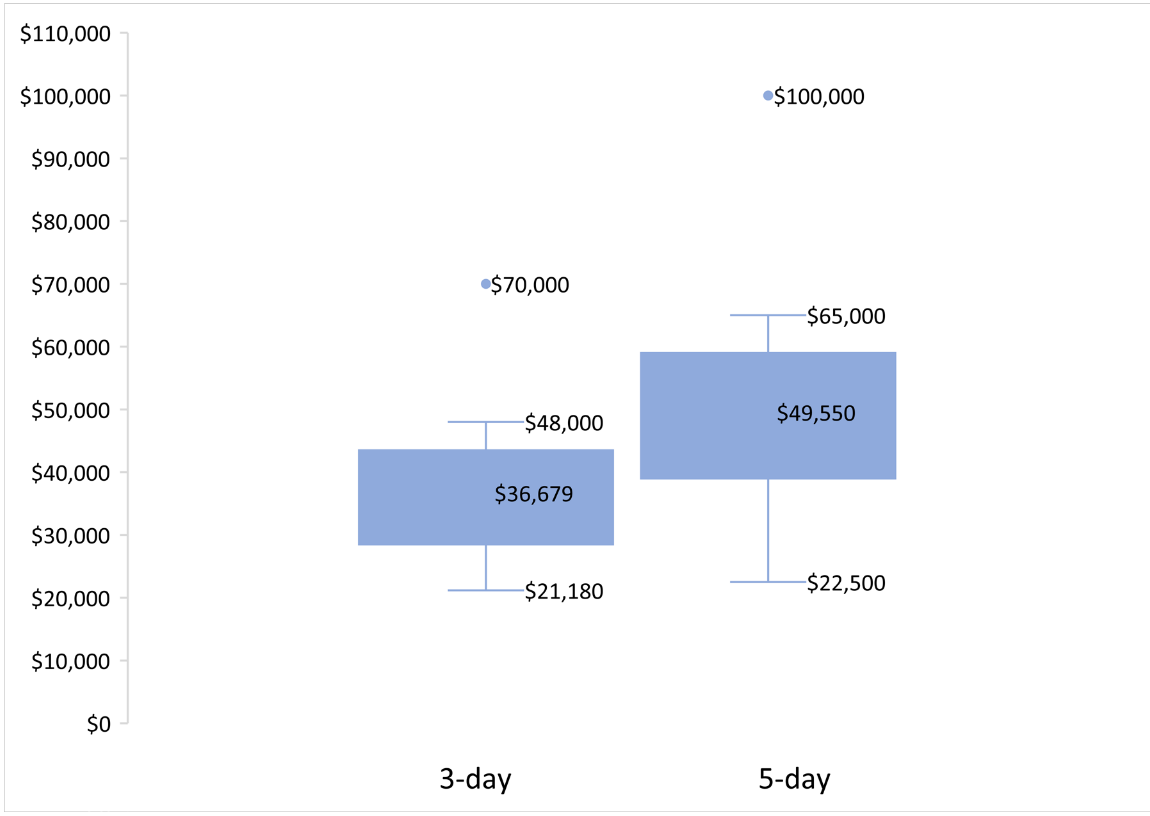
After conducting the Delphi Panel and receiving some cost estimates that were more consistent with larger HRSC sites, we decided to conduct an additional cost exercise to get cost ranges for 3- and 5-day HRSC investigations at a "typical" petroleum UST release scenario. To complete this process we contacted 11 participants, 10 of whom completed the exercise. Each participant provided cost ranges for 5-day investigations, while nine participants provided cost ranges for 3-day investigations.[21] **Figure 15** shows the costs that we received. This exercise revealed the following key findings:

- **Responses yielded an average cost of $36,679 for 3-day investigations and $49,550 for 5-day investigations.** The respondents pointed out that site investigation costs vary significantly based on provider, project location, and specific circumstances of the site. As such, each respondent had to make additional assumptions about the scenario that likely relied on their own experiences and therefore differed amongst respondents. Despite this, when asked to provide a cost estimate range, most respondents predicted ranges that centered around the averages in **Figure 15**.
- **State Respondents and Tech Providers/Consultants tended to be in close agreement on these cost estimates.** The estimates provided by both groups were similar, indicating that the perception of actual HRSC costs from the state and federal regulator perspective is reasonable.

The cost estimates for the low-end of a 3-day investigation cost ranged from $21,180 to $45,000, while the high-end estimates ranged from $26,000 to $70,000. For 5-day investigations, the low-end range estimates fell between $22,500 to $60,000, while the high end ranged from $41,000 to $100,000. **Figure 15** combines the low- and high-end range estimates, with $21,180 representing the lowest low-end estimate of 3-day investigations, while $100,000 represents the highest high-end estimate for a 5-day investigation. Based on the midpoints of each range, respondents predicted *per-day* costs of $12,226 for a 3-day investigation and $9,910 for a 5-day.

[21] One participant did not provide 3-day cost estimates because they believed that type of investigation to be very rare.

FIGURE 15. HRSC INVESTIGATION COST ESTIMATES FOR A 3- AND 5-DAY INVESTIGATION (STATE AND FEDERAL REGULATORS AND TECHNOLOGY 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.

V. CONCLUSIONS

Across all phases and respondent groups, the consensus was clear: HRSC provides substantial benefits in characterizing petroleum LUST cleanup sites, often in the form of cost and time savings. Despite this, HRSC is not used as a standard practice in most petroleum UST releases. This is largely driven by a lack of understanding, and the perception that HRSC is something "extra" that is not needed in an investigation. Through our discussions with state and federal regulators, technology providers, and independent experts, there was agreement that for many sites HRSC is not an "extra" so much as a necessary step in fully understanding the extent of releases, the site geology, and the most effective pathways to remediation. Additional education and available materials on HRSC technologies and their benefits, incorporating HRSC into state cost guidelines, and greater availability of HRSC providers could all lead to more widespread use of HRSC in petroleum UST release cleanups. Increasing the use of HRSC at LUST sites could have major time and cost implications for some of the roughly 60,000 open petroleum UST remediation sites.

APPENDIX A. ADDITIONAL PARTICIPANT INFORMATION

ACKNOWLEDGEMENTS/EXPERT BIOS

We are grateful for the time and participation of each interviewee from each phase of this project. Their perspectives were invaluable in telling the story of HRSC at LUST sites.

The Delphi Panel was made up of three accomplished experts with decades of experience in site characterization.

- **Murray Einarson, P.G., C.E.G., C.H.G., Haley and Aldrich:** "Murray focuses his work on developing and applying innovative approaches and technologies for more accurate and less expensive characterization of the subsurface environment. He is an industry leader who holds patents on innovative site assessment technologies, including the most widely used dual-tube soil coring system and multi-level groundwater monitoring system (CMT™ multilevel monitoring system). He also co-developed the popular DyeLIF™ system, which is an important new technology for delineating chlorinated solvents in the subsurface. By combining technologies, Murray efficiently and accurately characterizes his clients' sites while reducing their project costs. He has used his 35 years of experience to act as a strategic advisor, guiding clients through complex environmental issues around the globe." [22]
- **Michael Kavanaugh, Ph.D., P.E., BCEE, NAE, Geosyntec**: Dr. Kavanaugh's "professional consulting practice includes municipal and industrial wastewater treatment, water quality management, and water reuse and drinking water treatment, and contaminated site remediation. He embraced the technical and administrative challenges in representing clients on groundwater studies, particularly CERCLA-driven remedial investigations/feasibility studies, groundwater remediation, waste minimization and pollution prevention studies. Over the past two decades, Mike has served in a variety of unique roles such as third-party peer review, strategic consulting on environmental management and compliance issues, and serving on expert panels addressing complex issues in site remediation and water quality management." [23]
- **Chuck Newell, Ph.D., P.E., BCEE, GSI Environmental:** "Dr. Charles Newell is a Principal Engineer with GSI Environmental Inc. and has more than 35 years of experience as an environmental consultant. He is a member of the American Academy of Environmental Engineers, a NGWA Certified Groundwater Professional, and an Adjunct Professor at Rice University. His professional expertise includes site characterization, groundwater modeling, natural attenuation, LNAPL/DNAPL problems, groundwater and soil remediation, software development and tech transfer, and PFAS issues. He has served on several expert panels that addressed complex environmental issues."[24]

[22] Murray Einarson, Service Leader, Contaminated Site Management (haleyaldrich.com)

[23] Mike Kavanaugh (geosyntec.com)

[24] Charles J. Newell, PhD, PE, BCEE - GSI Environmental Inc.

APPENDIX B. ADDITIONAL MATERIALS

This Appendix includes the outreach emails, interview guides, and materials provided to interviewees prior to their participation in the study.

Phase One:

Interview Invitation E-Mail

Dear _______,

It was great to catch up with you at the National Tanks Conference. I think we discussed that the US EPA's Office of Underground Storage Tanks (OUST) is conducting a study on best practices for when to use high resolution site characterization (HRSC) at leaking underground storage tank (LUST) sites. EPA has identified you as someone with experience implementing HRSC who can speak about the costs and benefits relative to traditional site characterization techniques.

We are requesting your participation in a 90 minute Teams meeting along with four or five other states with knowledge in this area. Discussion topics will include how states identify situations where they recommend HRSC and situations where they do not recommend it. We are also trying to get a sense of the costs of HRSC and when it leads to overall project cost savings. We will use the information provided during the call to inform an expert elicitation with a panel to try to gain consensus around these topics.

If you would like to participate, please fill out this link to a When2Meet poll where you can select all 30-minute increments when you would be available. That will allow us to find a 90-minute block that works for different states to get on a call together. (Please note: You will need to "sign in" to the scheduler with your name, but you do not need to provide a password. Simply type in your name and click "Sign in".)

Thank you so much for your time, and feel free to follow up with any questions!

Alex Wardle, Geologist (202-564-2773)
Office of Underground Storage Tanks, Cleanup and Revitalization Division
William Jefferson Clinton West
1300 Constitution Avenue, NW (Mail Code 5401T)
Washington, DC 20460

HRSC Discussion Guide for States

BACKGROUND

1. Briefly, please introduce yourself (your state, agency, and role).

HRSC BACKGROUND

2. What are the typical use cases at sites where you have used HRSC, or would consider using it?
3. What has been your experience with using HRSC?
   a. At approximately how many sites have you used HRSC (number of sites, and/or percentage of total sites)?
   b. Are you using HRSC at more sites, or a greater percentage of sites, than you did in the past?
4. Can you describe any cases where you would not use HRSC?
   a. Have there been cases where you have used HRSC and later decided that this was not needed?
5. Briefly, what do you typically include in an HRSC investigation?
6. What HRSC technologies do you use most frequently?
7. When in the process did you use HRSC (e.g., before/after a 1st/2nd/3rd round of borings and monitoring well placements)?
8. What HRSC contractors do you work with?
9. Where could additional information about HRSC costs be beneficial in helping site owners/ stakeholders decide whether to invest in the technology upfront (e.g., EPA/ASTSWMO published resources)?

COSTS AND DURATIONS

10. What are typical per-day and overall costs of doing HRSC?
    a. How does this compare to non-HRSC site characterization/assessment costs?
    b. How does HRSC impact the final project costs? How does this vary across sites with remedial costs of $<50k, $50k-$200k, >$200k?
    c. In what situations is HRSC likely to save money in terms of the site's overall cleanup cost?
    d. Are there any situations where you are certain it will not save money relative to a non-HRSC characterization/assessment?
       i. If it will not save money, is there a reason it gets used anyway?
    e. How much do HRSC costs tend to vary, and what influences this variation?
11. How does HRSC impact project durations?
    a. How does it impact the time to complete the site assessment and make a remedial decision?
    b. How does it impact the time to complete the remedial action?
    c. Can HRSC help achieve NFA faster?
12. If you have a pool of sites and you don't have sufficient resources to do HRSC for all of them, which ones would you prioritize, and why?
13. What are typical geological and hydrogeological profiles of sites where you are doing HRSC, and how does hydrogeology impact the decision to use HRSC?

BENEFITS AND BARRIERS

14. Below, we list different characteristics at a cleanup site where HRSC might be used. For each characteristic we would like to understand the benefit, cost, and timing implications of using HRSC.

Examples of When a High-Resolution Site Characterization Might be Appropriate

SITE CHARACTERIZATION
1. 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.
2. When there is a need to differentiate between new and old releases.
3. Where a large release has occurred into complex layered soils and the pathways of travel are uncertain.
4. When determining what level to place monitoring well screens and select screen lengths in sites with soil layers that have highly contrasting permeability.
5. Before conducting a third round of monitoring well investigation to define the extent of the LNAPL source area or elevated dissolved phase plume.
6. Where LNAPL presence in monitoring wells or movement is inconsistent with the current conceptual site model.
7. Where there are sensitive receptors nearby and the extent and potential movement of contaminants need to be determined with certainty and speed
STAKEHOLDER COMMUNICATION
8. 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 extent contaminated groundwater.
REMEDIATION DESIGN
9. When chemicals, absorbents, or nutrients will be injected into the ground.
10. 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.
11. When contemplating a MNA or NSZD remedial strategy.
STALLED CORRECTIVE ACTIONS (WITHOUT A CLEAR EXPLANATION WHY)
12. Where one or more monitoring wells show persistent or recurring levels of LNAPL that is not explained by the CSM.
13. Where one or more monitoring wells show persistent or recurring levels of contaminants of concern in excess of target cleanup goals.
14. Where active remediation has been conducted for over 10 years.
15. Where a remediation method has failed, and a new remedial approach is being contemplated.
OTHER:

15. Which of the following do you think are barriers to using HRSC? (RATING: 1(not a barrier) to 10 (major barrier)

a. Lack of available expertise
b. Cost
c. Inertia (e.g., more support for traditional approach and/or lack of traction for HRSC support)

d. Owners or their consultants do not propose HRSC
e. Inability to interpret results
f. Not covered under allowable costs under fund guidelines
g. Not incorporated into the actual decision-making process or regulatory standards
h. Lack of correlation to monitoring well investigations
i. Lack of incentive for the owner to incur a higher upfront cost
j. Site geology/other underground factors (e.g., utilities) that prevent the use of HRSC
k. Information on cost savings that result from HRSC investigations (when can HRSC be beneficial)
l. Resistance from site consultants
m. Owners don't want detailed information on, and explicit graphics of the contamination
n. "Psychology" dealing with unexpected results from HRSC
o. Lack of guidance that identifies situations where HRSC is appropriate
p. Others [OPEN END RESPONSE]

16. Of the above, which would you consider to be the greatest barrier(s) to widespread use of HRSC in your sites?
17. Do you have a formal (written) policy or guidance for when to use HRSC?
    a. If yes, can you share it with us?
18. Does your rate schedule include HRSC?

CLOSING

19. As a next step in this process, we are planning to use a panel of impartial experts to try to gain consensus around how HRSC drives costs and when it is most beneficial in site cleanups. Do you have any recommendations for experts who could serve as panelists to provide information on this topic? [SURVEY]
20. Are there any other thoughts about the use of HRSC or ways to better provide information on site cleanup techniques that you would like to share?

HRSC Interview Guide for Technology Providers/Consultants/Site Owners

BACKGROUND

1. Briefly, please describe your current position/role in your organization.

HRSC BACKGROUND

2. What are the typical use cases at sites where you have used HRSC, or would consider using it?
a. At approximately how many sites have you used HRSC (number of sites, and/or percentage of total sites)?
b. Are you using HRSC at more sites, or a greater percentage of sites, than you did in the past?
3. What has been your experience with using HRSC?
4. Can you describe any cases where you would not use HRSC?
a. Have there been cases where you have used HRSC and later decided that this was not needed?
5. Briefly, what do you typically include in an HRSC investigation?
6. What HRSC technologies do you use most frequently?
a. Is HRSC used alone or with traditional site characterization approaches?
b. [IF HRSC IS USED WITH TRADITIONAL] When in the process did you use HRSC (e.g., before/after a 1st/2nd/3rd round of borings and monitoring well placements)?
7. Where could additional information about HRSC costs be beneficial in helping site owners/stakeholders decide whether to invest in the technology upfront (e.g., EPA/ASTSWMO published resources)?

COSTS AND DURATIONS

8. What are typical per-day and overall costs of doing HRSC?
a. How does this compare to non-HRSC site characterization/assessment costs?
b. How does HRSC impact the final project costs? How does this vary across sites with remedial costs of $<50k, $50k-$200k, >$200k?
c. In what situations is HRSC likely to save money in terms of the site's overall cleanup cost?
d. Are there any situations where you are certain it will not save money relative to a non-HRSC characterization/assessment?
i. If it will not save money, is there a reason it gets used anyway?
e. How much do HRSC costs tend to vary, and what influences this variation?
9. How does HRSC impact project durations?
a. How does it impact the time to complete the site assessment and make a remedial decision?
b. How does it impact the time to complete the remedial action?
c. Can HRSC help achieve NFA faster?
10. If you have a pool of sites and you don't have sufficient resources to do HRSC for all of them, which ones would you prioritize, and why?
11. What are typical geological and hydrogeological profiles of sites where you are doing HRSC, and how does hydrogeology impact the decision to use HRSC?

BENEFITS AND BARRIERS

12. I am going to read a list of different characteristics at a cleanup site where HRSC might be used. For each characteristic we would like to understand the benefit, cost, and timing implications of using HRSC.
a. How beneficial use of HRSC would be compared to traditional characterization/assessment techniques (assuming all other conditions are similar)?
b. Does HRSC save time (i.e., reduce cleanup process duration from discovery to remedial action complete/NFA) compared to traditional techniques?
c. Does HRSC reduce overall project costs compared to traditional techniques?

Examples of When a High-Resolution Site Characterization Might be Appropriate

Description	Utility (1 – 5)	Saves Time	Saves $
Site Characterization			
1. 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.			
2. When there is a need to differentiate between new and old releases.			
3. Where a large release has occurred into complex layered soils and the pathways of travel are uncertain.			
4. When determining what level to place monitoring well screens and select screen lengths in sites with soil layers that have highly contrasting permeability.			
5. Before conducting a third round of monitoring well investigation to define the extent of the LNAPL source area or elevated dissolved phase plume.			
6. Where LNAPL presence in monitoring wells or movement is not explained by the current conceptual site model or is inconsistent with the current conceptual site model.			
7. Where there are sensitive receptors nearby and the extent and potential movement of contaminants need to be determined with certainty and speed			
STAKEHOLDER COMMUNICATION			
8. 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 extent contaminated groundwater.			

REMEDIATION DESIGN			
9. When chemicals, absorbents, or nutrients will be injected into the ground.			
10. When contemplating an active remedy that will cost more than $100,000.			
11. When contemplating a MNA or NSZD remedial strategy.			
STALLED CORRECTIVE ACTIONS			
12. Where one or more monitoring wells show persistent or recurring levels of LNAPL that is not explained by the CSM.			
13. Where one or more monitoring wells show persistent or recurring levels of contaminants of concern in excess of target cleanup goals.			
14. Where active remediation has been conducted for over 10 years.			
15. Where a remediation method has failed, and a new remedial approach is being contemplated.			
OTHER:			

13. I'm now going to read a list of barriers. For each, please indicate if it is a barrier to using HRSC.
a. Lack of available expertise
b. Cost
c. Inertia (e.g., more support for traditional approach and/or lack of traction for HRSC support)
d. Owners or their consultants do not propose HRSC
e. Inability to interpret results
f. Not covered under allowable costs under fund guidelines
g. Not incorporated into the actual decision-making process or regulatory standards
h. Lack of correlation to monitoring well investigations
i. Lack of incentive for the owner to incur a higher upfront cost
j. Site geology/other underground factors (e.g., utilities) that prevent the use of HRSC
k. Information on cost savings that result from HRSC investigations (when can HRSC be beneficial)
l. Resistance from site consultants
m. Owners don't want detailed information on, and explicit graphics of the contamination
n. "Psychology" dealing with unexpected results from HRSC
o. Lack of guidance that identifies situations where HRSC is appropriate
p. Others
14. Of the above, which would you consider to be the greatest barrier(s) to widespread use of HRSC in your sites?
15. Do you have a formal (written) policy or guidance for when to use HRSC?
a. If yes, can you share it with us?

CLOSING

16. As a next step in this process, we are planning to use a panel of impartial experts to try to gain consensus around how HRSC drives costs and when it is most beneficial in site cleanups. Do you have any recommendations for experts who could serve as panelists to provide information on this topic?
17. Are there any other thoughts about the use of HRSC or ways to better provide information on site cleanup techniques that you would like to share?

Phase Two:

Interview Invitation E-Mail

Dear _______,

I am writing to invite you to participate as a member of an expert panel that will provide the U.S. Environmental Protection Agency (EPA) Office of Underground Storage Tanks (OUST) with critical input on the costs, benefits, and use cases for High Resolution Site Characterization (HRSC) at petroleum underground storage tank (UST) sites.

Traditional assessment techniques at UST sites involve placing successive rounds of monitoring wells and laboratory analysis of groundwater samples until the horizontal and vertical extent of the contamination has been determined. Generally, two or three rounds of well placement and sampling are needed; however, five or more rounds may be needed on more complex sites. This can lead to higher costs and multi-year delays in the implementation of the remedial action on complex sites. HRSC, which uses a variety of direct sensing methods to identify contaminants and soil characteristics, has been used for more than 10 years at complex sites. It can rapidly determine the extent of the source area and dissolved phase plume and can identify the soil strata in fine detail. While more expensive than a typical single round of monitoring well placement, HRSC has been promoted as saving money on complex sites by reducing the number of monitoring wells required and improving the effectiveness of remediation. While some practitioners report excellent results with HRSC, others say that HRSC is not necessary and the results are not worth the extra expense, especially for petroleum UST sites.

The primary goals of this study are: 1) to quantify the costs of HRSC and the potential project cost savings, and 2) identify situations where HRSC is likely to provide a benefit. The results of this study will help drive the 62,000 UST sites in backlog toward completion and will lay a more productive pathway for assessing the contamination at nearly 200,000 active petroleum UST sites. OUST will incorporate the study results into guidance on the appropriate use of HRSC at Indian country sites, where EPA leads the cleanups, and for state UST cleanup programs.

EPA has contracted with Industrial Economics, Inc. (IEc), an environmental and economic policy consulting firm based in Cambridge, Massachusetts, to conduct this study. We are convening an expert panel, specifically, a Delphi Panel, to address the study questions.

The rest of this letter provides additional information on the expert panel process. Please review this information carefully and consider your willingness and ability to participate. We know your time is valuable and we appreciate your consideration.

Panel Overview

The panel will likely include 3-5 independent experts. Panelists should have the following qualifications:

- Extensive experience or familiarity with petroleum UST site cleanups, petroleum refinery cleanups, and/or petroleum pipeline cleanups
    - Relevant experience may include project management experience, expert witness work (e.g., for hydrogeology cases), and/or published research on the topic areas.

- Understanding of how different site characteristics (e.g., geology) impact the ability to contain and clean up spills

- Familiarity with HRSC techniques

- Understanding of traditional site characterization approaches and how they work in conjunction with, or differ from, HRSC

- Ability and comfort to assign quantitative estimates (or ranges) to specific scenarios, including:
    - Estimating cost differences at sites where HRSC is/is not selected
    - Estimating differences in project cleanup durations where HRSC is/is not selected
    - Providing assumptions and drivers behind cost and duration estimates

- No financial interest in the use of HRSC or traditional site characterization techniques (i.e., participants will not benefit from HRSC being selected more or less frequently at sites across the US)

Panelists should be willing to spend up to a day of time reviewing background information necessary for providing informed input. The selected panelists will rely on materials provided by IEc, as well as their own experience and expertise. Background materials will include summaries of previous discussions that IEc led with state UST cleanup programs, HRSC technology providers, remediation contractors, and consultants to obtain information on the current use of HRSC. Those discussions focused on direct sensing technologies as being "HRSC," and, therefore, that is generally what the expert elicitation will be focused on too. The background materials will also include a synthesis of previous studies.

Participation in the process is likely to require a total of up to 12 hours of each expert's time between November and December 2022. IEc will compensate each expert for participation with a fixed honorarium of $1,500 per expert. To receive the honorarium, panelists must sign a short contract with IEc and submit a one-page invoice at the end of their participation (IEc will provide an invoice template).

IEc will first schedule a brief screening phone call with each potential expert to determine eligibility to participate in the panel. We will then conduct the process in two rounds. Once experts are selected, we will provide a dossier of information to review, and then schedule an individual phone interview with each expert to solicit their responses to an interview guide. Following the Round 1 interviews, IEc will synthesize responses and summarize them for communication back to the panelists; responses will be anonymized to protect confidentiality. The Round 2 interview guide will indicate to each panelist how their responses compare to their peers (while maintaining the confidentiality of individual panelists) and will prompt panelists to revisit the same questions as in Round 1, with the added benefit of input from their peers. It is through this process that expert panels typically coalesce around a narrow range of results.

Next Steps

We hope you will give the opportunity serious consideration; OUST needs expert assistance in understanding how the use of HRSC may help EPA and state cleanup programs clear the backlog of petroleum UST sites in a cost-effective manner.

Please let us know if you are interested in serving on this panel, and we will be in touch to schedule a brief screening interview. We have attached a brief document to this email to provide you with an overview of the expert elicitation process. If in the meantime you have any additional questions about the panel, please contact Greg Englehart of IEc at genglehart@indecon.com or 617.299.3660 or Tom Schruben of EPA OUST at schruben.thomas@epa.gov or 301.613.8858. If you would like more information about IEc, please visit their website: http://www.indecon.com. If you would like more information about EPA's OUST program, please visit https://www.epa.gov/ust.

We look forward to working with you and thank you for your assistance.

Sincerely,

Mark Barolo, Deputy Director

EPA, Office of Underground Storage Tanks

202/564-1661

Expert Elicitation Description

Overview of Expert Elicitation

Definition, History, and Use

Expert elicitation is a systematic process of formalizing and quantifying expert judgments about uncertain quantities. The uncertain quantities of interest in the current study are the costs and potential cost savings of using High Resolution Site Characterization (HRSC) at different types of petroleum underground storage tank (UST) sites. Expert elicitation is often used to address public policy questions when 1) conducting the research and data collection indicated is infeasible or cost-prohibitive, and/or 2) applicable analytical approaches are likely to produce a wide range of uncertainty.

Expert elicitation emerged from decision theory as a distinct process in the 1950s. Since the late 1970s, the U.S. Environmental Protection Agency has conducted expert elicitations as part of regulatory analyses of air pollutant regulations, and the Nuclear Regulatory Commission has used the approach to study aspects of nuclear reactor safety and policy. Expert elicitation has also been used for previous OUST efforts, including a rulemaking to estimate the economic benefits of the proposed rule from estimated reductions in leaks.

The current expert elicitation is a follow-up analysis to OUST's recent *LUST Cost of Cleanup* study, which found that investigation costs were similar for remediation sites, regardless of the overall cost of the cleanup, and that greater site assessment expenditures might be associated with lower overall project costs. These findings suggest that identifying best practices for site investigation might help states reduce their overall cleanup costs. However, the cost correlation was weak and there was not enough data in the state cleanup program databases that were available for the study to distinguish between assessment methods, so the report could draw only limited conclusions regarding site assessment. Similarly, discussions with states during the first phase of the current HRSC study showed that data are generally unavailable to compare the costs of cleanup at sites with and without HRSC. In some cases, the state's use of HRSC at petroleum UST sites is too new to determine long-term effects on site cleanups. In others, the use of HRSC at select sites followed a long history of stalled remedial attempts, which altered the conditions of the site, making direct comparisons between HRSC and traditional approaches infeasible. Given the infeasibility of collecting and analyzing empirical data to determine the cost implications of using HRSC at petroleum UST sites, EPA opted for an expert elicitation approach.

Expert Elicitation Process Steps

Expert elicitation processes involve the following general steps:

Develop a background information summary to explain the problem at hand to prospective experts.

2. Develop expert recruitment objectives. Objectives typically include: ensuring adequate expert coverage of all of the types of expertise required; gathering a diverse range of viewpoints; and defining and avoiding potential conflicts of interest.

3. Recruit experts based on qualifications criteria; qualifications criteria typically define specific expertise and experience. Experts also must agree to the time commitment required for the honorarium offered.

4. Develop more detailed background materials to be provided to experts.

5. Develop formal elicitation protocol by breaking down broad questions into a logical series of smaller questions for experts to consider. Develop a script based on this logic; the script may include graphical displays as well.

6. Pilot test the background materials and elicitation protocol, and revise as needed to hone the materials.

7. Administer the expert elicitation. The details of administration depend on the type of elicitation; see discussion of types below. Some types involve consensus-building across experts and/or combining responses of experts.

8. Develop a written communication of expert findings; the communication format can range from a short summary to a detailed report.

Types of Expert Elicitation

Individual Elicitation: Researchers use a standard protocol to interview experts individually and develop a range of results; this approach does not combine expert judgments or engage experts in consensus building to narrow the range of the potential answer. This approach is the most straightforward to conduct and avoids potential complexities and uncertainties in combining expert responses. However, it can lead to a wide range of outcomes. Moreover, individual expert judgments can suffer from biases including overconfidence and motivational biases. Individual elicitation is narrowly applied today, and typically used to elicit judgment on uncertainty around an existing, central estimate.

- *Group Elicitation:* Experts interact in a group, in real time, to evaluate information and work through the questions in the elicitation protocol. The meeting(s) can be in person or virtual. Using a framework of a robust, structured discussion, experts working in a group can develop a more accurate and/or more precise range of responses compared to individual assessments. A disadvantage, however, is that group dynamics often introduce biases, including conformity bias (or its opposite, group polarization bias), and/or deferral to perceived hierarchy or authority among participating experts. After the meeting(s), researchers may further analyze and combine expert responses; this can provide a more useful result but can also introduce a new source of uncertainty.
- *Delphi Panel*: Researchers conduct an iterative series of individual interviews with experts. Researchers aggregate individual results and prepare graphics and text tailored to each expert, explaining how their responses compare to their peers (while maintaining the confidentiality of individual panelists). The second round of questioning prompts experts to revisit the same questions as the first interview, with the added benefit of input from their peers. The process usually iterates for two to three rounds, typically narrowing the range of results and reducing uncertainty. The Delphi Panel combines the advantages of the group and individual elicitations and tends to minimize biases. However, it is the most resource and time intensive approach to administer.

Limitation

Expert elicitation has limitations that all project participants should be mindful of:

Expert elicitation is not a substitute for empirical research; expert elicitation is a method to be employed when empirical research is infeasible or impractical.

- It typically does not produce a single result, but it can narrow the range and uncertainty of results.
- Expert elicitation processes must be thoughtfully structured, and materials must be carefully developed and tested, to ensure the fidelity of the process.
- Biases of experts can affect outcomes. In addition to the biases noted above, which tend to be specific to particular types of elicitation, all expert processes can be subject to anchoring bias, wherein experts favor information provided earlier in the process over information provided later, and availability bias, wherein experts weigh information or examples they are familiar with more heavily than new information.
- Some experts will be better than others in providing insightful input and in predicting future states. Given this, some expert elicitation processes use objective testing of experts, and may use testing results to inform recruitment or to weight expert responses. However, testing experts is often impractical, and it further increases cost and time required. Moreover, weighting expert contributions needs to be approached carefully, as it can introduce a new source of uncertainty.

Expert Questionnaire

HRSC INTERVIEW GUIDE FOR ROUND 2 EXPERT ELICITATION

[Note: Blue text indicates where questions align with the Tech Provider and State Summary documents that we provided to the Expert Panel prior to these interviews.]

1. Please briefly describe your background.
2. What are your initial thoughts on the material we provided you with? Specifically, please provide us with where you agree, disagree, and your own thoughts on the following topic areas:

a. What are the typical cases where HRSC is used? Are these the appropriate cases for its use? [Typical cases where HRSC is used section]

b. Has HRSC use increased over time? [HRSC use over time section]

c. What elements are most beneficial to include in an HRSC investigation? [HRSC use and experience section]

d. What cases are there where HRSC may not be beneficial compared to traditional techniques? [Cases where HRSC is not beneficial section]

3. We asked all tech providers and state contacts who participated in the round one interview to describe how useful they considered HRSC to be in 15 scenarios compared to traditional rankings. We compiled these responses, and ranked the utility that respondents thought they provided from 1 (greatest usefulness to use HRSC in the given scenario) to 15 (least usefulness to use HRSC in the given scenario). [Use Cases section]

For each scenario, please indicate if:

a. You agree more with the tech provider or state rating?

b. Why you chose the higher or lower rating?

c. What you would rate the utility of using HRSC to be in the given scenario, using a 1 through 5 scale, where 1 means least useful and 5 means most useful?

Scenario	Tech Provider Ranking (Utility)[1]	State Ranking (Utility)[1]	a) Agree with State or Tech Provider Ranking?	b) Why did you choose this selection?	c) Usefulness of HRSC in this situation (1-5)
Site Characterization					
1. 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.	12	1 (tie)			
2. When there is a need to differentiate between new and old releases.	14	15			
3. Where a large release has occurred into complex layered soils and the pathways of travel are uncertain.	1	4 (tie)			
4. When determining what level to place monitoring well screens and select screen lengths in sites with soil layers that have highly contrasting permeability.	7	1 (tie)			
5. Before conducting a third round of monitoring well investigation to define the extent of the LNAPL source area or elevated dissolved phase plume.	8	10 (tie)			
6. Where LNAPL presence in monitoring wells or movement is not explained by the current conceptual site model or is inconsistent with the groundwater gradient.	2	4 (tie)			
7. Where there are sensitive receptors nearby and the extent and potential movement of contaminants need to be determined with certainty and speed	5	4 (tie)			
Stakeholder Communication					
8. 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 extent contaminated groundwater.	9	4 (tie)			
Remediation Design					

Scenario	Tech Provider Ranking (Utility)[1]	State Ranking (Utility)[1]	a) Agree with State or Tech Provider Ranking?	b) Why did you choose this selection?	c) Usefulness of HRSC in this situation (1-5)
9. When chemicals, absorbents, or nutrients will be injected into the ground.	3	4 (tie)			
10. 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	4 (tie)			
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.	15	10 (tie)			
Stalled Corrective Actions					
12. Where one or more monitoring wells show persistent or recurring levels of LNAPL that is not explained by the CSM.	6	1 (tie)			
13. Where one or more monitoring wells show persistent or recurring levels of contaminants of concern in excess of target cleanup goals.	10	13 (tie)			
14. Where active remediation has been conducted for over 10 years.	13	13 (tie)			
15. Where a remediation method has failed, and a new remedial approach is being contemplated.	11	12			

1. Note that tech providers were asked to rank the usefulness of HRSC in each scenario on a 1-5 scale, while states were asked to provide a “yes/no/maybe” response regarding whether or not HRSC would be beneficial. This difference in methodologies was due to time constraints in the state interviews.

4. What do you consider to be the three greatest barriers (in order) to HRSC adoption? [Barriers section]

a. For each barrier, please explain the parties involved and what role each stakeholder would need to play to help overcome these barriers?

5. I am now going to read a list of three scenarios for a hypothetical cleanup effort. For each scenario, can you please provide your best estimate of the following: [Corresponds with costs and durations section of summary]:

a. Total Costs of Traditional (i.e., non-HRSC) Site Characterization without HRSC.
b. Total Costs of Corrective Action over entire lifecycle of Site without HRSC.
c. Time to Closure without HRSC.
d. Total Costs of Traditional (i.e., non-HRSC) Site Characterization with HRSC.
e. Total Costs of HRSC Investigation.
f. Total Costs of Corrective Action over entire lifecycle of Site with HRSC.
g. Time to Closure with HRSC.
h. Would HRSC reduce the number of regulatory decision-making events (site assessment approval, remedial proposal accepted, and closure request granted)?
i. Any additional thoughts and assumptions that you considered in making these estimates.

Scenarios:

For each scenario, please assume the following:

- Site geology allows HRSC to be conducted
- o Note: While there are technical and practical constraints that often limit the feasibility of HRSC, we are "removing" some of those obstacles from these scenarios to get at the cost and duration implications for HRSC when it is used
- The release was found in the tank basin, which is 12 feet deep
- The sites are located on an alluvial plain
- Groundwater is expected within 20' of ground surface
- Property layouts are such that investigation locations will not be significantly restricted by access or utility conflicts
- Groundwater and any submerged NAPL can be reached with driven probe (a.k.a. direct push) methods.
- Private drinking water wells, both shallow and deep, may be located within 1,000 feet of the former tank area.
- There is a mix of commercial and residential properties adjoining the site

1) "Typical release": Investigation and scenario begin shortly after release discovery. The release was discovered during tank removal and the source and date of release is unknown. It has been an operating gas station for over 40 years. Some contaminated soil was removed at the time of tank removal. Some residual soil contamination was documented to remain in place. Two investigation monitoring wells were placed and confirmed groundwater exceeded state standards for benzene, BTEX, and MTBE.

2) Catastrophic release: Investigation and scenario begin shortly after release discovery. The release was approximately 5,000 gallons of gasoline and occurred over a weekend and was discovered Monday morning when they ran out of fuel. It has been an operating gas station for over 40 years. The fire department is checking basements and utilities for liquid petroleum and petroleum and vapors. The implementing agency is planning a public meeting in the next week to explain the release and measures to protect the public

3) Stuck in corrective action: Investigation and scenario begin shortly after release discovery. The release was discovered during tank removal in 2000 and the source and date of release was unknown. It had been an operating gas station for over 40 years and was closed at the time of tank removal. Some contaminated soil was removed at the time of tank removal. Some residual soil contamination was

documented to remain in place. LNAPL was removed by a series of short-term dual phase extraction events over a period of 3 years. Air sparging with soil vapor extraction was then conducted for five years at 10 feet below the water table. There are twenty-four monitoring wells, screened across the water table. Several show measurable free product, occasionally. Groundwater continues to exceed state standards for benzene, BTEX, and MTBE concentrations both on and off site. From 2008 to 2013 the site was monitored and elevated BTEX levels persisted. From 2013 to 2016 ISCO injections were made in the areas where free product continued to be detected. Three rounds of ISCO were conducted, but elevated BTEX levels eventually returned in several of the originally contaminated monitoring wells. In 2020 the consultant proposed to close the remediation based on technical infeasibility. The state has not agreed and is instead requiring continued quarterly monitoring of all 24 monitoring wells.

3a.) Are there points in Scenario Three where HRSC would have better informed the decision making in that scenario? Please explain the point(s) at which you would have conducted an HRSC investigation and why. At each point, please explain the impact that this would have had on total project costs and time to cleanup.

	Without HRSC			With HRSC					
Scenario	a) Total Costs of Traditional (i.e., non-HRSC) Site Characterization	b) Total Costs of Corrective Action over entire lifecycle of Site	c) Time to Closure	d) Total Costs of Traditional (i.e., non-HRSC) Site Characterization	e) Total Costs of HRSC Investigation	f) Total Costs of Corrective Action over entire lifecycle of Site	g) Time to Closure	h) Would HRSC reduce the number of regulatory decision-making events (site assessment approval, remedial proposal accepted, and closure request granted)?	i) Provide additional thoughts and assumptions that you considered in making these estimates.
Notes	Including all past, ongoing and future costs. Assume HRSC is never conducted at this site.	-	Estimate total time to site closure, from starting point listed in the scenario, assuming no HRSC investigation is ever conducted.	Including all past, ongoing and future costs. Assume that an HRSC investigation is conducted at the time listed in the scenario	Please explain assumptions, including what technology(ies) may be used and how you reached your total estimate (e.g., per-day costs for x days)	Including all past, ongoing and future costs. Assume that an HRSC investigation is conducted at the time listed in the scenario	Estimate total time to site closure, from starting point listed in the scenario, assuming HRSC investigation is conducted at time listed in scenario		
1.									
2..									
3.									

Phase Three:

Cost exercise invitation emails

Version One: People we spoke with in Round One

Hello ____,

I hope your new year is off to a good start! I'm following up on EPA OUST's HRSC study that you spoke with us about in the Fall of 2022. Thanks again for your valuable insights! The study has progressed since we last spoke; we have gathered valuable input from experts on the use cases and potential cost savings from using HRSC at LUST sites. The experts provided a range of cost estimates based on their assumptions about the type of site, including larger/more complex sites. To round out the information for our study, we are hoping to gather estimates for the costs of HRSC at a typical gas station LUST site.

Would you be comfortable providing a "bottom-line" cost estimate (ranges) for an HRSC investigation at a typical gas station release site? Specifically, we are interested in the total HRSC cost for a 3-day investigation and a 5-day investigation. To be clear, we are not asking you to query your database or do any calculations. Instead, we are asking for your best professional judgment on what the cost range would be based on your experience with HRSC. We will aggregate and present responses as a range; we will not attribute any specific cost estimates to individual respondents/organizations.

Please let us know by this Friday, January 13th if you are able to participate, and we will provide you with a worksheet. The worksheet includes details about the site characteristics and what we are asking you to estimate. Feel free to reply to this email if you have any questions. If you would rather not participate in this effort, please let us know so that we can reach out to alternate contacts.

The results of the study will be available in the Spring of 2023.

Thank you again for your time and consideration!

Best,

____

Version Two: People we have not spoken with in Round One

Dear ____,

The US Environmental Protection Agency (EPA) Office of Underground Storage Tanks (OUST) is conducting a study on High Resolution Site Characterization (HRSC) at leaking Underground Storage Tank (UST) sites. EPA has contracted with Industrial Economics, Inc. (IEc), an environmental and economic policy consulting firm, to support this effort. Based on your experience with HRSC, we are requesting your input for this study.

The primary goals of this study are: 1) to quantify the costs of HRSC and the potential project cost savings, and 2) identify situations where HRSC is likely to provide a benefit. The results of this study may help drive the 60,000 UST sites in backlog toward completion and lay a more productive pathway for assessing the contamination at the 175,000 currently active petroleum UST sites. OUST will incorporate the study results into guidance on the appropriate use of HRSC at Indian country sites, where EPA leads the cleanups, and for state UST cleanup programs.

During earlier phases of this study, we spoke with HRSC technology providers, consultants, and states that have used HRSC. We also consulted with experts on use cases for HRSC and potential cost savings. The experts provided a range of cost estimates based on their assumptions about the type of site, including larger/more complex sites. To round out the information for our study, we are hoping to gather estimates for the costs of HRSC at a typical gas station LUST site.

Would you be comfortable providing a “bottom-line” cost estimate (ranges) for an HRSC investigation at a typical gas station release site? Specifically, we are interested in the total HRSC cost for a 3-day investigation and a 5-day investigation. To be clear, we are not asking you to query your database or do any calculations. Instead, we are asking for your best professional judgment on what the cost range would be based on your experience with HRSC. We will aggregate and present responses as a range; we will not attribute any specific cost estimates to individual respondents/organizations.

Please let us know by this Friday, January 13th if you are able to participate, and we will provide you with a worksheet. The worksheet includes details about the site characteristics and what we are asking you to estimate. Feel free to reply to this email if you have any questions. If you would rather not participate in this effort, please let us know so that we can reach out to alternate contacts.

The results of the study will be available in the Spring of 2023.

Thank you for your time and consideration!

Best,

____

Cost Exercise Worksheet

What is the Range of Costs of 3- or 5-day HRSC Investigation of a Typical Release at a Gas Station?

Scenario Description:

Investigation and scenario begin shortly after release discovery. The release was discovered during tank removal and the source and date of release is unknown. It has been an operating gas station for over 40 years. Some contaminated soil was removed at the time of tank removal. Some residual soil contamination was documented to remain in place. Two investigation monitoring wells were placed and confirmed groundwater exceeded state standards for benzene, BTEX, and MTBE.

Site Assumptions:

1. Site geology allows HRSC to be conducted
2. The sites are located on an alluvial plain
3. Groundwater is expected within 20' of ground surface
4. Property layouts are such that investigation locations will not be significantly restricted by access or utility conflicts
5. Groundwater and any submerged NAPL can be reached with driven probe (a.k.a. direct push) methods.
6. Private drinking water wells, both shallow and deep, may be located within 1,000 feet of the former tank area.
7. There is a mix of commercial and residential properties adjoining the site

Scope of Services

1. Mix of EC + MIP, HPT, and LIF or OIP depending on what the site needs
2. Confirmatory water or soil samples
3. Daily reports
4. 3-D visualizations
5. Summary report of probe and laboratory results and conceptual site model

A three-day investigation of this "typical site" would cost $________ to $_________.

A five-day investigation of this "typical site" would cost $________ to $_________.